THE DISTRIBUTION OF CANAL WATER WITH SPECIAL REFERENCE TO OUTLETS.

BY J. O. WATERHOUSE,
ASSISTANT ENGINEER, LOWER CHENAB CANAL

Introduction—Shortage of water in the Lower Chenab Canal—Different types of outlets—Limitations of modules and of the Kennedy gauge outlet—Notch outlet—The Kirkan distributary.

Introduction.

The equitable distribution of the water available in the Punjab has become a serious problem since the triple canal scheme has come into operation, and there is now no surplus supply available anywhere during the rabi or more important, cold weather crop. In fact, there is often a shortage during the most important period of the crop, and the equal and fair distribution of short supply, in such a way that no one person suffers more than other, and so that all get a proportional share of the water at regular fixed intervals, is the ideal at which every canal engineer should aim.

At present, efforts are often made to attain this object in a very unsatisfactory manner, by such rule of thumb methods as are possible to the officer in charge at the time of the shortage, but as it is impossible even to guess the period of the short supplies, or the extent of the constantly varying shortage, it is obviously impossible to distribute the supply as it should be done, by such methods. The periodical closing of outlets, often combined with the rotational turns of distributaries, and further complicated by the closure of the branches, results in the utmost confusion in the proper distribution in the area irrigated by an outlet. Many zamindars, especially those who are liable to be oppressed by their more powerful brethren, suffer very badly, as can often be seen from the lists of failed crops.

If a regular supply of water were maintained at the outlet [illegible], the amount always being in approximate proportion to the percentage of full supply discharge entering with regard of the main canal or branch, there would be less interference with the rotational turns, and cultivators would reach with more than are at reasonable intervals. or fitted with Kennedy

Shortage of water on the Lower Chenab Canal.

Take for example the conditions existing during the rabi crop of the past two years on the Lower Chenab Canal. The supply at the critical period fell to between three and four thousand cusecs, while the full supply discharge was about eleven thousand cusecs. This meant that the Gugera branch and the Main Line had to be run alternately, usually in fortnightly turns. As the supply was still short on the Gugera branch the distributaries had to be periodically closed, that is to say each was closed for something like three days out of fourteen ; and as there was always a keen demand on a large number of distributaries the outlets had also to be closed down periodically, so that each outlet was often closed two days a week.

Periodical closures had also to be resorted to in the case of certain high level channels that were unable to take their full supply owing to the low level of the water surface in the main canal, so that each outlet got on an average only about seven or eight days supply in the month during this short supply period, and as the rotational turn of a village is often of ten days more duration, some cultivators had to wait about seven weeks for their next turn. In such circumstances, if the same amount of water could be given, distributed over the fortnight, to each outlet it would be more satisfactory. It has frequently happened that the shortage was so acute during the turn of a village that it got practically no water, while if the supply were distributed over a longer period there would be less chance of this.

If periodical closures were confined entirely to the lands branches of a canal, standard rotational turns of between seven and fourteen days in length could be prepared for every village, as each village would be sure of getting a continuous supply of water for fourteen days every month.

There is another point to which practically no attention has hitherto been paid ; namely, the use of surplus or excess supplies. A channel with its outlets should be of such design as to dispose usefully and proportionately of any excess supplies that may come its way. When this arrangement has settled down into working order the land would be in a better condition [illegible] on a permanent settlement.

T[illegible] to have been the objective of the off[illegible] [illegible]t for some time past, but their idea [illegible] [illegible]e in a different direction, *i. e.* givi[illegible]

an outlet a constant discharge of constant volume. It is perfectly obvious that under existing conditions this cannot be carried out, as there is not always the necessary volume of water available, so instead of thinking of modules, it would be better to try to devise an outlet which would only draw its proper proportion according to the proportion of the full supply discharge running in the distributary. For example, if a distributary were drawing eighty per cent. of its full supply at the head, each outlet should get eighty per cent. of its full supply, and the tail also eighty per cent. Similarly, if a distributary received a hundred and ten per cent. of its full supply, every outlet should be capable of taking that percentage of its full supply.

Different Types of Outlets.

To design a distributary of this nature will necessitate a considerable amount of experiment. Research however will have to be in an entirely different direction to that in which it is being carried out at present, and which aims at finding a module or machine to give a constant discharge under all conditions ; whereas the ideas mentioned above require a device to give a controlled, varying discharge, at a fixed rate of variation, according to the supplies available. The design of a distributary, and ted with such an outlet, is here attempted.

The distributary head should be much as at present, but in cases a vertical silt wall should be built in front of the head. his wall, by the trial and error method, should be raised or wered as necessary to give the distributary a more or less rmanent *regime*, allowing for the annual fluctuation of silt uring the various seasons.

The distributary should then be divided into three reaches. *he head reach*, where the silting fluctuation occurs ; *the middle ach*, which has a permanent full supply level, and *the tail reach*, here the outlets begin to draw more than twenty-five per cent. f the discharge of the distributary, where it passes them. Then he outlets on the distributary should be divided into two classes ; hose having more and those having less than 0·7 foot head, which has been chosen for reasons which will be apparent later.

Each outlet should be considered with regard to its circumstances.

(1). All outlets in the head reach with more than 0·7 foot head should be either moduled, or fitted with Kennedy gauge

outlets. The latter, with two feet submersion, will not work satisfactorily through any considerable range with less than 0·7 foot head. The fixing of such outlets would prevent the fluctuating silt level from altering the draw-off of these outlets to any extent, and so upsetting the water supplies lower down. It would also bring these outlets as nearly into line as possible with the remainder of the scheme. The head reach is usually a very small proportion of the distributary, and the discharge consumed in it is usually less than five per cent. of the whole.

(2). Outlets in the head and middle reaches with less than 0·7 foot head, should be given ordinary pipe outlets, but these should have sufficiently long masonry flumes on the down stream side to control the head, and to prevent the zamindars from gaining any advantage by frequent silt clearances, and thus taking more than their share. Outlets in this class are also usually in a considerable minority.

(3). The outlets in the middle reach, with heads of more than 0·7 foot, should be of the proportional discharge type of design. This is the type proposed to comply with the previous remarks, and will be described later.

(4). All groups of outlets in the tail reach, bifurcations etc., should be fixed on Gibb's contraction flume principle.

It will be seen from the above that outlets in the middle reach with heads of 0·7 foot or more will predominate except in distributaries of consistently bad command. It will also be noticed that no attempt has been made to instal one type of outlet everywhere, but rather to suit the outlet to the conditions at site. The use of modules or Kennedy gauge outlets has been thus limited, because they are only suited for special conditions, and beyond these conditions they are a source of considerable trouble.

Limitations of Modules and of the Kennedy Gauge Outlet.

Modules are only appropriate where there is sufficient head to work them, and at sites where the water level in the supply channel is liable to fluctuation without any alteration in supply, *i.e.* in silting reaches of a channel. The fact of a module being independent of its discharge water level is in its favour, but is not sufficient to warrant its use indiscriminately, as this independence can be obtained by other methods.

There is no advantage in using a Kennedy gauge outlet when the head exceeds the submersion, and it was noticed on a

certain channel fitted with this type of outlet, that the tail was always the first to suffer in cases of short supplies. This suggested that the working head or submersion of the outlet (two feet in this case) was not in proportion to the fluctuation of the supply in the distributary, but that the outlet continued to draw more than its share as the supply was reduced.

In order to find the head with which an outlet should work to draw off the same proportional discharge as that flowing in the distributary, a curve (Diagram No. 1) has been prepared, showing the relation between the head and the fluctuation of the discharge from any ordinary outlet. The percentage fluctuation at every 0·1 foot of head was obtained by taking the variation between the heads 0·05 foot above, and 0·05 foot below it, and with these figures the curve was drawn. Then, to find out the critical head for any outlet on any distributary, all that is necessary is to turn up Kennedy's hydraulic tables, and find out the variation in percentage between the full supply discharge, and the discharge given by foot less 1·0 than the full supply. This will give the variation, and projected on to the curve will give the critical head. This is, however, still not the correct head, and would only apply if the whole of the water entering the distributary were useful. To get the correct head, the absorption losses, etc., have to be calculated, and using these, the correct variation is given by the following equation.

$$A.V. - \frac{A.L. \times A.V.}{F.S.} \times 100$$
$$F.S.$$

Where $A.V.$ is the actual variation in cusecs per 0·1 foot depth, $A.L.$ the absorption losses in cusecs, and $F.S.$ the full supply in cusecs.

This equals the percentage of useful water variation per part of actual fluctuation in the distributary water level, and when projected on the curve (Diagram No. 1) will give the critical head. This has been found to be approximately 0·5 foot for almost any channel, designed from Kennedy's tables, having a discharge anywhere between ten and two hundred cusecs, and of normal non-silting proportions.

Diagram II was prepared to find the type of outlet best suited to fulfil these conditions. First, a discharge curve of the distributary was prepared in percentages which would be of general use, and then a curve for the discharge of the useful water only, as

this was evidently that to which the discharge curve of the outlet would have to conform. Discharge curves of a Kennedy's outlet, and also of an ordinary outlet with 1·5 feet head, plotted for comparison, clearly show the discrepancy; for instance, when the total discharge is sixty per cent., the useful water is only fifty-two per cent., while a Kennedy's outlet would draw eighty per cent. and an ordinary outlet with 1·5 feet head seventy-five per cent. As will be seen from the diagram the discharge curves of the outlets bend in the opposite direction to those of the distributary, and although by reducing the head on the outlet by a raised down stream flume, the two curves could be brought close together, the sill of the flume would be so high that the outlet would not be able to draw any water when the distributary was discharging less than about seventy per cent., and only its proper share when the distributary was drawing more than about eighty per cent. This was obviously much too narrow a limit to put upon the outlet, so a taper notch suggested itself, and a number were calculated and their discharge curves plotted to arrive at the one most nearly conforming to the conditions imposed upon it, namely, to give a more or less proportional discharge through fifty per cent. fluctuation, to draw off water with a discharge as low as twenty-five per cent. and to be a practical type so that one pattern would suit a large range of discharges.

Diagram III illustrates a design for a notch giving a discharge of two cusecs, which is a very average size for an outlet. This is capable of being adapted for notches giving a correct discharge of from 0·4 to ten cusecs at full supply, and varying less than five per cent. in the extreme sizes for fifty per cent., discharges. The discharge curve for the two cusecs size has been plotted, and shows that the maximum difference of proportional discharge to the useful water curve is only two and a half per cent. The formulae used for calculating the notches were based on those given in Punjab Irrigation Branch Paper No. 2, but modified with respect to the velocity of approach, which was omitted, owing to the design and the adoption of the constant 0·67 instead of those given.

At full supply a head of 0·5 foot combined with a notch of 0·8 foot in depth was found to give the best results with $N = 2 \tan \alpha = \cdot 44$; α being the angle of the side with the vertical.

The width of sill was also calculated for various discharges between 0·4 and 10 cusecs, when the points plotted showing a straight line from which the width of the sill could be obtained for any desired discharge. With these conditions, the percentage

deviation varied less than five per cent. from those desired in the extreme discharges.

The notch itself is composed of three iron castings of metal thick enough to resist easy fracture, and so designed that by sliding the side pieces on the sill plate any size of notch can be made. The sill plates can be made in various standard lengths, and the bolt holes specially drilled for each outlet.

The rest of the design is simply a tank, with the inlet at one end, the notch fixed across it, and open at the other end to the watercourse.

The Karkan Distributary.

An examination of the gauge sheets of the Karkan distributary in the Upper Gugera Division of the Lower Chenab Canal, showed how very sensitive the tail gauge was to fluctuation of the head gauge, the percentage of fluctuation apparently being greatly magnified as it reached the tail, and as there was only one type of outlet on the distributary for four-fifths of its length, it was presumed that the design of these outlets, was responsible for this state of affairs. It was also noticed that other distributaries, with ordinary outlets, suffered in the same respect, though not to the same extent.

Diagram IV was prepared to test this. The distributary was divided into reaches, each containing a group of outlets, and the discharge of each group plus the absorption, etc., in the reach was totalled to give the consumption of that reach. Assuming that the absorption figure was constant for all levels of supply in the distributary the points on the curves were fixed as follows :—

The percentage discharge drawn by a Kennedy outlet was calculated on the assumption that the head gauge had dropped to ninety per cent. and this percentage was taken as the amount of water drawn by the first group of outlets, which, added to the absorption losses, gave the total quantity of water used in this reach. This was then subtracted from the ninety per cent. discharge assumed at the head, and the remainder taken as the discharge passed on to the next reach. This quantity, considered as a percentage of the supply passed on with a full supply at the head, gave the first point on the diagram, and the operation was repeated for each group of outlets, taking the supply in each case as the amount passed on from the previous group of outlets. The points were calculated in a similar manner for sixty, seventy, and eighty, as well as for a hundred and ten, and a hundred and twenty

per cent. discharges at the head. As it was noticed that the proportion of the absorption losses, etc., to the water drawn by the outlet in each reach, varied, a curve was drawn showing the absorption water, etc., passed on by each reach as a percentage of the full supply of this reach. The difference between this curve and any of the above mentioned curves, then gave the amount of useful water passing in any condition or at any point of the distributary. Having obtained these curves, they proved a very instructive study, and clearly show that the Kennedy outlets, working with a submersion equivalent to a head of two feet, draw much more than their share of the water when the distributary is not running at full supply. The supply arriving at the last outlet is consequently very sensitive to any reduction at the head ; for instance, if the distributary is reduced to ninety per cent. discharge at the head with a drop of 0·15 foot, only seventy-five per cent. of the supply arrives at the tail, while a drop of twenty per cent. discharge produces fifty per cent. shortage at the tail, and when low supplies are running, for example sixty per cent. discharge at the head, only seven and a half per cent. arrives at the tail. A distributary with ordinary outlets, having an average head of 1 to 1·5 feet, would be nearly as bad.

Curves have also been drawn on the diagram, assuming the distributary to have been designed as advocated in this paper. These show considerable improvement, and for all practical purposes the percentage discharge is within a reasonable margin of the absolutely correct.

It will be necessary to experiment with this type of outlet in order to ascertain the co-efficients for the notch, as this is much smaller than any for which the formula was prepared, and friction, etc., may have some effect for which allowance cannot now be made, so that it is quite probable that the design of the outlet may require further modification. The calculations for the design are based on data, which although applicable, may be open to correction, and as far as details go, it is very possible that the design itself is susceptible of further improvement.

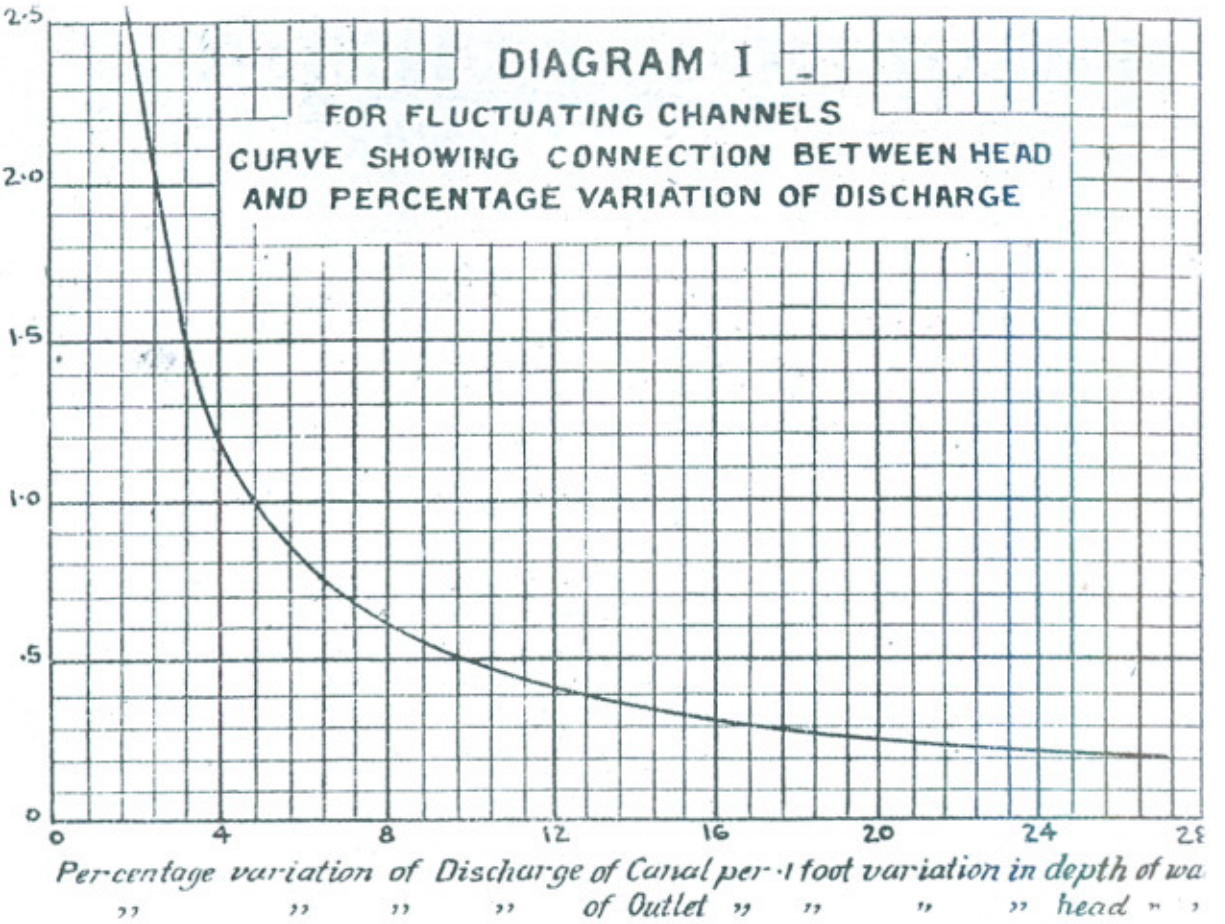


DIAGRAM I
FOR FLUCTUATING CHANNELS
CURVE SHOWING CONNECTION BETWEEN HEAD
AND PERCENTAGE VARIATION OF DISCHARGE
2·5
2·0
1·5
1·0
·5
0
0
4
8
12
16
20
24
Percentage variation of Discharge of Canal per ·1 foot variation in depth of wa
" " " " of Outlet " " " " head " "

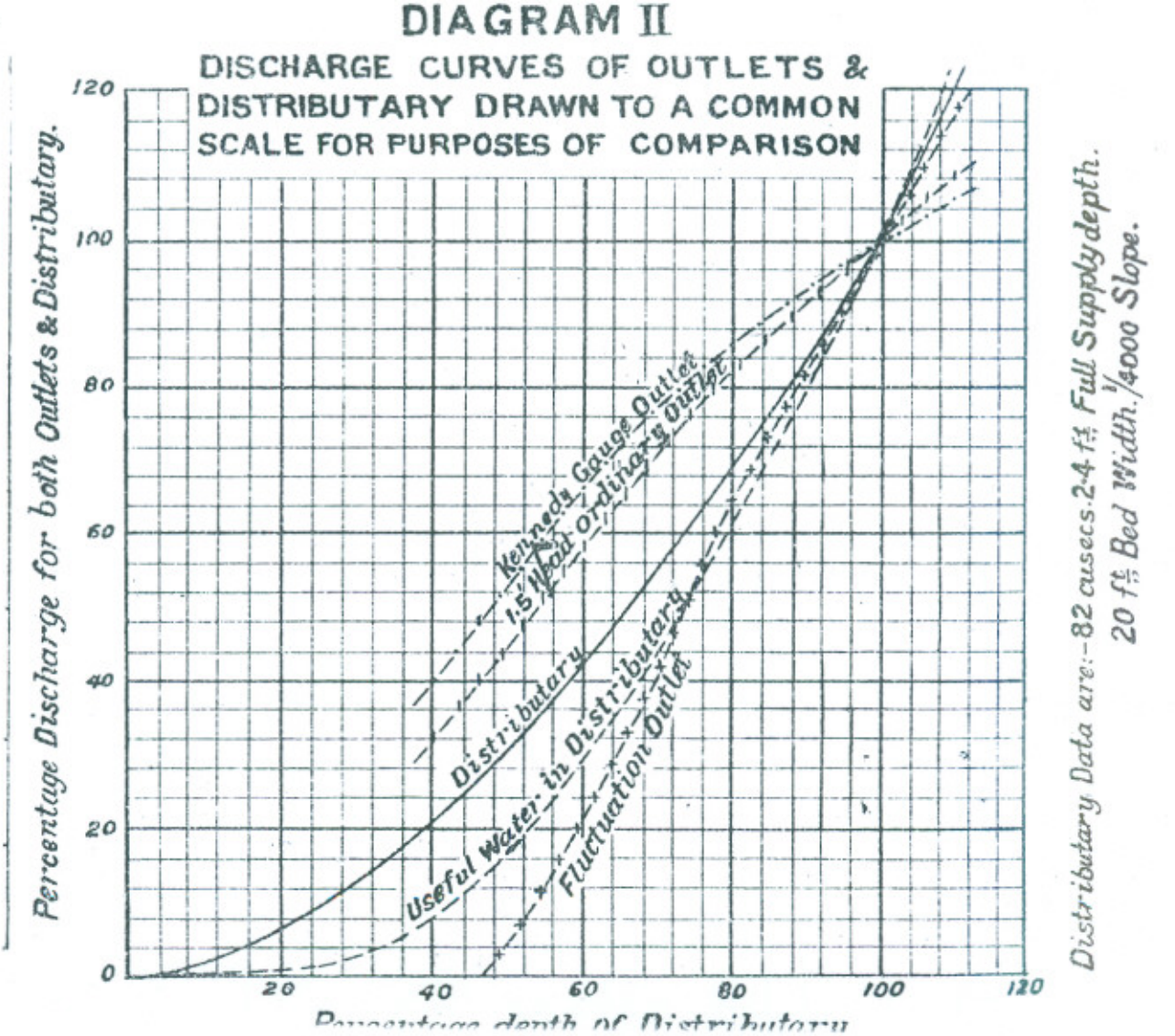


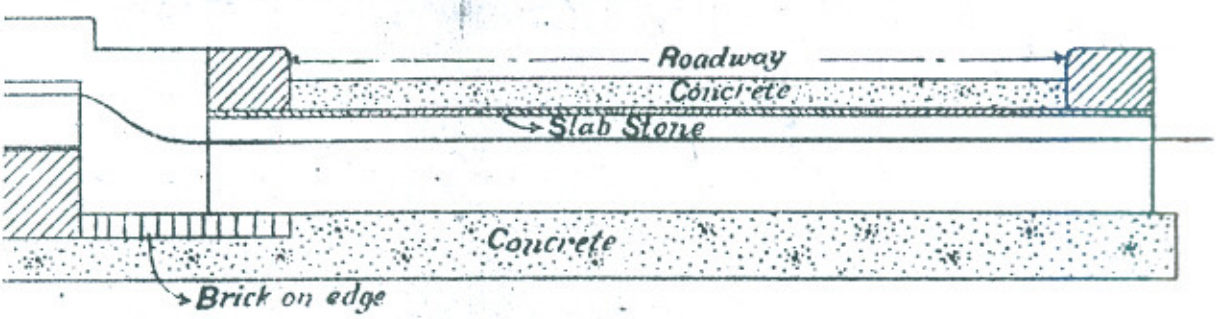
DIAGRAM II
DISCHARGE CURVES OF OUTLETS &
DISTRIBUTARY DRAWN TO A COMMON
SCALE FOR PURPOSES OF COMPARISON
Percentage Discharge for both Outlets & Distributary.
120
100
80
60
40
20
0
20
40
60
80
100
120
Kennedy Gauge Outlet
1.5' Head Ordinary Outlet
Distributary
Useful Water in Distributary
Fluctuation Outlet
Distributary Data are:- 82 cusecs. 2·4 ft. Full Supply depth.
20 ft. Bed Width. 1/4000 Slope.

DIAGRAM III

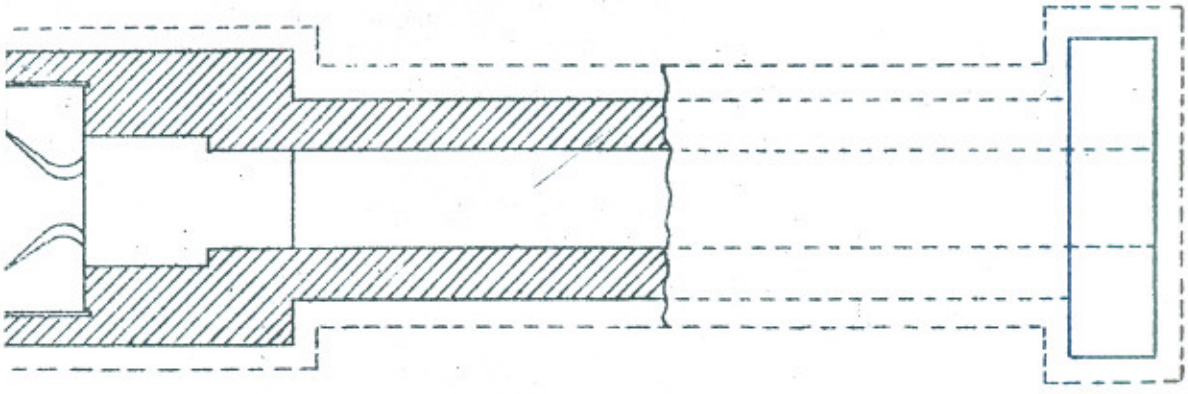
YPE OUTLET WITH BOUNDARY ROAD CULVERT

Scale 1/50 Feet

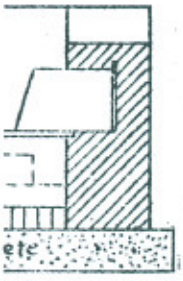
LONGITUDINAL SECTION



PLAN

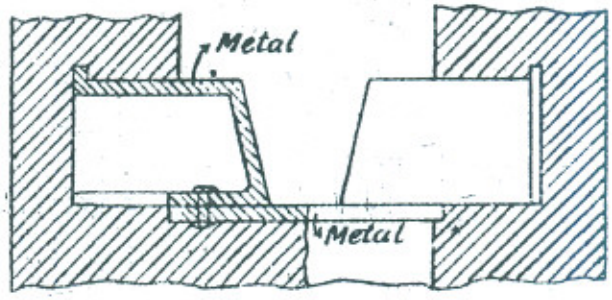


SECTION



DETAILS OF CAST IRON NOTCH

Scale 1/25 Feet



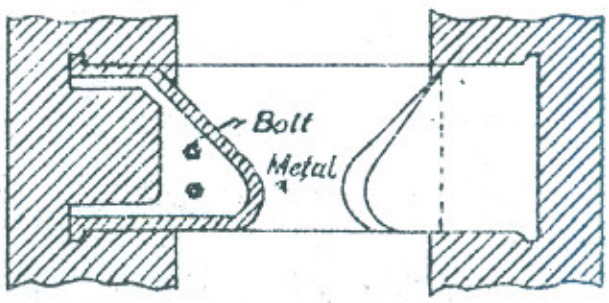
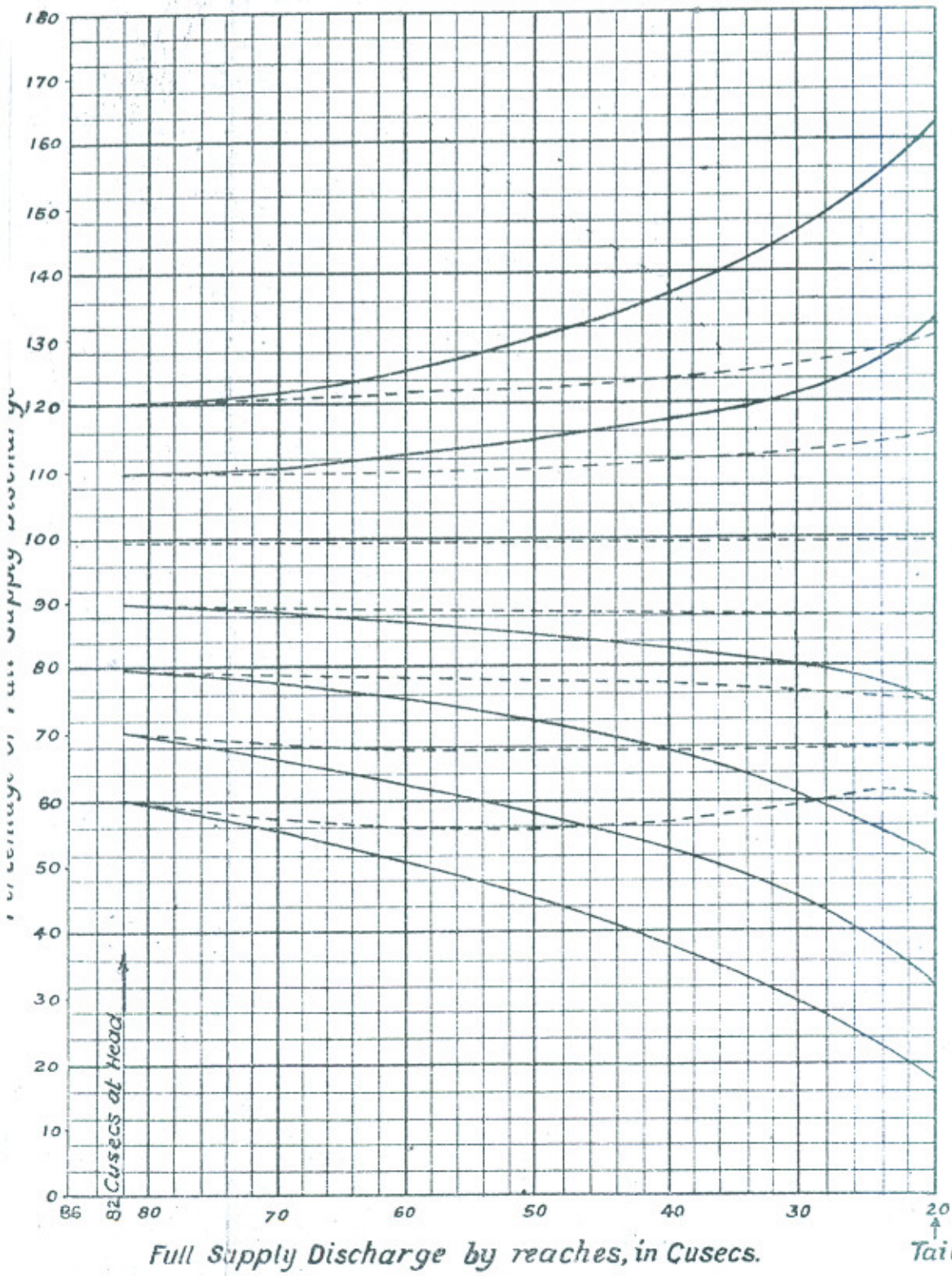


DIAGRAM IV

SHOWING THE EFFECT OF A FLUCTUATING SUPPLY ON THE DISCHARGE OF A DISTRIBUTARY

(1) With Kennedy Gauge Outlets fixed ————

(2) With Outlets designed as advocated in this paper ---------



DISCUSSION.

MR. WATERHOUSE, in introducing his paper, said that he appeared to have treated the subject too much in detail and with too little regard to the principles involved. Nobody would refute the statement that the number of low paid officials in charge of the regulation and control of the water did not lead to efficiency. It seemed to him that the aim should be towards centralizing the control of the supplies, similarly to the control of an electric railway, and fortunately a cheap source of power was available. With this object in view, the proposals in the paper were put forward as the first step necessary. After remodelling the distributaries, as proposed, electric recording gauges should be installed at the head and tail of each; the head regulator would be worked by electricity, and each system would have one centralized control like a signal box, with electrical recorders and automatic controls for the gates. He suggested that this would not only save water, but would probably prove cheaper in the end, than the present system of numerous low paid officials, etc. Another point, which he did not think he had brought out sufficiently, was that of excess supplies. He had never met an officer who was willing to take even five per cent. more than his indent in cases of emergency. Such a system led to the loss of much valuable water at times when it was badly wanted. He had seen quantities varying from one to five hundred cusecs going to waste on a canal carrying ten thousand cusecs, for want of interest in the matter. A system, such as proposed, would do away with this altogether. The regulating officer would distribute any such excess over the whole canal evenly, so that it would be usefully employed.

MR. A. N. LUCEY thought that it wss clear from Mr. Waterhouse's interesting paper that he disparaged the sound principle of "full supply or closed" in connection with the regulation of supplies in distributaries. In fact he advocated allowing channels to run with any fraction of their full supply, and provided his proportional discharge type outlets to take the same share of the discharge. Rather than thus encourage fluctuating supplies, with their host of attendant evils, not the least being silt troubles, it would be better that attention were first directed to ensure that the head of a distributary received only its full supply, neither more nor less. This was easier said than done, but it could be brought about by having a recognized policy

of rotational closures of distributaries, the management being in the hands of one person, deputed for the purpose, or by abolishing the present inaccurate method of measuring by the supply gauges, and maintaining a correct and constant supply at the head, by taking occasional discharges, and fixing indents, discharge tables, etc. The head regulator should be converted into a tended module, by which he meant one that was not automatic and rigid, because obviously it would be unsafe and impractical to instal a rigid type of module. Mr. Kennedy in his last pamphlet on gauge outlets wrote as follows :—The method of rotational closures by distributaries is undoubtedly the most efficient system and the only practical one when water economy has to be practised, though it still leaves those persistent minor fluctuations of supply which can never be overcome, due as they are to opening and closing of far distant channels, varying supply in the river, varying demand varying watercourse capacities, varying absorption losses, and to the difficulty of regulating and measuring a correct supply at distributary heads. This last trouble is accentuated by the primitive method of regulation in use, where a gauge reader merely does his best to keep the gauge reading at some given figure ; not an easy matter however conscientious the man may be. Moreover, a steady gauge reading would not necessarily mean a steady discharge, as the regime of all channels varies more or less during the seasons." If then the principle of rotational closure of distributaries were accepted, it was necessary to face the problem of reducing the effect of the necessary canal fluctuations on the distributary supplies, so that each distributary would, when in flow, give at the head a steady and constant discharge, which should be its authorized discharge. If this could be done efficient distribution followed naturally. The conversion of the present type of head regulator into what has been termed a tended module has already been mentioned. This presented no difficulties and only slight alterations in the design would be required. The sill directly under the gate would be redesigned and lowered somewhat ; a silt wall would be built ; and the springing of the archway supporting the patrol road would have to be quite clear of the distributary supply level. When the distributary was in flow, with the gate raised, the water area enclosed by the bottom edge of the gate, the sill, and the two side walls, would constitute a submerged orifice through which the discharge would vary as the square root of the working head, and to obtain a constant co-efficient for all fluctuations of head, the edge of the gate, sill and sidewalls

would have to be sharp edged. A table, showing the relationship between the working heads and the area of the orifice, could easily be prepared, and a copy given to the gauge reader, who would have to read periodically (say every two hours) two gauges, with their zeros fixed at the same level, one near the upstream and the other near the downstream end of the orifice but placed at a sufficient distance from it to be in smooth water. The difference of the readings of these gauges would give the working head and enable the gauge reader to correct the size of the orifice to the correct discharge by raising or lowering the gate. Two further suggestions were that the gauge reader should be provided with a timepiece for noting and recording the exact periods of rotation flow, and that a "tell tale" should be fitted downstream of the regulator to shew whether the gauge reader had, purposely, sent down during the night time an excess supply. Having thus dealt with the head of a distributary, it would be unnecessary to consider such outlets as mentioned by the author. Kennedy gauges would be installed in each outlet with a poor to medium working head, while for those with large heads ordinary pipes would suffice. These latter, however, would not be laid horizontally through the bank as at present, but the upstream end would be laid with its bottom level with the silted bed of the distributary, while the downstream end of the pipe was raised so that the bottom was level with the normal full supply level of the watercourse. Under these conditions, the pipes would discharge with a free fall, under a head equal to the difference in level of the full supply level in the distributary and the level of the axis of the downstream end of the pipe. A gauge would be fixed vertically over the upstream end, the discharge markings thereon being obtained by actual observations in the watercourse with a Cippoletti weir. These pipe outlets would be thus converted into gauge outlets, drawing their fair share of silt and being entirely tamper proof. Cultivators could not increase the discharge by silt clearing their watercourses ; on the other hand, if they were slack and allowed their watercourses to silt excessively, the level in the watercourse would rise above the bottom of the downstream end of the pipe, thereby decreasing the effective working head and lessing the discharge. The distributary being installed with Kennedy gauge and pipe gauge outlets, during every rotation flow, all the gauge scales would be read and recorded and their total compared with the steady head discharge given as described above. Any persistent errors in the discharge readings and facts dealing with regime, *i. e.* silt

deposits would be instantly detected and corrected. A few proper walls would be built, and the tail cluster could consist of taper notches similar to those suggested by the author.

MR. R. P. HADOW said that some members might have experienced the same difficulty as himself in following the discussion, for want of a definition of a "module". The word was used by early engineers, last century, to mean a meter for measuring water. Later the Kennedy module gate appeared, to give a constant discharge ; after that came the Gibb's module, the Kennedy semi-module, and now Mr. Lucey spoke of a "tended module". He thought it would clear the air for further discussion, if the word module were defined.

Mr. E. S. LINDLEY, referring to Mr. Hadow's remark, said that a module originally meant a device for measuring water, but in India the word module had come to mean a device to pass a fixed supply of water. He did not know when this interpretation started, but he found that the Irrigation Commission of 1901 had adopted it.

The semi-module was so called because the discharge through it was independent of the level of the tail water ; the tended module apparently measured the water passed, and was the system adopted by Sir John Benton, as detailed in Irrigation Branch Paper No. 8 "Experiments on gauging the supply entering rajbahas by means of the head gates."

Three points in Mr. Waterhouse's paper called for discussion ; his contention that rateable distribution would be better than modular ; his proposed system of outletting ; and his pattern of a rateable outlet. The author appeared to be under the impression that the attention given to developing modules was only due to the opinion of those who had designed them, and his treatment of the question showed that he was unaware that the policy followed was due to the Irrigation Commission of 1901-03, and so had more weight behind it. The Commission concluded that it was not only desirable eventually to substitute assessment by volume for the present system of assessment by area, and that this could only be attained gradually after popularising distribution by volume, but also tha[t] without any change of assessment, distribution by volume wa[s] desirable. The Commission discussed the relative merits o[f] metered and modular supplies, and pronounced strongly i[n] favour of modular. The zemindar was to pay "at a moderat[e]

and uniform rate for the supply placed at his disposal, and not, as under the meter system, at a much higher rate for the amount which he actually takes : under the latter system he might in a dry season have to pay more than the crop was worth, while in a wet year he might pay only a trifling sum for a single watering necessary to save a valuable crop, that he would not have sown but for the knowledge that he conld get water when needed." Distribution by meter would also greatly increase fluctuations of local demand, and there would be claims for the remission of the price of water indented and arranged for, if it rained while the water was on the way, on the ground that by the time it had arrived it was too late to be of use.

It was claimed that rateable distribution would make it possible to utilize any excess supply available ; and the enlarging of channels with this object was already under consideration, but there was a limit in this direction in that water really wanted at a certain date could not be replaced by water given more than a short time before or after ; there was also a limit to the extent to which it would pay to gamble in sowings on the possibilities of a supply to mature the sown area. It was also claimed that shortages could be better utilized under the system advocated ; but the limit that "command" set to this possibility was not realised. If a number of channels of different sizes were run at a low supply, say half supply, the ratio of the running to the full supply depth was the same in all ; that is, the drop from full to half supply level was proportionate to the depth. For the low supply to be of any use at all, it must be delivered at a level that would command the land on the watercourse, so that the distributary must have a command equal to its full rise from reduced to full supply. Similarly, a branch running with a low rate of supply would lose command of many of its distributaries. This lower limit, specified by Mr. Waterhouse, was therefore not workable in practice ; even seventy or eighty per cent. would exclude so many distributaries and outlets that the system would not be better than the present one of running within a small margin of the full supply.

The author claimed that various objectionable features ar.rotations would be done away with, but he neglected, for inmple, the objections of the cultivator, whose turn occurred ofring a low supply ; not only his rate of supply would be of than that of others, but also a low rate of supply would be press as not being capable of watering a field. They had

all experienced the difficulties due to the fluctuations of a silted bed caused by a varying supply in the branches, from which all the offtakes had been regulated, and similar variations of supply would cause similar fluctuations of regime in distributaries, and make any kind of exact distribution impossible.

As to the detailed proposals for outletting, no one would quarrel with the proposed moduling ; but the watercourses, with smaller working heads, which he proposed to fit with ordinary pipes, were just those that most needed moduling. A Kennedy gauge outlet, as ordinarily fitted, certainly consumed 0·30 of its depression head, but a ratio of 0·22 was attainable, and where necessary more careful fitting must be insisted on, and less depression used. Since such a gauge outlet multiplied, by about four, the head on which the discharge depended, it halved the variation of discharge, but it would be infinitely more to the point to refuse permission for irrigation by flow to all land that could not be commanded with a sufficient working head for the outlet. As to the " long masonry flume to control the head," what degree of control would be secured and at what cost ? It was not understood why the rateable outlet should not serve at the tail as well as higher up.

As to the outlet itself, one with 0·8 foot depth of notch and 0·5 foot working head, that is a drowned weir, had been specified, but according to commonly accepted theory the discharge would not be independent of silt clearance in the watercourse. Did Mr. Waterhouse calculate on the unproved and little known theory that the discharge of a broad-crested weir was independent of the downstream levels up to an appreciable degree of drowning ? From his description it was not clear that the crest of his notch was 0·8 + 0·5 ft. below the distributary water level. The notch being necessarily at the surface, he proposed to make the outlet draw its share of silt by a low level orifice in an advanced tank, and since as much of the working head as possible was wanted for the notch, the conditions at the mouth of this orifice were those of an ordinary outlet with next to no command, and such always silted themselves up hopelessly, even when the orifices were raised.

The system of distribution, that at present seemed to him best, was as follows. A careful restriction of any extension of flow irrigation to poorly commanded land, while as much as possible should be done to diminish this abuse where it had already crept in or been allowed. Taking into consideration

present conditions of supply, and what must be allowed as more or less established on running canals, full supply factors must be revised, as the proportion of kharif to rabi would depend on these, and the kharif should be the crop calculated for, as then supplies were assured, while annual permissible percentages and duties might well be taken nearer actuals, and distributaries moduled. In those reaches in which there were unavoidable fluctuations during the year, rigid modules should be fitted, and in the rest of the channel gauge outlets should be fitted with submersions gradually diminishing towards the tail. The tail cluster, and perhaps a few outlets above it, should be of the open weir pattern to absorb such excesses as were unavoidable. In kharif, the distributary would be run strictly at its authorised full supply, and all outlets fixed with regard to the levels at which this supply ran. In rabi rotational turns, the rate of supply to be run would be that found to give lower outlets such excess as would compensate them for the shorter length of turn reaching them. Partial cessation of demand seemed generally to be near the head, and if upper outlets, such as have great command, were fitted with weirs to prevent their drawing from low supplies, these supplies would go to the tail where they were wanted. It was not necessary to say that such a policy would be laid down only for guidance and not for rigid adherence, irrespective of its applicability to every outlet.

At the same time, distribution and statistics called for much improvement in the method of estimating supplies. Discharge observations were not accurate enough in general, and, though already a considerable labour, did not promptly catch all variations, and were not recorded at enough places. There were many works that could be accurately calibrated, and more that could be calibrated if they were slightly modified for the purpose ; while, where no such work existed at a point at which a record of discharge was wanted, a Venturi flume should be built.

MR. W. B. HARVEY stated that Mr. Waterhouse was incorrect in supposing that no effort was being made to provide an outlet which would give a supply proportionate to the supply in a distributary. Mr. Stoddard and himself had, after a number of experiments and much theory, arrived at two possible types, one of which partly and the other entirely satisfied the conditions of proportional discharge, as well as several other necessary condi-

tions. Both types depended on the formation of a standing wave for recovery of head. The first consisted of a rectangular orifice discharging into a rectangular open-topped flume. So long as a standing wave was formed in this flume, below the orifice, the discharge of the orifice varied as the square root of the submergence, *i.e.*, the depth from full supply water level in the distributary to the water level in the flume at the orifice. In fact it was similar in its action to the Kennedy gauge outlet. By sloping the floor of the flume suitably, the wave could be made partly to drown the orifice for the decrease of water level in the distributary. If this were done, and the submergence made equal to two-thirds of the depth of the distributary, the discharge of the outlet would decrease at the same rate as the discharge of the distributary, while it would increase at half the rate. The loss of head was about one-third of the submergence. A minor in the Mardan division had been fitted with outlets of this type, built in brickwork and reinforced concrete, at a cost of Rs. 40 per outlet. Exhaustive trials had not yet been made, but there had been no complaints. In the case of deep distributaries it was necessary to provide an orifice at the bed level of the distributary and set back the outlet suitably so as to take its share of silt.

The second type was not unlike Mr. Waterhouse's proposed outlet. In place of a notch, a rectangular contracted flume was used, the width of which, at the narrowest point, would ordinarily be three inches, while its depth would vary with the discharge beyond this point, the vertical walls of the flume diverging gradually. The floor might be either sloping or horizontal. Such a flume, if properly designed, would give a discharge independent of the water level at its outfall, until the difference between this water level and the water level upstream was about 0·1 or 0·2 ft. for usual discharges. This flume had been used by Mr. Jeffries for some years for distributing water at the tails of channels and had given satisfaction. Mr. Waterhouse's notch would apparently be drowned for high water levels downstream.

In order to use the flume for all outlets on a distributary, it was necessary to add an orifice at bed level, as shown by Mr. Waterhouse, and in order that the discharge of the outlet might vary as the discharge of the distributary, both for ordinary increases and decreases of supply, the level of the floor of the flume and the loss of head through the orifice would have to be

calculated for each case. A general equation for this could be obtained in the way explained by Mr. Padday last year in the discussion on Mr. Varma's paper on outlets.

MR. QUINN-YOUNG was of opinion that until a perfect non-berming, non-silting, distributary could be achieved, it was not possible to aspire to a perfect module. Two conditions were necessary for the distribution of water by modules, namely, the complete eradication of silt from canals, and the sale of water by bulk. Water must be given in a measurable, and not in a stipulated supply. The simple notch, which was nature's way of splitting up supplies, did not require any of these restrictions. There was no mystery about it and the cultivator was accustomed to it. He recommended that distributaries be raised, if necessary, until it was possible to replace every outlet by a notch with its lip at bed level. These notches would be designed so that each drew its proportionate share of the supply in the distributary as the latter rose or fell. He agreed with Mr. Waterhouse that the use of the Kennedy gauge outlet was limited, and that the gain or decrease in the discharge of the outlet was not proportional to the variations in the supply in the distributary.

MIAN IQBAL HUSSAIN said that Mr. Waterhouse had suggested restrictions in the use of the Kennedy gauge outlet. He had made experiments with these outlets in a case where it was not possible to obtain the head necessary for modularity, and found that the necessary head could be reduced if the delivery pipe were altered so that the standing wave occurred nearer the jet. Such an artifice would widen the opportunities for the use of this outlet.

MR. WOODS thought that Mr. Waterhouse's experience of the difficulties met with in the distribution of canal water had been gained chiefly on the distributaries of the upper Gugera branch of the Lower Chenab Canal. The conditions of these channels differed from those prevailing on other branches of this canal, as well as on other Punjab canals generally, with reference to the fact that the water surface level of the Upper Gugera branch of the canal could not be raised higher than its present full supply level, and that this level was not high enough to command adequately, by flow, a good deal of the ground surface to be irrigated by the distributaries of the canal. On other branches of the Lower Chenab Canal, and on other Punjab canals, if the water surface level of a distributary were not high

enough to command by flow all the ground surface, which it was designed to irrigate, it was generally possible to raise that water surface level, and even that of the parent canal, to the extent necessary to give adequate command ; and under these circumstances it was generally practicable to work the distributary under full supply conditions, and to distribute its supply with a fair degree of equity through pipes of masonry or metal, or through modules of fairly constant discharge.

Even in the case of the upper Gugera branch of the canal, it was practicable to ensure that it would always flow, in rotational periods, with a full supply ; and if this were done, its distributaries also could be worked rotationally with fairly constant conditions of flow. It happened that, during the winter of 1916-17, this canal was not worked on this system, but on one which gave it less than the full supply for relatively long periods, instead of a full supply for relatively shorter periods, and this, apparently, had led Mr. Waterhouse to devise a scheme that might ensure a distributary flowing with only a certain fraction of its full supply, giving each of its outlets or watercourses the same fraction of its own full supply. When, however, the Gugera branch was worked with a full supply, as would be generally practicable, the difficulties of distribution of supply, felt so keenly a year ago, would, for the most part, disappear.

Mr. Waterhouse was too sweeping in his condemnation of modules, possibly due to a limited experience of channels which worked under conditions that were admittedly unsuited to these machines. When a certain minimum head of pressure was available at an irrigation outlet, say not less than about six inches, not only the types of modules chiefly in use in the Punjab, but even plain pipes or tubes of masonry or of metal, could generally be relied on to control the distribution of the water supply equitably under normal conditions. It was when the head of available pressure was low, say less than six inches, that the module or pipe outlets failed, or gave trouble. A module or meter had yet to be discovered that would work accurately under low heads of pressure.

To meet the difficulty of dealing with the water supply to high lands, Mr. Lindley and other speakers had suggested that this could be got over by demarcating such lands on the contoured irrigation maps, and refusing to supply water to them. This, however, was an evasion of the difficulty rather than a useful solution of it. To exclude such land from irrigation

operations would sacrifice an element of the natural wealth of the country, whilst it would give rise to infinite administrative trouble. It would be difficult, in practice, to determine which particular fields in any locality were at so high a level as to merit exclusion from irrigation schemes, because the height of any field, relatively to the source of its water supply, varied not only with the relative levels of the water surface at the source of supply and of the land at the site of delivery, but also with the distance of the field from the source of supply and with the quality and proportion of silt in the water, and since this varied in different localities on the same canal, and even at different seasons of the year in the same locality, it would be realized that the same field might be well commanded or badly commanded at different seasons of the year, and that this fact alone would give rise to perpetual disputes, complaints, and administrative trouble.

MR. T. M. BOSTOCK wished to amplify one of Mr. Lindley s remarks. There was far too much hesitation in excluding poorly commanded land from flow irrigation. Compliance with the cultivators' wishes and science were in this case completely antagonistic, and the best engineer was the man who could say no, when giving a concession to any particular individual meant completely ruining a system of irrigation which had been scientifically designed. It was imposing no great hardship, as people seemed to think, to make a cultivator lift water one or even two feet. In fact he got a very good bargain, because he obtained without much trouble a good and certain supply at half the usual water rates. He had not experienced the difficulties alluded to by Mr. Woods, when converting flow irrigation into lift.

MR. C. A. COLYER thought that Mr. Waterhouse had assumed a good command with which his notch-outlet could work, whereas the real difficulty lay in many outlets having a poor command. It was in these latter cases where a notch outlet would fail that the Harvey-Stoddard outlet was useful. The fact had also been ignored that the discharge in a Harvey-Stoddard outlet varied up to a certain stage as Kh and thereafter as Kh^2, where h was the depression, and this gave great possibilities in the way of arranging the depression to suit the varying conditions of the head and tail reaches of a distributary.

MR. WATERHOUSE, in reply, said that the discussion on the "full supply or closed" as against a proportional supply really amounted to a comparison between the human element and a mechanical or automatic arrangement. In the full supply or

closed theory, everything depended on the integrity of the gauge reader, the zilladar, and the patwari, as they were the persons who carried out the opening and closing operations, and, as Mr. Lucey had stated, even if these duties were carried out in a conscientious manner, the results were far from perfect, while the average gauge readers, etc., were far from conscientious. On the other hand there was no practical limit to the development of automatic control. Modules and gauge outlets might be called automatic, and he had not intended to decry all such machines, but only those that were designed irrespective of the ruling conditions, of which the chief was that the working head should discharge proportionally to the discharge in the distributary. The machines chiefly in use at present, instead of compensating for the fluctuations due to imperfect control or other causes, aggravated their results. As the full supply or closed practice was in force, he did not think it necessary to go to the expense of elaborate machines, when a simple cast iron or steel pipe, especially if fixed as proposed by Mr. Lucey, would work quite as well, and be less liable to get, or be put, out of order. A module or gauge outlet, as designed at present, had its place in the reach of a distributary subject to silt fluctuations, while the extent of the reach depended on local conditions, but it was usually not more than fifteen per cent. of the total length of the distributary. The plea for uniformity was the reason for extending the use of these machines beyond a reach where such conditions prevailed, and this led to extra expense. As it was acknowledged that the supply to a distributary could not, under any circumstances, be kept steady at the head, there was no reason for using such unsuitable outlets in places where they were not required, as they only aggravated the unsteadiness of the discharge at the tail. As a steady and constant discharge was impossible, the aim should be to give a proportional distribution of whatever supplies reached the distributary. With reference to Mr. Woods's remarks that the 1916-17 conditions on the Upper Gugera branch were not likely to occur again, he thought it improbable that they would occur in such an acute form, but the difficulty would arise every year as to the fairest method of distributing the balance in the Gugera branch, when the lower section of the main canal were running with a full supply. The water surface level would be too low to give a full supply to most of the channels, and where these were moduled, the conditions discussed in the paper would re-appear, with a period of full supply in between, instead of a period of no supply.