face wall is set back by an amount represented by $\frac{q}{Q}$ of the water-way of the channel. The same waterway is given to the outlet at its mouth. The length of the flume downstream of the crest depends on the size of the distributary bank, but the width in feet of the flume at its downstream end is kept the same as the discharge of the outlet in cusecs. The slope of the downstream glacis is not defined and depends on the bed level in the watercourse.

The M. M. H. adopted is 0·15 to 0·2 of G.

(*ii*) *Haigh's modifications.* Mr. Haigh has suggested that the upstream approaches should be bell mouthed with the roof of the bell mouth removed (see plate 12). In his design, the length of crest and the length of throat is fixed at 2·5 ft. for all sizes. The slope of the downstream glacis is determined by the discharge of the outlet as shown on the drawing. The width in feet of the flume at its downstream end is kept $=\sqrt{q}$, but the length of the flume varies with the size of the bank.

(*iii*) *Sharma's modifications.* As a result of the experiments carried out by Mr. Sharma under the guidance of Mr. Crump, the following changes in the design of the Crump's original open flume were suggested*:

The radius of the upstream wing wall is made sharper than in the original design. The downstream wing wall instead of being straight is curved and is given a flare as shown in the plan in plate 8. The length of the crest and the length of the gullet is reduced to 2 H. The downstream glacis is given a slope of 1 in 5 for a length of 5 ft. and the downstream flume walls are curved in a radius of 25 ft.

The changes in the upstream approaches are designed to induce more silt into the outlet than in the original Crump's design, and the changes in the downstream flume are designed to make the work follow standard dimensions. The shape of the outfall otherwise is a matter of minor importance in the case of long throated flumes, for it only affects the M. M. H. to a small extent. Mr. Sharma contends that his experiments have shown that with the modifications mentioned above, the open flume outlet when set at 0·9 D will take its fair share of silt. The M. M. H. is about 15 per cent of the depth on crest.

When the width B_t of the flume works out to less than 0·3', Mr. Sharma suggests a narrow-throated flume in which the length of the gullet is only 6", but there is no level crest. His experiments, however, show that there is considerable variation in the value of the co-efficient K, and the values of M. M. H. are also not very consistent.

(*iv*) *Jamrao type open flume.* This type (see plate 9) was evolved as a result of experiments carried out by Mr. W. Kirkpatrick and introduced for the first time on the Jamrao Canal sometime about 1925. It is really a modification of the Harvey outlet described in para 6 *supra.* This outlet has no level crest and has a short-throated section about 2" or 3" wide, where an angle iron frame is fixed. The upstream approach is 2 ft.

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*Punjab Engineering Congress Paper, No. 237 "Improved Adjustable Proportional Module and open flume outlets" by K. R. Sharma.

long and has a splay of 1 in 4. The downstream approach flume is 10 ft. long and the width of the flume at its downstream end is 3 B_t. Mr. Kirkpatrick found that the shape of the upstream and downstream flumes were not susceptible of further improvement and that any further increase in their lengths or rates of divergence could not improve upon his type design. The values of co-efficient K in the formula $q = K\ B_t\ G^{1\cdot5}$ were not found to be constant for different values of G, but if the index 1·5 were changed to 1·6, the formula agrees within 3 per cent of the actual observations, which covered a wide range of both B_t and G. The discharge formula as evolved by Mr. Kirkpatrick for this type of open flume outlet is $q = 3\cdot2\ B_t\ G^{1\cdot6}$. The M. M. H. found to be necessary is $= \frac{G^{1\cdot6}}{7}$.

It will be seen that the M. M. H. required for this outlet is more than that required for the Crump type of open flume outlet; also the narrow open flume outlet suffers from two other defects :—

(a) The control section does not remain within the angle iron frame as the depth on crest increases.

(b) These outlets are more susceptible to getting choked with jungle than the long throated open flume.

The zamindars in the Punjab would look with scorn at any attempt to prevent tampering of the control section which consists of only an angle iron frame.

9. Orifice semi-module. An Orifice Semi-Module consists essentially of an orifice provided with a gradually expanding flume on the downstream side. The critical velocity is exceeded in the orifice and the discharge is thus independent of the water levels in the watercourse.

There are various forms of orifice semi-modular outlets, but the earliest of these is the one introduced by Mr. Crump about 1922 and called the adjustable proportional module. (A. P. M.)

(i) *Adjustable proportional module.*

(a) *Structural.* " Structurally* (see plate 10) it may be regarded as a long-throated flume with a roof block, capable of vertical adjustment, introduced into the upstream end of the parallel throat. With the roof block removed the A. P. M. differs from the flume module only in regard to the length of the throat. It belongs, however, to the orifice type of flexible module and may be regarded, from this point of view, as a modification of the Harvey-Stoddard (original) outlet."

" The A. P. M. is designed rather in imitation of, than in competition with the Harvey Stoddard improved (proportional) outlet."

The upstream and downstream approaches of the A. P. M. are exactly similar to those of the Crumps open flume outlet described in para. 8 (h) (i) *supra*. The length of crest is H + 1 ft., the latter being the width of the cast iron block comprising:

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* I. B. Paper No. 26.

(a) a base plate,

(b) two cheek plates,

(c) a roof block, which slides between the cheek plates and can be fixed in any position.

(b) *Discharge formula.* " Modularity " in the A. P. M. " is ensured by the formation of a standing wave", and so long as the wave is steady and " remains clear of the exit of the orifice " the discharge co-efficient does not alter. The roof block is so shaped that " the jet is made to fill the exit of the orifice and jet contraction is suppressed. Also by extending the parallel throat to a distance H below the exit, curvature of the jet is avoided, thereby ensuring a uniform velocity-distribution over the section of the jet ". Thus the discharge is dependent on $\sqrt{H_s}$ and the discharge formula is given by $q = 7{\cdot}3\ B_t\ Y\sqrt{H_s}$

(c) *Adjustability.* Adjustability is secured by raising or lowering the roof block. This is fixed by a couple of bolts which in turn are secured from tampering by a masonry key. This key can be broken out, the roof block adjusted and the key rebuilt within a few hours at the cost of a few rupees without injury to the rest of the work. This is one of the most important advantages that this form of outlet has over the open flume.

(d) *Flexibility.* The flexibility of this outlet depends just like the pipe outlet on the relation of H_s to D. As will be seen from Appendix I, proportionality (F = 1) is secured when the bottom of the roof block is submerged below the full supply level by 3/10 of the depth of water in the channel.

Mr. Crump's deign aimed at keeping $H_s = Y$ thus fixing the crest at a setting of 6/10 of the depth. Thus his design aimed at exact proportionality and that is why he called it Adjustable *proportional* module.

(e) *Silt drawing capacity.* No experiments were carried out by Mr. Crump on the silt drawing capacity of the A. P. M. but subsequent experience shows that as soon as the outlets on a channel were remodelled from pipes to A. P. Ms., the silt equilibrium of the channel was disturbed and the channel generally silted up.

(f) *Efficiency.* The discharge and M. M. H. formulae originally proposed by Mr. Crump in I. B. Paper No. 26 were based on 15 tests on an outlet of $B_t = 0{\cdot}5'$, with G up to 3 ft. While subsequent tests on other sizes showed that the discharge co-efficient 7·3 was correct within ± 4 per cent, the M. M. H. observed by Mr. Crump was insufficient, particularly in the case of outlets of narrow throat width.

In 1927, Mr. Burman carried out tests on A. P. Ms. with $B_t = 0{\cdot}2'$ and 0·25' and found that M. M. H. observed was much higher than that given by Mr. Crump's table. Mr. Sharma carried out further experiments, and prepared a table of varying co-efficients for determining M. M. H. These experiments* were also conducted over a limited range and many

*Punjab Engineering Congress Paper No. 176, 1934.

A. P. Ms. were found working non-modularly when designed according to his tables. As a result of observations carried out over a wider range Mr. Gulhati derived an empirical formula for determining M. M. H.* His formula is $M. M. H. = 0{\cdot}82\ H_s - \frac{B_t}{2}$. This has been found to be fairly accurate in the field for all practical purposes.

According to the extensive experiments recently carried out in the Irrigation Research Institute over a limited range, $M. M. H. = 0{\cdot}73\ H_s - 23'$. The formula actually authorised for use in the Department is simply $M. M. H. = 0{\cdot}75\ H_s$.

(*ii*) *Adjustable orifice semi-module.* As experience was gained of the working of Mr. Crump's A. P. M. (the term A. P. M. in this Paper is applied strictly to Mr. Crump's original design with crest at 6/10 setting), it was found that channels fitted with A. P. Ms. silted up badly. The same device, therefore, was used with the crest lowered to 8/10th setting, at bed level or even below it to improve the silt draw. The arrangement continued to be called the A. P. M. but as it is neither proportional, nor modular, it is proposed to call it in this Paper by its correct name, *viz.*, Adjustable orifice semi-module or A. O. S. M.

The proportionality in an outlet which was once considered an essential requisite, is no longer considered necessary. This aspect of the problem will be dealt with later in Chapter VI. The A. P. M. as evolved by Mr. Crump is now no longer in use in the Punjab, but its place has been taken by its modified form—the A. O. S. M.

(*a*) *Structural.* At first the only modification made was lowering the setting of the outlet, which improved the silt draw and made it more rigid, both very desirable improvements. As a result of some experiments carried out on the Lower Jhelum Canal, Mr. Sharma suggested certain changes in the shape of the upstream and downstream approaches. Subsequently, he was deputed to repeat his experiments under the guidance of Mr. Crump, as a result of which the following changes were suggested** in the standard design.

In the upstream approach, the upstream wing wall is given a sharp curve and the downstream wall given a curve and a flare as shown in the drawing on plate 11. The length of the gullet is made 2 ft. for all cases. The horizontal portion of the throat is omitted and a sloping glacis of 1 in 15 is substituted. The side walls below the gullet are given a fixed radius of 25 ft., the curves starting tangentially from the throat. Instead of the roof block having a horizontal base a lemniscate curve with a tilt of 1 in 7·5 is proposed. This will ensure the convergence of the filaments, whereas in the original design, these are divergent. A more steady value of the co-efficient is also expected, as in the original A. P. M. the jet is non-adherent and liable to pressure inflation.

* Punjab Engineering Congress Paper No. 218.

**Punjab Engineering Congress Paper No. 237.

(*b*) *Discharge co-efficient.* The formulae for calculating the discharge and M. M. H. for the A. O. S. M. are the same as for the Crump's A. P. M. described above.

(*c*) *Silt drawing capacity.* Mr. Sharma's experiments showed that the modification proposed by him in the shape of the upstream approach had the effect of increasing the silt draw as follows :

Crump's A. P. M.	...	92·4 per cent.
Crump's A. P. M. as modified by Sharma	...	99·5 per cent.

It was also found that the silt draw increased with a deeper setting, the following being the results obtained by Mr. Sharma on his modified type.

A. P. M.	...	6/10th	...	99·5 per cent.
A. O. S. M.	...	8/10th	...	109·7 per cent.
A. O. S. M.	...	10/10th	...	121·9 per cent.

In another case, where the silt induction at 10/10th was found to be 113·7 per cent, at 12/10th setting, it increased to 128·9 per cent.

As shown in Appendix I, this type of outlet is instantaneously proportional when the roof is built at 0·3 of the distributary channel F. S. depth. With a rise in the F. S. L., the flexibility which is equal to $\frac{3}{10} \cdot \frac{D}{G}$ is reduced and the outlet becomes sub-proportional. Similarly, with a fall in the F. S. L., the flexibility is increased and the outlet becomes hyper-proportional.

When the outlet is set near bed level, with a rise in the F. S. Level the value of $\frac{D}{G}$ is reduced and the outlet tends to move further from proportionality in the direction of rigidity. A fall in the F. S. L. similarly increases the flexibility and the outlet moves towards proportionality.

With the outlet set at bed level, the flexibility remains constant at 3/10.

When it is set near the bed, it is one of the best forms of outlets to adopt, except at tails which have to work as safety valves in case of any temporary excess and at control points where heading up may be required frequently.

Tampering. The A. P. M. is a strong and substantial structure, but cases of tampering with it are not infrequent. The roof block is sometimes raised bodily and re-fixed by the village mason but the tampering is easily detected. A wooden plank is sometimes inserted at the downstream side of the roof block and covered with earth and grass, thus forming an air-tight roof in continuation of the roof block. This increases the discharge due to the imperfect aeration of the jet.

(*iii*) *Khosla's interlocked adjustable module.* This is simply an O. S. M., built out of precast reinforced concrete units, and is described in detail in Punjab Engineering Congress Paper No. 108 (1927).

(*iv*) *Haigh's modifications.* In 1937, Mr. Haigh suggested that the approach of the A. P. M. should be made in the form of a bell mouth and called this form semi modular-meter outlet or S. M. M. O. In this type (see plate 12) the length of the horizontal crest and the length of the gullet below the bell mouth was kept=2·5 ft. The downstream flume was of the same shape as in Mr. Haigh's modifications of the open flume outlet. This type was tried in the Karnal Division of the Western Jumna Canal, where it was found that the formula for discharge and the minimum working head required were the same as for the A. O. S. M. There were, however, practical difficulties in the use of this type as the type was non-adjustable, and if the bell mouth was damaged it meant re-construction.

Recently, Mr. Haigh has prepared a new type design for an adjustable bell mouth orifice. In this type (see plate 13) the roof block can be raised or lowered between cheek plates. There is no horizontal crest, but a glacis of 1 in 15 has been substituted in the length of the gullet which is kept=2·5 H. The expanding flume below is of the same shape as for the other types of Mr. Haigh's modifications. This type has not yet been tried in the field, but experiments in this connection are in progress in the Irrigation Research Institute.

(*v*) *The Central Provinces type.** The conditions of irrigation obtained in C. P. are somewhat different to those in this Province.

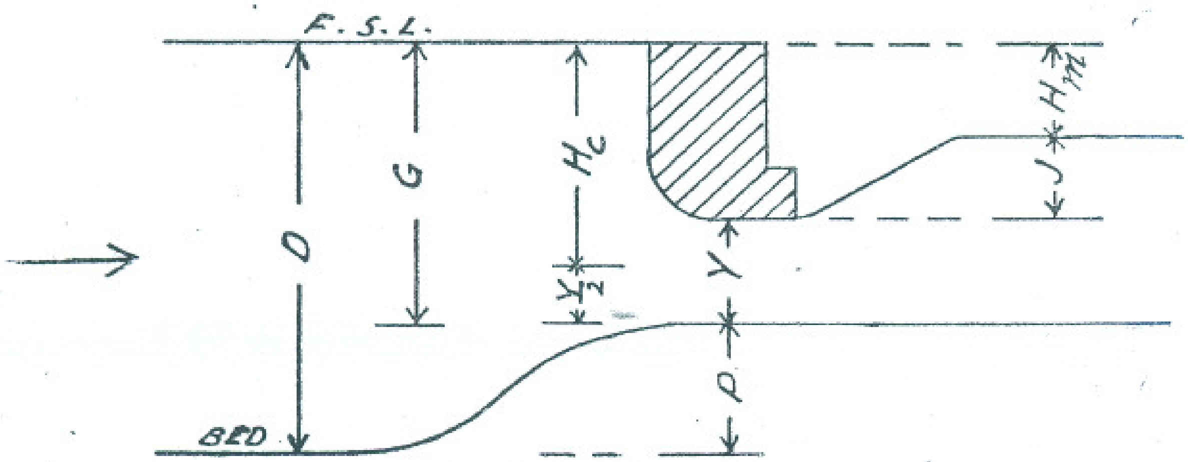
Adjustability in an outlet is considered to be of great importance as this is needed to meet the situation, when

(*i*) Certain villages commanded by a distributary do not renew their agreement or other villages enter into or are expected to enter into an agreement in the near future.

(*ii*) An appreciable expansion of the rice area is affected.

Proportionality is not considered of much importance as usually F. S. is required at all outlets that are in operation.

A simple form of semi-module as shown in the following sketch is generally adopted :—



* Semi-Modules in the C. P.

The radius of the upstream curve of the roof block is 6″, and it has a horizontal extension of 6″. The length of the gullet is 2·5 ft. and the downstream flume walls have a splay of 1 in 30.

The discharge is given by the formula :

$$q = C B_t Y \sqrt{2g H_c}$$

The value of the co-efficient C varies with both G, and Y and ranges from 0·6 to 0·92. This variation is due to the use in the formula of the head H_c instead of H_s .

The recovery of head J is given by the formula

$$J = 2 C Y \sqrt{\frac{H_c}{Y} + \frac{1}{16 C^2}} - 1{\cdot}5 Y.$$

10. The Jamrao type orifice module*. About the same time that Mr. Crump evolved the A. P. M. in the Punjab, Mr. W. Kirkpatrick brought into use in Sind the Jamrao type semi-module shown on plate 14.

(*a*) *Structural.* A perusal of the plan and sections of this type will show that it is an attempt, and a successful one, to reproduce in masonry the Kennedy's gauge outlet.

The upstream approach is only 2 ft. long and is of the shape of a truncated cone with a convergence of 1 in 4. The control section is a square orifice in an angle iron frame. The downstream flume, 10 ft. long, has a horizontal floor with the side walls at a splay of $\frac{B_t}{10}$. Mr. Kirkpatrick records that the co-efficient of discharge for the converging orifice as designed by him is as nearly constant as that of the elongated bell mouth and that his design of the downstream flume has been found to give the best results as regards the maximum recovery of head.

" The most novel feature of the Jamrao semi-module is the introduction of baffles as a means of recovering head." The baffles work as a "roof, sloping gradually upwards, in the downstream flume" and by their addition "considerable extra head is recovered." At the same time the outlet discharges under free atmospheric conditions : " Even if an aperture is closed, the effect is not considerable as air will enter from the next aperture and so on." " The optimum slope for the roof (*i. e.*, lower edge of baffles) is 1 in 15. . . . The optimum number of baffles is 9 of which the first 6 are equally spaced and the last 3 somewhat spread out."

(*b*) *Discharge formula.* The discharge formula applicable to this orifice semi-module was determined experimentally by Mr. Kirkpatrick and

*Bombay P. W. D. Technical Paper No. 12 (1925) and Sind P. W. D. Technical Paper No. 6 (1941).

is $q = 7{\cdot}2\ B_t\ Y\sqrt{H_c}$. As the orifice is square and $B_t = Y$ the formula may be rewritten as $q = 7{\cdot}2\ B_t^2\sqrt{H_c}$.

Adjustability. As will be apparent from the drawing, this type is not at all adjustable.

Flexibility. The flexibility depends on the relation of H_c to D and not of H_s to D as for the A. P. M. or the O. S. M. described above.

Silt drawing capacity. The capacity to draw silt will depend on the setting, and in this respect it may be considered similar to the O. S. M. except that the upstream approaches of the O. S. M. as shown on plate 11 are likely to be more conducive to silt induction than the truncated cone set back in the bank.

Efficiency. The monogram shown on plate 14 gives the M. M. H. required for different values of H_c with and without baffles. It will be seen that with the introduction of baffles considerable head is recovered, *e. g.*, when $H_c = 3'$, M. M. H. without baffles is 1·70', but with 9 baffles for an orifice 5" square, the M. M. H. required is only 0·66'. In this respect it is a great advance on the O. S. M.

C—Silt extracting semi-modules

It has been stated above that it is not possible to place the crest of the open flume outlet at or near bed level on account of the practical difficulty of constructing open flumes with B_t less than 0·2'. Similarly, on account of the limitations imposed by the available working head it is not possible to place the crest of O. S. M. outlets at or near bed level. Both the types are frequently so designed that their crest level is considerably above the bed of the channel. This is particularly true in the case of large distributaries.

With a high setting it is not possible for these semi-modules to take their fair share of the silt charge in the distributary. As such, various devices have been put forward in the past to enable these outlets to draw more silt than they normally do. The first attempt was made by K. B. Sh. Minhaj-ud-Din in 1925 when he invented the bend outlet.

11. The bend outlet.

(*a*) *Structural.* The bend outlet is a form of the orifice semi-module. It differs from the usual type inasmuch as the intake comprises a bent pipe of uniform rectangular section, the width of which is adjustable. The bend, as shown on plate 15, serves to change the direction of velocity from horizontal into an upward vertical direction which induces a direct sucking action on the bed silt, thus improving the silt draw.

Several experiments were conducted by the inventor on the Bhatinda Distributary to compare the silt draw of a bend outlet with other types. The results obtained by him were as follows :—

Ser. No.	Type of Outlet.	Setting.	Range of % silt-draw in various experiments.	Average silt-Draw.
1.	Wooden bend with mouth at bed level.	6/10th	81% to 132%	108%
2.	K. G. O.	Bed	81% to 124%	101%
3.	7″ Pipe.	Bed	100%	100%
4.	Crump's A. P. M.	6/10th	57% to 85%	74%

This table gives a clear indication of the efficacy of the bend outlet in drawing silt.

As an experimental measure, bend outlets were installed on Salam Distributary of the Lower Jhelum Canal, where it was found that in the inventor's original design the co-efficient of discharge was not constant for varying water levels in the watercourse, and that a standing wave in the flume was not an index of the designed discharge running. It was also found that the co-efficient of discharge and the formula for M. M. H. as given by the inventor and which were based on only a few observations were not correct.

Mr. Mahbub as Sub-Divisional Officer, carried out experiments with a view to improve the design so as to make the discharge co-efficient constant and also to determine the values of C and M. M. H. The experiments were conducted in the following range :

D varied from 1·2′ to 2·2′.

B_t varied from 0·2′ to 0·7′.

Y varied from 0·4′ to 0·8′.

As a result of these experiments, it was found that if the pipe was extended for a length = Y, as shown on plate 15, the standing wave became unsteady only when the discharge started to decrease. The value of C based on over 100 observations was found to be as follows :—

For B_t less than 0·3′, C = 5·75.

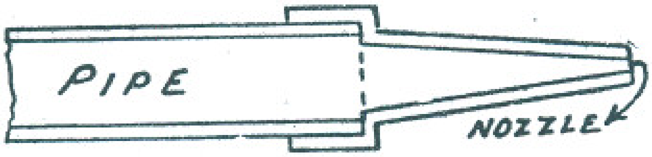
B_t = 0·3′ and above, C = 6·25.

The M. M. H. was found to be 0·66 H_s against 0·75 H_s for an O. S. M.

This outlet has thus a decided advantage over the O. S. M. both with regard to silt draw and to a lesser degree with regard to M. M. H.

12. Haigh's silt-extracting S. M. M. O. About 1937, Mr. Haigh prepared a design for a silt-extracting S. M. M. O. This design is shown on plate 16, but so far as the Authors are aware, it has never been tested. It consists of a bell mouthed opening at the bed of the distributary and joined to the raised crest at a slope of 1 in 3. This enables the outlet to suck the heavier silt near the bed more or less on the same principle as in the case of the bend outlet.

13. Gunn's nozzle outlet. Mr. Gunn carried out some experiments by adding a converging nozzle to the dowstream end of an ordinary pipe outlet as shown in the sketch below :—



The critical velocity is exceeded in the nozzle and the high velocity jet issuing from the nozzle falls into an open outfall of expanding section, the floor being level with the bottom of the jet and horizontal for a length of 1·5 ft. downstream of the nozzle.

Discharge formula. It is obvious that the discharge would greatly depend upon the extent to which air has access to the periphery of the issuing jet. For a jet leaping clear into air, the velocity of each filament of the jet depends on the depth of this filament below the total energy line at exit, and the filaments have a natural parabolic curvature. If, on the other hand, the jet falls into a cradle of the same section as itself, then for a horizontal floor, the filaments at exit are horizontal, and the velocity throughout the jet is the same, being that due to the head on the surface filament. For the first of these cases the correct discharge formula is that assumed by Mr. Gunn, *viz* :

$$q = C_1 A_p \sqrt{H_c} \quad \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

where H_c is the velocity head at the centre of the nozzle section. For the latter case, the correct formula is that adopted by Mr. Crump, *viz* :

$$q = C_2 A_p \sqrt{H_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots (ii)$$

In other words Mr. Gunn's formula applies to a free jet, while Mr. Crump's formula applies to a jet supported at the bottom and sides.

The average values of C_1 and C_2 in the above formulae, in the experiments conducted by Mr. Gunn, were as follows :—

No.	Section of pipe.	C_1	C_2
1.	5″ Circular (Floor horizontal)	7·25	7·95
2.	7″ ,, ,, ,, ...	6 66	8·70
3.	7″ ,, ,, ,, ...	7·00	8·26
	Mean for circular orifices	6·97	8·30
4.	7″ Sq : (Floor horizontal)	5·99	7·57
5.	,, ,, ,, ,, ...	5·84	6·97
6.	,, ,, (Floor parabolic)	6·10	7·36
7.	5″×9½″ (Floor horizontal)	5·71	7·70
8.	,, (Floor parabolic)	5·78	7·63
9.	14″×3½″ (Floor horizontal)	5·99	6·35
	Mean for rectangular and square orifices.	5·90	7·36

It appears that the circular nozzles were fully aerated to conform to formula (*i*). In the case of rectangular nozzles, the value of C_1, with the exception of the 14″ × 3½″ nozzle, is generally more than 7·0 which indicates that in these cases there was partial aeration and the actal behaviour was thus intermediate between that of a fully aerated jet and of a supported jet.

The M. M. H. required for a Gunn's nozzle outlet is appreciably more than that for an A. P. M. since there must be greater loss up to the nozzle exit in the former case. This loss can be reduced by increasing the pipe diameter, and giving it a bell mouthed entrance, but both these expedients would tend to reduce the silt drawing power. The chief merit of this outlet is its superiority over the O. S. M. as regards silt draw provided both have the same setting and the main drawback is the excessive working head required.

14. Pipe cum semi-module. The Scratchley type described in para. 2 of this chapter with its orifice working free fall is the simplest type among pipe cum semi-modules. If the orifice does not work free fall, it can be replaced by a semi-module of a modern type, *i. e.*, an open flume, an A. P. M. or an A. O. S. M. (see plate 17) which would require comparatively less working head for modularity. This type can also be regarded as a development of the Stoddard Harvey improved irrigation outlet.

(*a*) *Structural.* At its upstream end the pipe cum semi-module comprises a pipe taking off from a channel and opening into a tank about 3 ft square on the other side of the bank. In the downstream wall of the tank is fitted a semi-module which may be a pipe working free fall, an open flume with its crest at any suitable level, an A. P. M. set at 6/10, or an A. O. S. M. set anywhere above at or below the bed level of the distributary.

(*b*) *Discharge formula.* The discharge of the outlet will be equal to the discharge of the semi-module fixed at its lower end. But the head will be measured from the water level in the cistern below the pipe. There is bound to be some loss of head through the pipe, but the size of the pipe or barrel can be made sufficiently large to reduce this loss of head to a bare minimum subject, of course, to such a velocity in the barrel as is enough to pick up the silt on the bed of the distributary.

(*c*) *Adjustability.* To adjust a Scratchley outlet, it is only necessary to rebuild the orifice at small cost. The open flume cannot be adjusted short of re-construction, but the cost of re-constructing an open flume when fitted at the downstream end of the tank will be considerably less than if it were fitted in the bank of a distributary. An A. P. M. or an A. O. S. M. can be adjusted by raising or lowering the roof block.

(*d*) *Flexibility.* The flexibility of this device depends on the flexibility of the semi-module fixed at its lower end except that it will be modified to a slight extent by the action of the pipe or barrel between the distributary and the tank. For a detailed analysis see Appendix I.

(*e*) *Silt drawing capacity.* It is in this respect that this outlet has a great advantage over other devices. By placing the upstream end of the pipe below bed level, at bed level or at any distance above the bed level, complete control can be obtained over the silt induction by the outlet, at the expense of loss of head in the pipe which can generally be reduced to about 0·1′ for most cases. In the case of deep channels the pipe can be placed slanting with its upstream end at or below the bed level of the distributary as required, at a slope of about 1 in 12. The tank downstream of the pipe need not thus be built deeper than necessary for the designed head over the semi-module.

(*f*) *Efficiency.* The efficiency of this type will again depend on the type of semi-module fixed at the end of the device with the additional loss of working head through the pipe. As the silt induction into the outlet depends only on the position of the pipe with respect to the bed, the crest of the outlet can be placed at any level so that the loss in head through the pipe can be more than counter-balanced by a possible higher setting of the outlet.

This device thus gives a considerable range of flexibility. The position of the barrel does not affect either the discharge or the proportionality and the barrel can be raised or lowered depending on the requirements of the silt draw.

(*g*) *Other advantages.* The other advantages possessed by this type are :—

(*a*) A high degree of immunity from interference due to the certainty of early detection.

(*b*) Large range of modularity.

(*c*) Low consumption of head particularly with an O. F.

(*d*) Cheapness when in heavy channel banks.

(*e*) Ease of adjustment even with the channel running.

This type of outlet can be used with advantage for outlets which work in *kharif* only and not in *rabi*. The pipe can be placed with its bed above the *rabi* full supply level and since the head over the crest is to be measured in the tank, the design of the outlet is simple enough. No water will get into the tank until the water level in the distributary rises above the *rabi* full supply level.

D—Modules with moving parts

As already defined, modules are devices through which only a fixed quantity of water will be passed (within working limits) irrespective of the changes in the water level on the supply or the delivery side.

15. European modules. The earliest attempts to design modules were made about the middle of the last century in Europe. In 1868 Lt. C. C. Scott Moncrieff, R. E., an Executive Engineer in the then North Western Provinces of India was deputed to visit irrigation works in Southern Europe. In his report *published in 1868 he describes three modules which were in use at that time in different parts of Southern Europe. All the three devices are shown in plate 18.

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*Irrigation in Southern Europe.

(*i*) The first of these devices is the one used on the Marseilles Canal. It will be seen from the drawing "that at the bottom of a masonry cistern connected with the canal there is a circular orifice, into which is accurately fitted, by a water tight collar, an iron cylinder open at each end. This cylinder hangs to a wooden bar supported by two floats on the surface of the water, and slips freely up and down in its collar. By means of a screw the distance of the upper edge of the cylinder from the bar, and consequently from the water surface, is fixed and that being done so as to give the required discharge, it is never altered." From the bottom of the cylinder the water goes straight into the watercourse. The module is housed in a small locked room.

(*ii*) The second type which was regarded as an improvement on the first was used on the Isabella 2nd Canal. "The principle on which this module is founded is that the velocity of discharge through an orifice varies with the square root of the head of water, using the ordinary formula,

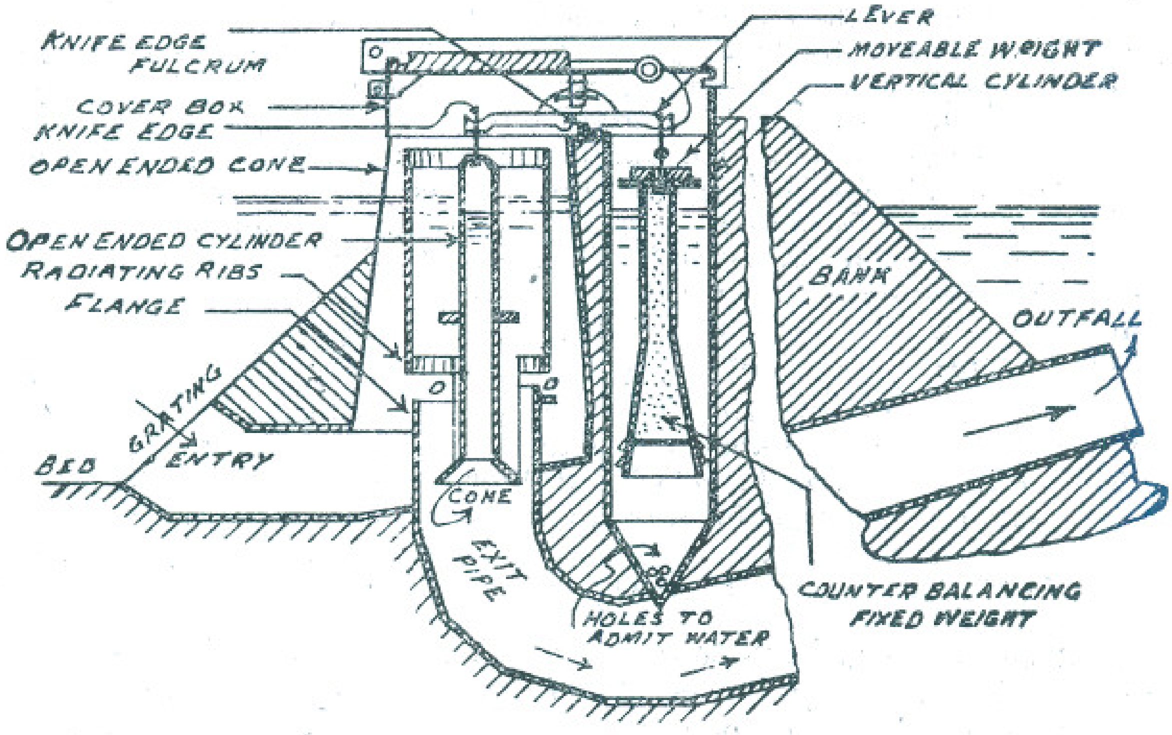
$$q = C\pi(R^2 - r^2)\sqrt{2GH_s}$$

where R and r are the radii of the orifice and plug respectively." The value of C as found for this type is $= 0{\cdot}63$. The shape of the curve of the plug "is such that the roots of the vertical abscissæ shall vary inversely as the differences between the squares of the radius of the orifice and of the horizontal co-ordinate."

(*iii*) In the third type, used on the Henares Canals, "the self acting principle has not been tried at all, but the regulation is affected, as shown in the drawing, by means of a very neatly fitting cast iron sluice, raised and depressed by a screw, and letting the water into a masonry chamber out of which it escapes over a bevelled iron edge. The guard in charge has orders to keep the water to a certain height denoted by a gauge, in this chamber, to do which he opens or shuts the sluice according to the fall or rise of the canal."

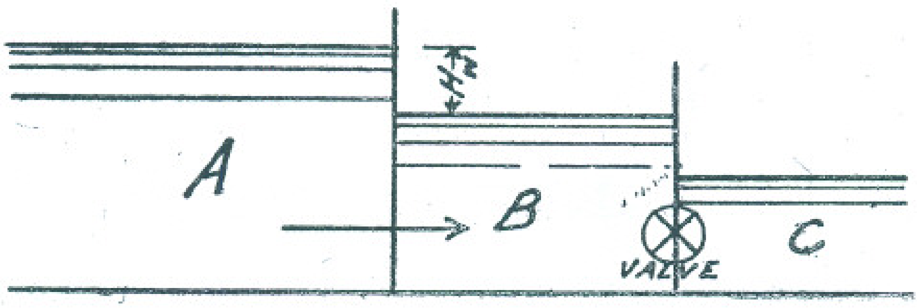
16. Visvesvaraya's self acting module. In India the first attempt appears to have been made by Mr. Visvesvaraya. His design was presented to the Irrigation Conference, Simla 1904. It consists of a hollow, water-tight, iron tank floating in a locked chamber connected with the distributary. The tank has two holes on the sides near the bottom into which water flows under a constant head depending on the submergence of the tank. The water which enters through the orifices into the tank is led into a flexible tube fixed to the bottom of the tank whence it passes into the watercourse. The float and the flexible tube move up and down in a vertical direction being restricted by means of suitable guide bars.

17. Kennedy's outlet module. The next attempt in this direction was by Mr. Kennedy in 1906, when he devised his historic outlet module. This is a complicated piece of mechanism as will be clear from the sketch on page 50.



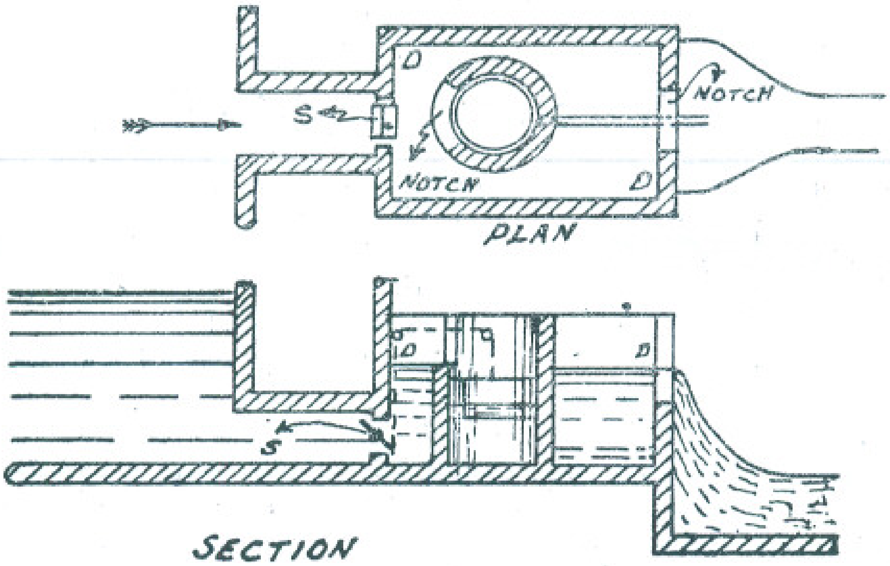
The opening at 0 is automatically adjusted by the vertical movement of the open ended cylinder caused by the difference in water level between the two cylinder so that the discharge passing through it remains constant. Its actual working is rather involved and the curious reader is referred for a full description to the Punjab Irrigation Paper. No. 12 (Blue cover) on the distribution of water for irrigation by measurement by Mr. R. G. Kennedy. Mr. Kennedy claims that this device meets all the requirements of an outlet as described in para. 16 of Chapter III, and that the variation in discharge found by him was only from $\frac{1}{2}$ per cent to 1 per cent for heads ranging from 3″ to 18″. The working head required for this device is claimed to be 3″ to 4″.

18. Wilkin's module. Mr. Wilkins presented to the Simla Engineering Conference 1913 a new module requiring a small working head. His device is shown diagramatically in the sketch below.



A is the distributary and C the watercourse. A is connected to an intermediate chamber B through a fixed opening in the partition. So long as the difference of water levels H_w between A and B is constant, the discharge passing from A to B and thence to the outlet will be constant. In the partition between B and C there is fixed a valve, "so devised that it shall be operated only by variations in the difference of level between the water surface in A and B from the fixed amount H_w and in such a manner that when this difference of level exceeds H_w, the valve shall close and when it is in defect the valve shall open". For further details the reader is referred to the proceedings of the Engineering Conference Simla 1913.

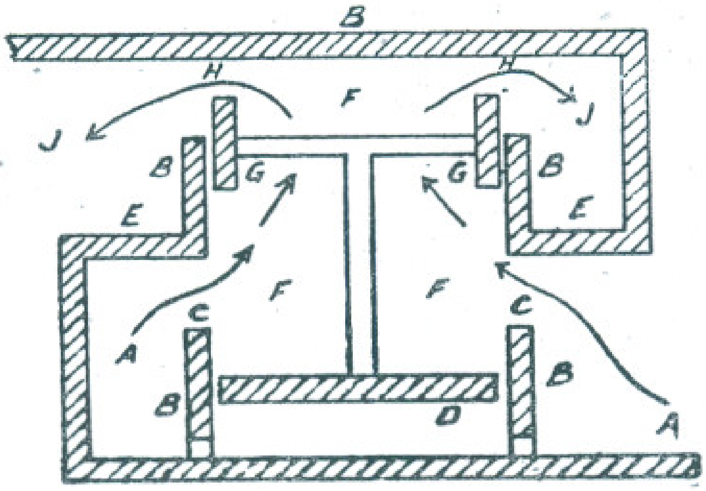
19. Joshi's module. In 1919 Mr. Joshi in a paper presented to the Bombay Engineering Congress gave details of another self-acting module.



This module is similar to the one described above in use on the Henares Canal. The only difference is that the manual control of the sluice is done away with and is replaced by an automatic control. The shutter at S is controlled by a float in the intermediate chamber DD.

20. Kent 'O' type module. This module has been described as follows by Mr. Lindley in the Paper No. 80 presented by him to the Punjab Engineering Congress in 1923.

"The principle on which this works is shown in the sketch below, which is merely diagrammatic. Supply A, and delivery J are separated by a horizontal diaphragm E; this diaphragm is pierced by a vertical cylinder BBB, open at the bottom, closed at the top, with short annular sections left out just below the top and the diaphragm forming annular orifices C and H. In the lower part of the cylinder B floats a flat circular piston D, carrying a short cylinder G, which regulates the orifice H as the floating cylinder moves; the inside of the cylinder B above the

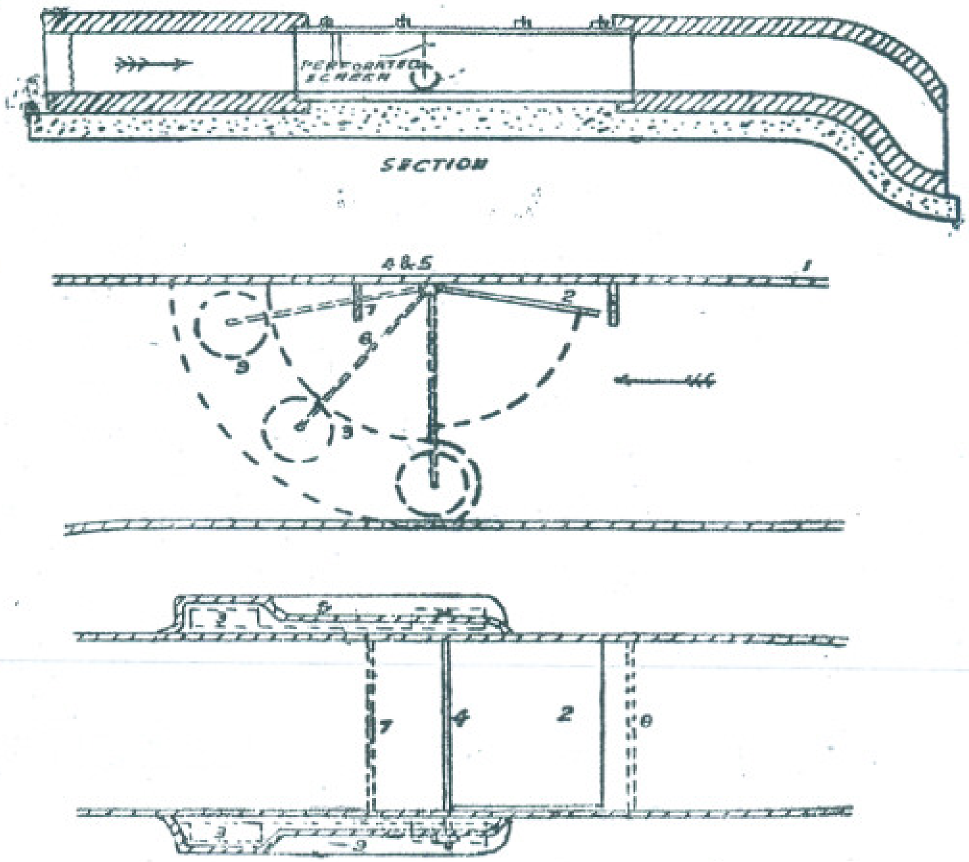


piston D thus forms an intermediate chamber F, fed from supply through the fixed orifice C, and feeding delivery through the regulated orifice H. For equilibrium the difference of pressure on the two sides of the piston (that is between supply and intermediate) must balance the weight of the piston and the parts it carries; for if it did not, the piston would be moved and would regulate the upper orifice H, increasing or decreasing the loss of head there until equilibrium was restored. The piston, therefore, maintains a constant head on a fixed orifice. Further, the orifice that has been described as fixed, can be adjusted from outside; thus the module can be rated."

21. Khanna's auto-adjusting orifice distributor. Another type of rigid module was evolved by Mr. R. K. Khanna in his Paper No. 128 presented to the Punjab Engineering Congress in 1929. It consists of an ordinary pipe or barrel, with swinging weight pockets built on the sides. Inside the barrel is a horizontal bar capable of rotating freely between two bearings. The bar has a vane rigidly fixed to it on one side and two counterweight suspension rods on the other side. With the rotation of the horizontal bar, the vane swings inside the barrel and the suspension rods and counterweights inside the side pockets. When water flows through the barrel, the counterweights exert a turning effect on the bar in the opposite direction. The area of the opening is thus reduced as the working head increases.

The length of the vane depends on the required maximum reduction in the area of opening of the orifice and the counterweights are calculated by equating the turning moments of the counterweights and the pressure on the vane about the pivot point in any position of equilibrium after making due allowance for the buoyancy of the counterweights in water.

For constant discharge, the area of the orifice should vary inversely as the square root of the working head, whereas in a rectangular orifice, as adopted in this case, the variations in the area would be proportiona



1 PIPE OR BARREL
2. SWIMING VANE
3. COUNTER WEIGHT
4. HORIZONTAL BAR
5. BEARINGS.
6. COUNTER-WEIGHT SUSPENSION RODS.
7&8. VANE PROTECTION STRIPS SWIMING WEIGHT POCKET.

to the sines of the angles through which the vane is turned. This variation is overcome by setting the vane and the rods at suitable angles, turning the ends of the vanes, fixing the position of the horizontal pivot at a suitable distance below the top of the orifice and by giving a suitable side clearance between the vane and the vertical walls of the orifice. Mr. Khanna has shown that by adopting the above the discharge is fairly constant except in the beginning of the range.

Disadvantages of modules with moving parts. The various types of modules described above, all have moving parts and have, therefore, little practical value when required on a large scale as in the Irrigation Works in the Punjab. Some of them are very expensive and not simple to design and construct. They are liable to derangement on account of silt and weeds in flowing water and on account of rusting of the moving parts. In some device the friction of the moving parts is liable to affect the working of the modules.

E—Modules without moving parts

As against modules whose working depends in floats or other moving mechanism, we have a few devices in which the discharge is automatically regulated by the velocity of water itself and there are no moving parts. The first of these is the Gibb's module which is now described.

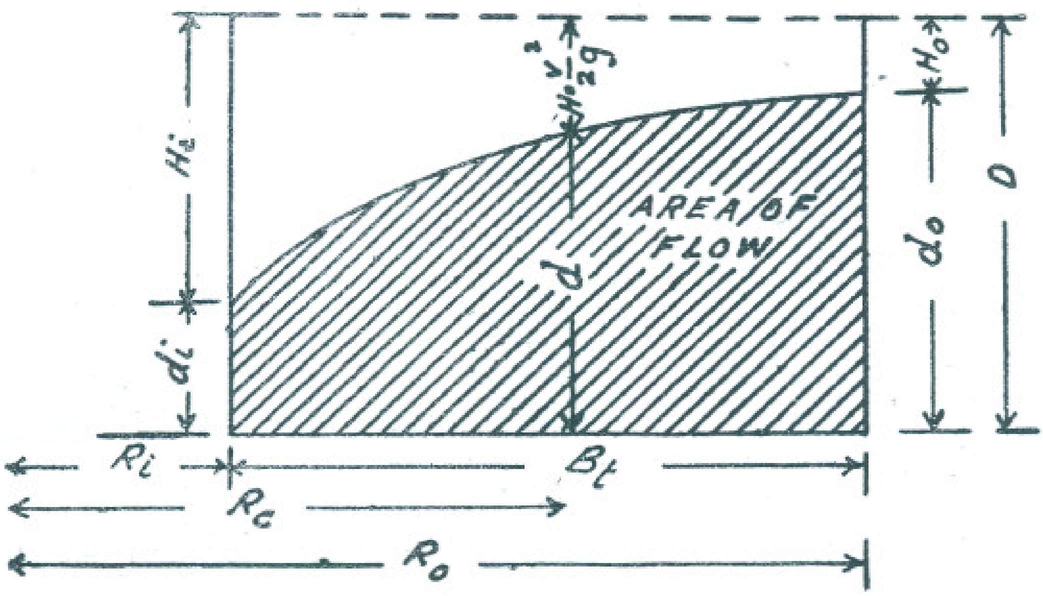
22. Gibb's module.

(*a*) *Structural.* There are no moving parts in this device (see plate 19). The water is led through an inlet pipe into a spiral rectangular trough (eddy chamber) in which free vortex flow is developed. In this form of flow the product of radius and velocity is constant for all filaments. Thus the water on the outside of the curve rises in level, and the water surface slopes towards the inner wall. A number of baffles are inserted in the eddy chamber with their lower edges sloping at the required height above the bottom. As the head increases, "the water banks up at the outer circumference of the eddy chamber and impinges against the baffles imparting an upward rotational direction of flow to the water, which spins round in the compartment between two successive baffles and finally drops on the on-coming stream of water, thus dissipating excess energy" and keeping the discharge constant.

The degree of turn of the spiral depends on the volume of discharge and the working range required and generally varies from one semi-circle to one and a half complete circles.

(*b*) *Discharge formula.* The following analysis is due to Mr. Crump*.

The discharge of a Gibb's module is given by the following general formula :



*Note dated 27-6-38 by E. S. Crump, Esq., C.I.E., on the Theory of Gibb's Module cyclostyled).

$$q = R_o \sqrt{2g}.\ D^{3/2} K^{\frac{1}{2}} \left[\log_e M + \frac{K}{2}(1 - M^2) \right]$$

where $M = \dfrac{R_o}{R_i}$ and $K = \dfrac{H_o}{D}$

In any particular outlet R_o and M are fixed and it will be seen from the general equation of discharge that the latter depends upon the value of D (the total energy) and of K [*i.e.*, of the depth $d_o = (l - K)\ D$]. For a particular value of D, the discharge may thus have a variety of values depending upon the value of K.

Mr. Crump has shown that the maximum value of the discharge would be given by

$$q \text{ max.} = R_o \sqrt{2g}.\ D^{3/2}.\ \frac{(\frac{2}{3} \log_e M)^{3/2}}{(M^2 - 1)^{\frac{1}{2}}}$$

For M=2, Mr. Crump has worked out the critical value of K=0·154. For this value

$$\frac{H_1}{H_o} = 0{\cdot}454$$

$$\frac{H_o}{D} = {\cdot}846$$

$$\frac{H_1}{D} = 0{\cdot}384$$

$$f = {\cdot}1815$$

$$\frac{D}{D_c} = 1{\cdot}0$$

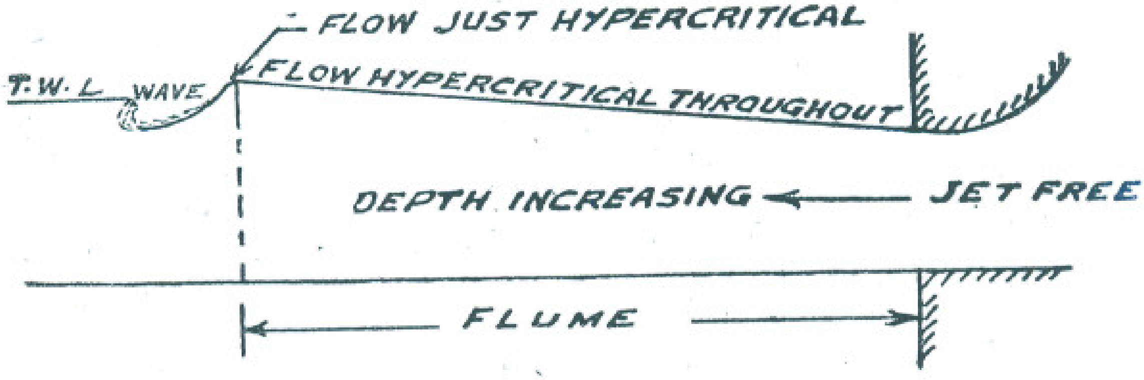
where $f = K^{\frac{1}{2}} \left[\log_e M + \frac{K}{2}(1 - M^2) \right]$

For values of K less than the critical value K=·154, the depths both at the inner and outer walls of the flume are greater than for critical conditions; whereas for values of K greater than K_c the depths throughout the section are less than for critical conditions. The former condition of flow is sub-critical and the latter hyper-critical.

It may be mentioned here that a straight flume corresponds to a value of M=1.

The flow on the downstream end of the curved flume should be just hyper-critical to enable the discharge to be independent of the downstream water level and to reduce the working head required for modularity to a minimum.

The baffles should thus be set to the condition of flow, as shown in the sketch below:—



Mr. Crump has shown that the action of the baffles merely depends on the sensitive conditions (as regards the depth of flow) which are known to attend the critical state of flow. He has calculated that if the flow is hyper-critical with the total head (D) one per cent in excess of critical, the decrease in depth, relative to critical depth is :

2·23 per cent of D_c at the outer wall } For Gibb's module
11·94 per cent of D_c at the inner wall } with $M=2{\cdot}0$

6 per cent of D at all points of the cross section for a straight flume.

In the Gibb's module, the surface is thus much more sensitive at the inner wall than at the outer and so according to Mr. Crump, better regulation could be obtained by shaping the baffles so as to deflect surplus water from the inner towards the outer wall instead of *vice versa* as in the Gibb's module.

The above analysis also indicates, as remarked by Mr. Crump, that a straight flume with properly shaped curved skimmers would give just as good a rigid module as Gibb's arrangement of a straight edged skimmer playing on a curved and banking jet. Not only would the straight device be much simpler and cheaper to construct, but it would have the additional advantage that the number of skimmers could be increased indefinitely and thereby be made to consume any desired surplus head over the minimum upstream level for which the module is designed. The evolution of such an outlet seems very desirable.

(*c*) *Standard designs.* As a result of experiments carried out by Messrs Inglis and Joglekar*, standard designs of the Gihb's module have been worked out for various discharges so that the variation in discharge is not more than 3 per cent.

In this standard design M has been kept=2 and $H_o = \frac{D}{7}$

The area of the inlet pipe has been kept equal to the area of flow in the eddy chamber, which gives a diameter$=0{\cdot}95\sqrt{H_t D}$.

*Research Publication No. 3 of the C. I. and H. R. Station, Poona.

The lower edges of the baffles are at the same level and meet the inner circumference at a height $= \frac{3}{4} d_0$ from the floor of the module and the outer circumference at a height of d_0. The distance between the baffles is not less than d_0 nor greater than $2\ d_0$.

The length of the spout is equal to 2 D to ensure the control section being in the throat, and there is a 1 in 10 diverging flume downstream of the spout.

The maximum depth of water permissible over the module floor was found to be 0·64 D against 0·56 D according to Gibb and was increased to 0·7 D with a 1 in 10 diverging flume downstream.

The height of the eddy chamber is kept equal to the minimum working depth + the range + free board of 6″.

The following table, showing dimensions of Gibb's module for various discharges, has been extracted from Research Publication, No. 3 of the Central Irrigation and Hydrodynamic Research Station, Poona.

1. Discharging capacity.	1 cusec.	2 cusec.	3 cusec.	4 cusec.	5 cusec	8 cusec	10 cusec	16 cusec
2. Cost of module Rs. ...	90	115	190	320	340	500	640	870
3. R_0 (ft.) ...	1·5	1·916	2·75	2·58	2·75	3·25	3·664	5·0
4. R_i (=B) (ft.) ...	0·75	0·958	1·375	1·29	1·375	1·625	1·832	2·5
5. $M = r_0 / r_i$ ...	2·0	2·0	2·0	2·0	2·0	2·0	2·0	2·0
6. D (ft.) ...	0·625	0·84	0·875	1·096	1·215	1·56	1·594	1·772
7. H_0 (ft.) ..	0·089	0·12	0·125	0·156	0·174	0·22	0·228	0·253
8. d_0 (ft.) ...	0·536	0·72	0·75	0·94	1·04	1·34	1·366	1·519
9. d_i (ft.) ...	0·268	0·36	0·375	0·467	0·52	0·67	0·683	0·76
10. B/D ...	1·20	1·14	1·59	1·30	1·10	1·04	1·15	1·41
11. Diameter of inlet pipe ...	9″	10″	12″	15″	15″	18″	21″	24″
12. No. of baffles in eddy chamber ...	5	5	6	7	7	7	8	10
13. Height of lower edge of baffle from module Floor — At outer circle	0·536	0·72	0·75	0·94	1·04	1·34	1·366	1·519
14. Height of lower edge of baffle from module Floor — At inner circle	0·402	0·54	0·56	0·70	0·78	1·0	1·025	1·14
15. Minimum working depth upstream over module floor (ft.) ...	0·76	1·06	1·10	(1·25)	(1·43)	1·95	(2·200	2·4)

16.	Minimum working head=Minimum W. L. upstream minus maximum W. L. downstream (ft.) ...	0·36	0·58	0·53	(0·59)	(0·69)	(1·00)	(1·23)	(1·32)
17.	Minimum working head with 1 in 10 diverging flume downstream of spout ...	(0·29)	(0·46)	(0·49)	(0·49)	(0·56)	0·87	(1·08)	1·15
18.	Module range with + 3 %. Variation in discharge (ft.) ...	0·93	(1·10)	1·30	(1·40)	(1·50)	(1·64)	(1 70)	1·80
19.	Range stated by Gibb (ft.) ...	0·70	1·20	1·50	1·40	1·60	...	...	...

Remarks :—(1) Figures in brackets are either calculated or interpolated from the experimental results.

(2) Figures for the minimum working depth upstream over the module floor in item 15 include losses in modules which take off from a chamber upstream, *i.e.*, loss in bell-mouth entrance, inlet and curved rising pipe. When modules take off directly from a canal or distributary loss in outlet pipes will have to be added.

(*d*) *Use of Gibb's module in the Punjab*. The original Gibb's module was first tried on Shah Kot Distributary in 1909, when 72 outlets of this type were put in. They proved useful and *tatiling* which had been resorted to on this channel to feed the tail, became unnecessary.

In 1915, it was found that the tail reach from R. D. 70,000 – 131,000 had silted up badly and the water levels attained were outside the working limit of the modules. The channel was silt cleared and all the outlets were replaced by the new type, as evolved by Mr. Gibb in 1917. The silt trouble, however, persisted. As this was considered to be possibly due to a defective head regulator it was equipped with King's silt vanes in 1927 and the vanes were further raised in 1928. This gave some relief from silt trouble, but Mr. Bedford ordered in 1933 that when a new outlet was to be constructed on this distributary it should be an O. S. M. The main reasons, which prompted this decision and later made Mr. Jesson recommend scrapping the Gibb's modules completely were :—

(*i*) The Gibb's outlet could be easily tampered with.

(*ii*) It was more costly than an O. S. M.

(*iii*) The working of the Gibb's module was not easily understood.

(*iv*) It had given a lot of trouble with respect to silt-draw.

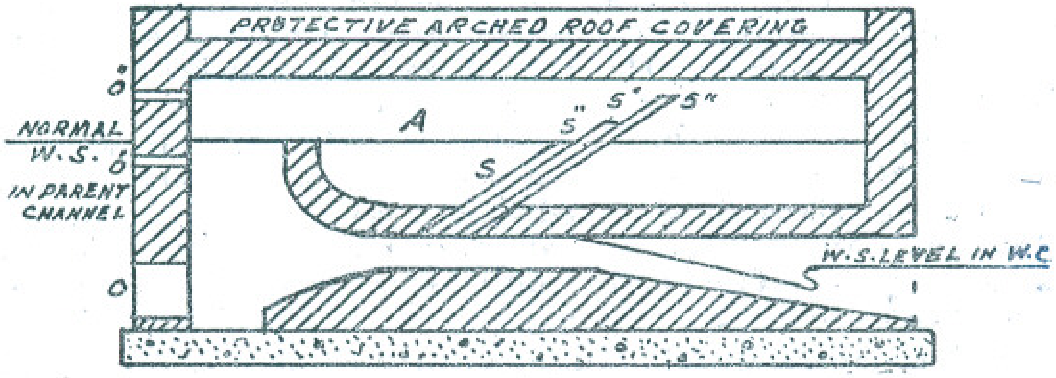
Some of these outlets have since been replaced.

23. Khanna's rigid O. S. M.*. This outlet is just an O. S. M. with sloping shoots fixed in the roof, as shown in the following sketch :—

" Water from the parent channel enters the outlet and the differential chamber A through the large opening at 0 and the smaller openings 0′,

*Theory of Flow of water and Hydraulics of Rivers and Canals by Radha Krishana Khanna, page 165.

0", etc. As long as water in the parent channel remains at or below its normal water surface level, the outlet acts as an ordinary O. S. M. When water surface in the parent channel rises above its



normal level water rises in chamber A and enters the first sloping shoots. The back flow impinges on the flow through the outlet and has the effect of dissipating the additional energy of flow and thus tends to keep the discharge of the outlet constant.

Mr. Khanna advocated three shoots at a slope of 1 in 2, with their upper ends at vertical intervals of 0·5′ from each other and their lower ends flush with the bottom of the roof of the outlet.

The size of the shoots "are arrived at by equating the known constant discharge of the outlet with the difference of discharges passing through the outlet and the differential shoots at increased working heads; care being taken to give a greater co-efficient of discharge to flow through the outlet than through the shoots for obvious reasons and also allowance being made for the reduction in the action of the lower shoot or shoots as soon as the upper shoots come into action."

Experiments on this type with B=0·3′, Y=0·6′, and H varying from 1·0′ to 2·0′, were conducted by Mr. B. K. Kapur at Chichoki-Malian Distributary. He found that the value of the co-efficient in the formula $q = C\, B_t\, Y \sqrt{H_s}$ was 6·0 against 7·3 for an O. S. M.

The best results were obtained with two shoots, at a slope of 1 in 2½, one fixed at F. S. L. and the other 0·5′ higher. The variation in this case was found to be 20 per cent over a range of H=1·0′ to 2·0′ as against 86 per cent for an O. S. M. and was only 7 per cent over a range of H varying from 1·6′ to 2·0′.

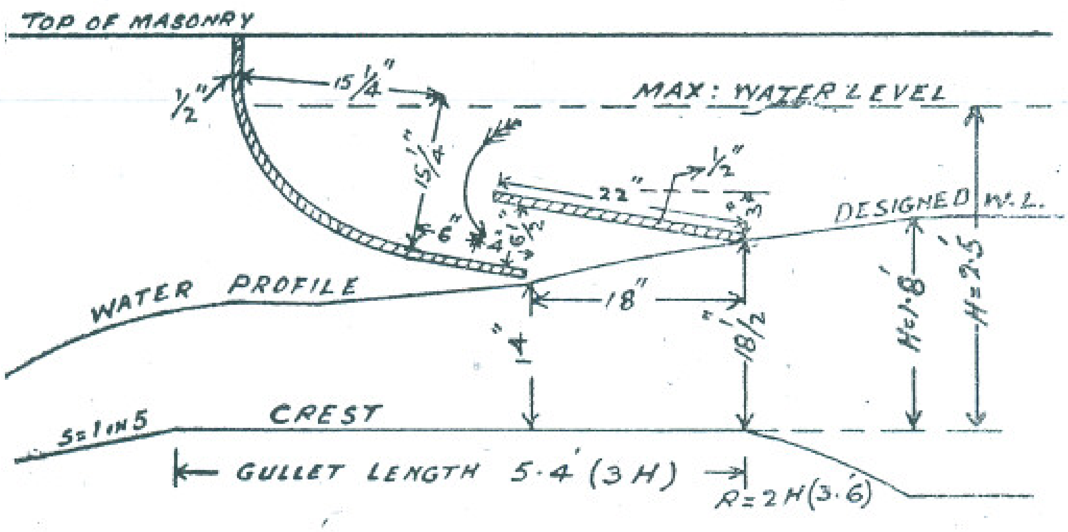
The M. M. H. was found to be equal to H_s with value of G up to 1·2′, which was gradually reduced to 0·75 H_s, with G=1·8′. The M. M. H. required for an O. S. M. being 0·75 H_s, the M. M. H. of Mr. Khannas' device may thus be taken as equal to or more than that of an A. P. M., especially with low heads.

To avoid tampering, the outlet can be roofed over without in any way affecting its discharge. Even if all the shoots get blocked, the outlet will remain working as an O.S.M.

This outlet may be considered to be still in its experimental stage, yet it seems possible to get a practically constant discharge within certain limits, by suitably adjusting the number, size, spacing and slope of the shoots. It may thus prove to be quite a useful type when developed in view of its simplicity and absence of moving parts.

24. Ghafoor's rigid flume module.* This type is a promising attempt by Mr. K. A. Ghafoor, at making an open flume rigid for a reasonable range above the designed water level practically on the same principle which Mr. Khanna applied to an O. S. M. The device consists of two plates ½" thick fitted in the gullet of the open flume, as shown in the sketch below :—

With a rise in the water level, the water flows over the first plate and then returns in the opposite direction through the gap between the plates. This damps the flow through the flume and tends to reduce the



discharge. The greater the rise of the water level in the channel and the consequent increase in the velocity of discharge through the flume the greater is the reverse pressure exerted by the flow between the plates in the opposite direction. By a suitable manipulation of

(*a*) the length of plates,

(*b*) the gap between them, and

(*c*) their inclination,

it was found possible by Mr. Ghafoor to make the reverse pressure, due to the rise of water level in the channel, just balance the increase of velocity in the flume, thus maintaining, practically, a constant discharge through the outlet.

*Rigid Flume Module by K. A. Ghafoor, Indian Engineering, September 1941.

Mr. Ghafoor carried out his original experiments with a depth on crest of 1·8′. He found that the range of rigidity was about 50 per cent of the depth on the crest, after which the discharge started increasing. Rigidity for a higher range can be obtained, however, by creating a second gap for increasing the back pressure.

Mr. Ghafoor found that the M. M. H. required by this outlet was not more than that required in an ordinary open flume. In the experiment in question he found that a working head of .95′ was required for a depth of 2.5′ on the crest. If the available working head with full supply in the channel was the minimum required for modularity in an O.F., *i. e.*, ·36′ (20 per cent of H), the working head available with H=2·5′ would be 1·06′, which is more than the required head of ·95′. In other words, the extra head due to the rise in water level above that designed in the channel is just killed by the device without affecting modularity.

To minimise the chances of any interference by zamindars, by blocking the gaps between the plates, Mr. Ghafoor suggests that the roof block referred to in para 8 (*g*) of this chapter be used in addition to the device described above.

This outlet is also in an experimental stage, and further experiments to perfect it are in hand by Mr. Ghafoor. Its main advantage over Khanna's rigid O. S. M. is the relatively small working head required and it ~~may~~ thus prove to be a very useful type when developed.

F—Volume measuring devices

25. Dethridge meter.* This is useful for measuring the exact quantity of water passed and is used extensively in Australia.

The details of the meter are given in plate No. 19. It consists of a wheel or drum to which projecting pieces of sheet metal are fastened. The drum is placed with its axle horizontal, and is set so that the projecting blades are in the current of the water to be measured. A special box, generally of 3″ reinforced concrete, is built around the wheel, so that all water in passing has to strike against the blades. In this way the wheel turns in proportion to the amount of water passing which can be measured by knowing the number of revolutions of the wheel. These are indicated by a. cyclometer driven off one end of the axle by means of an oscillating link and encased to protect it from spray.

The principle of the meter is positive measurement. Were it possible to make the edges of the cylinder and the vanes close fitting to the case, the quantity of water passed per revolution would be the same under all conditions of action. In ordinary field practice, however, it is usual to allow a clearance of $\frac{3}{8}$″ between the rotor and the case. The standard size in general use in Victoria and New South Wales has a capacity of from $\frac{1}{2}$ to $4\frac{1}{2}$ cusecs.

The merits claimed for this device are delivery with small loss of head, even up to 0·5 ft. It is also free from the risk of being tampered

*P. W. D., I. B. printed note dated 25th April, 1918 by Mr. F. W. Woods on the measurement of water by Dethridge Meter.

with as effective delivery ceases with stopping of revolution. It is found that ordinary floating debris causes no trouble, the rotor having power enough to crush it.

It is in no sense a module, and the discharge would be affected by variation of supply level in the channel. Its application may, however, be worth considering in cases where other types of outlets cannot be installed for lack of sufficient working head available.

26. Recorder-cum-semi-module. In a semi-module the discharge is only dependent on the water levels in the parent channel, and the depth over the crest is therefore a measure of the discharge that is passing through the outlet. If, therefore, arrangements could be made to maintain a continuous record of the depth on crest of a semi-module, it will be possible to calculate the volume of water passed through an outlet during any period. This can be done by installing an automatic gauge recorder indicating the depth on crest of the outlet. Automatic recorders are expensive equipment. The Leggett's recorder including the cost of the gauge well, etc., costs about Rs. 1,000, while the simpler recorder evolved by Mr. Munro would cost about Rs. 600. The use of this arrangement is therefore extremely limited in practice. Further, this arrangement will only record the quantity of water delivered at an outlet and will not determine the quantity of water given to any individual cultivator on the outlet.

27. Patwari*-cum-semi-module. If it is necessary to determine the quantity of water used by each cultivator on an outlet for purposes of assessment, the only possible arrangement in the absence of a recorder is to have a man noting down in a register the period during which water is used by a cultivator together with the G on the outlet.

This arrangement has been in use in different places in Europe and other countries where a watchman or guard is employed to record the time for which water is used by each cultivator together with the depth on crest above a weir installed in a watercourse.

In Punjab Engineering Congress Paper No. 188, Mr. K. R. Erry suggested that the *Patwari* instead of recording the area irrigated, should record the time for which water is used by a cultivator. He further advocated the installation of a standard flume below every outlet. The 'H' of this standard flume was to be 0·48′ so that the width in feet of the flume would be equal to the discharge in cusecs of the outlet. The working head required for this flume is also small being of the order of 0·1 ft.

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* A petty official who is entrusted with the duty of recording irrigation.

CHAPTER VI

Selection of outlet types

1. *Ideal conditions not available.* If an irrigating channel were to run with full authorised supply, at all times, and if the designed water surface levels were never to alter, the selection of the type required for any outlet would be a simple affair. The only governing factor would then be the available working head and any module or semi-module, which has a constant co-efficient of discharge, would be suitable provided the minimum working head required for modularity is available. Unfortunately, these ideal conditions are conspicuous by their absence.

2. *Causes of variations in full supply levels.* To appreciate the conditions which make it desirable to use a particular type of module or semi-module, it is proposed to consider here briefly the main causes of variation in the full supply level of a distributary. These are :

(*a*) Variation in discharge in the channel.

(*b*) A change in slope accompanied by an attempt at change in the channel cross section due to seasonal variations in the silt charge.

(*c*) A change in slope accompanied by a consistent effort to change the channel cross section due to faulty design in the first instance.

(*d*) The special requirements of rotational running.

Each of the above sources of variation will now be considered separately.

3. *Variation in discharge.* The ideal method of regulation which is generally adopted in the Punjab, is to run a distributary system always with full supply, or if sufficient water is not available, to close it altogether for short periods of six to twelve days. In practice, however, this is not always possible. Heavy rains in one part of the system may make it necessary to run channels with less than full supply. On the other hand a breach or some other cause may require the immediate closing of a distributary. Until the reduction of supply into the Main Canal can take effect, the channels above and below the defaulter must absorb the excess supply between them if there is no escape available. Such shortages or excesses must be distributed between the minor channels off-taking from a distributary and the outlets. Unless this happens, the tail reaches will either run short or burst. This consideration, therefore, indicates proportional distribution of supplies among the outlets.

It is sometimes necessary to supply additional water to some outlets for purposes of reclamation of *thur* lands. The increased discharge that is passed into a channel for this purpose raises the water level and thus induces a corresponding increase in the discharge of the outlets upstream of those to which the extra supply is to be given. In practice it has been found that with semi-modular outlets the supply to be put in at the head, sometimes, has to be two or three times as much as the discharge utilised in reclamation. This indicates the use of modules or semi-modules of a very low flexibility.

4. *Seasonal variations in silt charge.* The change in slope due to variations in the silt charge depends on the position of the channel with respect to the headworks, as such seasonal variations tend to decrease, the farther a distributary channel is removed from the headworks.

Such changes are generally small, but in some cases they may be persistent, specially in the head reach of a channel, and the problem then is to avoid shortage at the tail due to extra supply being drawn by the outlets in the upper reach. The effect of such silting up of channels generally becomes apparent during the month of September, and silt clearance is the only immediate remedy available short of a complete remodelling of the channel. The silt clearance necessary is carried out generally in October, but this is at best, a most unsatisfactory arrangement. The channels have to be closed when silt clearance is being done and this at a time when the demand for water is keen. Moreover some time is always lost before the remedy of silt clearance is applied and the crops in the tail reaches suffer appreciably before the defect is cured.

5. *Faulty design of channels.* The most important reason for the continual remodelling of channels which goes on in irrigation practice, is due to faulty design, not necessarily of the channel itself, but, possibly, of the channel head, the off-takes on the channel, or the outlets. Briefly, it may be stated that the location with respect to the reach of the river and the design of the head regulator of the canal determine the silt which enters the canal. Lower down, the design of the head regulator of a distributary determines the silt charge that is being taken into the distributary. Unless the slope and section of the distributary is capable of carrying the silt which enters at its head and the off-taking minors and outlets are capable of disposing of the entire silt which it carries, the channel will silt. It will be realised that any change in one of these factors not accompanied by a suitable change in the others, will disturb the silt equilibrium. It is outside the scope of this Paper to discuss the problem of a proper design of the distributing channel and its head regulator, but it may be accepted that some variations in the F. S. levels of the channels are bound to occur from time to time and the best design of outlets would be such that they are least effected by such changes, or in other words, they should be as rigid as possible.

6. *Rotational running.* The requirements of rotational running are peculiar. It is assumed that an effort will be made to run channels with full supply discharge or to keep them closed. Provided this is done, the time during which outlets are effected by rotational running is generally small and except where closures are too frequent, this factor can be ignored. In the latter case, the head reach of the channel should be fitted with outlets of a type which do not draw their full authorised discharge until the F. S. levels are attained.

Even then the distribution of supply is not quite equitable. The upper reach of a large channel may be running full supply while the approaching water is still only wetting the bed of the tail reach. As an offset to this, when the channel is closing, the outlets in the upper reach cease to draw before the supply has fallen appreciably, leaving the balance to run down to the tail reach outlets, as some compensation for their delayed opening supply.

Rotational running, therefore, postulates outlets of high flexibility in the head reach to enable them to take a share in the task of damping out fluctuations in supply.

7. *Use of control points.* The difficulties explained in para 4 and 5 *supra* can be eliminated, and the conditions of proportional distribution required *vide* para 3 *supra* can be secured to a large extent, by the introduction of control points in a distributing channel. A control point is so designed that the water surface level above it bears a fixed relation to the discharge passing. This level is independent of the varying silt charge in the channel and of any faults that may exist in the design of the section or slope of the channel. It varies only with the discharge and so long as the authorised discharge is passing, the water level immediately above the control point (in practice up to about 1,000 ft.) is the same as designed. Thus those outlets which are fixed within a short distance of the control points will pass their authorised discharges even if the silt charge varies or the design of the channel is faulty. For varying supplies proportional distribution is secured as explained in para 8 (*f*) of Chapter V.

A control point can only be constructed at the loss of some head in the distributing channel. Whenever a fall is otherwise necessary, it should be so designed that it works as a control point. Control points can also be introduced by raising the water levels upstream provided the command from the parent channel is not reduced to such an exten that the distributary is unable to take its due share of the supply.

The larger the number of control points on a channel, the more efficient is its working. A warning is necessary, however, that control points should not be introduced by flattening the slopes in the distributing channel as this would induce silt trouble and consequent silting below the control points which may render them non-modular. A minimum drop of 9" may generally be regarded as essential for the efficient working of a control point.

Where control points cannot be introduced, it is necessary to design outlets in such a manner that they are least affected by temporary or permanent changes in the regime of channels.

8. *Outlet requirements for varying channel behaviour.* To sum up, the considerations detailed above indicate :

(*a*) Temporary variations in discharge require proportional outlets to deal with the excess or distribute the deficiency.

The needs of reclamation require the use of outlets of low flexibility so that outlets other than those in which additional supply is to be passed do not take any discharge above their authorised capacity.

(*b*) Seasonal variations in slope require the use of outlets of a low flexibility. This would apply more to the tail reaches of channels where the F. S. level is appreciably affected by local silt movements.

(*c*) Faulty design can be combated only in part by the use of outlets of zero or low flexibility. This should not, however, be taken as indicating a method of avoiding the necessity for remodelling. Considerations of faulty design should be ruled out when deciding upon the type of outlets to be employed. The problem can only be solved by intelligent design and to drag this consideration in when selecting outlet types renders intelligent selection impossible.

(*d*) Rotational running indicates the use of outlets of high flexibility in the head reach of a channel. This is opposed, however, to (*b*) and (*c*) above.

9. *Silt conduction by outlets.* It has been stated in para 5 above that the outlets on a distributary system must be capable of disposing of the entire silt which enters the distributary. It must be remembered that water is continually percolating through the wetted channel perimeter in the entire length of the distributary. The steady reduction of the total discharge on this account is not accompanied by a proportional removal of the silt charge with the result that on a distributary the silt load if it does not deposit in the head reach actually increases as the water progresses further down the system unless the outlets in the head reach are so designed that they draw a large proportion of the silt charge in the channel. In a distributary system the absorption generally varies from 10 to 15 per cent. The silt charge in the water so lost must be removed by the offtaking outlets, or, in other words if the silt charge in a channel is 100 per cent, the silt conducive power of the outlets should be 110 per cent to 115 per cent to enable them to draw their share of the silt charge.

The silt draw in an outlet would depend on the following factors :—

(*a*) Position of entrance relative to the silted bed.

(*b*) Shape of entrance.

(*c*) Velocity through the outlet near its upstream end.

(*d*) Inclination of the pipe in the case of a pipe outlet.

With regard to (*a*) above, Mr. Crump wrote in a note dated 23rd May, 1930:

"It may be pointed out that the silt entering an offtake is generally speaking, wholly in suspension downstream of a certain cross section of the outlet approach and that the quantity of silt drawn from the parent by the outlet is entirely independent of the condition of flow downstream of this section. It is quite conceivable for instance that two A. P. Ms. (O. S. Ms.) of the same discharge, but having different crest levels might be identical in design upstream of the above mentioned cross section in which case they would draw the same amount of silt."

The above statement appears to be tenable, and is likely to lead to useful results if careful experiments are conducted on the lines indicated. The few observations so far made and actual experience gained, however, show that the deeper the setting of the outlet, the more silt it draws.

In I. B. Paper No. 26, Mr. Crump explained the basis of his tentative design for the approach to an A. P. M. and left it for future experience to decide whether this called for modification. Certain modifications were proposed by Mr. Sharma as described in para 9 (*ii*) of Chapter V and his observations showed that Mr. Sharma's modifications in the approach made for an improvement in the silt induction through an outlet. Also with settings deeper than in the A. P. M. the silt induction improved.

There are no comparative results available of various forms of outlets except the experiments of K. B. Sh. Minhaj-ud-din described in para 11 of Chapter V. These experiments cover a very small range, and there are many other types, whose comparative silt conducting power it is necessary to determine. In Chapter V, remarks have been made regarding the silt conducting power of the various types, but these require to be checked by detailed observations both in the laboratory and in the field. According to the experiments conducted by Mr. Sharma* a silt conduction of 110 per cent to 115 per cent is obtained in the following cases :—

(*i*) O. S. M. with approaches as desiged by Crump set at 9/10th.
(*ii*) O. S. M. with approaches as modified by Sharma set at 8/10th.
(*iii*) Crump's O. F. set at bed level.
(*iv*) Sharma's modified O. F. set at 9/10th.
(*v*) Bend outlet at 6/10th.

A pipe fixed at bed level is also considered to draw an equivalent amount of silt charge.

A possible method of increasing the silt conduction through the outlet is the introduction of a silt vane in the distributary opposite the offtake.

Attention is again invited, here, to the observations made in para 14 (*e*) of Chapter V. The pipe-cum-semi module is a useful device which offers complete control over the silt conduction by outlets.

It may also be observed that a watercourse should be given only as much silt as it can carry depending on the slopes available and the low silt induction capacity of some outlets should be compensated for by giving more than their due share of silt to other outlets, where conditions of command permit this being done.

In cases, where it is not possible to dispose of all the silt brought into the channel through the outlets, on account of consistently poor command on most of the outlets, the only solution is to raise the F. S. L. or alternatively to provide a silt selective head so that the total quantity of silt brought in is reduced.

*Silt conduction by Irrigation outlets. Punjab Engineering Congress Paper No. 168 by K. R. Sharma.

10. *Proportional distribution neither necessary nor feasible.* In the Punjab Engineering Congress, Paper No. 80 presented by Mr. E. S. Lindlay in 1923, he wrote as follows:

"For outlets, the writer contended that such version of proportional distribution as was possible with semi-modules entailed disadvantages that made it undesirable; and that the reasons in favour of proportional distribution (if that policy were possible) arise more from the convenience of the canal engineer than the needs of the irrigator. He also contended that positive modules, which would more nearly fulfil the needs of the irrigator under ideal conditions, were impossible under practical conditions: that by semi-modules used with low flexibility the needs of the irrigator could be satisfied without involving what is impossible in practice."

The observations made above have stood the test of time. Proportional distribution is necessary among the different channels of a distributary system or of a branch canal, but its application to outlets creates serious difficulties in the working of the system. The requirements of the cultivator do not make it necessary to adopt this method except on some channels where the conditions of supply are peculiar, *e.g.*, the non-perennial channels of the Sutlej Valley Canals. The proportional distribution of supplies on these canals has been dealt with in detail in Chapter VII.

11. *Limitations of available working head.* It will have been noticed from the description of the various types of outlets given in Chapter V, that a minimum working head (M. M. H.) is essential for the efficient working of semi-modules and modules. Unless the available working head is at all times more than the minimum modular head of an outlet, the device installed will not give the authorised discharge.

The minimum modular head required for an outlet is generally a function of the setting of the outlet, and as it is necessary to set the outlet with its crest at or near the bed level for silt conduction, the M. M. H. is indirectly a function of the full supply depth of the distributing channel. It follows that it is difficult to satisfy the opposing conditions of small loss of head in the outlet and efficient silt conduction in the case of outlets on large channels.

Before selecting the type of outlets to be used on a distributary system, it is essential to examine the available working head for each outlet. This is even more important in the case of channels whereon the proportional working of outlets is essential. The following steps are suggested for the examination of the available working head of an outlet compared with the M. M. H. required for a suitable device:

(*i*) An examination of the command statement of the outlet to consider the exclusion of high areas which have not received irrigation in the past.

(*ii*) Shifting the site of the outlet above a fall, and thus improving the command.

(*iii*) Raising the full supply level in the distributary wherever this is feasible, with reference both to the head available and the cost involved compared with the area to be benefited.

(*iv*) Removal of outlets from a big distributary by the introduction of a ditch minor. This will have the effect of reducing the 'D,' and thus the M. M. H. required for an efficient working of an outlet. The adoption of this method will again depend on the cost involved in relation to the areas to be benefited.

(*v*) Some improvement in command can also be effected by making the zamindars pay more attention to the upkeep and maintenance of their watercourses. Many watercourses are badly aligned and allowed to run at too steep a slope with a wide shallow section. Theoretically, for Lacey's $f=1$, the slope required in an unlined watercourse carrying 2 cusecs is 0·5 per °/oo and for a lined watercourse of "best discharging" section, carrying the same discharge and for the same value of f, the required slope is 0·324 per °/oo. In actual practice, however, the cultivator is expected to maintain his watercourse in such a manner that it runs with a slope of 0·2 per °/oo. If the watercourses are properly aligned and masonry profiles built at suitable intervals to serve as a guide for the cultivator, with regard to the section and the bed level of the watercourse, considerable improvement can be effected in the command of the outlet.

12. *Selection of the class of outlets*. In para 19 of Chapter III, outlets have been divided into three classes, and in Chapter V, the various types of each class have been described in detail. It is now proposed to study the relative merits of the three classes of outlets, and to see which class of outlet should be generally adopted.

A module may be regarded as the best type of outlet from the cultivator's point of view. In case of any variation in the full supply, however, modules by their very nature cannot absorb any fluctuations in the parent channel, and thus the channels are either flooded or run dry in the tail reach.

The above considerations would indicate that the use of modules should be limited to :

(*a*) Direct outlets on a branch canal subject to variations in supply.

(*b*) Above stop dams where heading up may be necessary for feeding other channels.

(*c*) In channels in which extra supply is sometimes run for delivery to certain selected outlets for purposes of reclamation of *thur* areas on those outlets.

Semi-modules, on the other hand, if properly designed can be made to distribute more or less equitably variations in the supply of the distributary. If however, the discharge in a distributary does not alter, but there is a change in the water level due to silting, the semi-modules in the silted reach draw a bigger share of discharge, and the tail runs short. The design of semi-modules therefore, should be such that they are least affected by changes in the regime of the channel.

In non-modular outlets, the discharge depends on the difference of water levels in the distributary and the watercourse. As already stated, the water levels in the watercourse vary considerably depending on the high or low areas which are being irrigated at any given moment ; also by silt clearances in the watercourse, the cultivators can alter the discharge whenever they like. Thus in channels fitted with non-modular outlets, there is always a flooding at the tail when the cultivators in the upper reach do not maintain their watercourses in first class order during periods of slack demand, and there is always a shortage at the tail in periods of keen demand, when cultivators silt clear their watercourses as much as they can.

Non-modular outlets, therefore, ahould be avoided as far as possible. There use is justified only when the working head available is so small that a semi-modular outlet cannot be designed.

13. *Selection of the type of outlets.* Having decided on the class of outlet to be used in a particular case the next step is to select the type. Outlets differ largely in respect to discharge command, volume of parent channel, size of channel bank, etc. It appears reasonable, therefore, that the type of outlet should be selected to suit the conditions at site. One particular type of outlet cannot be installed everywhere, simply because conditions do not permit.

(*a*) *Modules.* The various types of modules have been described in parts D and E of Chapter V. The modules with moving parts as described in part D have no use in a large irrigation system for the reasons explained at the end of part D of Chapter V. Of the modules without moving parts Mr. Gibb's device is the only one, on which sufficient work has been done so far, to enable an accurate design to be worked out. The Gibb's module is, however, liable to tampering and special safeguards are necessary to prevent this. The other two devices *viz.* Khanna's and Ghafoor's modules described in part E of Chapter V are still in an experimental stage, but there is every hope that one or both of these two, types can be developed into a practical and useful module.

(*b*) *Non-modular outlets.* There are only two types of non-modular outlets, the pipe or barrel and the Scratchley. For the reasons explained in para 2 (*c*) of Chapter V, the authors advocate the use of the Scratchley outlet in preference to the ordinary pipe or barrel.

(*c*) *Semi-modular outlets.* In part B of Chapter V, the various types of semi-modular outlets have been described in detail. Any type of the open flume or the O. S. M. may be used, and in the selection of the particular type for any situation, the following factors should be considered :

(a) Maximum rigidity possible with the working head available.
(b) Silt conduction.
(c) Immunity from tampering.
(d) Ease of adjustment.
(e) Cost.

It will be seen from Appendix I that the open flume outlet is the most rigid outlet for a given M. M. H., but the use of this type is very much limited by the minimum width $B_t = 0{\cdot}2'$ as described in para 8 (e) of Chapter V. For a normal two cusec outlet, the depth on crest cannot be more than $2{\cdot}3'$, and thus the use of this outlet in practice can only be limited. The open flume outlet also suffers from a serious handicap in its non-adjustability.

Attention is, however, invited at this stage to the remarks made in para 7 *supra*. The changes in regime do not affect the draw-off of outlets which take off immediately upstream of a control point. For these positions, therefore, the open flume outlet or the pipe-cum-open flume outlet is the best type. If it is possible to design the open flume outlet with its crest at or near its bed level and the size of the bank is not heavy, the simple open flume will do, but if either of the two conditions described above do not exist, it will be more useful to have a pipe-cum-open flume.

At all other sites, the O. S. M. set at or near the bed level is the best type of outlet. If the size of the bank is large the O. S. M. is relatively costly but the cost can be considerably reduced by the use of a pipe-cum-semi-module.

If sufficient working head is not available to design the O. S. M. with a crest at or near the bed level, there is no other alternative but to keep a higher setting and thus have a less rigid outlet.

It is useful to remember here that of all the O. S. Ms. described in Chapter V, the Jamrao type requires the minimum M. M. H and its use is commended to the engineers in Provinces other than Sind, where it is already in universal use.

On most of the Punjab canals, the silt problem is, however so acute that it is necessary to adopt sometimes one of the silt extracting semi-modules as described in Part C of Chapter V. Of the types described in this part, the pip-cum-semi-module offers the maximum possibility of silt control together with additional facilities regarding low cost, ease of adjustment, a large range of flexibility and a high degree of immunity from interference due to certainty of early detection.

The advantage of the pipe-cum-O. S. M. over the simple O. S. M. is only in the reduced cost of the former in the case of large channels, and in its additional silt extracting capacity.

The Scratchley type can be used conveniently where free fall conditions are available.

The above may be regarded as the types to be used in general. For specific cases, no general device can be recommended, but a perusal of the merits and demerits of the various types as described in Chapter V renders it possible to make a correct selection.

Another useful thing to remember is that the effect of regime changes on a channel is most marked below the control points. Therefore, it is desirable that no outlets be fixed immediately (say up to half a mile) below a control point. All such outlets should be brought upstream of the control point. Here also if the construction of an ordinary open flume or an O. S. M. is costly or offers any other difficulty, the pipe-cum-semi-module will offer an easy solution. The pipe can take off at any point in the masonry of the control point.

14. *Outlets on new canal systems.* It has been stated in Chapter IV that, in the early days, only temporary outlets were constructed in the first instance. Later on, it was possible to fix the site of an outlet from the contoured plan of the area, and many officers started to favour the fixing of permanent outlets in the first instance. Some of the advantages claimed at various times for the use of temporary outlets in the first instance are listed below :

(*a*) If permanent outlets are built they will not draw their full discharge until full supply levels are attained and thus the tail will be flooded. Later on, the head outlets will draw too much and water will not reach the tail. Thus a type of outlet is necessary in the early stages in which the size can be easily altered season by season.

(*b*) The use of temporary pipes would give definite data on which the final construction of outlets could be carried out.

(*c*) Unless the distributary attains its final silted bed the exact setting of the outlet cannot be known.

(*d*) Since alteration to an outlet is necessary in the early stages, it is useful to have temporary outlets to start with.

The objections to the use of temporary outlets are :

(*a*) Where temporary outlets are built in the first instance, there is great difficulty in getting them built *pucca*, later on.

(*b*) As long as outlets are temporary, no statistics of value are collected.

*(*c*) "There is something demoralising about temporary outlets that is hard to understand, but it seems that once the officers have got into the habit of using temporary outlets, they lose their nerve and do not seem able to pull themselves together and build *pucca* outlets and things drift on till a man of energy and force of character comes and builds them *pucca* in a hurry from the best information he can get at the time and thus many are built wrong."

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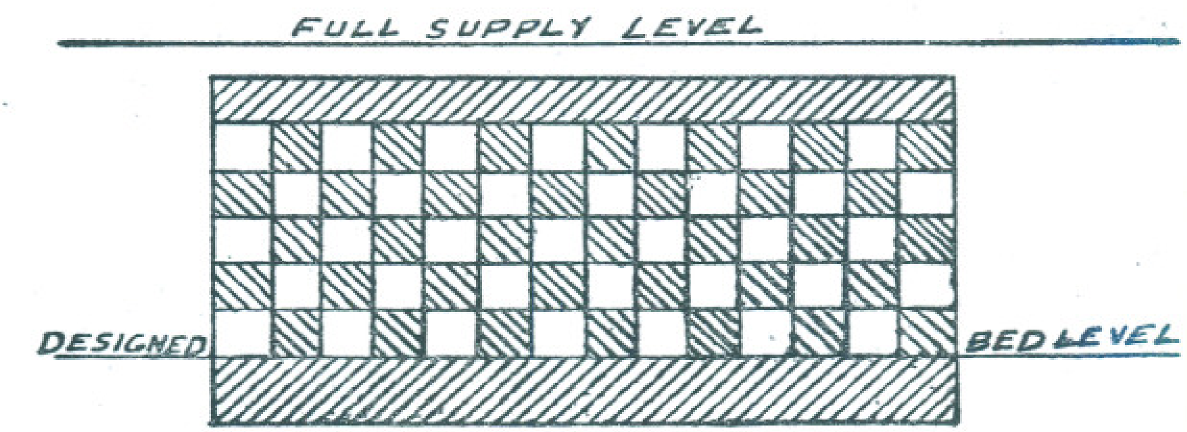
*Note dated 9th April, 1901 by Mr. T. R. Ward.

(*d*) *Pucca* outlets are more immune from tampering than temporary ones.

(*e*) From the contoured survey maps it is easy to fix the position of the outlet and subsequently alterations will only be in size.

(*f*) Wooden outlets are very expensive as they do not last long enough.

Whereas there can be no objection to fixing the permanent sites of outlets in the case of new canal systems, the question of fixing semi-modular outlets in the first instance requires further consideration. On the Haveli Canals Project recently executed, O. S. Ms. were installed in all new channels at the time of construction. The opinions of officers who had to run these channels immediately after construction differ as to the wisdom or otherwise of the step taken. On channels irrigating proprietary areas where the development of the area was a very quick affair and full supply discharges were let into the channels soon after construction, *pucca daffs** of the shape shown below were constructed at various points so as to raise the water levels in the new channels up to designed conditions. In one division, there were as many as 100 such *daffs* and the conditions of draw-off on outlets could not be very satisfactory. However, the advantage lies in the fact that all steps are directed towards attaining designed conditions as early as possible, and in this respect the constructing of O. S. Ms. in the first instance may not have been any worse than the fixing of temporary outlets.



On the other hand, on channels where there were large crown waste areas on which development was slow, even five years after construction, it is not possible to pass the full authorised supply into the channels. O. S. Ms. designed for a certain discharge and certain full supply level in the distributary could not, therefore, draw anything like their authorised discharges, and it became necessary to give auxiliary pipes to supplement the supply through the O. S. Ms. It is a matter for consideration if temporary outlets in the nature of pipes could not by themselves be sufficient under these conditions.

* Stop dams of masonry.

The Authors recommend that on any new channel where the development of irrigation is bound to take some time, pipe outlets should at first be built, and semi-modules should come in only at a stage when conditions have stabilised, and there is some hope of attaining the designed water levels in the channel.

15. *Outlets for lined channels.* For a given discharge, a lined channel is deeper than an unlined channel. The silt draw from such channels would, therefore, be more difficult to arrange on account of the high setting which must necessarily be given to outlets from considerations of working head available. There is no data available at present with regard to the silt distribution in a lined channel but in case this distribution is more or less of the same nature as in an unlined channel, the bend outlet or Haigh's silt extracting outlet would seem to offer the best solution, as they can draw much more silt than any other type.

In case, however, the silt distribution through the section of the channel is more uniform than in the case of an unlined channel, an A. O. S. M. or O. F. can be used with advantage.

16. *Summary of recommendations.* (*i*) The use of modules is indicated in the case of direct outlets taking off from a branch canal.

(*ii*) Non-modular outlets should be avoided, as far as possible, but where the available working head is limited the Scratchley type may be used.

(*iii*) The semi-modular outlet is the device recommended for general use. The type to be adopted in various cases should be as follows :—

(*a*) As many control points as possible should be provided on a channel. Wherever possible, outlets should be clustered above (within 1,000 ft.) a control point. In such cases open flume outlets, having their crest levels the same as that of the work in the parent channel should be adopted.

(*b*) The outlets at the tail cluster should be of the open flume type*.

(*c*) All other outlets should have as low a flexibility as possible. This can be secured by using A. O. S. Ms. provided they can be designed with their crest at or near bed level, failing which by open flumes fitted with roof blocks having a similar setting. The use of the Jamrao type semi-module is recommended on account of its low M. M. H.

(*d*) Wherever the section of the bank is heavy, and/or the crest of the outlet cannot be placed at or near the bed level, the pipe-cum-semi-module of the minimum possible flexibility should be used.

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*In the case of very long distributaries they should be of the spillway type (*i. e.*, at designed full supply level, there should be a ledge on all outlets). This ensures minimum rise of full supply levels in the channel in case of an excess reaching the tail.

CHAPTER VII

Special requirements of the non-perennial channels of the Sutlej Valley Canals*.

1. *Peculiarities of the Sutlej Valley Canals.* The supply in the river Sutlej except for a short period of about three months, is much below the requirements of the canals taking off from this river. For this reason the equitable distribution of supplies has always been a vexed problem on the non-perennial channels of the Sutlej Valley Canals. The non-perennial Sutlej Valley Canals flow for 6½ months during the year from 1st April to 15th October—and during this period full supply is available for less than 3 months only. The problem is all the more important as the periods of short supply synchronise with the periods during which the principal money-making *kharif* crop (cotton) is sown, the entire *kharif* crop is matured and preliminary irrigation (*rauni*) for *rabi* is done.

Elsewhere in the Province, when rivers are below the requirements of canals, the difficulty is overcome by running the channels in rotation. Any individual distributary is, however, always run with full supply discharge. This procedure cannot be adopted on the Sutlej Valley Canals, for reasons given below.

2. *Factors essential to a decision: Normal versus full supply.* To arrive at a decision whether a distributary should be run with full supply or less in the *kharif* sowing and maturing periods, the following factors need to be considered :—

(*i*) To enable all irrigators on an outlet to have their turn of water in the same rotational turn of a distributary it is necessary that the distributary should be run for a minimum period of eight consecutive days. Where this is not possible due to abnormally low supplies (such conditions are generally met with in April), distributaries should be run for a minimum period of four consecutive days to enable outlets to work for at least 28 *pahrs* (half a week). In such cases cultivators should be advised to work to half of their sanctioned *waris* (turns).

(*ii*) It is desirable that the length of a closure during the sowing period should not exceed 12 days.

(*iii*) The demand during the month of April is always slack.

(*iv*) During May generally no distributary requires to be run to the full authorised capacity and 80 per cent of the authorised discharge is amply sufficient for the needs of the cultivators.

(*v*) During June and in the *kharif* maturing period, from the 6th September to 15th October, demand is always very keen

* This Chapter and Appendix IV have been extracted from an official note on the subject.

and all channels should be run, if possible, with full authorised discharges.

(*vi*) The following are the actual supplies which were available at distributary heads from 1930 to 1941 during different periods detailed below :—

No. of full supply days available at distributary heads.

Year.	April.	May.	1—9 June.	Total sowing period : 1st April to 9th June.	Kharif maturing period : 6th September to 15th October.
1.	2.	3.	4.	5.	6.
1930	5·6	14·9	7·2	27·7	33·9
1931	6·1	6·9	2·3	15·3	35·3
1932	...	1·8	1·8	3·1	29·4
1933	2·4	4·8	6·0	13·2	23·2
1934	1·9	2·0	2·5	6·4	25·4
1935	2·8	6·9	4·5	14·2	30·1
1936	2·7	13·7	9·0	25·4	29·7
1937	6·5	8·3	5·8	20·6	33·9
1938	8·2	17·2	9·0	34·4	24·6
1939	3·1	8·6	2·8	14·5	29·1
1940	1 3	2·6	3·2	7·1	23·4
1941	0·4	2·6	1·2	4·2	21·3
Total ...	41·0	89·8	55·3	186·1	359·3
Average	3·4	7·5	4·6	15·5	28·3

Note :—(*i*) For the sake of comparison, the period taken in Col. 4 is up to 9th June when the official sowing period ends. Actually sowing operations go up to the end of June.

(*ii*) Figures in Col. 4 for the years 1930 to 1938 are approximate.

3. *Full supply running not possible.* An examination of the data given above shows that the river is generally low in April, May, and also in the *kharif* sowing period as a whole. Conditions in the *kharif* maturing period are generally better.

To be able to run channels for 8 consecutive days at a time with 80 per cent of the full authorised discharge and with intervening closures not exceeding 12 days, the net supplies required at distributary heads during the month of May should be

$$\frac{80}{100} \times 8 \text{ days} \times \frac{31}{8 + 12} = 9{\cdot}92 \text{ full supply days.}$$

It will be seen from the above statement that this supply was available only for 3 years out of 12 for which data is available.

If, however, the channels are run with less than full supply (say 55 per cent of full supply *called* normal supply) and other conditions remain the same, the total discharge required is

$$\frac{55}{100} \times 8 \text{ days} \times \frac{31}{8 + 12} = 6{\cdot}82 \text{ full supply days.}$$

This supply, it will be seen from the statement, was available in 7 out of the 12 years detailed in the statement.

It is thus clear that it is not possible to run the non-perennial distributaries of the Sutlej Valley Canals with anything much in excess of normal supply during April and May in particular and in the *kharif* sowing season in general.

4. *Aim of remodelling on Sutlej Valley Canals.* In view of the above it is desirable that in remodelling non-perennial channels of Sutlej Valley Canals, one should aim at equitable distribution at normal supply and within the range normal supply to full supply. Unless this is done, running of distributaries with normal supplies leads to numerous complaints on the part of cultivators in the tail reaches of the channels.

5. *Characteristics of proportional outlets.* In Appendix IV of this Paper detailed designs have been worked out for outlets which under certain conditions (of command being available) will give equitable distribution both with normal and full supply running. The conclusions arrived at the end of paragraphs 2 to 5 of Appendix IV may be briefly, summarised below:

(*a*) An open flume outlet having its crest at 0·9 D and having an available working head of not less than 0·4 D will draw proportional discharge at both full and normal supply conditions in a channel.

(*b*) An O. S. M. with its H_s = 0·43 D and an available working head of not less than 0·4 D will draw proportional discharge at both full and normal supply conditions in a channel provided G does not exceed 0·69 D (*Vide* paragraph 4 of the Appendix).

(*c*) An O. S. M. with G = 0·75 D and Y = H_s will draw its due share of discharge at full and normal supply levels. In the latter case it works as an open flume. The working head required in this case is also 0·4 D.

The relative merits of the various types have been discussed in paragraph 6 of Appendix IV.

6. *Working heads available.* It will be seen that a working head of 0·4 D is required for the design of outlets proposed in para 5 *supra.* An examination of the available working heads of outlets on the Sutlej Valley Canals shows that whereas conditions vary considerably a substantial

number of outlets do not possess a working head of 0·4 D. It will thus be recognised that whereas it is possible to design a large number of outlets such that they would work proportionally under both full and normal supply conditions, the number of those that cannot be so designed is considerable.

7. *Classification of outlets.* For purpose of design therefore the outlets on a non-perennial distributary on the Sutlej Valley Canals may be classified as follows:

A. Outlets that can be designed to work proportionally under both full and normal supply conditions—Such outlets must have an available working head of not less than 0·4 D.

B. Outlets that cannot be designed as Class A, but have sufficient working head to be modular at full supply conditions. Such outlets are those that have a working head of 0·2 D to 0·4 D.

C. Outlets other than those included in Classes A and B. Such outlets have very poor command, *i. e.*, less than 0·2 D.

After the outlets of a distributary have been classified as above and before proceeding with the design of outlets, an attempt should be made as explained in para 11 of Chapter VI to see if any of the outlets classed B cannot be converted into Class A or those classed C to Class B or A. For successful distribution it is essential that the number of outlets of Classes B and C should be reduced to a minimum.

8. *Design of outlets for various types.* The type of outlet that should be adopted for each class, as defined in paragraph 7 *supra*, may now be discussed.

(I) *Class A.* For this class of outlet which can be designed to draw correct discharge at both normal and full supply conditions, the following type should be adopted :—

(*a*) An open flume outlet with crest set at 0·9 D, provided B_t does not work out to less than 0·2′.

(*b*) If in (*a*) above B_t works out to less than 0·2′, an O. S. M. set at 0·75 D may be designed such that the value of H_s ranges from 0·375 to 0·43 D.

(*c*) If an O. S. M. outlet as above cannot be designed for a particular discharge then an O. S. M. set at 0·69 D may be designed satisfying the condition H_s = 0·43 D.

(II) *Class B.* For this class of outlet, it is not possible at present to arrange for proportional working at both full and normal supply conditions. The best type of outlets for this class would be either

(*a*) an open flume with H equal to *five* times the working head available, or

(*b*) an O. S. M. outlet set at 0·75 D with H_s from 0·375 D to 0·43 D, whichever of the two would give a lower setting, so as to enable the outlet to draw some discharge at low supplies.

(c) In case the width B_t of the open flume outlet works out to less than 0·2′ or it is not possible to design an O. S. M. according to (b) above for the particular discharge then the outlet should be designed as an O. S. M. with crest at 0·69 D, provided it could work modularly under full supply conditions.

(III) *Class C.* For this class of outlet which has a working head of less than 0·2 D, it is not possible to design an outlet of the module type. The only outlet possible is of the pipe or orifice type and the best type is the Scratchley outlet.

The working head H_w to be adopted for purpose of design of the outlet should be the average of working heads observed during the time of keen demand (1st to 15th September) for a period of 10 days. A fair proportion of these working heads should be personally checked by the sub-divisional officer (by surprise visits, if possible).

9. *Roof blocks for open flumes.* As stated in paragraph 6 (B) of Appendix IV when water level in a distributary rises above designed full supply level on account of changes in regime the open flume outlet draws a high percentage of excess. To guard against this, all open flume outlets whether of Class A or B should be fitted with roof blocks, as described in para 8 (g) Chapter V.

10. *Silt drawing capacity of outlets.* The outlets proposed above will have a high setting, and will not draw their due share of the silt charge in the distributary. To overcome this difficulty, all outlets of Class A and those of Class B, should be of the pipe-cum-semi-module type.

CHAPTER VIII

Conclusions

1. *What has been done.* An attempt has been made in this Paper to bring together and examine the vast knowledge which exists regarding the design of outlets, with a view to solve the problems created by the different channel behaviours, the needs of cultivators, and low river supplies.

The known fact that extensive remodelling of outlets and channels never ceases, is of itself a proof that the principles of distribution of supplies and selection of outlet types are not fully appreciated by many officers charged with the task of equitable distribution of water.

It is quite impossible that every single officer should have all the varied experience required for the production of a completely satisfactory system of distribution. The volume of published notes, papers, etc., most of which have been abstracted in this Paper, is considerable, and the judicious use of the experience of others cannot but be of great assistance.

2. *Scope for further research.* There is, however, still considerable field for further research and enquiry. The Irrigation Research Institute in the Punjab has been entrusted with some of this work, and their results will be awaited with interest.

Some of the points on which more knowledge is necessary are :—

(*i*) Silt conducting capacities of various types of outlets with different settings, both in their relative and absolute aspects *i. e.*, compared with silt in the parent channel.

(*ii*) Possible modifications in the approach and shape of A. O. S. Ms. like those proposed by Mr. Sharma so as to secure better silt drawing conditions and absolute consistency in the co-efficient of discharge.

(*iii*) The examination of the Jamrao type of O. S. M. and of its suitability for use in the Punjab and of other methods of reducing the M. M. H. of an O. S. M., *e. g.*, by the addition of a surge chamber suggested by Mr. Sharma in the Punjab Engineering Congress Paper No. 237.

(*iv*) Shape of the roof block for an open flume outlet so that there is no initial reduction in discharge when the roof block first comes into action.

(*v*) Evolution of a modification of the Gibb's module using a straight flume as suggested by Mr. Crump.

(*vi*) Development of Khanna's and Ghafoor's modules with a view to determine the best slope and spacing, etc., of the vanes.

If this Paper stimulates further interest in the distribution of water for irrigation and leads to a better appreciation of the subject, the Authors would consider themselves fully compensated for the time and labour they have expended.

APPENDIX I

Flexibility

1. *General.* Flexibility has been defined as the ratio, the rate of change of discharge of the outlet bears to the rate of change of the discharge of the channel.

In general, the discharge of a channel can be expressed by

$$Q = C D^n \quad \ldots \quad \ldots \quad (i)$$

where D is the depth and C is a constant

∴ the rate of change of discharge with respect to the depth is

$$\frac{dQ}{dD} = n C D^{n-1} \quad \ldots \quad \ldots \quad (ii)$$

From (*i*) and (*ii*) above

$$\frac{dQ}{Q} = n \frac{dD}{D} \quad \ldots \quad \ldots \quad (iii)$$

The discharge of an outlet is generally given by

$$q = C_1 H^m \quad \ldots \quad \ldots \quad (iv)$$

where H is the head acting and C_1 is a constant

∴ the rate of change of discharge with respect to the head acting is

$$\frac{dq}{dH} = m C_1 H^{m-1} \quad \ldots \quad (v)$$

From (*iv*) and (*v*), $\frac{dq}{q} = m \frac{dH}{H} \quad \ldots \quad \ldots \quad (vi)$

$$\therefore \text{ Flexibility, } F = \frac{dq}{q} \Big/ \frac{dQ}{Q} = \frac{m\, dH}{H} \Big/ n \frac{dD}{D}$$

As a rise or fall in the F. S. L., *i. e.*, in depth D postulates an exactly equal rise or fall in the head H, $dD = dH$

$$\text{and } F = \frac{m}{n} \cdot \frac{D}{H} \quad \ldots \quad \ldots \quad (vii)$$

2. *Proportionality.* It will be clear from the definition that for proportionality, F = 1

$$or\ D = \frac{n}{m} H \quad \ldots \quad .. \quad (viii)$$

$$\text{or the setting } \frac{H}{D} = \frac{m}{n} = \frac{\text{offtake index.}}{\text{channel index.}}$$

As an approximation, *n* may be taken = 5/3.*

* A detailed analysis is given in Appendix I, C. B. I. Publication No. 10.

This certainly has serious limitations*, as it postulates a horizontal bed, 1/2 to 1 side slopes and a constant water surface slope at all stages of the discharge.

3. *Orifice and weir types.* In the A.P.M., O. S. M. or a barrel type,

$$m = 1/2$$

and with $n = 5/3$,

$$F = \frac{3}{10}\frac{D}{H} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (ix)$$

or H = 3/10 D for proportionality

For an 0 F. outlet, $m = 3/2$, giving

$$F = \frac{9}{10}\frac{D}{H} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (x)$$

or H = 9/10 D for proportionality.

For outlets set for proportionality as described above, with a rise in the F. S. level on account of increased discharge in the channel the flexibility would decrease and the outlet would become sub-proportional, *i. e.*, the increase in the discharge of the outlet will be proportionately less than that in the discharge of the parent channel. With a fall in the F. S. level, the flexibility would increase and the outlet would become hyper-proportional.

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*To enable a more correct determination, Mr. Lacey suggested the following treatment in 1931, in the discussion on P. E. C. Paper No. 146.

If D be the elevation of water surface in the parent channel the general expression for proportionality is

$$\frac{q}{Q} = \frac{d\,q}{d\,Q} = \frac{d\,q}{d\,D} \times \frac{d\,D}{d\,Q}$$

$$\text{Now } \frac{q}{Q} = \frac{C_1 H^m}{Q} \qquad \text{From } (iv)$$

$$\text{Also } \frac{q}{Q} = \frac{d\,q}{d\,H} \times \frac{d\,D}{d\,Q} \qquad (\text{as } d\,D = d\,H)$$

$$= C_1\, m\, H^{m-1} \frac{d\,D}{d\,Q}$$

$$\therefore \frac{C_1 H^m}{Q} = C_1\, m\, H^{m-1} \frac{d\,D}{d\,Q}$$

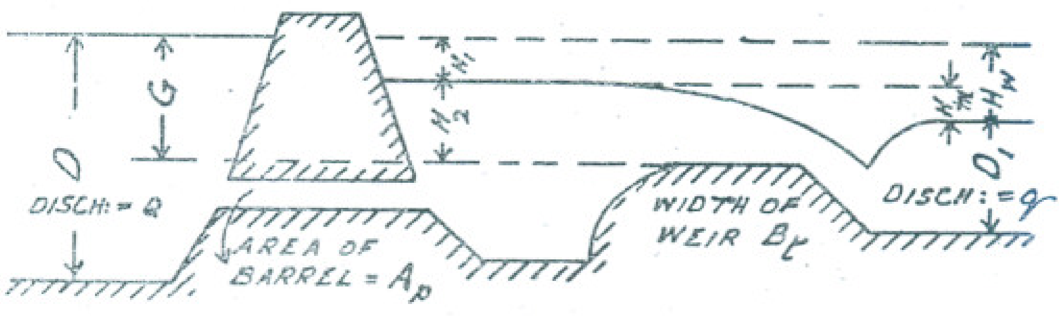
$$\text{or } H = m\, Q \frac{d\,D}{d\,Q}$$

This is a general equation applicable in all cases and the value of m can be determined easily by plotting a stage discharge curve, indicating the variation of discharge with the water surface, from actual observation for various sites at certain intervals throughout the channel. These curves would give the value of $\frac{d\,D}{d\,Q}$ at any point and for any discharge.

When the outlet is set lower than the setting required for proportionality, a rise in the F. S. level would tend to move it towards rigidity and a fall would move it towards proportionality. The movement would, however, be less pronounced in the case of a weir outlet, owing to the high proportion that H bears to D for flexibility.

The weir outlet with crest pitched higher than 9/10ths has a high flexibility, *i. e.*, is hyper-proportional.

4. *Pipe-cum-open flume.* In the case of Harvey-Stoddard improved semi-module or a pipe-*cum*-O. F. the flexibility may be similarly determined.



The discharge of this outlet is given by the formula

$$q = C_2 A_p H_1^{\frac{1}{2}} = C_3 B_t H_2^{\frac{3}{2}}$$

$$or\ q = C_4 H_1^{\frac{1}{2}} = C_5 H_2^{\frac{3}{2}} \qquad \ldots \qquad \ldots \qquad \ldots \quad (xi)$$

$$\text{where } G = H_1 + H_2$$

$$\therefore d\,D = d\,G = d\,H_1 + d\,H_2$$

$$\text{from } (iv)\ \frac{d\,q}{q} = \frac{1}{2} \cdot \frac{d\,H_1}{H_1} = \frac{3}{2} \cdot \frac{d\,H_2}{H_2}$$

$$= \frac{d\,H_1 + d\,H_2}{2\,H_1 + 2/3\,H_2} \qquad \ldots \qquad \ldots \qquad \ldots \quad (xii)$$

$$= \frac{d\,G}{2\,H_1 + 2/3\,H_2}$$

$$\therefore F = \frac{d\,q}{q} \Big/ \frac{5}{3} \quad \frac{d\,D}{D} \qquad \ldots \qquad \ldots \quad \text{From } (ii)$$

$$= \frac{3/5\,D}{2\,H_1 + 2/3\,H_2} = \frac{D}{10/3\,H_1 + 10/9\,H_2} \qquad \ldots \quad (xiii)$$

and for proportionality $D = 10/3\,H_1 + 10/9\,H_2$ ... ... (*xiv*)

Provided that lowering the weir cill below the bed of the channel is not contemplated in practice, for maximum flexibility H_1 and H_2 must both be a minimum. In the limit H_1 vanishes, *i. e.*, the barrel is removed and the weir is left with a crest of infinite width and infinitesimal H_2. The flexibility is then infinite. For minimum flexibility, $G = D$ and H_2

is a minimum, *i. e.*, zero and $H_1 = D$, *i. e.*, the weir is removed, and the barrel is 'free fall' at the bed level. The flexibility is then 3/10.

From these considerations, the diagram given in plate 1 has been made out by Mr. A. M. R. Montagu, so as to give all possible ranges of flexibility of this outlet, depending on the setting. The co-ordinates are ratio of $\frac{H_1}{D}$ vertical, and $\frac{H_2}{D}$ horizontal. The full lines at 45° are lines of constant G/D, as $\frac{G}{D} = \frac{H_1}{D} + \frac{H_2}{D}$. The inclined dotted lines are lines of constant flexibility. Thus for any setting G/D, the possible flexibilities as well as corresponding ratios of $\frac{H_1}{D}$ and $\frac{H_2}{D}$ can at once be read.

For example, for a setting of 0·7, there is the following range of flexibilities for different values of $\frac{H_1}{D}$ and $\frac{H_2}{D}$:—

For $\frac{H_1}{D} = 0{\cdot}1$, and $\frac{H_2}{D} = 0{\cdot}6$, $F = 1{\cdot}0$

For $\frac{H_1}{D} = 0{\cdot}15$, and $\frac{H_2}{D} = 0{\cdot}55$, $F = 0{\cdot}9$

For $\frac{H_1}{D} = 0{\cdot}21$, and $\frac{H_2}{D} = 0{\cdot}49$, $F = 0{\cdot}8$

For $\frac{H_1}{D} = 0{\cdot}3$, and $\frac{H_2}{D} = 0{\cdot}4$, $F = 0{\cdot}7$

For $\frac{H_1}{D} = 0{\cdot}4$, and $\frac{H_2}{D} = 0{\cdot}3$, $F = 0{\cdot}6$

For $\frac{H_1}{D} = 0{\cdot}55$, and $\frac{H_2}{D} = 0{\cdot}15$, $F = 0{\cdot}5$

For $\frac{H_1}{D} = 0{\cdot}65$, and $\frac{H_2}{D} = 0{\cdot}05$, $F = 0{\cdot}45$

The flexibility of orifice and weir outlets is also given by making H_2 and H_1 respectively equal to zero.

It may be pointed out that the discharge q in the watercourse varies approximately as $(D_1)^{5/3}$, whereas the discharge over the weir crest will vary as $(H_2)^{3/2}$. The full supply level in the watercourse thus tends to 'overtake' the supply level in the cistern. This will actually occur if insufficient margin is allowed between the watercourse and the cistern and 'drowned' orifice conditions will obtain.

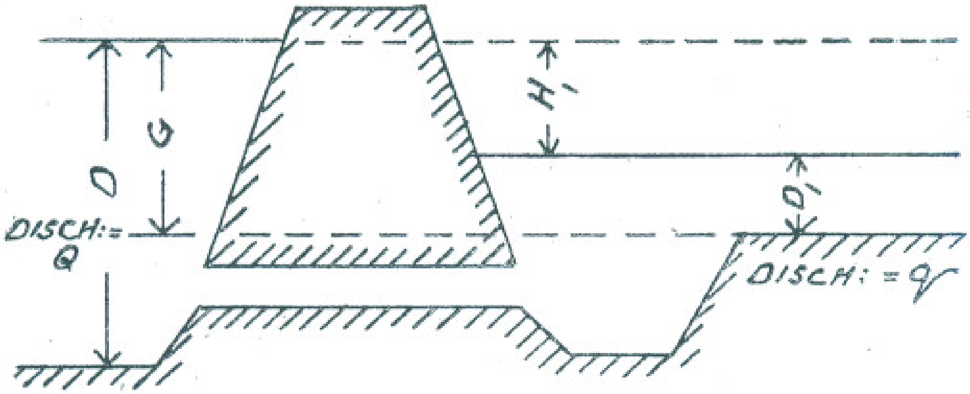
5. *Pipe-cum-O. S. M.* On the analogy of equation (*xiii*) the flexibility of a pipe-*cum*-orifice semi-module will be given by the equation

$$F = \frac{D}{10/3\, H_1 + 10/3\, H_2}$$

$$= \frac{D}{10/3\ H_s} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (xv)$$

Thus the introduction of a pipe before an O. S. M. does not alter its flexibility for the same value of H_s.

6. *Drowned Orifice.* Let us now consider the flexibility of a drowned orifice.



Assuming that the discharge of a watercourse varies as the 5/3 power of the depth

$$q = C_6 H_1^{\frac{1}{2}} = C_7 D_1^{\frac{5}{3}}$$

and $G = H_1 + D_1$

In practice the size of the watercourse is determined by the discharge. The width and depth are thus assumed implicit in the full supply discharge of the outlet and are not considered to vary for the purpose of this note.

It can be seen easily that in this case the flexibility would be given by

$$F = \frac{D}{10/3\ H_1 + D_1} \qquad \ldots \qquad \ldots \qquad \ldots \qquad (xvi)$$

where D_1 is a constant for a given discharge.

$\therefore$ for proportionality $D = 10/3\ H_1 + D_1$

The flexibility decreases rapidly as G is increased and can be read off the vertical ordinate of the 'flexibility diagram' by substituting

$$\frac{H_1 + 3/10\ D_1}{D} \text{ for } \frac{H_1}{D}$$

APPENDIX II

Sensitivity

1. *Definition.* Sensitivity has already been defined as the ratio that the rate of change of discharge of an outlet bears to the rate of change in level of the distributary water surface, referred to the normal depth of the channel.

The definition may thus be represented by the equation

$$S = \frac{dq}{q} \Big/ \frac{dH}{D} \quad \ldots \quad \ldots \quad \ldots \quad (i)$$

$$\text{Also, } F = \frac{dq}{q} \Big/ \frac{dQ}{Q} = \frac{dq}{q} \Big/ \frac{5}{3} \frac{dD}{D}$$

since $d\,D = d\,H$,

$$S = \frac{5}{3} F \quad \ldots \quad \ldots \quad \ldots \quad (ii)$$

For all types of outlets, Mr. Crump defines sensitiveness* (to be distinguished from sensitivity defined above) as the 'fractional increase (or decrease) of outlet supply per 0·1′ rise (or fall) in channel surface.'

This can easily be derived from (*ii*) above by dividing S by 10 D

$$\text{which gives sensitiveness } S_1 = \frac{F}{6D} \quad \ldots \quad \ldots \quad (iii)$$

2. *Importance.* Consideration of sensitivity may arise in three ways.

(*i*) An increase of discharge in the distributary channel, results in a rise in the water surface. Ordinarily the flexibility will be the criterion in such a case.

(*ii*) Seasonal variation of slope (consequent upon deposit or scour of bed silt) will cause the surface to swing about the control point next below. This corresponds to a bodily rise or fall in the channel section at the outlet, with consequent variation of the quantity H.

(*iii*) In the case of non-modular outlets, the cultivator may "silt clear" his watercourse. So long as the outlet remains drowned, this corresponds to a depression of watercourse system with consequent variation of the quantity H.

The modern practice of installing semi-modular outlets is directed towards the elimination of (*iii*), but the consideration of (*ii*) cannot be eliminated except by reducing the seasonal swing to a minimum.

3. *Various types.* The sensitiveness of the various common types can be easily deduced from equation (*iii*) above and equations (*ix*), (*x*), (*xvi*) and (*xiii*), Appendix I, and is as follows :—

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*Moduling of irrigation channels by E. S. Crump, Punjab I. B. Paper No. 26.

Weir type	...	$\frac{0{\cdot}15}{H}$
Pipe	...	$\frac{0{\cdot}05}{H}$
Pipe-*cum*-O. S. M.	...	$\frac{0{\cdot}05}{H}$
Pipe-*cum*-weir	...	$\frac{0{\cdot}15}{(1 + 2p)\ H.}$

where p is the fraction of the head used by the orifice or $H_1 = p$ H and $H_2 = (1 - p)$ H

Thus with H = say 3′, S_1 would be ·05 for a weir type outlet, or in other words, for 1 *hissa** rise in water level in the distributary the fractional increase in the discharge of the outlet will be ·05, *i. e.*, 5 per cent.

The setting is limited by the working head available which is as follows for the various types.

Weir type	...	$H_m = 0{\cdot}2\ H$
O. S. M.	...	$H_m = 0{\cdot}75\ H$
Pipe	...	$H_m = H$
Pipe-*cum*-weir	...	$H_m = H_1 + {\cdot}2H_2 = H\ ({\cdot}8p + {\cdot}2)$
Pipe-*cum*-O. S. M.	...	$H_m = H_1 + 0{\cdot}75\ H_2 = H\ ({\cdot}25p + {\cdot}75)$

If set to the limit, therefore, the sensitiveness is

Weir type	...	$\frac{{\cdot}03}{H_m}$
O. S. M.	...	$\frac{{\cdot}0375}{H_m}$
Pipe	...	$\frac{{\cdot}05}{H_m}$
Pipe-*cum*-weir	...	$\frac{{\cdot}15}{H_m}\ \frac{(0{\cdot}2 + 0{\cdot}8\ p)}{(1 + 2p)}$
Pipe-*cum*-O. S. M.	...	$\frac{0{\cdot}25\ p + 0{\cdot}75}{2\ H_m}$

Thus for a given value of H_m, the sensitiveness of the weir type is the minimum, *i. e.*, this is the most rigid type.

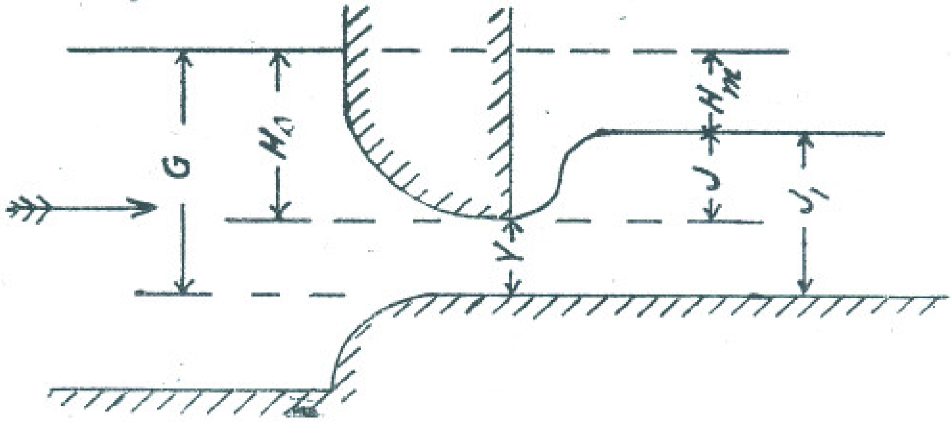
Also the sensitiveness of the pipe-*cum*-semi-module is obviously greater than for the semi-module alone.

*0·1′

APPENDIX III

Efficiency

The efficiency of an outlet may be defined as the ratio of the head recovered to the head put in. In the case of a weir type it is the same as the drowning ratio, *viz.*, $\frac{J_1}{G}$.



In the case of an O. S. M. it is the ratio of the height of the jump to the depression head, *viz.*, $\frac{J}{H_s}$.

Rai Bahadur A. N. Khosla* has shown that in an O. S. M. efficiency

$$E = \frac{1}{2R} \left(\sqrt{1 + 6R} - 3 \right). \qquad \ldots \qquad \ldots \qquad \ldots \qquad (i)$$

Where R = Depression ratio — $\frac{H_s}{Y}$.

This equation ignores friction, and holds only for a rectangular orifice opening into a flume of the same width and bed level as the orifice, with no downstream expansion. He has also shown that in an O. S. M. the maximum efficiency is obtained for values of R between 1 and 2.

Where $R = \frac{1}{2}$, efficiency $E = 0$ from equation (*i*)

$\therefore J = 0.$

This is a condition of critical flow, when the velocity through the orifice $V_c = \sqrt{2gH} = \sqrt{2g\frac{Y}{2}} = \sqrt{gY}$.

No standing wave will form, and there will be no recovery of head. An expanding flume provided downstream will, however, render a certain amount of recovery possible due to reduction in velocity and corresponding rise in head.

*Interlocked Adjustable Module in Precast R. C. Units Paper No. 108, P. E. Congress.

Rai Bahadur Khosla has shown in his Paper referred to above that the efficiency of a rectangular orifice is affected by its width height ratio. He has further devised a relation between efficiency E and the co-efficient of discharge C in the formula :

$$q = C\ B_t\ Y\ \sqrt{2gH_s} \text{ for an O. S. M.}$$

Consequently the co-efficient C, according to him, should be affected by the width height ratio of the orifice. This effect, however, cannot be very appreciable, as in actual practice the value of the co-efficient for an O. S. M. differs from 7·3 by $\pm$ 4 per cent only.

APPENDIX IV

Design of outlets for the non-perennial channels of the Sutlej Valley Canals.

1. *Depth at normal supply.* The discharge in a channel is generally proportional to $D^{5/3}$, or if C is a co-efficient

$$Q = C\ D^{5/3}$$

$$\text{and } Q_n = C\ D_n^{5/3} \qquad (Q_n = \text{normal discharge})$$

$$\therefore n = \frac{D_n^{5/3}}{D}$$

$$\text{or } 0{\cdot}55 = \frac{D_n^{5/3}}{D} \qquad \text{(Normal discharge = 55 per cent of F. S. discharge)}$$

$$\text{or } D_n = (0{\cdot}55)^{3/5} . D \qquad (D_n = \text{normal depth})$$

$$= 0{\cdot}7\ D \qquad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (i)$$

2. *Characteristic of a proportional open flume outlet.* It has been explained in Appendix I that for proportionality in an open flume outlet

$$G = 0{\cdot}9\ D.$$

Thus, if the crest of an open flume outlet is placed at 0.9 D it will draw within practical limits a share proportional to the available supply in the distributary. It has been tacitly assumed that the outlet will always be modular. For modularity in an open flume outlet, available working head must be 0·2 × depth on crest.

∴ at full supply conditions

$$M\ M\ H_f = 0{\cdot}2\ G$$

$$= 0{\cdot}2 \times 0.9\ D = 0{\cdot}18\ D$$

and at normal supply

$$\text{M M H}_n = 0{\cdot}2\ \text{G}_n$$

$$\text{Also H}_n = \text{G} - 0{\cdot}3\ \text{D}$$

$$\therefore \text{M M H}_n = 0{\cdot}2\ (0{\cdot}9\ \text{D} - 0{\cdot}3\ \text{D})$$

$$= 0{\cdot}12\ \text{D}.$$

$$\text{and M M H} = \text{M M H}_n + 0{\cdot}3\ \text{D}$$

$$= 0{\cdot}12\ \text{D} + 0{\cdot}3\ \text{D}$$

$$\text{or M M H} = 0{\cdot}42\ \text{D}, \quad \text{say } 0{\cdot}4\ \text{D} \qquad \ldots\ldots(ii)$$

Thus, an open flume outlet having its crest at 0·9 D and which has an available working head of not less than 0·4 D will draw proportional discharge, within practical limits, irrespective of the water levels in the distributary.

3. *Characteristic of an O. S. M. to draw proportional discharge at normal supply.* The discharge of an O. S. M. is given by the equation

$$q = 7{\cdot}3\ \text{B}_t\ \text{Y}\ \sqrt{\text{H}_s}$$

$$\text{Also } q_n = 7{\cdot}3\ \text{B}_t\ \text{Y}\ \sqrt{\text{H}_n}$$

$$\text{Dividing } \frac{q_n}{q} = \frac{\sqrt{\text{H}_n}}{\sqrt{\text{H}_s}}$$

$$\text{but } \frac{q_n}{q} = 0{\cdot}55$$

$$\therefore \frac{\sqrt{\text{H}_n}}{\sqrt{\text{H}_s}} = 0{\cdot}55$$

$$\text{or } \text{H}_n = (0{\cdot}55)^2.\ \ \text{H}_s$$

$$= 0{\cdot}3\ \text{H}_s$$

$\therefore$ for proportionality*

$$\text{H}_n = 0.3\ \text{H}_s \qquad \ldots \quad \ldots \quad \ldots \quad (iii)$$

$$\text{or } \text{H}_s - \text{H}_n = 0{\cdot}7\ \text{H}_s$$

Now $\text{H}_s - \text{H}_n$ = the difference in water levels in the distributary at full supply and normal supply

$$= 0{\cdot}3\ \text{D}\ (\text{For D}_n = 0{\cdot}7\ \text{D})$$

$$\therefore 0{\cdot}7\ \text{H}_s = 0{\cdot}3\ \text{D}$$

$$\text{or } \text{H}_s = 0{\cdot}43\ \text{D} \qquad \ldots\ (iv)$$

Thus if an O. S. M. is designed with $\text{H}_s = 0{\cdot}43$ D, it will draw its due share (neither more nor less) when either full supply or normal supply runs in the distributary. This statement however assumes that sufficient working head is available for the outlet to work modularly both under full supply and normal supply conditions.

For modularity

$$\text{M. M. H}_f = 0{\cdot}75\ \text{H}_s$$

$$= 0{\cdot}75 \times (0{\cdot}43\ \text{D})$$

$$= 0{\cdot}32\ \text{D}$$

*Within the range of water depth in distributary from D to 0·7 D.

$$\text{and M. M. } H_n = 0{\cdot}75\ H_n$$
$$= 0{\cdot}75\ (0{\cdot}3\ H_s)$$
$$= 0{\cdot}75 \times 0{\cdot}3 \times 0{\cdot}43\ D$$
$$= 0{\cdot}096\ D$$
$$\text{and M. M. H} = \text{M. M. } H_n + 0{\cdot}3\ D$$
$$= 0{\cdot}096 + 0{\cdot}3\ D$$
$$= 0{\cdot}396\ D, \text{ say } 0{\cdot}4\ D \quad \ldots \quad (v)$$

which is more than M M H_f

Thus, if in an O. S. M., $H_s = 0{\cdot}43$ D and it has an available working head of not less than 0·4 D it will draw proportional supply at both normal and full supply conditions in the distributary.

It will be seen that M. M. H for a proportional O. S. M. is slightly less than that for a proportional open flume outlet.

4. *Practical limitations of the relation* $H_s = 0{\cdot}43D$ *for a proportional* O. S. M.

(*i*) Assume crest at bed level or G = D

In this case when H_s is 0·43 D

$$Y = H - H_s$$
$$= {\cdot}57\ D$$

but in an O. S. M., Y should not be more than H_s therefore the crest of the outlet cannot be placed at bed level.

(*ii*) Lowest possible setting :

$$\text{With } Y = H_s,$$
$$H = Y + H_s$$
$$= 0{\cdot}43\ D + 0{\cdot}43\ D$$
$$= 0{\cdot}86\ D$$

∴ a proportional O. S. M. cannot have a crest level lower than 0·86 D.

But when the channel is running with normal supply then

$$H_n = 0{\cdot}13\ D$$
$$Y = 0{\cdot}43\ D$$
$$\text{and } G_n = 0{\cdot}56\ D$$

as Y is more than 2/3rd G_n the jet will be clear of the roof block and the outlet will not function as an orifice.

It has been calculated that as an open flume the discharge drawn by it will be 11 per cent in excess of its share.

(*iii*) Setting at 0 8 D

$$\text{as } H_s = 0{\cdot}43\ D$$
$$Y = 0.37\ D$$

When the channel is running with normal supply.

$$H_n = 0{\cdot}13\ D$$
$$G_n = 0{\cdot}50\ D$$

In this case also Y is more than 2/3 G_n and the outlet will not work as O. S. M. As an open flume the discharge drawn by it will be 8 per cent in excess of its due share.

(*iv*) Setting at 0·69 D

$$\text{As } H_s = 0{\cdot}43 \text{ D}$$
$$Y = 0{\cdot}26 \text{ D}$$

When the channel runs with normal supply.

$$G_n = 0{\cdot}39 \text{ D}$$

As Y is just 2/3rd of G_n the outlet will work as O. S. M. at normal supply.

(*v*) With crests above that corresponding to a setting of 0·69 D outlets designed with H_s=0·43 D will work as O. S. Ms. under normal supply conditions.

5. *Design of a proportional outlet which works as open flume at normal supply and as an* O. S. M. *at full supply**. It is also possible to design an outlet such that it works as an O. S. M. at full supply conditions but at normal supply it works as an open flume and draws a discharge proportional to the supply in the channel. Such an outlet must have a big Y but the limit is Y = H_s. For this value of Y and assuming a setting of S such that S D = G, for full supply conditions

$$q = 7{\cdot}3\ B_t \frac{S\ D}{2} \frac{\sqrt{S\ D}}{2} \quad \left(Y = H_s = \frac{G}{2} = \frac{S\ D}{2} \right)$$

$$= 2{\cdot}575\ B_t\ (S\ D)^{3/2}$$

$$\text{Also } q_n = 3{\cdot}0\ B_t\ S - 0{\cdot}3\ D^{3/2}$$

$$\therefore \frac{q_n}{q} = \frac{3{\cdot}0}{2{\cdot}575} \left(\frac{S - 0{\cdot}3}{S} \right)^{3/2}$$

$$\text{When } \frac{q_n}{q} = 0{\cdot}55,$$

$$\left(\frac{S - 0{\cdot}3}{S} \right)^{3/2} = \frac{0{\cdot}55 \times 2{\cdot}575}{3{\cdot}0}$$

$$\text{or } \frac{S - 0{\cdot}3}{S} = 0{\cdot}6$$

$$\text{or } S = 0{\cdot}75 \qquad \ldots \quad \ldots \quad \ldots \quad (vi)$$

Thus if an O. S. M. outlet has its crest at 0·75 D and Y=H_s it shall draw its due share at normal supply, working as an open flume.

The working head required for this type is as follows :—

$$\text{M. M. } H_f = 0{\cdot}75 \times 0{\cdot}375 \text{ D.}$$
$$= 0{\cdot}3 \text{ D}$$

*This design was evolved by S. Sarup Singh, I. S. E.

$$\text{M. M. H}_n = 0{\cdot}2\ \text{H}_n = 0{\cdot}2\ (0{\cdot}75-0{\cdot}3)\ \text{D}$$
$$= 0{\cdot}09\ \text{D}.$$
$$\therefore \quad \text{M. M. H} = 0{\cdot}09\ \text{D} + 0{\cdot}3\ \text{D}$$
$$= 0{\cdot}39\ \text{D}. \quad \text{Say } 0{\cdot}4\ \text{D}.$$

6. *Relative merits of the various types.* In paragraphs 2 to 5 *supra*, three types of outlets have been envolved which draw their due share at both normal supply and full supply and it is now necessary to determine the relative merits of the various types, *viz.*,

(*i*) An open flume outlet set at 0·9 D.

(*ii*) An A. P. M. with H_s = 0·43 D and G equal to or less than 0·69 D.

(*iii*) An A. P. M. with Y = H_s and G = 0·75 D.

To this end, statements were prepared showing the working of the three types mentioned above and a few other types which result from the combination of types (*ii*) and (*iii*) above. A perusal of these statements shows :

(*A*) For proportionality in the range normal supply to full supply :

(*i*) The open flume outlets set at 0·9 D is the best.

(*ii*) Second in order of merit is the O. S. M. set at 0·75 D and with Y = H_s.

(*iii*) The next best is the O. S. M. set at 0·69 D and with H_s = 0·43 D.

(*iv*) This is closely followed by the O. S. M. set at 0·8 D with H_s = Y and the O. S. M. set at 0·75 with H_s = 0·43 D.

(*B*) For rigidity above full supply levels in a distributary :

When the water level in a distributary rises above full supply level the open flume outlet draws a greater percentage of excess than the O. S. M. Among the different O. S. Ms. although the difference is small that with H_s = Y draws a greater percentage of excess than that with H_s = 0·43 D.

For the open flume the difficulty can be get over by fixing suitable types of roof blocks at the *Vena Contracta* just clear of the water profile for full supply conditions and with a small clearance.

(*C*) For least M. M. H :

Although there is not much to choose between the different types, the O. S. M. set at 0·75 D with Y = H_s is the best.

APPENDIX V

Optimum capacity of an outlet in relation to the size of the field

BY

DR. J. K. MALHOTRA, M.A., PH.D.

1. *Notation.* The following special notation has been used in this Appendix.

q_1 ... Discharge, in cusecs, cut into a field, *i. e.*, q, the discharge of the outlet, minus the absorption in the watercourse.

A ... Area of the field in acres.

X ... Area in acres irrigated up to a given time t.

T ... Time in hours taken in irrigating the whole field of A acres.

t ... Time in hours taken in irrigating X acres.

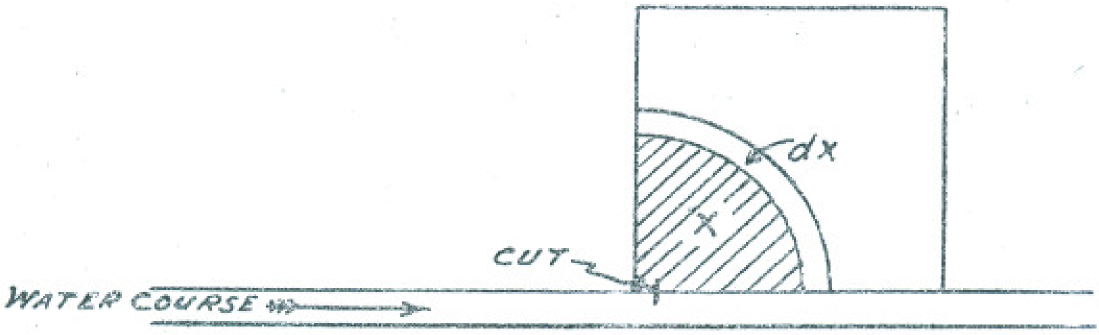
δ ... Depth of watering in inches.

D ... Rate of absorption into the soil and evaporation, in inches per hour.

2. *Assumptions.* (*a*) The depth of water over the irrigated portion is maintained, exclusive of absorption and evaporation at a constant value δ.

(*b*) The loss over the irrigated portion takes place at a constant rate of D inches per hour.

(*c*) The surface of the field is flat, *i. e.*, there are no furrows.



3. *Theory of flow.* Assume that at time t hours, after a watercourse has been cut into a field, X acres have been irrigated, *i. e.*, water is standing over X acres with a depth of δ inches.

The volume of water entering the field in a subsequent small interval of time, dt hours, is $q_1\, dt$ cusec hours, or $q_1\, dt$ acre inches (one cusec hour = one acre inch). This quantity is partly used up in feeding the absorption that is taking place over X acres already irrigated, at the rate of D inches per hour, and the balance in irrigating a further small area of dX acres up to the same depth δ inches.

The quantity used in absorption is DX.dt acre inches. The balance used up in irrigation is, therefore, equal to $q_1\, dt - \mathrm{DX}dt$. Therefore.

$$q_1\, dt - \mathrm{DX}dt = \delta .\, d\mathrm{X}$$

$$\text{or } \frac{d\mathrm{X}}{q_1 - \mathrm{DX}} = \frac{dt}{\delta}$$

Integrating,

$$-\frac{1}{\mathrm{D}} \log\ (q_1 - \mathrm{DX}) = \frac{t}{\delta} + \mathrm{B}, \text{ where B is a constant}$$

When $\mathrm{X} = 0,\ t = 0,$

and when $\mathrm{X} = \mathrm{A},\ t = \mathrm{T}.$

$$\therefore\ -\frac{1}{\mathrm{D}} \log q_1 = \mathrm{B}$$

$$\text{and } -\frac{1}{\mathrm{D}} \log\ (q_1 - \mathrm{DA}) = \frac{\mathrm{T}}{\delta} + \mathrm{B}.$$

Subtracting

$$-\frac{1}{\mathrm{D}} \log\ (1 - \frac{\mathrm{DA}}{q_1}) = \frac{\mathrm{T}}{\delta}$$

$$\text{or } 1 - \frac{\mathrm{DA}}{q_1} = e^{\frac{-\mathrm{DT}}{\delta}}$$

$$\text{or } q_1 = \mathrm{DA} \left[1 - e^{\frac{-\mathrm{DT}}{\delta}}\right]^{1} \quad \ldots \quad (i)$$

Equation (i) gives the relation between the discharge required at the field and other relevant factors, *viz*., area of the field, depth of watering, the rate of evaporation and absorption into the soil and the time in which the irrigation of the field is to be completed. To determine the discharge of the outlet, allowance has to be made for the loss in absorption in the watercourse.

It will be clear that q_1 must not be less than DA. The latter quantity represents the discharge necessary to meet the loss by absorption over the whole field. Obviously, to enable water to stand on the field to any depth, the discharge entering the field must be more than that required to meet the absorption loss over the whole field, otherwise water will not be able to reach the distant portions of the field.

In actual practice, in addition to the quantity required to meet the absorption loss in the field a certain minimum depth over the field is necessary to enable the water to flow at all. If this minimum depth is taken = 1″, the maximum area that it is physically possible to irrigate by the discharge q_1 in one hour with D = .0·5″, is given by (i) as,

$$q_1 = 1{\cdot}27\mathrm{A},$$

The minimum values of q_1 for different values of A are given in the statement below :—

Minimum q_1 (cusecs).	A (acres).
·10	·08
·15	·12
·50	·40
1·00	·79
1·50	1·18
2·00	1·57
4·00	3·15

If the area of the field is half acre, as is usual in practice a minimum discharge of ·64 cusecs is essential. As will be shown hereafter, the minimum discharge is not at all economic.

Expanding equation (*i*) in a series which is valid if DT is less than δ,

$$q_1 = DA\left(\frac{DT}{\delta} - \frac{D^2T^2}{2\delta^2} + \frac{D^3T^3}{6\delta^3}\cdots\right)^{-1}$$

$$= \delta\frac{A}{T} + \frac{DA}{2} + \frac{D^2}{12}\cdot\frac{AT}{\delta} + \cdots \qquad \cdots (ii).$$

From equation (*ii*), it will be obvious that when $D = 0$,

$$q_1 = \frac{\delta A}{T},$$

i. e., discharge is $= \dfrac{\text{area} \times \text{depth}}{\text{time}}$.

Further, if the absorption, D, is small as compared with the discharge, as a first approximation,

$$q_1 = \frac{\delta A}{T} + \frac{DA}{2}$$

i. e., in addition to the discharge required to cover the given area to the requisite depth in the given time, an additional discharge is required, equal to half the rate of absorption loss from the whole field.

This is rational; for that part of the field where the water enters first loses the water for the whole time T, while the most distant end hardly loses anything by absorption. Half of the loss in the upper part of the field is thus a fair average for the whole field.

It will have been noticed that the shape of the field does not appear in equation (*i*). The absence of any effect of shape on the rapidity of irrigation may, however, be explained as below.

With a given discharge q_1 the velocity of advance of water front $= \dfrac{q_1}{F}$, where F is the sectional area of the water front. If there are two rectangular fields of equal area, one of which is narrower than the other along the line of flow of water in the field, the water flow will have a greater velocity in the narrow field and will, therefore, cover the greater length of its diagonal in the same time as the water front with less velocity in the wider field along the shorter diagonal.

4. *Illustrative example.* Let δ or the depth of watering = 3″, and the rate of absorption loss into the field = ½″ per hour*, also time of irrigating the field may be kept as 1 hour.

Solving from either equation (*i*), or (*ii*),

$$q_1 = 3{\cdot}257 \text{ A} \qquad \ldots \qquad \ldots (iii)$$

If the area A is a square of side b ft, then

$$b^2 = 4840 \times 9 \times \text{A}.$$

$$\therefore b = 66\sqrt{10\text{A}} = 66\sqrt{3{\cdot}070\, q_1} \text{ from } (iii)$$

$$= 115{\cdot}6\sqrt{q_1}$$

$$= 116\sqrt{q_1} \text{ feet, say.} \qquad \ldots \qquad \ldots (iv).$$

The values of A and field size for different values of q_1 are shown below :—

q_1 (cusecs).	A (Acres).	Field size.	Remarks.
·10	·03	36′ × 36′	Well discharge.
·15	·05	45′ × 45′	
·50	.15	81′ × 81′	Small outlet.
1·00	·31	116′ × 116′	Average outlet.
1·50	·46	143′ × 143′	
2·00	·61	164′ × 164′	Large outlet.
4·00	1·23	232′ × 232′	

5. *Optimum discharge for a field*;

Equation (*i*) can be re-written as

$$\text{T} = \frac{\delta}{\text{D}} \log_e \left(1 - \frac{\text{DA}}{q_1}\right)$$

For δ = 3″, and D = 0·5″ per hour

$$\text{T} = -6 \log_e \left(1 - \frac{\text{A}}{2q_1}\right)$$

$$= -13{\cdot}8 \log_{10} \left(1 - \frac{\text{A}}{2q_1}\right) \qquad \ldots \qquad \ldots (v)$$

The value of T for some values of A and q_1 are given in the following statement. (N signifies that the entire area of the field cannot be irrigated by the given discharge.)

*Punjab Engineering Congress Paper No. 245—Rainfall Runoff by S. D. Khangar and N. D. Gulhati—Chapter III, para 2.

q_1 in cusecs	Area A in acres			
	·25	·50	1·00	2·00
·15	10·74	N	N	N
·50	1·73	4·15	N	N
1·00	·80	1·73	4·15	N
2·00	·39	·80	1·73	4·15

The above statement gives a vivid picture of the whole problem. For the same discharge, as area of the field increases, the time of irrigation increases proportionately more than the area. Thus a discharge of 2 cusecs irrigates ·25 acres in ·39 hours and 1 acre in 1·73 hours. If the latter were divided into 4 plots of ·25 acres each, the time would be 1·56 hours so that an additional ·17 hours (*i. e.*, about 11 per cent of total time) is taken owing to absence of partitions in the large field.

For the same area an increase of discharge similarly reduces the time of watering more than proportionately. Beyond a certain stage, however, the reduction is very nominal. This stage may be fixed from the above table at $A = q_1/4$.

Thus for a 3″ watering and with an absorption loss of ½″ per hour, for optimum conditions, the discharge in cusecs at the field should equal four times the area of the field in acres. Further assuming an absorption loss in the watercourse of 25 per cent of q_1, the discharge of the outlet should be 5 times the area of the field in acres.

Similarly the optimum ratio between the discharge of an outlet and the size of a field can be worked out for other conditions that may occur in practice.

Mr. Mithal stated that the authors had remarked that the distribution of water should be for the greatest good of the greatest number and observed that as the cultivator receiving canal irrigation water supply was better off than any other labouring class, it would be in the fitness of things if the sliding scale of water rates based on a fixed percentage on the value of crops as suggested by the authors was fixed in such a manner that the greatest good to the greatest number in the Province was achieved in practice. This however ran contrary to the growing idea of running the Irrigation Branch as a commercial concern and in such a manner that the working expenses and the water rates just balanced.

Regarding silt draw by outlets, the speaker remarked that the silt problem was created more by rolling silt than by silt in suspension, as the latter could be withdrawn without any difficulty. He had carried out experiments which showed that about 70% of rolling silt was found in the bottom 1/10th of the channel and unless attempts were made to exclude the major part of this harmful silt, the problem of frequent remodelling could not be solved. The silt problem, however, he stated could be overcome by keeping the setting of outlets low and therefore the high crests for channels on the Sutlej Valley Canals advocated by the authors in Appendix IV was worthy of reconsideration.

Mr. Mithal went on to say that on page 89 the authors stated that if the crest of the O. F. outlet was placed at 0·9D, it would draw a share proportional to the available supply in the distributary.

Mr. Crump worked out this relationship for small variations in full supply depth and not when normal (55%) supply was run. For this the relationship was worked out as below :—

$$\frac{H_n^{\frac{3}{2}}}{H_s^{\frac{3}{2}}} = 0{\cdot}55$$

$$\left(\frac{\frac{H_s}{D} - 0{\cdot}3}{\frac{H_s}{D}}\right)^{\frac{3}{2}} = 0{\cdot}55$$

$$\frac{H_s}{D} = 0{\cdot}92$$

Mr. Mithal pointed out that the additional pipe and tank arrangements as suggested by the authors would not be of any help.

Mr. Mithal then enumerated the conditions laid down for the remodelling of channels in Khanwah division and produced statements showing the effect of remodelling on the tails of channels which showed that out of 48 tails, 9 became altogether dry, 4 got less than 20% discharge and 10 got between 20% and 35%. He added that some of these channels had to be modified later, when the setting of A. P. Ms and O. Fs were kept at bed level and the number of the latter was kept to the barest minimum. Here Mr. Mithal produced a statement which showed that these modifications resulted in an improvement in the working of channels.

He however pointed out that the problem would be solved by means of proportional outlets which worked as an O. F. at normal supply and as an O. S. M. at full supply. Citing the example of such outlets on Gaja distributary, he concluded that the problem of sending normal supplies to the tail of a channel with normal supply at head deserved further research.

Mr. Mithal however stated that he had suggested a solution of the problem as far back as 1940. It consisted of an A. P. M. outlet with crest at bed level and designed to draw its share with normal supply running in the channel with an extra opening to make up its share of discharge at full supply level in the channel. Here he produced a plan of such an outlet with calculations. He also produced a graph which showed variations from strict proportionality.

Regarding the Scratchley type of outlets, Mr. Mithal stated that their use on a large scale should be discouraged.

He concluded by pointing out that channels which had been remodelled on the basis of Lacey's theory had not silted up for all practical purposes.

Mr. Kanwar Sain stated that the evolution of an outlet was a very fascinating study. In the early days outlets were fitted with *karri* grooves in order to enforce *tatiling* as a part of the design. To-day *tatiling* is almost unknown. Regarding the principles underlying the distribution of water as enumerated by the authors in paragraph 6 on page 8 of the paper, Mr. Kanwar Sain went on to say that in the case of a shareholder at the tail of a watercourse, there was a certain amount of absorption in the watercourse, particularly if the watercourse was a long one, and this factor introduced a certain amount of inequality in the distribution of irrigation water and he wanted to know if the authors would care to offer any suggestions to remove this inequality. He further remarked as follows :—

" In paragraph 12, the authors have detailed the systems of assessment. All the three systems mentioned by the authors are those followed in Java, Egypt and in Sind. The assessment of the land revenue is made on the basis of the average produce and account is taken of the increase of yield and income due to irrigation. In these countries there is no separate water rate. The only measurements made in Egypt are of such area which have remained without water throughout the year from no fault of the cultivator and on which the land tax is, therefore, remitted. In such parts of India, where crops are not wholly dependent on the canals as rainfall supplies the required moisture to a varying extent, the charge for cost of constructing works for irrigation supply is included in the land revenue and is considered to be made in return for a