PAPER No. 264.

IRRIGATION OUTLETS

BY

S. I. MAHBUB, K. B., I. S. E.,

AND

N. D. GULHATI, I. S. E.

CONTENTS

Chapter I

INTRODUCTORY

Chapter II

NOTATION AND DEFINITIONS

Chapter III

FACTORS BEARING ON THE DESIGN OF OUTLETS

Chapter IV

A HISTORY OF THE DEVELOPMENT OF VARIOUS FORMS OF OUTLETS IN THE PUNJAB

Chapter V

TYPES OF OUTLETS

Chapter VI

SELECTION OF OUTLET TYPES

PAGE

Chapter VII

SPECIAL REQUIREMENTS OF THE NON-PERENNIAL CHANNELS OF THE SUTLEJ VALLEY CANALS

Chapter VIII

CONCLUSIONS

Appendices

List of plates attached

CHAPTER I

Introductory

1. *An outlet defined.* An outlet may be defined as a device at the head of a watercourse which connects it with a distributing channel. In America it is termed a "turn-out." Its importance lies in the fact that while the distributing channel is under the management and control of Government, or a public organisation in charge of a canal system, the internal working on a watercourse is, in general, managed by the cultivator or cultivators whose lands are irrigated by the watercourse. This device, therefore, must be such that it not only passes a known and constant quantity of water, but must essentially be a measure of the discharge.

2. *The importance of the problem.* The number of outlets on the canals in the Punjab alone exceeds forty thousand. Different types are in use as will be seen from the following statement, which indicates the position, as it exists now on the canals in the Punjab.

Number of outlets of various types.

Name of Canal.	Pipe or barrel.	O. F.	O. S. M.	Harvey.	K. G. O.	Scratchley.	Bend.	Gibb.	Pipe cum weir.	Pipe cum O. S. M.	Open cuts.
Upper Chenab ...	2,008	340	414	3	23	...	...	...	1	...	...
Lower Chenab East ...	237	747	1,701	..	1	...	...	56	...	...	...
Lower Chenab West...	272	756	1,719	23	51	...	...	12	...	...	...
Upper Jhelum ...	3	368	847	..	...	...	...	...	...	...	...
Lower Jhelum ...	731	1,832	1,233	..	...	35	6	2	...	...	...
Lower Bari Doab	69	1,873	1,034	...	16	...	...	...	...	47	...
Western Jumna ..	1,781	1,031	1,259	60	2	..	...	...	...	...	11
Sirhind ...	257	539	1,641	3	3	...	...	...	...	...	...
Upper Bari Doab ...	1,640	1,413	1,113	30	11	...	...	4	...	...	...
Derajat Canals ...	4,019	672	240	16	...	...	...	...	...	...	235
Ferozepore Canals ..	699	850	1,617	...	...	14	..	..	...	...	2
Nili Bar } Mailsi } ...	1,001	1,048	1,433	...	...	...	...	...	5	3	...
Haveli Canals ...	96	987	1,438	...	...	...	...	...	...	...	...
Total ...	12,813	12,456	15,689	135	107	49	6	74	6	50	248
Grand Total ...		...	41,633	...	...	...	...	...	...	...	...

The forty thousand odd outlets on the Punjab Canals annually irrigate an area of about 14 million acres. The average area of a holding in the Punjab is less than seven acres. Assuming an annual intensity of 67 % there are in the Punjab alone at least three million cultivators who are directly connected with the efficient working of these outlets. "Each* irrigator must receive water in a quantity proportional to

*Principles of Irrigation Practice, Widtsoe, p. 358.

his interests in the canal, and at such a time as will each year ensure him a good crop. The irrigator, the owner of the water right, knows only one test of the efficiency of the canal management—does he have an ample supply of water whenever needed by his crops? The success of an irrigation enterprise depends on the success with which this test is answered; that is, upon the system of distribution of water under the canal."

This distribution of water is carried out by means of outlets, and there is probably no single item in the design of an irrigation system which has a greater effect on the distribution of water than the type and design of an outlet. Also it is with regard to this that there is so marked a difference of opinion and practice. The proper design of an outlet is, therefore, of first-rate importance to a canal engineer.

3. *Scope of the paper.* There is a huge mass of existing literature and information on this subject, which is as old as irrigation itself. Most of this information is buried in the various secretariat archives, another lot is lying in oblivion in the proceedings of Irrigation Conferences and Engineering Societies in various provinces of India and elsewhere.

An attempt has been made in this Paper to bring together all the information leading to the design of outlets, to trace the gradual evolution of various types of outlets in the Punjab and to describe most of the types that have been evolved so far whether in the Punjab or elsewhere. The advantages and limitations of each type have been examined critically so that the selection of a type for any particular set of conditions may be rendered easy.

4. *Acknowledgments.* Every one who has been connected with the distribution of canal water in the past has contributed his mite to the advancement of this subject. During their study, the Authors came across the names of a very large number of officers who had something useful to say on the subject, but the biggest contribution comes from two officers of the Punjab Irrigation, Messrs Kennedy and Crump— All honour to them.

The Authors are grateful to the Chief Engineers for having given them the opportunity of presenting this Paper to the Congress and for permission to quote from the secretariat files on the subject. They are particularly grateful to Mr. A. M. R. Montagu for permission to use an unpublished note written by him about ten years ago on the "Distribution of water." The Authors have drawn on this note freely. Other sources have been duly acknowledged in the text.

Chapter II

1. Notation

Unless otherwise stated, the following notation* has been used throughout this Paper :—

A	The cross sectional area of a stream at a stated point.
A_p	The area of a pipe or barrel outlet.
A. O. S. M.	Adjustable Orifice Semi-module.
A. P. M.	Adjustable Proportional Module.
B	The length of a channel bed transverse to the direction of flow, *i.e.*, the width.
B_t	The width of the throat of a weir, flume, etc.
C	An empirical co-efficient.
D	The depth below the surface of a stream at a stated point.
d	Diameter of a pipe outlet.
d_i d_o	Depth of flow at inner and outer walls in a Gibb's module.
E	Efficiency of an outlet.
F	Flexibility of an outlet.
F. S. D.	Fully suppl depth.
F. S. L.	Full supply level.
G	A gauge reading (zero of gauge must be specified) or the depth of water over a crest.
g	The gravity constant.
H	The head or energy required to produce a velocity V. $H=\frac{V^2}{2g}$
H_a	The head or energy equivalent to the velocity of approach.
H_c	The head measured from the water surface to the centre of an orifice.
H_i, H_o	Depths at inner and outer walls in a Gibb's module.
H_m	The minimum working head required between two points (M.M.H).
H_s	The head measured from the water surface to the soffit of an orifice.
H_w	The available working head.

*This notation is based largely on Mr. Montagu's notation given in Publication No. 5 of the Central Board of Irrigation.

K	The constant in the free fall discharge formula. Theoratically $K=\sqrt{g}\,(2/3)^{3/2}=3{\cdot}0888$.
L	The length of a channel or work measured along the centre line parallel to the direction of flow between two points.
L_t	The length of parallel sides of the throat or gullet of a weir, flume, etc.
m	Index of H in the discharge formula for the offtake.
n	Index of D in the discharge formula for the channel.
O. F.	Open Flume Outlet.
O. S. M.	Orifice Semi-Module.
q	The discharge in cusecs of an outlet.
Q	The discharge in cusecs of a distributary.
R	Depression ratio.
R_i, R_o	Radius of inner and outer circumferences in a Gibb's module.
S	Sensitivity.
S_1	Sensitiveness.
S. W. O.	Standing Wave Outlet.
V	The mean velocity in feet per second of a stream at any given point.
Y	The elevation of the roof block above the crest of an O. S. M. or A. P. M.

2. Definitions*

Available working head. The minimum difference between supply and delivery water-levels available. (H_w).

Capacity. The authorised or designed full supply discharge. (Q or q).

Control point. A fall, so designed that the water surface level above it bears a fixed relation to the discharge passing. The level is usually fixed with reference to the authorised full supply discharge.

Critical flow. The flow is said to be critical when for a certain discharge, the energy of flow consisting of the potential, kinetic and pressure energy is minimum.

Critical velocity. The velocity at which the minimum energy of flow is generated.

Cusec. The unit of discharge used in irrigation practice and means a rate of flow of one cubic foot per second.

*These definitions are based largely on C. B. I. Publication No. 5, and Punjab Engineering Congress, Paper No. 80—1923 by Mr. Lindley.

Depression. The depth below supply-level of some point of a semi-module fixed by its hydraulics, such that as supply-level varies a constant co-efficient multiplied by the correct power of that depth gives the discharge.

Depression ratio. The ratio between the depression and the height of the opening (H_s $/Y=R$)

Discharge. The rate of flow at a stated site, *i.e.*, the quantity of water passing in unit time.

Discharge and supply. Where not specifically stated otherwise, "discharge" is used for the flow given by a module or semi-module, and "supply" for the flow passing in the channel feeding it.

Distributary. A Government channel taking its supply from a main line or branch, the function of which is to supply water to minors and outlets.

Drowning ratio. The ratio between the depth over the crest of water level downstream to that upstream.

Duty. The area irrigated during a base period divided by the mean supply utilised in cusecs.

Efficiency. The ratio of the head recovered to the head put in (E).

Flexibility. The ratio which the rate of change of discharge of the outlet bears to the rate of change of discharge of the supply or parent channel (F).

Full supply factor. The area proposed to be irrigated in a project during the base period divided by the authorised full supply discharge of the channel at head.

Hyper-critical velocity. A velocity in excess of the critical velocity.

Meter. A device that indicates the quantity of water passing through it.

Minor. A small Government channel, usually taking its supply from a major distributary, the function of which is to supply water to outlets.

Module. A device for ensuring a constant discharge of water passing from one channel into another, irrespective of the water level in each, within certain specified limits.

Minimum modular head. That difference of water level or pressure between supply and delivery sides, which is the minimum necessary to enable a module or semi-module to work as designed (M. M. H.)

Modular limits. The extreme values of any factors at which a module or semi-module ceases to be capable of acting as such.

Modular range. The range of conditions between the said limits, within which a module or semi-module works as designed.

M. M. H. ratio. The ratio between the M. M. H. and the depth of upstream water over the crest (M. M. H/G).

Non-modular outlet. An outlet whose discharge is dependent on the levels both in the canal and in the watercourse.

Non-perennial channel. A channel which is designed to irrigate during only a part of the year, usually in the "*kharif*" or summer season. Generally these channels also supply water at the beginning and end of the "*rabi*" or winter season.

Proportional moduling. The fitting of semi-modules on a supplying channel in such a manner that when supply fluctuates each offtake draws always a constant proportion of the supply (F=1).

Ratable. An outlet is said to be ratable when it can be rated or set to give a fixed discharge under a given set of conditions.

Semi-module. A device that automatically delivers a discharge which is independent of fluctuations of water-level or pressure on the delivery side, and only varies with water level or pressure on the supply side in accordance with hydraulic law.

Sensitiveness. The variation (per cusec) of discharge of a semi-module for a tenth of a foot variation of supply-level. (S_1).

Sensitivity. 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. (S).

Setting. The ratio of the depth below F. S. L. of the crest of an outlet to the F. S. depth of the channel at that point. (G/D).

Standing wave.—When a stream of water moving with hyper-critical velocity strikes water moving with sub-critical velocity, a standing wave is produced which consists of an abrupt rise in the surface in the region of impact between the rapidly moving stream and the more slowly moving wall of water accompanied by a great tumbling of the commingling water, and the production of a white foamy condition throughout the moving mass.

Sub-critical velocity. A velocity less than the critical velocity.

Vena contracta. The section at which the boundaries of a jet passing through an orifice or over a weir become parallel.

Water allowance. The outcome of all considerations of the duty of water, intensity, proposed crop ratio, water available, etc., is the fixing of the water allowance. Water allowance may be defined as the number of cusecs of outlet capacity, authorised per 1,000 acres of gross or culturable irrigable area. The Water allowance, therefore, not only defines the size of outlet for each outlet area but also forms the basis for the design of the distributing channel in successive stages.

Watercourse. The term applied to an irrigator's channel taking its supply from a Government channel, from which fields are irrigated directly.

Weir. A fall extending across a channel usually provided with a raised crest and glacis.

CHAPTER III

Factors bearing on the design of outlets

1. *General considerations.* Before proceeding to discuss the various forms of outlets that have been devised in the past, or the factors that govern the selection of a particular type of outlet for a certain set of conditions, there are some considerations which form, so to say, a background of the whole problem and require to be kept in view in the design of *outlets as a class.* The chief of these are :

(*a*) The system of Irrigation.

(*b*) Principles underlying the distribution of water.

(*c*) The method of distribution.

(*d*) The system of assessment.

(*e*) The nature and source of the available supply.

(*f*) The design and system of working of the parent or distributing channel.

2. *The various systems of irrigation.* There are three main systems or methods by which water is artificially applied to land for the purpose of producing crops whenever and wherever the rainfall is not sufficient to meet the requirements of the crops.

(*a*) Application of water below the surface of the field—Sub-surface irrigation.

(*b*) Application of water from above the crops in the form of rain—Spray irrigation.

(*c*) Application of water at the surface of the field—Surface irrigation.

3. *Sub-surface irrigation.* In this system, water is applied at the place it is most needed, *i. e.*, the roots of the crops. It is economical in the use of water as evaporation losses are minimised. The method is costly and is only justified when this form of irrigation is necessary for the particular crops grown and water is scarce. The system suffers from certain intrinsic defects and is of very limited application. In this country a few examples of sub-surface irrigation exist at various places where the outflow from the domestic septic tank is utilised in the vegetable garden. No large scale undertaking of sub-surface irrigation is likely in this country.

For a detailed discussion of this method of irrigation reference may be made to ' Use of water in Irrigation ' by S. Fortier and ' Principles of Irrigation Practice ' by Widtsoe.

4. *Spray Irrigation.* In this system, water is applied to the crops and the surface of the fields in the form of rain or a very fine spray. It has been used recently in this country for the watering of lawns in big cities, but in the United States of America, the system is finding favour in the irrigation of fruit gardens and other valuable produce, and in spite of

its high cost it has been found to pay. The essential parts of this system are :—

(*a*) A central or local pumping unit.
(*b*) A system of feed pipes.
(*c*) Nozzles.

The nozzles may be portable, or the field may be equipped all over by equally spaced feed nozzles. Another system is to have a series of nozzles fitted to parallel overhead pipes fixed on supports high enough not to obstruct agricultural operations.

For further discussion on this system of irrigation reference may be made to the publications referred to in paragraph 3 supra.

5. *Surface irrigation*. In this system water is applied at the surface of the fields. This is the oldest and the most commonly used system of irrigation. The area under irrigation by the other two methods described above is an insignificant proportion of the area irrigated by surface flow.

Surface irrigation is carried out in a number of different ways, but they fall into two broad divisions :—

(*a*) By flooding the entire surface of the area to be irrigated.
(*b*) By letting the water flow into a number of furrows made with a plough or some other appliance.

Flooding is the most common method, but irrigation by furrows is also adopted on a wide scale in foreign countries and in the vegetable and fruit garden in this country. The furrow method is particularly suited to the irrigation of orchards, in areas where the slope of the land is steep, and where the discharge available in the field is small.

6. *Principles underlying the distribution of water*. Water flowing in natural streams and rivers is regarded as public property, and the duty of Government or any other organisation in charge of a canal system is to arrange and control the utilisation of this public property for the public good. Axiomatically the distribution should be for the greatest good of the greatest number.

Although a charge is made for the supply of water through a canal, it is not possible for any one to buy more than a fixed quantity of water, no matter what he may be prepared to pay for it. From the beginning of controlled canal irrigation in the Punjab, the quantities of water given to the cultivators were based on the irrigable area belonging to them which the project proposed to protect. Subsequently, mainly because of the difficulty of designing and constructing outlets to ensure at all times a fixed quantity of water to each cultivator or group of cultivators, outlets used to be remodelled on the basis of the irrigation effected on each in an attempt to let each cultivator have a uniform proportion of irrigated area to his entire irrigable area.

Early in the present century, it was recognised that this was not an equitable system of distribution and as it became possible to devise outlets to discharge a definite quantity of water at most times, the allotment of water to a cultivator or group of cultivators on an outlet was again made on a definite figure of so many cusecs per 1,000 acres of irrigable area. (Culturable commanded area). This figure is called the 'Water allowance,' and has been fixed from various considerations for each project or a part of the project.

7. *The method of distribution.* The various methods of distribution of irrigation supplies fall into three broad divisions :—

(*a*) Continuous flow.

(*b*) Intermittent flow.

(*c*) Supply on demand.

8. *Continuous flow.* In this system of distribution, water is supplied to each cultivator in a continuous stream according to his share. It follows that large cultivators will have large streams and small cultivators will have small streams. As will be shown hereafter there is an optimum discharge below which absorption losses in the watercourse are so high and the time taken for irrigating a field of normal size so much that a relatively large part of the water is wasted. This system of irrigation is only useful to the big farmer. For the small farmer it is a nuisance to be required to receive water at all times and the system is, therefore, generally wasteful of water.

9. *Intermittent flow.* In this system of irrigation water is given to each cultivator in a fixed quantity at definite intervals. On canals which have a good source of supply water is supplied at definite intervals during the entire irrigation season, but on canals on which the supply is not sufficient for the needs of all the irrigators on the system the supply available is distributed at the time and in the manner it is available. This system of irrigation in some form or another is in general use in most countries. It has also been called the system of constant rotation. The entire discharge from an outlet is taken by different farmers in turn; the turns being fixed in proportion to the irrigated areas owned by each individual. In this system the small and the big farmer on the same outlet spend an equal time for irrigating the same area while in the continuous flow system the small farmer with a small stream of water at his disposal would take a relatively longer period for irrigating an equal area. As the cultivator gets water for a fixed period at intervals he can manage to give his full attention to the irrigation of his lands at the time when water is available. This system is, therefore, conducive to an economical use of water.

10. *Supply on demand.* This system of distribution is the most economical and the ideal system from the cultivator's point of view. For obvious reasons it has, however, a very limited application. If water is to be supplied from a storage reservoir, it is quite possible to meet the indents of individual farmers provided the distribution system is not long and the total indent of all the farmers does not exceed the carrying capacity of the distributing system. On large canals supplied from "pick up" weirs on the rivers in this country this system of irrigation is entirely impracticable.

11. *Organisation for the distribution of water.* In America and other countries there is generally an elaborate organisation to control the water supply through the outlet and to distribute water emerging from the outlet. A man known as " water master " is employed to open and regulate the supply through outlets and between farmers. Careful records are kept of the distribution of water. On the other hand, in India, there is generally no manual control on the working of outlets, which are so designed that they work automatically and continuously. In the Punjab, even the distributary system (maximum capacity 300—400 cusecs) is so designed that there is no necessity for manual control or regulation at any point in the system which may extend to a length of well over 100 miles. The internal distribution of water among the various cultivators on an outlet is managed privately by the cultivators themselves and Government keeps no record of the distribution.

12. *The system of assessment.*

(*i*) *Assessment on volume.* On the analogy of a Town Water Supply Scheme the water supplied to irrigators could be charged for on the basis of the quantity delivered. While there are numerous appliances for measuring the quantity of water delivered through a closed pipe system reliable measurements for irrigation have always been difficult. The main difficulties are :—

(*a*) That irrigation water carries silt and floating matter which would debar the use of any of the meters employed in a pipe supply.

(*b*) Irrigation supplies are carried through open channels and very small heads or falls are available for measuring devices.

" *In some countries, such as Italy and to some extent in the United States, where irrigators are educated and experienced, distribution by volume is practised, but the appliances used are by no means ideal, require considerable supervision, and are rarely proof against interference with fraudulent intent."

Even if it were feasible (see chapter VI part F) to devise means, expensive as they must be, for determining the volume of water delivered to an outlet, it is definitely not practicable to instal devices for measuring the quantity of water delivered to an individual cultivator on an outlet.

(*ii*) *Assessment on capacity.* Another possible method of assessment is at some suitable rate on the discharge capacity of the outlet. This question of assessment on capacity has been examined in detail at various times in the past. A detailed discussion of this problem is outside the scope of the present paper. It may, however, be stated that the determination of a suitable rate for this method is not easy and it can only be based on considerations which are not very consistent with this method. Further, the distribution of the charges among the numerous cultivators on an outlet presents a very serious obstacle.

*The Principle of Irrigation Engineering by F. E. Kanthak, page 263.

(*iii*) *Assessment on acreage matured*. The other system of assessment is on the basis of the acreage matured, at a different rate for each crop. In this system of assessment the following considerations guide the fixing of rates for various crops :—

(*i*) The amount of water used by a crop.

(*ii*) The scarcity or plentifulness of the water at the time, *e.g.*, water in the *rabi* is less plentiful than in the *kharif*.

(*iii*) The value of the individual crops obtained from irrigation.

(*iv*) The comparative cost of irrigation by other means, such as open wells, *jhallars*, or tube-wells.

The most important of these considerations is the value of the crop to the cultivator ; the water rate to be charged for each crop is in general a small percentage of the benefit the cultivator derives from it.

As prices of produce vary from year to year this percentage also varies. To make the system more equitable than it is at present, a sliding scale of water rates based on a fixed percentage of the value of the crops is indicated.

13. *The nature and source of the available supply*. There are three main sources of irrigation supplies :—

(*i*) Rivers.

(*ii*) Storage reservoirs.

(*iii*) Open wells or tube-wells.

Water can be released from a storage reservoir to the extent and at the time required by the demand. Similarly, wells whether worked by animal power or by electricity can be used when required. But when the source of water supply is the river, water has to be used when it is available in the river and is limited to the supply available at the time.

When the supply is plentiful, the question of its distribution is simple, but when the supply is scarce and the demand is keen, the distribution of supply presents very complicated problems which have to be solved in a very careful manner.

14. *The design and system of working of the parent or distributing channel*. The fundamental difference in the nature of the available supply governs in a large measure the design of the distributing channels. When supplies are plentiful during the critical periods of agricultural rotation the design of channels is a straightforward process. But when the supplies available are not enough to meet the demand, these have to be distributed among the various distributary systems. This may be done in three ways :—

(*i*) By continuously running the various channels with their share of the available supplies.

(*ii*) By running the big channels continuously with their share of the discharge available and by running the small channels in rotation.

(*iii*) By giving the authorised full supply discharge to each distributary system in rotation.

The method now adopted in the Punjab aims at (*iii*) above, and it may be useful to remember that this has been evolved from mothod (*i*) gradually in the course of time. Method (*iii*) implies that manual control is to be exercised only on the Main Canal and Branches but not on the distributaries.

Axiomatically, a distributary should be so designed and worked that at all times and "at each point it will just carry as its full supply a discharge sufficient to supply all the outlets below that point, so that when the proper quantity enters the head all the watercourses should just run their calculated allowances with no surplus at the tail of the distributary ".*

On some canals in the Punjab the supply is so short during the critical sowing and maturing periods that if the distributary systems are run in the manner indicated above, the supply available is so short that the period of closures are long and crops would die out in the interval between successive waterings. On these channels the distribution is more complicated and the procedure adopted is a combination of the first and third method described above. Channels are run in rotation with less than full supplies. On the non-perennial channels of the Sutlej Valley Canals, channels are run in rotation with what is called normal supply which is about 55 per cent of the authorised full supply.

In some places, *e.g.*, North-West Frontier Province in India and Sudan in Africa, the cultivator will not irrigate at night. In North-West Frontier Province the water is allowed to run to waste, while in Sudan the distributary channels are so constructed that they act as storages during the night. In the Punjab, as at most other places, water is so valuable that it cannot be allowed to run to waste. Further the irrigation systems are so large that any such contingency of not irrigating at night would create almost unsurmountable difficulties in the working of the systems.

15. *The requirements of an ideal system of irrigation.* Having described briefly the main considerations which form a background to the problem of distribution of irrigation supplies, the requirements of an ideal system of irrigation may now be described. From the cultivator's point of view, water should be supplied :—

(*a*) At the place it is required by him.

(*b*) At the time required, and

(*c*) In the quantity required for the varying needs of his crops.

While it is generally possible to supply water to the cultivator at the place most suited to him, the latter two requirements could only be met if the quantity at the disposal of the canal management was much more than it generally is. When it is not possible to meet the cultivator's requirements in full, the next best thing is to distribute the water available in the most equitable manner among all the cultivators. The question of water rights of cultivators on different rivers in different parts of the country is outside the scope of this Paper. The purpose of this Paper is to describe how the distribution can be most equitably carried out on the

*Punjab Irrigation, Branch Paper No. 12 on the Distribution of water for irrigation by measurement—R. G. Kennedy, page 5.

basis of decisions taken by Government in this respect. In the Punjab the distribution of water among the various cultivators on a distributary is based on the irrigable area owned by each cultivator and is limited by the supply available at various times during the year. This distribution is carried out by means of outlets.

16. *Kennedy's desiderata for an outlet.* As long ago as 1906, Mr. Kennedy in Irrigation Branch, Paper No. 12 (published in Edinburgh) noted the following main desiderata for the design of an outlet :—

(*a*) "To keep the discharge automatically constant as adjusted, and indicated, however much (within working limits) the water levels may vary in the distributary channel, or in the watercourse, or in both at once.

(*b*) To allow of slight variations in the discharges as adjusted, so as to avoid the need of constantly removing and replacing the outlet, whenever the discharge must be somewhat altered.

(*c*) To work with low 'heads' as well as high—down to three inches or so.

(*d*) To be free from derangement by silt or weeds.

(*e*) To be light, portable, easily removed and replaced elsewhere.

(*f*) To be cheap and durable, with no complicated mechanism.

(*g*) To be all closed in and immune from outside interference or derangement in working.

(*h*) To be capable of being opened or closed off entirely by the cultivators from outside.

(*i*) To indicate from outside when the working head is insufficient to give the full discharge, and therefore also the necessity for clearance of the watercourse.

(*j*) If so desired and adjusted, to work as a module, only within certain limits of level in the feeder ; above and below these limits to give proportionately increased or decreased discharges. (This is with special reference to farmers' canals, where each man is entitled to a proportion of the whole available supply).

(*k*) Floods in the distributary to be passed off by increased discharges through the outlets, so as to avoid damage.

(*l*) When the distributary supply is very low and inadequate, it will be more or less proportionally distributed to all outlets, those with very high command not being allowed to draw off all the water there is.

(*m*) Discharges to be provided for may be anything between half and four cusecs, with possible duplication above the latter figure."

17. *Essential conditions for all outlets.* It will be realised that it is impossible to obtain all the conditions detailed above in one type. The

following conditions, however, must necessarily be complied with by any device of this nature :—

(*a*) An outlet must be strong and should not have moving parts liable to derangement or requiring periodic attention.

(*b*) Interference by the cultivator must be difficult, and, if made, should be readily detectable.

(*c*) The outlet should draw its fair share of the silt carried by the parent channel.

(*d*) It should be possible for the outlet to work efficiently with a small working head. The larger the working head the higher the water level required in the parent channel and the higher the cost of the distributary system.

(*e*) The cost should not be high.

18. *The optimum capacity of an outlet.* The optimum capacity of an outlet should be the discharge which the cultivator can handle efficiently and should be such that the absorption losses in the watercourse and in the field are minimum. The longer the time taken to irrigate a field, the greater is the amount of absorption in that part of the field already irrigated, while applying the minimum irrigation required for the remainder.

It is usual to see small '*kiaries*' when an area is irrigated by a well. Were it not so, the small discharge from a well would never be able to fill a field, say, half an acre in area. The irrigator from a canal watercourse can also utilise to the best advantage the water given to him by dividing his fields into small '*kiaries*,' but on the other hand a small '*kiari*' is a hindrance to other agricultural operations. It has been found that a two cusec outlet is generally the best for the cultivator in the Punjab who irrigates his area in fields of about ½ acre in area

At the request of the Authors, Dr. J. K. Malhotra of the Irrigation Research Institute has worked out a relation between the size of the field and the optimum discharge required for its outlet. This is contained in Appendix V. Briefly, for optimum conditions, the discharge of an outlet in cusecs should be five times the area in acres of the field it irrigates.

19. *Three classes of outlets.* Outlets may be divided into three classes :—

(*a*) Modular outlets or modules are those outlets whose discharge is independent of the water levels in the distributary and the watercourse within reasonable working limits.

(*b*) Semi-modular outlets or semi-modules are those outlets whose discharge although depending on the water levels in the parent channel is independent of the water levels in the watercourse, so long as the minimum working head required for the working of the semi-module is available.

(*c*) Non-modular outlets are those outlets whose discharge is a function of the difference in levels between the water surface in the distributing channel and the watercourse. Variations in either affect the discharge.

20. *Flexibility of an outlet.* Before closing this chapter it is desirable to explain a few terms which are used in connection with the working of outlets as a clear understanding of these is necessary for a proper study of the various forms of outlets which will be discussed in a subsequent chapter.

The property of an outlet to vary its discharge with the change in the discharge of the distributing channel is studied by calculating its flexibility. Flexibility is 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. As worked out in Appendix I of this Paper, flexibility

$$F = \frac{dq}{q} \Big/ \frac{dQ}{Q} = \frac{m}{n} \cdot \frac{D}{H}$$

where the various letters have the same significance as given in chapter II of this Paper. When an outlet is fully proportional, *i.e.*, the discharge through the outlet varies in the same manner as the discharge in the parent channel, flexibility $F=1$. When the outlet is perfectly rigid, *i.e.*, it functions as a module, flexibility$=0$. When the variation in discharge through an outlet is proportionally more than the variation in the discharge in the distributary, the outlet is said to have a high flexibility or is hyper-proportional. Similarly when the variation in the outlet discharge is less than that in the distributary, it is said to have a low flexibility or is sub-proportional.

21. *Sensitivity of an outlet.* Sensitivity bears the same relation to the water level in the parent channel as flexibility does to the discharge. While the discharge in the parent channel may remain unaltered, water levels may change. The behaviour of the outlet with respect to varying water levels in the parent channel is studied by calculating its sensitivity. Sensitivity may be defined as the ratio that the rate of change of discharge of an outlet bears to the rate of change in the level of the distributary water surface referred to the normal depth of the channel. Thus sensitivity

$$S = \frac{dq}{q} \Big/ \frac{dG}{D}.$$

The sensitivity of a module is zero. The larger the variation in the discharge of a particular outlet for the same rise or fall in the water level, the higher its sensitivity. For further details, see Appendix II.

22. *Efficiency of an outlet.* The minimum working head necessary for an adequate working of the outlet is a measure of its efficiency. The efficiency of an outlet may be defined as the ratio of the head recovered o the head put in. The smaller the working head required for an outlet, the greater is its efficiency.

23. *Minimum modular head ratio.* This is defined as the ratio between minimum modular head and the depth of water in the channel, over the crest.

In an O. S. M., it is $\frac{H_s - J}{H_s} = 1 - \frac{J}{H_s} = 1 - \text{Efficiency}.$

In an O. F., it is $= 1 -$ Drowning ratio.

CHAPTER IV

A history of the development of various forms of outlets in the Punjab

1. *Outlets in the early days.* The Western Jumna Canal was opened in 1825, the Upper Bari Doab Canal in 1859, and Sirhind Canal in 1872. It is not proposed to investigate the form of outlet and the considerations governing their design that were followed on those canals in the early days. There is, however, no doubt that a very large number of outlets were open cuts in irrigation channels and were gradually replaced by some form of the pipe or barrel outlet*.

The Lower Chenab Canal was opened in 1892 and the Lower Jhelum in 1901. It was during this period that for the first time keen interest was evinced on the question of design of outlets. Some time in 1893, the Chief Engineer called upon the superintending engineers of the Department, as it then existed, to submit detailed notes on the practice of granting and building outlets as followed on the canals in their charge. These reports form very interesting reading and it is proposed to describe below in some detail the problem as it then presented itself to the canal officers in this province.

2. *Fifty years ago.* The survey of the problem made in 1893 may best be described under the following heads :—

(*i*) *Location of an outlet.* Normally the site of the initial temporary outlet was fixed by the cultivators in the first instance. No contoured plans of the irrigated area existed and it was left to the judgment of the village headman or the biggest land-owner in the village to decide where the outlet should be fixed. In actual practice, the site of the outlet was changed frequently with or without the permission of the executive engineer until after a few years experience the site found to be the best was finally adopted.

(*ii*) *The size of an outlet.* On the Sirhind Canal water was allowed for 25 per cent of wet land (gross area less unculturable less area on

*The oldest printed literature that the Authors have been able to trace is a pamphlet issued in 1882 by Mr. J. S. Beresford, a Punjab Engineer on deputation to the then North-Western Province, entitled, " Proposed Standard Designs with Estimate and Specification for masonry outlet for distribution ". The general type described is the 6" pipe with flap and face walls.

wells). A *colaba** of standard size (6 inch diameter) was allowed for every 100 acres of annual irrigation from the main *rajbaha*** and for every 50 acres from the minors. Different duties on the main *rajbahas* and the minors were given for three reasons :—

(*a*) It was assumed that the minor would run half the time only while the *rajbaha* would be in constant flow.

(*b*) The working head in the minor was considerably less than in the *rajbaha*.

(*c*) Supply in the minor was generally deficient on account of silt deposit at the head.

In the words of Mr. (later Sir) Thomas Higham, the then Superintending Engineer on the Sirhind Canal, the assumption that the duty of a *colaba* on a minor would be half of that attained on the *rajbaha* was in fair accordance with actual practice.

It will have been noticed that the size of the outlet was directly related to the area to which water was allowed. The working head of the outlet was not taken into account and the discharge of the outlet was an unknown and neglected quantity. The unit was the pipe or *colaba* and the efficiency of irrigation was calculated at so many acres per *colaba*.

On the Western Jumna Canal, the capacity of an outlet was calculated as follows :—

" It is assumed that 1 c.ft. will irrigate 6·8 acres (*kharif*† season) per diem. The turn (or '*war*') of the outlet is estimated as seven days. The *kharif* irrigation to be provided for being X area, then

$$D = \text{Discharge} = \frac{X}{7 \times 6{\cdot}8}.$$

D being thus obtained, the area of the outlet is calculated from the formula :

$$cd.\ A.\ 8.025 \sqrt{H} = D.$$

where $cd = 0{\cdot}62$

$A =$ Area of outlet,

$H =$ head.

H is *assumed* to be 0·5 as it is found in practice that it is difficult to ascertain the exact conditions and there is less liability to error in so doing than by attempting great theoretical accuracy."

On the Swat River Canal, one cusec was given for 270 acres of gross commanded area. The size of the outlet was determined from consideration of working head available.

On the Chenab Canal, different water allowances were fixed for different areas. The duty of one cusec varied from 275 to 457 acres in

---

*Earthen-ware pipe.

**Distributary.

†Summer season—April to September.

different parts of the canal. The working head of the outlet was assumed in each case = 0·5′ with two-third full supply running in the canal.

(*iii*) *Design of an outlet.* On the Sirhind Canal, to start with, all outlets were built as temporary works, "consisting simply of one or more rows of pipes without collars laid in banks, without concrete, puddle or masonry work." In 1893, some of these outlets were reported to have been working satisfactorily for 10 years. Most of the outlets were single *colabas* of the standard size 6″. A few outlets were of half the standard size, 4¼″ in diameter, and there were some outlets of two or three rows of *colabas*.

The type designs of permanent outlets as originally prepared in 1884 for the Sirhind Canal agreed "closely with that proposed by Mr. Beresford for the North-Western Provinces." The considerations regarded as important in those days, are listed below:—

(*a*) 'The mouth of the outlet' should be set back 'from the vertical plane passing through the junction of the bed and side slope,' and in practice it was set back 1′, 1·5′ and 2·0′ according as the maximum depth of water in the channel was less than 3′, over 3′, or over 4′ respectively.

(*b*) The bed of the pipe was kept flush with the bed, 0·5′ or 1·0′ above the bed of the *rajbaha* in the three conditions above described.

(*c*) Whether the downstream wing walls should be on the splay or on the square? Whether they should be built up to the point where they got out of the bank or should extend up to canal boundary? And whether their top levels should be different or at the same level with some relation to the full supply level in the distributary?

(*d*) Whether the boundary road culvert should be a separate structure or on an elongation of the outlet barrel?

On the Western Jumna Canal, the outlets consisted of standard pipes 0·4′ in diameter. A type design of the outlets as used in the Karnal Division is shown on plate 2 (Fig. 4). The level of the bed of the outlets was fixed according to the reach of the channel in which they lay. The channel was divided into four portions and the outlets were placed 1′ above bed level in the first portion, 6″ in the second, 3″ in the third and at bed level in the fourth portion.

On the Swat River canal, in addition to pipe outlets, rectangular outlets having a uniform height of 1′ and varying widths of 6″, 9″ and 12 were in use. The *colabas* in use were those made on the Bari Doab Canal″ 0·4′ in diameter, having areas in multiples of 1/8 of a sq.ft., Rectangular orifices were preferred to rows of pipes. There is an interesting objection recorded to the use of concrete as a floor for rectangular orifices. It is stated that in an outlet 18″ *x* 12″ "the cultivators by assiduously working away at it with large poles, etc., under the pretext of clearing it" succeeded in enlarging the size of the outlet "so as to allow a full-grown man to pass through it." It was, therefore, advocated that the bed and sides of a rectangular orifice should be laid in dressed stone or very hard bricks with fine joints with the top bricks in cement mortar.

On the Chenab Canal, both rectangular and pipe outlets were in use. The standard pipe outlet had a diameter of 0·4′. The bed of the outlet was usually 1′ to 2′ above the bed of the canal in the upper reaches of the *rajbaha* and at bed level toward the tail. The pipe outlets were built with a face of stone masonry.

On the Bari Doab Canal in new distributaries, cultivators were allowed to put in temporary outlets in the form of wooden troughs and they were replaced by permanent outlets (pipe or rectangular) when officers were satisfied that their location had been wisely chosen.

In the Derajat Circle, on the inundation canals 3′ span arched outlets were built for *jhallari* or lift areas but the rest, and a very large number of them, were mere *kacha** cuts which cultivators shifted about to find the best site.

It was about this time (1893) that Mr. Kennedy suggested that all outlets should be placed at bed level of the distributary so as to draw the maximum amount of silt out of the *rajbaha*. Other officers did not agree with his view and considered that the outlet barrel should be placed as high as may be compatible with the capacity of discharge required subject to the condition that the top of the pipe's exterior surface should never be above natural surface.

(*iv*) *Flap valves.* All outlets that had been built permanently on the Sirhind Canal were provided with cast iron flap valves by which they could be readily closed when water was not in demand. A section of the flap valve is shown on plate 2 (Fig. 13). It was stated that these cast iron valves "save the zamindars much trouble in opening and closing their watercourses and without them an outlet will often be allowed to remain open when water is not really in demand, so that the trouble of making a bund or otherwise closing the outlet may be avoided, and in this they greatly contribute to economy of water."

On the Western Jumna Canal, outlets were provided with flaps as per drawings shown on plate 2 (Fig. 14).

On the Swat River Canal, the pipe outlets were supposed to be closed by wooden plugs fastened by a chain to the outlet and the rectangular outlets by wooden shutters. Neither was a success and a wooden plank moving up and down against the face of the outlet was advocated.

On the Chenab Canal, all the outlets were closed with wooden flaps which were considered satisfactory although a preference was indicated for the cast iron flaps.

(*v*) *Tatiling***. With the sizes of outlets determined in what appears now to be an arbitrary manner, and the cultivators being able to increase the discharge through their outlet by silt clearance of their watercourses, it was natural that supply could not be delivered at the same time to all

*In earthwork, with masonry no structure.

**Running outlets or channels in rotation.

the outlets on a channel designed to carry a certain fixed maximum discharge. *Tatiling* of channels and *tatiling* of outlets on the same channel was, therefore, a normal and recognised feature of irrigation practice in those early days. To quote from a report by Colonel S. L. Jacob, Superintending Engineer, Western Jumna Canal Circle :

"It is impossible to get an automatic system which works at all times without *bandi** but the outlets in this circle are generally far too large and there are all descriptions of '*wars*'** and '*tatils*' and there are outlets big enough for a man to walk through without stooping . . . . . Some of the old *rajbahas* have most complicated system of '*wars*' which I much dislike, and think that the nearer we get an automatic system the better ".

(*vi*) *Remodelling of outlets.* It is no wonder that, with the system described above the necessity of remodelling of outlets should have been felt at a very early stage.

The duty attained per *colaba* varied very considerably on different outlets on the same channel, and on different channels. Short of changing the size of an outlet some of the remedies suggested were as follows :—

(*a*) For cases where the high duty attained showed that the head was very large, "Probably the best plan would be to leave the size of the pipe unaltered but to reduce the head under which it will work either by laying the pipes at a higher level or by building an uptake at the downstream end of the outlet as proposed by Mr. Kennedy ".

(*b*) When the outlets on a particular channel have a very high duty "the general duty could be reduced without altering the discharging capacity of the outlets at all by placing such minors under longer or more frequent *tatils* than those which are less favourably situated ".

As the unit of those days was not the discharge but the pipe and the discharges of outlets were not observed, the basis of remodelling was the irrigation effected in the past which was carefully recorded. "When permanent outlets were built to replace temporary ones, a reduction or increase in size of outlet was given according to whether the area irrigated was much in excess or defect of the prescribed proportion of the commanded area on the outlet ".

(*vii*) *In Retrospect.* The above was the practice and the state of knowledge with regard to various aspects of the design of outlets in the Punjab fifty years ago. It has been described in some detail as this forms the foundation from which the present efficient and highly organised practice of the distribution of water has been built in this Province. To sum up the position, as it was then understood, the following extract from a note recorded by the Chief Engineer in 1896 is reproduced below :—

"A perusal of the various Papers on this subject serves to show that the question resolves itself into a consideration of the following main heads or aspects under which the question can be considered :

---

*Closure.

**Turns.

(1) The level of the floor or cill of the outlet with reference to the bed of the distributary channel and the natural surface outside.

(2) The position of the face of the outlet with reference to the line of the bank of the distributary.

(3) The height of the face and tail walls.

(4) The length of the barrel of the outlet in the case of a road alongside the distributary and the method of carrying the road over the watercourse.

(5) The question of the size of the barrel with reference to the correct size of the discharge orifice.

(6) The method of closing the orifice.

(7) The unit to be used in calculating the discharging capacity of outlets.

(8) The question of when permanent outlets should be built.

(9) The employment of clustered pipes or rectangular orifices.

(10) The general form of the face and rear walls of the outlet.

It is not proposed to consider any structural questions because these may vary in various parts of the Province."

It will be noticed that the problem as it then presented to the officers of the Irrigation Department was much simpler than it is now. Irrigation in the Punjab and the science of Hydraulics were both in their infancy. The full value of canal water had not been realised and the demand for water was not half so keen.

3. *Subsequent history.* Since the beginning of the twentieth century the various problems connected with irrigation outlets have been studied in great detail and the present practice in some cases is contrary to that described above. The developments that have taken place in the last fifty years are now described under the same sub-heads as adopted in para: 2 *supra*.

(*i*) *Location of the outlet.* When the Lower Chenab Canal was constructed in the nineties of the last century contoured plans of the area to be irrigated were prepared before the outlets were constructed. It was then possible to locate the best site of an outlet from a perusal of these plans and the sites of outlets came to be fixed by the engineer officers. In all subsequent projects the same method was followed and the site of outlets for each *chak** was fixed with regard to the lie of the land in that *chak*. The site of the outlet should generally be the highest point in the *chak* adjacent to the irrigation channel.

(*ii*) *The size of an outlet.* It has been described in para: 2 (*ii*) *supra* that, to start with, the size of an outlet was based on the area to be irrigated, but later on the size was fixed from considerations of the discharge of the outlet based on a fixed full supply factor for the particular distributary. The normal full supply factor on the Punjab canals is 250—300 acres. It has also been stated that in the early days the size was calculated assuming a working head of 6″ in every case.

* The area included in the irrigation boundary of an outlet.

Gradually the difficulties created by this assumption came to be recognised and steps were taken to measure the working heads of outlets. But so long as the outlets were of the non-modular type, the working head observed at any moment was no index to the working heads at other times. Although an attempt was made to ensure that the outlets should have a fixed discharge, in actual practice discharges varied considerably depending on the state of the watercourse and on the area which was being watered at a particular moment.

(*iii*) *Design of outlets.* Various attempts were made to perfect the design of the barrel or pipe outlets to make tampering difficult and to obtain constant co-efficients of discharge, etc. One of the attempts by Mr. Kennedy on the Western Jumna Canal was to fit a cast iron orifice at the head of a rectangular outlet to prevent the entrance being tampered with.

Many officers worked to obtain modular or semi-modular conditions on the outlets. The first attempt was Kennedy's cill outlet, which was tried and abandoned by 1902. This was followed by Scratchley's outlet, in which the object was to make tampering difficult, adjustment easy and co-efficient of discharge constant.

In 1908, it came to notice that in the United Provinces the use of Beresford's masonry type of outlets had been entirely given up in favour of cast iron pipe outlets. This type was adopted in the Punjab for the first time on the Chenab Canal and subsequently on the Upper Bari and Upper Sutlej Canals. The main advantages claimed for this type were :

(*a*) ease of construction.

(*b*) ease in remodelling and possible re-use of pipes and immunity from alterations by zamindars.

The cast iron pipes were also obtainable in long lengths, thus reducing the number of joints. Considerable discussion took place whether cast iron, wrought iron or steel pipes should be used, but the ultimate decision was in favour of the cast iron pipes.

A great advance in the design of outlets was made in 1906 when Mr. Kennedy evolved his gauge outlet. This outlet was in an experimental stage for a number of years, but some distributaries on the Lower Chenab Canal were fitted wholesale with Kennedy's gauge outlet.

About the same time as Mr. Kennedy evolved his gauge outlet, Mr. Gibb, then an Assistant Engineer on the Lower Jhelum Canal, devised a module form of outlet, which was built for the first time on the Melay distributary of the Lower Jhelum Circle. In November 1908, Mr. Gibb took over charge of the Shahkot distributary and prepared a scheme for equipping the whole channel with his modules. These were further improved by him in 1917.

In the meantime, Mr. Harvey introduced his outlet in 1912 which was the fore-runner of the O. F. Another type known as the Stoddard

Harvey was later evolved in 1918, this being really a combination of a pipe and an O. F.

The Kennedy gauge outlet and the Gibb module remained in an experimental stage and were being perfected by their inventors in this period. The general form of outlets in use in the Punjab Irrigation, right up to 1920, was, however, the pipe or barrel outlet. On the Sirhind and Western Jumna Canal a rectangular type of masonry outlet introduced by Mr. Kennedy was in use. The type was fitted with cast iron orifices. On the Lower Jhelum Canal the Scratchley type of outlet was in universal use; the orifice was lined with stone in order to prevent tampering. On the Upper Bari Doab Canal and the Lower Chenab Canal steel and cast iron pipes were in favour. The pipes were embedded in concrete and provided with face and tail walls. The steel pipes were lap welded and painted inside and outside with Dr. Angus Smith's rust proof solution. The pipes were obtained ready made from Messrs Steward & Lloyd, Bombay.

The most important landmark in the history of development of irrigation outlets was the publication in 1922 of Punjab I. B. Paper No. 26 on the moduling of irrigation channels by Mr. E. S. Crump. Following the publication of this Paper "*Active steps were taken by Chief Engineers to further the application of the principles and devices described in the Paper." By the beginning of 1924, orders had been issued that " the A. P. Ms—or where more suitable the O. F. type of outlet—should be generally adopted in future remodelling. It was left to the option of the local officers either to indent on the Central Workshops for cast iron orifices or to arrange for these to be made locally at a small cost."

In the years following, a large number of distributaries on all running canals had been completely remodelled on these lines.

In addition to the Central Workshops standard pattern cast iron orifice, Messrs Balmer Lawrie & Co., were supplying orifices made up from galvanised sheet iron. Similar orifices of local manufacture were also used as well as concrete bed and side blocks with brick and concrete roof blocks. On the Upper Chenab Canal and Sirhind Canal, Mr. Murphy adopted an unadjustable modification of the A. P. M. which he designated the orifice semi-module. This consisted of an orifice of fixed dimensions cast in cement concrete *in situ*.

As the A. P. Ms. did not draw their fair share of silt, K. B. Minhaj-ud-din in 1925 introduced his Bend outlet.

In 1929, Mr. Khanna evolved a module which suffered from the defect of moving parts. Later, Mr. Haigh introduced his S. M. M. O. which had a bell-mouthed approach. He also suggested a silt extracting outlet to draw more silt. The combination of a pipe and O. S. M. was also tried about this time on channels with heavy banks.

In 1938, Mr. Gunn brought forward his nozzle outlet. A lot of work on Gibb's outlet had been done in Sindh by this time. Messrs Khanna & Ghafoor also evolved modules without moving parts by the introduction

*Extracts from an unpublished note dated 23-5-1930, by Mr. E. S. Crump.

of vanes in an O. S. M. and O. F. respectively. These attempts are, however, yet in an experimental stage.

Recently Mr. Haigh has introduced another adjustable bell-mouthed O. S. M. which is being tried out in the Irrigation Research Institute.

(*iv*) *Flap valves.* The authors have not been able to find the exact year in which flap valves described in para 2 (*iv*) above were discarded. Evidently as zamindars found it simple enough to close an outlet at its mouth and as the need of such closures became less frequent the flap valves were gradually discarded.

(*v*) *Tatiling*. The *tatiling* of outlets on distributaries or among channels on a distributary system continued as normal irrigation practice until about 20 years ago when with the installation of semi-modular outlets and the installation of flumes and control points in distributaries it was gradually found possible to give regular supplies to all outlets on a channel when running. The *tatiling* of channels is now resorted to, not on account of any defects in the design of outlets, but during *rabi* when the water supply available in the rivers is not enough to feed all the distributaries on a canal. The unit of distribution is now a distributary and all outlets and minors of a distributary are always running full supply when full supply is let into the distributary. The *tatiling* of outlets on any channel is regarded as inefficient working of a system and is looked upon with disfavour.

(*vi*) *Remodelling of outlets*. The remodelling of outlets is still a vexed problem on the irrigation systems in the Punjab. Much of the trouble is due to faulty design of the channel itself but partly it is also due to insufficient knowledge of the possibilities and limitations of the various forms of outlets.

It is hoped that a study of the following chapters, in which the various forms of outlets have been described together with their advantages and limitations, will go a long way in enabling a better appreciation of the problem and in making future remodellings more successful.

CHAPTER V

Types of outlets

A—Non-modular outlets.

1. The pipe or barrel outlet.

(*a*) *Structural.* Apart from a cut in the bank of a distributary the simplest and the oldest known type of outlet is a pipe outlet. To start with, it was an earthenware pipe (*colaba*) placed in the bank of the distributary at bed level. Later on, it was provided with face and tail walls of masonry and embedded in concrete.

As will have been seen from the history given in the last chapter these pipe outlets were gradually replaced by rectangular, wooden and masonry barrels. The steel or cast iron pipe was brought into the field at a subsequent stage.

Enough has been said about the structural details of the pipe and barrel outlets in the previous chapter and it is not proposed to deal here with this aspect in any detail.

(*b*) *Discharge formula.* The discharge of a pipe or barrel outlet is given by the formula.

$$q = C \times Ap \times \sqrt{2\,gH}$$

If the outlet has a free fall, H is generally measured from the centre of the pipe or barrel to the full supply level in the distributary (H_c). If it is drowned, *i.e.*, discharges into a watercourse in which the water level is above the top of the barrel, then H is the difference in the water level in the watercourse and the distributary (H_w).

If the outlet has a free fall, the discharge through it is independent of the water level in the watercourse and under these conditions, it is semi-modular. This and other similar devices of semi-moduling pipe outlets will be dealt with in part B of this chapter. For the present, this outlet will be examined as working under drowned or non-modular conditions.

In a Paper on 'Canal Outlets' presented in 1917 by R. B. B. P. Varma to the Punjab Engineering Congress, he described in detail the variations in the value of the co-efficient C for varying heads and for different types and lengths of barrels. The value of the co-efficient C also increases if water level in the watercourse rises and changes the outlet from a free fall into a drowned outlet. This well known phenomenon is clearly due to the recovery of a proportion of the velocity head which occurs in a drowned outlet. For a barrel of rectangular section 15 ft. long and 0.6. sq. ft. in area, the value of the co-efficient C under free fall conditions was found to be 0.63 and for the same barrel under submerged conditions the co-efficient increased to 0.74.

This would indicate that if the outlet is just working as a free fall, its discharge can be increased, up to a certain range, by allowing the watercourse to silt up and thus drown the outlet. After a certain stage, however, the increase in the value of the co-efficient would be compensated by a decrease in the working head and further silting up would reduce the discharge through the outlet.

More recently Mr. Inglis has found *that under drowned conditions the co-efficient of discharge for an ordinary cast iron pipe of 6″ diameter is almost constant and averages 0.74. With different diameters of pipe and for pipes of different materials and lengths the co-efficient will naturally vary.

The variations in the discharge co-efficient is thus a serious drawback in this type of outlet.

(*c*) *Adjustability*. Adjustability of pipe outlets is sometimes secured by putting in a pipe of a bigger size than actually required and by fitting it with a reducing socket of the correct size. No observations exist, however, as to whether a reducing socket fitted in this manner alters the co-efficient of discharge as applied to the area of the reducing socket.

(*d*) *Flexibility*. The flexibility of a pipe or a barrel outlet depends on the ratio that H bears to the full supply depth in the distributary.

In the United Provinces, the centre of the pipe is usually placed 1·5 ft. below full supply level. It is claimed that there is a great advantage in this setting as the outlets in the head reach of a channel, run in rotation, cannot draw their full authorised supply until the channel is running full. Also a cultivator cannot get a greater head than 1·5 ft. on his outlet, however much he may dig out his watercourse downstream.

In the Punjab wherever pipe outlets are used it has been the general practice to place them at the bed level of the distributary. This setting is given to enable the outlets to draw their fair share of the silt charge in the distributary.

(*e*) *Silt drawing capacity*. No elaborate experiments have been carried out so far on the silt drawing capacity of pipe outlets at different settings and with different velocities through them, but it has been the experience of most officers that distributaries fitted with pipe outlets at bed level seldom give any silt trouble. Also see para. 11 (*a*) of this chapter.

(*f*) *Efficiency*. Pipe or barrel outlets acting under non-modular conditions suffer from all the defects inherent to this type of outlet as described in para 12 of Chapter VI of this Paper. Their importance, however, lies in the fact that given the proper size they can pass the required discharge with a very small working head, even 0·1′ with which no semi-modules can function. This is their chief merit.

2. The Scratchley outlet.

(*a*) *Structural*. This type of outlet differs from the pipe outlet only at its downstream end. In the Scratchley outlet (see plate 3) the pipe

*Bombay P. W. D. Technical Paper No,23—" A note on standing wave pipe outlets ".

opens into a cistern 2 or 3 ft. square, at the other end of which is fixed a cast iron or stone orifice of the correct dimensions required for the authorised discharge of the outlet. While the pipe is fixed at bed level, the orifice can be fixed at a higher level to ensure semi-modularity. If, however, the orifice is submerged it functions in the same manner as the non-modular pipe outlet.

(*b*) *Discharge formula.* The formula for calculating the discharge and other hydraulic conditions of this outlet are the same as for the pipe outlet described above, but the co-efficient $C=0{\cdot}82$ for drowned conditions

(*c*) *Special merits.* The main advantages claimed for the use of this type are*:—

(*i*) That the size of the orifice can be modified with channel running.

(*ii*) That the cost of alteration is small. (It is only the down-stream end wall which is to be dismantled and re-built. The barrel under the bank is always large and requires no alterations for a small alteration in the authorised discharge).

(*iii*) That the co-efficient of discharge is the same for all orifices provided that the length of orifice is from one and a half to three times the least transverse dimension.

(*iv*) That it is difficult for a subordinate to build the orifice incorrectly as it can be checked at any time without closing the distributary.

(*v*) That at a small additional cost the orifice can be built in stone to prevent the zamindars from enlarging it."

Another advantage lies in the facility of measuring the head, as it is done on either side of the same wall.

The main objection to this type of outlet is that if the orifice were not built in stone or cast iron, the zamindars would try to knock it about and enlarge it. By merely rounding the lips they can increase the discharge considerably. Another disadvantage is the possibility of the zamindars making a hole in the cistern wall and thus taking unauthorised additional discharge in the watercourse. Since, however, the outlet is easily open to inspection at all times, these objections are not of great importance.

B—Semi-modular outlets.

The main disadvantage of a non-modular outlet is the ease, with which cultivators can increase the discharge by silt clearing the water-course and thus increasing the head.

3. Kennedy's cill outlet.—The first step in the solution of this difficulty was an attempt to eliminate the fluctuations in the discharge of the outlet from the above mentioned cause, by constructing a masonry cill below the outlet. This was tried on the Upper Bari Doab Canal by

*Note dated 6-4-1901 by Mr. L. Jacob, Superintending Engineer, Chenab Canal.

Mr. Kennedy, but was subsequently abandoned in about 1902 because it was found that the zamindars broke up the cill and it was further considered that the use of the cill induced silt deposit in the distributary. Shortly afterwards it was recorded,* "It should have been quite possible to build the cill in such a way that it would be indestructible. I do not think that the cill can have been responsible for much silt deposit; the water is drawn into the outlet at bed level of the distributary and any difficulty of the kind might certainly have been minimised by shaping the cill at its downstream face into a curve."

Details of this type of outlet may be seen at plate 3. It will be noticed that this is only a fore-runner of the pipe-cum-open-flume outlet to be described later.

A similar device was introduced in 1910 on the Jamrao Canal, where masonry profiles were built in the watercourse a thousand feet below the outlet site to keep the discharge independent of fluctuations in the watercourse level due to silt clearance, etc. An attempt was made to ensure that the channel upstream of the profile should be of the same section as the profile and should be non-silting and non-scouring.

4. Semi-modular pipe outlet.—As described in part A of this chapter, pipe or Scratchley outlets working under free fall conditions are semi-modules. The structural details of such outlets are the same as those of drowned pipe outlets.

This is a very good type to use as it is cheap, is immune from tampering, and can also draw a fair share of silt if set at bed level, as it generally is.

As will be seen from Appendix I, proportionality (F=1) can be secured in the case of a semi-modular pipe outlet by fixing it at 3/10th of the depth in the distributary. This relation was, so far as the Authors are aware, first worked out by Mr. Padday in his written criticism of Mr. B. P. Varma's Paper, already referred to.

In an attempt to fix the pipe at the bed level of the distributary and yet obtain free fall conditions (where the levels permit) pipes have some times been laid with their upstream end at the bed level of the distributary and sloping upwards through the bank until the lower lip of the pipe at the watercourse end is raised 6″ above the highest water level of the watercourse. There are, however, practical limits to the amount of slope that can be given and it should not generally be more than 1 in 12 (based on existing practice in the Western Jumna Canal).

Mr. E. S. Lindley indicated in 1922 another method of using the pipes as semi-modules. In his note on the subject, he stated, "Pipes could be made to force back a watercourse level that slightly submerged it by building a similar flume that continued the pipe invert and above that had vertical walls." In other words, the pipes at its downstream end should open into a channel having its bottom of the same size and shape as the invert of the pipe, but with vertical walls. As a result of his experiments, he indicated the height of jump that could be expected for

* Extracted from a letter dated 30th March, 1911, by Mr. A. S. Scratchley, Superintending Engineer, Upper Bari Doab Circle.

various pipes for different depressions of soffit at the downstream end and advocated a length of flume equal to four times the height of the jump.

In 1928, Mr. Inglis published the results of some experiments on what he called " Standing Wave Pipe Outlets ". The details of construction are shown on plate 4. As a result of his experiments, he concluded :—

(*i*) That with free fall downstream, if the depression head is measured from $\frac{d}{5}$ below the soffit of a 6″ pipe, 9 feet long, the co-efficient is practically constant at 0·78 for depths of 0·8′ to 1·5′ over soffit.

(*ii*) So long as the head is more than double the diameter of the pipe, the error in using a co-efficient C = 0·73 in the formula $q = C.A_p \sqrt{2g\,Hc}$ is small, but the value falls off rapidly for smaller heads.

(*iii*) For normal conditions where the head is less than three times the diameter of the pipe, a length of parallel flume equal to two times the diameter of the pipe, makes the outlet semi-modular and helps to create a standing wave ; for bigger heads, the length of parallel portion should be increased.

(*iv*) With a downstream expansion of 1 in 3, about 23 per cent recovery can be obtained.

(*v*) In such cases, with 1 in 10 divergence downstream, the discharge formula for the whole range is $q = 0{\cdot}92\ A_p \left(2gH_s\right)^{\cdot 463}$ but for the normal working range where H_s is less than the diameter of the pipe, $q = {\cdot}92\ A_p \sqrt{2g\ Hs}$. In other words, measuring H to the soffit is, for all practical purposes, correct for this normal range.

(*vi*) A downstream hood increases the discharge markedly with small heads, but has no effect for heads greater than four and a half times the diameter of the pipe. It would, however, be difficult for any one to tamper with outlets in this way. This hood is shown in plate 4.

(*vii*) The modular limit for an 8″ pipe is very approximately $= \frac{\sqrt{H_s}}{2}$ for a range of $H_s = \frac{2}{3}$ diameter of pipe to $2\frac{1}{2}$ diameters, and the recovery of head is limited to the diameter of the pipe.

5. **Kennedy's gauge outlet.** This is one of the earliest attempts at producing a rateable semi-module and was invented in 1906 by Mr. R. G. Kennedy of the Punjab Irrigation Department.

(*a*) *Structural.* This outlet consists of :

(*i*) A cast iron orifice having a bell-mouth.

(*ii*) A truncated cone with its base resting against the above orifice, and having a slightly larger diameter than the orifice. The intervening space between the orifice and the base of this cone is *supplied with air* from a vent pipe standing in an upright chamber. The effect of this arrangement of parts is to permit the orifice to discharge *into free air.* Its discharge is, therefore, independent of what happens in the remaining length of the gauge outlet, and of the downstream water level, so long as the minimum modular head required is available. This was found to be ·22 times the depression measured to the centre of the bell mouth ($M.M.H = 0{\cdot}22\, H_c$).

(*iii*) A long expanding cone of sheet iron usually about 10 feet long designed to ensure a smooth transition from high velocity to low.

This outlet is cast in definite sizes, for definite ranges of discharge ; the intermediate discharges are obtained by varying the depression, depending on the depth at which it is fixed in the bank. The theoretical discharge in cusecs is noted on the face of the vent pipe.

It may also be noted that if the water rises in the vent pipe, the *orifice will no longer be discharging into free air and the gauge outlet becomes inoperative.* Such a state of affairs can easily be recognised by the 'bubbling' of the outlet and can only occur when the minimum modular head is not available.

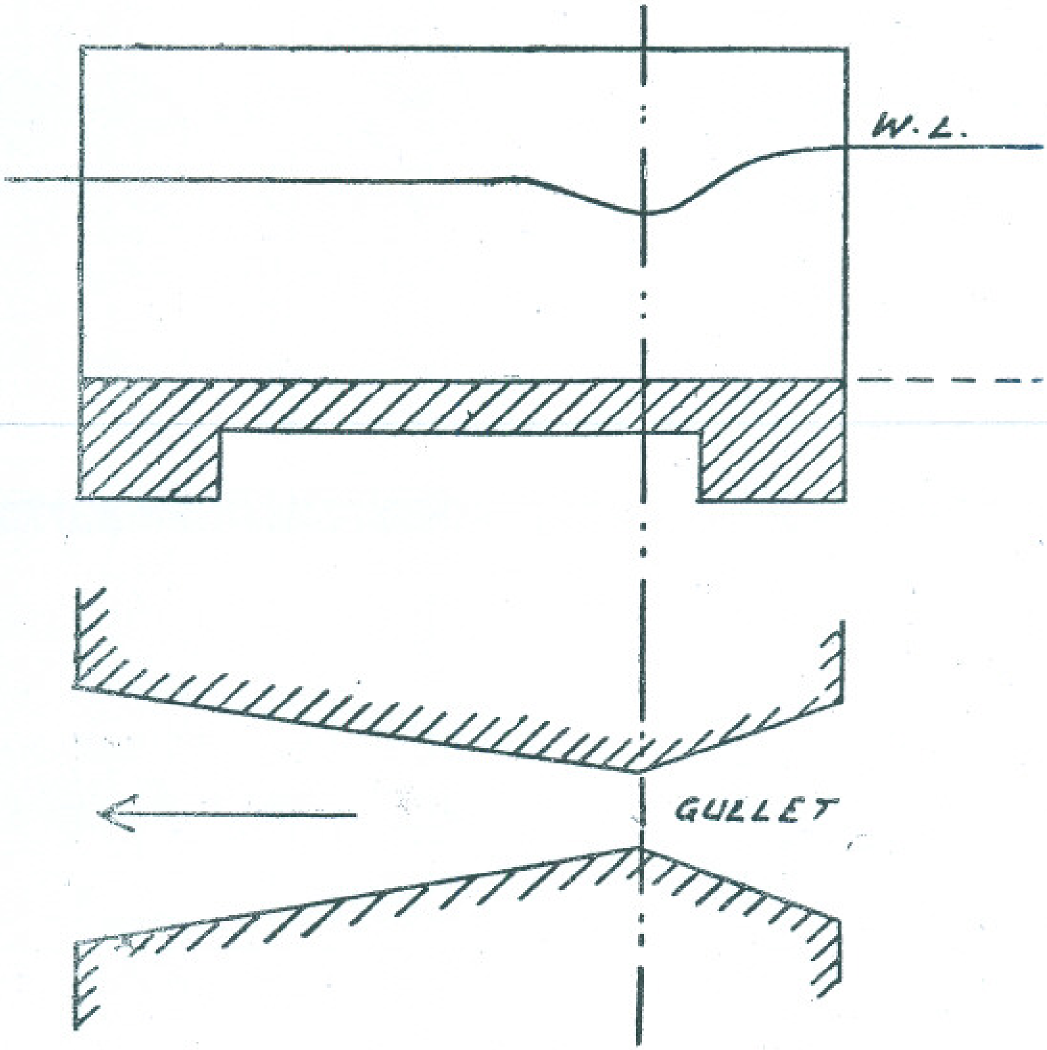
Detailed tests were made of the working of these outlets between 1907 and 1910 and the results are recorded in the Punjab I. B. Paper No. 12. Briefly it was found that this outlet was easily tampered with as the cultivator could plaster up the vents on the top of the air column, so reducing the throat pressure and increasing the discharge.

Various attempts were made to overcome this defect, and finally about 1915, Mr. Kennedy introduced a 'Modified and Tamper Proofed Gauge Outlet' (see plate 5). The former vertical vent pipe was abandoned, and in its place a sloping angle iron having an enamelled scale on each outer side and a protected air pipe inside the angle was substituted. The whole was screwed up tight by an inside lock nut in the orifice box to a 10' long bank stay, consisting also of an angle iron, laid angle upwards, with a one inch galvanised pipe welded into the angle, along with a strip of expanded metal between the two. This and other modifications made tampering more difficult. This type was tried in a few cases but it was considered that it could still be tampered with easily by plugging the pipe through the bell mouth and the improvements only gave a sense of false security.

(*b*) *Discharge formula.* The discharge of the Kennedy gauge outlet is proportional to H_c so long as the M.M.H. is available. The M. M. H. required is just over one-fifth of H_c.

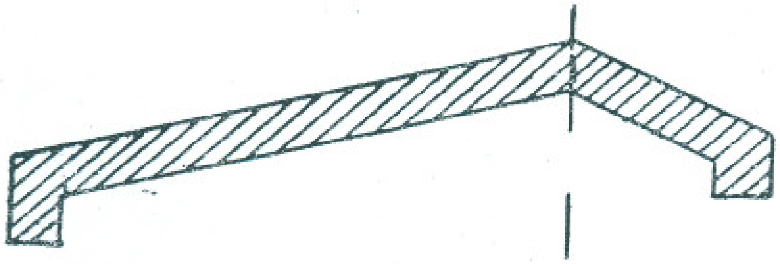
The main disadvantage of this type, however, is that for a given size of outlet, the depression head is fixed by the discharge required, and this automatically fixes the flexibility, no variation of which is possible, short of fitting a fresh outlet of a different size capable of coping with the range of discharge required. It is also expensive to manufacture and difficult to instal.

6. **Harvey's outlet**. This was first designed by Mr. Harvey in 1912. The original type* was as shown in the sketch below :—



This was designed to enable the discharge through the outlet to remain independent of the downstream conditions, within a certain range, on account of the creation of a standing wave. Subsequently, Mr. A. E. Jefferies suggested that the floor need not be left horizontal but might, with advantage, be as shown below :—

*Harvey's Irrigation Outlet—Punjab I. B. Paper.



This outlet has since been developed into the Open Flume which will be dealt with in detail later.

7. Harvey-Stoddard improved irrigation outlet. The ideas underlying the design of the Scratchley outlet and the Harvey outlet, both of which have already been described, were utilised by Messrs Stoddard & Harvey in the evolution of a new form of outlet in 1918. This outlet which is known by the names of its inventors, permits of a range of design which renders it a very useful outlet for the distribution of irrigation water.

(*a*) *Structural.* The outlet consists of an adjustable orifice connected by a rectangular masonry pipe to a narrow long-crested weir, which discharges into a flume of the form shown in plate 6. The main features of this outlet are :

(*i*) The orifice is fixed with its centre at the bed level of the distributary, so that the outlet will take a fair share of silt. The actual height of the orifice is kept slightly greater than necessary to pass the required discharge.

(*ii*) After construction of the outlet, the size of the orifice is reduced by means of the gate shown on the plan until the exact discharge is passing the weir, when the gate is fixed firmly in position by grouting with cement and filling above with cement concrete. The width of the orifice is kept as ·4′, ·8′ or 1·6′, and the width of the weir 0·25′, ·5′ or 1·0′.

(*iii*) The most important dimension in this outlet is the width of the weir. It should be possible to fix it correctly to 1/32″ if care is taken to bolt the vertical angle irons to the transverse angle iron at the bottom.

(*iv*) The inventors of this outlet gave formulae for calculating the discharge of the outlet, but since the outlet in its original form is seldom used and the co-efficients have undergone considerable change, these are not being mentioned. For further details, reference may be made to the printed Note on the subject issued by the Punjab I. B.

(*v*) A very important part of the outlet is the downstream plate as shown in plate 6. This plate is to be added initially if the crest of the weir is fixed comparatively high or, subsequently, if the bed of the distributary rises much above designed. In both these conditions, the plate would come into action when discharges above authorised pass over the weir, and thus it would reduce the flexibility of the outlet. This idea was subsequently used in the roof blocks on open flume outlets.*

(*b*) The main advantages of this outlet are :

(*i*) The head required by a small "long-crested" free fall or "standing wave" weir, as it is variously termed, is exceedingly small, being about 15 % to 20 % of the depth over the weir crest. The water surface in the cistern need thus be only the merest trifle in excess of that in the watercourse.

(*ii*) A considerable range of flexibility is made possible by correct proportioning of the width and height of the weir, each variation of which could be combined with corresponding variations in cistern level and barrel dimensions.

(*iii*) Attention is invited in this connection to the flexibility diagram given in plate 1. It will be seen that as the setting H/D decreases, the range of flexibilities fall off, but the actual flexibilities available are higher.

(*iv*) In extreme cases this pattern of outlet can be designed to consume the absolute minimum working head at the expense of some reduction in the silt drawing capacity.

(*v*) The precise position of the barrel does not affect either the discharge or the proportionality. The barrel may be raised to decrease the silt draw, when the velocity through it must necessarily be low, and adequate silt draw can be ensured by depressing the barrel.

8. The open flume. The open flume outlet is a development of the idea underlying the Harvey outlet. It can also be regarded as a Stoddard-Harvey improved irrigation outlet, in which the orifice and the masonry barrel have been done away with and the weir is placed directly in the side of the channel. Whereas the weir in the Stoddard-Harvey outlet is short-throated, the open flume has a long throat.

(*a*) *Structural*. The open flume outlet is simply a smooth weir with a throat constricted sufficiently to ensure a velocity above the critical and long enough to ensure that the controlling section remains within the parallel throat at all discharges up to the maximum. A gradually expanding flume is provided at the outfall, to obtain the maximum recovery of head. The entire work is built in brick masonry, but the controlling section is generally provided with cast iron or steel bed and cheek plates.

There are various forms of the open flume outlet which differ from each other only in details. These forms will be described later.

(*b*) *Discharge formula*. The discharge is given by the formula :

$$q = k\ B_t\ G^{3/2}$$

As the width of the open flume outlet is comparatively small the value of the co-efficient K is assumed to be less than the theoretical value 3.09 on account of additional frictional losses in narrow flumes. The

* See para 8 (g) of this Chapter.

co-efficient remains constant for varying heads over the crest so long as the minimum modular head required is available. A visual test of the outlet taking its authorised discharge under full supply conditions is provided by the presence of a standing wave below the outlet. So long as a steady standing wave forms, the discharge through the outlet is independent of the water levels in the watercourse.

(*c*) *Adjustability*. This outlet is not easily adjustable. Adjustability can only be secured by dismantling one side wall and either raising or lowering the crest, or by reducing or increasing the width of the flume by rebuilding the side wall at the required distance. In other words an adjustment means practically a reconstruction.

(*d*) *Flexibility*. As will be seen from appendix I, flexibility F = 1 can be secured by keeping the crest of the outlet at 0·9 of the depth of the channel. If the cill is kept higher than this, the outlet becomes more flexible, *i.e.*, hyper-proportional, and if lower, it tends towards rigidity.

With a fall in the F. S. level, the flexibility would increase and with a rise in the water level it would decrease.

(*e*) *Silt drawing capacity*. It may be taken as axiomatic that the higher the crest of the outlet compared with the bed level of the distributary, the less is its silt drawing capacity. In practice, the width of the outlet is limited to a minimum of 0·2 ft. and, as such, it often becomes necessary to raise the crest of the outlet much above the bed level. The table below gives the minimum discharges for which an open flume outlet can be designed at bed level of the distributary for varying full supply depths. ($B_t = 0.2'$, $K = 2.90$)

D.	1.0'	1.5'	2.0'	2.5'	3.0'	3.5'	4.0'
q.	0.58	1.07	1.64	2.29	3.01	3.8	4.64

From the above, it will be apparent that except in small channels it is seldom possible to place the crest of an open flume outlet at bed level of the channel.

(*f*) *Efficiency*. The working head required in an open flume outlet with a suitably expanding downstream flume is from 10 % to 20 % of the depth of water above the crest of the outlet. Further, as it is perfectly possible to construct the crest of the outlet high, these outlets can work with just a fraction of the head on the outlets. This is their chief merit.

This type of outlet is most suited

(*a*) to tail clusters.

(*b*) to proportional distributors.

At tail clusters, it is useful in distributing the supply proportionately and in easily absorbing any excess that reaches the tail. The low working head required also avoids undue raising of the F. S. L. in the channel.

Standard designs with 2, and 4 flumes are given in plate 20. In the 3 and 4 flumes, the crest of the outer flumes is sometimes built ·02′ lower than that of the inner flume or flumes to compensate for velocity of approach. The standard one feet gauge should in this case be fixed with its zero at the crest level of the inner flume.

As a proportional distributor, the O. F. affords an opportunity of inserting a control point with a minimum loss of head. The cills of all the offtakes are pitched at the same level and proportionality secured by adjusting the widths of the offtakes. Generally the cill level is kept such that the weir crest extends right across the distributary channel, to reduce the working head and also to reduce the action below the work.

Experience has proved that a design of this nature does not cause silting above the work, except when low supplies are run for considerable periods. Such silt as may be deposited under these conditions is soon swept away during high supply.

Another advantage of this type of design is that the water surface at the control point is relatively steady during small fluctuations in supply.

(*g*) *Disadvantages.* The main disadvantage is that in many cases the open flume outlet is either deep and narrow in which case it is easily blocked, or is shallow and wide, in which case it is hyper-proportional and also fails to draw its fair share of silt.

To overcome the defect of a high flexibility, a roof block corresponding to the plate in the Stoddard-Harvey outlet is sometimes fitted in the gullet of an O. F. at the *vena contracta* clear of the water surface in the gullet when the outlet, is drawing its F. S. discharge. This clearance is generally set as 0·05′ in the head reach and 0·1′ in the tail reach of distributaries. This device enables the O. F. to start working as an orifice, as soon as the roof block comes into action. This is accompanied by a reduction in discharge because with a sharp edged roof block, the co-efficient of discharge in the formula $CA\sqrt{H}$ is only 5. With a further rise in the water level the rate of increase of discharge is much slower than in an O. F. because of the lower flexibility of an orifice type.

The sharp initial reduction which takes place in the discharge of an outlet fitted with a roof block sometimes creates serious difficulties in the channel itself and it is desirable to determine the shape of the roof block which will give a co-efficient of 6·5 to 7 and will not cause a reduction in the discharge of an outlet when it comes into action.

It may be mentioned, however, that the roof block device is not entirely fool proof because the reduction in discharge caused by its use can be counteracted by converting the effluent either into a jet from an orifice with a slanting roof or into a jet from a narrow-crested weir, provided that in each case, the jet flows free of the block. This form of tampering can easily be done by suitably placing a slanting brick or bundle of grass in the aperture of the flume.

Another form of interference with this outlet is by placing a thin wooden plank fitting the gullet, half-way between the crest and the water level. This increases the discharge, if the outlet is working as a free-fall, as shown below:

Let G be the depth of water on the crest of an O. F. and suppose a plank is inserted at a height of G/2. This will divide the outlet in two compartments, the top half working as an O. F. and the lower half as an orifice.

Neglecting the thickness of the plank, the discharge of the upper half will be approx: $= 3B_t\ (G/2)^{3/2} = 1{\cdot}06 B_t\ G^{3/2}$. The discharge of the lower half (in case of a free fall outlet) will be

$$= CA\sqrt{2g\ (\cdot 75\ G)}$$

Taking $C = \cdot 7$, this will be

$$= 5{\cdot}6\ \frac{B_t\ G}{2}\left(\frac{3G}{4}\right)^{\frac{1}{2}} = 2{\cdot}42\ B_t\ G^{3/2}. \quad \left[A = \frac{B_t\ G}{2}\right.$$

The discharge of the outlet would thus be

$$= 1{\cdot}06\ B_t\ G^{3/2} + 2{\cdot}42\ B_t\ G^{3/2} = 3{\cdot}48\ B_t\ G^{3/2} \text{ against}$$

$3\ B_t\ G^{3/2}$ as designed. This means an increase in discharge of about 16 per cent, which has been found to be approximately correct on taking actual observations in the field. If the outlet has not got a free fall, such tampering cannot be materially useful.

(*h*) *Various types of open flume outlet.* As the idea of a long crested weir came into use in the design of outlets, different type designs were introduced by different officers. The most important of these types are now described:

(*i*) *Crump's open flume outlet.* This type was introduced on the Lower Bari Doab Canal in 1922 and was subsequently standardised throughout the Punjab Irrigation Branch. It is fully described in Punjab I. B. Paper, No. 26. The main features (see plate 7) are as below:

The length of the crest L_t is 2·5 G. The length of the throat (end of upstream approach to beginning of downstream splay of the side wall) is $2G - 0{\cdot}25'$. The discharge is given by the formula $q = 3{\cdot}0\ B_t\ G^{1{\cdot}5}$, where B_t is 0·4′ or more. For lower values of B_t, the following co-efficients are adopted:

B_t 0·4′ to 0·3,′ C = 2·95.

B_t 0·3′ to 0·2′, C = 2·90.

As already stated, the minimum value of B_t adopted in practice is 0·2′.

The upstream approaches are designed with a view to enable the outlet to take its fair share of the silt in the distributary. The upstream