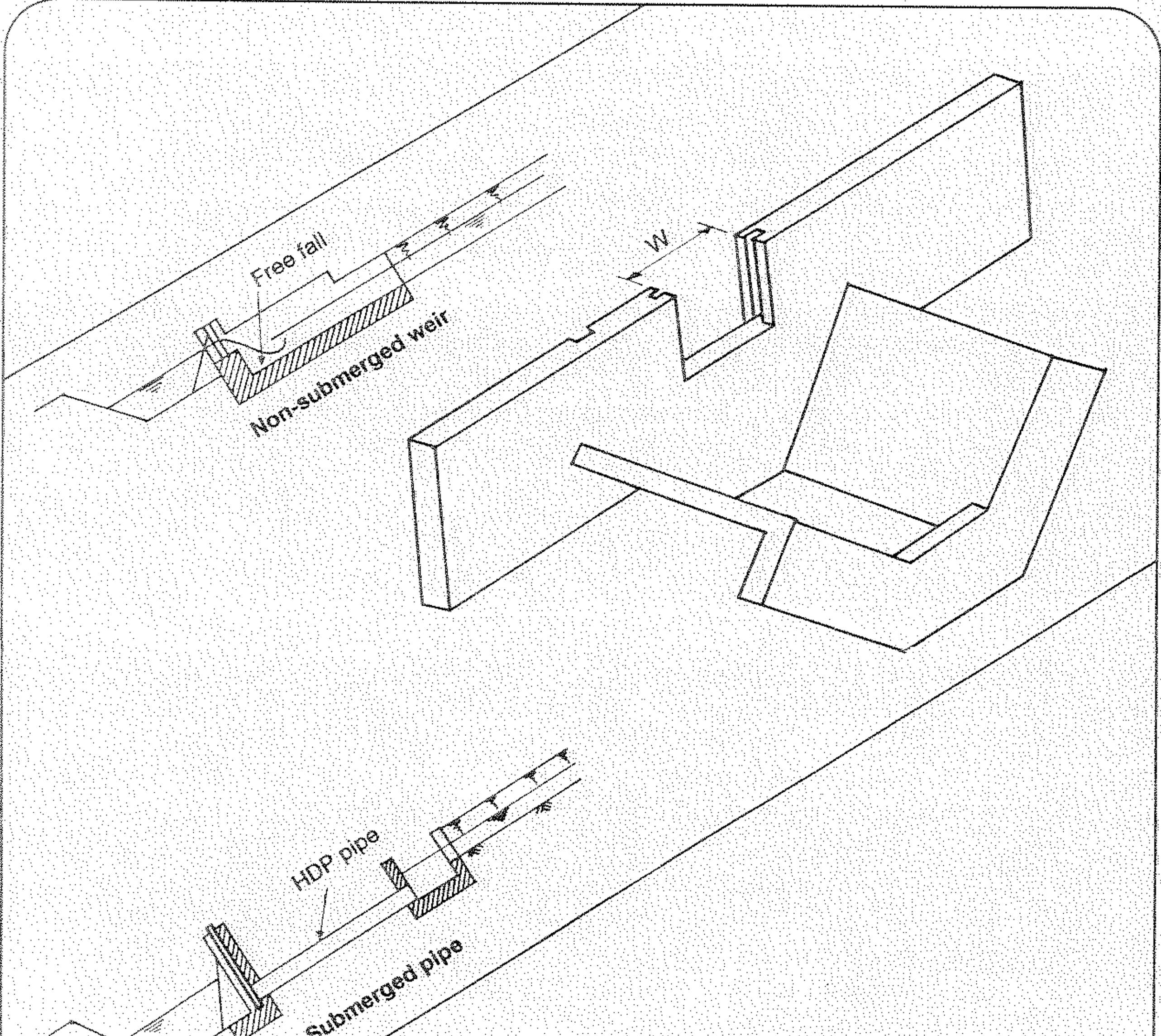
*Poverty Alleviation Through Employment Generation in Irrigation Works Programmes*

# APPROPRIATE DESIGN OF SMALL-SCALE HILL IRRIGATION STRUCTURES




# Outlet Structures for Hill Irrigation Schemes

NEPAL SPECIAL PUBLIC WORKS PROGRAMME
MANUAL NO. 2

**Module No 9**

# OUTLET STRUCTURES FOR HILL IRRIGATION SCHEMES

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# What are Outlet Structures?

An outlet is a structure at the head of a water course, a farm irrigation canal, or a farm or field channel, which connects it to the parent canal.

These structures are essential for water distribution and have a decisive influence on the proper functioning of an irrigation system.

Appropriate design and correct location of these structures will ensure that the farmers receive their due share of water at the right time.

# Appropriate Design

Appropriate design of outlet structures is necessary to:

- allow farmers to apportion the available water among the users in a manner that is clear and agreeable to all,
- allow farmers maximum flexibility of outlet operation during normal and low-flow periods in the supply canal.

## Flexibility: To Apportion Available Water Based on Need

The distribution of available water has always lead to conflict among users, especially during periods of low water availability. Farmers will be able to resolve most conflicts when traditional and clear water proportioning concepts such as *saachos* (shown in Photograph 9A) are used.

When rigid water proportioning structures which do not allow any flexibility to vary flow rates, such as those shown in Photograph 9B, are built without consulting the users, the farmers have no choice other than to break them in order to achieve equality of water distribution.

## Flexibility: To Operate Outlets Effectively During Periods of Low Flow in the Supply Canal

During periods of low flow in the supply canal more effective water distribution can be achieved by rotating the available flow among the users. This will require every outlet to be designed in such a manner that:

- on/off flow control through the outlet is possible,
- efficient flow rates are maintained through the outlet even when the water level in the supply canal is low.

## On/Off flow Control of Outlets Using Simple Wooden Gates

Simple wooden planks/gates are the most appropriate for on/off flow control. When gates are not provided, farmers resort to the use of mud plugs borrowed from the canal banks, progressively weakening the strength of the banks and contributing to the silt load in the water.

A simple arrangement using wooden planks consists of a set of correctly situated vertical grooves set in masonry which allow the planks to be inserted, as shown in Photograph 9C. Undersized, rough faced grooves are not very effective because they do not allow wooden planks to be inserted properly and cause gates to get stuck, while oversized grooves lead to leakage of water. These problems can be overcome by using correctly sized U-shaped iron strips embedded and anchored well in the masonry, see Photograph 9D.

# Farmers Appreciate Open, Clear and Flexible Water Proportioning Devices

***Photograph 9A***
***Weirs of Varying Width Cut on a Wooden Log for Proportioning Water***

This wooden *saacho* diverts part of the flow in the main supply canal into a branch canal.

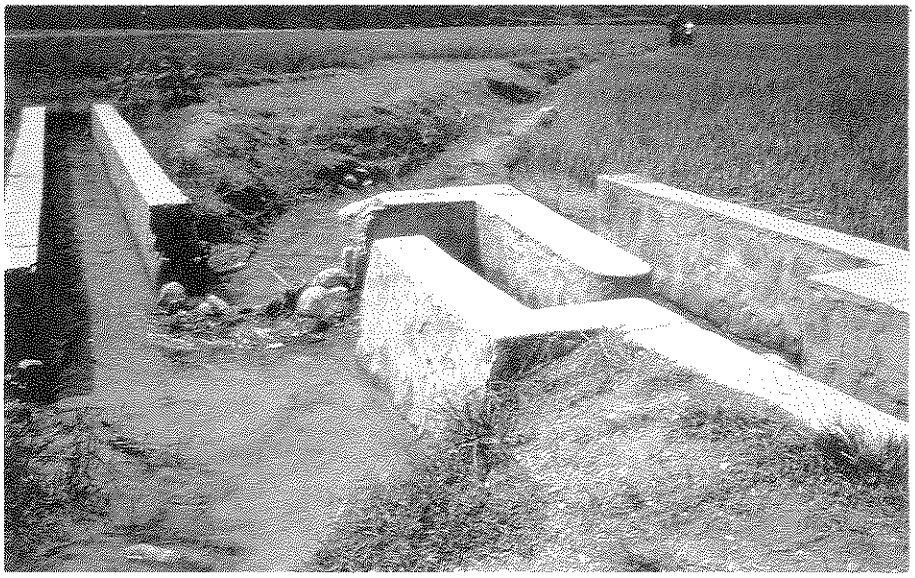
The portion of the flow diverted into the branch canal is determined by the width of the weir leading to the branch canal.

When water is not needed in the branch canal the weir leading to it is closed with a mud plug.

Different *saachos* with different weir settings can be used at the same location depending on the cultivation season and the amount of water required in the canal.

WARNING

# Farmers Do Not Appreciate Rigid Water Proportioning Devices



***Photograph 9B***
***Damaged Flow-Dividing Structure***

This is a flow-dividing structure at the end of a main canal which divides the flow between two branch canals. The situation here requires that the flow in the branch canals be continually adjusted, depending on a supplementary spring flow which is available to a portion of the command area. The original rigid structure allowed the farmers no flexibility to vary the flow according to requirements, leading them to break the structure.

# Maintaining Efficient Flow Rates Through Outlets

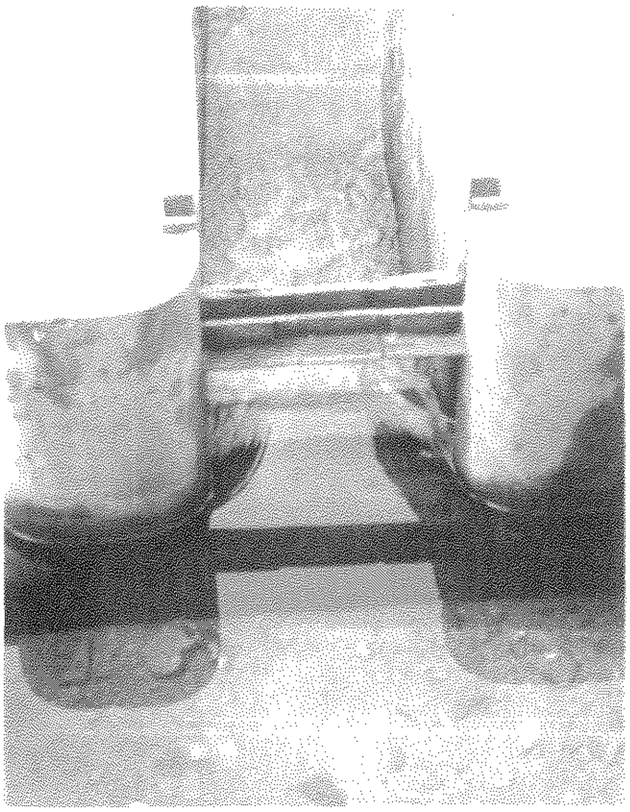
Water levels in the supply canal are proportionately lowered during low water availability. Water levels in the supply canal which are lower than design levels lead to reduced flow rates through outlets.

Outlets will therefore need to remain open for longer periods in order to deliver the full quantity of water to the user. Under these conditions farmers will need to wait longer for their turn. The waiting time can be shortened by providing simple structures, called check structures, across supply canals to head-up the water so that outlets can function fully. Simple wooden checks consisting of several narrow planks placed horizontally inside vertical grooves and built across the supply canal a little upstream from the outlet will raise the water level in the supply canal during times of low flow and ensure efficient functioning of the outlet. Photograph 9E shows a makeshift check structure built by farmers using corrugated tin sheets. Such structures are neither permanent nor strong, and will need to be rebuilt very often. Frequent rebuilding in earthen canals will result in the weakening of the canal banks.

***Photograph 9C***
***Simple Arrangement for On/Off Flow Control Using Wooden Planks Placed in Vertical Grooves set in Masonry***

This arrangement usually provides no flexibility for control. The outlet is either fully open or completely shut.

# More Flexibility than Simple On/Off Flow Control is Desirable in Many Cases



***Photograph 9D***
***Modified Arrangement for Flexible Flow Control Using Strips of Vertical Wooden Planks***

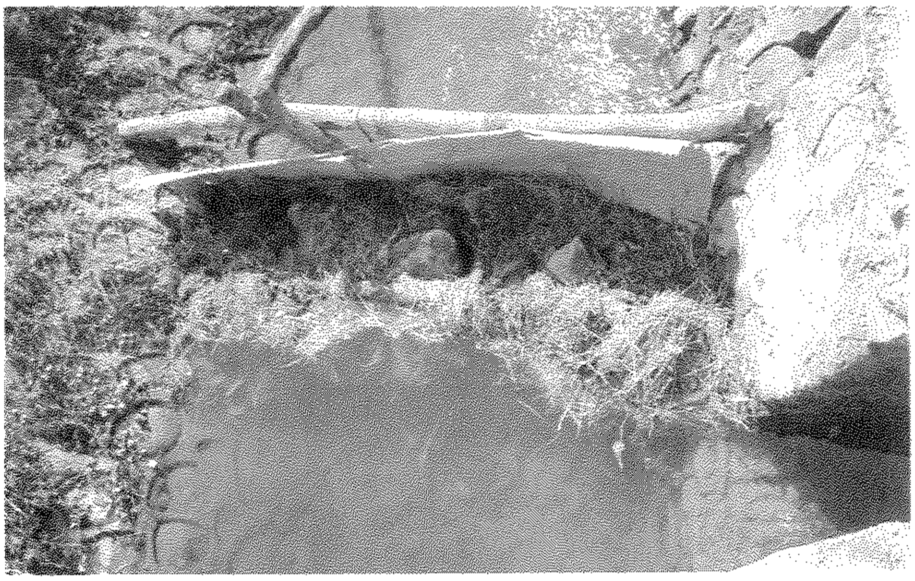
Photograph 9D shows a modified arrangement of grooves and supports for placing strips of wooden planks vertically to make gates for an outlet. With this arrangement complete shut-off, by positioning all the vertical strips to close the opening, as well as partial flow, by removing one or more vertical strips, is possible.

# Improved Design of Outlets Incorporating Traditional Farmer Concepts

The *saacho* is a traditional farmer-built structure. It employs the basic principle of proportional water division using weirs of different sizes carved out of wooden logs. Farmers usually place *saachos* perpendicular to the flow in the supply canal, as seen in Photograph 9A, because the construction of the downstream conveyance channels in mud is easier when the incoming and outgoing water flows in the same direction. The main disadvantage of this arrangement is that it requires more space. Photograph 9F shows a design improvement on the farmers' concept of proportional water division using side weirs. The main advantage of this design is that the structure is more compact.

WARNING

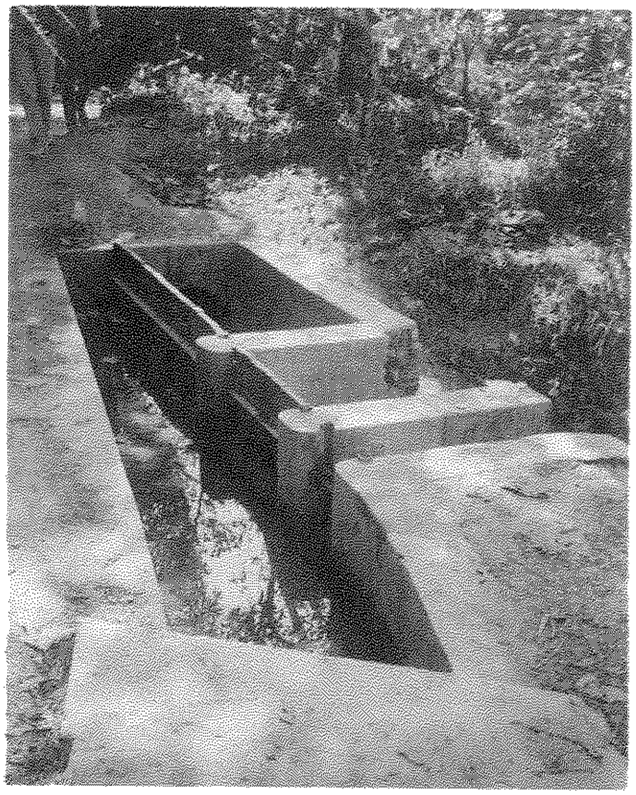
# Temporary Check Structures Are Not Efficient



***Photograph 9E***
***Makeshift Check Structure Using Corrugated Metal Sheet and Timber Props***

This is an example of a makeshift check structure to raise the water level in the supply canal during a low flow period. Using checks to raise water levels to design levels means that outlets can function effectively, delivering higher flows into the distribution canal and minimising delays in a rotational system of water sharing. A temporary structure such as this is not hydraulically efficient, can leak, and will require frequent rebuilding. Frequent rebuilding in earthen canals can result in the progressive weakening of the canal banks.

# Improved *Saacho* Concept



***Photograph 9F***
***Outlet Structure Using Proportional Side Weirs***

The photograph above shows an outlet structure built on the main canal to feed two distributory canals.

The design employs a concept of water distribution familiar to the farmers: the use of proportional weirs.

There are three side weirs in the structure. The first weir seen from the bottom of the picture serves one distributory canal, the middle weir another distributory canal, and the last allows the water to continue along the main canal through a short concrete pipe tunnel. All the weirs are gated with wooden planks that slide smoothly inside iron grooves built into the masonry walls. Each gate is made up of several removable narrow vertical strips of wood, permitting a wide range of flow control.

## Types of Outlets

Three different design types are possible. They are:

- modular;
- semi-modular; and
- non-modular outlets.

## Modular Outlets

In a modular outlet the discharge is, within reasonable working limits, independent of the water level in the parent canal and the water course or field channel. A low water level in the supply canal, provided it is not extremely low, does not affect the flow extraction rate at the outlet. However, the main disadvantage of this type of outlet is that it cannot absorb fluctuations of water supply in the parent canal and the parent canal can either flood or become dry in the tail reach as a result. Flooding in hill canals must be avoided because it increases the risk of breaching the canal.

Modular outlets are too complicated for hill conditions because they are either fully automated or mechanised and require a specialist to modify the settings to increase the flow beyond the normal working range. Their operation and maintenance is difficult for hill farmers. Khanna's module, shown in Figure 9.1, is an example of a modular outlet.

## Semi-Modular Outlets

So long as a minimum working head is available for the device to operate, the discharge of a semi-modular outlet is independent of the water level in the water course or field channel, but dependent on the water level in the parent canal.

A pipe outlet or an unsubmerged weir discharging freely into a farm plot, farm ditch or distributory is an example of a semi-modular outlet.

## Non-Modular Outlets

The discharge of non-modular outlets depends on the difference between the water levels in the parent canal and the water course or field channel. The disadvantage of this type of outlet is that siltation at the downstream end can reduce the discharge through the outlet.

The tail reach can be liable to flooding if the farmers at the head reach do not draw their full share of water, as in times of low demand, or keep their outlets free from silt.

On the other hand, when water is in short supply, the head reach farmers tend to draw too much water from the canal, depriving the tail end farmers.

A submerged pipe outlet or a submerged weir is an example of a non-modular outlet. See Figure 9.2 for examples of non-modular and semi-modular outlets.

For reasons given below, semi-modular and non-modular outlets are preferred in hill irrigation systems:

- outlets need to be simple and flexible: modular outlets have complex designs and are not able to accommodate large variations in flow in the supply canal.
- outlets need to be sensitive to flow variations in the supply canal: semi-modular and non-modular outlets are quite sensitive to water level variations resulting from flow variations in the supply canal. This sensitivity is essential for efficient water rotation schedules.

# Flow Rates Through Modular Outlets are Pre-set and are Difficult to Adjust

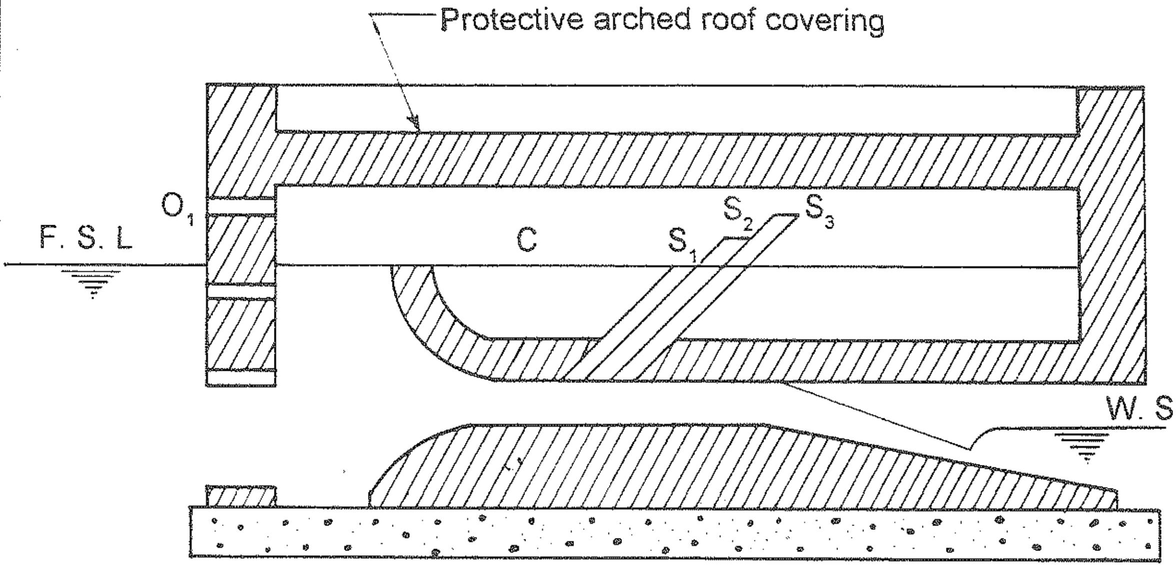



***Figure 9.1***
***Khanna's Rigid Orifice Semi-Module***

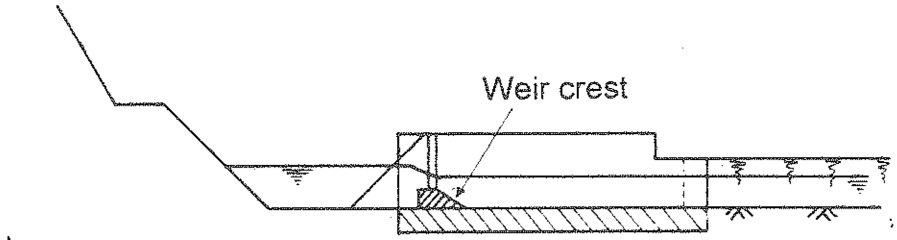
The figure above shows a sectional elevation of one of several types of modular outlets commonly used in large flat area irrigation systems.

Constant flow control is achieved in this outlet by the inclined shoots fixed to the roof of the structure at vertical intervals of 15 cm with their lower ends flush with the bottom of the roof. During normal operation, the water level in the differential chamber C is below the opening of the first inclined shoot $S_1$. When the water level in the supply canal rises, more water enters the differential chamber through $O_1$, forcing a backflow in the shoots.

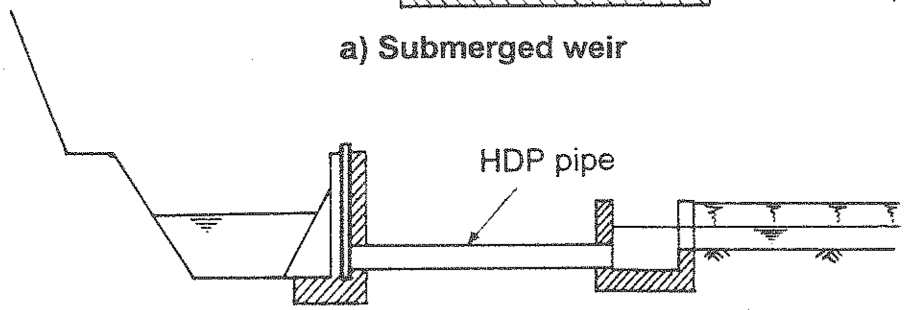
This backflow impinges on the normal outlet flow thereby reducing the rate of flow through the outlet. When the supply water level is very high, backflow is produced through all three shoots and the flow through the outlet is normalised.

The main disadvantage of this and other types of modular outlets is that the flow rates through these structures are pre-set and dismantling is often necessary in order to adjust the flow.

***Figure 9.2***
***Examples of Non-Modular and Semi-Modular Outlets***

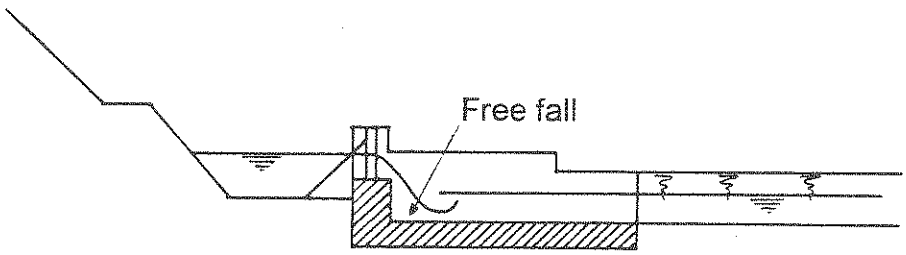



a) Submerged weir

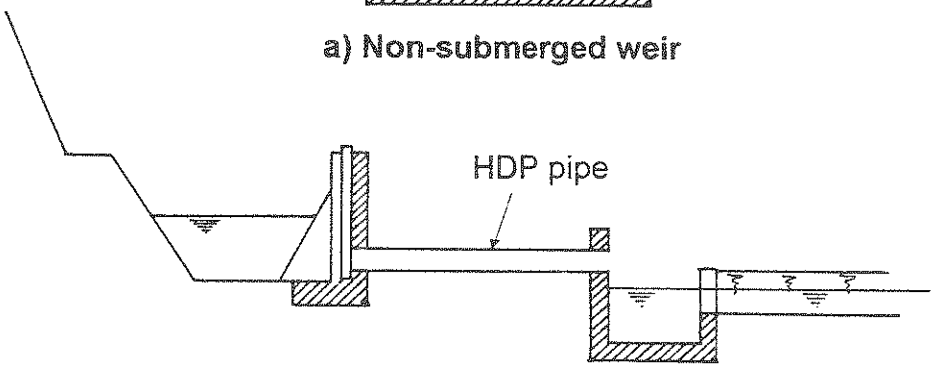



b) Submerged pipe

***Non-Modular Outlets***




a) Non-submerged weir




b) Pipe with free outlet

***Semi-Modular Outlets***

# Hydraulic Design of Outlets

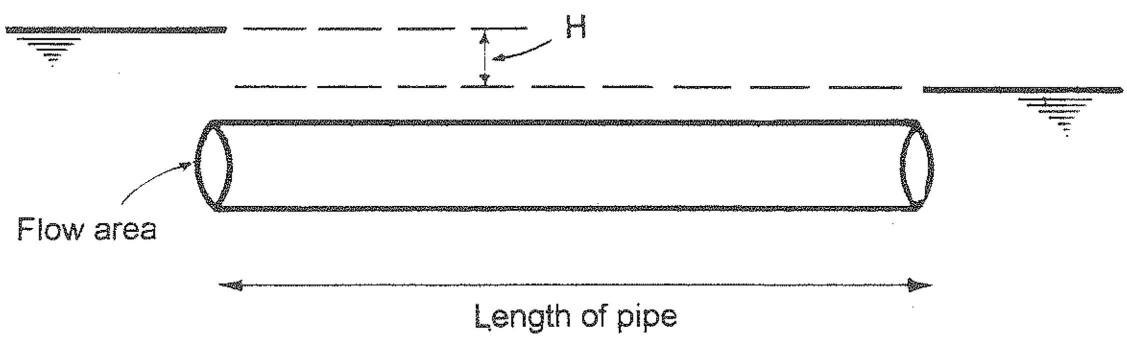
## Hydraulic Design of Pipe Outlets

Pipe outlets can be designed as submerged outlets, in which case they behave as non-modular outlets.

The flow rate through a submerged pipe outlet is governed by the cross - sectional area of the pipe and the difference between the upstream and downstream water levels.

$$Q = C\,A\,\sqrt{H}$$

Where:
- Q = Flow through the pipe (litres per second)
- C = Constant : 2800 for pipe length greater than 6 metres
  : 3300 for pipe length less than 6 metres
- A = Area of cross-section of the pipe ($m^2$)
- H = Difference between upstream and downstream water levels (m)



When pipe outlets are designed as free outlets they behave as semi - modular outlets.

The flow rate through a free pipe outlet is governed by the cross-sectional area of the pipe and the depth of water in the supply canal above the centre of the pipe.

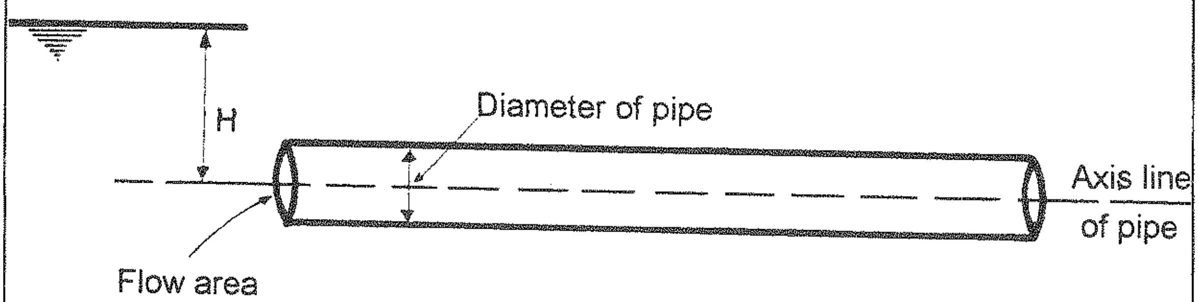
$$Q = C\ A\ \sqrt{H}$$

Where:

| | | | |
|---|---|---|---|
| Where: | Q | = | Flow through the pipe (litres per second) |
| | C | = | Constant : 2760 |
| | A | = | Area of cross-section of the pipe ($m^2$) |
| | H | = | Head above the centre of the pipe (m) |

The flow rate, Q, obtained from the above formula is correct only if the static head above the centre of the pipe is greater than or equal to the diameter of the pipe.

When H is less than the diameter of the pipe the formula does not hold true.



## Hydraulic Design of Gated Outlets

In larger outlets, such as an outlet to a branch canal where gates or weirs are used to control flow, the following formula is applicable for undershot gates (an undershot gate is one where water flows under the gate):

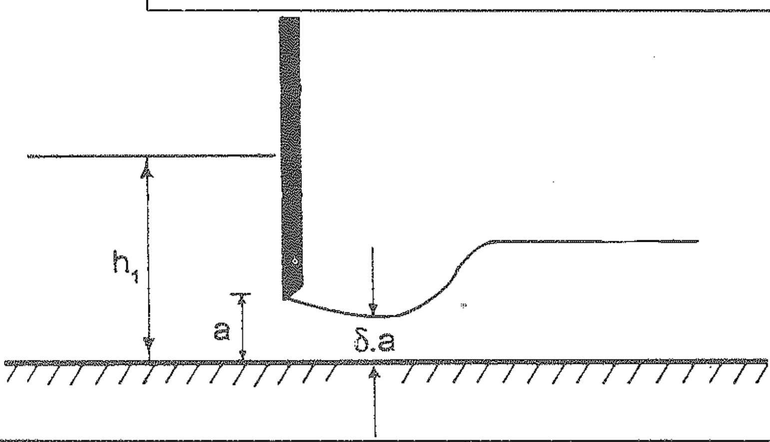
For Free Flow Conditions:

$$Q = C_D\ C_V\ W a^{3/2} \sqrt{2g\,(h_1 / a - \delta)}$$

Where:
- $Q$ = Discharge (cumecs)
- $C_D$ = Discharge coefficient dependent on $h_1$ and a
- $C_V$ = Velocity coefficient = 1 approximately
- $h_1$ = Head of water upstream of the opening (m)
- $W$ = Width of gate (m)
- $\delta$ = Contraction coefficient
- $a$ = Gate opening (m)

Relationship Between $h_1$, a, $\delta$ and $C_D$

| $h_1/a$ | $\delta$ | $C_D$ |
|---|---|---|
| 1.5 - 2.5 | 0.63 | 0.60 |
| 2.5 - 3.5 | 0.625 | 0.60 |
| 3.5 - 5.0 | 0.625 | 0.605 |
| > 5.0 | 0.62 | 0.61 |



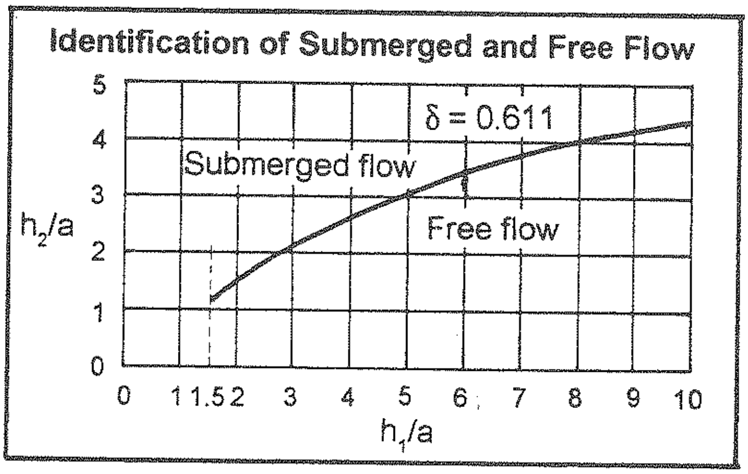
For Submerged Flow Conditions:

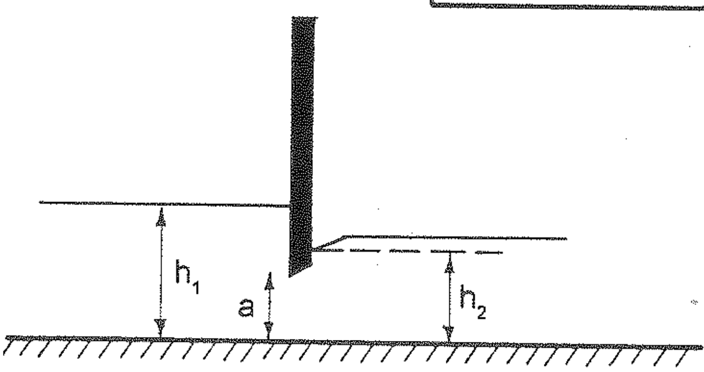
$$Q = C_D \, C_v \, A \sqrt{2g(h_1 - h_2)}$$

Where:

$Q$ = Discharge (cumecs)
$C_D$ = Discharge coefficient = 0.66 approximately
$C_v$ = Velocity coefficient = 1 approximately
$h_1$ = Head of water upstream of the opening (m)
$h_2$ = Head of water downstream of the opening (m)
$A$ = Area of gate opening ($m^2$)

See Chapter 2.5 of M8, Part 2, Vol. 1 of the PDSP Design Manuals for more details of the design of undershot gates.



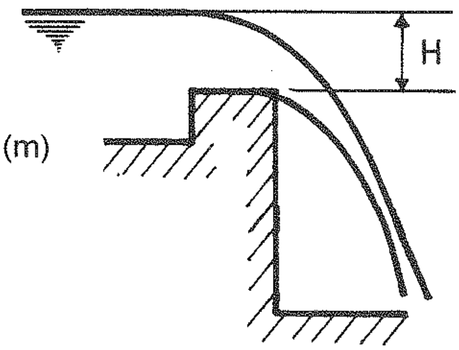



## Hydraulic Design of Ungated Weir Outlets

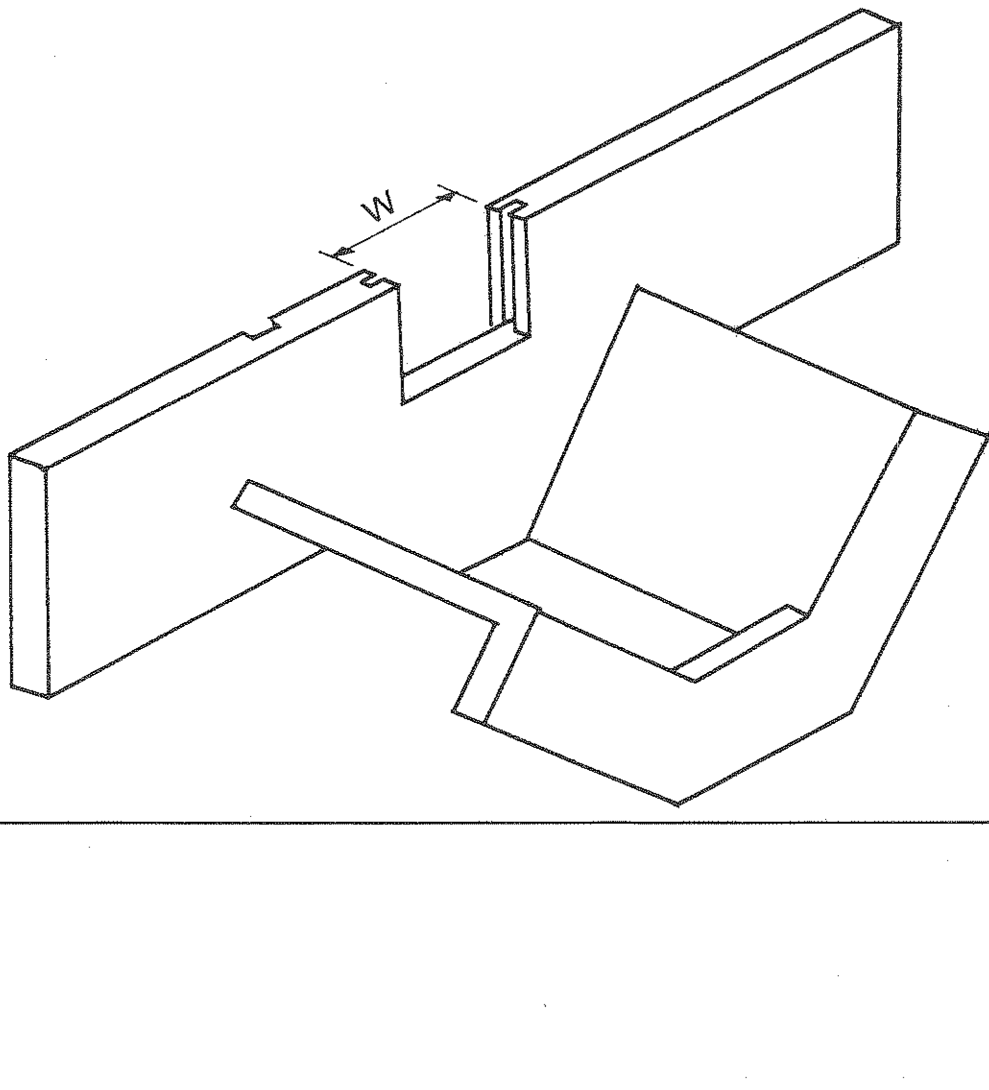
When weirs are used to control flow in outlets the following formulae are applicable:-

For Free Fall Conditions:

$$Q = 1.7\,W\,H^{3/2}$$




Where:
- Q = Discharge (cumecs)
- W = Width of gate (m)
- H = Head of water over the weir (m)

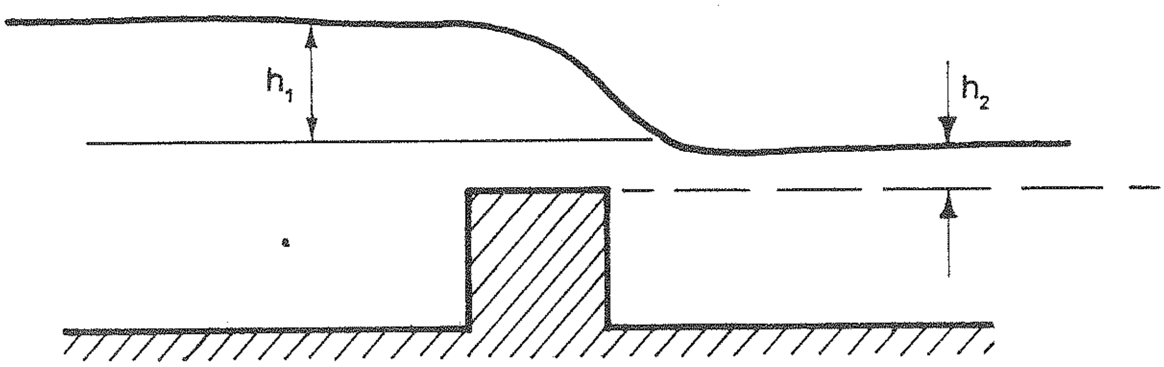


For Submerged Flow Conditions:

$$Q = \frac{2}{3} C_D \sqrt{2g}\, W\, h_1^{2/3} + C_D\, W \sqrt{2gh_1}\; h_2$$

Where: Q = Discharge (cumecs)
W = Width of gate (m)

See figure below for $h_1$, and $h_2$ (m)
$C_D$ = Discharge coefficient = 0.63 approximately for rectangular weirs




Submerged weirs tend to show a large variation in flow rate depending on the extent of submergence, which in turn will vary with the amount of siltation in the structure. For this reason submerged weirs are not recommended for outlets.

# Silt Load in the Supply Canal and its Effect on Outlets

Silt and siltation affect the performance of outlets. Silt interferes with water measurement while siltation in general affects the flow rate through the outlet. Flow rates, particularly in non-modular outlets, are affected by downstream siltation.

In hill systems the preferred design is one that allows an equal proportion of the silt to enter each farm. Silt entering through outlets can block the downstream portion of the outlet leading to a reduction in flow rates, particularly in non-modular types of outlets. Farmers will therefore need to constantly desilt canal sections, both downstream and upstream of outlets, to maintain correct design levels and correct flow rates.

# Water Measurement and Outlets

Water measurement provides the basic tool for prudent water use. Although much has been said about the need to conserve water use in irrigation, water measurement devices have yet to be introduced in hill irrigation systems. Flumes and weirs are two appropriate devices that can be incorporated into outlets for water measurement purposes. Because water measurement is not yet widely practised in the hills, it may not be wise at this stage to include these devices in small outlets supplying individual or small groups of farms. It would be worthwhile, however, to include them in larger outlets supplying branch canals and to train the users in water measurement techniques, thereby slowly introducing the concept of water measurement and control to hill farmers.

Flumes and weirs built across canals for water measurement often appear to farmers as restrictions to flow and are quickly destroyed. Such devices can therefore be only slowly introduced at farm level, along with appropriate education of the farmers.

One way to introduce the idea of water measurement to farmers is to calibrate weirs built in existing structures such as drops, head regulators and cross regulators.

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