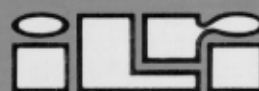


**IRRIGATION
WATER MANAGEMENT
Training manual no. 8**

**STRUCTURES FOR WATER
CONTROL AND DISTRIBUTION**



FOOD AND AGRICULTURE
ORGANIZATION
OF THE UNITED NATIONS



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WATER MANAGEMENT**
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**STRUCTURES FOR WATER
CONTROL AND DISTRIBUTION**

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Preface

This is one in a series of training manuals on subjects related to irrigation, issued in the period from 1985 to 1993.

The papers are intended for use by field assistants in agricultural extension services and irrigation technicians at the village and district levels who want to increase their ability to deal with farm-level irrigation issues.

The papers contain material that is intended to provide support for irrigation training courses and to facilitate their conduct. Thus, taken together, they do not present a complete course in themselves, but instructors may find it helpful to use those papers or sections that are relevant to the specific irrigation conditions under discussion. The material may also be useful to individual students who want to review a particular subject without a teacher.

Following an introductory discussion of various aspects of irrigation in the first paper, subsequent subjects discussed are:

- topographic surveying
- crop water needs
- irrigation scheduling
- irrigation methods
- scheme irrigation water needs and supply
- canals
- structures for water control and distribution.

A further two subjects to be covered are:

- drainage
- scheme irrigation management.

At this stage, all the papers are provisional because experience with the preparation of irrigation material for use at the village level is limited. After a trial period of a few years, once enough time has elapsed to evaluate the information and the methods outlined in the draft papers, a definitive version of the series can be issued.

For further information and any comments you may wish to make, please write to:

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ABOUT THIS PAPER

STRUCTURES is the eighth in a series of training manuals on irrigation. The manual presents some of the common open channel structures that can be found in small irrigation schemes and in small units of larger schemes. It explains the system of water distribution and related structures which are needed to control the flow of water and water delivery from the water intake to the fields.

Furthermore, the manual presents different types of structures for flow measurement and for the protection of the canals. Common technical problems that are often encountered in the operation of structures as well as the necessity of maintenance and repair works are discussed.

The consequence of minor scheme extension for the existing structures is also discussed.

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Final language editing, layout and preparation of camera-ready copy was done by Thorgeir Lawrence in close collaboration with N. Hatcho.

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Chapter 1

Introduction

Operating an irrigation scheme without hydraulic structures is like trying to drive a car downhill without a brake or steering wheel + you cannot control your speed and you cannot control where you are going. With the help of hydraulic structures water reaches the fields at the proper time and in the quantities needed.

Reference is made to Training Manual 7, *Canals*, where the structure of a canal network is compared to that of a tree: fields, the smallest units of a scheme, are like the leaves of the tree; tertiary canals the twigs; secondary canals the branches; and the main canal is equivalent to the stem of the tree. In the canal, the volume and the level of flow are controlled by hydraulic structures + very often referred to simply as *_structures_* + and without them there will be too little water available, or too much water and so wasted.

In an irrigation scheme, many structures with different functions exist. It is not the aim of this Training Manual to give a complete overview of all the many types of structures in use, with a precise description of each. That would take up too much space and confuse the reader with too much detail. If details are needed, then a good source of information is *FAO Irrigation and Drainage Paper*, N° 26. This present Training Manual concentrates on presenting some typical structures that are commonly used for small irrigation schemes, or for small units of large schemes. To give the reader an idea of the different types of structures used in an irrigation scheme and where they would be found, an overview of a typical scheme is presented in 0.

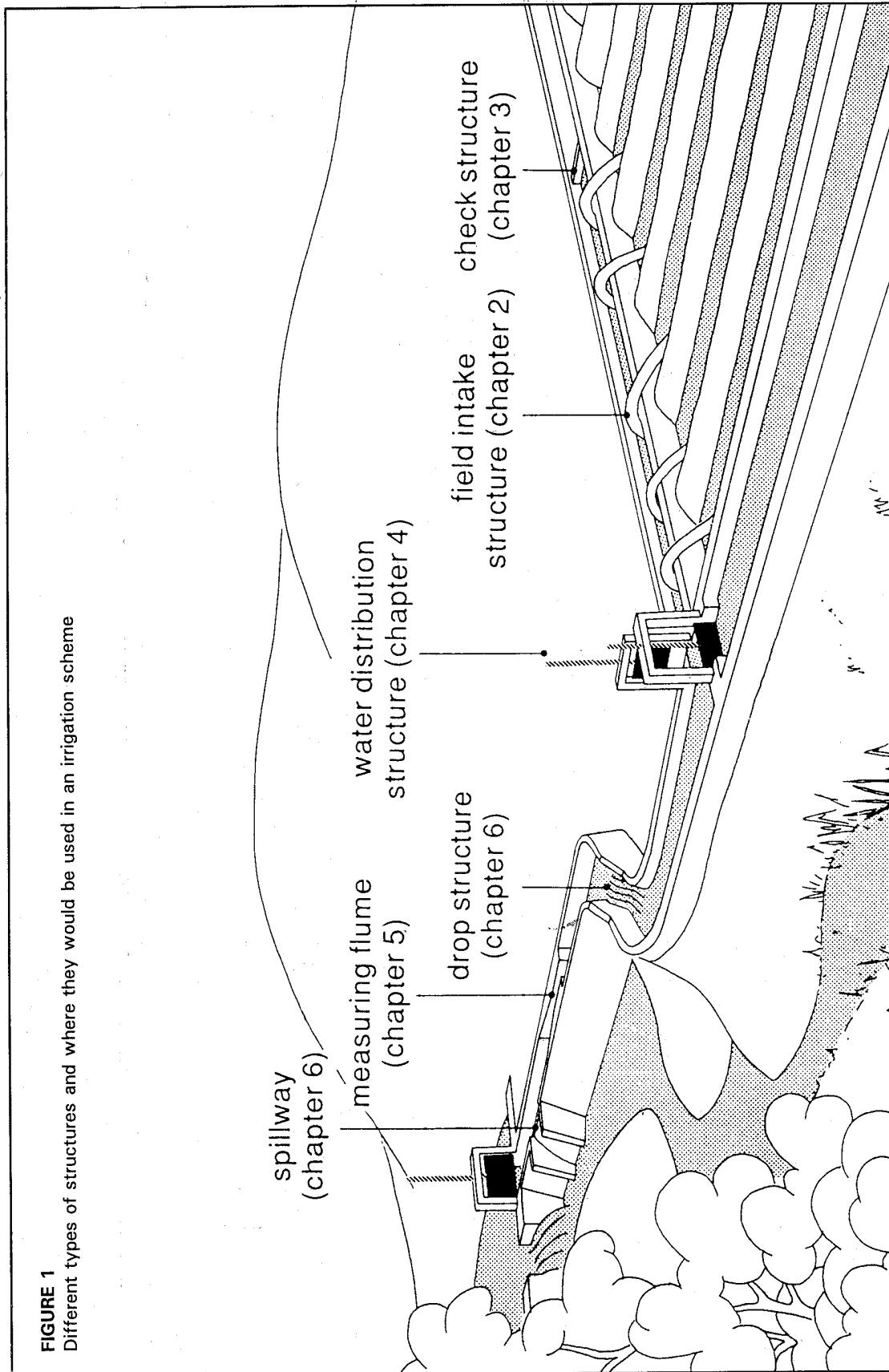
This manual should help extension officers and farmers to understand the functioning and use of the most common structures. It must be emphasized here that for the design of new structures and for the construction of complex ones, experts should be consulted.

Chapter 2 describes the water intake structures which divert water from the canal to the fields. Then in Chapter 3 the problem of controlling the water level in field channels is discussed, followed in the next chapter by a description of water distribution structures in the canal network. Chapter 5 is devoted to discharge measurement structures so that farmers or operators of a canal can know how much water is flowing in the canal, in order to obtain precise water control.

Because the canal structures change the direction or speed of water flowing in the canal, the canal and the structures themselves are often damaged by erosion and scouring. Chapter 6 discusses this problem and presents some protective structures. Chapter 7 describes some of the most common problems in structures, while Chapter 8 deals with maintenance and repair works.

Finally, in Chapter 9, there is an explanation of how to construct small diversion and check structures when a scheme is extended.

Annexes describe a method of flow measurement through a field intake, and presents discharge-head tables for flow measuring devices sited in canals.



Chapter 2

Water intake to a field

In an irrigation scheme, water is taken from a water source, passes through a network of irrigation canals and is delivered to the farmers' fields. The entrance of water from the field channel to the farmer's field is called the field intake or the farm turnout. This chapter describes different types of field intake structures and discusses how they are matched to local conditions.

2.1 METHODS OF WATER INTAKE

The next four figures present four common methods of water intake from a field channel, with illustrations of a breach, a gated intake, syphons and spiles.

A breach is a temporary opening in the embankment of the field channel, made by a farmer whose field is to be irrigated (Figure 2). This method of water intake involves no capital cost, but it has disadvantages:

- frequent opening and closing of breaches weakens the embankment;
- opening and closing a breach changes the cross-sectional shape of the field channel; and
- there is no discharge control.

A gated intake structure is made of wood, masonry or concrete, and is equipped with a gate (Figure 2). Such a structure enables the farmer to control the water inflow, but, in comparison with a breach, it is expensive.

A spile is a short pipe, commonly made of a hard plastic such as PVC, but clay pipes are also used. The pipes are buried in the canal embankment (Figure 3). Good water intake control can be obtained either by adjusting the water level in the field channel, by use

FIGURE 2
A breach



of a water-level regulator, until it is above or below the opening of the spiles, or by closing off individual spiles with a plug or lid, or by a combination of the two methods. Disadvantages are that spiles can become blocked with mud or plant debris, and that the pipes can be expensive.

A syphon is a curved pipe, often made of a plastic such as PVC. The pipe is filled with water and laid over the channel bank at every irrigation (Figure 5). Good water flow control is possible by changing the number of syphons, the diameter of the syphons, or both. Their disadvantage is the price of the pipes. Also, for efficient operation, the water level in the field channel needs to be some 10 cm above the field.

FIGURE 3
Spiles

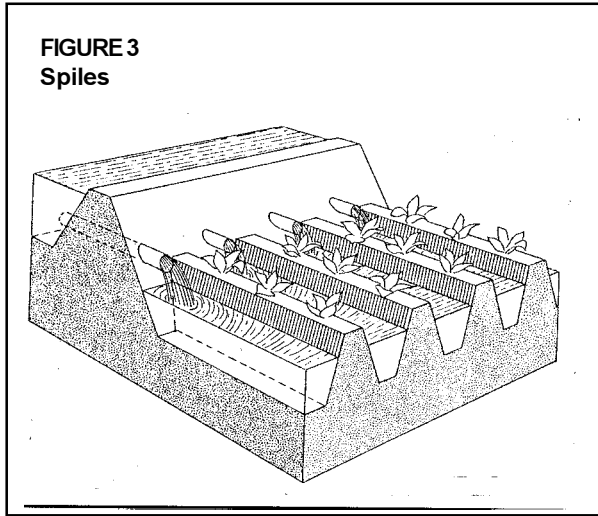


FIGURE 4
A gated intake



FIGURE 5
Syphons



A fifth method of water intake to field is by pumping. Because of the high costs - capital costs for the equipment as well as operating costs - this is only justified if the water level in the field channel is lower than the level of the field to be irrigated. In order to allow efficient operation of the pump, the water depth and discharge in the field channel must be comparatively large + much larger than is required for the other four methods. For an illustration of pumping see Figure 10.

The choice of water intake method depends on local conditions. The factors that have to be considered include:

- the water level in the field channel;
- discharge control;
- the irrigation method(s) to be used;
- the scheduling of irrigation (duration of water delivery; whether continuous or rotational supply); and
- the location of the farmer's field in the canal system (upper or lower end).

2.2 SELECTION OF A METHOD

Which method to use depends on the local circumstances. The advantages and disadvantages of the different methods are considered here in relation to the factors that influence the decision, as listed above.

- **The water level in the field channel**

When the water level in the field channel is only slightly higher than the level of the field, say 5 cm or less, a gated intake of the type illustrated in Figure 4 is a good choice. Breaches are also used in these cases. If the difference in water level is small, either a large opening through which water is delivered or a long time of delivery is needed in order to get the required volume of water into the field.

When the difference in level between the water in the field channel and the field level is small, it is rather difficult to get syphons started, see Figure A-1.1-E in Annex 1.

Where the water level difference is large, say more than 15 cm, the use of a breach is **not** recommended, as the flow through a breach will be strong and will quickly erode the bank of the channel.

- **Discharge control**

Not only the difference between the water level in the field channel and the field level, but also the size of the intake opening determines the flow that enters the field: the larger the opening, the larger the flow.

In the case of breaches, control is almost impossible.

Control is good when gated intake structures are used, and also when syphons or spiles are used. When syphons or spiles are used, their number can be adjusted or different diameters used according to the discharge required.

- **Irrigation method**

The mode of water intake should match the irrigation method - whether basin, border or furrow.

For border or basin irrigation, the water can enter the field at one point. Furrow irrigation requires more delivery points, as each furrow should have its own delivery point. This means that border and basin irrigation can be practised by using breach or gate intakes, while furrow irrigation needs the use of spiles or syphons.

- **Irrigation schedule**

Two factors are important when considering the influence of the irrigation schedule on the choice of intake method: what is the duration and frequency of water supply to the field, and is only one field supplied or are two or more supplied simultaneously?

If the duration of water delivery to a field is short, then the use of a gated intake is the most practical because it can be opened and closed easily as many times as needed.

The opening and closing of a breach in a canal embankment will take some time, and, when a canal bank is opened and closed frequently, the cross-section of the field channel will be eventually become badly degraded.

For effective use of syphons, the duration of water delivery should be long in relation to the time it takes to get them all started.

For furrow irrigation, the use of spiles should be considered when the duration of water delivery is short.

When several farmers are taking water at the same time, each should have an equal share. The use of breaches in such a case is bad, since the discharges are not easy to control. The same applies to gated intake structures because, although gates may be equal in size, the water level in the channel in relation to the respective field levels may not be the same. To ensure equal water intake, syphons or spiles are recommended because the total discharge is determined by the number and diameter of tubes, and so is easier to control than when breaches or gated intakes are used.

- **Field location**

If the field to be irrigated is situated in the upper part of a channel, then the use of a breach should be avoided, because breaches can seriously damage the shape of a channel and thus affect the delivery of water to farmers downstream. When a large opening is needed, a gated intake is much more practical.

2.3 DISCHARGE

The volume of water that enters a field each second + the discharge + depends on the area of the opening through which water enters the field, and the difference in water level between the channel and the field. The larger the area of the opening, the larger will be the flow, and the greater the difference in water levels, the more the flow.

In most cases it is possible to control the flow by manipulating the water level in the field channel. This can be done by using check structures, as will be described in Chapter 3. The higher the water level is in the field channel, the greater will be the discharge. To reduce the discharge into the field, the water level in the field channel should be lowered.

Discharges through breaches or gated intakes may vary from 10 to 30 l/s. Discharge through a single syphon or spile is generally between 0.5 and 2-to-3 l/s. A method to determine the discharge through a field intake is given in Annex 1.

The discharges through water intakes are usually adapted to local circumstances by experience. Elements that play an important role in determining suitable discharges are

- the method of irrigation chosen, influenced by soil type, field slope, the size and area of the field, etc. (see Manual 5: *Irrigation Methods*);
- availability of water;
- the type of crop; and
- its stage of growth.

The table below summarizes the operational activities involved, problems, and quality of discharge regulation of the various options for water intake to the field.

	Breach	Gated intake	Syphon	Spile
Operational activity	Opening and closing	Gate setting	Starting	None or opening
Problems	Bank erosion Channel damage Poor control	Cost	Head loss in the syphon (high water level required in the channel)	Blocked openings
Discharge regulation	Possible, but very rough	By manipulating the gate	By number and diameter	By number and diameter

Chapter 3

Water level in field channels

The rate of the flow through water intakes, whether breaches in the field channel bank, gated intakes, syphons or spiles, is determined by the area of the opening of the inlet and by the difference between the water levels either side of the water intake.

The opening of the intake can be adapted to supply the discharge required: breaches can be made smaller or larger; gates can be opened partly or fully; and the number of syphons or spiles and their diameter can be reduced or increased.

The difference in water level between the channel and the field also affects the flow rate through the field intake, and can also be adapted to meet the need of water intake. Chapter 3 discusses this subject.

3.1 WATER LEVEL AND INTAKE DEVICE

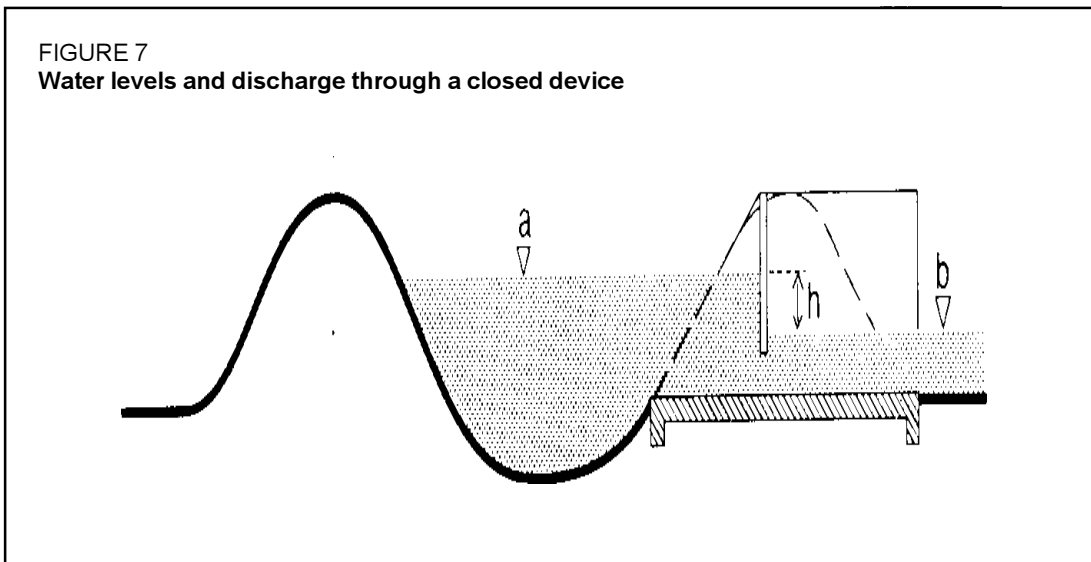
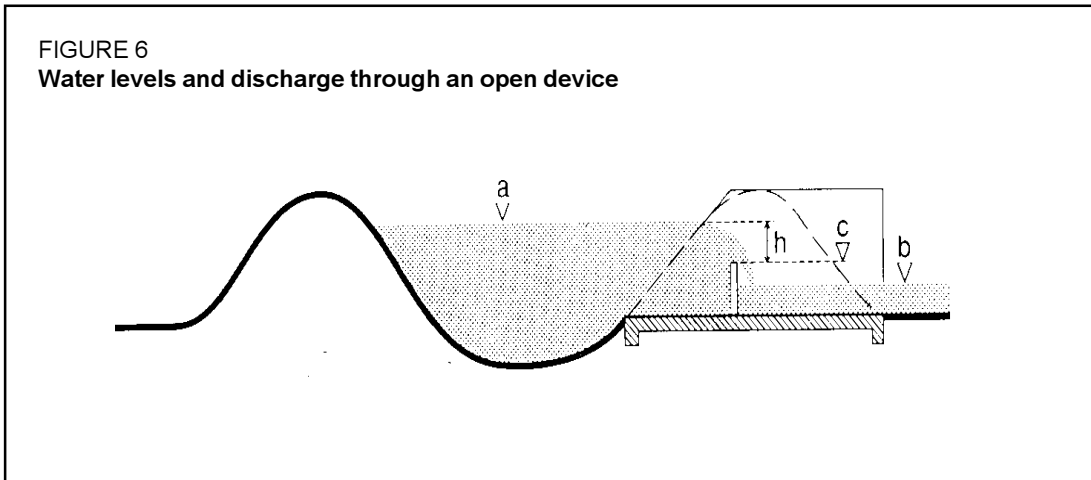
The effect of the water level difference on the discharge through a particular intake varies according to the type of intake used. When an open type of intake is used, then the upstream water level has a far greater influence on the discharge than when a so-called closed type is used.

Typical open-type devices are, for example, breaches, or an intake structure equipped with flash boards, as shown in Figures 2 and 4. In an open-type intake, water that enters the field stays in contact with the air, and one can see water flowing through the opening.

A closed-type device is a syphon, a spile or a structure equipped with a gated opening under the water surface. See Figures 3 and 5 for examples of closed devices. In a closed device water flows through an opening which is situated under the water surface, and which thus cannot be seen, and the water flow is not in direct contact with the open air.

Figures 6 and 7 present cross-sections of intake devices. In both cases the channel is on the left and the field on the right-hand side. Figure 6 is of an open device, a weir in this case, and Figure 7 shows a closed device, an intake structure with the opening below the water surface in the field channel.

The water level downstream of the intake device is determined by the topography of the field and by the irrigation method: border, basin or furrow irrigation, which means that this level is more or less fixed.



The upstream water level is marked 'a' and the downstream level is marked 'b' in both Figure 6 and Figure 7. The level of the crest of the weir in the open device is marked 'c'.

The difference in water levels + known as the hydraulic head + is expressed as 'h', where $h = a - c$ for the open device, and $h = a - b$ for the closed device. If h increases, then the discharge through the device will increase. For open types (Figure 6), one can say that if h increases by 10%, the discharge increases by some 15%. For closed types (Figure 7), if h increases by 10% the discharge will increase by only 5%. Thus the variation in discharge is larger with open devices than with closed devices.

3.2 WATER LEVEL CONTROL

If the discharge through a field intake is too low to satisfy the farmer's needs, he or she can either enlarge the opening of the intake, or raise the water level upstream of the intake, according to local conditions. When a concrete or masonry structure is used for an intake device, the opening cannot be enlarged. In this case another, larger structure should be constructed. When

FIGURE 8
A series of permanent check structures

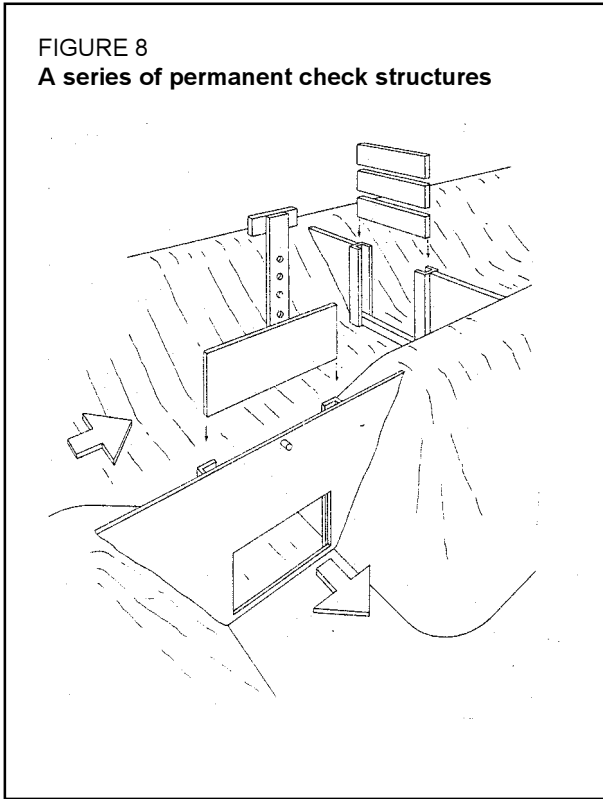


FIGURE 9
A series of permanent check structures



a breach is used, the opening can be enlarged by excavating more out of the canal embankment. To obtain a higher total discharge using spiles or syphons, the number must be increased or larger diameter pipes used.

In most cases, however, the water level in the field channel is raised to increase the flow through an intake. By how much the level can rise depends on the circumstances: if the water level has already reached the freeboard level, a further rise is dangerous and must be avoided. See also Chapter 4 of Manual 7, *Canals*. If the water has not yet reached the maximum level possible in the channel, the level could be raised by using a so-called 'check structure'.

A check structure obstructs the flow in the canal and consequently the water level will rise. These check structures can be permanent or they can be temporary. See Figures 8 to 11 for some examples.

The check structures shown in Figure 8 and Figure 9 are permanent. The check shown in Figure 8 controls the water level for the field intake that is a short distance upstream of the check. The checks in Figure 9 can be closed with flash boards, as shown in the drawing in Figure 8, to allow the use of syphons in the canal sections in between the checks.

Figure 10 and Figure 11 show two transportable check structures. The one in Figure 10 consists of a wooden board that is installed in a trapezoidal, lined canal. The water level here is raised to enable the engine to pump. The transportable check in Figure 11 is made from jute and easily installed. Other materials, such as cloth

or plastic sheeting, can be used as transportable checks. In small canals, the use of sandbags is also a well-known method for raising the water level.

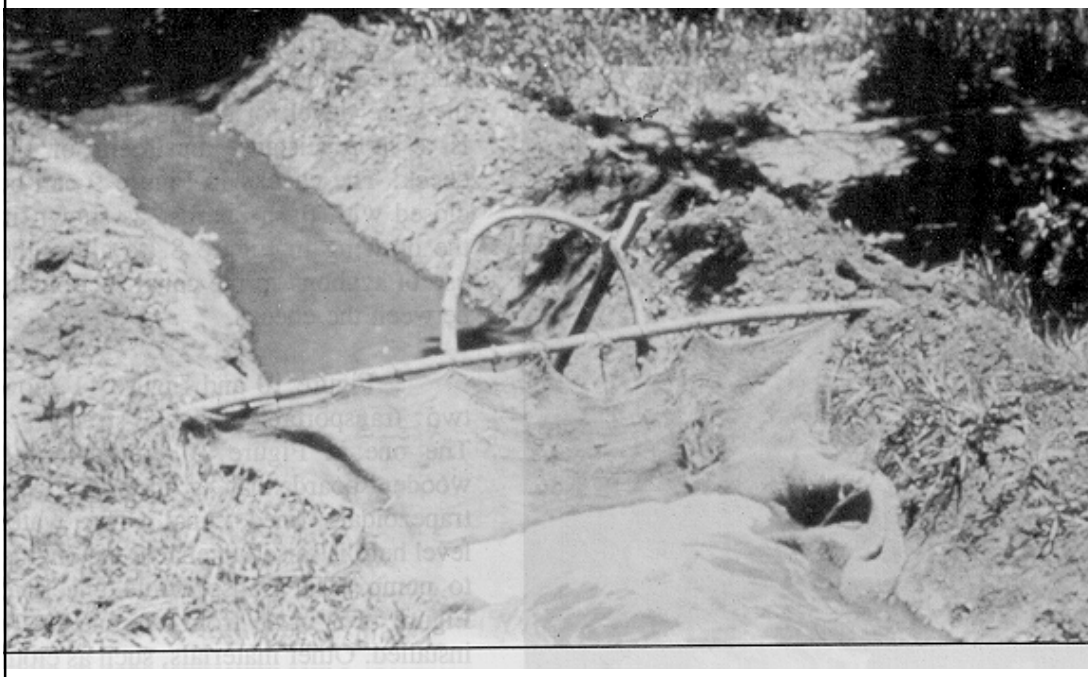
The decision to choose permanent, temporary or transportable check structures depends on local conditions. Typical questions that should be asked include:

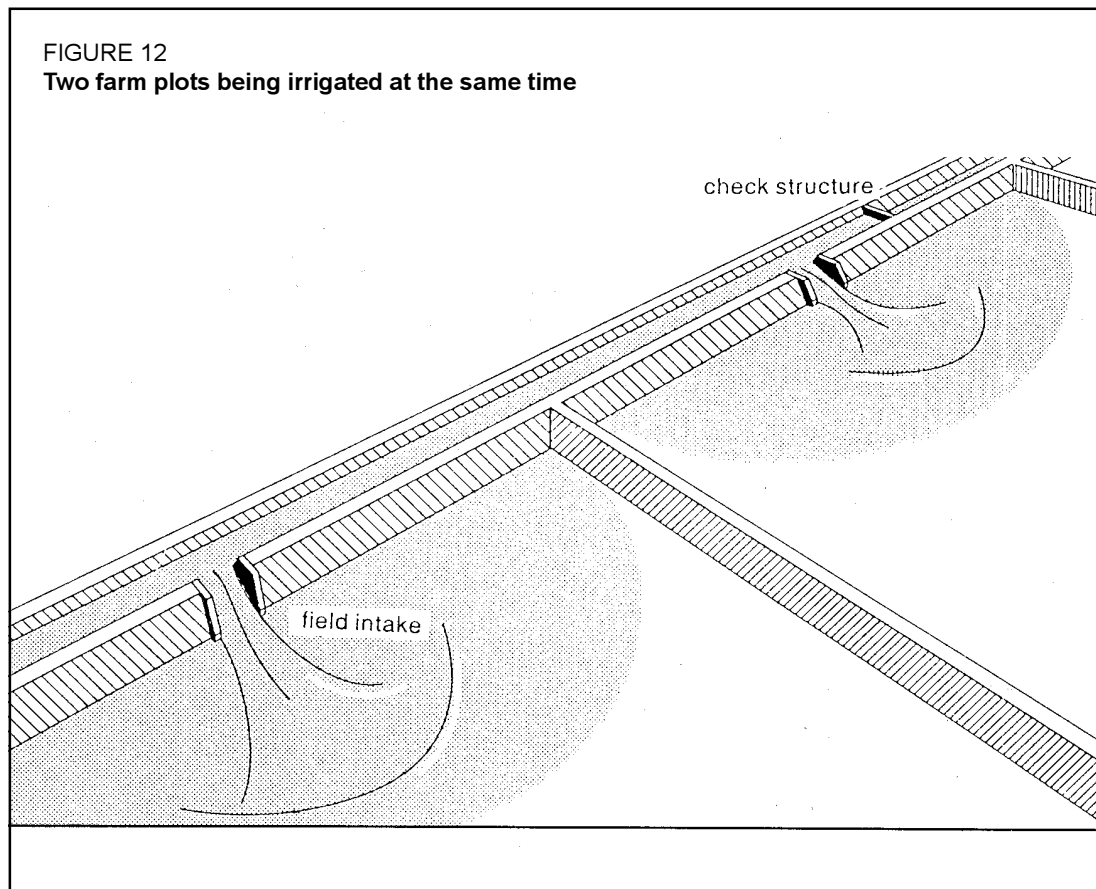
- What will be the function of the check?
- Should the water level rise be a few centimetres or some 10 to 20 cm?
- Is the field channel, in which the check structure is to be installed, a lined or an unlined canal?
- Is the check needed regularly? and
- Is the place of installation fixed?

FIGURE 10
A transportable check structure (wooden board)



FIGURE 11
A temporary check structure (cloth)





3.3 THE USE OF CHECKS

When flashboards in a check structure are down, when gates are closed or when transportable checks are installed, the water level upstream of the structure concerned will rise. This higher water level allows higher flow rates through field intake structures or spiles or it allows the use of syphons. As a result, the discharge in the field channel downstream of the check is seriously reduced or may even become zero.

Water in a field channel is most commonly distributed among the farmers in rotation. Check structures can be very useful, because the farmer whose turn it is can be given the full channel discharge. The discharge downstream of the check in such cases can be zero.

When the discharge in a field channel is large, several farm plots can be irrigated simultaneously (See 12).

For example, a discharge of 60 l/s can be shared by two farmers, each receiving 30 l/s, by using a check structure and maintaining the water level.

However, control of the water level and hence the flow into fields will be more difficult as the number of farmers irrigating at the same time increases.

3.4 SUMMARY

The table below presents a summary comparison between fixed and transportable checks with reference to the operational activities involved, water level rise obtained, and problems associated with particular check structures.

	Transportable checks	Fixed checks
Operational activities	Installed each time	Gate setting
Water level rise	5 to 10 cm	10 to 20 cm
Problems	Leakage	Erosion downstream

Chapter 4

Water distribution within the canal network

Water flowing in a secondary irrigation canal can be divided over the tertiary canal network in several ways. One way is to divide the flow proportionally over these tertiary canals; another is to divide the time of supply and thus to divert the flow to each tertiary canal in turn; and a third way is to supply a tertiary canal with water upon request.

The same three options apply to the flow in the main irrigation canal regarding its distribution over the secondary canals of the system: proportional distribution; rotational distribution; or delivery on demand. The different methods of water distribution require different structures, and these structures are described here. The last sections of this chapter deal with the problem of how to deliver a fixed discharge to a canal, and what types of offtakes are commonly used for water supply to a branch canal.

4.1 PROPORTIONAL DISTRIBUTION

Proportional distribution of irrigation water means that flow in a canal is divided equally between two or more smaller canals. The flows in these canals are proportional to the areas to be irrigated by each of them.

4.1.1 Division of the flow

Each canal is given a portion of the flow. These portions correspond to the portion of the total area which is irrigated by that canal. This is considered in Exercise 1, in which the flow in a main canal is divided among three secondary canals. Figure 13 illustrates the problem.

EXERCISE 1

QUESTION: What discharges should be given to the secondary canals under the following conditions? See Figure 13.

- The discharge in the main canal is 170 l/s.
- It is to be divided among the three secondary canals in proportion to their command areas.
- The command areas of the secondary canals are 60 ha, 45 ha and 30 ha.

ANSWER: The total area commanded by the secondary canals is $60 + 45 + 30 = 135$ ha.

- The first canal will receive $60/135$ of the 170 l/s flow, i.e., $(60/135) \times 170 = 75$ l/s.
- The second will get $(45/135) \times 170 = 57$ l/s.
- The third will get $(30/135) \times 170 = 38$ l/s.

NOTE: The discharges in the three secondary canals are proportional to the three command areas, i.e., $75:57:38 = 60:45:30$. However, these theoretical values for the discharges in the three canals will be difficult to obtain in practice, and the actual discharges would be rounded to 70, 60 and 40 l/s.

FIGURE 13
Flow is divided proportionally

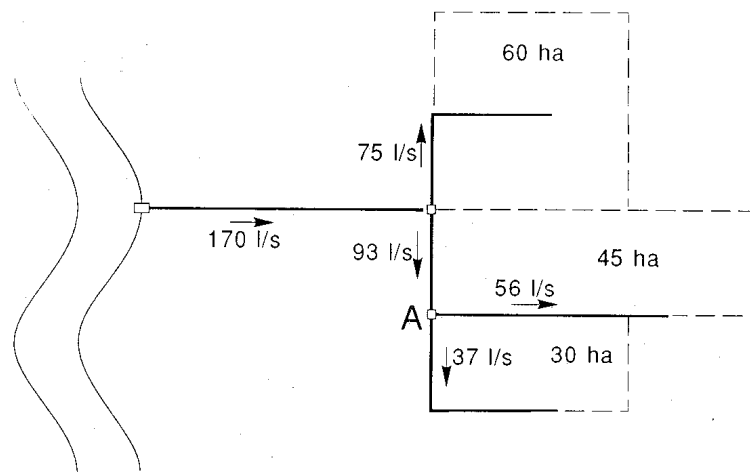


FIGURE 14
Two-way proportional flow division structure

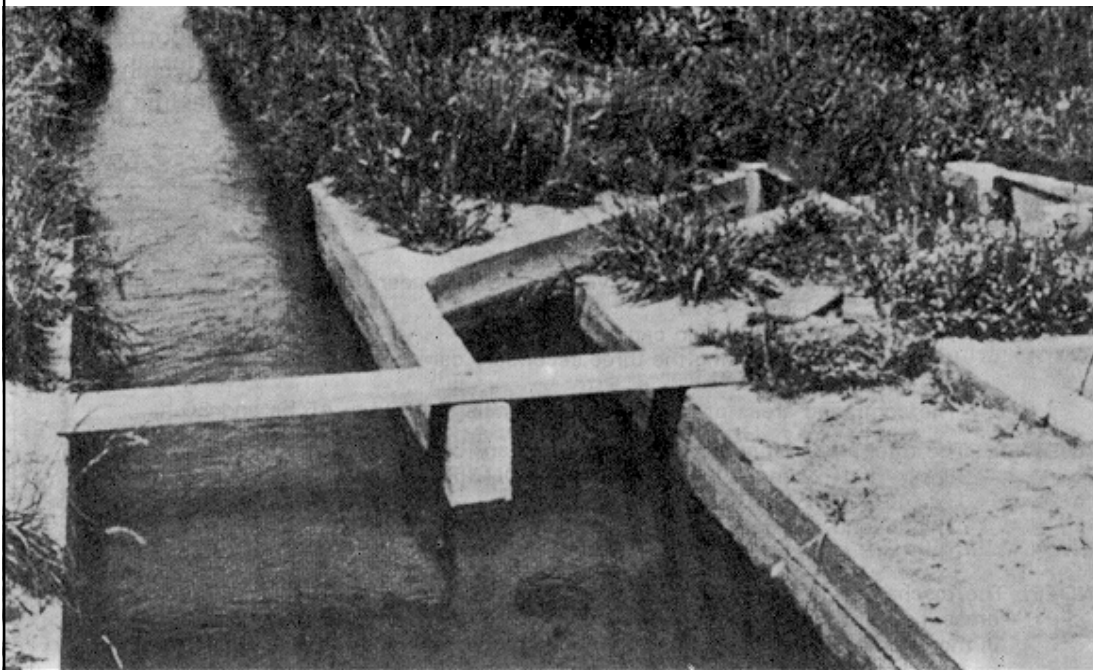
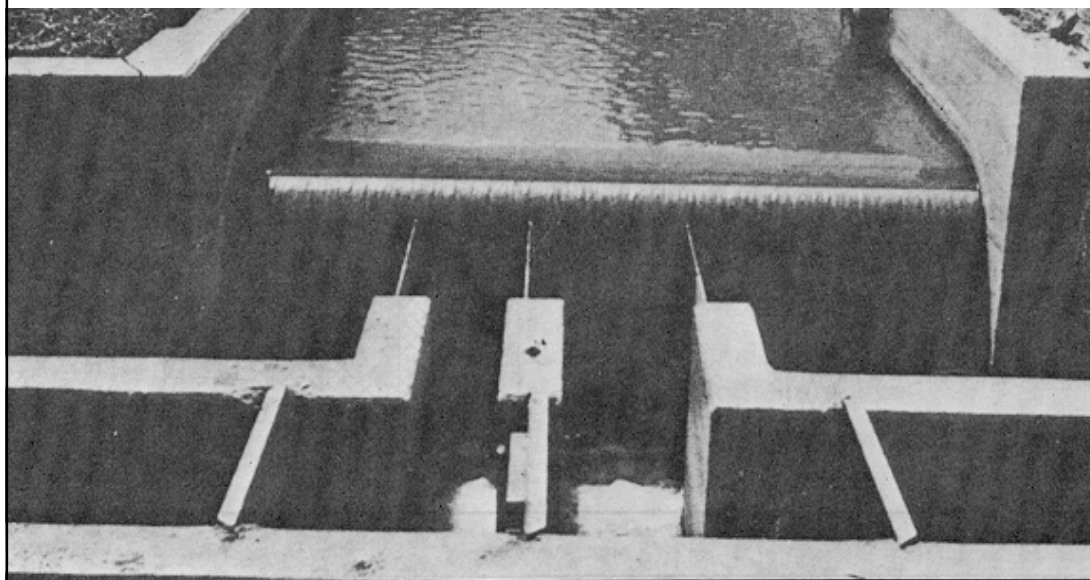


FIGURE 15
Accurate proportional flow division structure



4.1.2 Proportional flow division structures

The type of structure chosen to obtain proportional flow division depends on the accuracy that is required, on the number of offtake canals at the same distribution point, and on the local topography. Three common types are illustrated in Figure 14, Figure 15 and Figure 16.

The division of the flow in the structures in Figure 14 and Figure 15 is fixed and cannot be changed. This means that if the flow in the source canal changes, the flow in the branch canals will also change, but the flows remain proportional to the respective command areas of the branch canals. The flow division in the structure in Figure 16 can be adjusted according to changes in either water supply in the source canal or water demand in the branch canals.

The accuracy of flow division in the structure in Figure 14 is low, and the division can easily be manipulated - by farmers who want a larger share - by blocking off one of the canals with stones or sand.

The accuracy in the structure in Figure 15 is high, but, to obtain such accuracy, a drop in water level is required. The costs of such an accurate structure are higher than for a structure like the one in Figure 14.

Proportional flow division structures frequently used in small scale irrigation schemes are shown in Figure 17. The flows to the branch canals are proportional to the widths of the respective openings.

These boxes are sometimes combined with other structures, such as with a drop structure (Figure 17-B) or a culvert (Figure 17-C). These structures are discussed later, in Chapter 6.

FIGURE 16
Variable proportional flow division structure

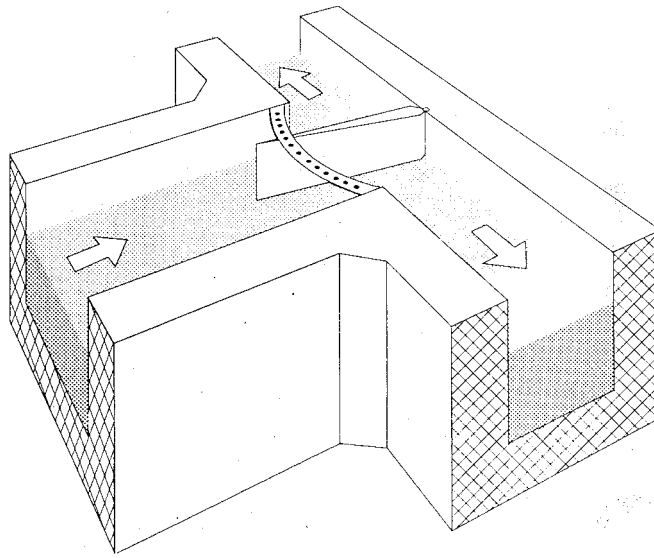


FIGURE 17
Proportional flow division structures

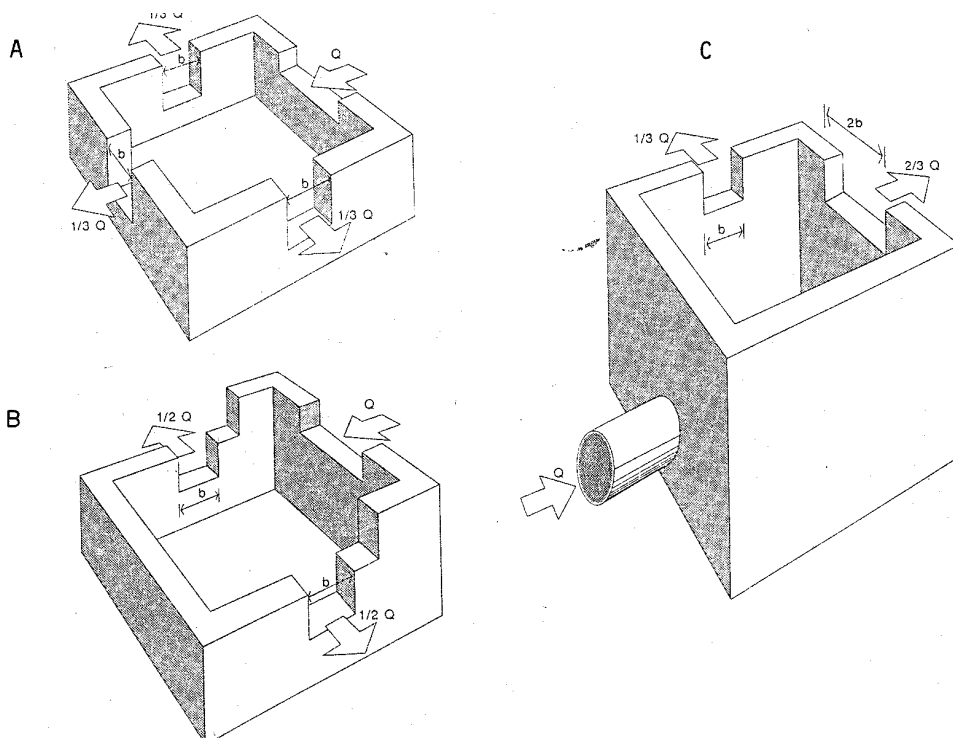
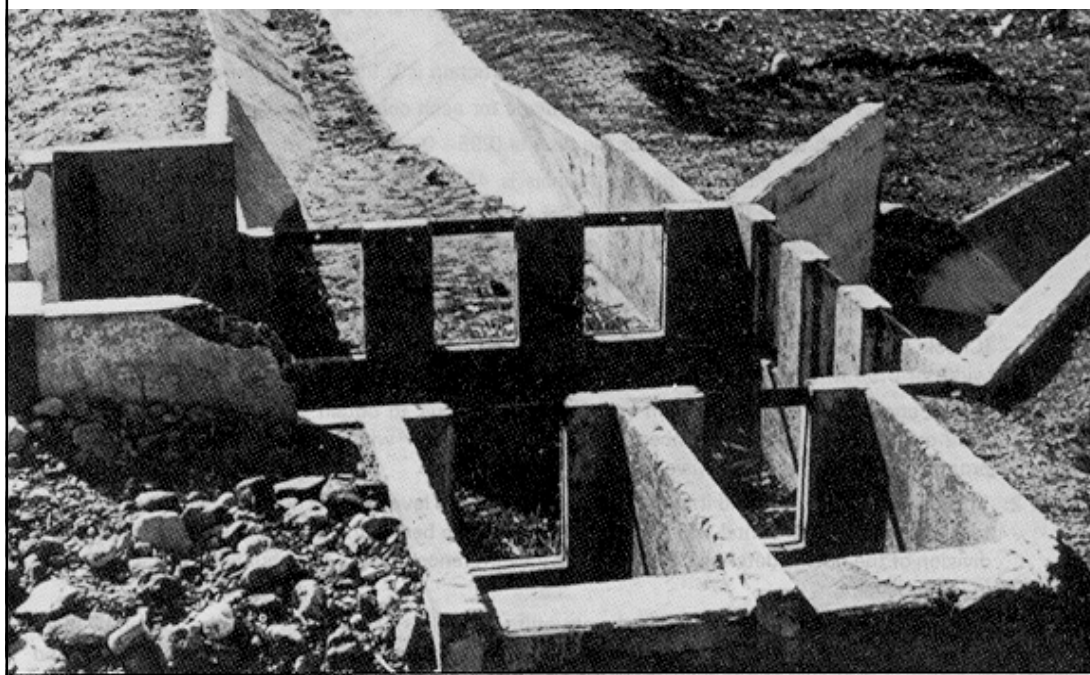


FIGURE 18
Overflow division box



Another common proportional flow division structure is shown in Figure 18. This can supply the two branch canals with portions of the flow. The flow comes from an inverted siphon and enters the box through the two gates in front. The flow is then divided between the main canal and the two branches, in proportion to the number of gates that are opened.

The proportionality of the flow division in the structures shown in Figure 15 to Figure 18 is related not only to the widths of the openings, but even more so to the elevations of the crests of the openings. A change in elevation of one of these crests has a more important effect on the flow division than a change of one of the widths: a 10% change in crest elevation will give a 15% change in discharge over that crest, whereas a 10% change in width of an opening gives a 10% change in discharge through that opening.

4.2 ROTATIONAL DISTRIBUTION

Rotational distribution of irrigation water means that the whole flow in an irrigation canal is diverted to the branch canal in turn. For instance, in the case of primary and secondary canals, it means that each secondary canal is without water for part of the time and, when supplied, it transports the whole “primary” flow. The same can apply to the distribution of the flow of secondary canals into tertiary canals, and rotational distribution can be carried out within the tertiary canals.

EXERCISE 2

PROBLEM: A proportional division structure has to be designed for site A in the scheme shown in Figure 13. This structure should divide the available flow between the two canals in proportion to their respective command areas.

One canal commands an area of 45 ha, the other an area of 30 ha.

A two-way flow division structure like the one in Figure 14 is to be used, and the separation wall will have to have a width of 0.15 m.

The total available canal width at the site of construction is 0.95 m. See Figure 19.

QUESTION: How large should the canal openings be made for each command area?

ANSWER: The total width that is available for the flow is $0.95 - 0.15 = 0.80$ m.

The total area commanded by the two canals is $45 + 30 = 75$ ha. The larger canal should therefore receive $45/75$ of the total; the other canal should get the other $30/75$.

The openings of each canal should be proportional to their command areas.

Therefore the larger canal opening should be $(45/75) \times 0.80 = 0.48$ m wide, while the other opening should have a width of $(30/75) \times 0.80 = 0.32$ m.

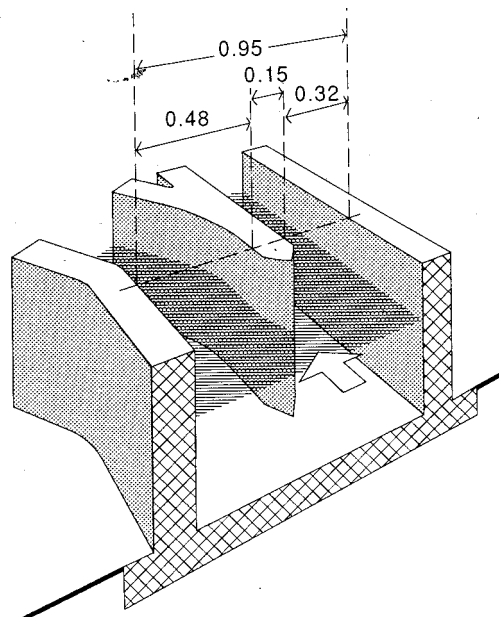
[Check: Do larger and smaller canal widths, plus separation wall thickness add up the available canal width of 0.95 m ? $0.48 + 0.32 + 0.15 = 0.95$ m , correct!]

NOTE 1: When constructing the separation wall it will be difficult to obtain widths of exactly 0.48 and 0.32 m, but one should remember that smaller or greater widths have a direct impact on the proportionality of the flow division.

NOTE 2: This calculation is only valid if the structure has a flat and level floor. Therefore care must be taken to make the floor horizontal when constructing it. If the bed of the structure is not horizontal, the division of the flow is determined not only by the difference in bed width, but also by the difference in water level.

NOTE 3: Care must also be taken to maintain the structure properly. If one of the flows is blocked by plant growth, silt or rubbish, the division will no longer be proportional to the width of the openings and hence to the areas served.

FIGURE 19
Diagram for calculation of
proportional flow division



4.2.1 Division of the time

The portion of the time during which a branch canal carries water is proportional to the area served by that canal. This is illustrated in Exercise 3, which should be considered together with Exercise 1.

EXERCISE 3

QUESTION: How many days during each period of 7 days will each secondary canal receive water under the following conditions? (See Figure 20)

- The continuous flow in the main canal is to be diverted in turn to three secondary canals.
- The command areas of the secondary canals are 60 ha, 45 ha and 30 ha.

ANSWER: The flow in the main canal is given to the whole scheme, which has a total area of $60 + 45 + 30 = 135$ ha.

Each secondary block will receive the entire flow for a period within the 7 days that is proportional to its command area.

The first secondary canal serves an area of 60 ha. It will carry the full flow for $(60/135) \times 7 = 3$ days in every period of 7 days.

Similarly, the other canals will carry water for $45/135 \times 7 = 2\frac{1}{2}$ days, and $(30/135) \times 7 = 1\frac{1}{2}$ days respectively in each period of 7 days.

NOTE: In this example the portions of a period that a branch canal carries the whole flow have been calculated. The first secondary canal carries the full flow for 3 days in every 7 days, but this does not mean that the irrigation interval in the fields is 7 days. This interval depends on soil type, crop, stage of growth and rate of evapotranspiration.

If the irrigation interval is 7 days, then the canal can be given the whole flow for 3 consecutive days. If the interval is 14 days, then the first secondary canal may carry water for 6 consecutive days, and then be dry for the other 8 days of the 2-week period.

FIGURE 20

Supply time divided proportionally

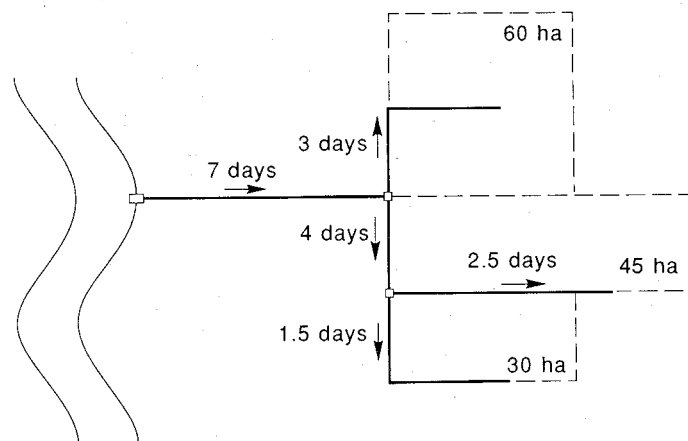


FIGURE 21
Gated canal offtake

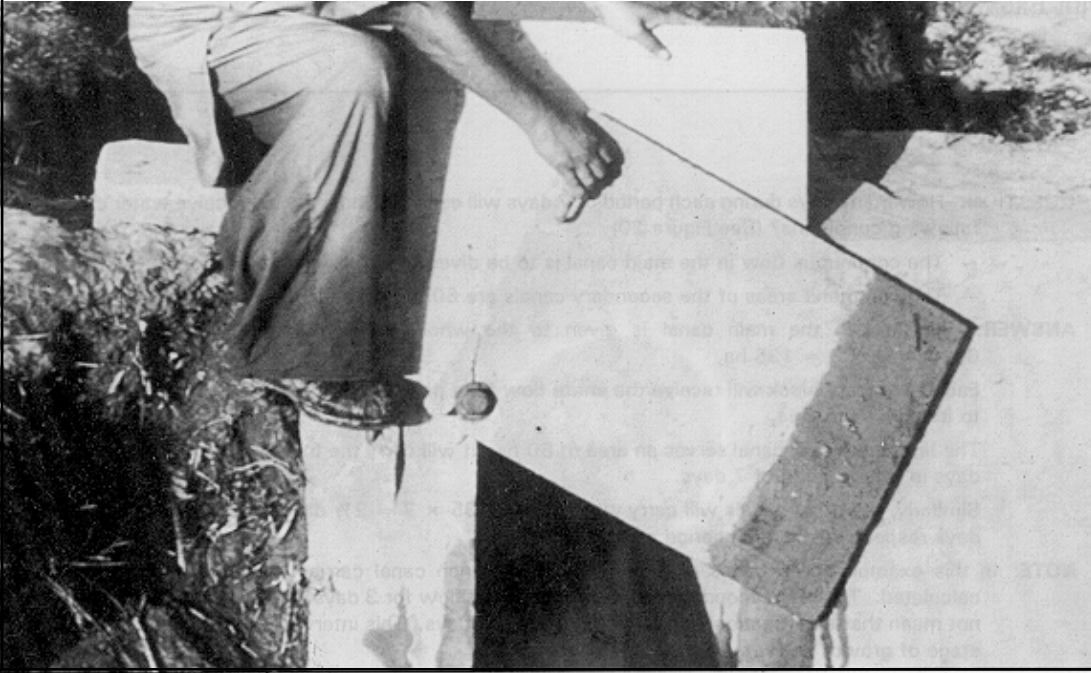
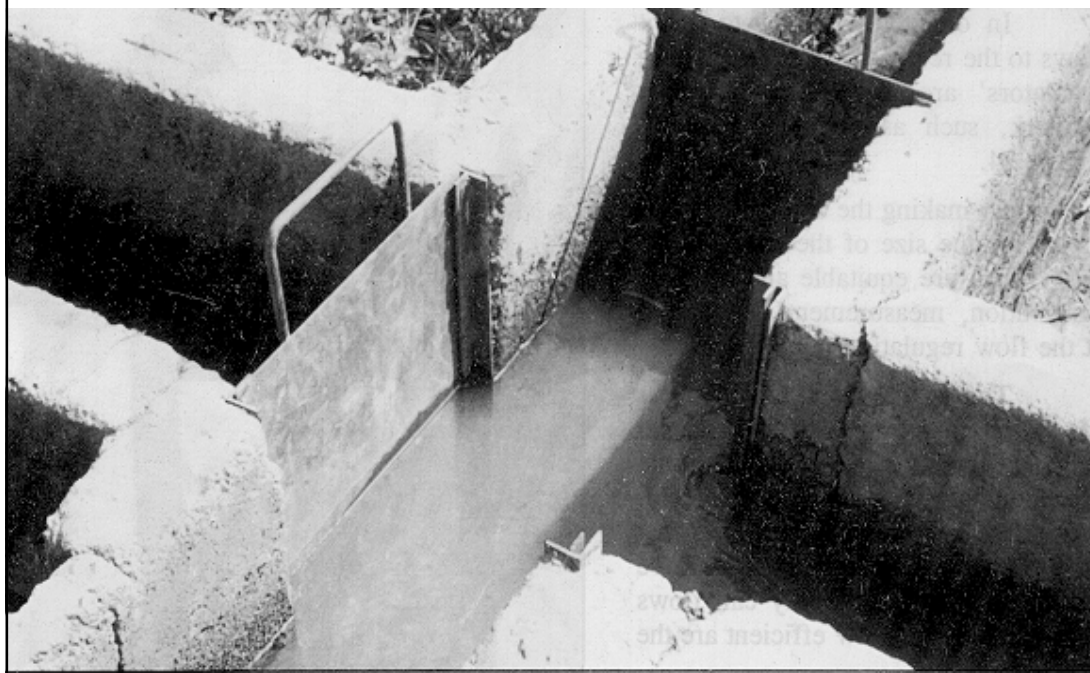


FIGURE 22
Canal with simple division boxes



FIGURE 23
Close up view of a division box



4.2.2 Flow diversion structures

Canals that are supplied with water according to a rotation schedule or on an ‘on demand’ basis must be equipped with gates at the offtake. (Delivery ‘on demand’ is discussed later, in Section 4.3). Sand bags can also be used instead of gates in small tertiary canals.

Figure 21 shows a canal offtake which can be closed by a gate, and Figure 22 shows a canal equipped with division boxes. A close-up of such a division box is presented in Figure 23, and, as can be seen, the whole flow can either be directed to a branch canal at the division box, or the flow continues down the main canal for diversion at a subsequent point. Therefore, under rotational distribution, a canal which receives water should have the same capacity as the supply canal, as flow is not divided. In Exercise 3, each secondary canal should have a capacity of 170 l/s, which is equal to that of the main canal.

4.3 DELIVERY ON DEMAND

Instead of water delivery based on areas, as in proportional or rotational supply, delivery can be based on requests from farmers or a group of farmers. In such a delivery system, water is directed only to those canals where farmers have announced that they need water.

Because the demand varies, the duration or the size of flow, or both, need to be controlled to accommodate this variation.

In simple and small schemes it may only be possible to control the duration of irrigation, with no flow control. Note that the possibility of water losses increases when demand is relatively small compared to the canal capacity. In more sophisticated schemes it may also be possible to adjust the quantity of water flowing so that the flow can also be subject to request.

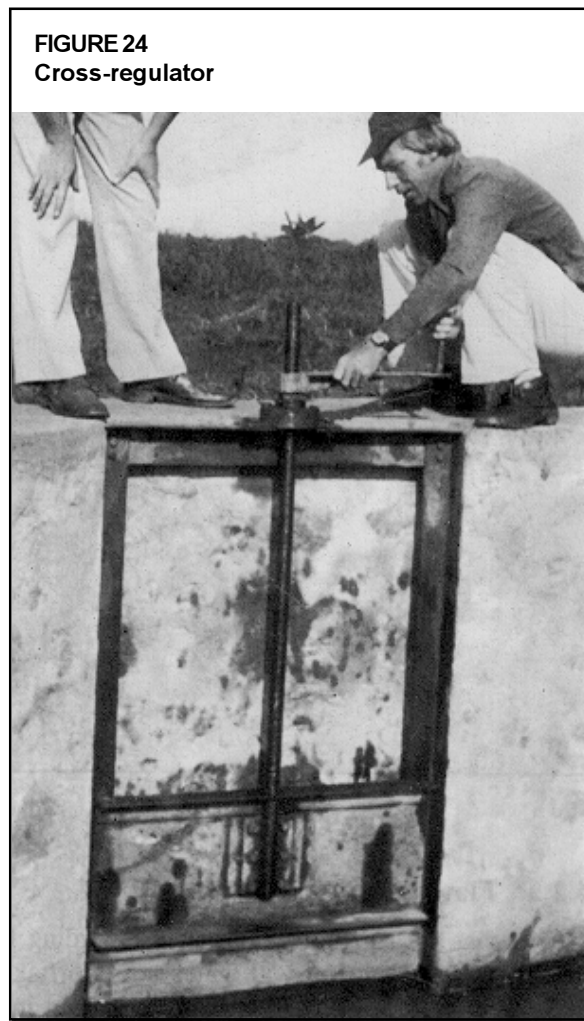
In order to be able to adapt flows to the requests, so-called ‘cross-regulators’ are needed in the canal network, such as that illustrated in Figure 24.

By making the opening smaller or larger, the size of the flow can be set. To ensure equitable and efficient distribution, measurement is required at the flow regulating point.

The accuracy and effectiveness of water delivery with respect to demand depend on the flexibility of the system: how much water is available, taking into account other requests that have been made; what capacities have the canals; how accurately can flows be regulated; and how efficient are the operators?

For such a system to work efficiently two things are needed:

- good structures in which gate settings can be easily and accurately adjusted; and
- a team of well-trained operators.



4.4 DELIVERY OF A FIXED DISCHARGE TO A TERTIARY CANAL

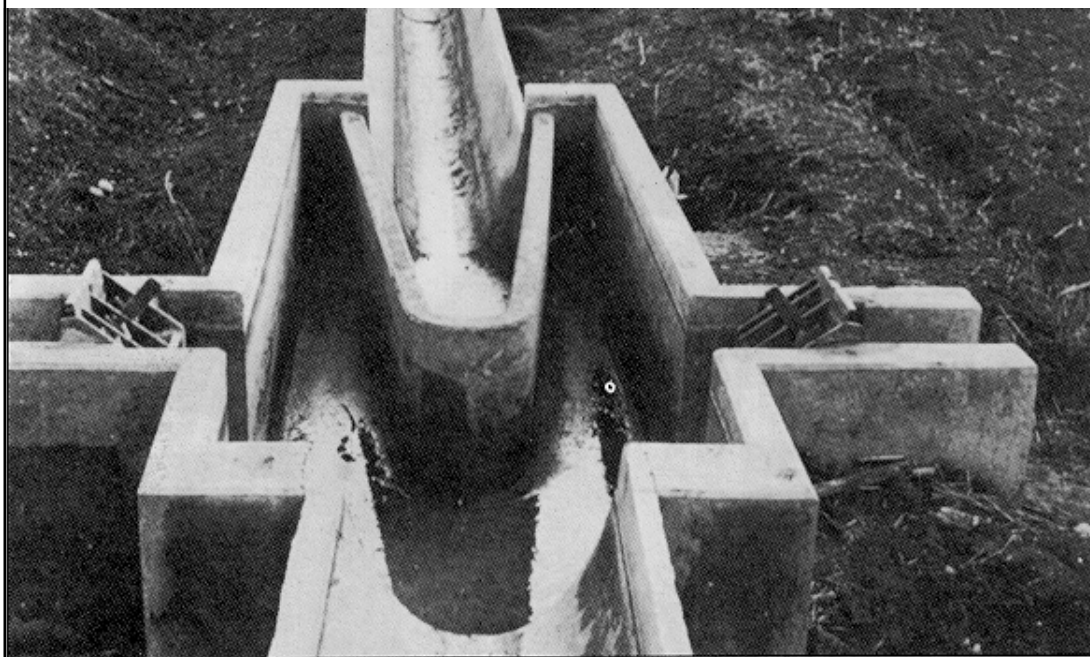
Main canals and secondary canals in an irrigation scheme may carry variable flows. This can be caused by fluctuations in water supply from the water source, or by the flows being adjusted to meet varying needs within the scheme.

Obviously the discharges in tertiary canals will also vary as a result of these fluctuations if no precautions are taken.

If the water level in a tertiary canal rises to above its design level there is a risk of overtopping, and if the level drops the discharges to the fields could be too small for proper irrigation. Therefore the water levels in tertiary canals should be kept constant as far as is possible.

One factor that is very important in maintaining a constant water level in any canal is the discharge that enters that canal. The smaller the fluctuation in the incoming flow, the less will be the fluctuation in water level in the canal. There are other factors that also play a role, such as canal maintenance, gate settings in field turnouts, installation of checks, etc., and these will be discussed later in this manual.

FIGURE 25
A duckbill weir



The type of tertiary offtake + whether it is an overflow gate (open device) or an underflow gate (closed device) + and the water level in the secondary canal determine to a great extent the discharge delivered to the tertiary canal. The water level in the secondary canal is more important when offtake is by an overflow structure than when an underflow structure is used, as discussed earlier, in Section 3.1 of this manual.

Therefore, in order to obtain a constant discharge in a tertiary canal, attention should be paid to controlling the water level in the secondary canal.

Water in a secondary canal can easily be maintained at a more-or-less constant level by installing a long-crested weir, such as the duckbill weir illustrated in Figure 25. Such a weir blocks the flow. Being blocked, water rises and spills over the weir.

A small flow gives a small water layer over a weir; a larger flow causes a thicker water layer. The advantage of a long-crested weir is that this water layer is very thin, a few centimetres only. The longer the crest of the weir, the thinner the water layer and thus the smaller the variation in water level upstream of the weir.

A duckbill weir has two important functions:

- under normal flow conditions it blocks a canal and maintains the water level upstream; and,
- in the event of large flows it helps to maintain the level within a certain range immediately upstream of the weir.

Thanks to the length of the crest of the weir, the level of the water that spills over will be only a little higher than the level of the crest.

FIGURE 26
Long-crested weir in a small canal



For smaller canals, other forms of weirs may be used, such as the type illustrated in Figure 26, where the weir is placed parallel to the long axis of the canal and can thus have a long crest.

The water level upstream of the long-crested weir is almost constant, and, as was explained above, a constant water level at the offtake is maintained in order to obtain a constant discharge into a tertiary canal. As can be seen in Figures 25 and 26, the canal offtakes are situated immediately upstream of the long-crested weirs. In this situation one can say that the diverted discharges are constant.

4.5 SMALL CANAL OFFTAKES

Canal offtakes are usually sited just upstream of a structure for water-level control, and the Figures 27 to 30 show four different types that are commonly used as offtakes for smaller, tertiary canals.

Figure 27 shows a concrete or masonry structure equipped with wooden flash boards. This type is easy to construct but is difficult to make leakproof.

The structures in Figure 28 and Figure 29 can be quite leakproof, but they are more expensive than the one in Figure 27, and they are difficult to make.

Figure 30 shows a concrete structure equipped with a concrete panel. Such a structure can be leakproof, but it is heavy to operate.

FIGURE 27
Offtake with wooden flash boards

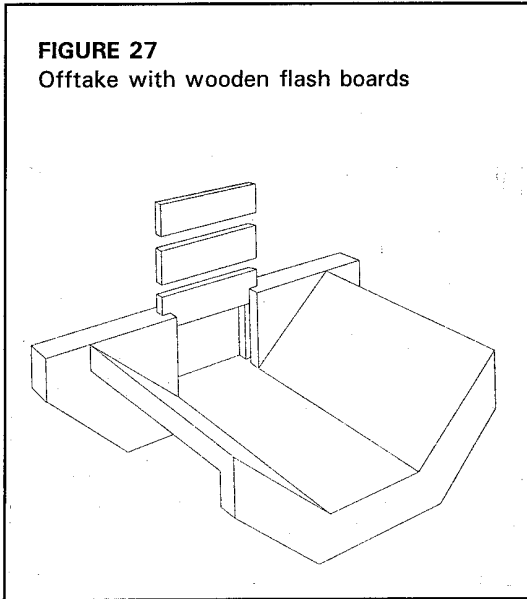


FIGURE 28
Offtake with sliding lid

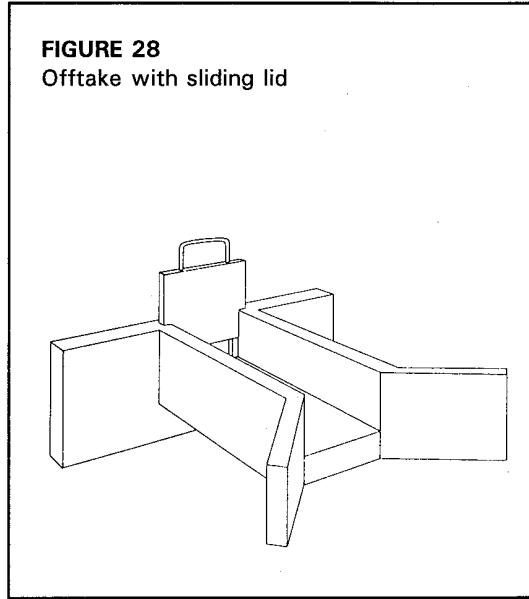


FIGURE 29
Offtake with slide gate

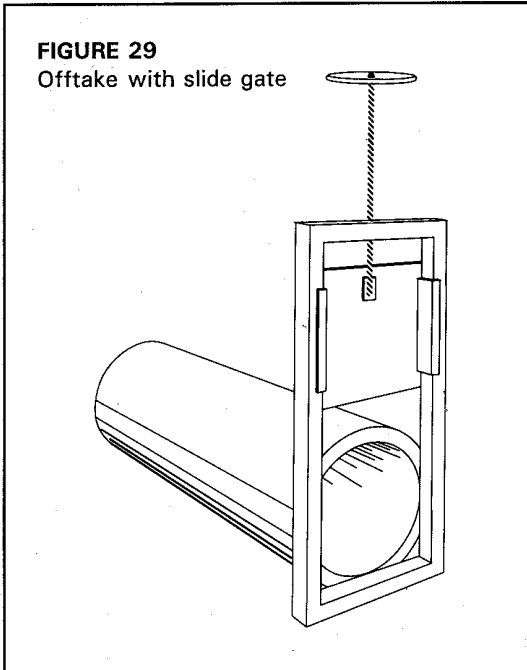
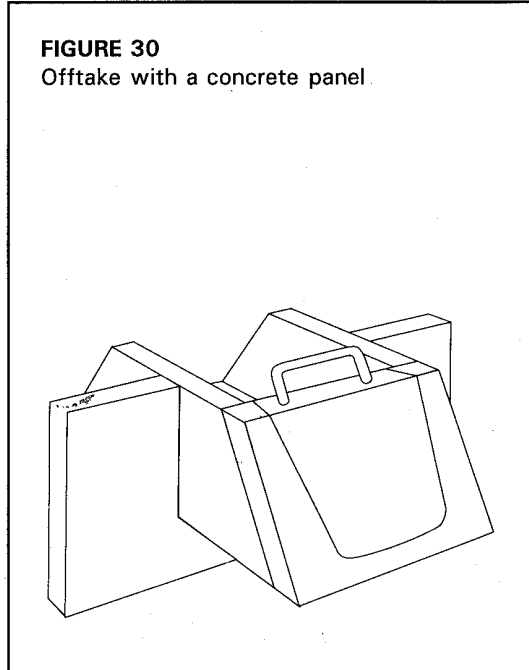


FIGURE 30
Offtake with a concrete panel



Chapter 5

Flow measurement

When the water available from a particular source is limited and must be used very carefully, it is useful, and even necessary, to measure the discharge at various points in the system and the flow at farmers' intakes. Also, where farmers have to pay for the water used, discharges should be measured. Flow measurements may also be useful for settling any disputes about the distribution of the water. In addition, measurement of the flows can provide important information about the functioning of the irrigation system.

Canal discharges can be measured without structures, as was shown in Manual 7, *Canals*, in this series. Discharges can also be measured with the use of discharge measurement structures, and such devices are discussed in this chapter, starting with weirs and followed by flumes.

5.1 WEIRS

Weirs are sharp-crested, overflow structures that are built across open canals. They are easy to construct and can measure the discharge accurately when correctly installed. However, it is important that the water level downstream is always below the weir crest, otherwise the discharge reading will be incorrect.

The water level upstream of the structure is measured using a measuring gauge, as shown in Figure 31, where the difference - the head - between the water level and the crest of the weir is marked 'H'. The discharge corresponding to that water level is then read from a table which is specific for the size and type of weir being used, or the gauge post can show the discharge directly, as will be discussed in Section 5.1.2.

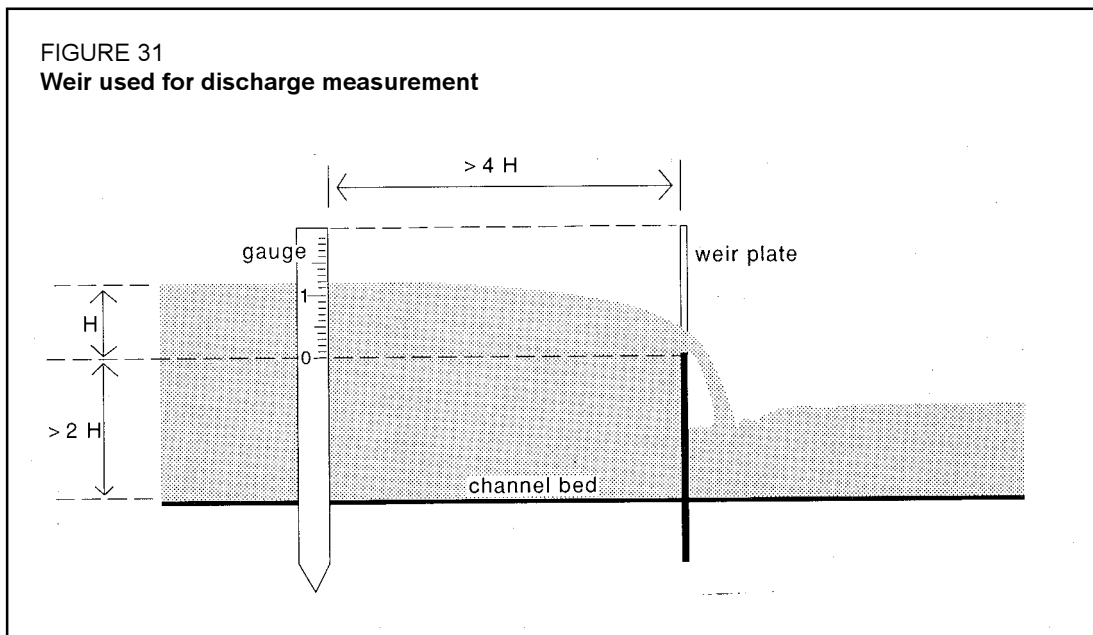
5.1.1 Types of weirs

Examples of three well-known weir types are illustrated: the Rectangular weir (Figure 32), the Cipoletti trapezoidal weir (Figure 33) and the 90° V-notch weir (Figure 34).

As can be seen in the figure, the Rectangular weir has a rectangular opening.

The Cipoletti trapezoidal weir is in fact an improved rectangular weir, with a slightly higher capacity for the same crest length. Its opening is trapezoidal with the sides inclining at a slope of 4 (vertical) to 1 (horizontal).

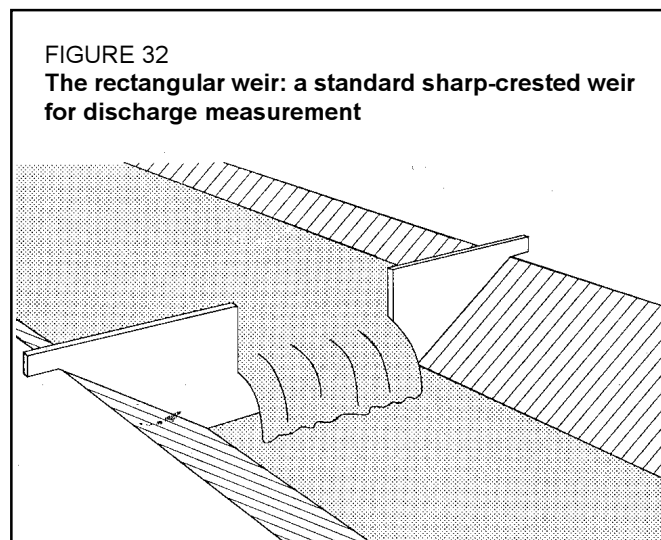
The 90° V-notch weir has a triangular opening, and this type is well suited to measuring small flows with high accuracy.



5.1.2 Measurement procedures using weirs

To obtain a true measurement of the flow over weirs, certain dimensions must be respected because they are critical to correct operation. These are indicated in Figure 31, and are

- the level of the weir crest relative to the channel bottom
- the horizontal distance between the measuring gauge and the weir, and
- the level of the gauge relative to the level of the crest of the weir.



Establishing the correct dimensions for the structure

The procedure for getting the correct set up for the structure is given in the form of a practical example. The measurement structure in this example, illustrated in Figure 31, is assumed to be the overflow type, namely a rectangular weir with a crest length of 1 m.

Step 1

Estimate the maximum discharge that is likely in the canal to be measured. This defines the corresponding maximum head of water over the weir crest for the structure concerned.

The maximum discharge to be measured is estimated at 200 l/s.

FIGURE 33

The Cipoletti trapezoidal weir: a standard sharp-crested weir for discharge measurement



Using Table A-2.1 in Annex 2, one can see that for discharge of 200 l/s, the head, H , is a little less than 0.25 m. (Refer to the column for $L = 1.0$ m: when discharge Q is 219 l/s, $H = 0.25$ m.)

Step 2

Check the level of the weir crest.

The level of the crest above the canal bed should be at least 2 times the maximum head, $2H$ in 31. In this case the weir should have a crest level which is at least $2 \times 0.25 = 0.50$ m higher than the canal bed.

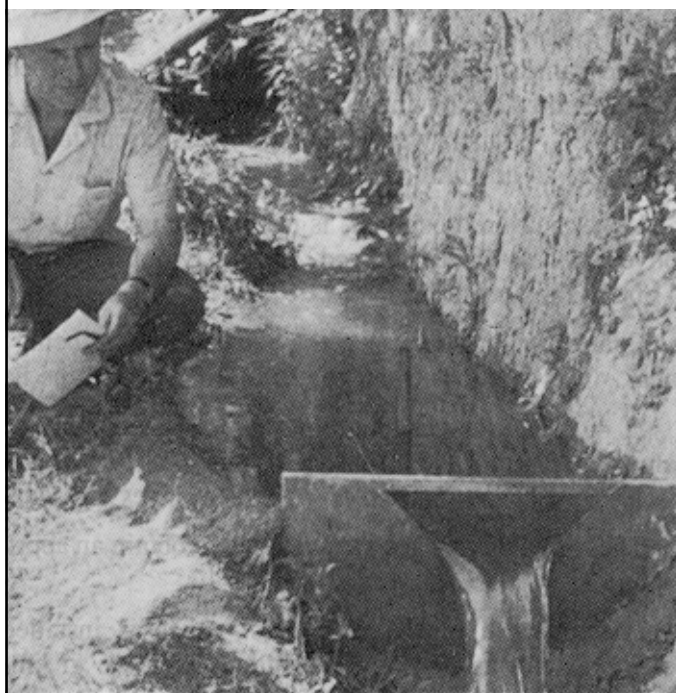
Step 3

Check the distance between the gauge and the weir.

The distance between the gauge and the weir should be at least 4

FIGURE 34

The 900 V-notch weir: a standard sharp-crested weir for discharge measurement



times the maximum head, $4H$ in Figure 31. In this case the gauge should be located at least $4 \times 0.25 = 1.00$ m upstream of the weir.

Step 4

Check the elevation of the 0 (zero mark) on the gauge.

The 0 on the gauge, which indicates a discharge of 0 l/s - i.e., no flow - should have the same elevation as the weir crest. This can be checked using a carpenter's level or by the water level when there is no flow over the weir.

Discharge measurement

The measurement procedure described here is standard for the three types of overflow weir shown in Figure 32, Figure 33 & Figure 34, except that there is a different table for each type. These are given in Annex 2, where Table A-2.1 is used for a rectangular weir; Table A-2.2 for a Cipoletti trapezoidal weir; and Table A-2.3 for a 90° V-notch weir.

Assume the structure in Figure 31 is a rectangular weir with a crest length of 1.25 m.

Step 1

Read the water level on the gauge. In 31 the reading is 0.12 m, so $H = 0.12$ m.

Step 2

Go to Table A-2.1 in Annex 2, find the row corresponding to 0.12 m, and move across that row till it meets the column for the weir crest being used, 1.25 m. The value at the point where the column and row cross is 94, and that is the discharge in litres per second: $Q = 94$ l/s.

The same procedures + for establishing the proper dimensions for the set up of the structure and for carrying out discharge measurements + apply to Cipoletti trapezoidal weirs and to 90° V-notch weirs, except that different tables are used to obtain the value of the discharge, as noted above.

If the measured head, H , is not found in a table, the rows with the H values immediately above and below are followed, and the two discharge values found in the table are averaged to obtain the actual discharge.

For example, suppose a trapezoidal weir is being used to measure the discharge in a canal. The crest has a length, L , of 1.00 m and the head reading, H , is 0.17 m.

$H = 0.17$ m is not found in Table A-2.2 in Annex 2, so the nearest H values above and below are used. These are 0.16 and 0.18 m. $H = 0.16$ m gives, when $L = 1.00$ m, a discharge, Q , 119 l/s, and $H = 0.18$ m gives a discharge of 142 l/s.

These two discharges are averaged to obtain an approximate value for the canal discharge, namely $Q = (119 + 142) / 2 = 131$ l/s.

If the length of the weir crest which is installed in an irrigation scheme does not correspond to the one of the lengths which are given in the tables, an engineer should be consulted to make a specific table for the weir concerned.

5.2 FLUMES

Other well-known structures for discharge measurement are flumes. Flumes consist of a narrowed canal section with a particular, well-defined shape.

The advantage of flumes over weirs is the small drop in water level (head loss), and so flumes can be used in relatively shallow canals with flat grades. The drop in water level is only one quarter of the drop needed to be able to use a weir, for the same discharge under similar conditions. Because of this, smaller flumes can easily be used as transportable measuring devices.

A disadvantage of flumes is that they are relatively expensive and they cannot easily be combined with other structures, whereas that is possible with weirs.

Like measurements with weirs, the water level upstream of the flume is a measure of the discharge through the flume, and when the head has been measured the discharge can be obtained by reading the value on a diagram which is specific for the flume being used. This will be discussed in Section 5.2.2.

5.2.1 Types of flumes

Three of the most common types of measuring flumes are illustrated. They are the Parshall flume (Figure 35), the Cut-throat flume (Figure 36), and the RBC flume (Figure 37).

The abbreviations used in the plan and longitudinal section views of the three common flume types are as follows: *c.b.* - canal bed; H_a - upstream water level, relative to the bottom of the structure; H_b - downstream water level, relative to the bottom of the structure; L - length of flume; *c.s.* - converging section; *t.(s.)* - throat (section); *d.s.* - diverging section; W - throat width; and B_c - throat bottom width.

A Parshall flume consists of three principal sections: a converging section at the upstream end, a constricted section or throat in the middle and a diverging section downstream. The floor of the throat slopes downwards and the diverging section has slopes upwards. It is shown in Figure 35, together with plan and longitudinal section views.

Parshall flumes have standard dimensions which must be followed closely in order to obtain accurate measurements.

A Cut-throat flume (Figure 36) has two principal sections: a converging section at the upstream end and a diverging section at the downstream end, and has a flat bottom. The advantage of a Cut-throat flume over a Parshall flume is that its construction is made easier by the horizontal floor, the use of flat metal sheets and the absence of a throat section.

As for Parshall flumes, the standard dimensions must be followed carefully to obtain accurate measurements.

The RBC flume (Figure 37) has a short trapezoidal section with a contraction inserted in the flume bottom. When constructing an RBC flume, it is not absolutely necessary to follow the standard measures exactly, since for each RBC flume a flume-specific head-discharge table can be established. This is not possible for the Parshall or Cut-throat flumes.

5.2.2 Measurement procedures in flumes

When using a flume to measure discharge in a canal it is assumed that the flume has been made using standard dimensions, and that flume-specific tables are available. In the case of an RBC

FIGURE 35
The Parshall flume

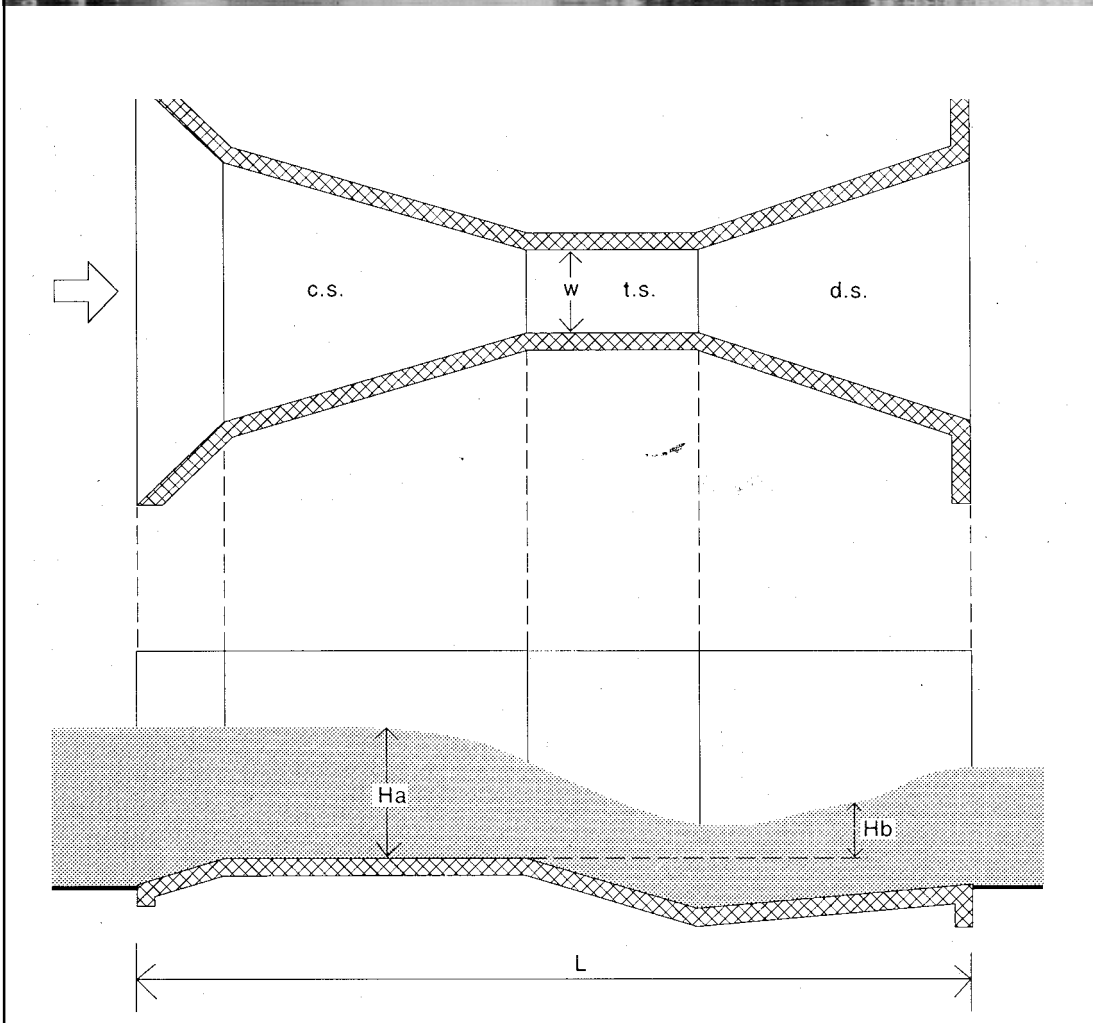


FIGURE 36
Cut-throat flume

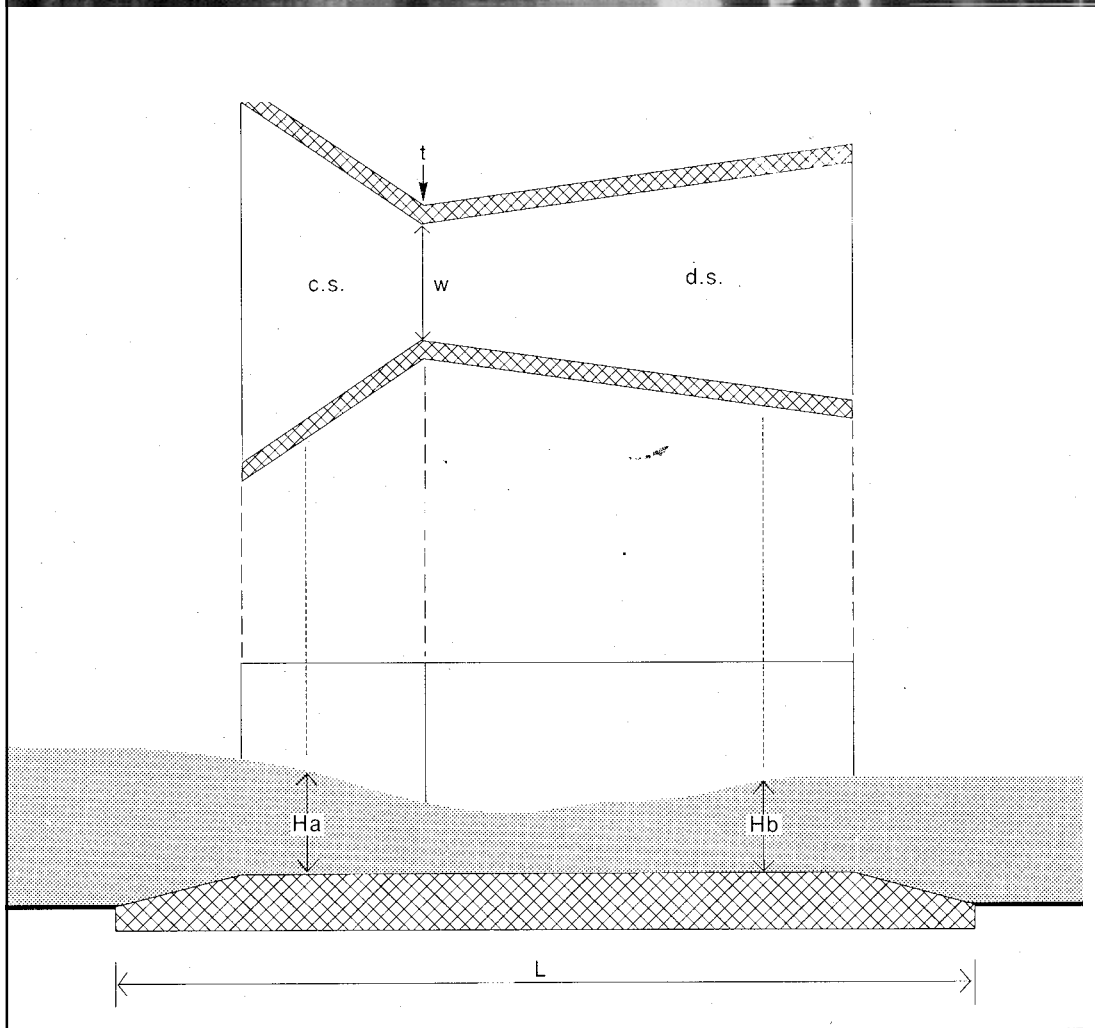
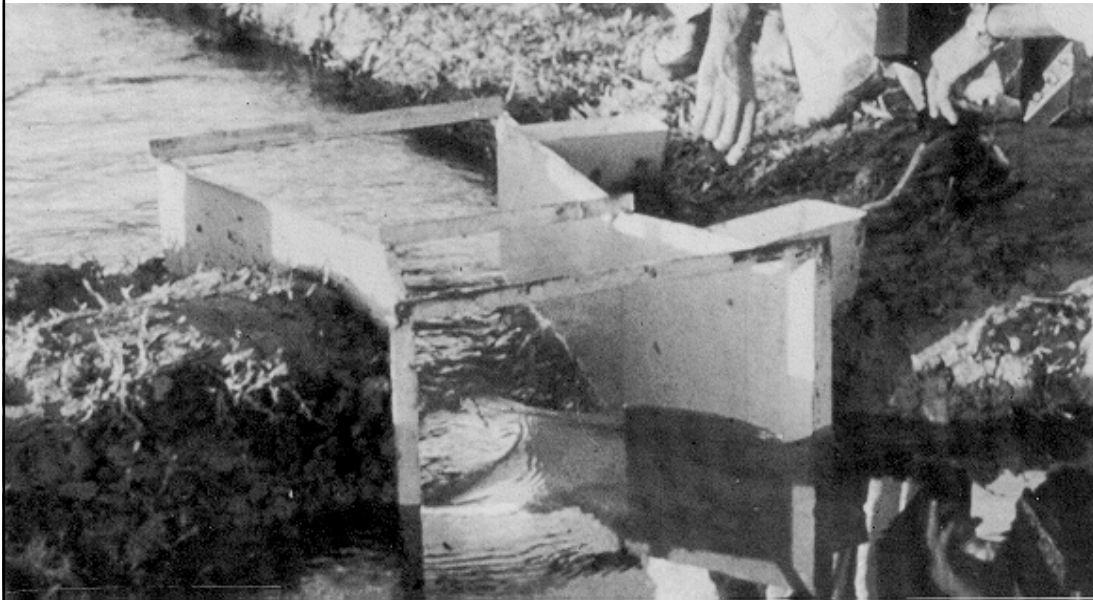
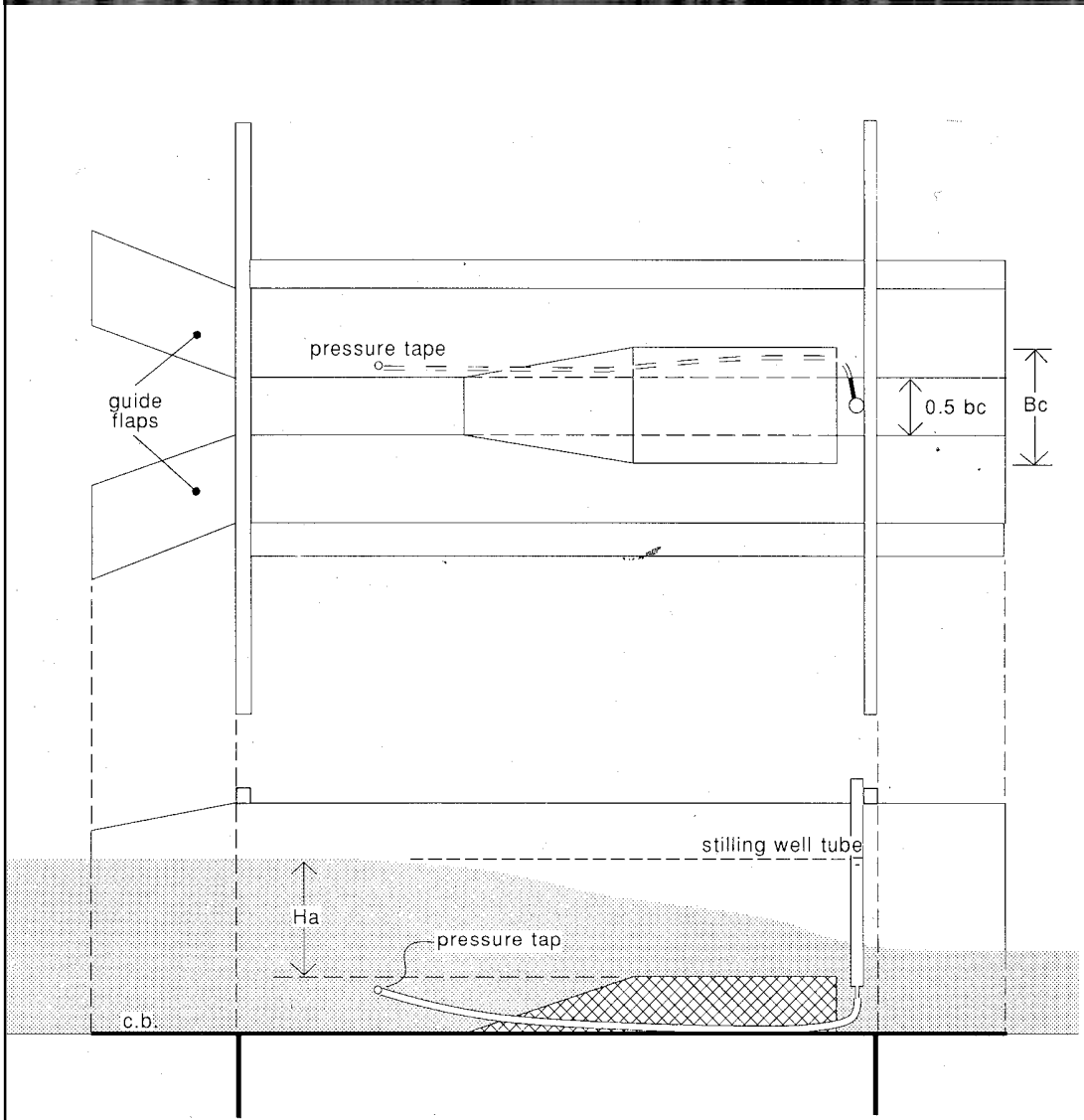


FIGURE 37
RBC flume



flume, the assumption is made that a table has been established especially for the flume being used.

Examples of tables for the three types of flumes can be found in Annex 2 of this manual. The tables are applicable for so-called 'free flow' conditions, which means that the upstream water level is not affected by the downstream water level.

For detailed information on free flow conditions and for more information on measuring flumes, the publications *Small Hydraulic Structures*¹ and *Discharge Measurement Structures*² can be consulted.

The method for measuring discharge using a flume is illustrated by Exercise 4.

EXERCISE 4

QUESTION: What is the discharge in a canal if:

- a Parshall flume with throat width $W = 0.46$ m (1.5 ft) is used to measure the flow; and
- the reading, taken under free flow conditions, is 0.23 m?

ANSWER: $H_a = 0.23$ m (read from the gauge).

Using Table A-2.4 in Annex 2 for a Parshall flume with a throat width of 0.46 m, read from the table the discharge when $H_a = 0.23$ m. The discharge $Q = 110$ l/s.

¹ *FAO Irrigation and Drainage Paper*, N° 26/2

² Bos, M.G. (ed). 1989. *ILRI Paper*, N° 20.

Chapter 6

Protective and other canal structures

Canals need to be protected against the erosive force of flowing water. In particular, in places that are susceptible to erosion, canals can be seriously damaged by a scouring water flow. For instance, canal sections immediately downstream of a structure can suffer from the effect of a water jet; low sections of a canal embankment can easily overtop and will suffer from erosion by water that spills over; or curves in a canal can be eroded by the water flow due to locally high flow velocities.

Chapter 6 describes the structures and devices most commonly used to protect canals. In addition, the last section of this chapter deals with crossing structures.

6.1 WHEN IS CANAL PROTECTION NEEDED?

Canal protection may be needed under various circumstances.

- The flow velocity in a culvert can become high, and water that spills over a weir can have a high velocity. Such high flow velocities can cause serious damage to canals if the canals are not protected. In these cases, a *stilling basin* is commonly used as a protection.
- A rising water level within the canal may damage the canal embankments when it reaches the level of the crest of the banks and spills over, known as overtopping. A *spillway* is used here to protect the embankments.
- Where water drops from one canal section into another, the bed of the lower canal section needs to be protected against the force of the falling water. Here a so-called *drop structure* is installed, commonly in combination with a stilling basin.

6.2 STILLING BASINS

A stilling basin is a basin with protected walls and floor and which is filled with water. Its function is to convert the energy of fast flowing water into turbulence, so that the flow enters at low speed into the canal downstream of the basin. Stilling basins are required downstream of structures where flow velocities can be high, such as intake structures, offtakes, culverts, weirs, or drop structures.

Flow velocities in intake structures, for instance, may be high when water flows through a pipe before entering the main canal of an irrigation scheme, and the velocity of water which spills over a weir may be high. Fast-flowing water is highly erosive and can easily damage a canal bank or bed, and so the energy of this fast-flowing water must be dissipated in order for it to flow smoothly into the downstream canal section.

Three common forms that stilling basins can take are illustrated on the next pages.

FIGURE 38
Oil drum used as basin at a tertiary
offtake



FIGURE 39
Concrete stilling basin at main intake

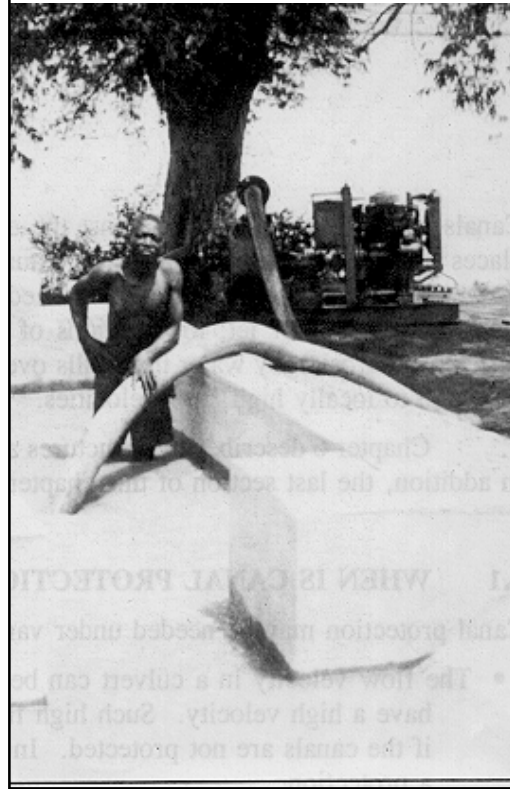


Figure 38 shows a tertiary offtake, where the tertiary canal has a lower level than the secondary canal. The gate is open and water flows at high speed through a PVC pipe into the oil drum. The velocity is broken by the water mass in the drum, and water flows at low speed into the tertiary canal. (The water level is still low because the gate had just been opened).

The concrete basin in Figure 39 is designed for a large flow. Three pumps are going to deliver water into the basin. One of them is pumping water into the basin, and the fast-flowing water that leaves the hose will lose its energy in the basin, and then flow smoothly into the canal.

FIGURE 40
Concrete stilling basin downstream of a weir

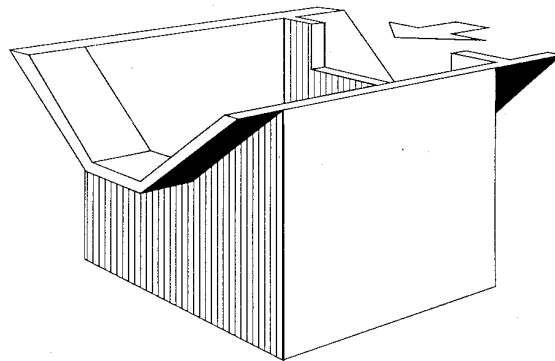
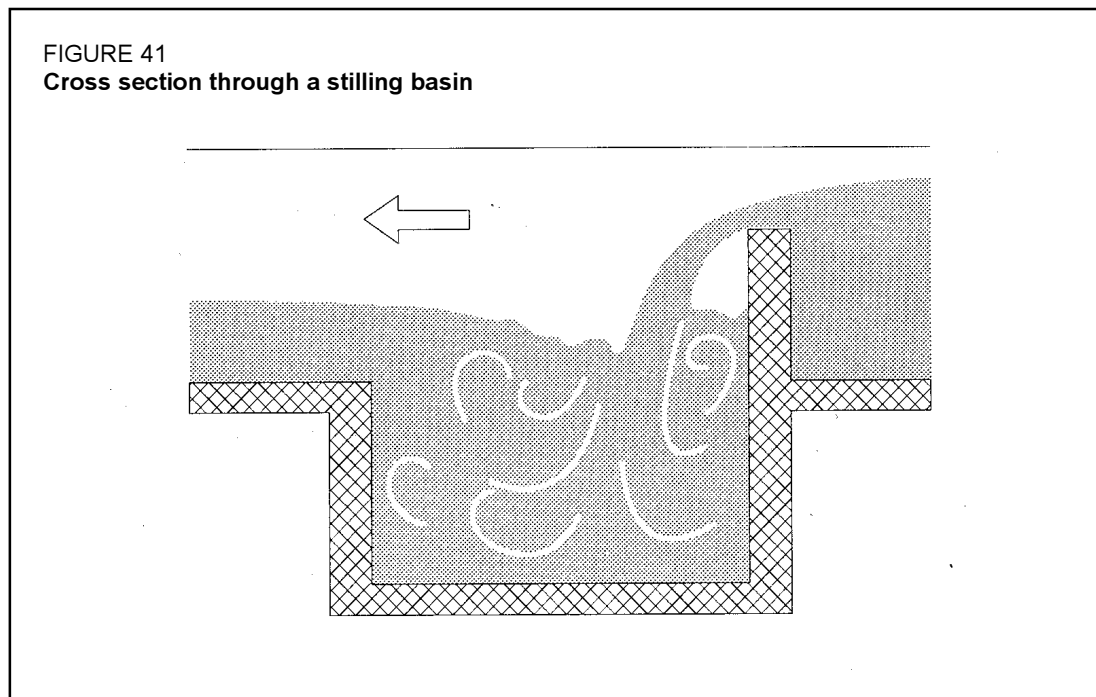


Figure 40 shows a stilling basin downstream of a weir. Water that spills over the weir falls in the basin, loses its energy, and enters the downstream canal section at low speed.

The way a stilling basin functions can be seen in Figure 41. The drawing is a cross-section view of the basin shown in Figure 40. One can see the water jet falling into the basin, but, thanks to the relatively large volume of water in the basin, the energy of the water jet will be absorbed. Having lost its energy, and therefore speed, the water flows smoothly into the downstream section of the canal.



6.3 SPILLWAYS

A spillway is a structure that guides excess water safely to the drainage system.

Water levels in irrigation canals are seldom constant. Depending on the inflow and outflow of the canal section concerned, the water level changes. The water level may rise if the gate of an intake structure is open instead of being closed, or if field intakes are closed instead of open. This can happen even in well managed schemes! When rising, water may pass the free board level, reach the crest of the canal embankment, and start overtopping.

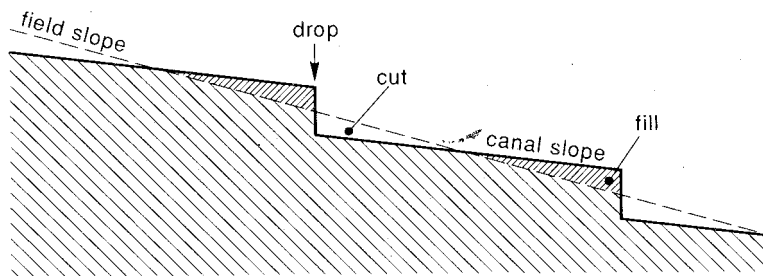
If water reaches the crest of a canal bank and overtops, this can result in destruction of the bank. To avoid this problem, a small section of the canal bank is lowered and is reinforced with concrete or with masonry. As this is the lowest part of the canal bank, rising water will spill over here. This water will be guided to the drainage system.

Figure 42 shows such a structure + a *spillway*, but also called an *emergency outlet* + in a lined canal. One can see the lowered section of the canal bank in the front. The water level in the canal has just reached the crest of the spillway, and if it rises more, water will spill over and be guided to the drainage system of the scheme.

FIGURE 42
Spillway or emergency outlet



FIGURE 43
Longitudinal section of a canal, showing bed level drops



6.4 DROP STRUCTURES

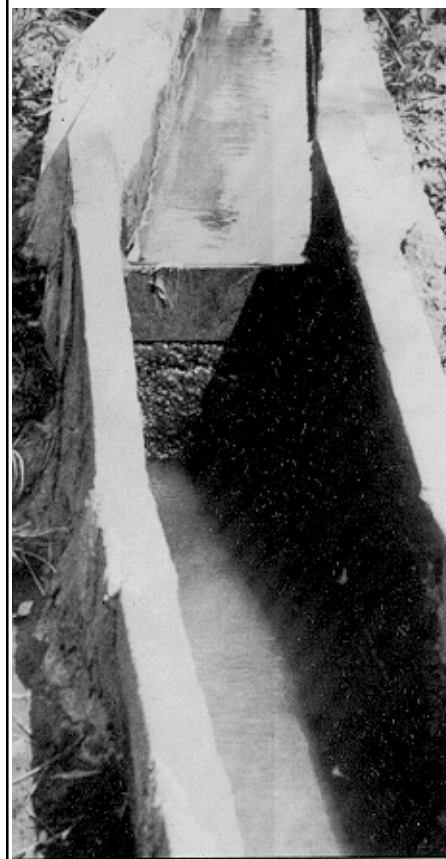
Irrigation water may need to be transported over steeply sloping land. If a canal had the same slope as the surrounding steeply sloping field, the flow velocity in the canal would be very high. In these cases the canal is given a slope which is less than the field slope in order to avoid unacceptably high flow velocities. See also Chapter 4 of Manual 7, *Canals*.

In order for a canal to have a gentler slope than the field, it is split into sections, and part of each section is constructed in cut, and part in fill, with each section having a bed level which is lower than the canal section upstream of the section concerned.

FIGURE 44
Series of drop structures



FIGURE 45
Drop with weir



Bed levels should not be excavated much lower than the field, nor should the bed be much higher than the field. So, in order to avoid large volumes of cut and fill, the drop in bed level is limited and will not exceed some 0.30 to 0.80 m. See Figure 43.

The canal sections are connected to each other by so-called *drop structures*. Such a drop structure can also include a stilling basin, especially if the canal is unlined or the drop in level is relatively large, say 0.50 m or more. See Figure 44.

In Figure 45 note that the sill + the weir crest + functions as a check and maintains the upstream water level above the level of the sill.

6.5 CANAL LINING

Some canal sections are susceptible to erosion because of the type of soil they are constructed in. In particular, those sections where there is a change in flow velocities can suffer a lot. Those sections are, for instance, sharp curves, or sections downstream of a culvert. In the first case the direction of the flow is being changed; in the second case the flow velocity is changed as a result of a sudden change in canal cross-section. Such sections need to be protected, and protection is usually given by lining the section concerned.

FIGURE 46
Protected section of canal



Figure 46 shows a canal section which is lined especially to provide protection for the transitional zone between the start of the wider, unlined section of the canal after the narrow, lined part upstream in the same canal.

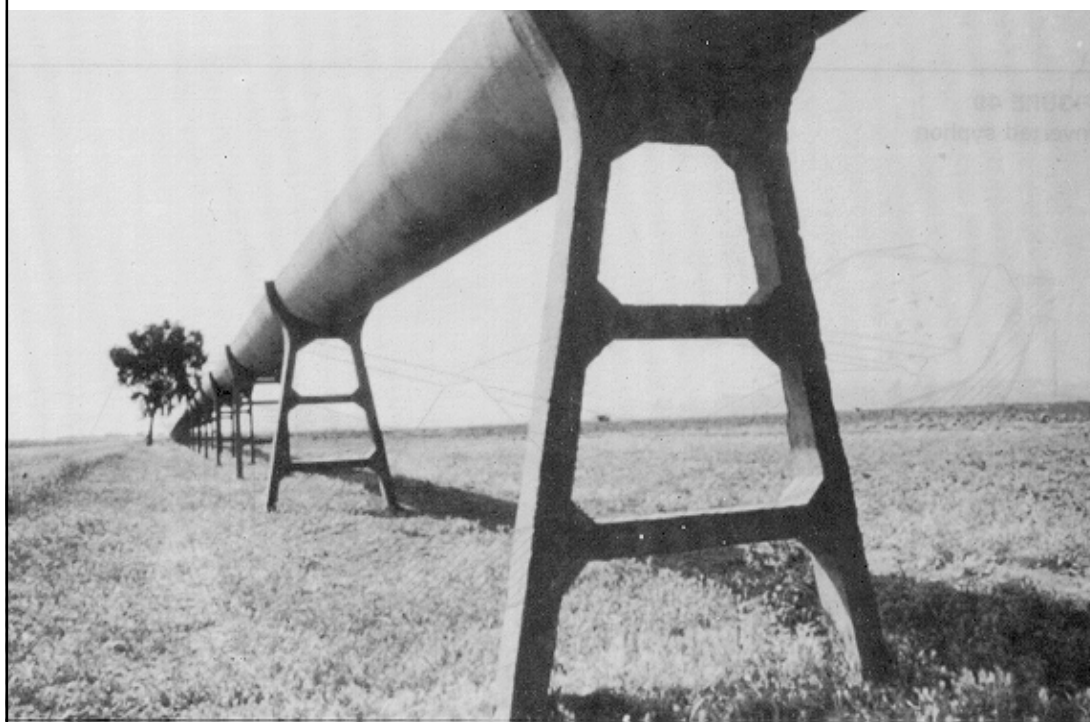
6.6 CROSSING STRUCTURES

Crossing structures are used to pass over or under obstacles in the field. There are three types of crossing structure to transport irrigation water, namely: aqueducts, culverts, and inverted siphons, and there also are crossing structures not meant for water conveyance bridges.

Aqueducts

Aqueducts are self-supporting canal sections used to carry water across drainage canals, gullies or depressions. They can be constructed from wood, metal or concrete. The aqueduct in Figure 47 carries water across a large depression.

FIGURE 47
Aqueduct



Culverts and inverted syphons

Culverts and inverted syphons are buried pipes used to carry irrigation water underneath roadways, drainage canals, natural streams or depressions.

Flow through a culvert may have a free water surface or may be submerged, see Figure 48.

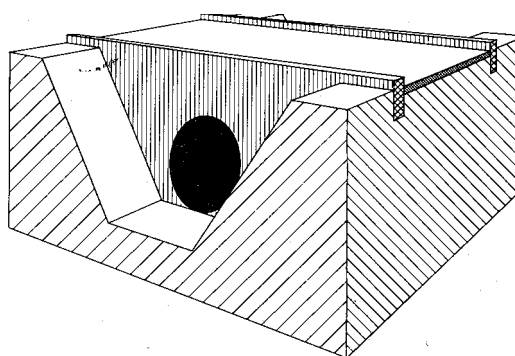
Flow through an inverted syphon does not have a free water surface, and the water is under pressure, see Figure 49.

Bridges

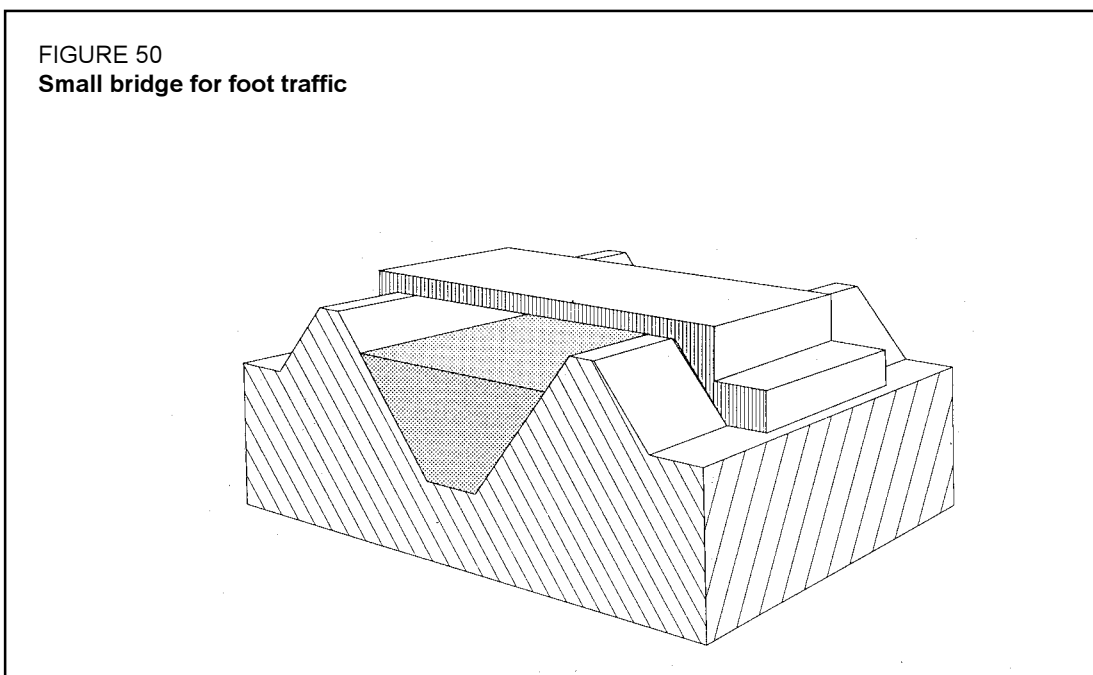
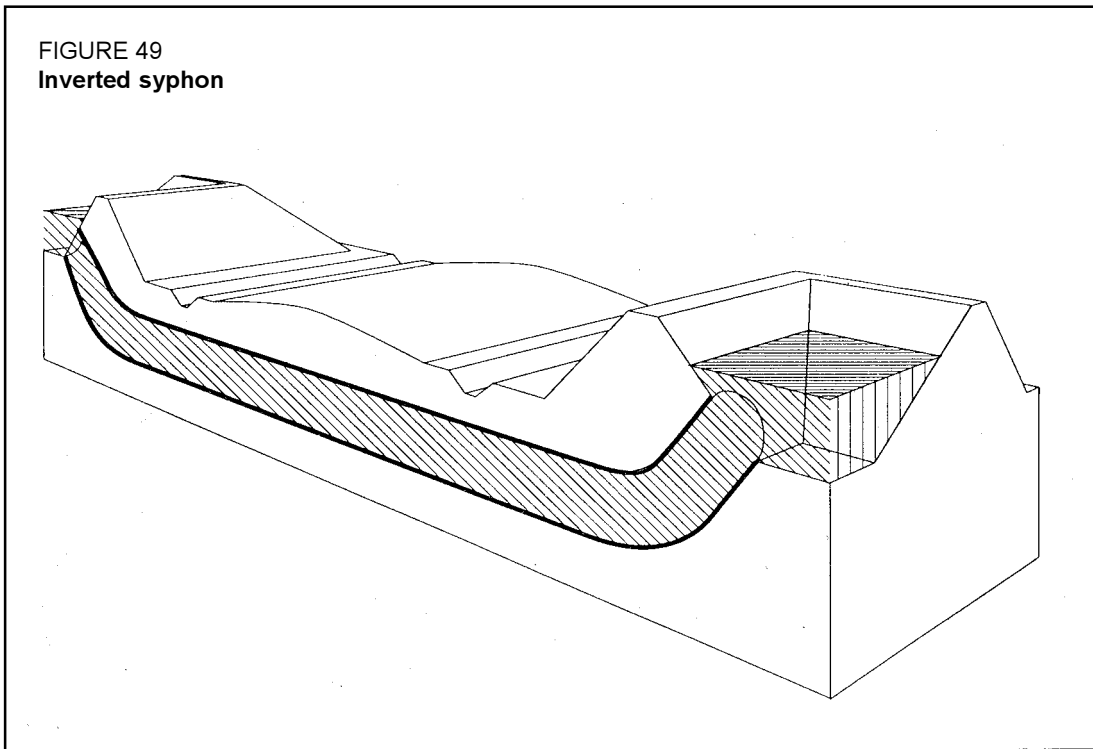
A bridge is a structure that enables people or traffic to cross a canal. If a new canal has to cross a footpath which has been in use for a long time, a bridge may be constructed to let people pass over.

If such a canal is constructed in fill, the outside slopes should be reinforced to prevent it from destruction. See Figure 50.

FIGURE 48
Culvert



Heavy bridges should be supported by pillars which are constructed at the foot of the embankments. The construction of these bridges may be more expensive than the construction of culverts.



Chapter 7

Common problems in structures

The functioning of an irrigation canal network depends not only on how the network is operated, but also on the condition of the canals and on the condition of the hydraulic structures. This chapter looks at some of the common problems that can affect structures.

7.1 INTRODUCTION

The main problems, which in many cases result from incorrect operation and lack of proper maintenance, that affect the proper functioning of hydraulic structures can be simply summarized as:

- leakage,
- erosion,
- siltation, and
- rot and rust (corrosion).

Problems such as the disappearance of movable parts from structures or vandalism and demolition are difficult to prevent, but they can be minimized by involving farmers in canal operation and maintenance, and by cultivating the sentiment that structures are a communal resource and therefore proper maintenance is a responsibility of the community.

Leakage and erosion can be the result of poor design or construction, such as:

- walls may be too thin,
- foundations of structures may be too weak,
- materials used, such as the blocks from which a structure is made, may not be strong enough for the purpose,
- the concrete mix used in constructions may be too sandy,
- back-fill may not have been compacted sufficiently, or
- the structure may not be properly connected to the canal.

At the time of design and construction, consideration should be given to the supporting capacity and workability of soil involved. Soil conditions such as easily disaggregating soil material will affect the support and bearing capacity as is the case in many organic soils (Histosols), very sandy soils (Arenosols) and hygroscopic saline soils (Solonchaks). Cracking clay soils (Vertisols) are very hard and crack when dry and are sticky and often impassable when wet. The internal movement of these soils may damage structures. Sodic and saline soils and acid sulphate soils (Solonetz, Solonchaks and Thionic Fluvisols respectively) often have a corrosive effect and are best avoided; they are not favourable for irrigation anyway.

FIGURE 51
Leakage around a structure



FIGURE 52
Cut-off walls in concrete intake

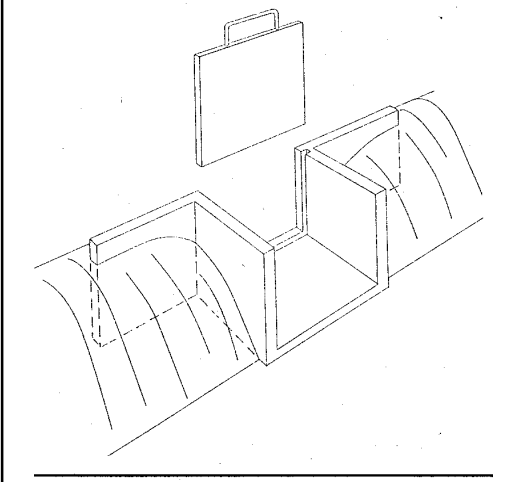
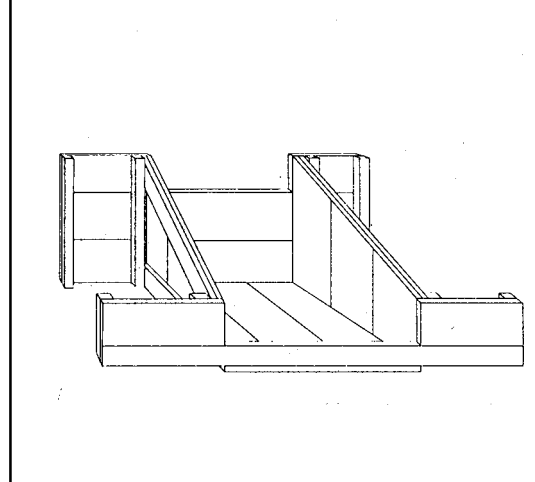


FIGURE 53
Wooden drop structure with cut-offs



It is difficult to improve the functioning of a wrongly designed or constructed structure. Soil scientists and engineers should be consulted in such cases. Minor problems, such as small leaks or early signs of erosion around a structure, can be solved by the users themselves. A description of such small repairs is given in Chapter 8.

7.2 SOME COMMON PROBLEMS IN AND AROUND STRUCTURES

The most common problems seen in structures are leakage, erosion, siltation, rot and rust.

7.2.1 Leakage

The water level upstream of a structure is higher than the downstream water level. Therefore water may search for another way underneath or along the structure, or even through a crack in the bottom or sides of the structure to this lower level. The moment that water has found a small path there is a leakage problem, and at the same time the beginning of an erosion problem. Leaking water will enlarge the path by washing out the soil and so the leakage will increase. Finally the structure will collapse if the process is not stopped.

Such a situation is shown in Figure 51, where the upstream water level is so high that water can flow along the dam. If no action is taken to remedy this the structure can be undermined by erosion and will collapse.

To avoid such a problem, the structure can be equipped with vertical cut-offs. They hinder the water flow along and underneath the structure. The cut-offs are part of a structure and can be driven into the bed and the embankments of a canal. See Figure 52 and Figure 53.

The intake structure in Figure 52 is provided with cut-offs. They are dug deep into the canal banks and into the canal bed.

The drop structure in Figure 53 is also equipped with cut-offs. After installation, the earth of the canal banks around the cut-offs should be well compacted.

Figure 54 shows the result of a leakage that has been neglected for a long time. Most probably the connection between the canal lining and the pipe was not correctly made and water could leak between them and then flow along the pipe, and as a result has washed away the soil around the drum.

7.2.2 Erosion

Sections of an unlined canal immediately downstream of a structure or downstream of a lined canal section often suffer from erosion.

Downstream of a structure the canal bed may suffer from a water jet that flows through a gate or pipe, or it will be caved in by water that spills over a weir.

In both situations a stilling basin is needed to dissipate the energy of the incoming water. The basin should be constructed immediately downstream of the weir or pipe. It is usually part of the structure. See also Chapter 6.

The transition from a lined section of a canal to an unlined section is also a risk zone, as shown in Figure 55. If no care is taken, the lining will be undermined and will finally collapse. (See Section 8.3 of this Manual.)

FIGURE 54
Leakage that resulted in erosion

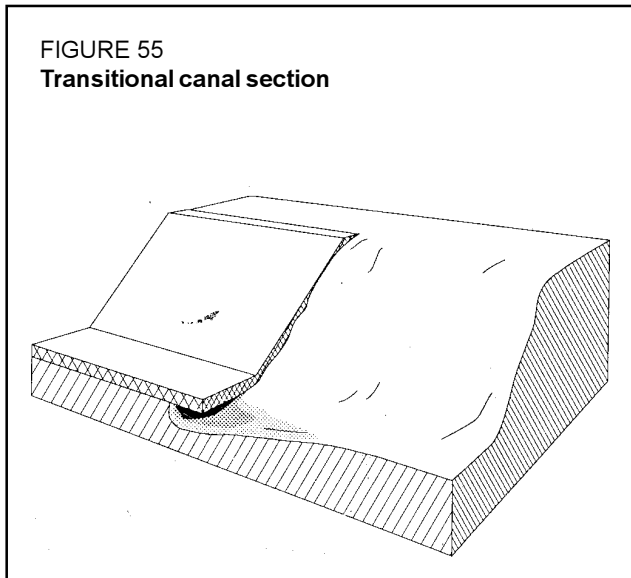


7.2.3 Siltation

The deposition of soil and debris can affect the functioning of a structure. If, for instance, a stilling basin collects soil deposits the available water mass diminishes and energy dissipation will be less effective. Similarly in the case of soil deposits in a flow division box, the division of the flow will be less accurate due to changes in flow velocities and water levels.

The same applies for intake structures, such as the pumping station in Figure 56. Large volumes of sand in the intake chamber of the pumps causes damage to the pumps and will lead to sand deposits in the canal system too.

FIGURE 55
Transitional canal section



Siltation is difficult to avoid. Depending on the local conditions, large sand traps could be constructed at the upper end of the main canal. Deposition of sand will be concentrated in these traps and can be removed by regular cleaning.

FIGURE 56
A silted-up pumping station

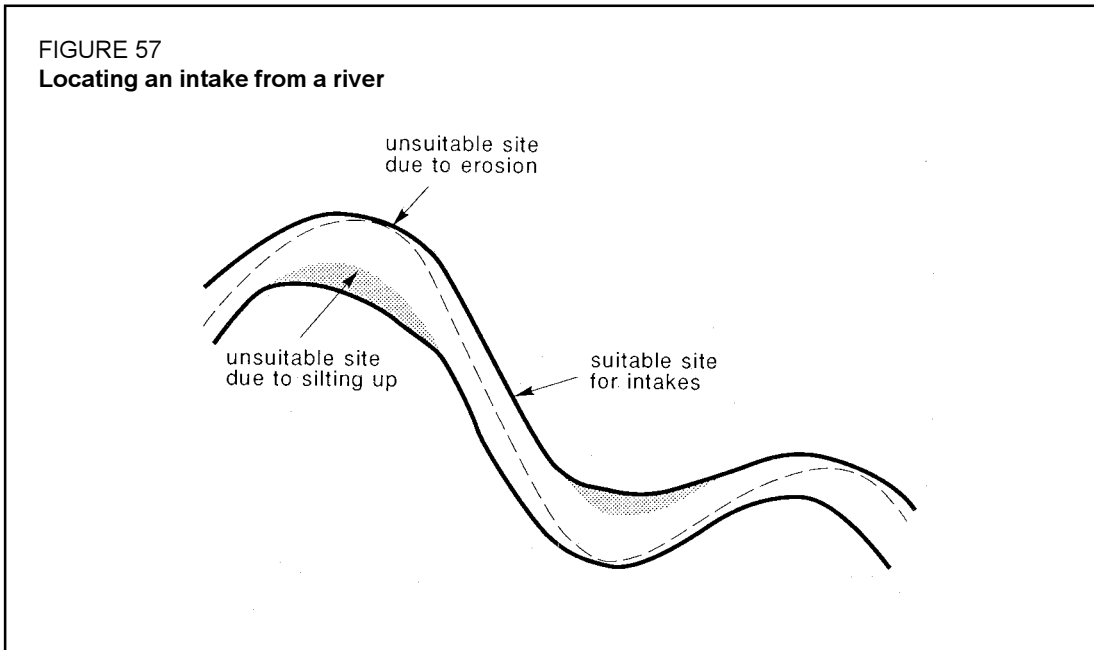


Siltation of the intake of an irrigation scheme can be reduced by choosing the right location. In general, one can say that in case of a river intake, the intake should be located on a relatively straight section. An intake located on an inner curve of a river will suffer from siltation, and if sited on an outer curve, it will suffer from erosion. See Figure 57.

7.2.4 Rot and rust

Wooden and steel parts in structures suffer from being alternately wet and dry. The wooden parts will rot and disintegrate, while steel parts will rust, expand and get jammed in the slides. All such corrosion affects in a negative way the operation of the structures.

Routine maintenance is necessary to avoid these problems, or to reduce their effect to a minimum.



Chapter 8

Maintenance and repair works

A properly designed and constructed hydraulic structure functions well for as long as it is operated well and maintained with care. That means that there is neither leakage nor erosion, that the channels and structures are clean, and that there are no rusty or rotten movable parts in the structures.

To achieve such a situation, regular maintenance is required, and even if maintenance is well carried out, repairs may be needed after some time. This chapter deals with maintenance and describes some common minor repair works.

It should be noted that the general remarks concerning maintenance and repairs which are made in Chapter 5 of Training Manual 7, *Canals*, apply equally here and so will not be repeated.

8.1 INSPECTION AND MAINTENANCE OF STRUCTURES

Minor problems in structures, like a leakage or rusty iron parts, may become important if they are neglected. Frequent inspections and regular maintenance will help limit any damage.

8.1.1 Inspection

A canal system, and in particular the structures, can be safeguarded from problems such as leakage, erosion, siltation, rot and rust by regular inspection and immediate repair action.

Since the canals are inspected regularly, structures can be inspected at the same time. This makes it possible quickly to spot the beginning of leakage, erosion or rust. A quickly executed repair will stop the problem while it is still a small one, and before it escalates into serious damage.

Inaccessible structures and lots of plant growing on the canal embankments make inspection time-consuming, and it will also be difficult to see water leaking if the walls of a structure are hidden from view. See also Training Manual 7, *Canals*, on this subject.

8.1.2 Maintenance

Maintenance of structures consists of two main activities:

- cleaning and de-silting, and
- painting and lubricating.

Cleaning and de-silting

Sand deposits and plant growth can cause changes in flow velocity through structures, and so the functioning of the structure will be less effective.

Removal of sand deposits and other obstacles such as stones and plants should be carried out frequently. Plant growth should also be removed from the outside of structures. This is necessary to allow quick inspection. See also Training Manual 7, *Canals*, and Section 7.2.3 of this manual.

Painting and lubrication

Structures are alternately wet or dry, and this causes rot in wooden parts and rust to form on iron parts. Frequent painting preserves these parts from rot or rust.

To prevent movable iron parts like sluice gates and valves from being jammed, regular lubrication is essential.

8.2 HOW TO REPAIR A LEAK

A crack in a wall or in the floor of a structure and through which water leaks must be repaired as soon as it is observed. Such a repair on a check structure constructed of blocks is described here.

- Step 1** Clean the wall or the floor round the crack. Remove any sand, clay and plant growth. (Figure 58)
- Step 2** Make the crack larger and deeper. (Figure 59)
- Step 3** Fill the hole with a cement-sand mortar and smooth with a trowel. (Figure 60)

8.3 HOW TO AVOID UNDERMINING OF A STRUCTURE

It happens often that the bed and banks of a canal immediately downstream of a

FIGURE 58
Cleaning the area around the crack

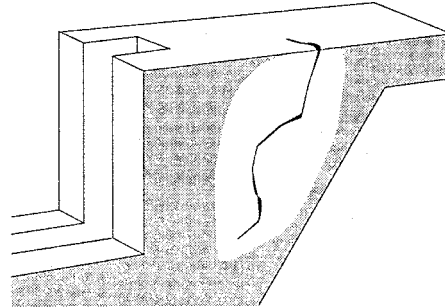


FIGURE 59
Enlarging the crack

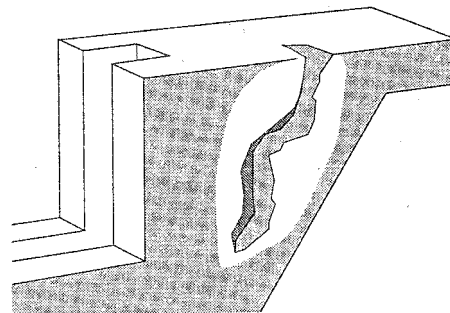
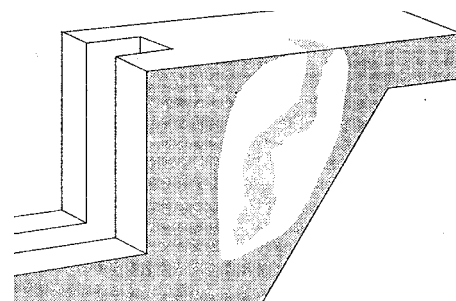


FIGURE 60
Filling and smoothing



structure, or downstream of a lined canal section, are undercut by the erosive force of the water flow and cave in. If such an erosion process is allowed to continue the structure or canal lining will be undermined and finally it will collapse, as was illustrated in Figure 55.

Undermining can be avoided by the construction of a screen or cut-off. The cut-off protects the foundation of the structure.

A procedure for the repair of an undermined structure and the construction of a screen is given opposite, and illustrated by Figure 61 to Figure 64.

- Step 1** Excavate a trench in the eroded canal bed and sides. The trench should be at least 0.20 m deeper than the eroded bed. (Figure 61)
- Step 2** Refill the hole under the lining with earth, and compact. (Figure 62)
- Step 3** Erect a concrete or masonry screen in the canal bed and in the banks of the canal, and connect it correctly to the lining of the canal or structure. (Figure 63)
- Step 4** Refill the rest of the hole and firmly compact the backfill. (Figure 64)

FIGURE 61
Excavating a trench in the canal bed and sides

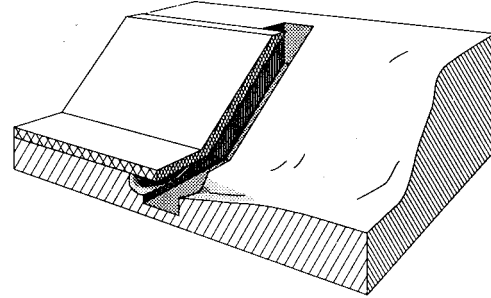


FIGURE 62
Refill partly

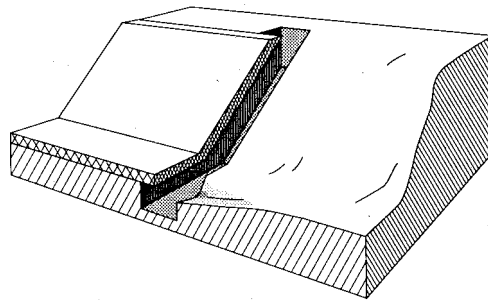


FIGURE 63
Erect the screen

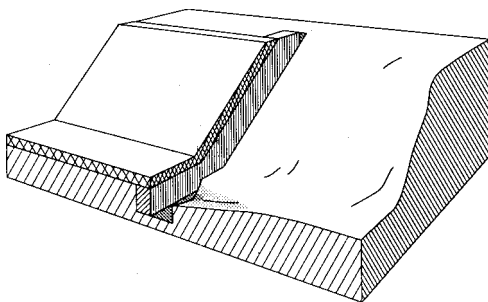
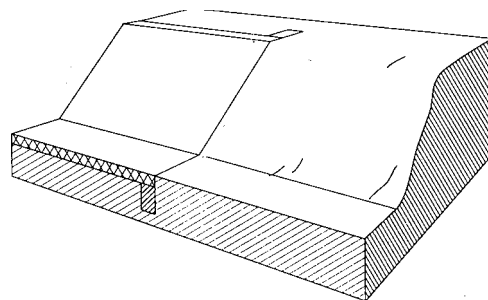


FIGURE 64
Refill the canal bed and sides



Chapter 9

Structures and minor scheme extensions

Irrigation schemes are equipped with many structures that have different functions. For the design of structures in new schemes, irrigation technicians should be consulted. In the case of a minor extension to an existing scheme, some of the new structures required may be copied from existing ones.

This chapter describes the construction of two common structures which are usually needed when a scheme is extended: a division box and a check structure.

9.1 GENERAL

If an irrigation scheme is extended, the flows in some existing main and secondary canals will have to increase. The location of the extension will determine which canals will carry a larger flow.

A method for estimating the capacities of existing canals is given in Training Manual 7, *Canals*, and a method for increasing them, if necessary, is also given in there.

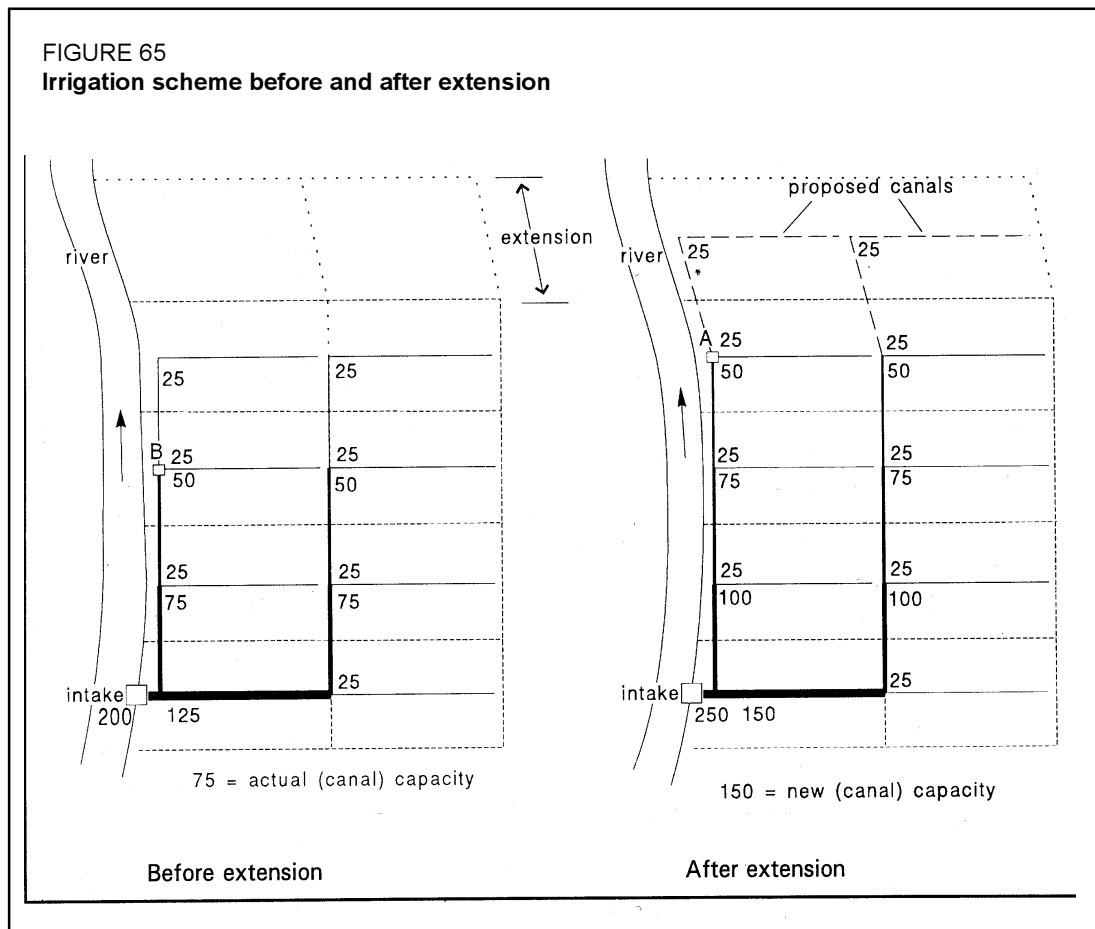
Structures in an irrigation scheme are, like the canals, usually designed for the discharges required for the existing scheme. As a consequence, the capacities of the structures are limited and they cannot carry larger flows than those planned. Structures, which are most commonly constructed in concrete or in masonry, are difficult to enlarge, unlike earthen canals.

From the foregoing discussions, it is clear that some structures may no longer be suitable if a scheme is extended and flows have to increase. In such a case an engineer should be consulted to make new designs for the structures concerned.

In an extended scheme, new structures are needed to guide water to the new area. If the flows are similar to flows in the existing scheme and the same type of structures are needed, the new structures can be copied from the existing ones, as shown in the example in Section 9.2.

Materials used for the construction of structures include steel, concrete, brick, stone, concrete block masonry, soil-cement, and wood, straw or leaves. Each of these materials have advantages and disadvantages.

- Steel is expensive and, if not attached firmly to a structure, steel parts may be lost through theft.
- Wood has a short life and can be stolen for use as fuel.
- Concrete can be subject to chipping and breakage if not properly made.



- Brick, stone masonry and soil cement require high labour inputs in the field.

In general, one can say that the choice of the construction material will depend on local conditions, such as familiarity with the materials, ease of maintenance and repair, and costs.

9.2 CONSTRUCTION OF A SMALL DIVISION BOX

This section should be read in connection with Chapter 7 of Training Manual 7, *Canals*, as the scheme extension presented there, and shown here as 65, is used as an example.

The additional division box that needs to be constructed is marked 'A' in Figure 65. This box is required in order to supply a new irrigation canal. It will divide a flow of 50 l/s into two equal flows of 25 l/s, as described in Training Manual 7. The new box can be copied from an existing box in the old scheme, such as the one marked 'B' in Figure 65, which, in the old scheme, also divided a flow of 50 l/s into two flows of 25 l/s.

However, when the scheme is extended, box 'B*' will have to divide a flow of 75 l/s into a flow of 50 l/s (in the main canal) and a flow of 25 l/s in the secondary canal. This means that box B must be redesigned and rebuilt.

The box that is to be copied is a two-way division box constructed of cement blocks, as shown in Figure 66.

The five steps in constructing the division box are:

Step 1 Identify the level of canal bed connected to the division box. Depending on the method of enlarging the canal capacity, the bed level might change - see Annex 1 of Manual 7. Prepare the site for the division box by digging to 0.3 m below the level of the canal bed. Pour a 0.15 m thick horizontal concrete foundation in the bottom of the pit. This created stilling basin has a depth of 0.15 m.

Step 2 Lay the first course of blocks (0.40' 0.20' 0.20 m) in a bed of mortar on top of the foundation, or in the fresh concrete. See Figure 67.

Step 3 Build up each layer horizontally. It is important to level the blocks to ensure appropriate flow division.

Step 4 Pour concrete in the hollow blocks to strengthen the structure.

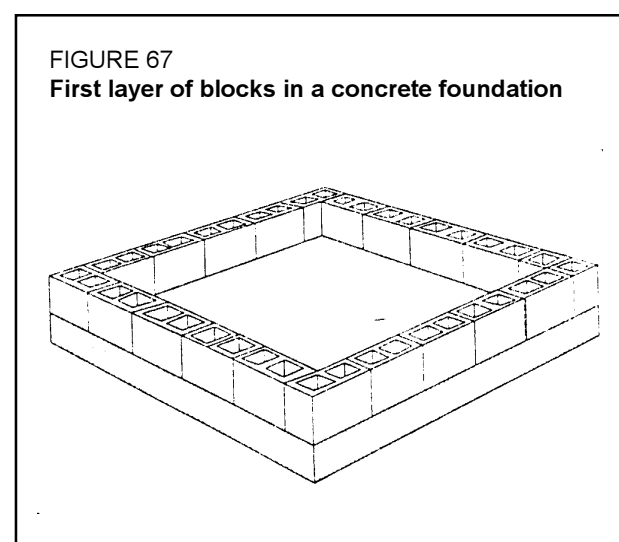
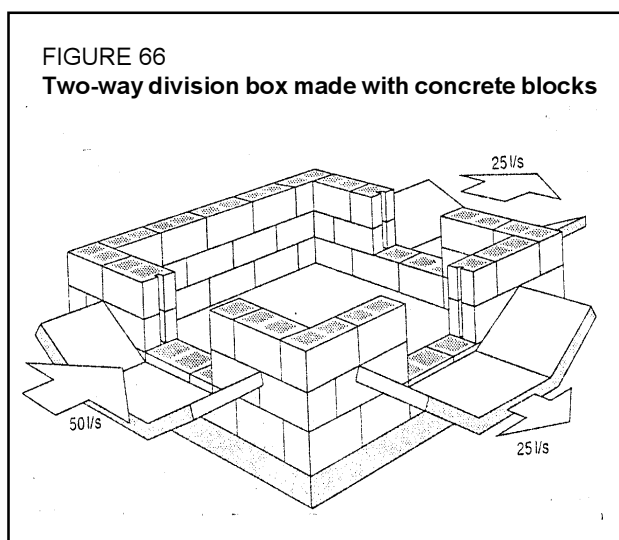
Step 5 The size of the openings should be adjusted so as to be proportional to the flows required downstream.

Step 6 Protect the two canals downstream of the structure for at least 1 m with a concrete or masonry lining. Line also the transition zone between the approach canal and the box. These linings are to protect the structure from undermining by the incoming and out-flowing water.

9.3 CONSTRUCTION AND INSTALLATION OF A WOODEN CHECK STRUCTURE

A simple wooden check structure can be installed in an irrigation canal if the water level needs to be raised to irrigate the fields. The construction and installation of a wooden check with a rectangular closable top opening is described below.

The example described has an opening 0.50 m long and 0.25 m high.



9.3.1 Construction of the check structure

Step 1 Construct a board which is large enough to enter at least 0.25 m into the canal embankments and 0.25 m into the canal bed. Strengthen the board with support planks, as in Figure 68.

Step 2 Mark the vertical centreline on the board. Measure 0.25 m each side of the centre and mark the opening of 0.50 m [wide] x 0.25 m [deep].

Step 3 Saw out the opening.

Step 4 Make gate guides by attaching:
 2 planks of 0.30x0.025x0.025 m
 1 plank of 0.65x0.025x0.025 m
 2 planks of 0.325x0.05x0.025 m
 1 plank of 0.55 x 0.10x0.025 m
 The gate can be closed with 1 plank of 0.60 x 0.30 x 0.025 m. (69)

9.3.2 Installation of the check

Step 1 Excavate a trench in the canal bed and in the banks, perpendicular to the axis of the canal. (69)

Step 2 Install the structure, making sure that it enters at least 0.25 m into the bed and 0.25 m into the banks of the canal. Make sure that the check has the correct elevation. (71)

Step 3 Refill the trench with earth, and firmly compact.

Step 4 Reinforce the canal bed downstream of the check. (72)

This reinforcement, or lining, prevents the canal from erosion by the overflowing water. Lining can be done with masonry or concrete. For larger canals, where discharges are 100 l/s or more, it will probably be necessary to construct a stilling basin to protect the canal.

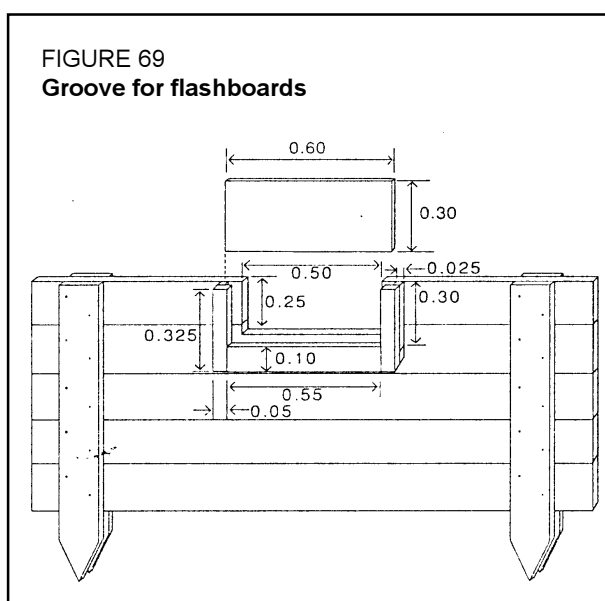
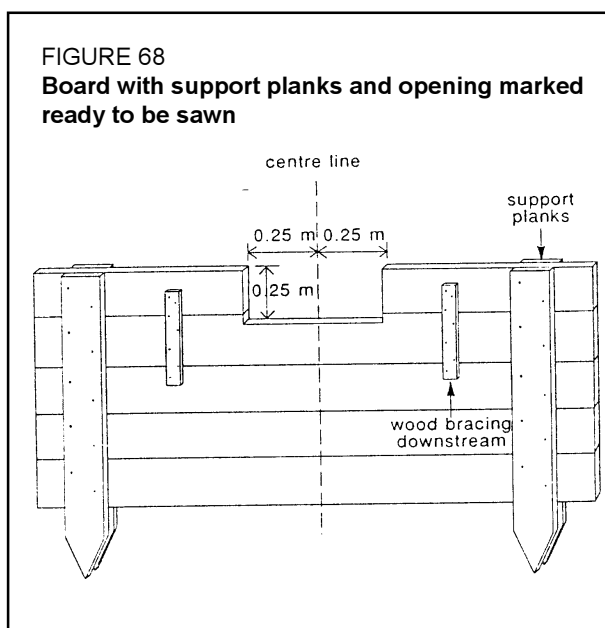


FIGURE 70
Excavating a trench

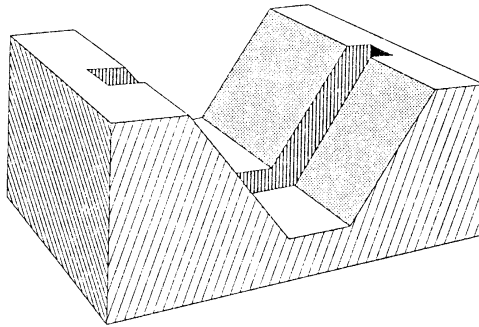


FIGURE 71
Installing the check

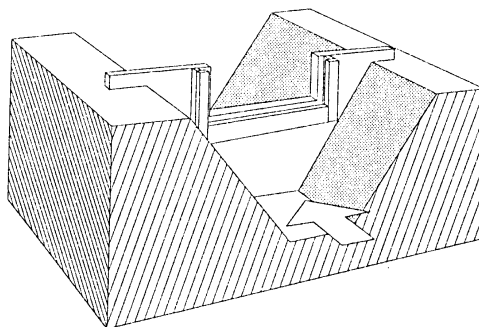
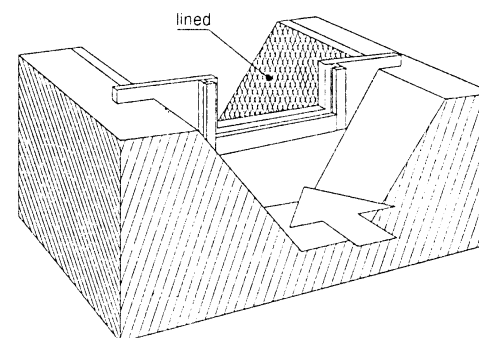


FIGURE 72
Lining the canal downstream of the check

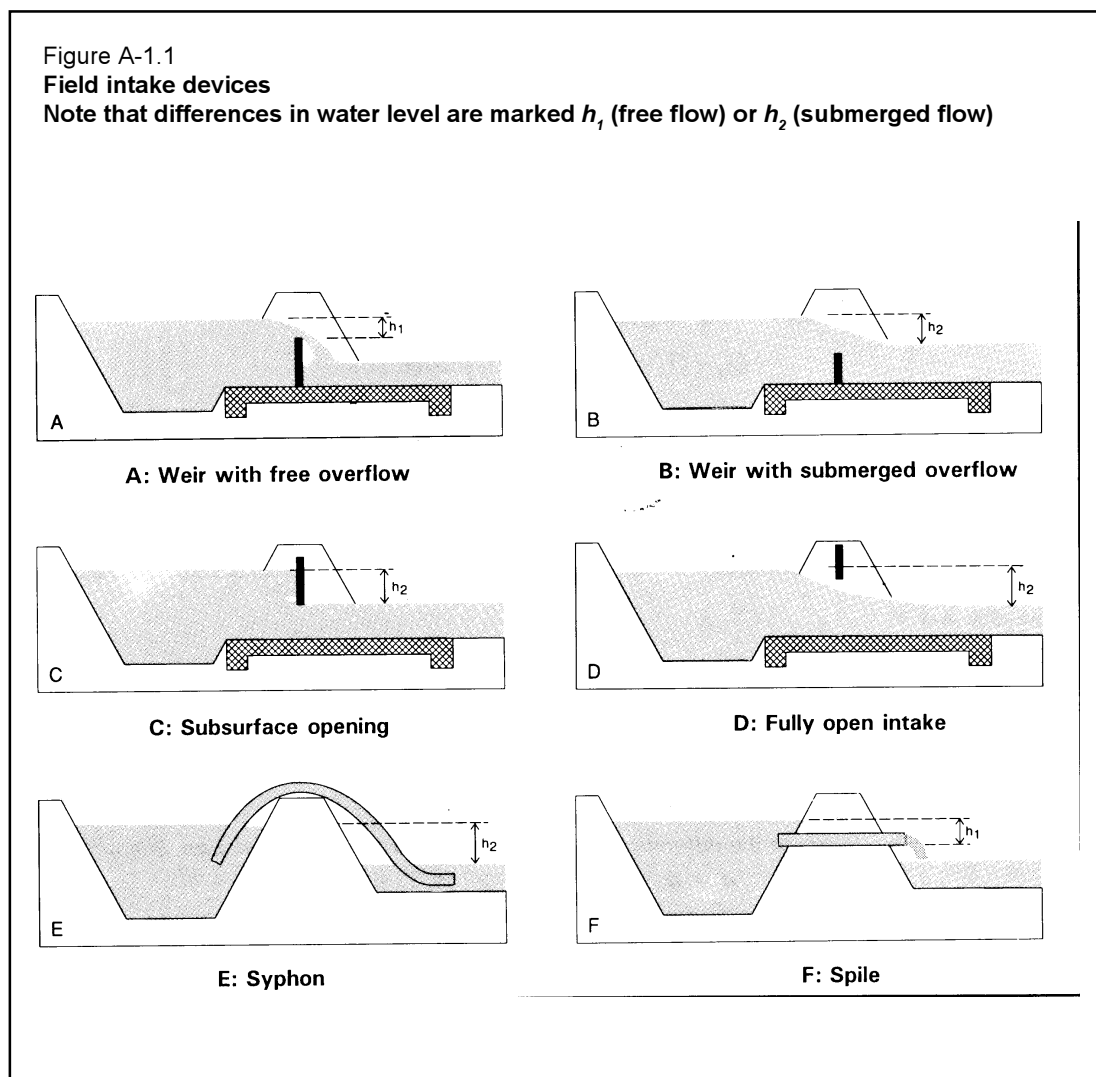


Annex 1

How to determine the discharge through a field intake

The discharge through a field intake depends on the *type* of intake (gated intake with free flow or submerged flow, or an opening under the water surface, such as syphons or spiles); the *difference in water levels* between the water surface upstream and downstream of the opening, or, in the case of free flow, the difference in levels between the upstream water surface and the crest of the weir or level of openings for syphons and spiles; and on the *area of the opening*.

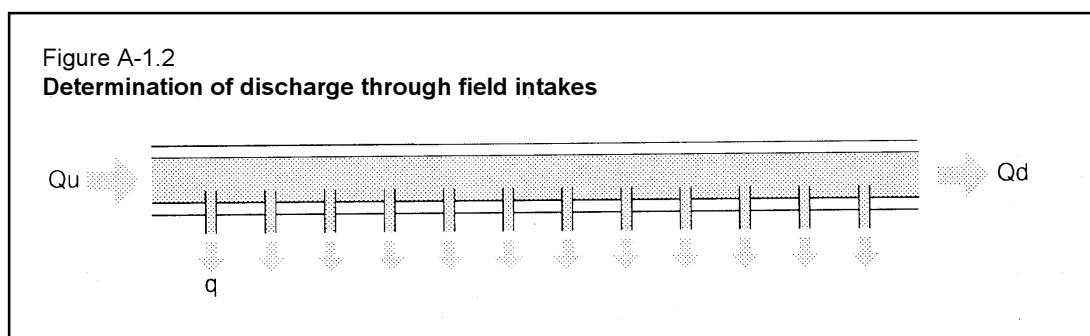
See Figure A-1.1 for diagrams of these various structures.



The formula by which the discharge through an intake can be determined depends on the type of structure and on whether the flow is free or submerged. The variables used in the formula are the difference in water level, h_1 or h_2 , and the area of the opening.

With all these factors, the calculation of the discharge through an intake device by using a formula is not only complicated, but also is not very accurate. A simpler method is given below.

The flow through an intake can be calculated easily by measuring the discharge in the channel upstream of the intake, then measuring the discharge in the channel downstream of the intake, and the difference between the two values must be the discharge that is supplied to a branch canal or to a field. See Figure A-1.2, where Q_u and Q_d are the discharges upstream and downstream respectively of the field intake being assessed, which consists, in this case, of 12 syphons.



The value, q , for the field intake discharge is given by;

$$Q_u - Q_d = q \text{ litres per second (l/s)}$$

Q_u and Q_d can be estimated using the floating object method, as was explained in Training Manual 7, *Canals*.

An example is given below.

Exercise A-1.1

QUESTION: What is the total discharge through the syphons numbered 1 to 12 in Figure A-1.2?

ANSWER: The procedure is given in steps.

Step 1: Estimate the discharge in the channel upstream of the syphons: $Q_u = 65$ l/s.

Step 1: Estimate the discharge in the channel downstream of the syphons: $Q_d = 32$ l/s.

Step 3: Calculate the difference between the upstream and downstream discharges:

$$q = Q_u - Q_d = 65 - 32 = 33 \text{ l/s.}$$

RESULT: The total discharge through the 12 syphons is **33 l/s**.

Annex 2

Discharge-head relationships of flow measuring devices

The discharge over a weir or through a flume can be determined by measuring the water level upstream of the device, as discussed in Chapter 5. The measurement is done with a gauge. The gauge reading is then used in a formula which gives the relation between the reading and the discharge. However, each formula is only valid for the device concerned.

Instead of calculating the discharge for each measured water level, using the formula, tables can be used. A table gives the result of the calculation for many different water levels.

Tables for the rectangular, Cipoletti trapezoidal, and 90° V-notch weirs are provided below, as well as tables for the Parshall, Cut-throat and RBC flumes.

TABLE A-2.1

Discharge-head relationship for a rectangular weir

Discharge values Q l/s for specific combinations of head and crest length

Head (H) in m.	Discharge (Q) in l/s					
	Length of crest (L) in metres					
	0.25	0.50	0.75	1.00	1.25	1.50
0.01	0	1	1	2	2	3
0.015	1	2	3	3	4	5
0.02	1	3	4	5	6	8
0.03	2	5	7	10	12	14
0.04	4	7	11	15	18	22
0.05	5	10	15	20	26	31
0.06	6	13	20	27	33	40
0.08	10	20	31	41	51	62
0.10	13	28	42	57	72	86
0.12	17	36	56	75	94	113
0.14		45	70	94	118	142
0.16		55	85	114	143	173
0.18		65	100	135	171	206
0.20		76	117	158	199	
0.25		104	161	219		
0.30			209			

TABLE A-2.2**Discharge-head relationship for a Cipoletti trapezoidal weir**Discharge values Q l/s for specific combinations of head and crest length

Head (H) in m.	Discharge (Q) in l/s					
	Length of crest (L) in metres					
	0.25	0.50	0.75	1.00	1.25	1.50
0.01	0	1	1	2	2	3
0.015	1	2	3	3	4	5
0.02	1	3	4	5	7	8
0.03	2	5	7	10	12	14
0.04	4	7	11	15	19	22
0.05	5	10	16	21	26	31
0.06	7	14	21	27	34	41
0.08	11	21	32	42	53	63
0.10	15	29	44	59	74	88
0.12	19	39	58	77	97	116
0.14		49	73	97	122	146
0.16		60	89	119	149	179
0.18		71	107	142	178	213
0.20		83	125	166	208	
0.25		116	174	233		
0.30			229			

TABLE A-2.3**Discharge-head relationship for a 90° V-notch weir**Discharge values Q l/s for different heads, H m

H	Q
0.01	0.0
0.02	0.1
0.03	0.2
0.04	0.4
0.05	0.8
0.06	1.2
0.07	1.8

H	Q
0.08	2.5
0.09	3.3
0.10	4.3
0.11	5.5
0.12	6.8
0.13	8.3
0.14	10

H	Q
0.15	12
0.16	14
0.17	16
0.18	19
0.19	22
0.20	24

TABLE A-2.4

Discharge-head relationship for a Parshall flume with throat width of $W = 0.46$ m (1.5 ft)Discharge values Q l/s for different upstream water levels, H_a m

H_a	Q	H_a	Q	H_a	Q	H_a	Q
0.03	5.8	0.11	35	0.19	82	0.27	141
0.04	7.4	0.12	41	0.20	89	0.28	149
0.05	11	0.13	46	0.21	96	0.29	157
0.06	18	0.14	51	0.22	103	0.30	166
0.07	22	0.15	57	0.23	110	0.31	174
0.08	26	0.16	63	0.24	118	0.32	183
0.09	31	0.17	69	0.25	125	0.33	192
0.10	35	0.18	76	0.26	133	0.34	201
						0.35	210

TABLE A-2.5

Discharge-head relationship for a Cut-throat flume of length $L = 0.90$ m and throat width $W = 0.30$ mDischarge values Q l/s for different upstream water levels, H_a m

H_a	Q	H_a	Q	H_a	Q	H_a	Q
0.01	0	0.11	19	0.21	62	0.31	127
0.02	1	0.12	22	0.22	68	0.32	135
0.03	2	0.13	26	0.23	74	0.33	143
0.04	3	0.14	30	0.24	80	0.34	151
0.05	4	0.15	34	0.25	86	0.35	159
0.06	6	0.16	38	0.260	92	0.36	168
0.07	8	0.17	42	.27	99	0.37	177
0.08	11	0.18	47	0.28	106	0.38	185
0.09	13	0.19	52	0.29	113	0.39	195
0.10	16	0.20	57	0.30	120	0.40	204

TABLE A-2.6

Discharge-head relationship for an RBC flume of throat bottom width of $B_c = 0.20$ mDischarge values Q l/s for different upstream water levels, H_a m

H_a	Q	H_a	Q	H_a	Q	H_a	Q
0.03	1.8	0.08	9.3	0.13	22	0.18	40
0.04	2.9	0.09	11	0.14	25	0.19	45
0.05	4.2	0.10	14	0.15	29	0.20	49
0.06	5.7	0.11	16	0.16	32		
0.07	7.4	0.12	19	0.17	36		