Provisional edition

IRRIGATION WATER MANAGEMENT
Training manual no. 7

CANALS

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS

IRRIGATION WATER MANAGEMENT
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CANALS

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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.

A further three subjects to be covered are:

- structures
- drainage
- scheme irrigation management.

At this stage, all the papers are marked 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.

In addition some complementary manuals are planned, the first of which, *Small-scale pumped irrigation - energy and cost*, is being published simultaneously with this volume.

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

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ABOUT THIS PAPER

CANALS is the seventh in a series of training manuals on irrigation. The manual explains the functioning of a canal network and describes the basic principles of water flow in small canals. It considers the elements that affect canal capacity.

Furthermore, this manual deals with maintenance aspects of a canal network and describes in detail some important technical problems that commonly arise in connection with small canals, and provides practical guidance in dealing with them.

Three annexes are included to provide the reader with additional information on how to increase a canal's capacity, on how to construct an irrigation canal, and on how to measure the slope of a proposed canal alignment.

ACKNOWLEDGEMENTS

Much appreciation is expressed to the various specialists in irrigation for their valuable comments and suggestions: Mrs M. Heibloem and Messrs W. Genet, M. Jurriens, M. Kay, M. Smith and P. van Steekelenburg. Particular thanks are due to Mr Thorgeir Lawrence and Ms C.D. Smith-Redfern for the editing, typing and finalization of the manual for printing.

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Chapter 1

Introduction

Manuals 1 to 3 in the Water Management Training Series introduce the reader to basic irrigation principles. Manual 1, *Introduction to irrigation,* describes soil, plant, climate and water relationships; Manual 2, *Elements of topographic surveying,* deals with simple topographic measuring techniques; and Manual 3, *Irrigation water needs*, makes the reader familiar with irrigation water needs at crop level.

Manual 4 provides an introduction to *Irrigation scheduling*, and Manual 5 describes various *Irrigation methods*.

Manual 6, *Scheme irrigation water needs and supply*, describes methods of calculating scheme water needs as a function of cropping pattern.

Manuals 7 and 8 deal with the system by which irrigation water is transported from the water source to the farmers fields. This manual, number 7, describes the canals, and Manual 8, *Structures*, deals with the structures, which are important elements in an irrigation canal system.

A problem that is frequently observed in irrigation schemes is the inefficient way in which farmers use and maintain their canal network. Irrigation extension officers can be of great assistance to farmers by helping them to make better and more durable use of the irrigation canal system. It is the aim of this volume to assist the extension officers in their efforts to improve the exploitation of the canal system.

To achieve this goal, the functioning of a canal system is explained, as well as some basic concepts involved, such as discharge, capacity, friction and slope. Attention is paid to the usefulness of canal maintenance, and how to achieve this. The manual looks at some problems that occur frequently in irrigation systems, and provides a guide to avoiding or overcoming these problems. The final part describes how a minor extension of an existing scheme can be carried out and how a small new scheme can be constructed.

The manual is limited to open canal systems, which worldwide are the most commonly used systems.

The irrigated areas dealt with in this manual may be independent or they may be part of larger schemes. The areas are limited in size, 200 ha or less, and the extensions or the new construction schemes are for areas of less than 50 ha.

It is not the aim of this manual to teach the reader how to make complicated hydraulic calculations, nor to educate her or him in making complicated designs for new irrigation schemes. The manual's object is to provide support to irrigation extension officers in their efforts to improve the exploitation of minor irrigation schemes or small sub-units within large schemes.

Whenever a problem arises for which a solution is not given in the manual, the reader is requested to contact an irrigation engineer for help.

Chapter 2

Canal network and irrigation plan

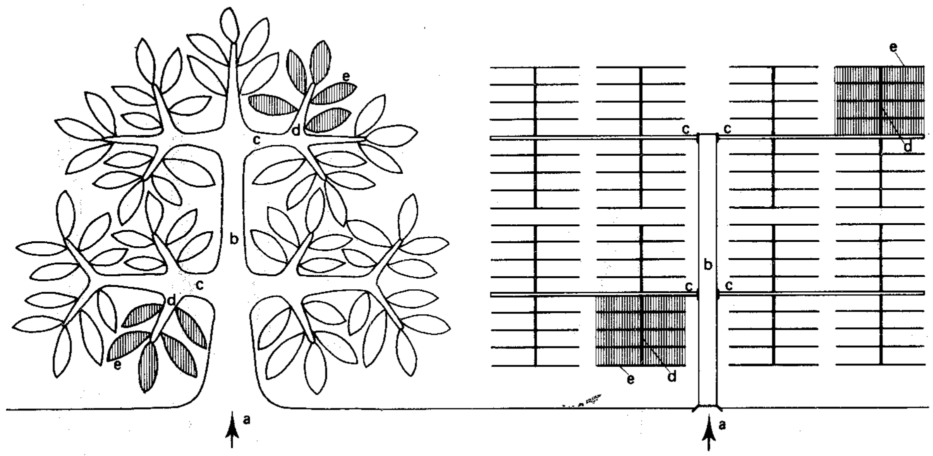
2.1 INTRODUCTION

This chapter introduces the functioning of an irrigation canal network and the use of an irrigation plan.

2.2 FUNCTION AND PERFORMANCE

A system of irrigation canals, also known as a 'canal network', transports water from its source to the fields, and is made up of many canals. To illustrate the functioning of an irrigation canal network, it can be compared to a tree, as in Figure 1.

FIGURE 1
An irrigation canal network compared to a tree



The main stem of a tree taps water from the soil and transports it to the branches. The branches supply the twigs with water and finally it enters into the leaves, where it will either be used for growth or will evaporate.

The same can be seen in an irrigation scheme: the main or primary canal (the stem) taps water from the water source. This may be a river, a lake, a reservoir or groundwater. Water is then distributed by the smaller secondary canals (the branches) to the tertiary canals (the twigs) which are even smaller. From these tertiary canals the water finally enters the fields (the leaves), where it will be used to irrigate a crop, and evaporate or soak away.

The canals are positioned in the field so that use is made of the natural slope, and water flows downhill through the canals and enters the fields by gravity. See also Figure 2, which shows part of a small irrigation canal system.

FIGURE 2
Part of a small irrigation canal system

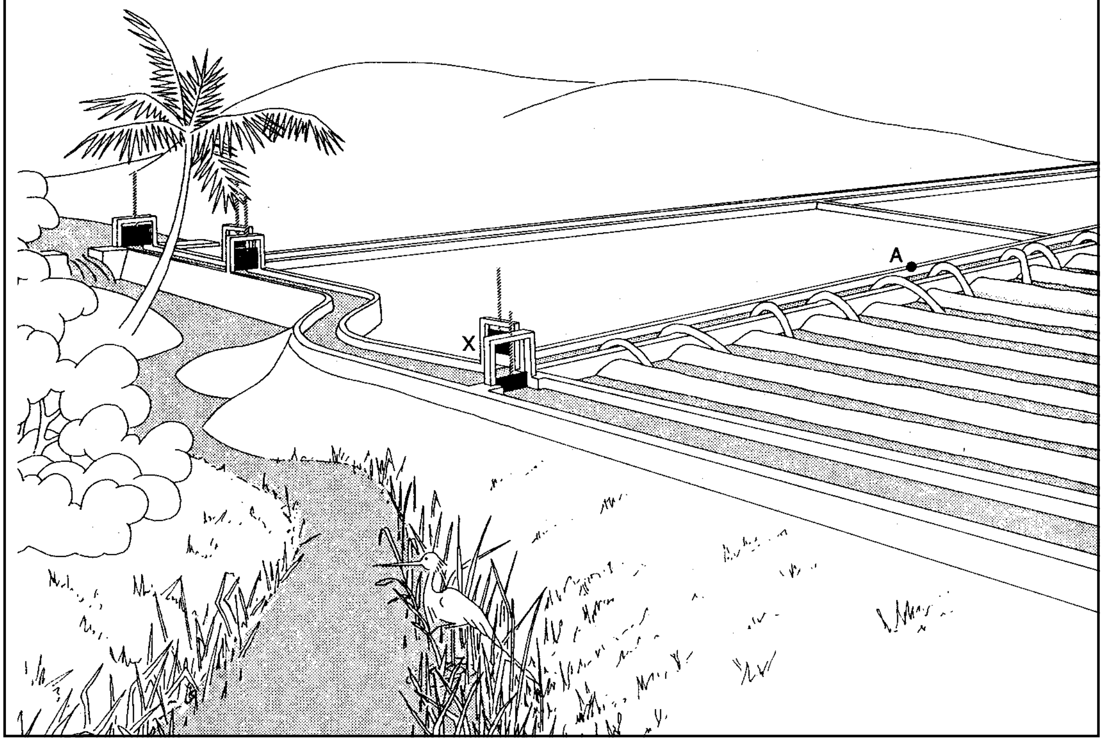
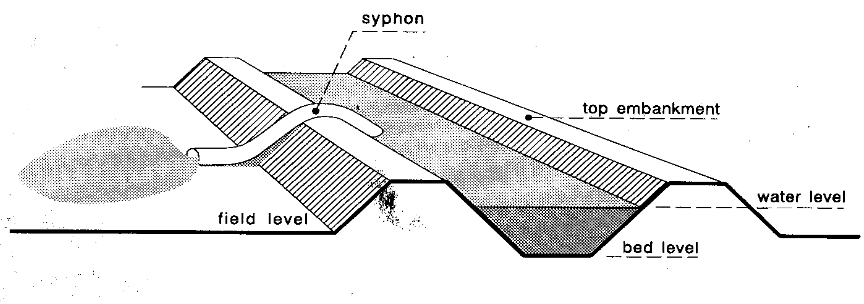


Figure 2 shows a dam on a river, from which water is tapped and passes into the main canal. The water then passes into two smaller canals, and finally enters the fields through siphons.

The smallest canals in a system serve the fields. Water in these canals should therefore be at a higher level than the fields. This can be seen in the following figures. Figure 3 shows a tertiary canal from which a field is irrigated by syphons. Figure 4 shows a longitudinal section of this canal and Figure 5 shows its cross-section.

FIGURE 3
Tertiary canal serving a field



It is best if the canal bed is lower than the field, as shown in the figures, but if a canal crosses a depression in the field, the canal bed may have to be partly raised above the field.

FIGURE 4
Longitudinal section

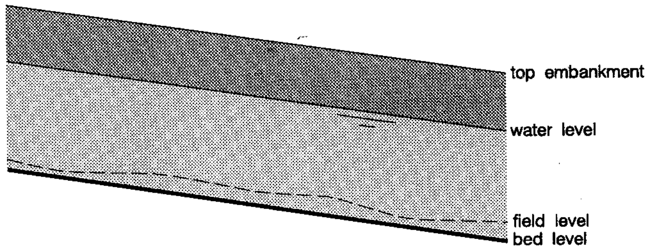
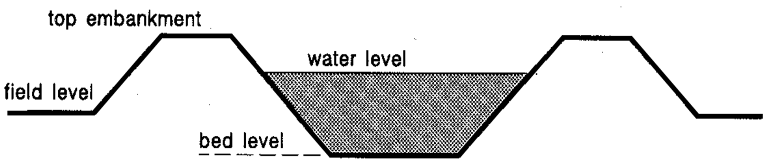


FIGURE 5
Cross-section

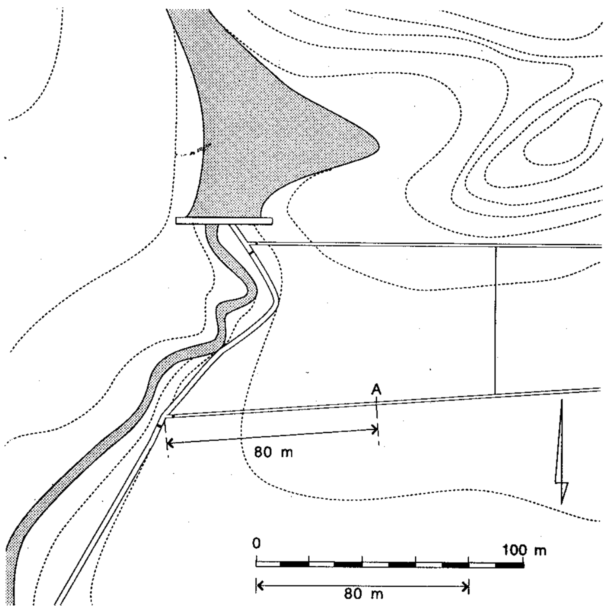


2.3 IRRIGATION PLAN

Before designing a canal network, a topographical survey of the area should be done and a topographical map of the area drawn. On this map the layout of the canal system is planned so that water delivery will be as efficient as possible. This map is called the irrigation plan. Figure 6 shows an example of such an irrigation plan, which corresponds to the canal system in Figure 2.

Figure 6 shows how the irrigation network is positioned in the field. The main canal and the field canals can clearly be seen in the plan. The correspondence between the plan and the canal system is made clear in Exercise 1.

FIGURE 6
Irrigation plan



An irrigation canal network can be drawn as a schematic lay out

EXERCISE 1

Question: Which point in the field corresponds to point A on the irrigation plan? Point A is situated along a field canal.

Solution:

Step 1 Look for a point on the map that is close to point A and which is easy to find in the field; in this case it is the offtake of the field canal concerned.

Step 2 Measure the distance on the map from this reference point to A.

Step 3 If the map has a line scale, then measure the distance found in Step 1 along it and read off the true distance.
If the scale is given in figures, then multiply the measured distance (in centimetres) by the scale figure, and convert to metres. E.g., if the scale of the map is 1:2 000, then 1 cm on the map is equivalent to 2 000 cm [= 20 m] on the ground.

Step 4 Go into the field and find the reference point used , the field canal offtake marked 'X' in Figure 2. Measure downstream along the bank of the field canal for the distance determined in Step 3.
That is point A on the map and in Figure 2.

as well as as a topographically correct map. Such a schematic irrigation plan shows the main and secondary canals, and the off-takes and the areas served by each. Figure 7 shows the schematic irrigation plan of the scheme which is given in Figures 2 and 6. The irrigation units are symbolized by small squares in which, in this case, the area served by each offtake is written.

EXERCISE 2

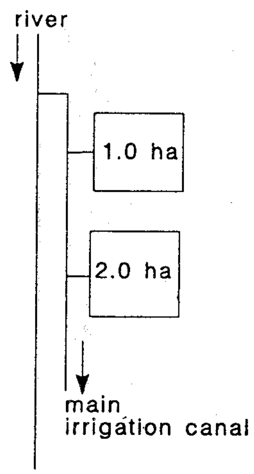
Question: Which offtake in the schematic lay-out in Figure 7 corresponds to the tertiary offtake which is marked X in the field in Figure 2?

Solution:

Step 1 Offtake X is offtake number 2 along the main canal.

Step 2 Find offtake number 2 along the main canal in Figure 7.

FIGURE 7
Schematic irrigation plan



Chapter 3

Discharge

3.1 INTRODUCTION

Irrigation canals transport water from the water source to the farmers fields. The more fields that are served by a canal, the more water has to be transported. The rate at which water is transported by a canal is called its *discharge*, and the maximum discharge that any canal can transport is *canal capacity*. These are described here. The chapter also gives dimensions of canals as a function of their capacities.

3.1.1 What is discharge?

The discharge is the volume of water that is transported each second, and the volumes are expressed in litres (l) or in cubic metres (m^3) [1 m^3 = 1000 l], and the letter Q is commonly used as the symbol for the discharge.

FIGURE 8
Discharge in a canal

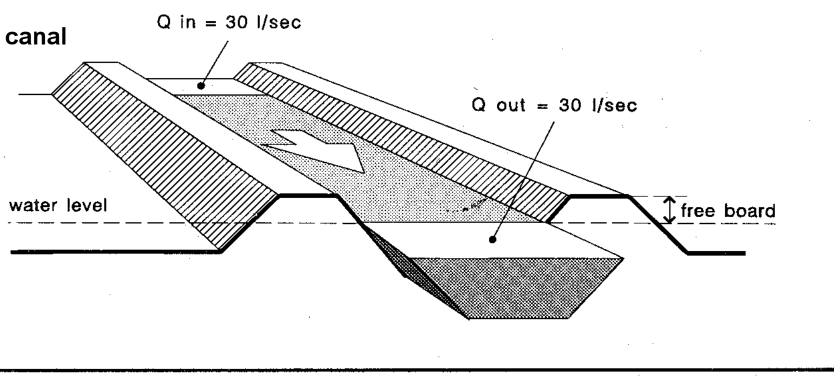


Figure 8 shows a short section of an irrigation canal which transports 30 litre of water every second (l/s). At the upper end of the section a volume of 30 l enters each second. In the same second a volume of 30 l leaves the section at the lower end. If, for example, a container with a volume of 30 l is placed at the end of this canal section, it will be filled every second. In symbols, this discharge is expressed as Q = 30 l/s.

3.1.2 Discharge and demand

The demands for irrigation water in a scheme are not constant during the irrigation season since they are largely affected by the amount of rainfall and by the water requirement of crops growing in the scheme. At the beginning of the season large amounts of water may be needed for land preparation, followed by a period of low water demand during the initial growth of the crop. As the crop develops and reaches full growth, water requirements will increase. Finally the demand decreases as the crop is maturing and ready for harvesting.

There are several ways of meeting the changing water demands of the farms:

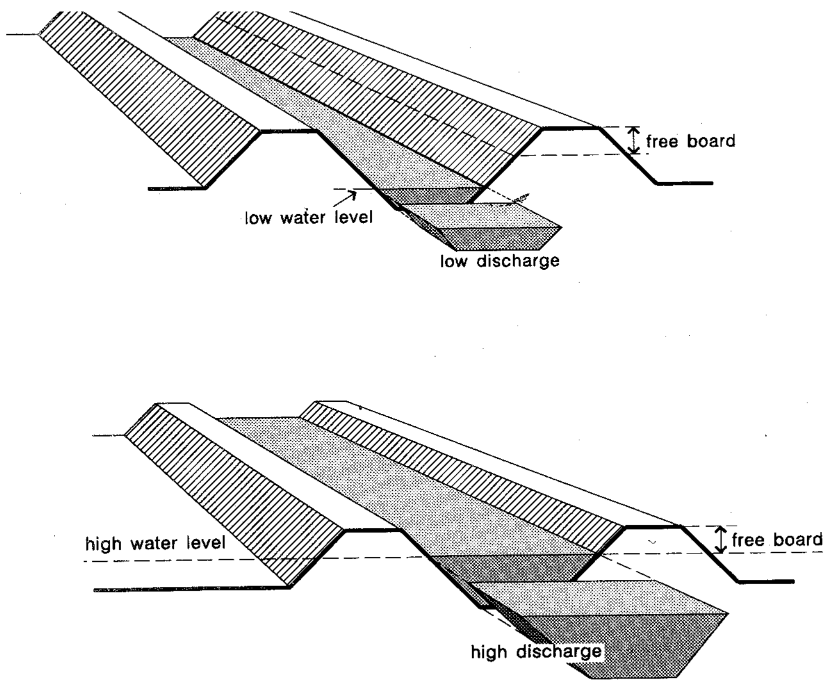
- the discharges in the canals can be adapted to the actual demands by manipulating the control structures or gate settings (See Training Manual 8: *Structures*);
- the duration of water delivery to the farms can be reduced or increased while discharges remain constant (not applicable in the case of continuous supply);
- the period between water deliveries , the interval , can be made longer or shorter, while the discharge and the duration of water delivery remain constant (not applicable in the case of continuous supply); or
- a combination of these.

3.1.3 Discharge control

Whichever of the options above is chosen to meet the actual water demands in an irrigation scheme, the water supply to the scheme and its distribution through the canals and over the fields need regulation and control. In order to supply the required amounts of water to the crops and to avoid waste by supplying too much, it is important to know the discharges in the canals. A procedure to estimate the discharge in a canal is presented in Section 3.2.

In general, in the same canal section, one can say that the water level is low for small discharges and it is high for large discharges, as shown in Figure 9.

FIGUE 9
Water level and discharge: low water level - low discharge; high water level - high discharge



As the discharge in a canal increases and the water level rises, there is a danger that the canal embankment will be overtopped. In order to avoid spillage of water and also to prevent the embankments from being damaged by overtopping water, a certain safety margin, called *minimum required free board*, is provided between the top of the canal banks and the maximum water level. In Figures 9, 11 and 12, the free board is indicated as *fb*. The concept of free board is explained in Section 3.2.2.

When the water level reaches the maximum water level, the discharge in the canal is the maximum allowed discharge, and is called canal capacity. Q_m, or Q_{max}, is commonly used as a symbol for canal capacity. Factors that influence the capacity of a canal are discussed in Section 3.3.

3.2 ESTIMATING THE DISCHARGE

The aim of good irrigation management is to obtain a correct flow division within the canal network and over the fields. This means that discharges in canals should meet the demand for water from the farms. A poor flow division may result in discharges being too high in some canals and too low in others, and could lead to water disputes between farmers. To achieve sufficient and equitable delivery of water to the fields it is useful to know the discharge in the canal. The discharge in a canal can be measured with or without a discharge measurement structure. Methods using structures are described in Training Manual 8, *Structures*, in this series. A method that does not require a structure is described below, and the flow measurement method described here is called the _floating method_. This method is a quick and cheap way to estimate discharge in a canal. However, this method is not very accurate and errors of at least 10% can be expected.

The method consists of estimating the average flow velocity (*V*), and measuring the area of the cross-section, called the 'wetted cross-section' (*A*). The discharge (*Q*) can be calculated by the following formula:

$$Q = V \, ' \, A$$

where: Q is the Discharge in m^3/s;
V is the Average Flow Velocity in m/s; and
A is the area in m^2 of the Wetted Cross-section.

If one wants to know the discharge in l/s instead of m^3/s, the formula to use is:

$$Q = 1\,000 \, ' \, V \, ' \, A$$

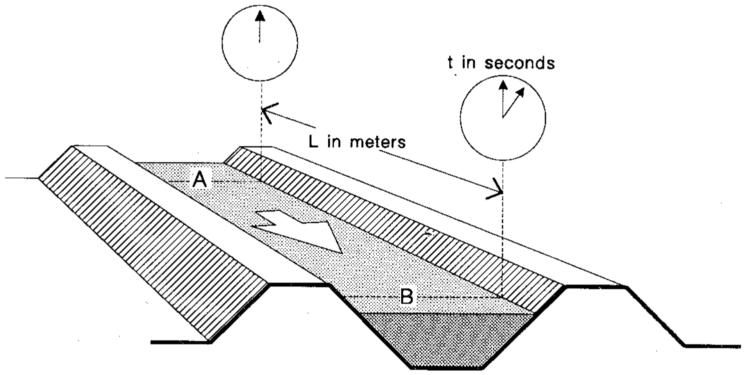
where Q is the Discharge in l/s;
1 000 is a factor to convert m^3 to l [1 m^3 = 1 000 l]; and
V and A are as before.

Section 3.2.1 describes a method to estimate the average flow velocity and Section 3.2.2 gives a method for determining the area of the wetted cross-section.

3.2.1 Average flow velocity

To estimate the average flow velocity, the flow velocity of the water at the surface , the surface velocity, V_s , is first determined. The surface velocity is determined by measuring the time it takes for a floating object, such as a stick, a bottle or a coconut, to travel through a previously measured distance of, say, 10 or 20 metres along the canal. The floating object should be placed

FIGURE 10
Measuring the surface velocity



in the centre of a canal and the time measurement should be repeated several times to avoid mistakes. The stretch of canal used for measurement should be straight and uniform, in order to avoid changes in the velocity and in the area of the cross-section, because any such variation reduces the accuracy of the velocity estimation. See Figure 10.

To compute the surface velocity, V_s, the selected length, L, is divided by the travel time, t:

$$V_s = L / t$$

where: V_s is the Surface Velocity in metres per second (m/s);
L is the distance in metres between points A and B; and
t is the Travel time in seconds between point A and B.

The surface velocity must be reduced in order to obtain the average velocity, because surface water flows faster than subsurface water. For most irrigation canals this reduction factor is about 0.75. The average velocity is therefore found from:

$$V = 0.75 \times V_s$$

where: V is the Average Flow Velocity in m/s;
0.75 is a constant, the Reduction Factor; and
V_s is the surface velocity in m/s found from the previous calculation.

EXERCISE 3

Question: What is the average flow velocity in a canal if:
- the measured length within a straight and uniform portion of the canal was 20 m [L = 20 m], and
- the time needed for a stick to travel along the measured length was 50 seconds [t = 50 s].

Solution:

Step 1 Find the surface velocity, V_s. V_s = L / t = 20 / 50 = 0.40 m/s.

Step 2 Find the average velocity, V. $V = 0.75 \times V_s$ = 0.75 × 0.40 = 0.30 m/s

3.2.2 Area of the wetted cross-section

General

To transport the canal discharge, various shapes and sizes of canal can be used, but the most commonly used shape is a trapezoidal cross-section. It can be used for every type of canal, and whether the channel surface is covered with waterproof material , a lined canal , or not , an unlined or earthen canal. However, rectangular and circular shapes are also used for lined canals. This manual covers only trapezoidal and rectangular shapes, as illustrated in Figures 11 and 12.

FIGURE 11
Rectangular canal

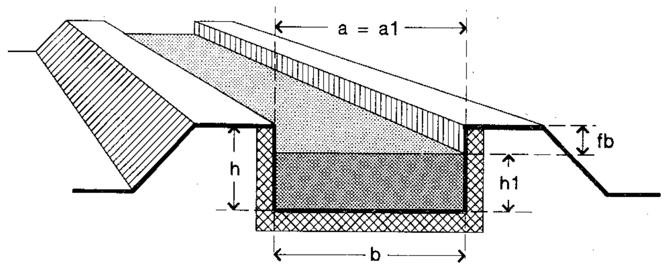
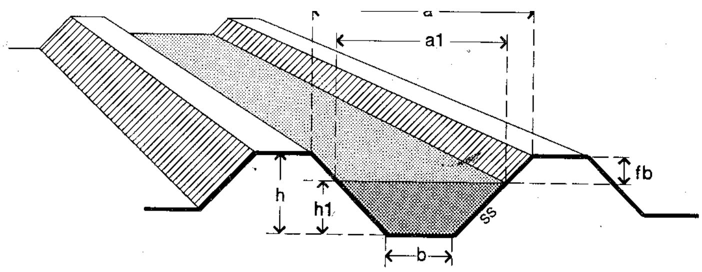


FIGURE 12
Trapezoidal canal



In both Figures 11 and 12 the following symbols are used: **a** is the Top Width, and for rectangular canals **a** = $\mathbf{a_1}$ = **b**; $\mathbf{a_1}$ is the Water Surface Width; **b** is the canal Bed Width; **h** is the Height of the Embankment above the canal bed level; $\mathbf{h_1}$ is the depth of water; **fb** is the Free Board; and **ss** is the Side Slope (not applicable for rectangular canals)

The term free board (fb) was introduced in Section 3.1.3. In order to avoid overtopping of canal embankments and thus spillage of water and possible destruction of the banks by water erosion, a buffer is needed to accommodate fluctuations in water levels in canals. This buffer is called the free board. It is defined as the difference between the water level and the level of the crest of the embankment. The height of the minimum required free board depends on the water depth and on the material used for constructing the embankments. Embankments constructed using sandy material should have more free board than where clay has been used to make the embankments. When embankments are also used as pathways, free board should be increased to help protect them from destruction. As a rule of thumb, the following minimum required free board levels for small and medium canals should be respected:

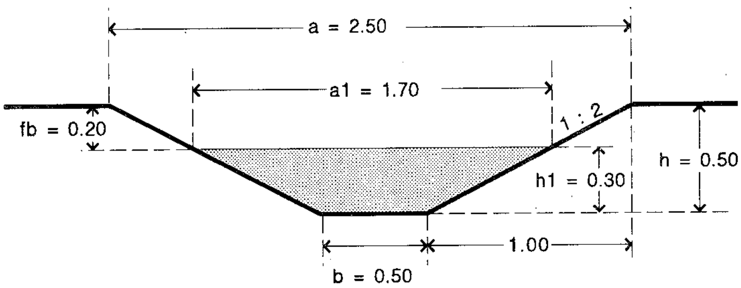
fb = 0.20 m for water depths of 0.40 m or less. The minimum height for an embankment should be the maximum water depth + 0.20 m, or $h = h_1 + 0.20$ m;

fb = 0.5 ′ water depth for water depths of 0.40 m or more. The minimum height of an embankment should be 1.5 x water depth, or $h = 1.5 \times h_1$.

The water surface width, a_1 depends on the side slope, *ss*. a_1 becomes closer to bed width (*b*) as *ss* becomes larger. The side slope depends on the material which is used for constructing the canal, and canals constructed with heavy clay can have steeper side slopes than those built with sandier material. Lined canals which are constructed from bricks or concrete can even have vertical side slopes. Typical side slopes for different canal materials are discussed in Section 4.2.3.

The side slope is expressed as a ratio, for example 1 in 2, 1 to 2, or 1:2. This means that the embankment rises one unit for each 2 units that it goes sideways, e.g., 10 cm up for every 20 cm out, or 50 cm vertical rise for each 100 cm horizontal displacement. This is illustrated with an example in Figure 13.

FIGURE 13
Side slope



The side slope in Figure 13 can be calculated from:

$$ss = \frac{\text{height of embankment}}{\text{width[1] of embankment}}$$

$$ss = \frac{0.50}{1.00} = \frac{1}{2} = 0.5 \text{ or } ss = 1:2$$

Note:

$$ss = \frac{h}{(a-b)/2} = 2 \times \frac{h}{a-b} = 2 \times \frac{0.50}{2.50 - 0.50} = 2 \times \frac{0.50}{2.00} = 2 \times \frac{1}{4} = \frac{1}{2}; \; ss = 1:2$$

or:

$$ss = \frac{h_1}{(a_1-b)/2} = 2 \times \frac{h_1}{a_1-b} = 2 \times \frac{0.30}{1.70 - 0.50} = 2 \times \frac{0.30}{1.20} = 2 \times \frac{1}{4} = \frac{1}{2}; \; ss = 1:2$$

[1] "width" is defined as the horizontal distance from the foot of the slope to the inner edge of the crest.

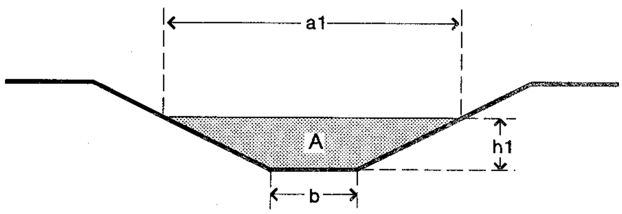
Calculating the area of the wetted cross-section

For measuring the flow with the floating method, the area of the wetted cross-section (A) should be determined for a selected straight and uniform portion of the canal. If the canal is trapezoidal this area is calculated from measurements of the bed width (b), width of the surface water (a_1) and the water depth (h_1) (See Figure 14), using the following equation:

$$A = \frac{(b + a_1)}{2} \times h_1$$

where:
A is area of wetted cross-section (m^2);
b is bed width (m);
a_1 is surface water width (m);
h_1 is water depth (m).

FIGURE 14
Trapezoidal cross-section

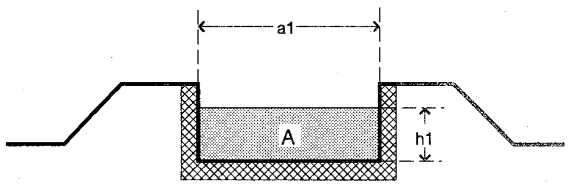


For rectangular canals the equation is as follows (see Figure 15):

$$A = a_1 \times h_1$$

where:
A is area of wetted cross-section (m^2);
a_1 is surface water width (m);
h_1 is water depth (m).

FIGURE 15
Rectangular cross-section



See also Sections 1.1.2 and 1.1.4 of Training Manual 1, *Introduction to irrigation*, in this series, and Figures 16, 17 and 18 below.

Cross-sections of unlined irrigation canals seldom have a regular shape. The bed width and the water depth may vary, even over short distances along the canal. The same applies for lined canals. However the changes in bed width and water depth in lined canals are less than in unlined canals. Because of these irregularities that are typical of unlined canals, the area of the cross-section should be measured several times to get the average area. In Exercise 7 an irregular shape of cross-section is measured.

FIGURE 16-A
Measuring the bed width

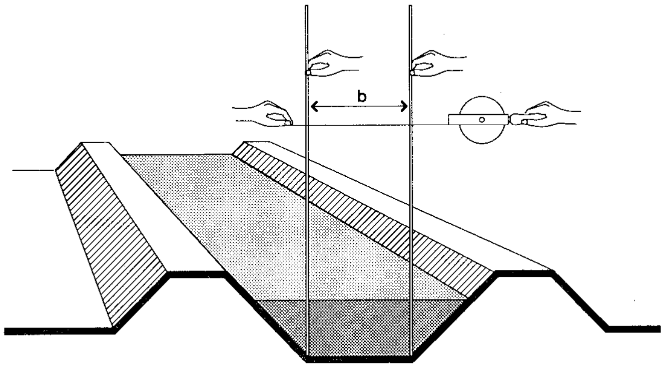


FIGURE 16-B
Measuring the surface water width

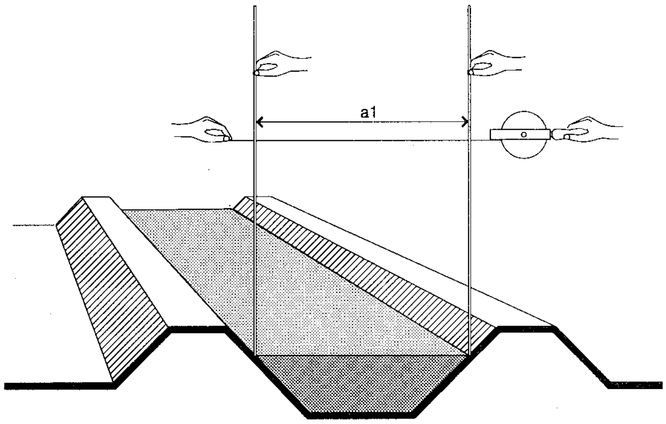
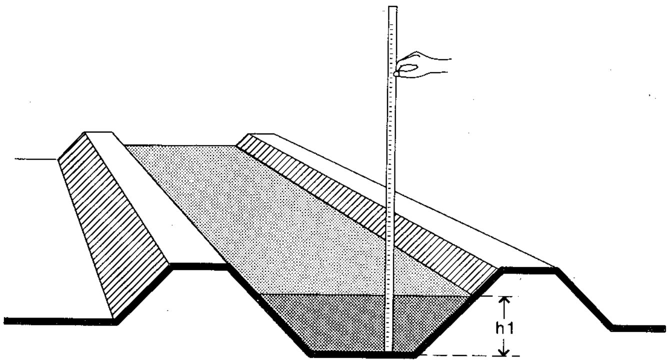


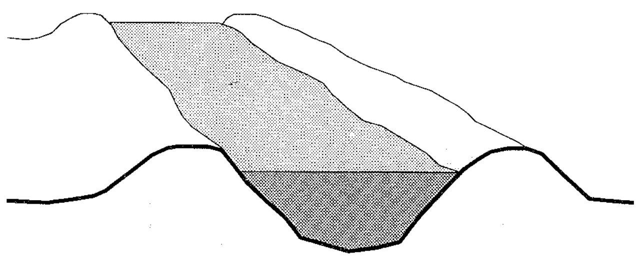
FIGURE 16-C
Measuring the water depth



EXERCISE 4

Question:
How wide are the bed width (b) and surface water width (a_1) and how deep is the water (h_1) of the canal with the slightly eroded cross-section shown in Figure 17?

FIGURE 17
Cross-section of an irregular canal

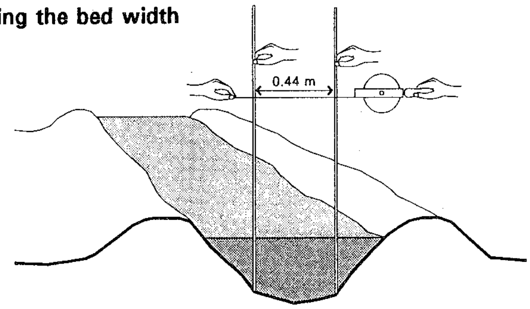


Solution:

Step 1
Find the approximate location of the points where the bed of the canal starts to slope up into the canal banks. Poles or sticks can be used to locate these points. See Figure 18-A. Measure the distance between these points.

It is 0.44 m.

FIGURE 18-A
Measuring the bed width

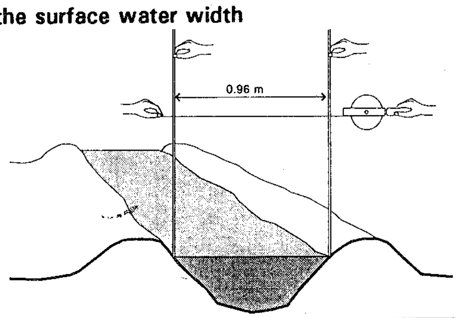


Step 2

Measure the width of the water surface. See Figure 18-B.

It is 0.96 m.

FIGURE 18-B
Measuring the surface water width

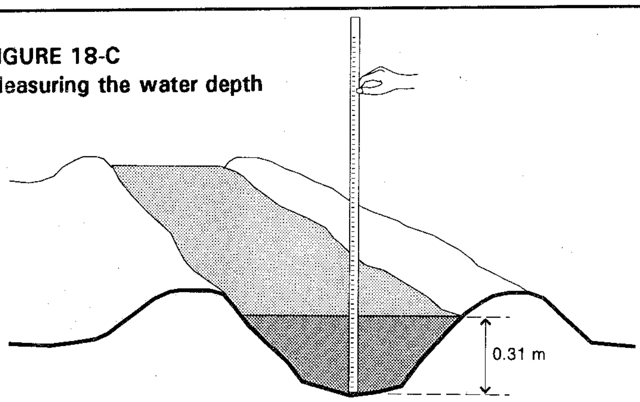


Step 3

Measure the water depth in the middle of the water surface.
See Figure 18-C.

It is 0.31 m.

FIGURE 18-C
Measuring the water depth



3.2.3 Flow estimation procedure

The following presents the procedure for measuring the discharge using a floating object.

Equipment:
- Measuring tape at least 5 metres long
- 4 Stakes
- Stopwatch or watch capable of measuring time in seconds
- Floating object such as a bottle or coconut

Procedure:

Step 1 Select a straight section of the canal at least 10 metres long. The shape of the canal along this section should be as uniform as possible

Step 2 Place two stakes, one each side, at the upstream end of the selected portion of the canal. They should be perpendicular to the centreline of the canal. These correspond to point A in Figure 10.

Step 3 Measure 10 metres or more along the canal.

Step 4 Place two stakes at the downstream end of the selected section of the canal, also perpendicular to the centreline of the canal. These correspond to point B in Figure 10.

Step 5 Place the floating object on the centre line of the canal at least 5 m upstream of point A, and start the stopwatch when the object reaches point A.

Step 6 Stop the stopwatch when the floating object reaches point B, and record the time in seconds.

Step 7 Repeat steps 5 and 6 at least four times in order to determine the average time necessary for the object to travel from point A to point B. The object should not touch the canal embankment during the trial, but if it does the operation must be repeated and the time for the bad trial must not be included when calculating the average time.

Step 8 Measure the following in the selected canal section:
- the canal bed width, b
- the surface water width, a_1
- the water depth, h_1

The cross-section within the selected portion of the canal will usually not be regular, and so b, a_1 and h_1 need to be measured in several places to obtain an average value.

If working with a canal with a rectangular cross-section the surface water width a_1 will equal the bed width b.

Step 9 Calculate the surface velocity, V_s, and then the average flow velocity, V, using the equations given in Section 3.2.1:
- $V_s = L / t$, where t is the travel time is seconds, based on the average of four clear runs of the floating object, and
- $V = 0.75\ '\ V_s$.

Step 10 Calculate the wetted area of the cross-section A, using the formula from Section 3.2.2:

$$A = \frac{(b + a_1)}{2} \quad \text{x } h_1$$

(b, a_1 and h_1 are average values)

Step 11 Calculate the discharge, Q, in the canal, using the formula from section 3.2:

$$Q = V\ '\ A \text{ m}^3\text{/s} \quad \underline{\text{or}} \quad Q = 1\,000\ '\ V\ '\ A \text{ l/s}$$

EXERCISE 5

A straight and uniform portion of a trapezoidal canal was selected. Within this portion a length of 20 m was marked with pegs (Steps 1 to 4 above).

A coconut was used to determine the surface velocity (Steps 5 and 6). This was repeated 4 times with the following results (See Exercise 3):

t_1 = 50 seconds; t_2 = 52 s; t_3 = 53 s; t_4 = 53 s.

The wetted area of the cross-section has been measured 4 times (Step 8) (See Exercise 4:

b = 0.44; 0.42; 0.40 and 0.45 m
a_1 = 0.96; 1.02; 1.03 and 0.94 m
h_1 = 0.31; 0.28; 0.29 and 0.30 m

Question: What is the discharge Q?

Solution:

Step 1 Calculate the average travel time:
$t_{(average)}$ = (50 + 52 + 53 + 53) / 4 = 208 / 4 = 52 seconds.

Step 2 Calculate the average values of b, a_1 and h_1:
$b_{1\ (average)}$ = (0.44 + 0.42 + 0.40 + 0.45) / 4 = 1.71 / 4 = 0.43 m.
$a_{1\ (average)}$ = (0.96 + 1.02 + 1.03 + 0.94) / 4 = 3.95 / 4 = 0.99 m.
$h_{1\ (average)}$ = (0.31 + 0.28 + 0.29 + 0.30) / 4 = 1.18 / 4 = 0.30 m.

Step 3 Calculate the surface velocity V_s and the average flow velocity V:
Surface velocity is given by: $V_s = L / t$
L = 20 metres (marked); t = 52 seconds (Step 1)
Therefore V_s = 20 / 52 = 0.38 m/s.

Average flow velocity is given by: $V = 0.75$ ´ V_s
Therefore V = 0.75 ´ 0.38 = 0.29 m/s.

Step 4 Calculate the wetted area (A) of the cross-section, from Step 2:
The area is given by: $A = ((b + a_1) / 2)$ ´ h_1
b = 0.43 m; a_1 = 0.99 m; and h_1 = 0.30 m.
A = ((0.43 + 0.99)/2) ´ 0.30 = (1.42/2) ´ 0.30 = 0.71 ´ 0.30 = 0.213 m^2

Step 5 Calculate the discharge
Discharge is given by: $Q = V$ ´ A:
V = 0.29 m/s (from Step 3); A = 0.213 m^2 (from Step 4)
Therefore Q = 0.29 ´ 0.213 = 0.062 m^3/s
or
Q = 1 000 ´ V ´ A = 1 000 ´ 0.29 ´ 0.213 = 62 l/s.

Answer: The discharge in the canal is 62 litres per second.

3.3 FACTORS AFFECTING THE MAXIMUM DISCHARGE

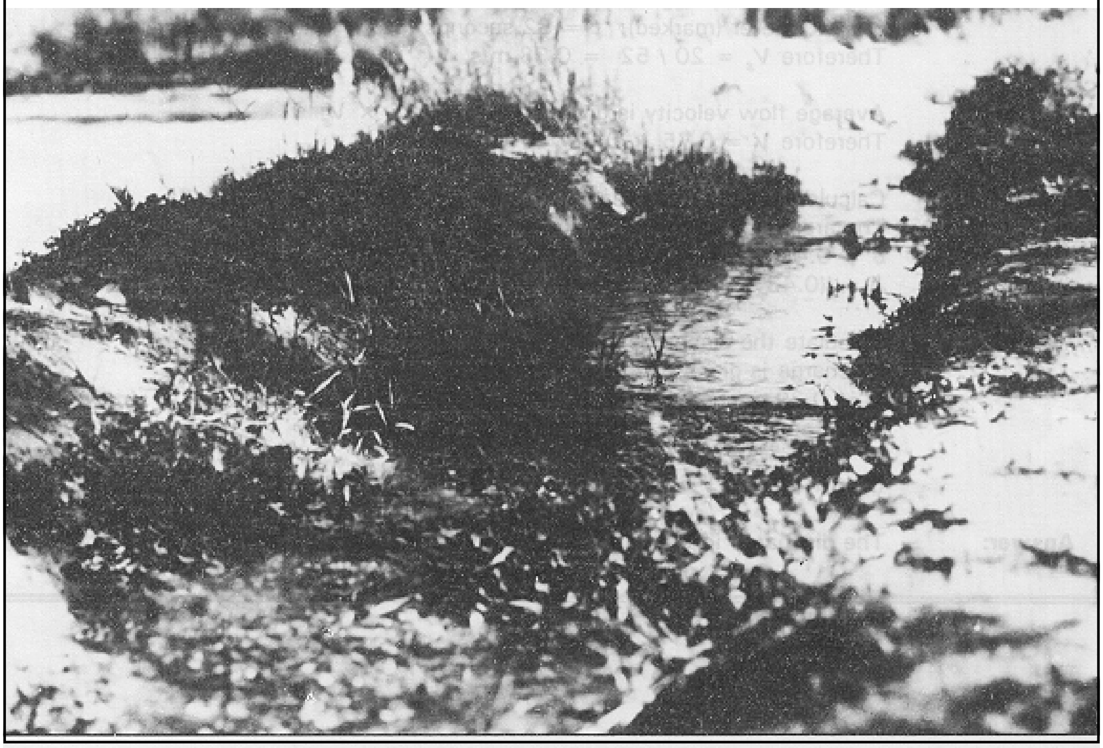
In order to avoid water levels in a canal being too high, the buffer between the water level and the top of the embankment should never be smaller than the minimum required free board for the canal. This means that each canal has a maximum water level which should be respected. Since water level and discharge are related, each canal has a maximum discharge that can safely be transported. This maximum discharge is also called canal capacity. Factors that determine the maximum discharge of a canal are:

- area of the maximum wetted cross-section,
- resistance to the flow, or roughness of the bed and sides, and
- bed slope or longitudinal slope in the direction of water flow.

3.3.1 Area of the maximum wetted cross-section

The area of the wetted cross-section has a great influence on the capacity of a canal. A big cross-sectional area permits a large flow to pass, and the flow velocity will also be higher when the area of the cross-section is larger. For example, if the bed width and the maximum water depth, while still respecting the minimum required free board, both increase by 10%, the capacity of the canal will increase by some 30%. If both increase by 20% or 30%, the capacity increases by some 60% and 100% respectively.

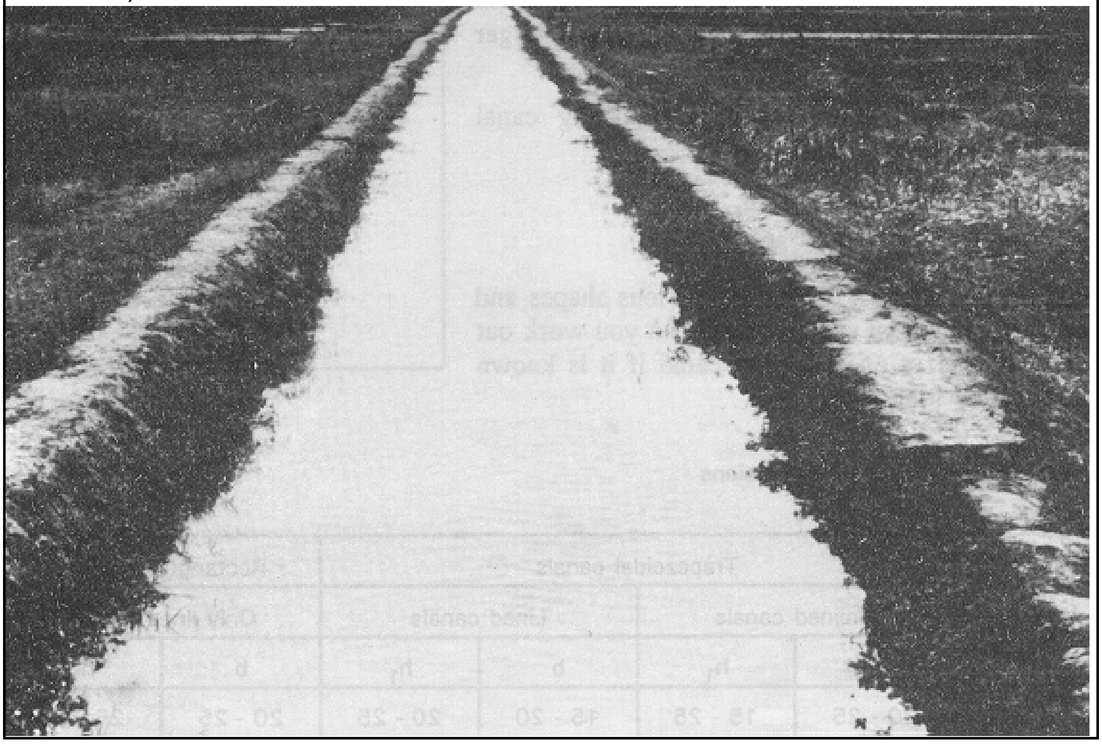
FIGURE 19
Rough, poorly maintained canal



3.3.2 Roughness of the canal bed and sides

The condition of the canal bed and sides also influences the capacity of a canal. In badly maintained canals, especially earthen canals, plant growth develops and becomes an obstacle to the free flow of water. The flow velocity and thus the capacity of a canal will be reduced. This

FIGURE 20
Smooth, well maintained canal



may be illustrated by comparing canals to roads: cars on rough roads will move more slowly than cars on good smooth roads. Similarly, water flows more slowly in a rough, poorly maintained canal than in a smooth, well maintained canal. An example of a rough canal is shown in Figure 19; a smooth, well maintained canal is presented in Figure 20.

If the canal in Figure 20 is allowed to develop plant growth and the canal becomes rough like the one in Figure 19, then its capacity may decrease by some 40%. In other words, the discharge which can safely be transported in the canal may be 40% less than before.

If a canal becomes rough, the flow velocity in the canal will decrease. Referring to the formula $Q = V ' A$, it should be clear that for the same discharge and a smaller average flow velocity, the area of the wetted cross-section has to increase. Thus, due to a lower flow velocity, the water depth will increase and the canal will risk overtopping.

3.3.3 The longitudinal slope

The longitudinal slope of a canal influences its capacity too. The steeper the slope of a canal, the faster will flow the water and thus the larger will be its capacity. See Figure 21.

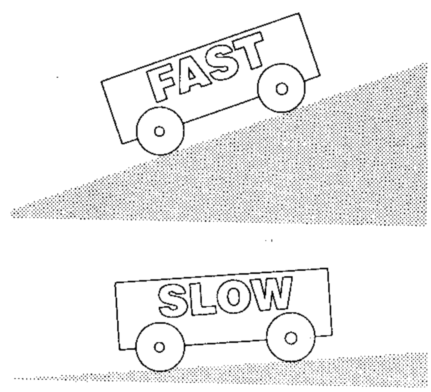
Figure 21 shows two lorries moving down hills. One hill has a steep slope, the other one is almost flat. The steeper the slope, the higher will be the speed of the lorry.

The longitudinal slope of a canal is generally expressed in percent or %. When the elevation of the canal bottom goes down 1 m with 1 000 m of canal length, the slope is 1/1 000, or 0.1%. (See Training Manual 1: *Introduction to irrigation*.) In general, the canal layout is made so that the longitudinal slope of a canal is somewhere between 0.05% and 0.15%, as discussed in Annex 3 of this Manual.

To illustrate the effect of canal slope on canal capacity, two canals with the same cross-section can be compared: one canal has a slope which is 10% steeper than the other. The canal with the 10% steeper slope will have a capacity which is 5% larger than the other canal.

Of course the slope of an existing canal cannot be made any steeper.

FIGURE 21
Longitudinal slope and velocity



3.4 CANAL DIMENSIONS

To transport the canal discharge, various shapes and sizes of canal can be used, so how can you work out the dimensions of an irrigation canal if it is known what capacity it should carry?

TABLE 1
Indicative values for canal dimensions

Capacity (l/s)	Trapezoidal canals				Rectangular canals	
	Unlined canals		Lined canals		Only lined canals	
	b	h_1	b	h_1	b	h_1
25	20 - 25	15 - 25	15 - 20	20 - 25	20 - 25	25 - 30
50	20 - 30	20 - 30	25 - 30	20 - 25	30 - 35	30 - 35
75	25 - 35	25 - 35	25 - 35	25 - 30	35 - 45	35 - 40
100	30 - 35	25 - 40	30 - 35	30 - 35	40 - 45	35 - 45
125	30 - 40	30 - 45	30 - 35	30 - 40	45 - 50	40 - 50
150	30 - 45	30 - 45	35 - 40	35 - 40	45 - 50	45 - 55
175	35 - 45	35 - 50	35 - 40	35 - 45	50 - 55	45 - 60
200	35 - 50	35 - 55	40 - 45	35 - 45	50 - 60	50 - 60

As was discussed in Section 3.3, the capacity of a canal is determined by the area of the wetted cross-section, the bed roughness and the longitudinal slope of the canal. Table 1 gives indicative figures for required bed widths and water depths for different canal capacities. The table covers both lined and unlined canals with trapezoidal cross-sections, and lined rectangular canals, and is valid for longitudinal slopes of between 0.05% and 0.15%; side slopes between 1:2 and 1:1 in unlined canals and between 1.5:1 and vertical in lined canals. Since different combinations of longitudinal slope, side slope and bed roughness , with smooth beds and sides without plant growth, or rough due to plant growth , are possible, margins of variation are given for the dimension of the cross-section of the canals.

The lower limits of bed width *b* and water depth h_1 are valid for canals which have a steep slope (close to 0.15%) and which are clean and well maintained. The higher limits are valid for canals with flatter slopes and which are covered with plant growth.

The table shows that for the same discharge, a larger canal size is required when it is not well maintained (rough surface) or the longitudinal slope is flat, and even more if both apply. For exact dimensions, detailed information is needed on the side slope, the longitudinal slope and on the roughness of bed and sides.

Chapter 4

Main problems in a canal network

4.1 INTRODUCTION

This chapter looks at problems which are frequently encountered in irrigation canal systems. Some of these are described in detail. The last section of this chapter explains why regular inspection of the system is required.

The main problems that can be found in an irrigation canal network include:

- limited amounts of water available at the water source;
- high water consumption in fields close to the water source resulting in water shortages at the tail end of the scheme;
- illegal manipulation of canals and structures;
- siltation;
- plant growth;
- water losses;
- frequent overtopping; and
- low water levels due to canal erosion.

Some of these problems may be caused by sub-optimal management and organization within the scheme, and Training Manual 10 in this series will cover that subject.

Bad design or bad construction may also be the cause of sub-optimal functioning of a scheme. A canal may be too small to supply enough water to irrigate the area served by the canal, and if the discharge needed is supplied to such a canal, it will be excessive and water will overtop. Also the water level in a canal may have been wrongly determined, and if it is too low water may not enter the fields by gravity. Check structures or even pumps will then be needed to supply the fields with sufficient water.

If the minimum required free board levels are not respected, canals can easily overtop in emergencies.

Canal slopes which are too steep may suffer erosion from high flow velocities. When construction materials are not well chosen, canals may collapse.

Lack of maintenance of the canal network will also cause severe problems, which are discussed later, in Chapter 5.

4.2 TECHNICAL PROBLEMS

Three of the problems mentioned above, and which are of a technical character, are described below in detail: water losses; overtopping; and canal erosion.

4.2.1 Water losses

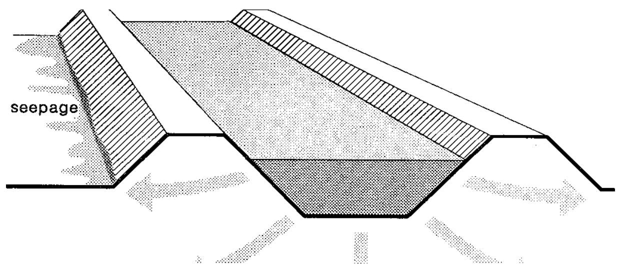
A well designed and constructed canal system transports water from the source to the farmers fields with a minimum amount of water loss. However, water losses will occur and can seriously reduce the efficiency of water delivery. Water may be lost by seepage, leakage, or both.

Seepage

Water that seeps through the bed and sides of a canal will be lost for irrigation. This so-called 'seepage loss' can be significant where a canal is constructed from material which has a high permeability: water seeps quickly through a sandy soil and slowly through a clay soil, and so canals constructed in sandy soils will have more seepage losses than canals in clay soils.

The results of seepage through the sides of a canal can sometimes be very obvious, such as when fields adjacent to a canal become very wet, and even have standing water (See Figure 22).

FIGURE 22
Canal with seepage water at the toe of the canal embankment



Seepage loss through the canal bed is difficult to detect because water goes down and does not appear on the nearby ground surface. Seepage can be reduced by:

- reinforcing the canal bank (See Section 5.3), or
- sealing or lining the canal bed and sides (See Chapter 6).

Leakage

Water may also be lost for irrigation by leakage. This water does not seep, but flows through larger openings in the canal bed or sides.

Leaks can develop in several ways:

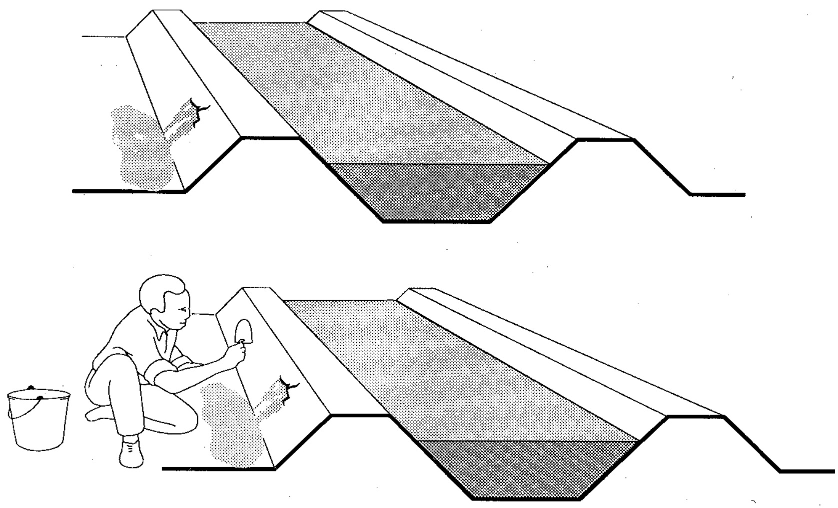
- by rat or termite holes in a canal bed or sides;
- eroded and washed canal bank;
- small tunnels started by seepage water in a badly compacted or sandy section of a canal bank;
- seepage around structures, leading to severe leakages;
- gates which are not tightly sealed;
- cracked concrete canal linings, or joints that are not tightly sealed; or
- torn asphalt or plastic lining.

Leakage often starts on a small scale, but the moment that water has found a way through a canal embankment a hole will develop through which water will leak. If the leakage is not stopped in time, the tunnel becomes larger and the canal bank may be washed away at a certain moment. In the case of a lined canal, the canal foundation may be undermined after some time and the canal will collapse.

Serious leakage can be avoided when the canal system is inspected frequently and when repairs are carried out immediately. The longer a hole or crack is left, the larger it will become.

Figures 23 and 24 show that quick action can save time and money.

FIGURE 23
A crack in a canal bank is repaired soon after it has been observed



In Figure 23, a small hole in a canal bank is repaired soon after it has been observed. In Figure 24, no attention has been paid to the leak, and, after some weeks, part of the canal bank has been washed away by the continuously leaking water. More time and money is needed to repair the canal in this case.

Repair of a leak is described in Section 5.4.

4.2.2 Overtopping

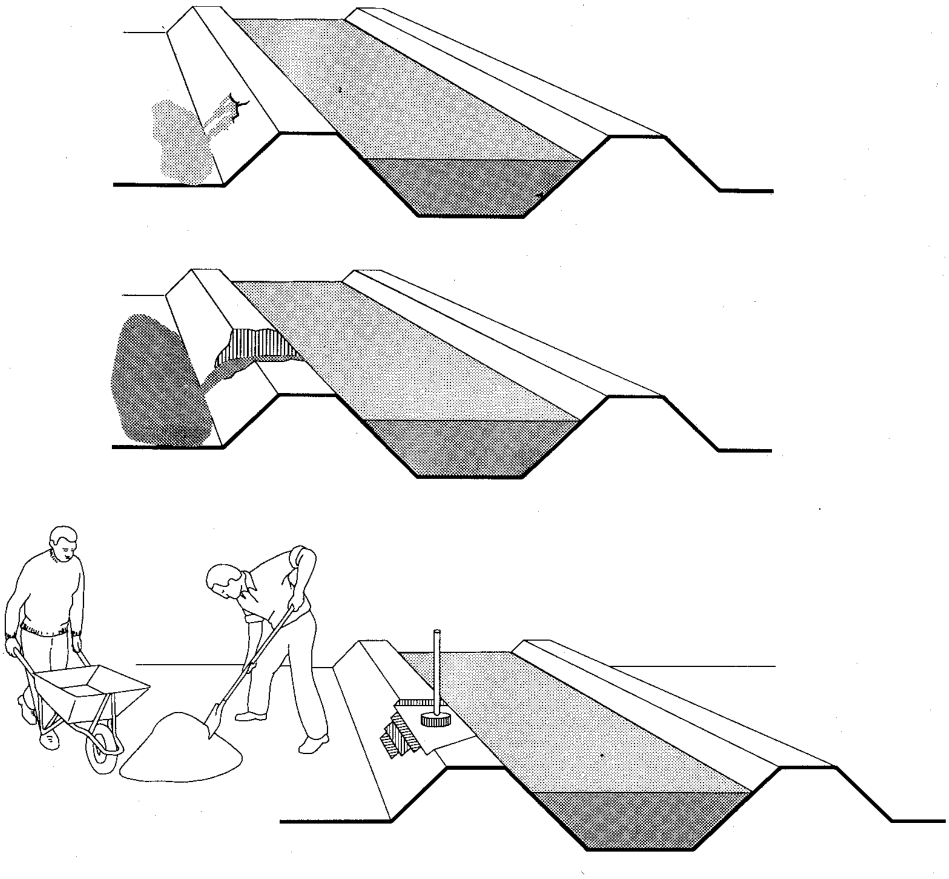
Water in a canal may rise unexpectedly due to several reasons:

- the incoming flow through the canal offtake may be much greater than the canal capacity;
- obstacles such as stones, blocks or plant growth in the canal may dam up the water;
- outlets from a canal may be closed which should be open;
- rain or other water may be draining into the irrigation canal; or
- farmers may make temporary weirs to raise the water level.

If no action is taken, the water level can reach the top of the canal banks and overtop. See Figure 25.

Overtopping causes erosion of the canal banks and may lead to serious breaches. It can be avoided by improving the operation of the system. Discharges should be limited and gates should only be closed and opened according to the planned schedule. To prevent overtopping, which can happen even in the best irrigation systems, a spillway - also called an emergency

FIGURE 24
Delayed repair of a leakage



outlet - can be installed in the canal bank so that excess flow can be spilled without harming the canal. See also Section 5.5, and Training Manual 8: *Structures*.

4.2.3 Canal erosion

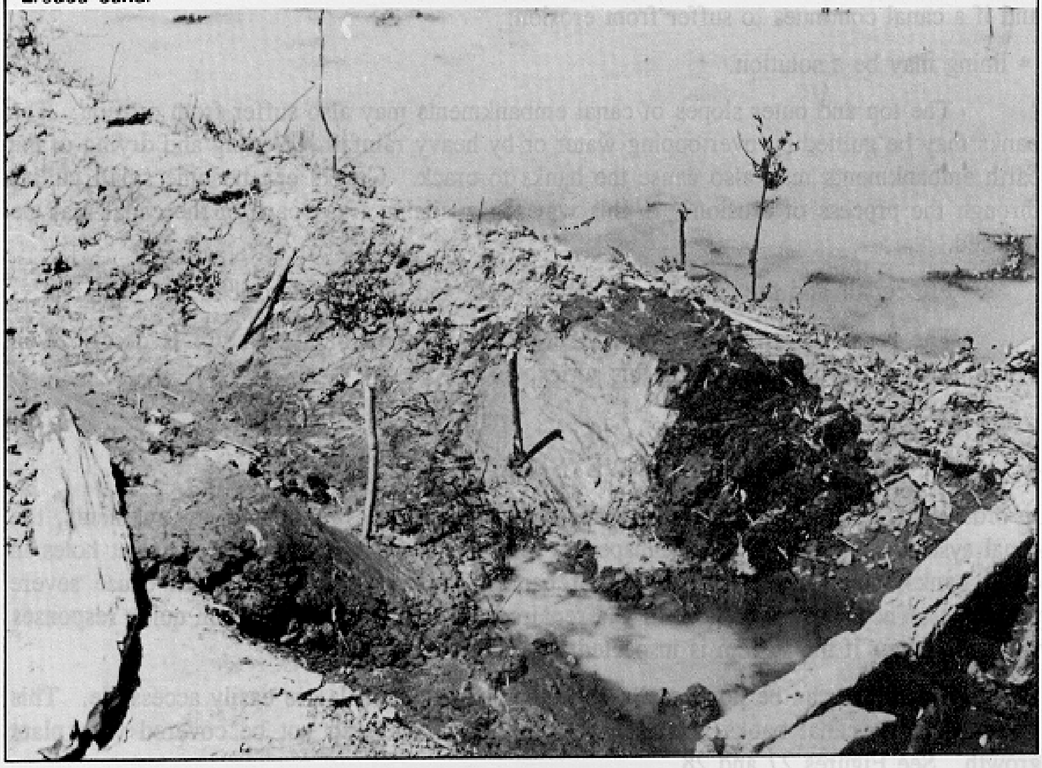
The sides and bed of an unlined canal are sometimes badly attacked by scouring water. This process is called erosion. Canal bends and sections downstream of structures in particular are susceptible to erosion, since local flow velocities can be very high and the direction of flow changes suddenly, causing turbulence.

The inner side slopes of a canal which are too steep or which are not well compacted, may slide. The soil will be washed away by the flowing water and the canal will erode if the flow velocity is excessively high.

Figure 26 shows an eroded canal. The original and the actual cross-section can be clearly seen. The embankments have collapsed and the cross-section no longer has its original shape: it has become irregular. The canal banks have become smaller and the bed is wider than before. As a consequence, more water is needed to fill the canal and to attain the water level required, and there is more danger of a breakdown of the narrowed banks. When the embankments of a canal are not very solid, erosion can result in leakage.

FIGURE 25
Overtopping of a canal bank

FIGURE 26
Eroded canal



Another problem is that the eroded soil will be deposited , known as siltation , in structures downstream of the eroded canal section. This may cause a malfunctioning of the structures. Eroded soil could also be deposited in canal sections, thus reducing the capacity and causing the flow to overtop the bank.

Canals that are constructed with soil that contains a high content of sand are very susceptible to erosion. To avoid erosion of such a canal, the flow velocity must be very low, and the side slopes must be flat. In this respect limits are set on the flow velocity and the side slope, and these are given in Table 2.

When the velocity in a canal exceeds the limiting flow velocity, unacceptable erosion of the canal is to be expected, and, when the side slopes of a canal are steeper than the limiting side slopes, the canal banks may collapse.

TABLE 2
Limiting side slopes and flow velocities for canals

Construction material	Limiting side slope	Limiting flow velocity (m/s)
Sand	1:3 (1/3)	0.4
Sandy loam	1:2 (1/2)	0.6
Clay loam	1:1.5 (2/3)	0.8
Clay	1:1 (1)	1.2
Bricks	1.5:1 (1.5) or vertical	1.5
Concrete	1.5:1 (1.5) or vertical	2.0

These limiting values depend on the material which has been used for constructing the canal. The flow velocity in a canal made with a clay soil can be higher than the flow velocity in a canal made from sandy material. The banks of a clay canal can also be made steeper than the banks of a sandy canal.

Erosion by water can be prevented by:

- reducing the flow velocity, and
- making the inner canal banks more stable,

and if a canal continues to suffer from erosion:

- lining may be a solution.

The top and outer slopes of canal embankments may also suffer from erosion. The banks may be gullied by overtopping water or by heavy rainfall. Wetting and drying of the earth embankments may also cause the banks to crack. Cracks can become small gullies through the process of erosion. In this way the available free board of the canal may be reduced.

For repair and prevention, see Section 5.6, and lining is described in Chapter 6.

The repair of an eroded canal section downstream of a structure is described in Training Manual 8: *Structures*, in this series.

4.3 INSPECTING THE CANAL SYSTEM

In order to prevent major problems such as leakages and destruction of embankments, the canal system should be regularly inspected throughout the irrigation season. Rat holes in canal banks, small leakages, erosion of canals and cracks in linings can cause severe problems. They must to be noticed and repaired as soon as possible. Such quick responses will only occur if the system is inspected frequently.

Inspection can be done easily and quickly if the canals are easily accessible. This means that the canal banks should have good pathways, and not be covered with plant growth. See Figures 27 and 28.

Who inspects the canal system?

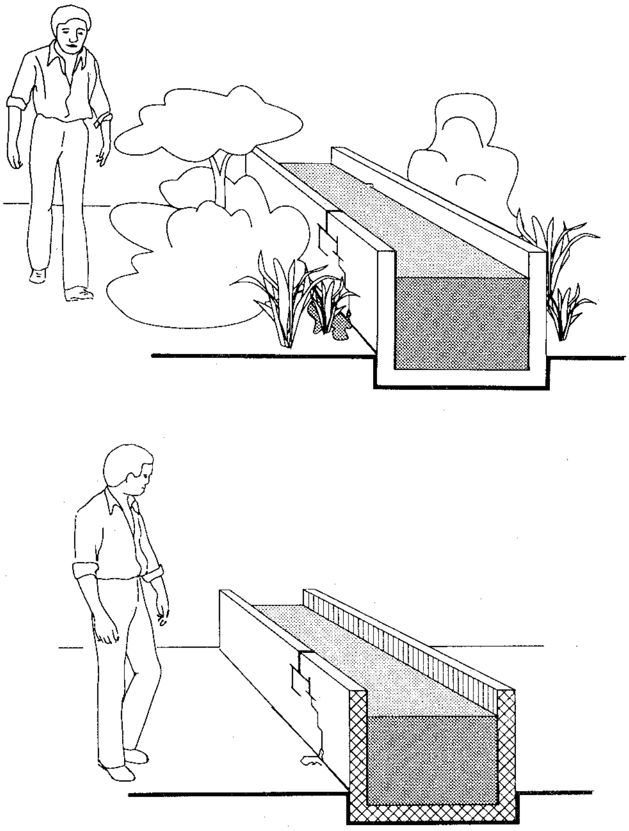
Small irrigation systems are usually operated and managed by the farmers themselves through their own irrigation committees. They can take care of daily inspections of the canal system while passing the canals on their way to and from the fields.

In larger schemes, inspection of the smaller tertiary canals can be done every day by the farmers using the canal. Inspection of the secondary and primary canals in these larger schemes needs to be systematically organized by the irrigation committee.

Whoever inspects a canal and finds a shortcoming in the system should inform the irrigation committee as quickly as possible. The irrigation committee should then take action for immediate repair.

FIGURE 27
Heavy plant growth makes inspection difficult

FIGURE 28
Clean canal embankments are conditional for rapid inspection



Chapter 5

Maintenance and repair works

5.1 INTRODUCTION

This chapter describes why and how a canal system should be maintained. The chapter also looks at some of the most important repair works in connection with canals.

The performance of an irrigation canal system depends not only on how the system is operated, but also on the condition of the canals. Irrigation canals function well so long as they are kept clean and if they are not leaking. If no attention is paid to the canal system, plants may grow and the problem of siltation may arise. Even worse, the canals may suffer from leakages.

Plant growth and sedimentation not only impede the flow in a canal, they also diminish the area of the cross-section. As a consequence, the canal capacity may diminish (see Section 3.3). A reduction in the capacity may result in overtopping and a limit on water supply to the fields. The available water will also be reduced when there are leakages in a canal. To protect the system from these problems, the canals should be maintained on a regular basis.

It is not just the smaller, tertiary irrigation canals that need to be maintained, it is the primary and secondary canals as well. Sometimes these canals may be located far from the farmers' fields and this can be one reason why farmers show no interest in maintaining them. However, the smaller canals receive water from these canals and so maintenance of the larger canals is of vital importance for the proper functioning of the whole system.

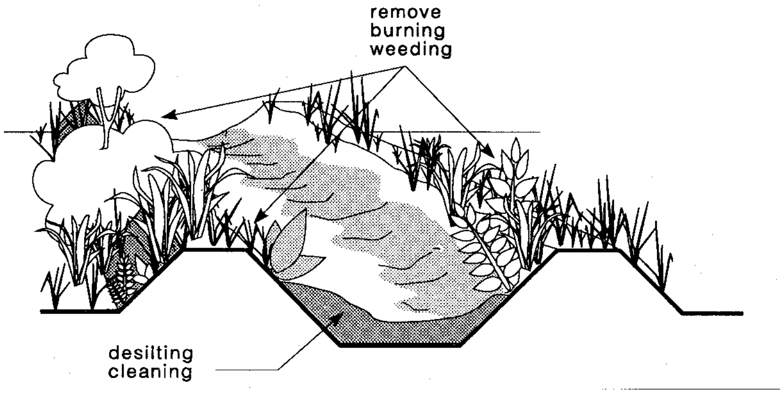
Even when a canal is well maintained, serious technical problems may arise. These problems need to be solved by repair or improvement works. A repair should usually be done as soon as possible, depending on the severity of the problem. Improvements, such as the lining of a canal section, may be postponed until the end of an irrigation season, when canals are dry and farmers have more time available.

After a serious problem is found on an inspection tour, a team of workers or farmers should be available for repair as soon as possible. Such a team should be formed at the beginning of the irrigation season in order to have it on call in case of emergencies. The same team may be asked to do the improvement works. If necessary, a contractor may be asked to do the job.

5.2 CANAL MAINTENANCE

A good maintenance programme can prolong the life of canals. A routine, thorough programme should be kept to. Maintenance of an irrigation canal system is usually carried out in between two irrigation seasons, or at times of low water demand. It consists of cleaning, weeding, de-silting, re-shaping, and executing minor repairs.

FIGURE 29
Weeding, cleaning and de-silting



- Bushes or trees on canal embankments should be removed. They may obstruct the water flow and their roots will open the compacted soil in the banks and cause the development of leakages.
- Plants, silt and debris in the canal should be removed. While cleaning the canal bed, care must be taken that the original shape of the cross-section is kept. For this, a wooden frame, or template, with the exact dimensions of the designed cross-section of the canal being cleaned, can be of great help (see Section 5.6.1).
- Breaches and rat holes in the embankments should be filled with compacted soil, inside as well as outside of the embankment. For compacting, the soil should be wetted.
- Weak sections and sections of canal embankments where people or animals cross the canal should be strengthened with compacted soil or with bricks.
- Eroded sections of a canal should be rebuilt to the original shape.

See also Figures 29 and 30.

For maintenance operations it is important to organize farmers and to involve them in the activities. See Figure 31.

5.3 REDUCTION OF SEEPAGE LOSSES

Parts of a canal bank or the entire bank can be highly permeable to water. Water that seeps through the banks will be lost for irrigation and may create waterlogging in the fields and roads adjacent to the canal.

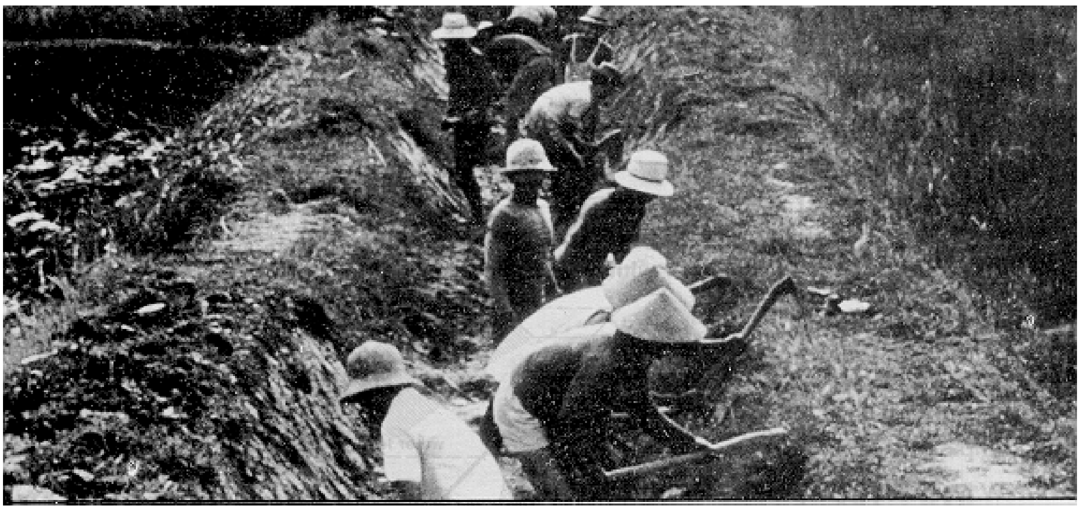
There are two ways to overcome seepage problems, either

- reduce the permeability of the canal bank, or
- line the canal.

The second solution, lining, will be described in Chapter 6.

FIGURE 30
Fully covered canal bed

FIGURE 31
Canal maintenance



Reducing the permeability of a canal bank

The permeability of a canal bank can be reduced by compacting the centre, or core of the embankment. The core is first excavated by digging a narrow trench, and then replaced with soil in layers, compacting each layer. The compacted core should extend above the water level.

The procedure is:

Step 1 Remove the vegetation on the canal bank and the top of the bank. (Figure 32-A)

Step 2 Excavate a narrow trench near the inner side of the canal bank.

A trench is excavated in the permeable section of the canal. The width of the trench is at least 0.5 x the water depth in the canal. The bottom of the trench should be some 20 cm below the original ground surface elevation (Figure 32-B)

Step 3 Compact the bottom of the trench with a manual tamper and replace the soil in layers of about 5 to 10 cm each. The soil should be moist when being compacted.

When the excavated material is rather

FIGURE 32-A
Preparation for core compaction

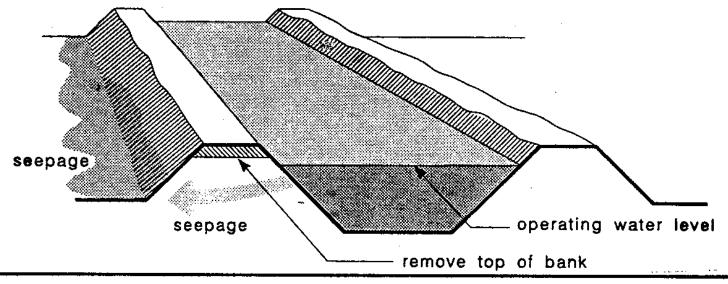


FIGURE 32-B
Excavation of a narrow trench

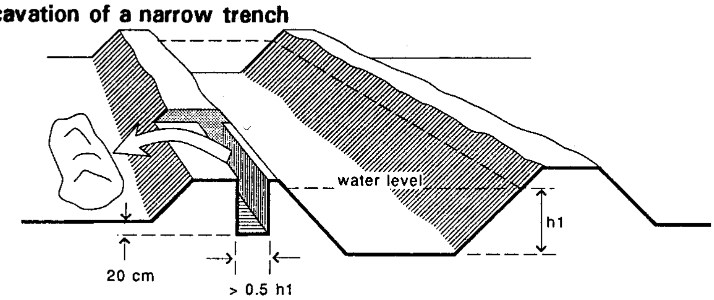


FIGURE 32-C
Refilling the trench and compacting each layer

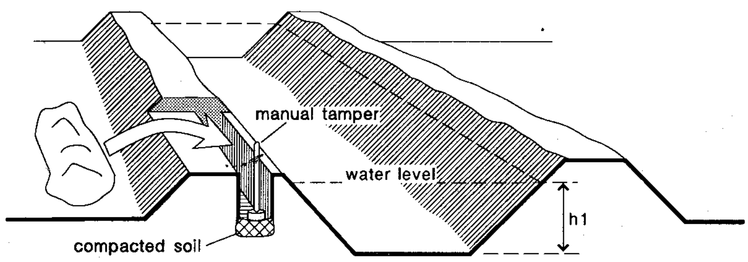
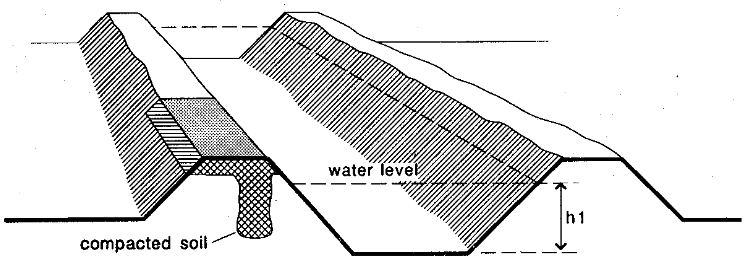


FIGURE 32-D
Canal bank with compacted core



sandy, the core should be filled with other material which contains more clay. Each layer is wetted and the wetted soil is then compacted. Wetting the soil is conditional for good compaction, since the aggregates in soil that is moist will disintegrate by tamping, while those in dry soil will not. (Figure 32-C)

Step 4 Fill and compact the trench until the top is reached. (Figure 32-D)

5.4 REPAIR OF A LEAK

Most irrigation canals will leak.

A hole or a crack in the bank of a canal, through which water is leaking, is easily observed since the fields adjacent to the leaking canal will be wet. A hole or a crack in the bed of a canal is difficult to see, unless the canal is dry and the bed is inspected very carefully.

Leaks should be repaired immediately after they have been observed.

The procedure for repairing a leak is:

FIGURE 33-A Indication of the leak

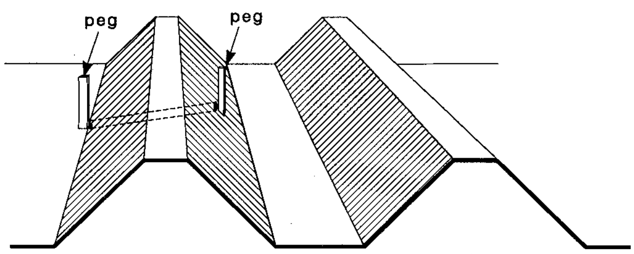


FIGURE 33-B Excavation of the canal bank below and beside the leak

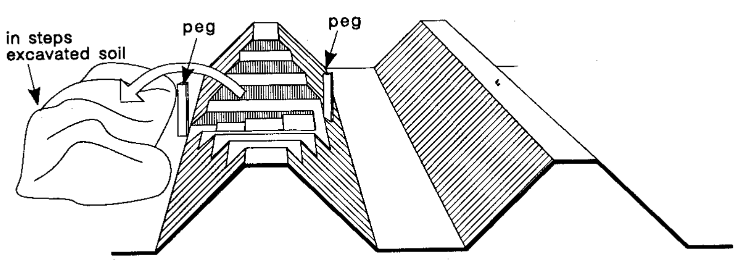
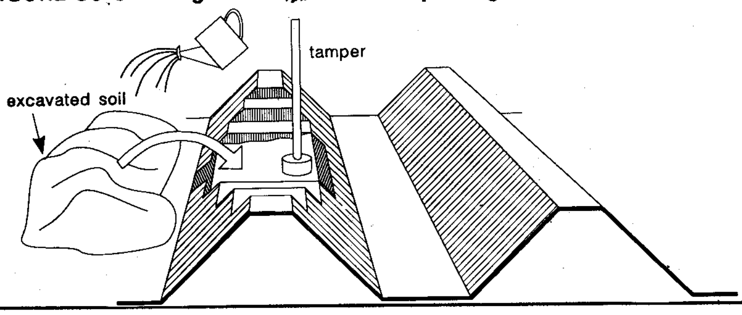


FIGURE 33-C Filling each layer and compacting the moist soil



Step 1 Empty the canal and indicate the location of leakage with pegs. They are placed at its entrance in the canal bed and at its exit in the outer bank.

Step 2 Remove the vegetation and keep it apart. Excavate the canal bank to well below and besides the leak. The canal bank which leaks is excavated in steps, with the smallest step well below the leak. (Figure 33-B)

Step 3 Rebuild the canal bank by filling the bank in layers with moist soil, and compact each layer well. (Figure 33-C)

For lined canals, the same procedure as above can be followed but with one difference: before the bank is excavated, part of the canal lining should be removed. After filling and compacting the earth bank, the lining should be reconstructed.

NOTE 1: Repair of a crack in the canal lining alone will not be sufficient, as the lining could be severely undermined by the leaking water, which will quickly cause a new hole or crack to appear in the lining.

NOTE 2: Joints between lined sections of a canal should be sealed periodically to avoid leakages.

5.5 HOW TO AVOID OVERTOPPING

Overtopping of a canal section is caused by an excessive discharge in that section in relation to the actual canal capacity. Canal banks which are frequently overtopped are very probably eroded and lowered, and thus the actual capacity will be less than the original capacity for which the canal has been designed. Overtopping can be avoided in two ways, either:

- reduce the discharge, or
- increase the canal capacity.

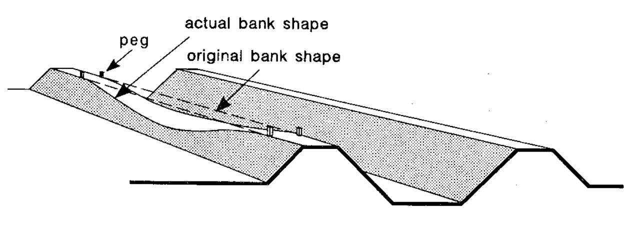
No explanation is necessary for the first solution, and so only the second solution, which re-establishes the canal capacity, is described below.

The procedure to re-establish a canal capacity by rebuilding its banks is:

Step 1 Remove the vegetation, if any.

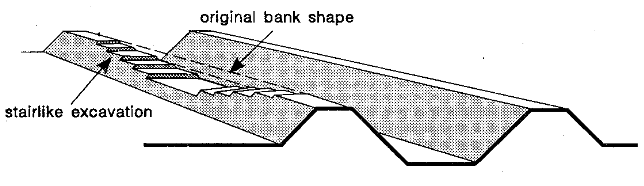
Hammer pegs in the canal bank at both sides of the section concerned. (Figure 34-A) (With these pegs and a rope the level of the section can be checked).

FIGURE 34-A Lowered section of a canal bank



Step 2 Excavate the top and sides of the bank like stairs. (Figure 34-B)

FIGURE 34-B Stair-like excavation of the bank



Step 3 Rebuild the bank by filling the excavated portion with clayey soil. Fill by layers of 5 to 10 cm and compact it in wet condition. (Figure 34-C)

While raising the embankment, check the level regularly.

Step 4 Trim the sides and lay grass sods on the bank when the top is reached. (Figure 34-D).

When it is impossible to avoid high water levels, an emergency outlet, or spillway, can be installed. An emergency outlet consists of a protected lowered section of a canal embankment and a protected outlet to the drainage system. Such a structure will allow water to escape into the drainage system without damaging the canal banks.

The level and the length of the structure should be such that the excess discharge can be safely evacuated and the water level will not rise higher than the highest allowed water level (free board level).

FIGURE 34-C Refilling and compaction of each layer in a wet condition

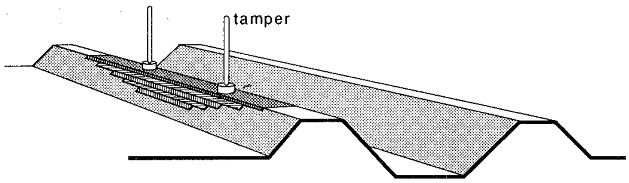


FIGURE 34-D Finishing the bank and laying grass sods once the top is reached

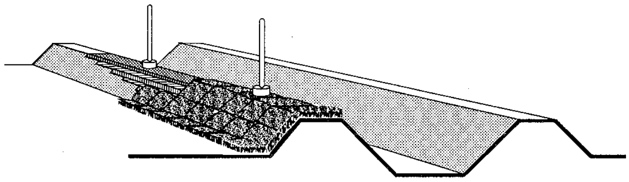


FIGURE 35
Emergency outlet

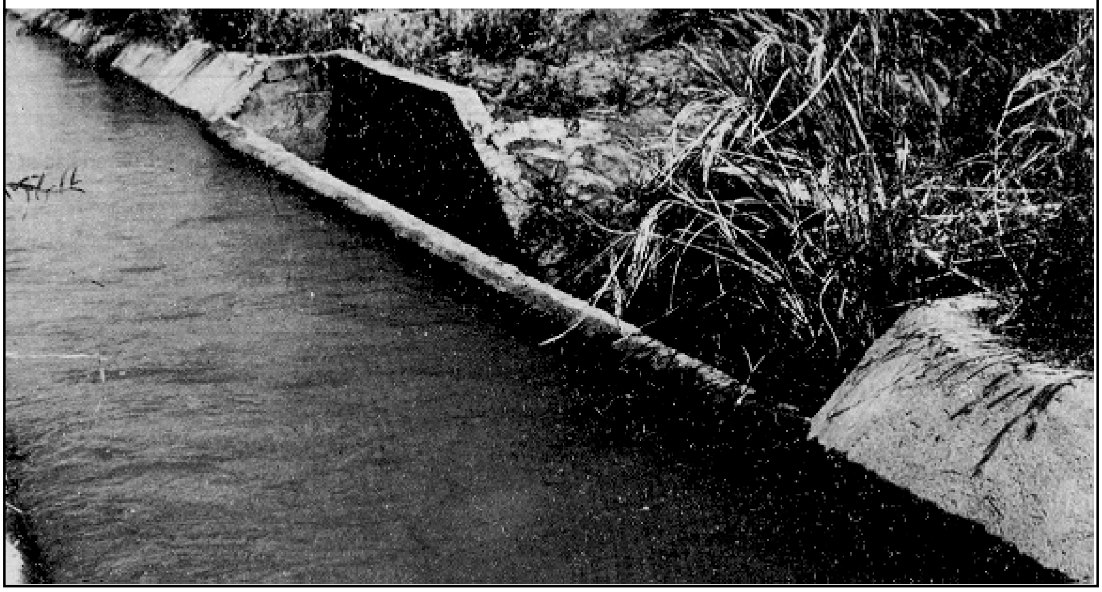


Figure 35 shows an emergency outlet. The water level is lower than the crest of the emergency outlet. An engineer should be consulted for the design and the installation of an emergency outlet.

5.6 CANAL REPAIR AND PREVENTING EROSION

5.6.1 Repair

An eroded canal or canal embankment needs at some time to be reshaped. First the repair of an eroded canal is described, and second the repair of gullies and cracks in an eroded canal embankment.

Reshaping an eroded cross-section

The reshaping and widening of an eroded cross-section involves the following steps:

Step 1 Construct a wooden template.

If the original side slopes had been constructed too steeply and thus were unstable, make the template so that the new side slopes are flatter. The top width of the canal is then larger while the bed width remains the same. Care must be taken to avoid narrowing the original canal bank crest widths. (Figure 36-A)

FIGURE 36-A Template for (a) original cross-section; (b) cross-section with flatter side slopes

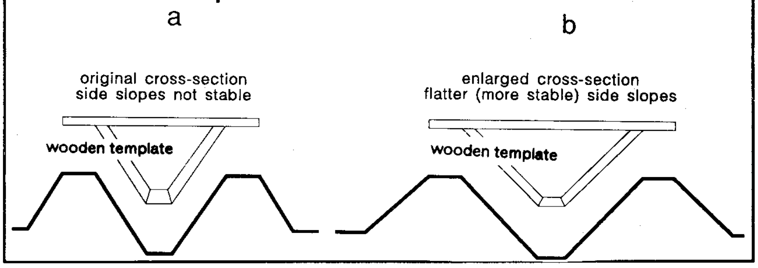
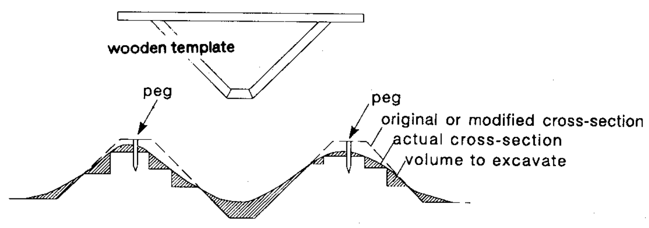


FIGURE 36-B Using the template to set the profile for the rebuilt cross-section



Step 2 Hammer in reference pegs to indicate the original level of the canal banks on each side of the canal. Excavate the bed and sides of the eroded canal section in steps until they reach slightly below the actual bed level so that the new soil to be placed will make better contact with the original ground surface. (Figure 36-B)

Step 3 Fill and compact moist soil layer by layer, using the template for final shaping. Each layer to be compacted should not be thicker than 5 to 10 cm. (Figure 36-C)

FIGURE 36-C Building up in layers compacted when moist

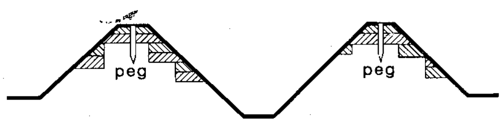
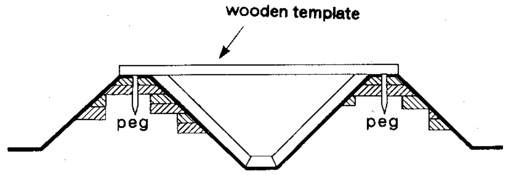


FIGURE 36-D Check the repaired cross-section and level using the template and reference pegs

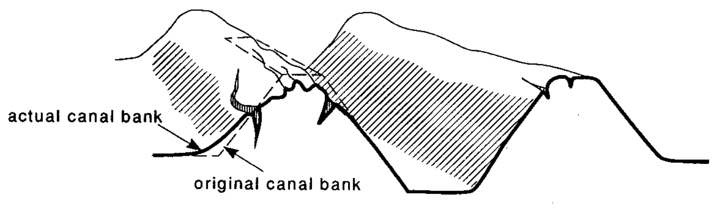


Step 4 Check the cross-section and bank levels with the template and the reference pegs. (Figure 36-D)

Repair of cracks and gullies in a canal embankment
The repair of cracks and gullies can be executed as follows:

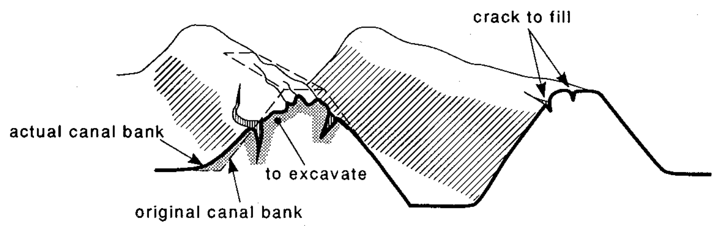
Step 1 Remove any plants from banks which show cracking and in which small gullies have been formed by overtopping water or by heavy rainfall. (Figure 37-A)

FIGURE 37-A Identification of cracks and gullies to be repaired



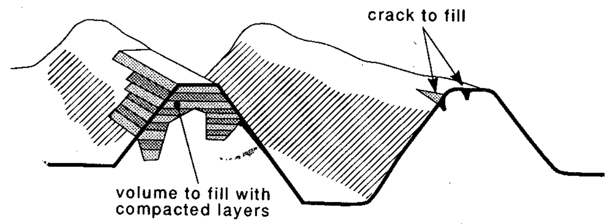
Step 2 In the case of deep cracks and gullies, excavate the bank partly. Small cracks are to be filled with fine-textured soil, moistened and compacted. (Figure 37-B)

FIGURE 37-B Excavating the weakened areas



Step 3 Rebuild the bank by filling in layers and compacting the moist soil. (Figure 37-C)

FIGURE 37-C Repairing with compacted layers of moist soil



5.6.2 Preventing erosion

Erosion of an irrigation canal may be prevented by either:

- reducing the flow velocity, or
- lining the canal.

Reducing the flow velocity

The flow velocity in a canal can be reduced by reducing the canal bed slope. Usually the canal bed follows the slope of the terrain, which may have a slope which is too steep for a canal. To avoid such an excessive canal bed slope in the steep area, the slope of the canal can be modified by constructing part of the canal in cut and part in fill, which however involves moving large volumes of earth. The volume of earth movement in cut and fill can be reduced by installing drop structures, which connect two sections of a canal with different elevations. See Figures 38-A to C.

FIGURE 38-A
Steep canal to be modified

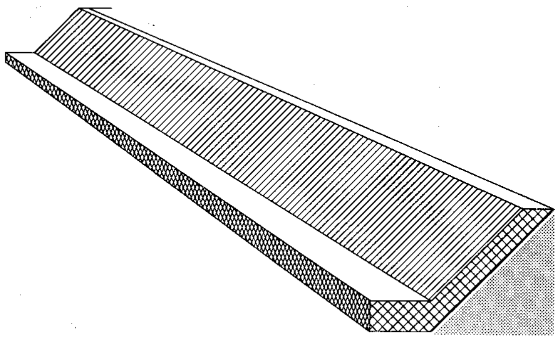


FIGURE 38-B
Reducing canal slope by fill

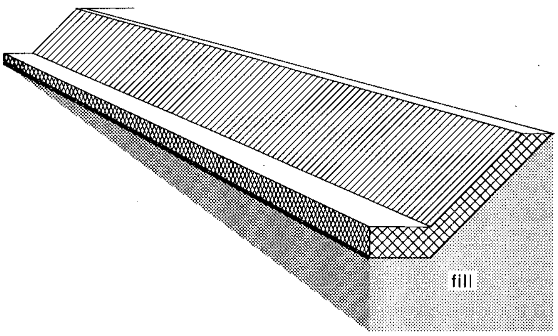
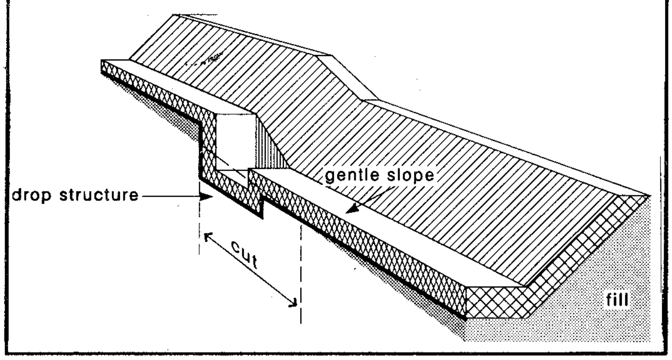


FIGURE 38-C
Reducing slope in a canal by use of a drop structure



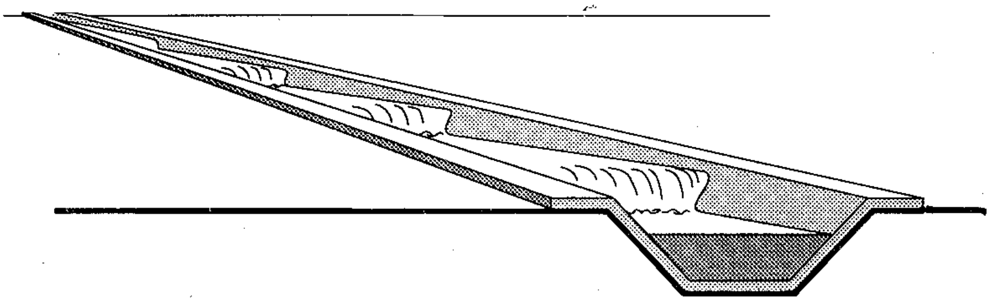
When the slope of a canal is reduced with the installation of drop structures, the flow velocity will be less than before. In order to have the same canal capacity, the canal cross-section has to be made bigger.

Figure 38-A shows a canal section which has the same slope as the field. The field slope is steep and the flow velocity in the canal exceeds its limiting value, causing erosion of the canal. Figure 38-B shows a canal section where a flatter slope is obtained by modifying the existing field slope by cut and fill, but a large volume of earth has to be moved in this case to achieve a canal bed slope which does not cause erosion. The volume of earth to be moved increases as the differ-ence between the natural field slope and the canal slope is made larger. Figure 38-C shows a canal section with the same overall canal slope of the section in Figure 38-B, but the volume of earth to be moved in this case is much less than in Figure 38-B, but at the cost of including a drop structure, which has to be constructed.

Of course, it is not easy to rebuild an existing canal in order to modify its bed slope. In such a case it is possible to install series of check structures in the canal to reduce the flow velocity, as in Figure 39. See also Training Manual 8, *Structures*, in this series.

Consult an engineer for installing drop or check structures.

FIGURE 39
Series of checks in a steeply sloping canal



Lining the canal

Canal sections which are eroded by fast flowing water can be lined.

- The limiting flow velocity of a lined canal is higher than that of an equivalent unlined canal. Thus the canal slope can be steeper.
- Because the flow velocity in a lined canal can be higher than that in an unlined canal, the cross-section of a lined canal can be smaller than that of an unlined canal carrying a similar discharge.

Lining of canal sections is described in the next chapter.

Chapter 6

Canal lining

6.1 INTRODUCTION

Should a canal be lined? This question is often asked by farmers or those engaged in the operation of irrigation schemes. Some relevant considerations are discussed in this chapter, including:

- the necessity for lining,
- selecting the type of lining, and
- implementing the lining.

See also the publication by D.B. Kraatz, *Irrigation Canal Lining*, (published by FAO in 1973) which considers these subjects in detail.

6.2 ADVANTAGES AND COSTS OF LINING

Before the decision is made to line a canal, the costs and benefits of lining have to be compared. By lining the canal, the velocity of the flow can increase because of the smooth canal surface. For example, with the same canal bed slope and with the same canal size, the flow velocity in a lined canal can be 1.5 to 2 times that in an unlined canal, which means that the canal cross-section in the lined canal can be smaller to deliver the same discharge.

Possible benefits of lining a canal include:

- water conservation;
- no seepage of water into adjacent land or roads;
- reduced canal dimensions; and
- reduced maintenance.

6.2.1 Water conservation

An important reason for lining a canal can be the reduction in water losses, as water losses in unlined irrigation canals can be high. Canals that carry from 30 to 150 l/s can lose 10 to 15% of this flow by seepage and water consumption by weeds.

Lining a canal will not completely eliminate these losses, but roughly 60 to 80% of the water that is lost in unlined irrigation canals can be saved by a hard-surface lining.

Minimizing water losses is very important, and especially so in schemes where irrigation water is pumped. Reduced water losses means less water to pump and thus a reduction in pumping costs.

6.2.2 No seepage of water to adjacent land or roads

If canal banks are highly permeable, the seepage of water will cause very wet or waterlogged conditions, or even standing water on adjacent fields or roads. Lining of such a canal can solve this problem, since the permeability of a lined canal bank is far less than that of an unlined bank, or may even be zero, depending on the lining material.

6.2.3 Reduced canal dimensions

The roughness - resistance to flow - of a lined canal is less than that of an unlined canal, and thus the flow velocity will be higher in the lined canal when the canal bed slope is the same. Moreover, the hard surface of the lining material allows a higher velocity compared to an earthen canal surface as it is not so easily eroded. As discussed earlier, canal discharge is the product of the cross-section of a canal and the velocity of the flow. Therefore, with the higher velocity allowable and obtainable in lined canals, the canal cross-section for a lined canal can be smaller than that of an unlined canal.

6.2.4 Reduced maintenance

A surface lining, such as concrete, brick or plastic, on the canal prevents the growth of plants and discourages hole-making by rats or termites, and so the maintenance of a lined canal can be easier and quicker than that of an unlined canal. Moreover, the higher velocity that can safely be allowed in the lined canal prevents the small particles of soil carried in the water from settling out, accumulating and causing siltation.

The bed and sides of lined canals are more stable than those of unlined canals and are thus less susceptible to erosion.

6.2.5 Costs of lining

The costs of lining can be very high, depending on the local cost of lining material and of labour, as well as on the length of canal to be lined. Prices of lining material vary from place to place. Irrigation committees and farmers who are considering lining the canals in their irrigation scheme should gather information on prices of material and of the labour required.

6.3 SELECTING THE TYPE OF LINING

The most commonly used types of lining are shown in Figure 40, and include:

- concrete;
- concrete blocks, bricks or stone masonry;
- sand cement;
- plastic; and
- compacted clay.

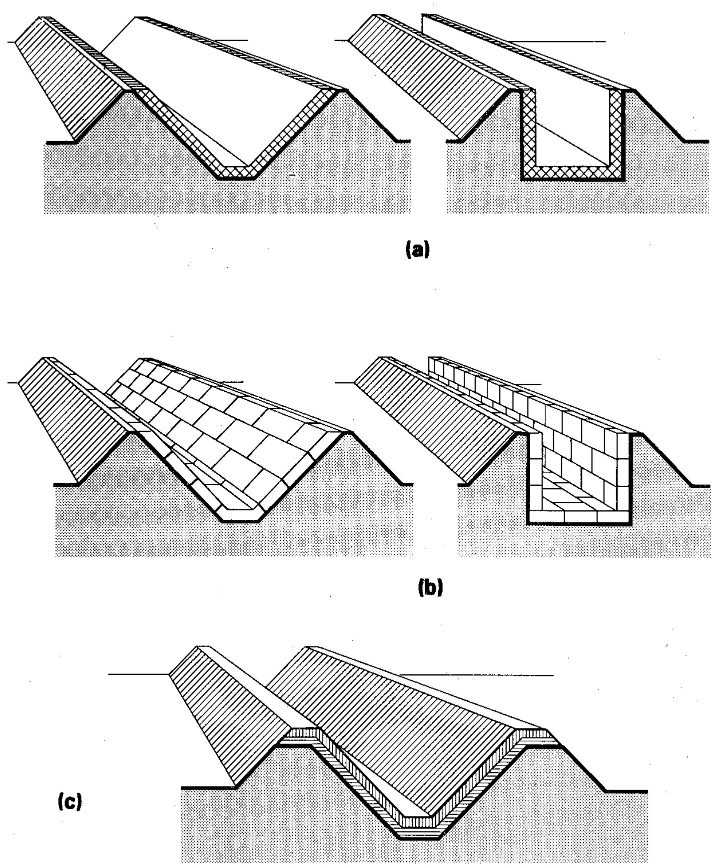
The choice of lining material depends primarily on:

- local costs;
- availability of materials; and
- availability of local skills (local craftsmen).

If cement, gravel and sand are relatively cheap and locally available, concrete lining is generally a good choice. Although the initial investment in concrete lining is generally high, if it is properly constructed and maintained it could last for many years, which thus offsets the high initial cost.

If a local fired brick industry produces cheap bricks or if construction stone or precast concrete slabs are locally available, brick or stone masonry or a concrete slab can be considered. Large amounts of cement are required for mortar and plastering. The construction of this type of lining requires more labour than other methods, thus its use tends to be limited to where labour is abundant and the material cost is relatively low.

FIGURE 40
Different types of lining: (a) concrete lining; (b) masonry lining; (c) compacted clay or soil (sand) cement lining



If a sufficient volume of heavy clay is available near the irrigation scheme, a clay lining could be considered. Lining canals with clay is rather labour intensive, and so the costs of labour should be taken into account when comparing costs and benefits. The use of clay can reduce seepage losses and improve the smoothness of the canal surface, but does not stop weed growth and possible erosion.

If coarse aggregates are not available and cement is relatively cheap, soil (sand) cement lining could be considered.

6.4 IMPLEMENTATION

6.4.1 Preparation

Construction of a canal lining begins with the earthworks. The canal is usually constructed in earth except for where concrete flumes or pedestals on or above the ground are needed.

To save lining material and to facilitate forming, the soil subgrade should be excavated and compacted to the exact shape, grade and alignment of the canal.

Careful attention must be paid to the foundation of any canal lining, especially when fills are involved. The fill should be carefully made, compacted when moist and wetted prior to placement of lining material.

Linings for rectangular canals are generally done on flat ground. First the bottom section is constructed, and then the vertical sides are added, which will be supported by an earth bank backfill, as shown in Figures 40 and 44-D.

6.4.2 Concrete lining

Concrete lining can be placed in many ways, including:

- hand placing by plastering on sides and bed (Figure 41);
- using forms and pouring alternate panels (Figure 42); and
- using prefabricated concrete elements (Figure 43).

FIGURE 41
Hand plastered canal lining

When the concrete lining is hand placed, attention has to be paid to the concrete mix. The concrete must not be very fluid to avoid it creeping downward from the sides. On steep side slopes, formwork is necessary to hold the concrete in place until it sets.

When the lining is placed using the alternate panel method, guide forms are used. Sections are poured alternately, with the finished sections being used as forms for the sections in between.

Small openings or expansion joints spaced at intervals of 1.5 to 3 m are needed for the expansion and contraction of non-reinforced concrete. These joints are filled with flexible, asphaltic material to prevent water leakage.

For small canals, prefabricated concrete elements can also be used, such as the units shown in Figure 43, although the prefabricated elements in Figure 43 are provided with gates.

FIGURE 42-A
Installation of guide forms

FIGURE 42-B
Pouring the concrete

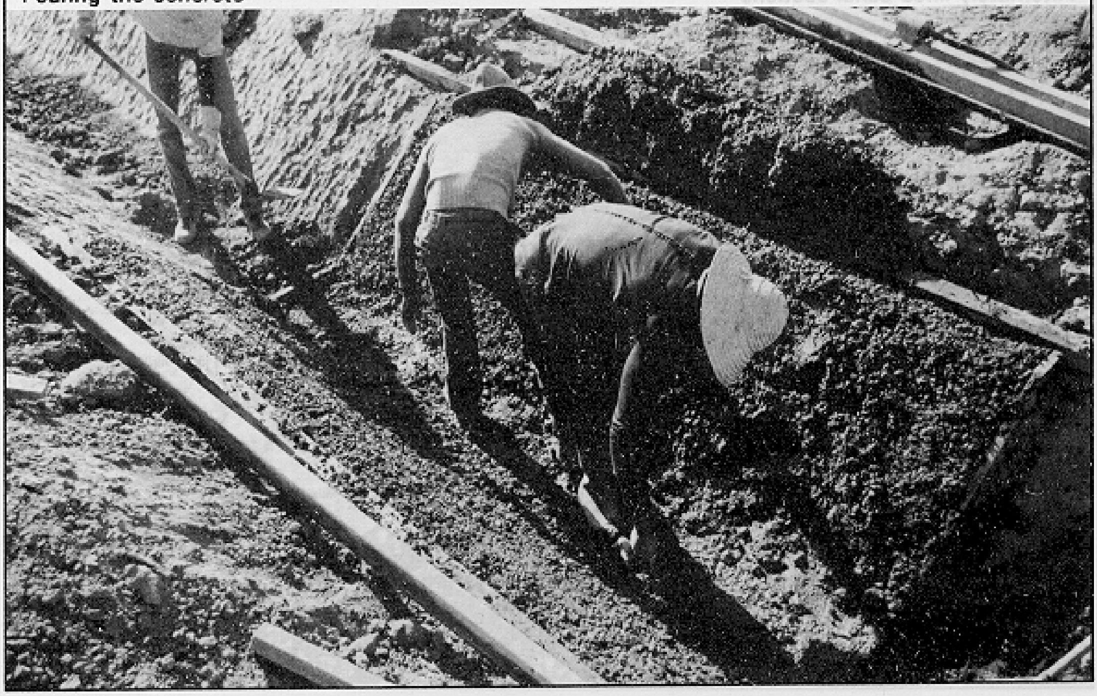


FIGURE 42-C
Compacting, forming and smoothing with a screed

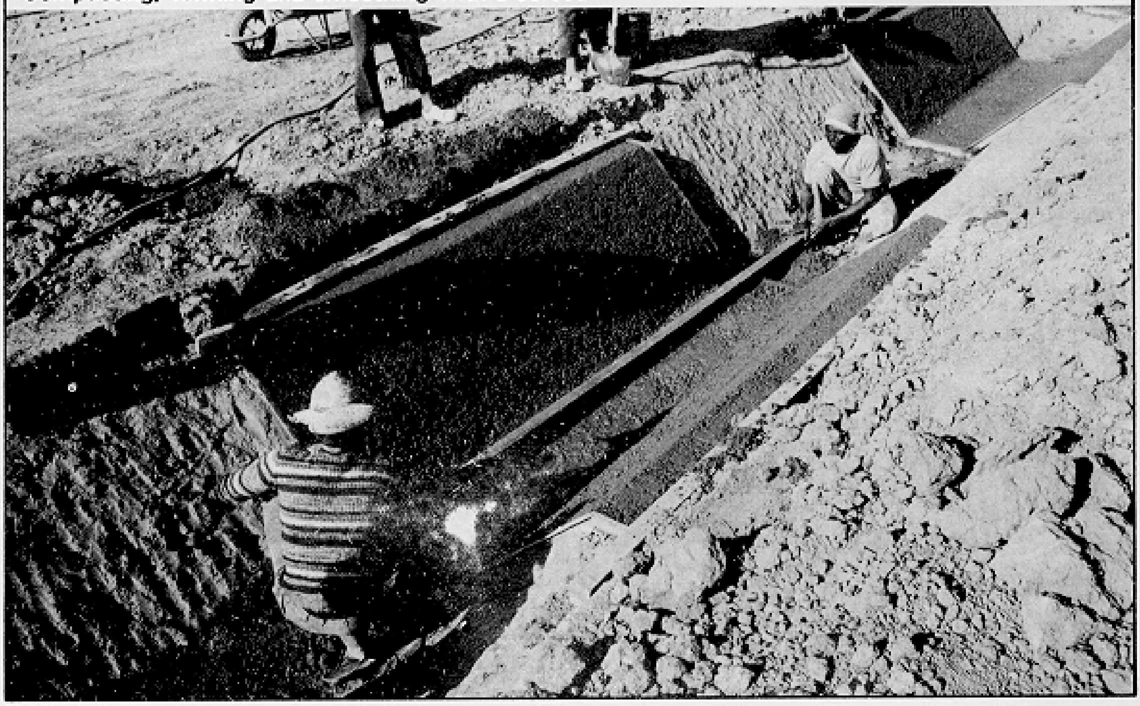
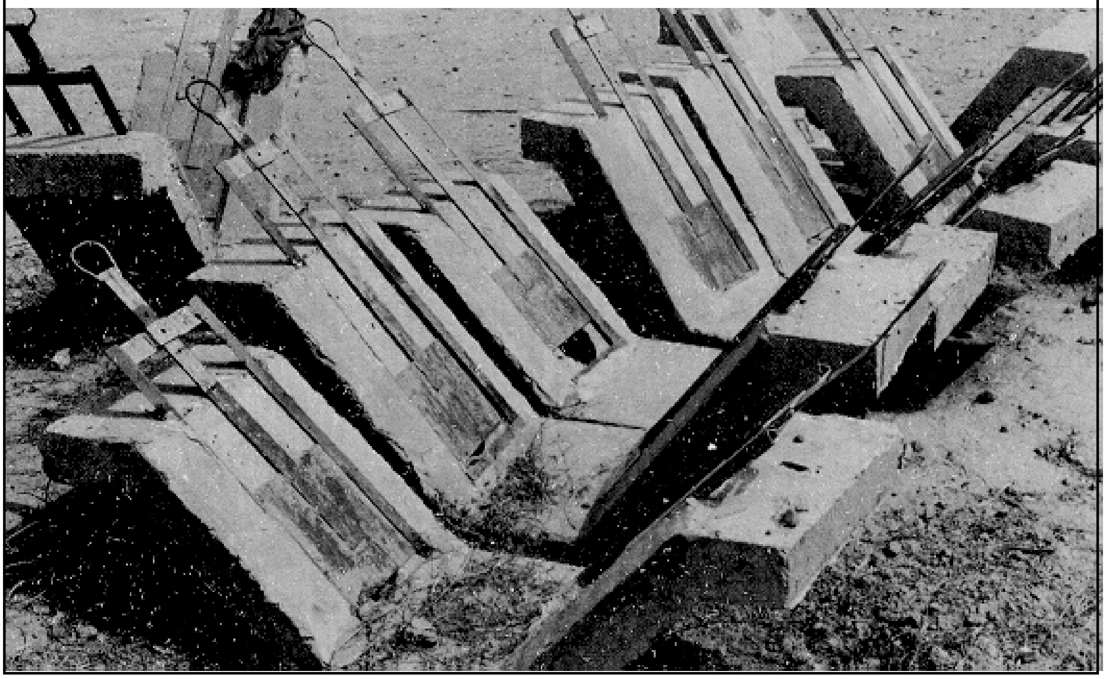


FIGURE 42-D
Alternately lined canal sections

FIGURE 43
Prefabricated concrete canal elements



6.4.3 Concrete block, brick or stone masonry lining

The concrete blocks, bricks or stones are laid flat on the compacted sides and bed of the trapezoidal canal. The joints are filled with cement mortar, which should have a cement-to-sand ratio of 1:3 to 1:4 (one part of cement to 3-4 parts sand, by volume).

A rectangular canal can be constructed with a concrete or masonry bed and vertical masonry walls. See Figures 44-A to 44-D.

Figure 44-A shows the destruction of the old unlined canal bed. The foundation for the concrete block lining is in preparation. The block in the foreground will be used as a reference level.

The blocks in Figure 44-C need to be plastered. Usually the water side of the masonry structure is plastered, particularly if the bricks are not of good quality.

6.4.4 Compacted clay or plastic lining

One of the oldest methods for reducing seepage losses and improving canals is to remove the porous earth and replace it with clay material. The clay is moistened and placed in layers on the bed and sides of the canal. Each layer should be compacted.

Canals can also be lined with plastic or asphalt. These materials can be covered with earth or gravel to protect them from weathering and mechanical damage. However weed growth and soil erosion could continue on such cover. See Figure 45.

FIGURE 44-A
Destroying the old canal bed

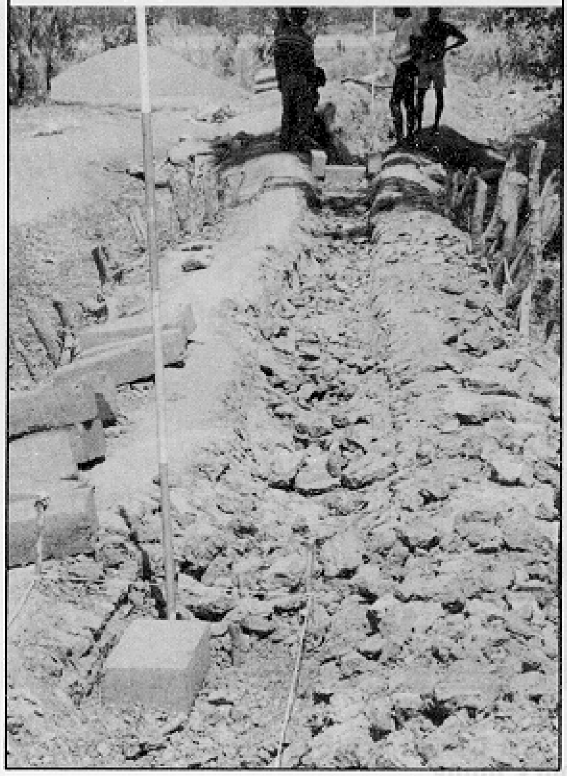


FIGURE 44-B
Laying the concrete block floor

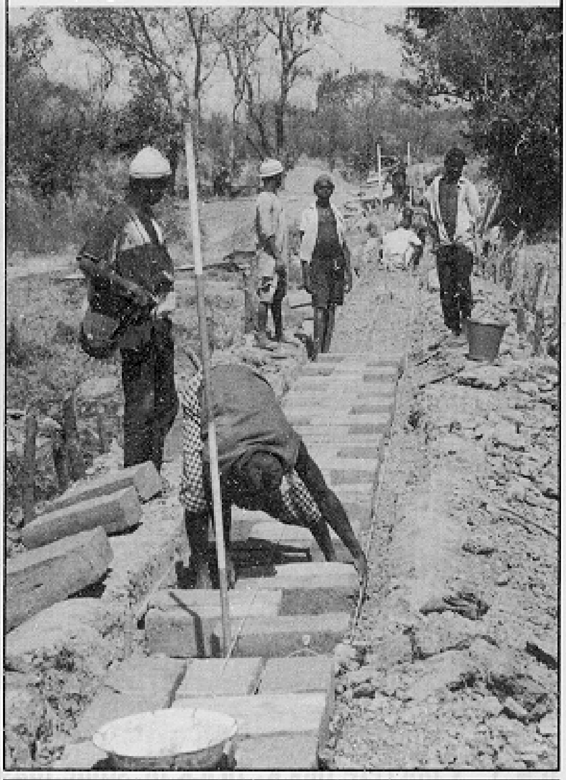


FIGURE 44-C
Making the walls

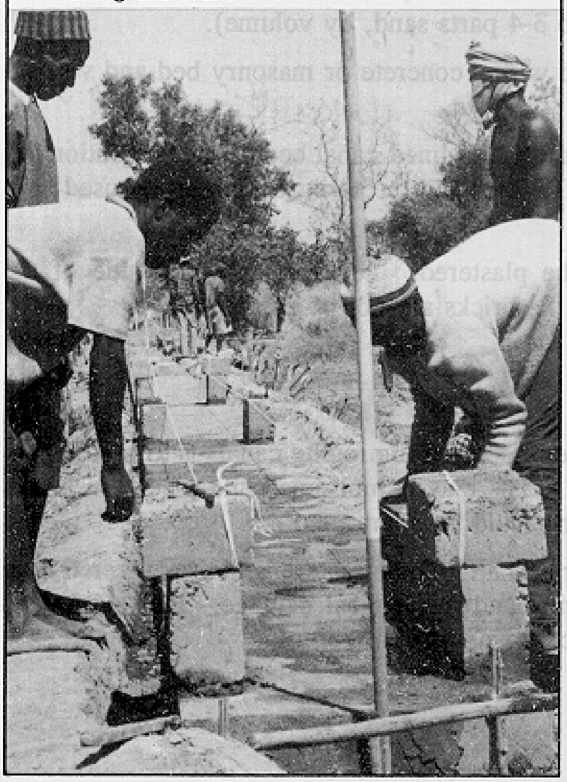


FIGURE 44-D
Earthen support banks are added

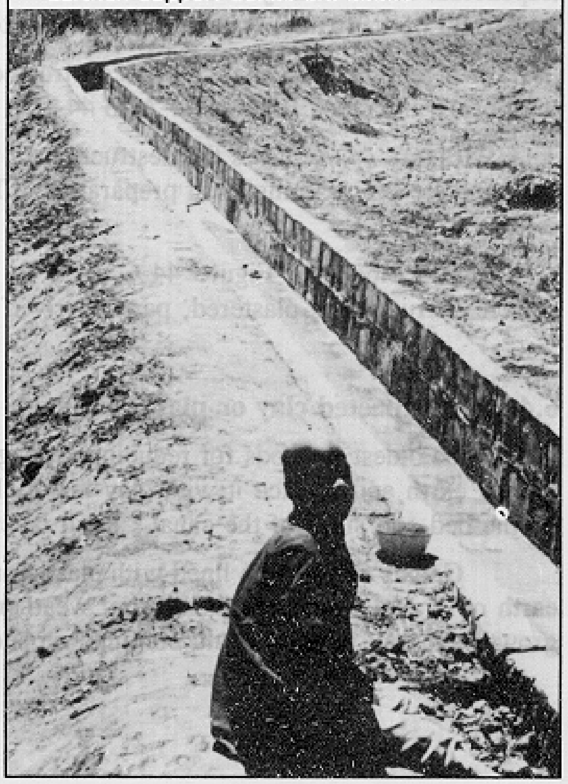


FIGURE 45
Plastic lining

The plastic lining in Figure 45 is easy to install. Such a flexible lining is useful in soils that contain swelling clays or gypsum. However, plastic linings are easily damaged by vegetation, mavhines, people or animals. When exposed to strong sunshine over prolonged periods, the plastic may disintegrate.

Chapter 7

Minor scheme extension and design

7.1 INTRODUCTION

This chapter covers important issues involved in the creation of a new irrigated area, by either extending an existing scheme or designing a new, independent one. Some of the basic problems are considered, and procedures are given for extending an existing scheme.

It is the aim of this chapter to present to the readers some of those issues that they must pay attention to before making any decision to start construction.

The discussion is limited to small schemes - with a command area not greater than 50 ha - as for such an area discharges in new canals would be small, and this limits the size of these canals. When the target area is larger than 50 ha, or where difficult design problems are involved, the irrigation extension officer is requested to contact an irrigation engineer for advice.

It should be emphasized here that the participation of future beneficiary farmers is a very important factor in designing and constructing new irrigation networks. If farmers are encouraged to collaborate from the beginning, then operation and management of the scheme can well be organized, and farmers will hopefully feel an element of personal pride in the scheme. This will be far more difficult if individual farmers are not involved in design and construction, and are arbitrarily assigned to a new scheme.

7.1.1 Minor scheme extension

Land which is adjacent to an existing irrigation scheme could be considered for incorporation into the scheme. When studying such an extension, several questions need to be answered:

- Is the soil suitable for irrigated crop production ?
- Is the topography suitable for irrigation?
- Who owns the area or who controls tenancies, and hence, who will use the new fields?
- How much water will be needed to irrigate the new area?
- Is enough water available from the source?
- Is water supply to the new fields possible by extending the existing irrigation canal network, or will a new one have to be constructed?

7.1.2 New scheme planning

The same questions apply when the creation of a new, independent irrigation scheme is considered. The crucial problem, which should be solved first, is to locate a water source with good quality and quantity. Another question to answer is "How to get water from the source?" Can the water be extracted by gravity or will it be necessary to install pumps?

Experiences from neighbouring irrigation schemes can be used for the design of a new scheme. For instance, aspects that can be considered when looking at nearby schemes include:

- What are the types of canals in neighbouring schemes, and are they satisfactory?
- What are the sizes of the farmers' fields in those schemes, and should they be larger or smaller in the new scheme?

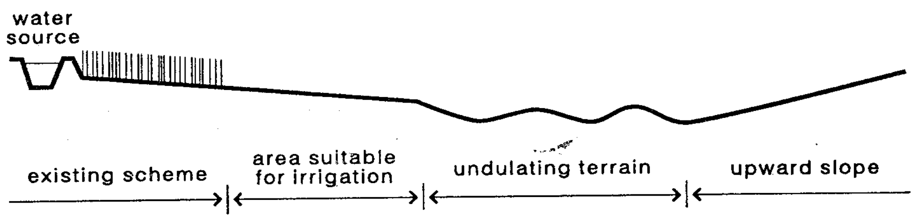
The following sections cannot cover these questions in detail because many factors depend on local circumstances, which of course vary from place to place. This chapter rather tries to give the reader an idea as to how to approach the problems associated with extending an old or constructing a new irrigation scheme. Again it is emphasized that for complicated matters an irrigation engineer should be consulted for help.

The questions about soil characteristics and land ownership will not be discussed here, because they are beyond the scope of this Manual.

7.2 TOPOGRAPHY OF THE AREA CONSIDERED

Any area which is considered for an extension or for a new scheme should not have steep slopes but be rather flat, with a gentle slope downwards from the existing scheme or from the water source. See Figure 46, which shows the profile of the land area along the line from the water source to possible new irrigation areas. Such a land profile map can be used to judge whether extension of a old scheme or construction of a new irrigation scheme is feasible with regard to water delivery.

FIGURE 46
Extension of an irrigation scheme



When it is not certain whether the new area can be irrigated without difficult problems, an irrigation engineer should be consulted. The engineer can make a detailed topographical survey of the area and can give advice.

7.3 WATER REQUIREMENTS

When an area generally suitable for irrigation is identified, the exact area that would receive irrigation water should be determined. Methods of calculating the surface area of a field are presented in Training Manual 2: *Elements of Topographic Surveying*.

After the surface area to be irrigated is determined, the irrigation needs for this area must be calculated. This can be done with the help of Training Manual 6: *Scheme Irrigation Needs and Supply*.

In the case of a scheme extension, the irrigation water needs for the extension area will be added to that of the old scheme, so the calculation must show that the total irrigation water needs will not exceed the capacity of the intake structure or the main canal of the original scheme. When the supply capacity of the intake structure or the main canal is not enough to cover the needs of the extended area as well as of the existing area, the supply capacity of the main canal and the structure will have to be expanded before the extension can become feasible.

7.4 WATER CONVEYANCE TO THE NEW AREA

If enough water is available at the water source and the capacity of the intake and the main canal is large enough (or can be expanded), water for the new area can be supplied by extending the existing canal network. The capacity of the existing canal network should be determined, and should be compared to the discharges which are required for the extended scheme. When the capacity of the network is sufficient to transport the required amounts of water, only the canals in the extension area need to be constructed. If the network capacity is not large enough to transport the required discharges, its capacity should be increased. In this case, not only have new canals to be constructed, but also the existing supply canals will have to be enlarged.

A method for estimating a canal's capacity, as well as a method for increasing it, are given in Annex 1 of this Manual.

If it is for a new scheme, a complete layout of the canal network will have to be established, starting at the water source. A discussion of how to design a network layout is not given here. Since the network layout depends on local circumstances, such as soil type, slopes, crops, etc., only some general remarks can be made here.

It is advisable that feeder canals are placed along ridges or across the main land slope so that the water level in these canals can be kept as high as possible. Furthermore, the layout of a canal network should coincide as far as possible with the boundaries of existing farms, and crossings by roads and natural drains should be avoided.

Attention must be paid to the water level in the new canals. In order to supply a field with water, the water level in the supply canal should be at least 10 cm higher than the highest part of the field to be irrigated.

The method for constructing new irrigation canals is described in Annex 2.

7.5 MINOR SCHEME EXTENSION - AN EXAMPLE

An example of a minor scheme extension is presented in this section. After general description of the scheme, the procedure to follow in extending the scheme is given.

Description of the irrigation scheme

An existing irrigation scheme is located along a small river and the area of the scheme is 80 ha (800 m wide by 1000 m long). The terrain has a slope to the east and to the north, although the slope to the north is relatively flat. The scheme is divided into 8 blocks of equal size, with a tertiary canal supplying water to each block. Irrigation water is diverted from the river at a rate of 200 l/s. This flow is divided over the canal network in such a way that each block receives 25 l/s. An area which is located immediately north of the scheme is being considered for incorporation into the scheme. See Figure 47.

The farm ditches each have a length of about 100 m. See Figure 48.

The procedure for extending the scheme concerned involves the following steps:

Step 1 Mark the area for extension and measure the size of the new area.

Step 2 Mark the alignment of the canals in the extension area.

Step 3 Check the slope of the proposed canal alignments.

Step 4 Calculate the required discharges in the new canals.

Step 5 Add the irrigation needs of the extension to the water needs of the existing scheme, and check the capacity of the water intake structure and the availability of water at the source.

Step 6 Determine the required discharges of the existing canals which will supply the new area and check their capacities.

Step 7 If necessary, enlarge the capacities of the intake structures or existing canals.

Step 8 Determine the dimensions and elevations of the new irrigation canals and construct them.

Step 9 Construct the new structures and, if necessary, enlarge the capacities of the existing structures.

FIGURE 47
Existing irrigation scheme and location of possible extension

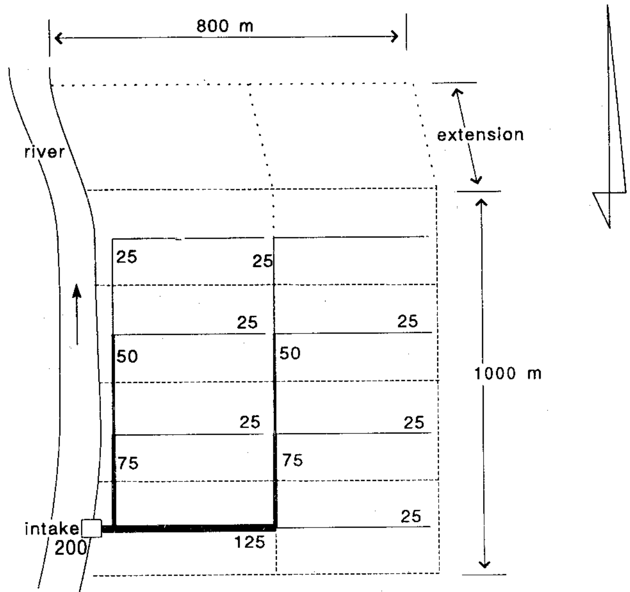
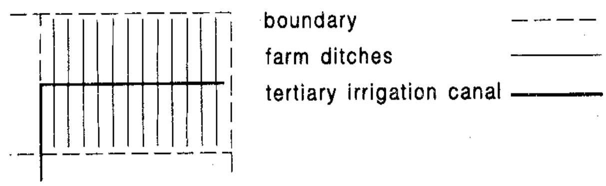


FIGURE 48
Block with tertiary canal and farm ditches

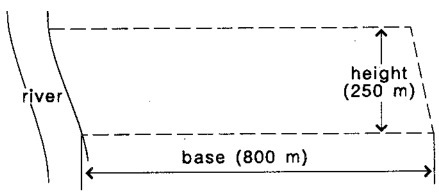


The first eight steps are described in detail below, but Step 9 is beyond the scope of this manual and is discussed in Training Manual 8: *Structures*.

Step 1 *Mark the area for extension and measure the size of the additional area*

The boundaries of the area concerned are marked. Check the field slope: the area for extension should have good soil and a gentle slope downwards from the existing scheme. This information can be obtained from observations in the field. For example, runoff during the rainy season shows the direction of the slope.

FIGURE 49
Determining the surface area of the extension



The new area is measured and its surface area is calculated (See Figure 49).

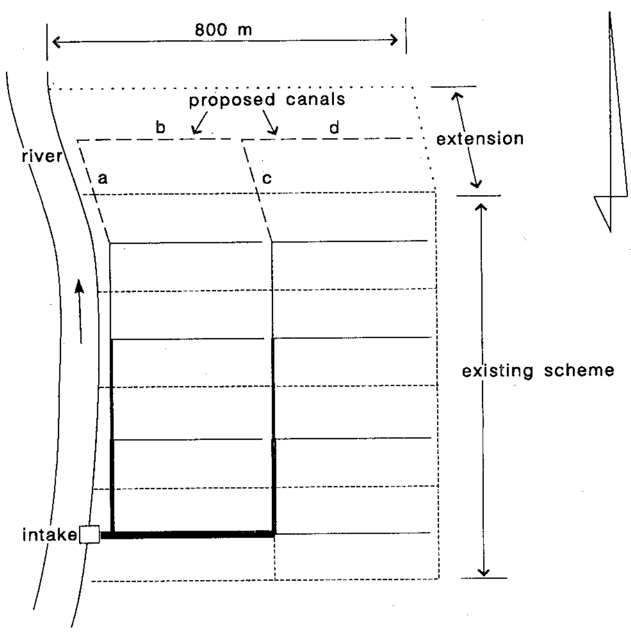
The new area has the shape of a parallelogram. The length of the area, or base of the parallelogram, is 800 m. The width of the area, or height of the parallelogram, is 250 m. So the surface area is 800 x 250 = 200 000 m^2. (See also Section 1.1.3 of Training Manual 1: *Introduction to Irrigation*).

The new area is divided into two blocks of 100 000 m^2, i.e., 10 ha, each. The new blocks thus have a similar surface area to the blocks in the existing scheme.

Step 2 *Mark the alignment of the canals in the extension area*

When studying the alignments of new canals, attention should be paid to the size of irrigation block to make. The block size should be equal to that in the existing scheme so that the farm ditches can have about the same length as the existing farm ditches. The new area in this example is divided into two blocks. (See Figure 47). Figure 50 shows the alignment of the new canals.

FIGURE 50
Proposed alignments of new irrigation canals



Step 3 *Check the slopes of the proposed canal alignments*

Determine the slopes of the proposed canal alignments. When the slope of the terrain is between 0.05% and 0.15%, the canals can follow the same slope as the terrain. If the slope is less than 0.05%, the cross-section of the new canal needs to become rather large, and if it is steeper than 0.15% then it may be necessary to construct the canal partly in cut and partly in fill, with drop structures to slow down the flow velocity. (See also Figure 38 in Section 5.6.2). When the field slope of a proposed canal alignment is not between 0.05% and 0.15%, it is advisable to consult an irrigation engineer for guidance.

A method to determine the slope of a canal alignment is given in Annex 3.

Canals a , b and c , d are the proposed new canal alignments. The slopes of these four alignments are between 0.05 and 0.15%, and the canals to be constructed can have the same slope as that of the terrain.

Step 4 *The irrigation water needs for the new blocks can be calculated*

Calculate the discharge required in the new canals. The peak irrigation flow for the existing scheme was 2.5 l/s/ha. (For the method of calculation, see Training Manual 6: *Scheme Irrigation Needs and Supply*). The water requirement for the extension area will be the same if the same crops are grown, and thus 2.5 x 10 = 25 l/s is required for each new block. So, canals a , b and c , d should each have a capacity of 25 l/s.

Step 5 *Add the irrigation water needs of the extension area to the needs of the existing scheme, and check the capacity of the water intake structure and of water availability*

The irrigation requirements for the new area are 2 x 10 x 2.5 l/s, or 50 l/s.

The irrigation needs for the existing scheme are 80 x 2.5 = 200 l/s.

The irrigation water needs for the extended scheme are thus 200 + 50 = 250 l/s. The capacity of the intake structure should thus be equal to or larger than 250 l/s.

In this example, let us assume that the intake structure of the existing scheme has enough capacity to supply the additional water demand of the new area.

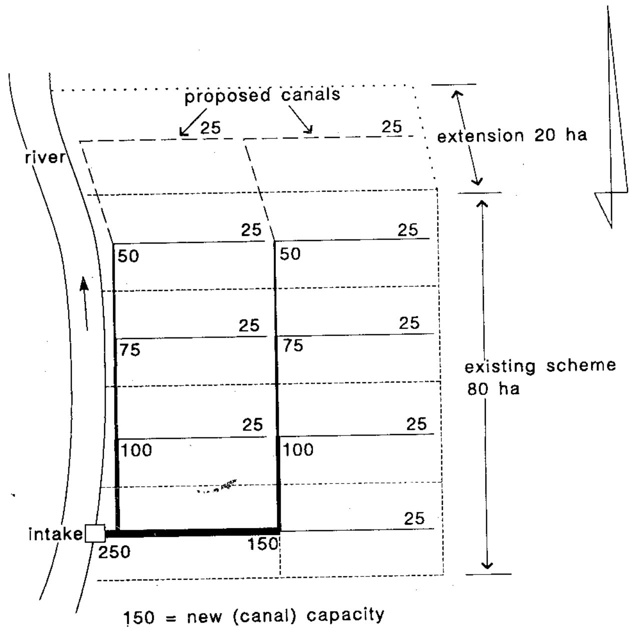
Step 6 *Determine the required discharges of the existing canals which will supply the new area and check their capacities*

The discharges required in the new canals are added to the actual discharges of the existing canals which supply the new blocks. See Figure 51, where the new discharges in the canal system are given.

Having determined the new discharges required, the capacity of the existing canals should be verified. The procedure for estimating canal capacity is given in Chapter 2 of Annex 1 of this Manual. The estimation for canal section **e** in Figure 50, for example, shows that Q_{max} = 33 l/s for that canal section.

The capacity of this canal section will have to be 50 l/s (See Figure 51) so this section will need to be enlarged.

FIGURE 51
Extended scheme and required discharges



Step 7 *If necessary, enlarge the capacities of the existing canals*

The capacities of the existing canal sections concerned should be enough to transport the new discharges. When they are too small, the canals should be enlarged.

A canal's capacity can be enlarged by raising the canal embankments or by widening the bed width. For the procedures to do this, see Section A1.3 of Annex 1.

Step 8 *Determine the dimensions and elevations of the new canals and construct them*

Since the slopes of the new irrigation canals are between 0.05% and 0.15% (from Step 3), Table 1 (in Chapter 3) can be used to determine the dimensions of the canals. The canals will be made with earth. For a discharge of 25 l/s the table gives a bed width of 20 to 25 cm and a water depth of 15 to 25 cm. The minimum required free board for such a canal is 20 cm (see Chapter 3). The cross-section of gently sloping canals can thus be given a bed width of 25 cm and a height of 45 cm. The clay-rich soil in the area allows a side slope of 1:1 to be used safely.

Attention should be paid to the water level in the canals. To supply a field with water, this level should be at least 10 cm higher than the field level. If necessary, the water level can be raised by installing checks in the canal, but then care must be taken to ensure that the embankments of the canal are high enough to maintain the minimum required free board above this higher water level.

Having determined the dimensions of the cross-sections of the new canals, their construction can start. See Annex 2 of this Manual for construction of canals.

Annex 1

How to enlarge the capacity of an existing canal

A1.1 INTRODUCTION

When extension of an irrigation scheme is considered, information is needed on the capacity of the existing canal network because at least part of this network will have to transport the additional water required to supply the new area.

If detailed information is not available on either the current operational carrying capacity of the existing system or on the maximum discharges that could be needed at the time of highest water demand, then this must be collected by surveys in the field and reference to records of water usage in previous seasons. Even if detailed plans are available from when the system was constructed, they need verification in the field in case carrying capacities have been reduced by damage, erosion, siltation or blockage by plant growth - in other words, if the system has not been carefully and regularly maintained, then it is the present capacity that is the controlling factor.

If the total required discharges in periods of high water demand are smaller than the maximum allowed discharges in the existing canals that will be involved in the planned extension, it is not necessary to enlarge them, but when the existing canal capacity is limited, it has to be increased to supply the additional water required for the new area.

Increasing canal capacity is possible by enlarging the area of the cross-section of the canals concerned.

In Chapter A1.2 of this Annex a method of estimating the canal capacity is presented, and in Chapter A1.3 methods are given for increasing a canal capacity, by increasing the maximum water depth or by enlarging the bed width.

A1.2 ESTIMATING CANAL CAPACITY

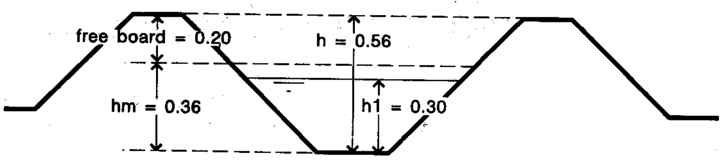
The capacity of a canal is the maximum discharge that can safely be transported. This means that when the discharge equals the capacity, the water level reaches the minimum required free board (*fb*) level. The height of the free board depends on the material used for constructing the embankments: embankments constructed using sandy materials should have more free board than embankments constructed from clay-rich material. Also, when embankments are used as pathways free board should be bigger to protect them from possible destruction. As a rule of thumb, the following minimum required free board levels for small and medium canals must be maintained:

fb = 0.20 m for water depths of 0.40 m or less. (Height of the embankment is water depth + 0.20 m, or $h = h_1 + 0.20$ m);

fb = 0.5 x water depth for water depths of 0.40 m or more. (Height of the embankment is 1.5 x water depth, or $h = 1.5 \times h_1$)

Suppose the actual water level in a canal is lower than free board level, then the capacity of the canal is larger than the actual discharge, see figure A1.1.

FIGURE A1.1
Discharge in a canal is less than canal capacity



What will be the capacity of this canal?

A method to estimate the canal capacity is given below. The method is based on the principle that the higher the maximum water depth in a canal, the larger will be its wetted cross-section and the higher will be the flow velocity. As the maximum allowed water level rises, the canal capacity increases.

The ratio between capacity and discharge is a function of the ratio between the maximum water level and the actual water level. In formula form it is:

$$\frac{Q_{max}}{Q_1} = f \qquad \frac{h_{max}}{h_1} = p$$

where: Q_{max} is canal capacity, in l/s;
Q_1 is actual discharge, in l/s;
h_{max} is the maximum allowed water level, in m;
h_1 is the actual water level, the depth, in m, from the water surface to the canal bed;
f is a factor which depends on p;
and p is the ratio of maximum to actual water level.

It is clear that when the actual water depth reaches free board level, p, and hence factor f, is equal to 1, and the capacity of the canal is equal to the actual discharge.

TABLE A1
Factors for estimating canal capacity
(Average *f* values for different *p* values and side slopes)

	***f* values**				
p	ss[1] = v[2]	ss = 1.5 1:0.7	ss = 1.0 1:1	ss = 0.7 1:1.5	ss = 0.5 1:2
1.05	1.06	1.09	1.10	1.11	1.11
1.10	1.13	1.19	1.21	1.22	1.23
1.15	1.19	1.29	1.32	1.34	1.35
1.20	1.26	1.40	1.43	1.46	1.49
1.25	1.33	1.50	1.55	1.59	1.62
1.30	1.39	1.62	1.68	1.73	1.77
1.35	1.46	1.73	1.80	1.87	1.92
1.40	1.53	1.86	1.94	2.02	2.08
1.45	1.60	1.96	2.06	2.16	2.23
1.50	1.67	2.09	2.21	2.32	2.40

Notes: 1. side slope. 2. vertical

Factor f has been calculated for several values of $p = h_{max}/h_1$ and for different cross-section shapes, as set out in Table A1. Note that Table A1 has been calculated on the basis of two limiting values, namely that h_1 should be more than half the bed width (b) (i.e., $h_1 \geq b/2$) and that h_{max} should be less than one-and-a-half the bed width (i.e., $h_{max} \leq 1.5 ´ b$).

EXERCISE A1.1

Problem: What is the capacity of the canal whose cross-section is shown in Figure A1.1?

Solution:

Step 1 Measure the water depth in the canal (h_1 in Figure A1.1). It is 30 cm. h_1 = 0.30 m.

Step 2 Measure the height of the canal embankment above the canal bed (h). It is 56 cm. h = 0.56 m.

Step 3 Calculate the maximum allowed water level:

h_{max} = height of embankment (h) - free board (fb), or $h_{max} = h - fb$, in which h = 0.56 m (measured), and fb = 0.20 m (the minimum value as the water depth is less than 0.40 m).

h_{max} = 0.56 - 0.20 = 0.36 m. The maximum water depth is less than 0.40 m, so the minimum required free board remains 0.20 m.

Step 4 Measure the water surface width and the bed width, and estimate the discharge, using the method given in Section 3.2.

The water surface width is 90 cm, or a_1 = 0.90 m; the bed width is 30 cm, or b = 0.30 m; h_1 = 0.30 m (from Step 1).

Using the formula $A = \{(a_1 + b)/2\} \times h_1$, the area of the wetted cross-section (A) is 0.18 m^2.

The time taken for a floating object to travel 10 m is measured four times, and the average time is found to be 35 seconds. The surface velocity, V_s, is given by the length, (L) divided by the time (t). L is 10 m, and t is 35 s,
$V_s = L/t$ = 10/35 = 0.29 m/s.

To find the average flow velocity (V), the surface flow velocity (V_s) is corrected by a standard factor of 0.75.
$V = 0.75 \times V_s$ = 0.75 x 0.29 = 0.22 m/s.

The discharge, Q_1 l/s, is obtained by using the formula $Q = 1000 \times V \times A$.
Q_1 = 1 000 x 0.22 x 0.18 = 39 l/s.

Step 5 Check that h_1 and h_{max} fall within the limits that are a condition for using this method, namely that $h_1 \geq$ bed width/2, and that h_{max} £ 1.5 x bed width.

The bed width here is 0.30 m, so h_1 should be 0.15 m or larger, and h_{max} should be 0.45 m or smaller. Both h_1 and h_{max} are within the limits (h_1 = 0.30 m and h_{max} = 0.36 m, see Step 3). If h_{max} becomes larger than 1.5 ´ bed width, then that value (i.e., 1.5 x bedwidth) should be seen as the maximum water level, and this procedure may continue with h_{max} = 0.45 m (for a bed width of 0.30 m).

Step 6 Calculate the side slope (ss) using the formula given in in Section 3.2.2:
$ss = 2 \times (h_1 / (a_1 - b))$ = 2 x (0.30 / (0.90-0.30)) = 2 x (0.30 / 0.60) = 2 x 0.5 = 1.

Step 7 Calculate the ratio p with the formula $p = h_{max}/h_1$.
h_{max} = 0.36 m (from Step 3) and h_1 = 0.30 m (from Step 1), so p = 0.36 / 0.30 = 1.20.

Step 8 Look in Table A1 for the factor f for a p ratio of 1.20 and an ss of 1.0: f = 1.43.

Step 9 Estimate the canal capacity, Q_{max}, using the formula $Q_{max} = f ´ Q_1$, in which f = 1.43 (from Step 8), and Q_1 = 39 l/s (from Step 4):
Q_{max} = 1.43 x 39 = 56 l/s.

Answer: The maximum safe capacity of the canal is 56 l/s, or Q_{max} = 56 l/s.

A1.3 ENLARGING CANAL CAPACITY

When the area served by an irrigation canal increases, the discharge required in the canal must also increase. If the capacity of the canal is smaller than the discharge required, then this capacity will have to be increased.

There are three ways to increase the capacity of a canal:

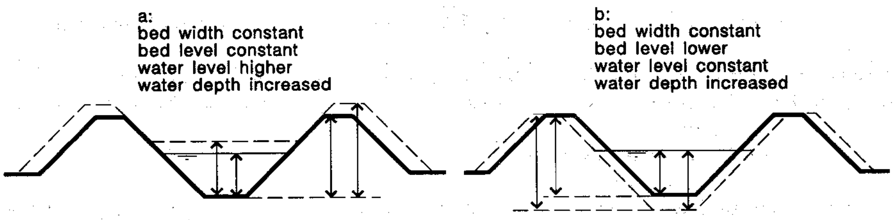
- increase the maximum allowed water depth;
- increase the the bed width; or
- reduce the bed roughness;

and these may be used singly or in combination.

Increasing the maximum allowed water depth

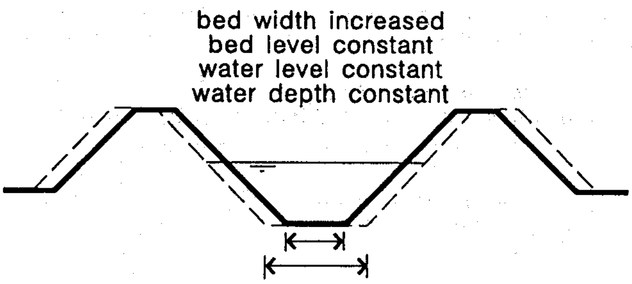
The maximum water depth in a canal can be increased in two ways: either by raising the canal banks and thus maintaining the bed level (Figure A1.2 a) or by lowering the bed level and thus maintaining the water surface level (Figure A1.2 b).

FIGURE A1.2
Increasing a canal capacity by increasing the water depth



Depending on the new minimum free board requirement, the banks in option b may need to be raised.

FIGURE A1.3
Increasing a canal capacity by increasing the bed width



Increasing the bed width

By increasing the bed width of a canal, its capacity increases, but the bed level and the water level will not necessarily be changed (Figure A1.3).

Reducing the bed roughness

Canal capacity could also be increased by reducing the bed roughness. If, due to lack of maintenance, the canal bed becomes rough because of plant growth, accumulation of debris or deterioration, its roughness can be reduced by proper maintenance. Then the flow velocity will increase, and hence the discharge will also increase.

To obtain a substantial increase in capacity, the canal can be lined if it was an unlined canal. However, because of the high costs involved, this alternative is not realistic if canal capacity increase is the only reason for lining.

A1.3.1 Enlarging canal capacity by increasing the water depth

Suppose the area which is served by the canal used for Exercise A1.1 is to be extended. The total maximum discharge which will need to be transported by this canal is 80 l/s. The existing capacity has been estimated to be 56 l/s, and so must be increased.

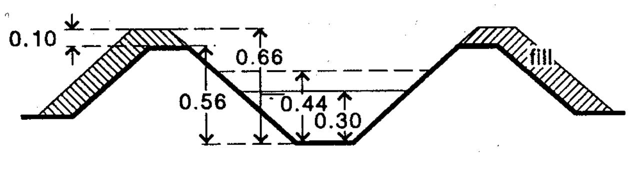
The procedure which is described here and used in Exercise A1.2, is in fact the contrary of the procedure for capacity estimation used in Section A1.2. In that section the discharge was estimated for a calculated maximum water level. Here the water level is estimated for a given discharge which is larger than the maximum discharge in the actual canal. Having calculated this new maximum water level, the new height of the embankments needed to accommodate this new canal capacity is calculated.

Which of the two options identified in Exercise A1.2 to adopt depends on such factors as the possibility of raising water level (the water level at water source), the volume of earth work involved, or availability of good (clay-rich) soil suitable for embankment.

Note: The water depth is raised by 0.14 m (from 0.30 m for Q_1 = 39 l/s, to 0.44 m for Q_{max} = 80 l/s). Since the water level for the measured actual discharge (39 l/s) has not yet reached the minimum required free board level, it is not necessary here to raise the embankments by 0.14 m but only by 0.10 m.(Option A)

The canal embankments are to be heightened and enlarged as shown in figure A1.4.

FIGURE A1.4
Increased canal capacity, higher banks



When the water level in the canal cannot be increased because of a limit in the supply water level, the canal bed can be dug and deepened (Option B). In such a case, the new bed in this example will be at a level which is 0.14 m lower than the original bed level, since the new water depth needed is 0.14 m more than the original water depth. See Figure A1.5.

Note: For the new canal discharge, the free board is 0.7 - 0.44 = 0.26 m. This free board is still larger than the minimum required free board of 0.22 m for a water depth of 0.44 m (See Step 6), and so it is not necessary to raise the canal embankments.

EXERCISE A1.2

Problem: What should be the new height of its embankment if the capacity of the canal in Figure A1.1 is to be increased to 80 l/s?

Solution:

Step 1 Measure the current water surface width, bed width and water depth, and estimate the discharge, as described in Section 3.2. The results obtained are:

- Water surface width is 90 cm, or a_1 = 0.90 m
- Depth of water is 30 cm, or h_1 = 0.30 m
- Bed width is 30 cm, or b = 0.30 m
- Discharge is 39 l/s, or Q_1 is 39 l/s.

Step 2 Calculate the side slope, using the formula given in Section 3.2.2:

$ss = 2 \times (h_1 / (a_1 - b)) = 2 \times (0.30 / (0.90\text{-}0.30)) = 2 \times (0.30 / 0.60) = 2 \times 0.5 = 1$.

Step 3 Calculate factor f, using $f = Q_{max}/Q_1$, in which Q_{max} = 80 l/s (the new canal capacity required), and Q_1 = 39 l/s (from Step 1): $f = 80 / 39 = 2.05$

Step 4 Look in Table A1 for the respective ratio value for p, when ss = 1.0 and f = 2.05.

The factor f value in column ss = 1.0 which is nearest to f = 2.05 is f = 2.06. This value is found on the line for p = 1.45.

Step 5 Calculate the maximum water level for Q_{max} = 80 l/s.

As $p = h_{max}/h_1$ (Section A1.2), and knowing p = 1.45 (from Step 4) and h_1 = 0.30 (from Step 1): $1.45 = h_{max}/0.30 \Rightarrow h_{max} = 1.45 \times 0.30$. h_{max} = 0.44 m

Note that h_{max} is smaller than 1.5 ´ bed width. If h_{max} exceeds 1.5 ´ bed width, this method of increasing the canal capacity should be rejected. In this case the bed width may be increased to enlarge the canal capacity.

Step 6 Calculate the new height of the embankment. The new maximum water level is 0.44 m, so the minimum required free board is 0.5 x 0.44 = 0.22 m (Section A1.2). The height of embankment = maximum water level + free board, or $h = h_{max} + fb$, in which h_{max} = 0.44 m (from Step 5) and fb = 0.22 m (this step).

Hence h = 0.44 + 0.22 = 0.66 m.

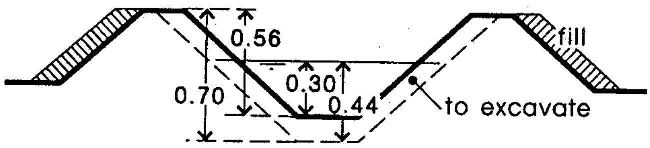
Answer: The existing canal embankment with a height of 0.56 m (see Section A1.2) should be increased by 0.10 m to give a new height of 0.66 m.

This can be attained in two ways:

Option A - Raise the existing canal bank.

Option B - The existing canal bed can be lowered by 0.14 m to get the required depth of 0.44 m.

FIGURE A1.5
Increase canal capacity by lowering canal bed



A1.3.2 Enlarging canal capacity by increasing the bed width

Another way to increase the wetted cross-section of a canal, and thus its capacity, is to increase the bed width. This may be preferred to increasing the water depth in a canal.

In fact, the same procedure as described in Section A1.3.1 is followed. Factor *f*, which is the ratio between new capacity and old capacity, is first calculated. Then a table is used to find factor *r* (See Table A2 below). Factor *r* is the ratio between the new bed width and the old one.

TABLE A2
Factors for determination of new bed width
(Average *r* values for different *f* ratios and side slopes)

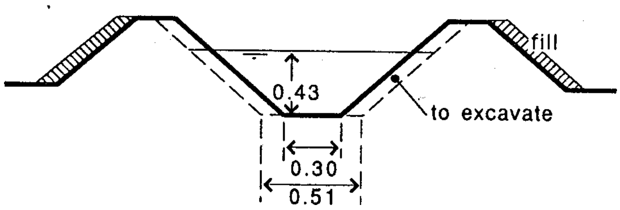
	f			
r	ss = 1.5 1:0.7	ss = 1.0 1:1	ss = 0.7 1:1.5	ss = 0.5 1:2
1.1	1.08	1.07	1.05	1.04
1.2	1.16	1.13	1.10	1.09
1.3	1.24	1.20	1.15	1.13
1.4	1.32	1.26	1.20	1.17
1.5	1.40	1.32	1.25	1.21
1.6	1.48	1.38	1.30	1.25
1.7	1.55	1.44	1.34	1.28
1.8	1.63	1.50	1.39	1.32
1.9	1.71	1.56	1.43	1.35
2.0	1.79	1.62	1.48	1.39

The symbols used are: *ss* - side slope; *f* - ratio of new canal capacity to old canal capacity ($f = Q_{max\ (new)} / Q_{max(old)}$); and *r* - ratio of new bed width to old bed width ($r = b_{new} / b_{old}$).

Suppose an irrigation scheme is to be extended. After completion of this extension, the existing canal which has also to serve the new area will have to be able to transport a discharge of 60 l/s. At present this canal has a bed width of 0.30 m, a canal capacity estimated at 45 l/s, the maximum water depth for the canal at full capacity is 0.43 m, and the side slope is 0.8. If the measured *ss* value does not appear in the table, then use the *ss* value closest to it.

The canal will be excavated while maintaining the side slope of the embankments (See Figure A1.6).

FIGURE A1.6
Increased canal capacity



EXERCISE A1.3

Question: What should be the new width of the canal bed if the canal capacity is increased from 45 l/s to 60 l/s? (See Figure A1.6).

Step 1 Determine the ratio *f* between the new capacity and the old capacity, where $f = Q_{max\ (new)} / Q_{max(old)}$.
$Q_{max\ (new)}$ = 60 l/s (new capacity required)
$Q_{max(old)}$ = 45 l/s (existing capacity)
$f = 60 / 45 = 1.33$

Step 2 Determine the ratio *r* between the new and old bed widths, using Table A2.
The side slope (*ss*) earest to the measured field value is found in Table A2, and it is 0.7.
Look in the column with *ss* = 0.7 for the factor *f* which is closest to the calculated value of *f* = 1.33. The closest value is 1.34, found in the 7th row under *ss* = 0.7.
Follow that row across, and find that it corresponds to *r* = 1.7.

Step 3 Determine the new bed width
Factor *r* is the ratio of the new bed width to the old bed width: $r = b_{new} / b_{old}$
$r = 1.7$ (from Step 2); and $b_{old} = 0.30$ m (the existing bed width).
$1.7 = b_{new} / 0.30 \Rightarrow b_{new} = 1.7 \times 0.30 = 0.51$ m.

Answer: The canal bed should be enlarged by 0.21 m, from 0.30 m to a new bed width of 0.51 m, or, in round figures, by 20 cm, from 30 cm to 50 cm.

Annex 2
How to construct a canal

A2.1 INTRODUCTION

Annex 2 describes the technical aspects of canal construction. However, attention should also be paid to social aspects of canal construction, as it is important to involve farmers in the project from the very beginning of the designing of an irrigation scheme. Designers and authorities resonsible should be in close contact with the farmers in order to identify their needs and to form consensus for the proposed project design. Only when farmer participation is well developed should construction of the system be carried out, and that construction must be done in close cooperation with them. At the same time, farmers should be brought to realize that the system needs to be maintained, and that they are responsible for this. Again, this can only be possible when farmers are participating in every stage of the project from the first beginnings right through to the first water delivery.

A2.2 CANAL ALIGNMENT

A2.2.1 Layout

With regard to the layout of a canal system, reference can be made to Section 7.4 of this manual.

One additional general remark can be made here. That is that the main canal of a system will be laid along the high edge of the irrigable area in order for the largest possible area to be commanded for irrigation. In most cases, the canal will closely follow the land contours, losing only enough elevation to maintain the slope needed for suitable flow velocity. The land commanded by the main canal will be subdivided into irrigation units of about 10 ha each.

From the main canal, secondary canals will be laid out to each irrigation unit, following the line of highest elevation in each unit so as to maximize the area served by each secondary canal. Tertiary canals, or field channels, will then be laid out from the secondaries to deliver water throughout the unit.

A2.2.2 Bed slope

On flat sloping, non-undulating lands, canals will generally have the same slope as the terrain. In steeply sloping lands, canals will be given a slope which is less than the terrain to avoid high flow velocities. In such cases, drop structures will have to be installed to connect the canal sections. See also Section 5.6.2 of this manual.

When a canal crosses a depression or a gully, it cannot follow the terrain and should be constructed in fill, and if a ridge in the terrain has to be crossed the canal will have to be constructed in cut. See Figures A2.1 and A2.2 in Section A2.2.3.

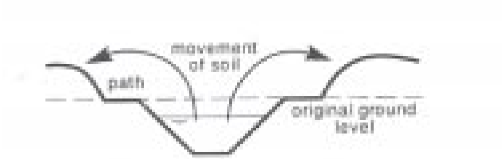
Whatever the slope of the canal, abrupt changes in the slope should be avoided. If the bed slope changes suddenly the flow velocity in the canal will also change, and such a change in flow velocity can cause erosion or may lead to siltation in the canal bed.

A2.2.3 Bed elevation

Depending on local circumstances, canals can be built in fill or in cut. A typical cross-section of a canal in fill is shown in Figure A2.1, and in cut in Figure A2.2.

FIGURE A2.1
Cross-section of a canal in fill

FIGURE A2.2
Cross-section of a canal in cut



There are three factors that play a role in deciding the level of the canal bed.

The first factor is that the slope of a canal should be as constant as possible. Abrupt changes in slope should be avoided. This may result in canal sections having to be constructed in cut or in fill, depending on topography.

Another factor is that the volume of cut should preferably equal the volume of fill when constructing the canal (See Figure A2.3).

FIGURE A2.3
Cross-section of a canal with balance between cut and fill

When the elevation of a canal bed is so high that the volume of fill is larger than the volume of cut, soil has to be brought from elsewhere. This may result in high construction cost. Also, if a canal is to be constructed in cut, the excavated soil is to be spread out over the fields or it should be used elsewhere, which also increases the cost of canal construction. Construction costs are usually at a minimum when there is a balance between the volumes of cut and fill.

The third factor to take into account when determining the bed level of a canal is the water level in the canal. The water level in field channels should be about 0.10 m higher than the level of the fields to be irrigated from those canals, and the water level in a secondary canal which supplies a field channel should be about 0.05 m higher than the design level in the field channel. This is because of the loss in water level at the canal offtake.

The bed elevation and water level at the downstream end of a tertiary canal is determined as the first step, assuring at least 0.10 m difference between the water level in the canal and the field level. Going upstream, it should be checked that the water level in the field channel all along the channel is at least 0.10 m higher than the fields. Further upstream, the water level in the secondary canal can also be determined, taking into account the 0.05 m loss at the canal off-takes.

A2.3 DESIGN AND CONSTRUCTION OF A CANAL EMBANKMENT

As has been discussed, canals may be constructed in cut or in fill depending on local circumstances.

Canals in fill are constructed above ground level by building embankments with soil brought from other locations or scraped from the adjacent field. For small canals, sometimes only one large embankment is constructed, and then the canal cross-section is excavated in the middle.

See Figure A2.4.

FIGURE A2.4
Canal in fill

A.2.3.1 Design of an embankment

Before an embankment is to be constructed, its elevation and its width have to be calculated.

The elevation of the top of the embankment (ETE) can be calculated as follows:

- For a canal with a bed elevation higher than the field (See Figure A2.5-A)

$$\text{ETE} = h + \text{bed elevation}$$

- For a canal with a bed which is lower than the field (See Figure A2.5-B)

$$\text{ETE} = h - \text{bed elevation}$$

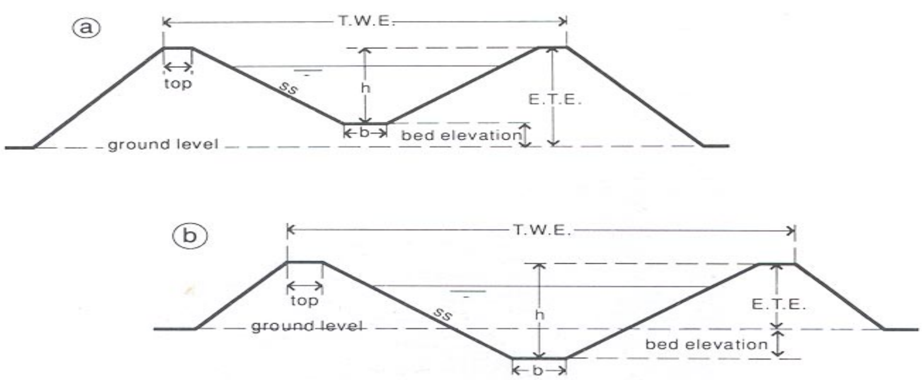
in which: ETE is the Elevation of the Top of the Embankment in metres; h is the Height of the canal cross-section (relative to bed elevation) in metres; and Bed elevation is the elevation of the canal bed in relation to the adjacent field, in metres.

The top width of the embankment (TWE) (See Figure A2.5) can be calculated using:

$$TWE = b + (2 \text{ x } (h / ss)) + (2 \text{ x top})$$

in which: TWE is the Top Width of the Embankment (the distance at the top between the two outer edges of the embankments, in m; b is the Bed width in m; h is the height of the cross-section (relative to bed elevation) in m; ss is the side slope of the cross-section; and top is the width of the top of the canal bank in m.

FIGURE A2.5
Elevation and width of a canal embankment



EXERCISE A2.1

Question 1: What should be the elevation of the top of an embankment, given the following (See Figure A2.7-A):

- Height of the cross-section of the canal to be excavated in the embankment is 0.70 m;
- Elevation of the bed of the canal to be constructed will be 0.20 m lower than the field.

Answer: For a canal with a bed which is *lower* than the field, use: ETE = h - bed elevation.
h = 0.70 m; bed elevation = 0.20 m below ground level.
Hence ETE = 0.70 - 0.20 = 0.50 m.
The canal embankment should be 0.50 m above the original field level.

Question 2: What should be the top width of the embankment (See Figure A2.6), given:

- The bed width of the canal to be constructed is 0.30 m;
- The height of the cross-section is 0.70 m;
- The side slope of the cross-section is 1:1.5 or 1/1.5;
- The canal banks will be used as a path and should have a minimum width of 0.40 m.

Answer: Use the formula: TWE = b + (2 x h/ss) + (2 x top), where b = 0.30 m; h = 0.70 m; ss = 1/1.5; and top = 0.40 m.
TWE = 0.30 + (2 x 0.70/(1/1.5)) + (2 x 0.40)
= 0.30 + (2 x 1.05) + (2 x 0.40) = 3.20. TWE = 3.20 m.

The canal embankment to be constructed has a top width of 3.20 m.

Soil used for building an embankment should have a good texture. Clay-rich soil is to be preferred, if available. Soil containing weeds, plant stubble or roots must not be used for construction as it is difficult to compact properly, and when the plant material rots it leaves small holes that allow water to seep through the banks. If any of the plants sprout in the channel this will increase the maintenance need.

The fill section should be constructed in layers of 5 to 10 cm thick, and should be compacted moist by tamping and rolling. Moistening is done by sprinkling each layer.

A.2.3.2 Construction of an embankment

The following steps can be used as guidance for the construction of an embankment.

Step 1 *Based on the canal layout, locate the alignment of the canal and plough a strip in the terrain where the embankment is planned*

A strip in the field is ploughed to clear all vegetation and roots. The material removed can be used to dress the sides and top of the completed embankment before planting grass. The width of the strip should be larger than the total width of the future canal embankment.

FIGURE A2.6
Determination of elevation and width of an embankment

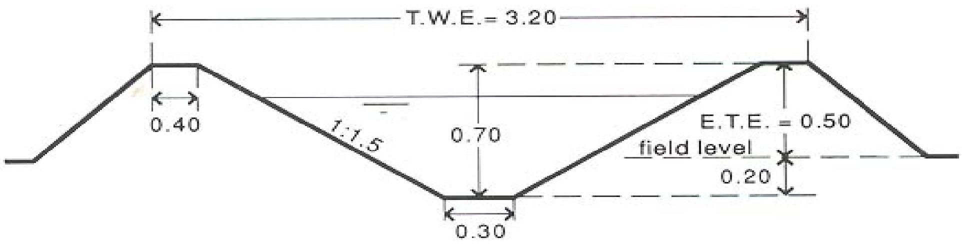
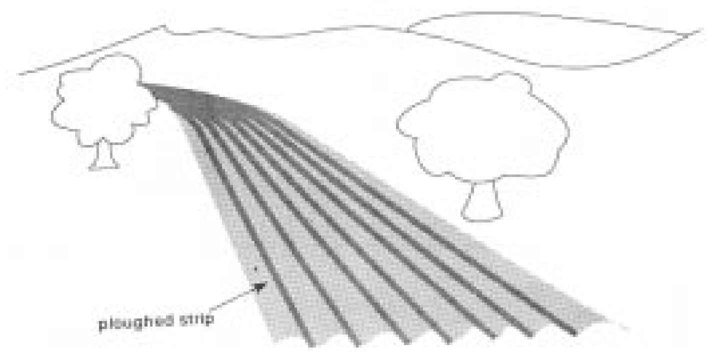


FIGURE A2.7-A
Ploughing the field as preparation of embankment construction

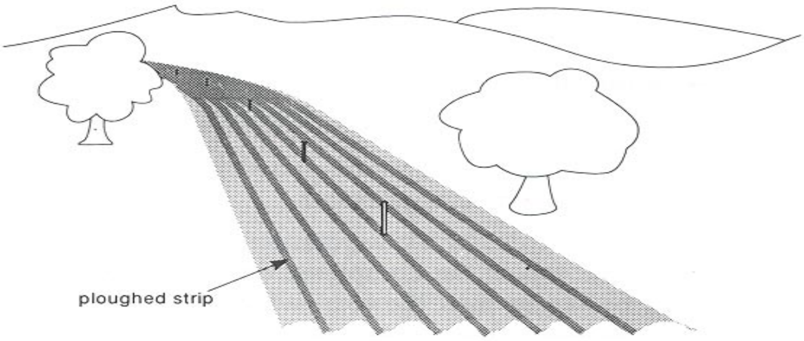


Step 2 *Hammer pegs in the soil every 50 m in a line to mark the centre line of the embankment and its final level.*

The top of each peg should indicate the top level of the embankment at that point.

Mark the centre line of the embankment in between these points with boning rods every 10 m. (See Figure A2.7-B, and also Training Manual 2, Section 6.1.2)

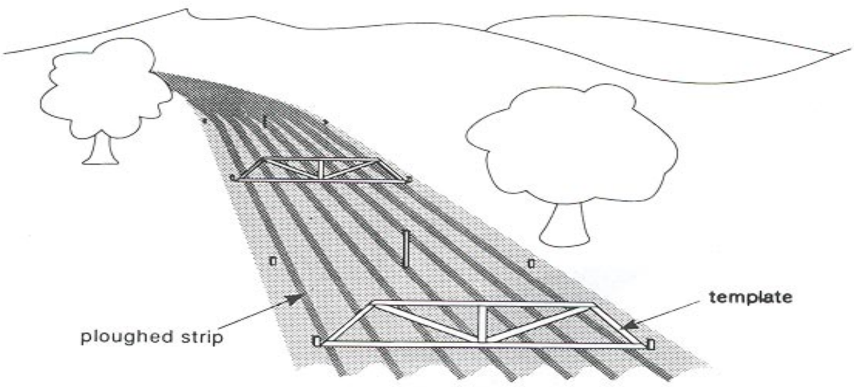
FIGURE A2.7-B
Staking out the centre of the embankment



Step 3 *Every 10 m, mark the outer line of the body of the embankment to be constructed*

The top level of the embankment has been marked in Step 2. The outside slope of the embankment must be stable and depends on the material which is used. As a rule of thumb, a slope of 1:2 [1 vertical to 2 horizontal] may be taken. Marking for the outside line of the embankment can be done by using a template, which can be made from sticks, bamboo or other material. See Figure A2.7-**C**.

FIGURE A2.7-C
Marking of the embankment to fill



Step 4 *Construct the embankment*

The embankment is constructed by adding soil in 5 cm thick layers, with each layer compacted moist. See Figure A2.7-**D**.

Figure A2.8 shows an embankment under construction. Mark the width of the embankment at the foot.

FIGURE A2.7-D
Construction of the embankment

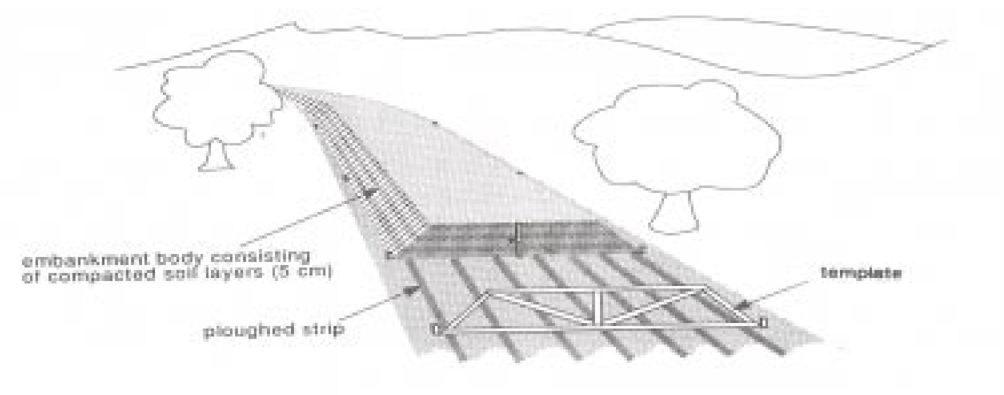


FIGURE A2.8
Embankment under construction

A2.4 CONSTRUCTION OF A CANAL - AN EXAMPLE

Small irrigation canals are either dug in the original soil or they are excavated in an embankment, constructed as described in the previous section. In the former case the soil is generally well compacted and stable, while in the latter case the embankment may not be very stable even after elaborate compaction during construction. Therefore it is good practice to wait at least one rainy season before excavation of a canal in an embankment can start, having thus allowed the soil in the embankment to fully settle down.

In this section the procedure for canal construction is presented. As an example the section of the embankment which was determined in Section A2.3 will be used. The embankment has been constructed and has been allowed to settle. The elevation and size of the embankments has been checked, and is according to the specification.

NOTE 1 Larger canals in fill or partly in fill are usually constructed by bringing up soil from two sides. The two canal banks are then re-shaped to conform to the designed cross-section of the canal.

NOTE 2 The construction of small canals in cut is identical to the construction of small canals in fill, assuming that the latter is excavated in an embankment.

NOTE 3 Canals should be built continuously from one end, not as scattered small sections. This results in uniform construction, and makes supervision easier.

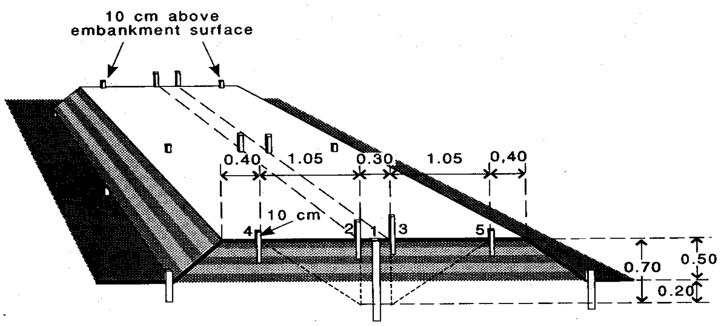
Before the canal is constructed, all plant growth, rubbish, stones and other debris should be removed from the site.

The procedure for constructing a canal is given in steps. The dimensions of the canal are as follows (See Figure A2.9-A):

- Height of the cross-section: *h* = 0.70 m
- Bed width: *b* = 0.30 m
- Side slope: *ss* = 1/1.5 or 1:1.5
- Top width of canal banks: top = 0.40 m

Step 1 *Mark the cross-section with pegs.* (Figure A2.9-A)

FIGURE A2.9-A
Placing the pegs

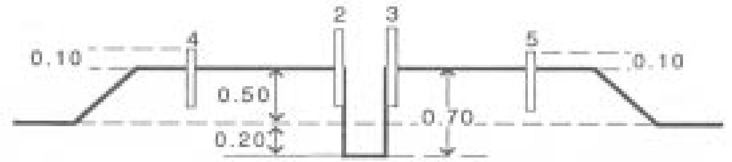


- Hammer a peg in the centre line of the canal, which is usually done during the embankment construction period. This is Peg 1.
- Measure the bed width: 0.15 m to each side of Peg 1. Place Pegs 2 and 3 perpendicular to the centre line of the canal.

- Calculate the width of the inner side of the canal bank by dividing the height of the cross-section by the side slope. In this case, w = h / ss = 0.7 / (1/1.5) = 1.05 m.
- Measure 1.05 m from Peg 2 and from Peg 3, and drive Pegs 4 and 5 firmly into the soil, because later they will serve as reference pegs. Fix the level of these pegs in relation to the top of the embankment, by, for instance, putting a mark at 0.10 m above the design top of the embankment. The difference in level between the marks at Pegs 4 and 5 and the canal bed is then 0.80 m (height of the cross-section + 0.10 m).
- For a canal in cut, measure a path of 0.50 m next to Pegs 4 and 5, marking the points with Pegs 6 and 7. As earth is excavated it should be placed outside of these pegs so that the earth will not fall back into the excavated canal section.

Step 2 *Excavate a trench*

FIGURE A2.9-B
Excavation is started



- Remove Peg 1. Excavate the soil between Pegs 2 and 3 until approximately 0.1 - 0.15 m above the final bed level.
- Deposit the excavated earth at the foot of the embankment, or outside of Pegs 6 and 7 in the case of a canal in cut. The deposited soil may be spread out over the adjacent fields later. (Figure A2.9-B)

Step 3 *Excavate the cross-section*

FIGURE A2.9-C
Excavation nearly completed

- Remove Pegs 2 and 3, and excavate a rough canal cross-section approximately 0.1 - 0.15 m above the final section. Final trimming and finishing should be done by checking the final canal section carefully. (Figure A2.9-C)

Figure A2.10 shows a canal under construction. Step 3 is almost finished.

Step 4 *Check the cross-section of the canal*

- Hold a solid frame (template) against Pegs 4 and 5, and check the bed and the side slopes at the same time, remembering that the marks on Pegs 4 and 5 are 0.10 m higher than the design top of the canal banks. Any over-excavation or slide in side slope should be carefully filled and compacted, as for the embankment in Section A.2.3.2.
  - The canal should be checked at intervals of 10 metres. (Figure A2.9-D)

FIGURE A2.9-D
Bed level and side slopes are checked

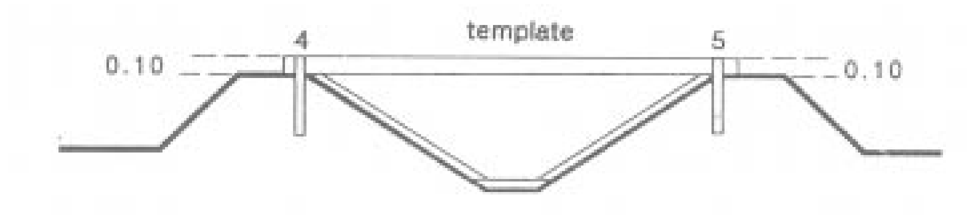


FIGURE A2.10
Canal construction at step 3

A2.5 ENLARGING THE CAPACITY OF AN EXISTING CANAL

It may be necessary in existing irrigation schemes that some canal sections have to be enlarged in order to give these canals a larger capacity. This can be done by increasing the maximum allowed water depth, either by raising the banks or by deepening the bed. It is also possible to enlarge the bed width (See also Annex 1). Examples of enlarging capacities by these three methods are given in the following sections.

A2.5.1 Enlarging canal capacity by raising the canal banks

The procedure to follow for enlarging a canal capacity by raising the banks will be given for the canal discussed in Annex 1, Section A1.3.1, based on the following assumptions (See figure A2.11):

- capacity before enlargement: 56 l/s
- capacity after enlargement: 80 l/s
- height of the cross-section before enlargement: 0.56 m
- height of the cross-section after enlargement: 0.66 m
- Bed width: 0.30 m

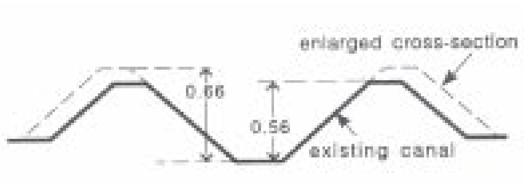


FIGURE A2.11
Cross-section before and after enlargement

Step 1 *Construct a template for the existing cross-section*

A template of plywood is made with the dimensions of the actual cross-section: bed width, b_{old}; top width, *a*, of the cross-section, and embankment height, *h*. See Figure A2.12-A.

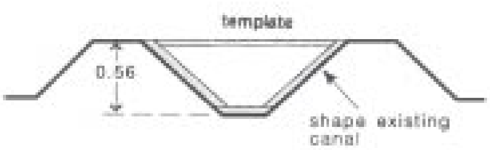


FIGURE A2.12-A
Template for canal cross-section

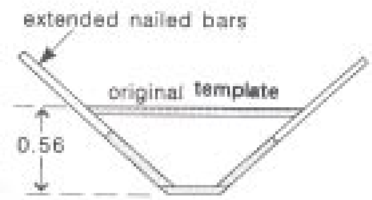


FIGURE A2.12-B
Template with bars

Mark the elevation from the canal bed so that the height of the canal cross-section can always be checked. The sides of the template has bars nailed to it which are long enough to mark the height of the new embankments. See Figure A2.12-B.

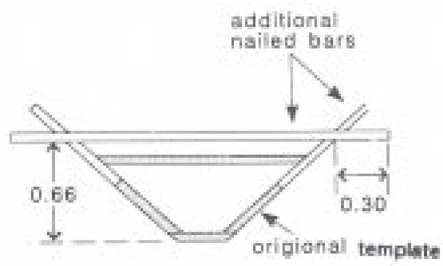


FIGURE A2.12-C
Template gives the size of the new cross-section of the canal

Step 2 *Adapt this template for the new enlarged cross-section*

Another bar is nailed on the template, parallel to the bed at a height of 0.66 m, which is the new height of the embankments. The same bar indicates the widths of the crests of the banks, here 0.30 m. See Figure A2.12-C.

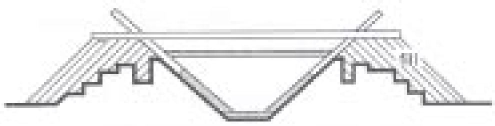
Step 3 *Excavate the canal embankments partially*

The canal embankments are partially excavated to have better contact between old and new embankments, as in Figure A2.12-D. In the middle of the embankments, a deeper trench is excavated in order to avoid seepage between the old and new soil.

Step 4 *Fill the embankments, layer by layer, and compact moist; check the new cross-section regularly using the template.*

FIGURE A2.12-D
Partially excavated embankments

FIGURE A2.12-E
Filling the new embankment and checking the cross-section

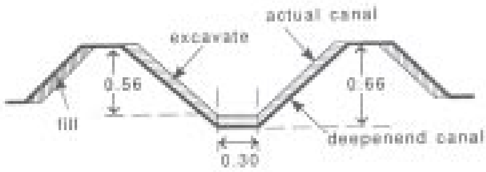


The new embankments are built up with moist soil. The filling of the embankments is done layer by layer, with each layer compacted moist. The new cross-section can be regularly checked with the template. Attention should be paid to the width of the crests of the embankments. They should be at least 0.30 m wide, and more if they will be used as paths. (Figure A2.12-E)

A2.5.2 Enlarging canal capacity by deepening the bed

Instead of raising the embankment of a canal, its bed can be deepened to increase water depth. As an example, the procedure is given for the same canal as was discussed above, in Section A2.5.1. See Figure A2.13.

FIGURE A2.13
Actual and deepened canal



Step 1 See Step 1 in Section A2.5.1.

Step 2 See Step 2 in Section A2.5.1.

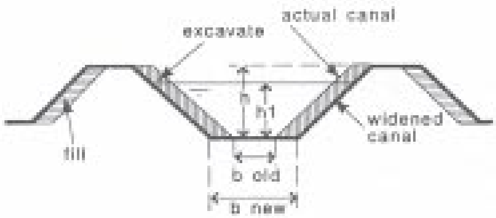
Step 3 *Excavate the bed and sides of the canal and check the cross-section regularly.*

The sides and bed of the canal are excavated until the template fits. The excavated soil can be used as fill for the embankments. See Figure A2.13.

A2.5.3 Enlarging a canal capacity by enlarging the bed width

A canal's capacity may also be enlarged by widening the bed width. In this case the height of the canal banks remain the same, and only the sides of the cross-section are to be excavated. The same procedure as described above can be followed, by using a template for a wider canal. See Figure A2.14.

FIGURE A2.14
Actual and widened canal



Annex 3
How to determine the slope of a canal alignment

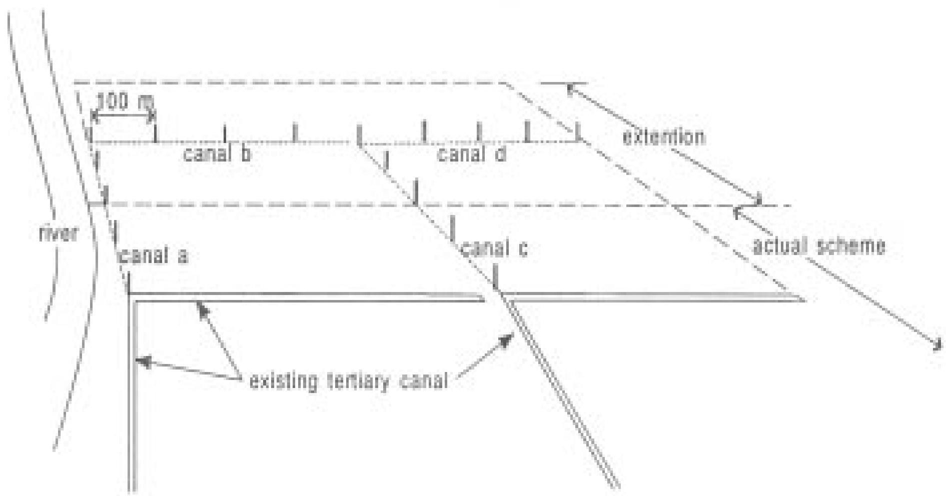
Annex 3 describes a method for determining the slope of a new canal alignment. Reference is made to the extension of the irrigation scheme that was discussed in Chapter 7.

In Figure 50, canals a and b, and c and d are the proposed new canals. The slope of the terrain where canal b is planned will be determined here as an example. See Figure A3.1. The procedure is given in the following steps.

Step 1 *Mark in the field the centre line of the proposed canal, marking at regular intervals of say 50 or 100 m*

See Figure A3.1, in which the canal alignments of the extension in Figure 50 are marked.

FIGURE A3.1
Marking of canal alignments



Step 2 *Measure the elevations of the marked points and calculate the differences*

Calculation of the difference in elevation between distant points is described in Training Manual 2: *Elements of Topographic Surveying.*

The following data have been obtained by the field survey for canal alignment b:

- difference in elevation between point 1 and point 2: 0.16 m
- difference in elevation between point 2 and point 3: 0.12 m
- difference in elevation between point 3 and point 4: 0.13 m

Step 3 *Determine the average slope between the marks*

For determination of the average slope, the differences in elevation are divided by the distance between the two marks concerned. As a formula:

$$s_1 = \text{difference in elevation}_1 \;/\; \text{distance}_1$$

where: s_1 is the average slope of the terrain between points 1 and 2; *difference in elevation*$_1$ is difference in elevation between points 1 and 2, in metres; *distance*$_1$ is the distance between points 1 and 2, in metres.

The following average slopes have been calculated for canal alignment b:

- Average slope between points 1 and 2: $s_1 = 0.16 / 100 = 0.0016$
- Average slope between points 2 and 3: $s_2 = 0.12 / 100 = 0.0012$
- Average slope between points 3 and 4: $s_3 = 0.13 / 100 = 0.0013$

Step 4 *Determine the average slope of the field where canal alignment* ***b*** *is projected*

The average slope of (future) canal b is determined by adding up the different average slopes of the sections and by dividing this sum by the number of measurements. In this example, three measurements were made, thus

$$\text{Average slope of canal alignment b: } S_b = (s_1 + s_2 + s_3) / 3$$

$$S_b = (0.0016 + 0.0012 + 0.0013) / 3 = 0.0014$$

Step 5 *Check whether the average slope of the canal alignment is within the range 0.0005 (0.05%) and 0.0015 (0.15%)*

The slope of the alignment calculated (0.14 %) is within the range of 0.05 to 0.15%, and so in this case the canal can be given the same slope as the terrain. If the calculated slope falls outside of this range, an irrigation engineer should be contacted for advice.