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

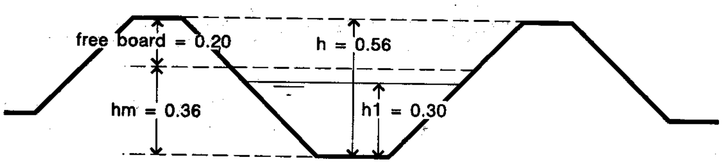
The capacity of a canal is the maximum discharge that can safely be transported. This means that when the discharge equals the capacity, the water level reaches the minimum required free board (*fb*) level. The height of the free board depends on the material used for constructing the embankments: embankments 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:

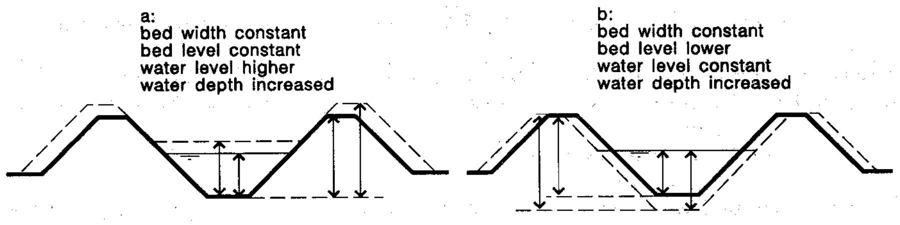
- increase the maximum allowed water depth;
- increase the the bed width; or
- reduce the bed roughness;

and these may be used singly or in combination.

Increasing the maximum allowed water depth

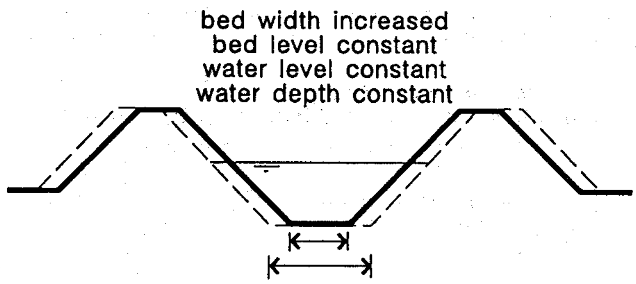
The maximum water depth in a canal can be increased in two ways: either by raising the canal banks and thus maintaining the bed level (Figure A1.2 a) or by lowering the bed level and thus maintaining the water surface level (Figure A1.2 b).

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.

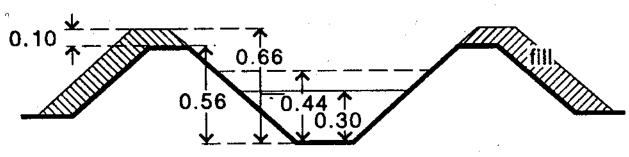
The procedure which is described here and used in Exercise A1.2, is in fact the contrary of the procedure for capacity estimation used in Section A1.2. In that section the discharge was estimated for a calculated maximum water level. Here the water level is estimated for a given discharge which is larger 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 x (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 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 x 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.

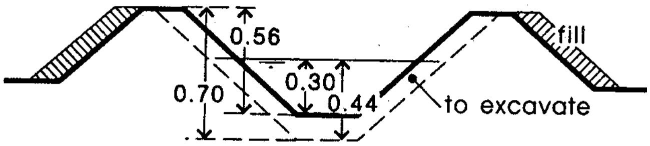
Answer: The existing canal embankment with a height of 0.56 m (see Section A1.2) should be increased by 0.10 m to give a new height of 0.66 m.

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)

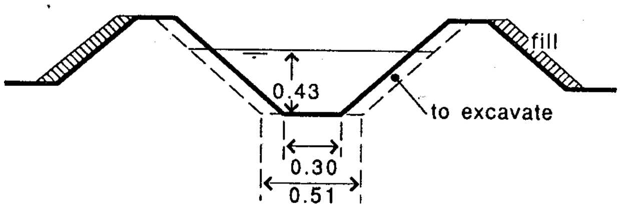
	f			
r	ss = 1.5 1:0.7	ss = 1.0 1:1	ss = 0.7 1:1.5	ss = 0.5 1:2
1.1	1.08	1.07	1.05	1.04
1.2	1.16	1.13	1.10	1.09
1.3	1.24	1.20	1.15	1.13
1.4	1.32	1.26	1.20	1.17
1.5	1.40	1.32	1.25	1.21
1.6	1.48	1.38	1.30	1.25
1.7	1.55	1.44	1.34	1.28
1.8	1.63	1.50	1.39	1.32
1.9	1.71	1.56	1.43	1.35
2.0	1.79	1.62	1.48	1.39

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.