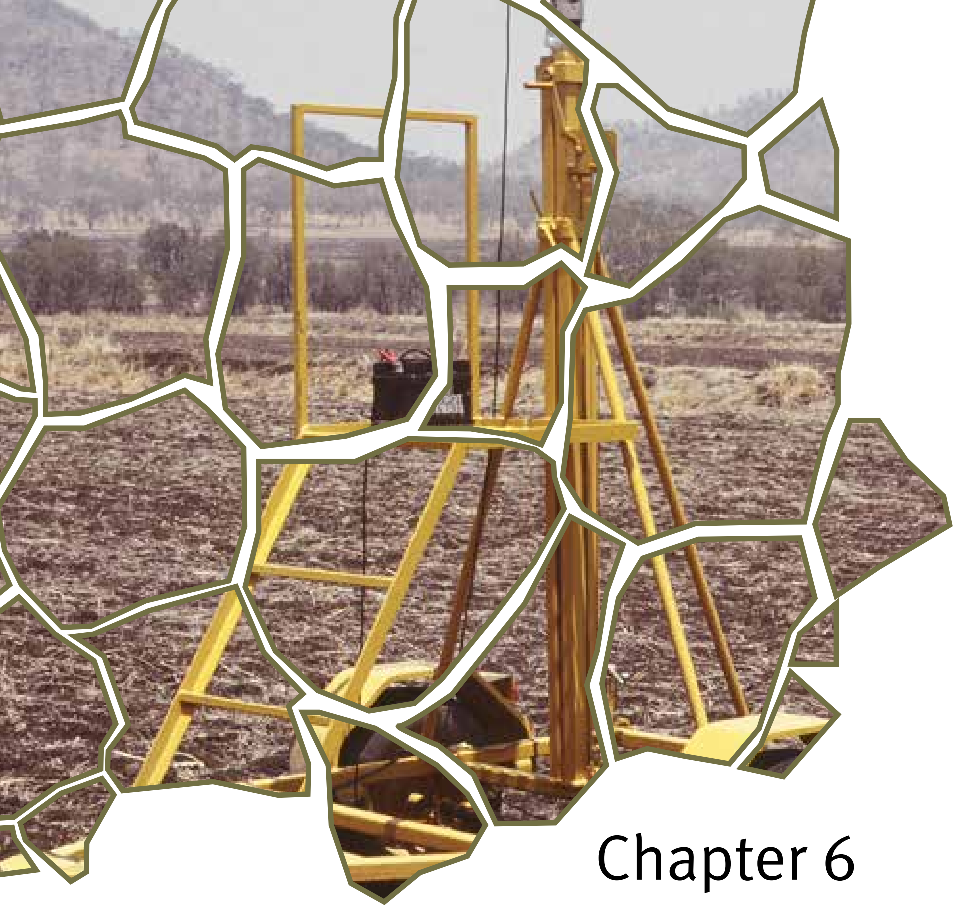

Chapter 6

Channel design principles

Key points

- The faster water flows in a channel the greater the likelihood that it will erode. The predicted flow velocity can be calculated from the channel slope, cross-sectional shape and size, and the roughness of the channel surface.
- The major influence on channel roughness in soil conservation structures is the amount and type of vegetation lining the channel. The extent to which vegetation retards flows depends on its density, height, and physical characteristics (such as flexibility).
- The flow in a channel is also affected by the inherent tendency of water to become turbulent as the cross-sectional area decreases and flow rate increases. Turbulent water is more likely to erode the bed and banks of a channel.
- When planning soil conservation structures it is important for long-term maintenance and security that a margin is added to the design cross-section to allow for settlement following construction and to ensure there is adequate freeboard under design conditions.

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Glossary

Average Recurrence Interval (ARI): the average period in years between the occurrence of an event (usually a storm or a flood) of specified magnitude and an event of equal or greater magnitude.

broad-crested weir: a flat-crested weir structure (also known as a ramp flume), with a long crest compared to the flow depth, where the water follows the surface of the structure continuously.

freeboard: the vertical distance between the maximum water level and the crest of a bank, dam, or similar structure. Freeboard is provided for in designing such structures to prevent overtopping. Freeboard should include an allowance for settlement.

Froude number (Fr): a dimensionless parameter expressing the ratio between inertia and the gravitational forces in a liquid. In general terms this falls into three categories:

- **Critical flow (Fr = 1):** when critical flow occurs, surface disturbances (e.g. the ripples caused when a rock is thrown into a stream) will not travel upstream.
- **Subcritical flow (Fr < 1):** when ripples created by surface disturbances will travel upstream. Occurs when the water in the channel is relatively deep and travelling slowly.
- **Supercritical flow (Fr > 1):** when ripples created by surface disturbances will only travel downstream. Occurs when the water in the channel is relatively shallow and travelling quickly.

geotextiles: permeable fabrics, typically made from synthetic materials, which when used in association with soil have the ability to separate, filter, reinforce, protect, or drain.

hydraulic jump: an abrupt rise in the surface of a liquid occurring when a high-velocity flow discharges into a zone of lower velocity.

hydraulic radius: the ratio of the cross-sectional area of a liquid flowing into a channel to the wetted perimeter of that channel.

Manning coefficient (of roughness): see **retardance**.

Manning formula: a formula used to predict the velocity of uniform water flow in an open channel or pipe based on the velocity, slope, and channel conditions.

nappe: a sheet or curtain of free-falling water flowing from a structure such as a weir.

Ogee spillway: a structure used to provide for the controlled release of flows from a dam or weir that is designed to follow an ‘ogee’ (or sigmoidal) curve.

retardance: a measure of resistance to flow in a channel; the more the resistance the higher the retardance. It is calculated using the **Manning formula** and has the symbol ‘n’. Retardance is influenced by the physical roughness of the internal surface of the channel (e.g. the vegetation that lines it), channel cross-section, alignment, and obstructions.

riffle: a short, relatively shallow, and coarse-bedded length of stream over which the stream flows at lower velocity but greater turbulence than it does through a pool.

rock gabion: a rectangular wire-mesh cage filled with rock, brick, or similar material usually assembled on site to construct retaining walls and anti-erosion structures.

sharp-crested weir: a weir that has a crest with a thin upstream edge often constructed of metal plates that allow the water cresting the weir to fall cleanly away from the weir. Contrasts with **broad-crested weir**.

stream power: the rate the energy of flowing water is expended on the bed and banks of a channel.

6.1 Introduction

The primary function of soil conservation structures is to control runoff water by intercepting it and transferring it safely into the local drainage network. Such structures are designed to carry the expected runoff discharge for an event with a chosen average recurrence interval.

Erosion in the structures themselves is controlled either by reducing the water velocity or by protecting the surface. Surfaces of soil conservation structures in cropping lands are usually protected with vegetation. Materials such as geotextiles, rock gabions, and concrete are commonly used in urban situations.

6.2 Channel flow concepts

The behaviour of water flowing through channels has been the subject of much research. As a consequence it is possible to predict with some confidence how water will flow provided key characteristics of the channel are known or can be determined. A number of models and rules have been developed to quantify these relationships for use in designing works and structures.

6.2.1 Channel capacity

Equation 6.1

$Q = A*V$

Where

Q = the discharge or hydraulic capacity of the channel (m^3/s)

A = cross-sectional area (m^2)

V = average velocity in (m/s).

The hydraulic capacity of a channel can be determined by multiplying its cross-sectional area by the mean velocity of water flowing through it (see Equation 6.1).

6.2.2 The Manning formula

Equation 6.2:

$V = (R^{0.66} * S^{0.5}) / n$

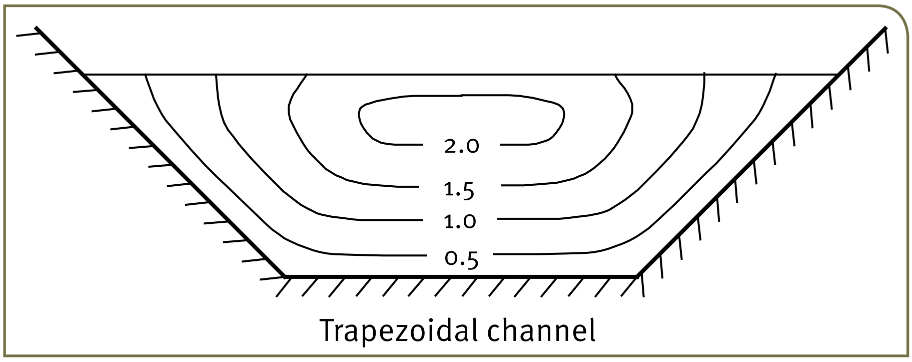
Where:

V = mean velocity of flow (m/s)
n = Manning coefficient of roughness
S = channel slope (m/m)
R = hydraulic radius (m).

The mean velocity of water flowing in a channel can be calculated using the Manning formula (Equation 6.2). The Manning formula applies to steady uniform flow. For design purposes it is assumed that flow is constant and uniform. Flow in channels can be described as critical, subcritical or supercritical (see Section 6.3.1).

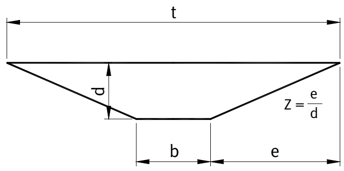
Although it is assumed that the mean velocity is constant along the full length a channel, actual velocities will always vary between one cross-section and another. Frictional losses occur where runoff comes in contact with the walls and the base of a channel. As channel roughness increases (or conversely decreases), so does the amount of friction. Friction reduces velocity the most at the edge of the channel and least in the middle (Figure 6.1).

Figure 6.1: Variation in flow velocities across a trapezoidal cross section



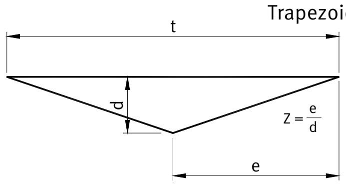
The hydraulic radius (R) is dependent on the cross-sectional area of flow and the wetted perimeter and is expressed in Equation 6.3.

Figure 6.2: Formulae for dimensions relating to trapezoidal, triangular, and parabolic cross-sections

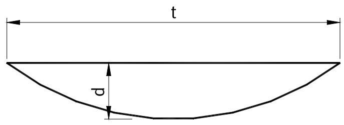


	Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
Trapezoidal cross section	$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2+1}}$
Triangular cross section	Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z^2+1}}$
Parabolic cross section	0.66td	$t + \frac{8d^2}{3t}$	$\frac{t^2 d}{1.5t^2 + 4d^2}$

Trapezoidal cross section



Triangular cross section



Parabolic cross section

Equation 6.3:

R = A / P

Where:

A = the cross sectional area of flow (m^2)

P = the wetted perimeter i.e. the length of the line of contact between the water and the channel boundary (m).

6.2.3 The Manning roughness coefficient, *n*

The Manning coefficient (*n*) is related to the roughness characteristics of the channel boundary surface. Characteristics of soil conservation structures that affect the value of *n* include:

- the roughness or texture of the channel surfaces
- the presence of vegetation in the channel and its nature. This effect can be complex and variable. For example, grasses will offer significant resistance at low discharge but less resistance under high flows as they are forced flat by the water (see notes below under n-VR relationships)
- the depth of the discharge (or flow). The value of *n* is likely to be higher when depths are shallow as at shallow depths more of the flow adjoins the coarse material of the channel bed.
- the alignment of the channel. Flow is retarded by bends, irregularities, or obstructions along the channel.

Values of *n* for a range of conditions are given in Table 6.1. Values of n for a range of stream types developed using a method described by Chow (1959) are provided in the appendices.

Table 6.1: Values of the Manning *n* coefficient for roughness (Pilgrim 1987, Queensland Transport and Main Roads 2010, Ree 1954)

Channel/stream condition	Manning's *n*
Earth channels subject to intermittent flow and vegetal lining	The n/VR relationship applies (see 6.2.4)
Contour bank channels	
Smooth and bare	0.02 to 0.03
Roughly cultivated	0.04
Sparse grass cover	0.05
Wheat crop or standing wheat stubble	0.07 to 0.15
Sorghum (25 cm rows)	0.04 to 0.12
Lined channels excavated in rock	
Smooth and uniform rock	0.025 to 0.040
Jagged and irregular rock	0.035 to 0.050
Concrete—smooth forms or trowelled	0.012
Small natural streams	
Straight, uniform and clean	0.025 to 0.033
Clean, winding, with some pools and shoals	0.033 to 0.045
Sluggish, weedy reaches with deep pools	0.050 to 0.080
Very weedy reaches with deep pools	0.075 to 0.150

6.2.4 The n–VR relationship in channels lined with vegetation

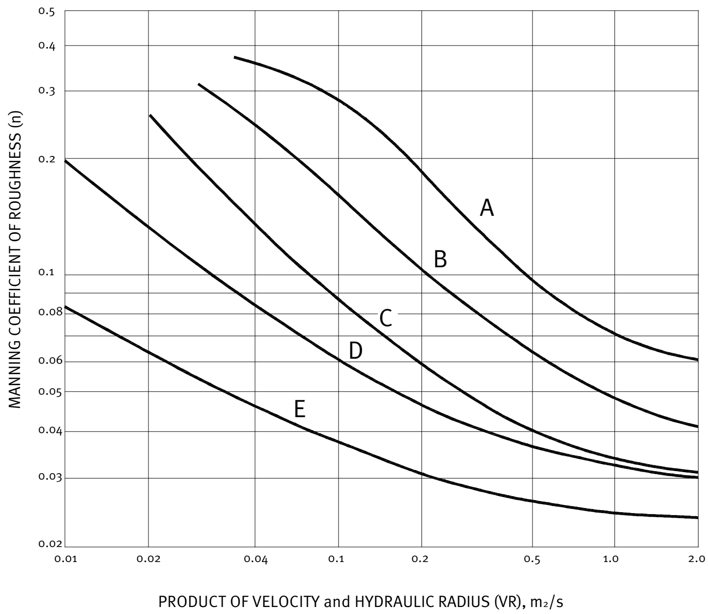
For their long-term maintenance, waterways designed for soil conservation are usually planned to be vegetated quickly, and the design of waterways normally assumes that this vegetation will remain in place throughout the life of the waterway. However, the nature of this vegetation cover can vary significantly from season to season and with changes in management practices.

The Manning 'n' factor for vegetated waterways is strongly influenced by the nature of the vegetation, particularly when the flow completely or almost completely submerges the vegetation. The extent of retardance provided by vegetation varies with the velocity and depth of flow.

It is commonly misconceived that under the weight of strongly flowing water, vegetation bends over completely to shingle and form a protective shield over the bed and hence provides minimal retardance under such conditions. However field observations (Ree 1954) have shown that in fact vegetation tends to bend and oscillate continuously during a flow.

The n-VR relationship refers to the fact that n varies with the product of velocity (V) and hydraulic radius (R). The design of vegetation-lined channels requires that n be compatible with the value of V*R. To assist in designing channels in such situations, general n-VR curves for five degrees of vegetal retardance (A to E) have been developed (Figure 6.3). Figure 6.3 also lists the equations used to determine the curves for each retardance. By using these equations, it is possible to apply the Manning formula by considering Manning's n to be a function of V and R for any specified retardance.

Figure 6.3: Graphical solution for five degrees of vegetal retardance for the Manning formula



Curve A n= 0.440 - 1.674 VR VR ‹ 0.1542
n= 0.046 + 0.0223/VR VR › 0.1542
} Ref. Green, JEP and Garton, JE (1983)

Curve B n= 0.032 + 0.01545/(VR) $^{7/8}$

Curve C n= 0.030 + 0.00501/VR

Curve D n= 0.027 + 0.00534/(VR) $^{3/4}$

Curve E n= 0.022 + 0.003014/(VR) $^{2/3}$

} Ref. Findlay, GH and Ellul, GA (1976)

The Manning formula can be solved graphically using the n-VR curves and other charts. The graphical solution of the Manning formula for vegetal retardances ‘C’ is shown in Figure 6.4 (adapted from Ree 1954). Graphical solutions for all retardances are provided in the appendices.

Figure 6.4: Graphical solution to the Manning formula for retardance C (adapted from Ree 1954)

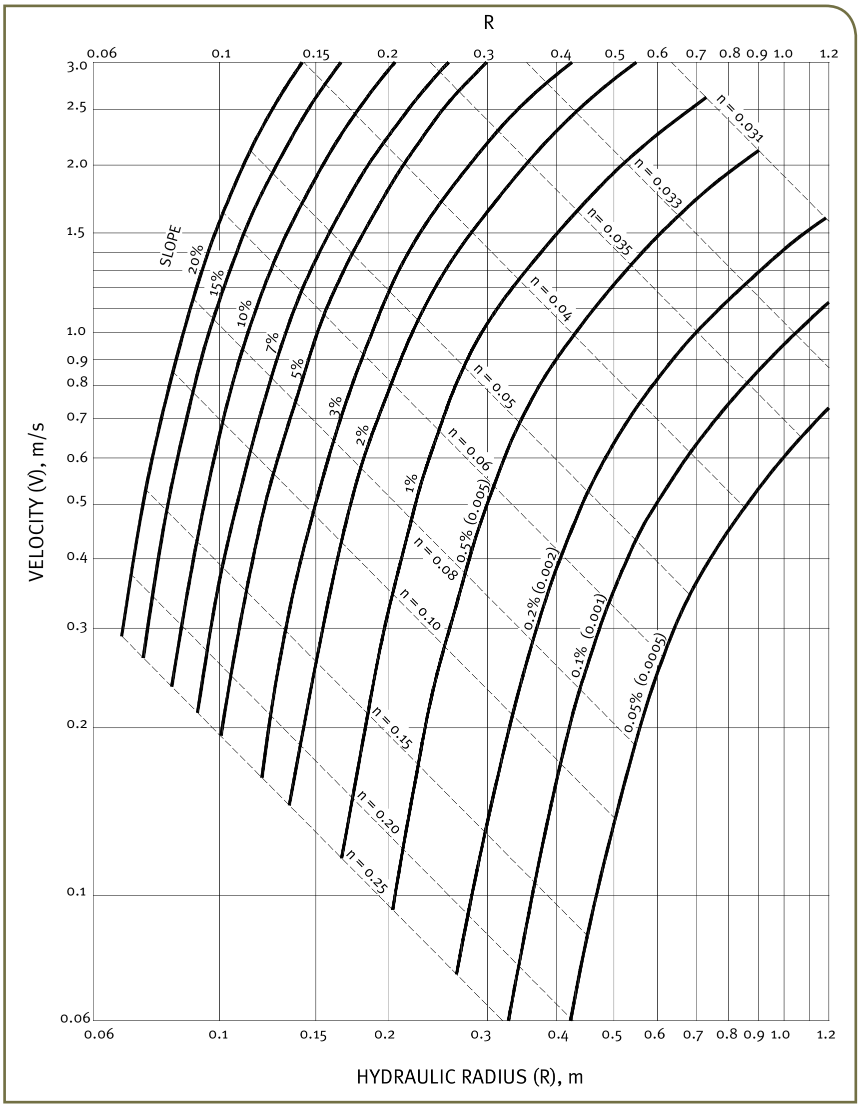


Table 6.2 provides guidance in selecting the appropriate vegetal retardance to apply. It should be noted that the A to E retardance charts apply to runoff flows where vegetation is completely submerged or nearly so. For shallow flows through upright vegetation with limited submergence, Manning's n ceases to be related to VR (Ree 1954) and the Manning formula can be solved just with an appropriate selected value for n (Table 6.1).

Table 6.2 Guide to selection of vegetal retardance

Average height of vegetation	Highly retardant vegetation	Moderately retardant vegetation
Greater than 75 cm	A	B
30 cm to 60 cm	B	C
15 cm yo 25 cm	C	D
5 cm top 15 cm	D	D
Less than 5 cm	E	E

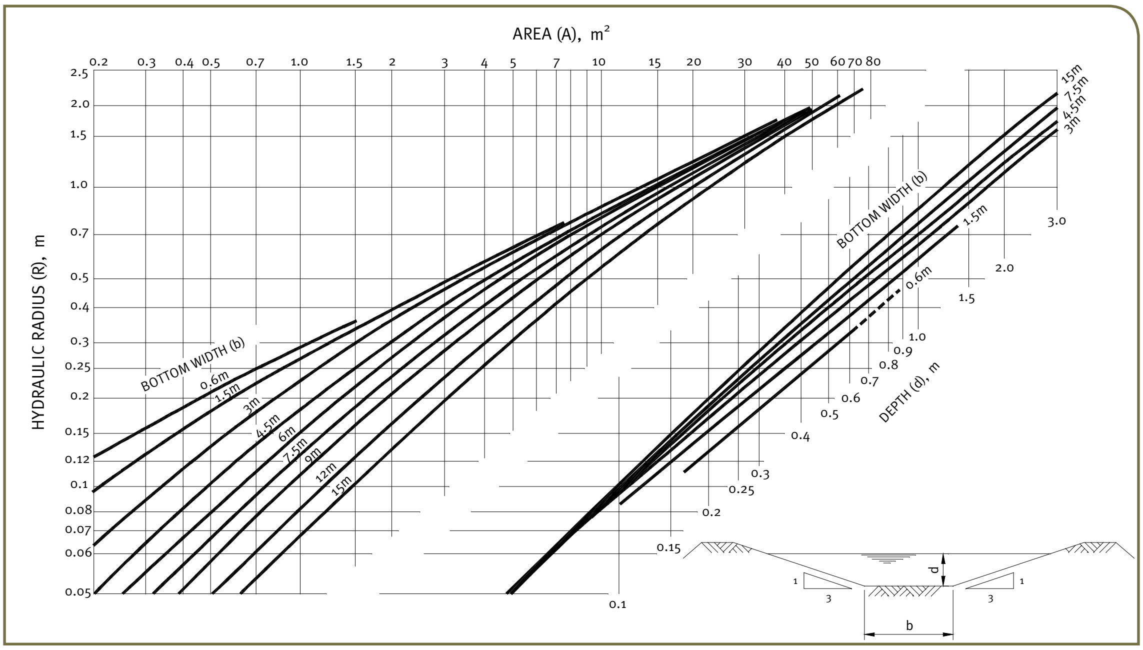
6.2.5 Hydraulic radius

For a given cross-sectional area, the shorter the wetted perimeter the greater will be the hydraulic radius and the greater the resulting velocity in the channel. The channel cross-section shape with the maximum hydraulic radius is a semicircle. For a trapezoidal channel, the maximum hydraulic radius (and highest velocities) will be when the channel cross-section most closely approximates a semicircle. For channels with triangular cross-sections, the hydraulic radius is approximately equal to half the depth.

For waterways wider than 20 metres it is safe to assume that the depth of flow is equal to the hydraulic radius. For example, a trapezoidal waterway with 1:3 (V:H) side batters and a bottom width of 20 metres will have a hydraulic radius of 0.29 when carrying a depth of flow of 0.3 metres. Adopting this assumption can greatly simplify the task of designing wide waterways.

Charts have been developed to determine the hydraulic radius of channels of various shapes and sizes. An example for trapezoidal channels is shown in Figure 6.5 (adapted from Ree 1954). Other charts for a range of shapes are included in the appendices. For channels with differing internal batters, the recommended approach is to firstly determine the average of the two and then use the chart appropriate for that average dimension for the channel as a whole.

Figure 6.5: Dimensions of trapezoidal channels with 1:3 (V:H) side channels (adapted from Ree 1954)



6.3 Stability of channels

Earth channels, either bare or lined with vegetation, should be constructed to carry the design discharge at non-erosive velocities. Chapters 7, 8, and 9 provide specific information on recommended velocities to ensure stability for contour banks, diversion banks, and waterways respectively.

6.3.1 The Froude number

The Froude number (Fr) describes different flow regimes in open channels. The Froude number measures bulk flow characteristics such as waves, sand-bed forms, or flow/depth interactions at a cross-section. It characterises the conditions in flowing water in terms of its velocity and depth and the resultant wave patterns. An understanding of critical flow conditions and the appreciation of Froude numbers can assist in the design of channels, so that erosive damage to the channel does not occur.

Using the Froude number a given design flow can be classified as subcritical, critical, or supercritical. These terms are defined as follows:

- Critical flow is when the Froude number is equal to one ($Fr = 1$). When critical flow occurs, surface disturbances (e.g. the ripples caused when a rock is thrown into a stream) will not travel upstream.
- Subcritical flow is when the Froude number is less than one ($Fr < 1$). When subcritical flow occurs, ripples created by surface disturbances will travel upstream. Subcritical flow tends to occur when the water in the channel is relatively deep and travelling slowly.
- Supercritical flow is when the Froude number is greater than one ($Fr > 1$). When supercritical flow occurs, ripples created by surface disturbances will only travel downstream. Supercritical flow tends to occur when the water in the channel is relatively shallow and travelling quickly.

For safe design of vegetated channels, the Froude number of the design flow should be between 0.8 and 1 depending on the degree of erosion resistance provided by the vegetation. Where values exceed 1 it is necessary to ensure that the channel is lined to protect it against erosion.

The Froude number is a dimensionless parameter expressing the ratio between the inertia and gravitational forces in a liquid. It is defined (in general) by the expression:

Equation 6.4

$$Fr = \propto Q^2 B/gA^3)^{0.5}$$

Where

Fr = Froude number
Q = the discharge (m^3/s)
$\propto$ = velocity head coefficient (commonly assumed as unity)
B = the surface width of flow (m)
A = the cross-sectional area (m^2)
g = the gravitational acceleration (9.8 m/s^2).

For the particular case of a channel of rectangular cross-section, Equation 6.4 reduces to:

Equation 6.5

$$Fr = V/(gd)^{0.5}$$

Where

Fr = Froude number
V = the mean flow velocity (m/s)
d = the flow depth (m)
g = gravitational acceleration (9.8 m/s^2).

For a trapezoidal channel, Equation 6.4 becomes:

Equation 6.6

$$Fr = \left[\frac{V2\ (b + 2Zy)}{gy\ (b + Zy)}\right]^{0.5}$$

Where

Fr = Froude number
V = the mean flow velocity (m/s)
b = bottom width (m)
Z = side slope ratio (vertical distance / horizontal distance)
g = gravitational acceleration (9.8 m/s^2)
y = the flow depth (m).

6.3.2 Stream power

Whether a channel erodes, or deposition occurs, depends on the relative soil strength and discharge compared with the stream power or shear stress exerted by that discharge (Loch and Thomas 1987). Further information on stream power is provided in the section on design velocity in Chapter 7.

Stream power is defined as the product of the shear stress exerted by the flow and average channel velocity and is expressed in Equation 6.7.

Shear stress is calculated in Equation 6.8

Equation 6.7

w = T*V

Where

w = stream power in W/m2 (Watts per square metre)
T = shear stress in Pa, or N/m2 (Pascals, or Newtons per square metre)
V = average channel velocity (m/s).

Equation 6.8

T = ρ*g*R*S

Where

T = shear stress (in Pa or N/m2)
ρ = density of the fluid (kg/m3)
g = gravitational acceleration (9.8 m/s2)
R = channel hydraulic radius (m)
S = channel slope (m/m).

6.4 General design approach

Equation 6.9

$$\frac{Q}{A} = V = \frac{R^{0.66}\, S^{0.5}}{n}$$

Where

Q = the discharge or hydraulic capacity of the channel (m^3/s)
A = cross sectional area (m^2)
V = average velocity (m/s)
R = hydraulic radius (m)
S = channel slope (m/m)
n = Manning's coefficient of roughness.

When carrying out a design for a soil conservation structure, it is useful to combine Equation 6.1 and Equation 6.2 as expressed in Equation 6.9.

Usually, when designing soil conservation works the following factors in the above equation would be known:

- discharge (Q)
- velocity (V) (it is normal to design for a selected maximum permissible velocity)
- channel slope (S) would be known in the case of a waterway design. However, in the design of a contour or diversion bank, channel slope is a variable. In those circumstances different channel slopes (gradients) across the range that could be expected can be compared.
- Manning's coefficient of roughness (n) should be selected as a fixed value (Table 6.1); or as a retardance value (Table 6.2) where n/VR relationships apply.

The design may however be constrained in other ways, for example as follows:

- Conditions in the channel may be subject to considerable variation depending on seasonal and management conditions.
- The top width for a waterway may be restricted because the waterway needs to fit within a confined location.
- The length of a contour bank batter may be predetermined to accommodate the requirements of the planting machinery used by a farmer.

By incorporating the known values of Q, V, S and n into Equation 6.9 it is possible to determine design values for the cross-sectional area A and the hydraulic radius R. This is a straightforward exercise if the value of Manning's n is constant, but in cases where n varies with the product of V and R an iterative process is required to solve the equation. This includes when the value of n varies with seasonal and management conditions, for example, a waterway that has abundant growth in a good season but is virtually bare during a drought, or a contour bank channel that varies from a ploughed condition to an advanced crop or stubble depending on the cropping cycle. Further advice on how to account for this variability is provided in Chapters 7 and 9.

The design exercise then becomes a geometrical one in which it is necessary to determine which dimensions of the selected cross-section will give the required values for R and A. Charts similar to that in Figure 6.5 can be used for this purpose. Alternatively an iterative process can be undertaken to determine the optimum dimensions. The Excel workbook RAMWADE can be used to determine appropriate dimensions for soil conservation structures.

6.5 Freeboard and settlement

Freeboard and settlement should also be allowed for in designing soil conservation structures. Freeboard is included to prevent overtopping due to surcharge or wave action. Freeboard also provides an additional margin for irregularities in construction. Operator skill, machinery used, and soil properties at the time of construction can all contribute to irregularities in the height of a structure over its entire length. For most soil conservation structures with flow depths of 20–75 cm, a freeboard of 10–15 cm should be adequate.

An allowance should also be made for settlement of banks following initial construction. The amount of settlement depends on how well the structure was compacted during construction, and on soil type and soil moisture conditions at the time of construction. The degree of compaction is also related to the type of machinery used. Table 6.3 provides a guide to estimate the amount of settlement likely to occur.

Table 6.3: Estimated settlement rates for bank construction

Construction equipment	Estimated settlement rate (%): • for swelling clays	• for light textured soils
Bulldozer	50%	30%
Grader	30%	20%

Equation 6.10 can be used to calculate the constructed height of a bank (Hc) from the settled height (Hs) and the expected amount of settlement (y).

Equation 6.10

$$Hc = \frac{H_s}{1 - \frac{y}{100}}$$

Where

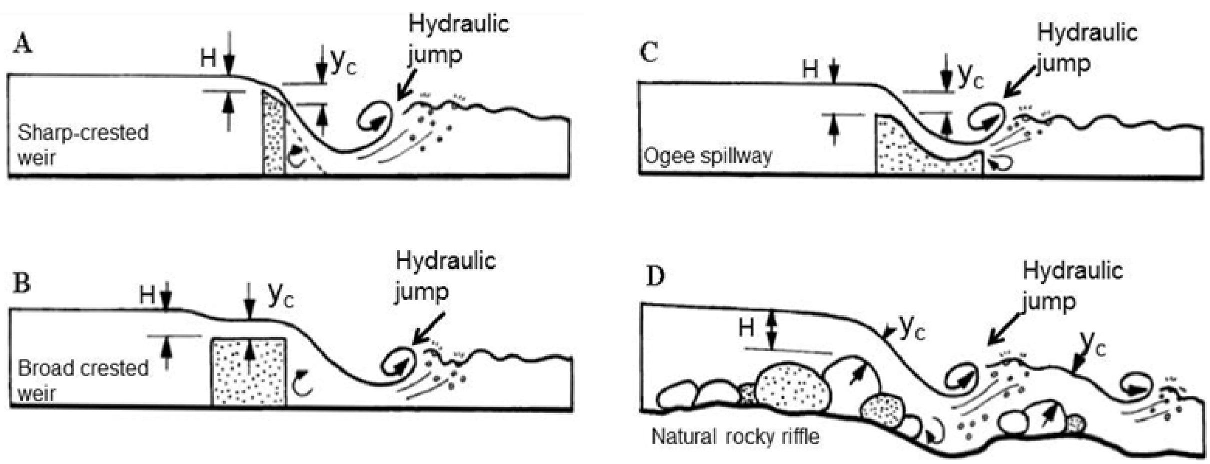
Hc = constructed bank height (m)
H_s = settled bank height (m)
y = settlement (%)

6.6 The Weir formula

The discharge of water over a level sill such as a drop structure, dam spillway, chute, pondage bank outlet, and some diversion and contour bank outlets is controlled by conditions at the outlet. When water is given free outlet over a level sill it flows at critical depth and velocity. This phenomenon can be explained mathematically and can be used, in the case of irrigation channels or experimental procedures, for regulating or measuring rates of flow.

Figure 6.6 demonstrates flow conditions above and below critical flow, for (A) a sharp-crested weir, (B) a broad-crested weir, (C) an Ogee spillway, and (D) a natural rocky riffle. Flow condition is the head or depth above the obstruction (at sub-critical flow); yc is the critical depth, being equal to 2/3H (point of critical flow just above the fall where super-critical flow occurs). Sub-critical flow returns at a point below the hydraulic jump.

Figure 6.6: Demonstrating flow conditions above and below critical flow



The major difference between a broad-crested weir and a sharp-crested weir is that with a broad-crested weir, the water follows the surface of the structure continuously, and with a sharp-crested weir it is thrown clear and forms a *nappe*. Most drop inlet structures are sharp-crested weirs. The Weir formula can be used to estimate the discharge capacity of gully control chutes and drop inlet structures, dam spillways, pondage bank sills, and weirs. Generally, it can be assumed that for gully control chutes, dam spillways and bank sills, broad-crested weir conditions apply. The simplest form of the Weir formula is expressed in Equation 6.11.

Equation 6.11

$Q = CLH^n$

Where:

Q = discharge (m^3/s)
C =a coefficient for the structure
L = length of the crest (width of the flow), (m)
H = the total energy head of the approach flow
n varies with the structure (for example 1.5 for a horizontal weir and 2.5 for a V-notched weir

The value of the coefficient C depends on several parameters including:

- whether the form of the crest is broad or sharp
- crest roughness, and
- flow approach conditions, including channel shape and approach velocities.

The following C values (metric units) may be used:

- 1.55 for level dam spillways–broad-crested
- 1.60–1.65 for pondage bank sill or for flows over road embankments–broad-crested
- 1.70 for drop structures or verandah chutes where water ponds upstream of the weir crest–sharp-crested, and
- 1.75–1.90 for drop structures with steeper approach gradients–sharp-crested.

The y_c value in Figure 6.6 depends on the shape of the weir. Sharp weirs are rare in engineering. Water flowing over a road acts like a very broad weir with a lot of friction, and the value of y_c will not be constant across the road. The critical value occurs if the water flows like a waterfall after it has crossed the road. In Figure 6.6 the flow at H is sub-critical. The critical depth of flow (y_c) for a broad-crested weir in a gully would normally be two-thirds of H. After water flows over the crest, gravity comes into effect and it goes into super-critical flow. It accelerates and gets thinner and thinner until the increased friction changes the kinetic energy into potential energy and it reaches its terminal velocity. A chute in a river seldom reaches terminal velocity because it normally flows into water. But in a gully there is seldom a significant depth of water below the chute (Table 6.4).

Table 6.4: Weir equations for short spillway crest lengths lengths where only minor friction loss occurs within the approach channel (Catchments and Creeks 2010)

Weir cross-sectional profile	Side slope (H:V)	Weir equation
Rectangular (b = base width)	vertical sides	$Q = 1.7\ b\ H^{1.5}$
Triangular	m:1	$Q = 1.26\ m\ H^{2.5}$
Parabolic (T = 3.3(Y)0.5)	N/A	$Q = 2.06\ H^{1.5}$
Trapezoidal (where :b = base width and m = side slope)	1:1	$Q = 1.7\ b\ H^{1.5} + 1.26\ H^{2.5}$
	2:1	$Q = 1.7\ b\ H^{1.5} + 2.5\ H^{2.5}$
	3:1	$Q = 1.7\ b\ H^{1.5} + 3.8\ H^{2.5}$
	4:1	$Q = 1.7\ b\ H^{1.5} + 5.0\ H^{2.5}$
	m:1	$Q = 1.7\ b\ H^{1.5} + 1.26\ m\ H^{2.5}$

For any given value of Q, there will be a number of solutions to the Weir formula depending on the value chosen for the approaching depth of flow (H). This value can be controlled by the method of construction of the weir. Inlet weir capacities for trapezoidal chutes vary with the width of the chute and with 2:1 (H:V) side slopes (Table 6.5).

Table 6.5: Inlet weir capacity for various trapezoidal chutes (m^3/s)

	Crest width (b) of a trapezoidal chute with 2:1 (H:V) side slopes									
Head (H) upstream of the chute inlet (m)	0.3	0.5	1	1.5	2	2.5	3	4	5	6
0.1	0.0	0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.3	0.3
0.2	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.7	0.8	1.0
0.3	0.2	0.3	0.4	0.5	0.7	0.8	1.0	1.2	1.5	1.8
0.4	0.4	0.5	0.7	0.9	1.1	1.3	1.6	2.0	2.4	2.8
0.5	0.6	0.7	1.0	1.3	1.6	2.0	2.3	2.9	3.5	4.1
0.6	0.9	1.1	1.5	1.9	2.3	2.7	3.1	3.9	4.7	5.4
0.7	1.3	1.5	2.0	2.5	3.0	3.5	4.0	5.0	6.0	7.0
0.8	1.8	2.1	2.7	3.3	3.9	4.5	5.1	6.3	7.5	8.7
0.9	2.4	2.7	3.4	4.1	4.8	5.6	6.3	7.7	9.2	10.7
1.0	3.0	3.4	4.2	5.1	5.9	6.8	7.6	9.3	11.0	12.7

Examples of the application of the Weir formula can be found in the design of chutes and drop structures in Chapter 13.

6.7 Further information

References

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Other information

The appendices contain design charts for a range of channel profiles and retardances.

The Excel workbook RAMWADE is available from qld.gov.au/environment/land/soil/erosion.