Chapter 8

Channel design principles

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.

8.1 Channel flow concepts

8.11 Channel capacity

The hydraulic capacity of a channel can be determined by multiplying its cross-sectional area by the mean velocity as in the following formula:

Q = AV ....Equation 8.1

Where

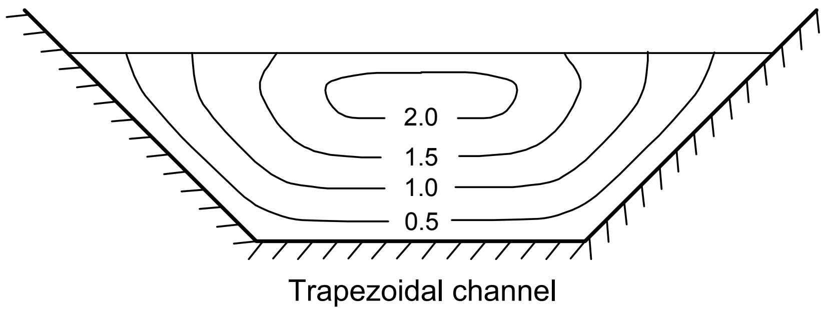
Q = the discharge or hydraulic capacity of the channel (m^3/s)
A = cross sectional area (m^2)
V = average velocity in (m/s)

8.12 The Manning Formula

The mean flow velocity in a channel can be calculated using the Manning Formula. The formula is applicable to steady uniform flow, which for design purposes assumes that flow is constant and uniform. Flow in channels can be described as critical, subcritical or supercritical. For definitions of these terms refer to the section on Froude number in this chapter.

Although it is assumed that the mean velocity is constant at each cross-section, there is variation in actual velocities at each cross-section. Frictional losses occur where the runoff comes in contact with the walls and the base of the channel. The greater the degree of roughness in the channel, the greater the amount of friction, which results in reduced velocities. Figure 8.1 shows an example of such variations in velocity.

Figure 8.1 Variation in flow velocities across a trapezoidal cross-section



The Manning Formula is expressed as follows:

$$V = \frac{R^{0.66} S^{0.5}}{n} \qquad \text{Equation 8.2}$$

Where

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

The hydraulic radius (R) is dependent on the cross-sectional area of flow and the wetted perimeter and is expressed by the formula:

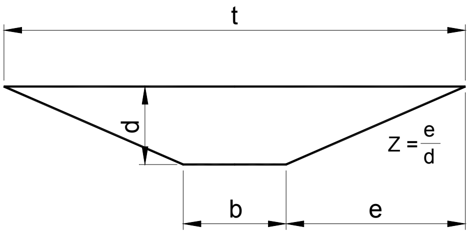
$$R = \frac{A}{P} \qquad \text{Equation 8.3}$$

Where

A = the cross sectional area of flow (m^2)
P = the wetted perimeter ie. the length of the line of contact between the water and the channel boundary (m).

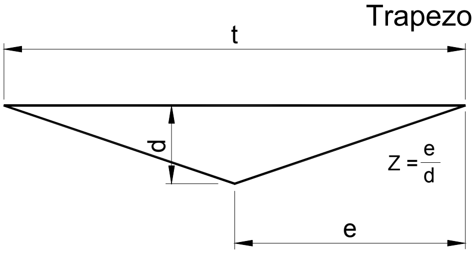
Figure 8.2 provides formulae relating to the hydraulic radius and wetted perimeter for trapezoidal, triangular and parabolic cross sections.

Figure 8.2 Formulae for dimensions relating to trapezoidal, triangular and parabolic cross-sections



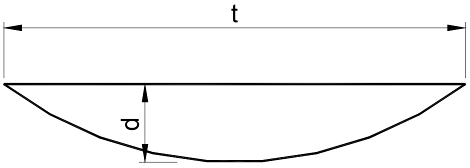
Cross - Sectional Area a	Wetted Perimeter	Hydraulic Radius R
$bd + Zd^2$	$b + 2d\sqrt{Z^2+1}$	$\frac{bd + Zd^2}{b + 2d\sqrt{Z^2+1}}$

Trapezoidal cross section



Zd^2	$2d\sqrt{Z^2+1}$	$\frac{Zd}{2\sqrt{Z^2+1}}$

Triangular cross section



$0.66td$	$t + \frac{8d^2}{3t}$	$\frac{t^2 d}{1.5t^2 + 4d^2}$

Parabolic cross section

8.121 The Manning roughness coefficient, n

The Mannings coefficient (*n*) is dependant on the roughness characteristics of the channel boundary surface. The characteristics relevant to the design of soil conservation structures include:

- the surface roughness or texture of the channel boundaries
- the presence and composition of vegetation – this effect can be complex and variable eg. grasses will offer significant resistance at low discharge but less resistance under high flows (see n-VR relationships below)
- discharge (or flow) depth – the value of *n* is likely to be high at shallow depths when much of the boundary to the flow consists of the coarse material of the channel bed
- the presence of bends, irregularities and obstructions.

Representative values of *n* are given in Table 8.1 for a range of conditions.

Table 8.1 Values of Mannings *n* coefficient of roughness

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

Source: Pilgrim (1987), Queensland Main Roads Department (1979), Ree (1954)

Estimates of the coefficient for a range of stream types are provided in the Appendix. These estimates were developed using a method described by Chow 1959.

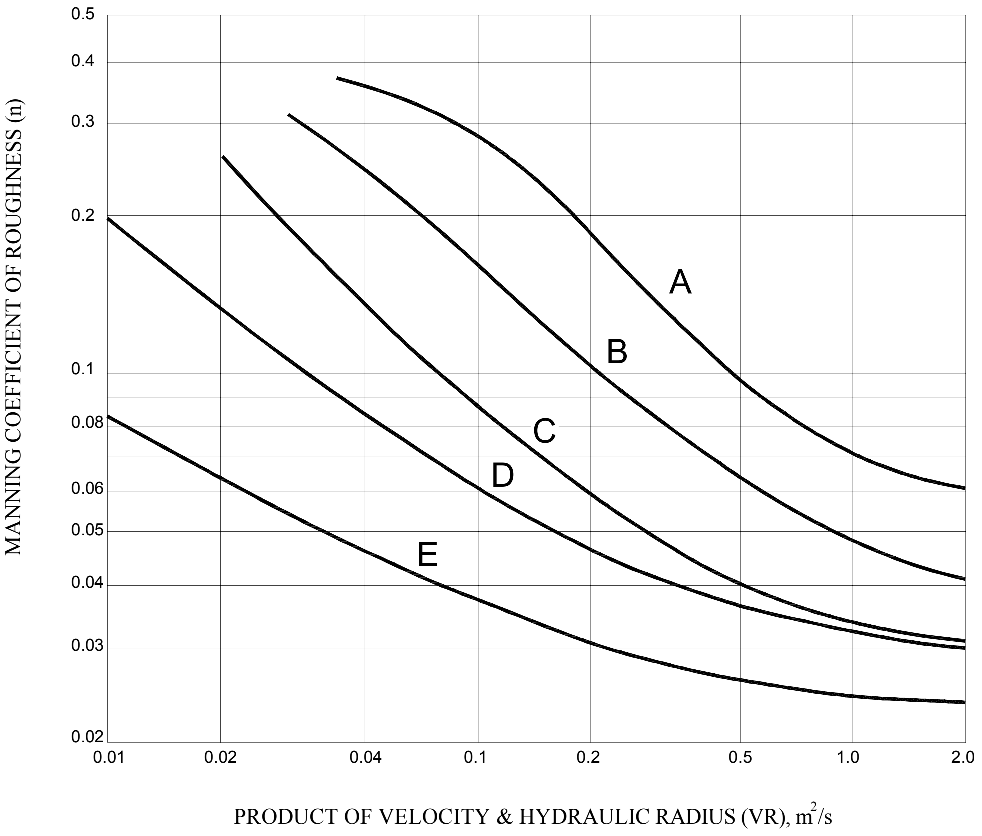
8.122 The n-VR relationship in channels lined with vegetation

Waterways used in soil conservation layouts usually depend on a well established vegetal cover for long-term stability. The nature of this cover can change significantly depending on the seasonal conditions and management practices. The Mannings '*n*' factor in such waterways is greatly affected by the composition and depth of the vegetation, when the flow completely or nearly submerges the vegetation. Under the influence of velocity and depth of flow, vegetation tends to bend and oscillate continuously. Such conditions have an effect on the retarding of flows and the retardance varies as the velocity and depth of flow, changes. Ree (1954) points out that there is a common misconception that flowing water causes vegetation to bend over completely to shingle the bed and to form a protective shield. Observations through vertical glass walls in experimental channels lined with a range of vegetation species revealed that vegetation waved and moved back and forth during a flow.

The n-VR relationship refers to the fact that *n* varies with the product of velocity and hydraulic radius (VR). The design of vegetation-lined channels requires that *n* be compatible with the value of

VR. To aid in design, general n-VR curves for five degrees of vegetal retardance (A to E) have been developed (Figure 8.3). Figure 8.3 also includes the equations for the curves associated with each retardance. By using these equations, it is possible to apply the Manning formula by considering Mannings *n* to be a function of V and R for a specific retardance.

Figure 8.3 Graphical solution for five degrees of vegetal retardance for the Manning formula



Curve A $n = 0.440 - 1.674\ VR \quad VR < 0.1542$
$n = 0.046 + 0.0223/VR \quad VR > 0.1542$ Ref. Green, J.E.P. & Garton, J.E. (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, G.H. & Ellul, G.A. (1976)

The n-VR curves together with other charts, can be used to provide graphical solutions of the Manning Formula. The graphical solution of the Manning Formula for vegetal retardances C is shown in Figure 8.4 (adapted from Ree 1954). Graphical solutions for all retardances are provided in the Appendix. Table 8.2 provides a guide to the selection of vegetal retardance.

Figure 8.4 Graphical solution to the Manning Formula for Retardance C

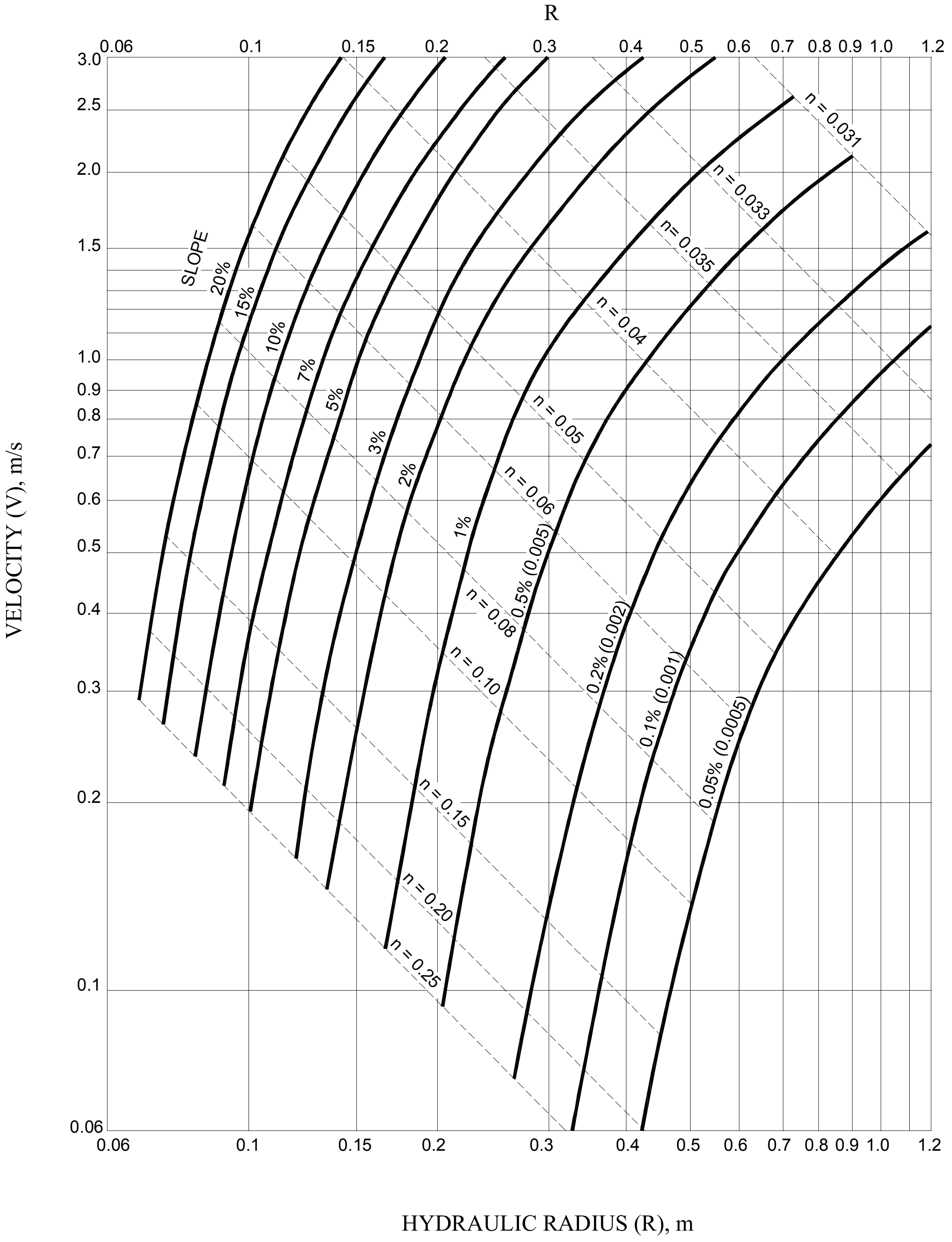


Table 8.2 Guide to selection of vegetal retardance

Average height of vegetation	**Degree of retardance based on quality of vegetation**	
	Good	**Fair**
Longer than 75 cm	A	B
30 cm to 60 cm	B	C
15 cm to 25 cm	C	D
5 cm to 15 cm	D	D
Less than 5 cm	E	E

Note that use of the A–E retardance charts apply to runoff flows with vegetation completely submerged or nearly so. For shallow flows through upright vegetation with no submergence, Mannings n ceases to be related to VR (Ree 1954) and the Manning formula can be solved with an appropriate selected value for n (Table 8.1).

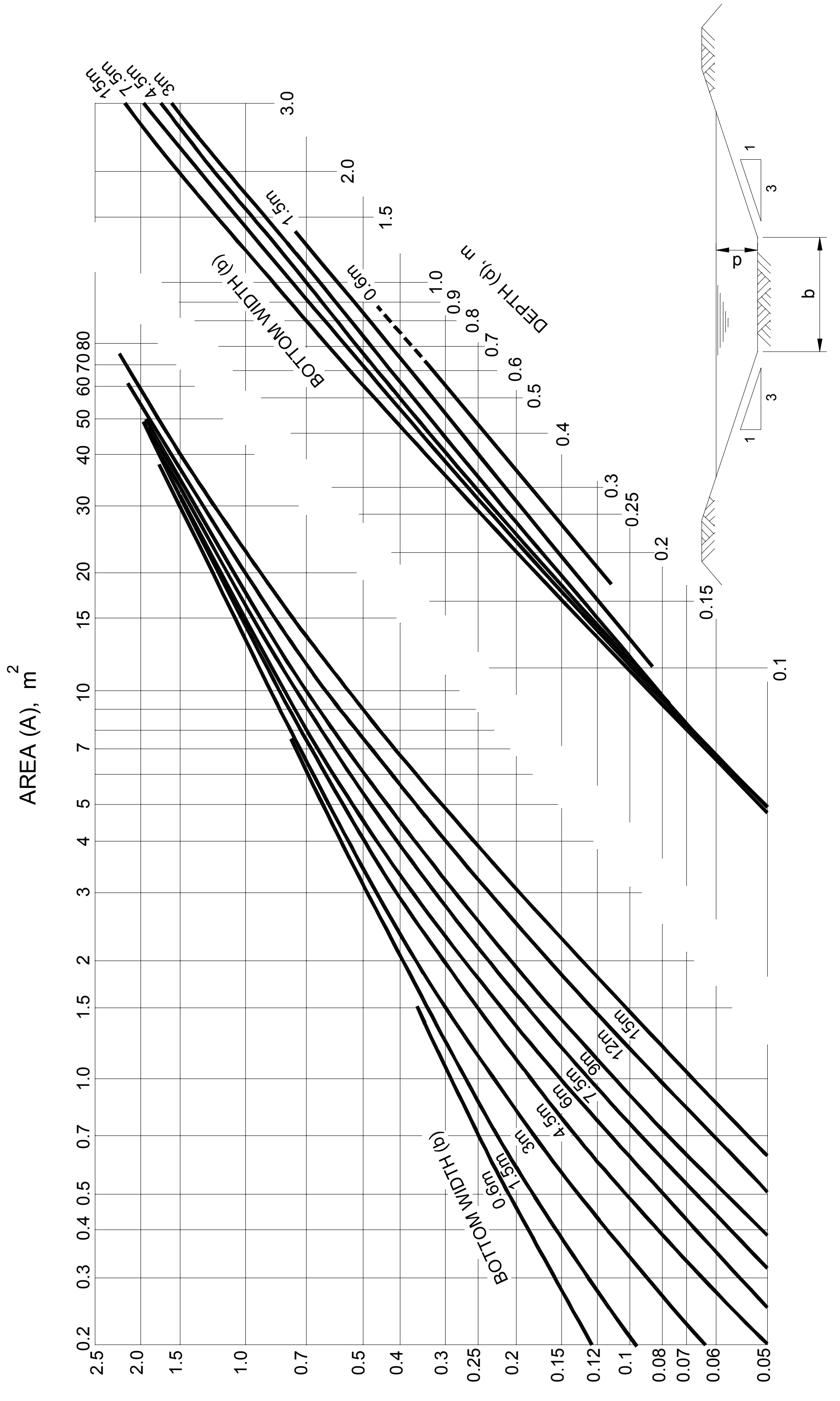
8.123 Hydraulic radius

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 with the maximum hydraulic radius would be a semi circle. For a trapezoidal channel, the maximum hydraulic radius (and highest velocities) would result for a channel that most closely approximates a semi circle.

For triangular cross-sections, the hydraulic radius is approximately equal to half the depth. For waterways of width greater 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 an hydraulic radius of 0.29 when carrying a depth of flow of 0.3 metres. This assumption can greatly simplify the task of designing wide waterways.

Charts showing dimensions for various shaped channels are included in the Appendix. An example of such a chart is shown in Figure 8.5 (Adapted from Ree 1954). For a trapezoidal channel with different inlet and outlet batters, it is possible to calculate the average batter dimension and then use the appropriate chart.

Figure 8.5 Dimensions of trapezoidal channels with 1:3 (V:H) side channels



8.2 Stability of channels

Earth channels, either bare or lined with vegetation, should carry the design discharge at non-erosive velocities. The following chapters on contour banks, diversion banks and waterways provide specific information on recommended velocities to ensure stability.

8.21 The Froude Number

The Froude Number (Fr) characterises the conditions in flowing water in terms of its velocity and depth. 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.

The Froude Number provides a means for determining whether a given flow is subcritical, critical or supercritical. These terms are defined as follows:

- Critical flow is flow in which the Froude Number is equal to unity (Fr = 1) and surface disturbances (eg. the ripples caused when a rock is thrown into a stream) will not travel upstream
- Subcritical flow is flow in which the Froude Number is less than unity (Fr <1). For subcritical flow the depth tends to be relatively large and the velocity relatively low (ripples travel upstream)
- Supercritical flow is flow in which the Froude Number is greater than unity (Fr >1). For supercritical flow the depth tends to be relatively small and the velocity relatively high (all ripples resulting from a disturbance are downstream).

For safe design of vegetated channels, the Froude Number of the design flow should be between 0.8 and unity depending on the degree of erosion resistance provided by the vegetation. Where values exceed unity it would be necessary to ensure that the channel lining had a very high degree of erosion resistance.

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

$$\mathbf{Fr = (\alpha Q^2 B/ gA^3)^{0.5}} \quad \text{.......... Equation 8.4}$$

Where

Fr = Froude Number
Q = the discharge (m^3/s)
α = 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 8.4 reduces to:

$$\mathbf{Fr = \frac{V}{(gd)^{0.5}}} \quad \text{.......... Equation 8.5}$$

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 8.5 becomes

$$Fr = \left[\frac{V^2 (b + 2Zy)}{g\ y(b + Zy)} \right]^{0.5}$$ ....Equation 8.6

Where

Fr = Froude Number
V = the mean flow velocity (m/s)
b = bottom width (m)
Z = side slope ratio (1 vertical : Z horizontal)
g = gravitational acceleration (9.8 m/s^2)
y = the flow depth (m)

8.22 Stream Power

Whether erosion or deposition occurs in a channel depends on the relativity between soil strength and discharge and the stream power or shear stress exerted by that discharge (Loch and Thomas 1987). More information on stream power is provided in the section on design velocity in Chapter 9, *Contour banks*.

Stream power is defined as the product of the shear stress exerted by the flow and average channel velocity and is expressed in the following formula:

w = TV..........Equation 8.7

Where

w = stream power in W/m^2 (Watts per square metre)
T = shear stress in Pa or N/m^2 (Pascals or Newtons per square metre)
V = average channel velocity in m/s

Shear stress is calculated from the formula:

T = ρ gRS..........Equation 8.8

Where

T = shear stress in Pa or N/m^2
ρ = density of the fluid, kg/m^3
g = gravitational acceleration, 9.8 m/s^2
R = channel hydraulic radius m
S = channel slope, m/m

8.3 General design approach

When carrying out a design for a soil conservation structure, it is useful to combine equations 8.1 and 8.2 as follows:

$$\frac{\mathbf{Q}}{\mathbf{A}} = \mathbf{V} = \frac{\mathbf{R}^{0.66}\,\mathbf{S}^{0.5}}{\mathbf{n}} \quad \text{.......... Equation 8.9}$$

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 coefficient of roughness.

In a design exercise the following factors in the above equation would normally be known:

- discharge Q
- velocity V – it is normal to design for a selected velocity
- the channel slope S would be known in the case of a waterway design; however in the design of a contour or diversion bank it is a variable and different channel slopes (gradients) can be compared
- the Manning coefficient of roughness *n* would be selected as a fixed value (Table 8.1) or as a retardance value (Table 8.2) where n/VR relationships apply.

The design may however have other constraints. Examples are as follows:

- conditions in the channel are subject to considerable variation depending on seasonal and management conditions
- the top width for a waterway may be a limiting factor because a waterway needs to fit into a confined location
- the length of a contour bank batter may be set by the planting machinery used by a farmer.

By incorporating the known values of Q, V, S and *n* into the above equation it is possible to determine values for the cross-sectional area A, and the hydraulic radius R. This is a straightforward exercise if the value of Mannings *n* is constant but in the case where *n* varies with the product of V and R an iterative process is required to solve the equation. The value of *n* will also vary with seasonal and management conditions eg. a waterway can have abundant growth in a good season or be virtually bare during a drought. A contour bank channel may vary from a ploughed condition to an advanced crop or stubble depending on the cropping cycle. Examples of how this is taken into account are provided in Chapter 9, *Contour banks* and Chapter 11, *Waterways.*

The 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 8.5 can be used for this purpose. Alternatively another iterative process is required to obtain the correct dimensions.

The computer program RAMWADE provides assistance in determining appropriate dimensions for soil conservation structures.

8.4 Freeboard and settlement

Freeboard and settlement should also be allowed for in the design. Freeboard is included to prevent overtopping due to surcharge or wave action. It also accounts for some irregularities in construction. Depending on factors such as operator skill, machinery used and soil properties at the time of construction, there will always be some 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 8.3 provides estimates of the amount of settlement likely to occur.

Table 8.3 Estimated settlement rates for bank construction

Construction equipment	**Soil characteristics**	
	Swelling clays e.g. black, cracking clays	**Light textured soils**
Bulldozer	50%	30%
Grader	30%	20%

Equation 8.10 can be used to calculate the constructed height of a bank (Hc) from the settled height (Hs) and the expected amount of settlement (y).

$$Hc = \frac{H_s}{1 - \frac{y}{100}} \qquad \text{..........Equation 8.10}$$

Where

Hc = Constructed bank height
Hs = Settled bank height
y = % settlement

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