

Chapter 11

Waterways

In soil conservation terminology, the term ‘waterway’ has a different meaning from the more conventional use of the term. Waterways for soil conservation purposes collect runoff from contour bank systems and convey it at a safe velocity to a drainage line or creek system. Waterways are especially vulnerable to erosion because of the concentrated flows they need to accommodate. They should be carefully designed, constructed, stabilised and maintained to reduce the risk of failure by gullyng or by overtopping. Where the failure of a waterway would have serious consequences, its design should be based on an increased ARI of 20 to 50 years.

Waterways are designed by taking into account the size of the catchment area, soil type, land slope, land use, and expected grass cover in the channel. They are constructed with farm dozers, bulldozers, graders or self-loading scrapers and are usually constructed from the inside.

There is a tendency for many farmers to consider the land occupied by waterways to be a loss of valuable land. This can lead to the construction of waterways that are too narrow, leading to high runoff velocities and gullyng within the waterway. The area of land occupied by a waterway is often less than people imagine. A 1 km long waterway with a 20 m width would occupy only 2 ha of land. Waterways can be used for strategic grazing but if stock have regular access to waterways, erosion is likely to occur.

Waterways can be a neglected component of a soil conservation system. Insufficient attention is often given to their stabilisation and maintenance. The fact that it may take 2 to 3 years for a waterway to have enough grass growth to safely accept runoff can disillusion farmers who are keen to implement soil conservation measures to control erosion in their paddocks. Farmers may be willing to accept an eroding waterway at the side or the middle of a paddock provided the erosion within a paddock is under control. However this can lead to considerable soil loss within the waterway with impacts on downstream water quality. It may also lead to erosion at the outlets of contour banks flowing into the waterway.

Where possible, waterways should be located in natural drainage lines. Here the slopes are usually lower than adjacent parts of the catchment, and the topography tends to confine the flow to the waterway. Soils and moisture levels are usually more favourable to vegetative growth in natural drainage lines.

Ideally, waterways should conform with natural meanders in a drainage line. It is generally not desirable to ‘straighten’ watercourses by removal of the natural meanders. Such action leads to higher construction costs and inhibits the natural inclination for water to flow in a meandering pattern. However there are many situations, especially in small paddocks, where there is no natural drainage line. In these cases a straight waterway, often following a fence line, will usually be the best option. Such waterways are referred to as ‘perched waterways’.

Waterways are generally not recommended for construction on floodplains. In these situations the aim is to ensure that flood flows spread across the floodplain as they would under natural conditions. Such spreading can be facilitated by the use of strip cropping practices. Small subsurface waterways may be required to accommodate residual flows. As these waterways have no above ground banks, flood flows are not diverted.

Prolonged flows in waterways may occur during low intensity rainfall events that occur over several days on saturated catchments. Such flows will be more pronounced where there are long contour banks and zero tillage farming systems. Soils and grass cover that are capable of withstanding a short duration flood peak above that which they were designed for, may fail when subjected to a prolonged low flow when soils are super saturated with greatly reduced cohesive strength. Such conditions may also have a negative impact on vegetative growth in the waterway.

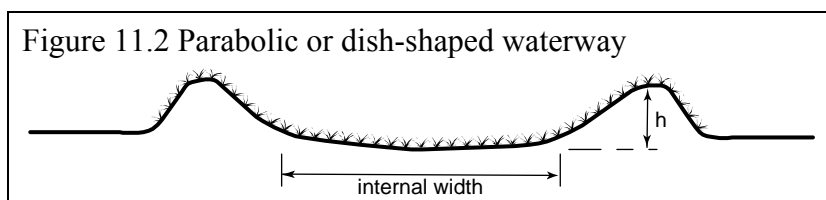
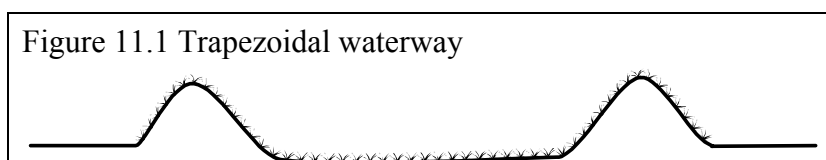
The installation of sub-surface drainage systems in waterways has rarely been implemented in Queensland. However such a system could greatly improve the stability of waterways by minimising the damage resulting from small trickle flows.

The widespread adoption of zero tillage systems means that runoff with low turbidity will usually be exiting from contour bank outlets. Such runoff has a greater potential to cause erosion in a waterway than turbid runoff.

While trees are a natural feature of riparian zones and provide many benefits including the stabilisation of creek banks, they are not considered to play a beneficial role in the stabilisation of waterways constructed for soil conservation purposes. Tree roots provide stability to steep creek banks but this function is not required in a constructed waterway. In waterways for soil conservation purposes, stability is provided by close growing swards of vegetation on the soil surface. The presence of trees in such systems can inhibit grass growth by competition for water and nutrients and by shading out the grass species. Grazing animals are attracted to the shade provided by trees and such areas are usually devoid of surface cover. It is desirable to have clumps and corridors of trees in a cultivation paddock but it is considered that there are risks associated with locating them in and immediately adjacent to constructed waterways.

11.1 Waterway cross-sections

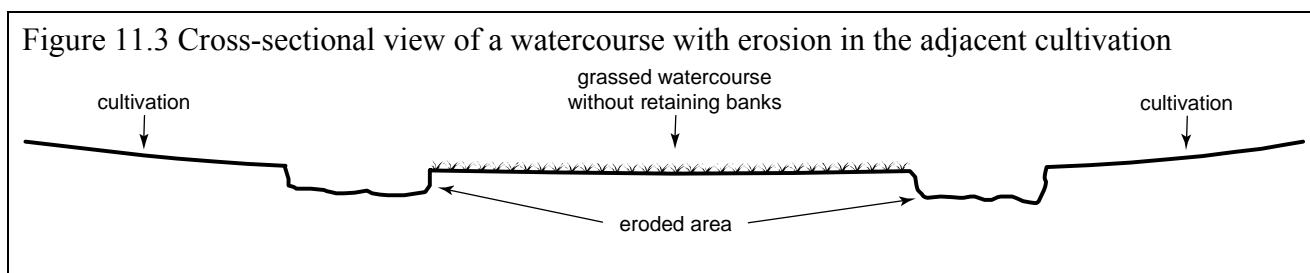
Waterways for soil conservation purposes are normally constructed to a trapezoidal (Figure 11.1), parabolic (Figure 11.2) or a triangular shape.



Parabolic cross-sections (or trapezoidal waterways constructed with a slight 'dish') most closely resemble those found in natural waterways and small flows will be carried with less meandering than a flat-bottomed channel. Providing soil depth is not limiting, the 'dish' can be constructed to provide a 10 cm additional depth. A flat-bottomed waterway is recommended on land slopes over 5% where a shallow depth of flow is required to prevent excessive velocities.

Retaining banks are essential to ensure that the flow remains in the waterway. If they are not constructed, runoff will have a strong tendency to flow along the cultivation on either side of the grassed drainage line (Figure 11.3). This leads to gullying on one or both sides of the grassed

drainage line. Retaining banks also define the exact area of land occupied by the waterway. This prevents a farmer from gradually expanding the cultivated land into the waterway.



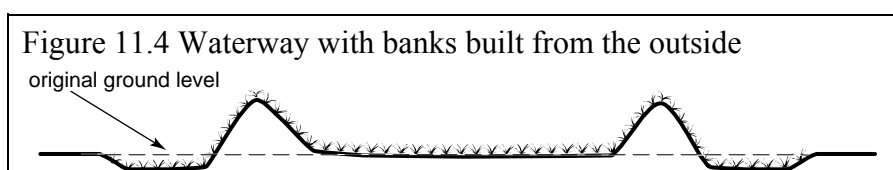
Triangular shaped channels are generally avoided, as they are more likely to erode because of the higher velocities in the 'V' of the channel.

Graders and scrapers are suitable for constructing trapezoidal shaped channels. Parabolic channels are more difficult to construct than flat-bottomed channels and are usually constructed with bulldozers or ploughs.

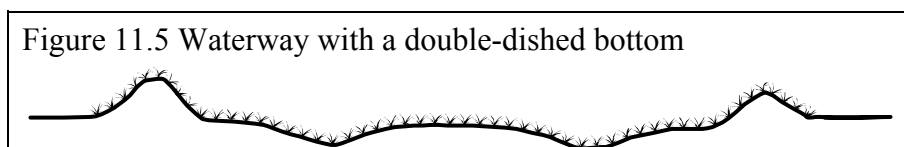
Soil type may control the maximum depth of excavation. Stability problems may be encountered if infertile, or unstable subsoils are involved. Whenever possible, topsoil should be spread over excavated channels as part of the construction process. One way to achieve this is to construct the first 20 metres of the waterway deeper than it needs to be. Topsoil can then be moved in from the 20 metre section below and the process continued.

A minimum excavation depth may be required where drainage is important, for example, where deep furrows are required to discharge directly into waterways.

In situations with highly erodible subsoils, it is desirable to avoid disturbing the area where concentrated flow will occur. In such cases, the waterways are constructed by excavating the retaining bank from the outside so that the section for water flow is left undisturbed (Figure 11.4). Another approach on low sloping situations is to obtain soil for use in the banks from a series of excavations in the centre of the waterway. Such an operation requires the use of a scraper.



A double-dished bottom can be used in low sloping situations on waterways wider than 30 metres (Figure 11.5). This type of construction allows the central area of the waterway to remain undisturbed.



11.11 Perched waterways

In some paddocks there may be no suitable natural depression available and it can be convenient to construct a waterway adjacent to a fence. Such waterways will have some degree of side slope unless the fence runs directly up and down the slope. As these waterways are elevated in comparison to any adjacent natural watercourses they are referred to as 'perched' waterways

(Figure 11.6). They may only need a bank on one side depending on the amount of side-slope involved. Perched waterways generally require a significant amount of excavation across the waterway to produce a relatively flat channel. Such construction requires a higher level of skill than that required for a conventional waterway. Perched waterways should be avoided where subsoils have high levels of sodicity.

In the event of a perched waterway overflowing, damage to adjacent areas is likely to be greater than with waterways located in natural depressions.

An advantage of perched waterways is that they do not receive runoff until diversion and contour banks are constructed into them. This means that they can be constructed and planted to vegetation several years prior to the construction of contour banks. Where waterways are constructed in natural depressions they are referred to as 'live' waterways and must accept runoff as soon as it occurs. This creates a period of risk until the waterway has stabilised with vegetation.

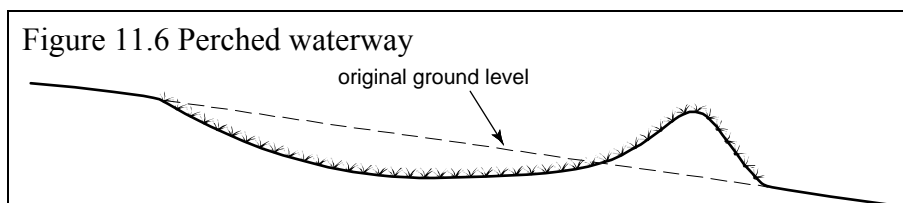
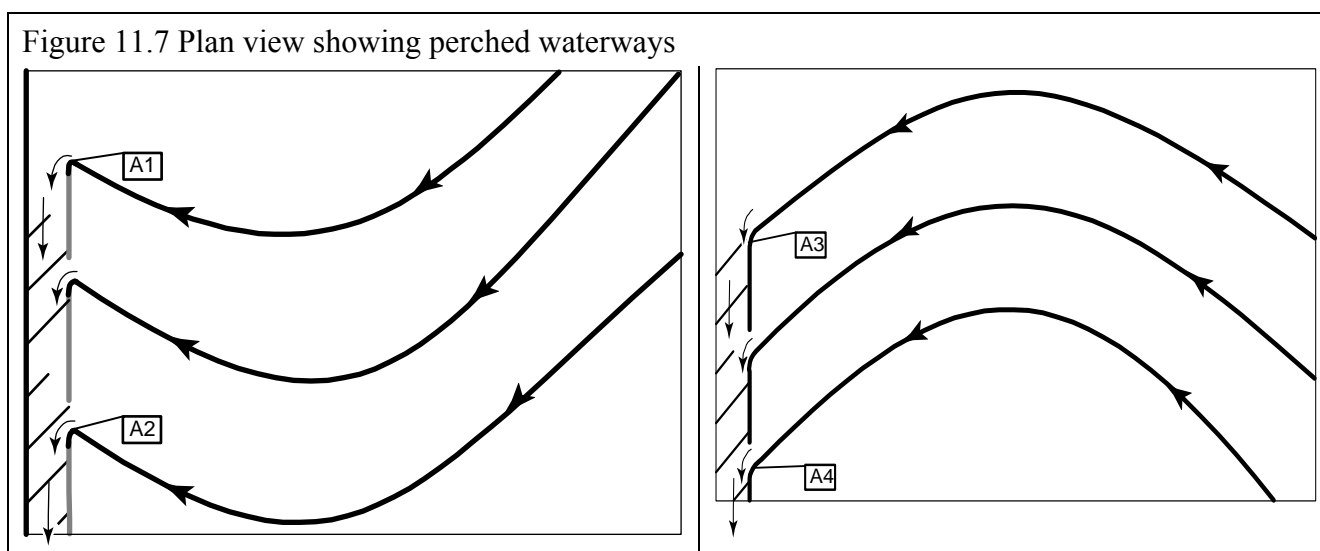


Figure 11.7 is a plan view showing two perched waterways in fenced paddocks. For waterway A1–A2 the orientation of the contours means that there is a natural tendency for runoff to flow against the waterway bank adjacent to the fence. Failure of this waterway would mean that runoff would enter the neighbouring property (if the fence was a property boundary). In such situations it would be advisable to design for a higher than normal return period. In waterway A3–A4 the tendency is for runoff to flow against the bank furthest from the fence. Care needs to be taken to ensure that there is adequate capacity at the point where the contour bank enters the waterway (eg. design points A3 and A4) as this can be a common point for structure failure through overtopping. Other examples of perched waterways are provided in Chapter 2, *Soil conservation planning*.

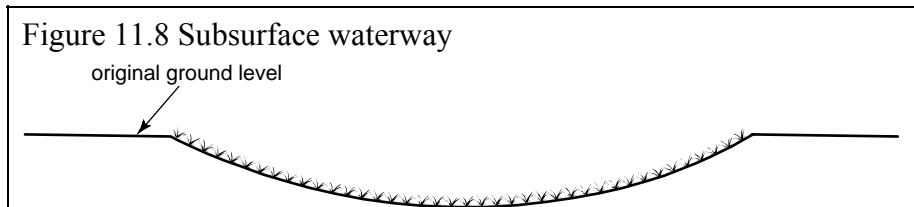


11.12 Subsurface waterways

In horticultural situations, subsurface waterways are often constructed (Figure 11.8). They can be crossed by tractors and machinery to improve workability of the paddock. They also have an application in catchment outlets where they may be used in conjunction with strip cropping.

Batter slopes should be 1:4 or flatter. Waterways that are maintained by slashing should have batters flatter than 1:3 and the dimensions of the waterway should ideally be multiples of the width of the slashing equipment.

When crossing subsurface waterways with implements, they must be lifted so that the grass lining of the channel is not damaged. The waterway channel should be deeper than the channel of adjacent structures so runoff from these structures can flow freely into the channel.



11.2 Design velocity

Recommended maximum velocities vary for different types of cover and soil types. Issues to consider are:

- physical nature of the vegetation (type and distribution of root growth, and density and physical condition of top growth)
- erodibility of soil
- channel shape
- degree and uniformity of cover
- bed slope.

A guide to maximum recommended permissible velocities for use in design is provided in Table 11.1, which incorporates the effects of waterway slope, fraction of cover and soil erodibility.

Channel gradient %	Recommended maximum velocities (m/s) related to percentage of anchored surface cover			
	0% cover	50% cover	75% cover	100% cover
	Bare surfaces which are consolidated but not cultivated	Tussocky species (includes most native grasses)	Rhodes grass and creeping species such as couch grass in moderate condition	Creeping species such as kikuyu that can be maintained as a permanent dense sod
A. Erosion resistant soils (eg. Krasnozems)				
1	0.7	1.6	2.1	2.8
2	0.6	1.4	1.8	2.5
3	0.5	1.3	1.7	2.4
4		1.3	1.6	2.3
5		1.2	1.6	2.2
6			1.5	2.1
8			1.5	2.0
10			1.4	1.9
15			1.3	1.8
20			1.3	1.7
B. Easily eroded soils (eg. Black earths, fine surface texture-contrast soils)				
1	0.5	1.2	1.5	2.1
2	0.5	1.1	1.4	1.9
3	0.4	1.0	1.3	1.8
4		1.0	1.2	1.7
5		0.9	1.2	1.6
6			1.1	1.6
8			1.1	1.5
10			1.1	1.5
15			1.0	1.4
20			0.9	1.3

Adapted from Gregory and McCarthy (1985)

The Froude Number (Equations 8.4 to 8.6) can be used to determine the susceptibility of a waterway to erosion. 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. Table 11.2 provides values of Froude numbers for a trapezoidal waterway with a bottom width of 7 m, side slopes of 1:3, slope of 6% and retardance C.

Flow depth	Velocity	Froude No
0.14	0.9	0.8
0.16	1.2	1.0
0.18	1.6	1.2
0.20	1.9	1.4

Parameters:

- bottom width of 7m
- side slopes of 1:3
- bed slope 6%
- retardance C

Froude numbers can be reduced by adopting a design with a lower velocity. This can be best achieved by using a cross-section incorporating shallower flows. If the Froude Number was to exceed unity, the vegetation in the waterway would have to be selected and managed so that it provides a high degree of erosion resistance.

11.3 Waterway stabilisation

Soil conservation waterways usually rely on a lining of vegetation to give protection from erosion. Vegetation protects the channel by reducing the velocity near the bed and covering and binding the soil together.

A uniform sod-forming grass having a dense relatively deep root system will offer the best protection against erosion. Species commonly used in Queensland are kikuyu, couch, African star grass, Rhodes, pangola, *Bothriochloa pertusa* and *Bothriochloa insculpta*. All of these species are exotics but are commonly found in agricultural areas. Local advice should be obtained to determine if a proposed species has weed potential in a particular area.

The small seeds that are a feature of most grass species lead to germination difficulties on cracking clay soils and this is a significant reason why farmers have difficulties in establishing stable waterways. Sods can be planted as an alternative to planting seed but this process is labour intensive, suitable planting material may not be readily available, and watering may be necessary until the sods become established.

Most native species grow in tussocks and have much less resistance to erosion than special purpose vegetation normally used in waterways. However native species are the best option where suitable stands already exist. It may be possible to construct waterway banks from the outside to ensure that the grass in the waterway is not disturbed.

Tussocky species will have lower recommended maximum velocities and will require a wider waterway than sod-forming species. Recommended maximum velocities for tussock grasses are lower than where sod-forming species are used, because:

- areas bare of vegetation exist thereby reducing the surface cover fraction
- tussock grasses generally produce the effect of very rough beds that disturb the smoothness of flow
- tussock grasses lack a dense, uniform root system.

11.31 Non-vegetative options for stabilisation

Bare soil waterways have been used on relatively flat irrigation land (<1%) in Coastal Burnett cane growing areas where a surface drainage function is required as well as runoff control. On such low slopes, grassed waterways may have widths that farmers consider to be excessive. Table 11.1 shows that bare, consolidated waterways (i.e. not cultivated) can have permissible velocities at 0.5 m/s on 1% slopes on easily erodible soils. Where slopes are less than 1%, experience has shown that design velocities were much lower than 0.5 m/s unless depths were so great that the waterway would be impractical to construct.

In urban situations, a wide variety of options are used for lining waterways. Although more costly than the use of vegetation, they offer advantages such as stability under higher velocities and they can accept runoff immediately after construction. Such options have rarely been used in agricultural applications. However they would be worthy of consideration in high value horticultural applications and chutes used in gully stabilisation. Specifications provided by suppliers should be checked to determine recommended maximum velocities for these surfaces. Examples of such options include:

- *Reinforced turf*. Greater protection from erosion can be obtained by using specially grown turf reinforced with a UV stabilised mesh. This turf can withstand much higher runoff velocities than normal turf and is available from commercial suppliers.

- *Turf reinforcement mats.* These consist of various products woven into a three dimensional web. They provide good initial ground coverage while allowing the growth of vegetation through the mat. Sediment is trapped in the three dimensional mat and provides additional stability to the system.
- *Rock.* Rocks may be set in cement or contained by wire netting
- *Concrete.* Not recommended in clay soils subject to cracking.
- *Geocells or cellular confinement systems.* Honeycombed shaped cells made of polyethylene that are filled with topsoil and turfed or filled with gravel and covered with a close weave wire netting.
- *Butyl rubber or UV resistant PVC sheets.* Useful for providing immediate protection to relatively small areas with minimal need for preparation of the surface to be covered.

11.4 Freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 8, *Channel design principles*.

11.5 Bends in waterways

Soil conservation layouts occasionally require the use of a 90° bend in a waterway to direct runoff around a corner of a rectangular paddock. Bends in waterways should have as large a radius as possible and as a general guide, the outside bank on the curve should be given an additional height of 0.2 metres to 0.3 metres. An alternative is to construct a small dam with the spillway coming off at 90° to the inlet waterway.

11.6 Design approach

Consideration should be given to the locations in which specific designs are required. Refer to the section *Selection of design points* in Chapter 2, *Soil conservation planning*.

As discussed in the chapter on channel design principles, it is useful to use Equation 8.9 when determining the approach to waterway design.

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

Where:

- Q = the discharge or hydraulic capacity of the channel (m³/s)
- A = cross-sectional area (m²)
- V = average velocity (m/s)
- R = hydraulic radius (m)
- S = channel slope (m/m)
- n = Manning coefficient of roughness.

In the following sections, examples are provided for the design of waterways. Since the design runoff event may occur when the waterway condition varies from low levels of cover (eg. retardance E) to high levels of cover (eg. retardance B), a decision must be made on whether the design will be based on a single retardance or a high and low value for retardance.

If the design is based on two levels of retardance, the width of a waterway would be based on the velocity related to a low retardance value (eg. retardance D) and the depth based on a higher retardance value (eg. retardance B) where velocity will not be a limiting factor.

An example is provided on how to design a waterway from first principles. To simplify the task, charts are available based on a trapezoidal shape with 1:3 (V:H) batters, retardances of C and D and a range of slopes from 0.2% to 10%. Examples of such charts are provided in Figures 11.9 (slope 2% and retardance C) and Figure 11.10 (slope 2% and retardance D). Copies of all of the charts are provided in the *Appendix*. The computer program RAMWADE (**R**ational **M**ethod **W**aterway **D**esign) can also be used to design waterways. The program can design for a range of retardances from B to D.

Figure 11.9 Waterway design chart for retardance C and land slope of 2%

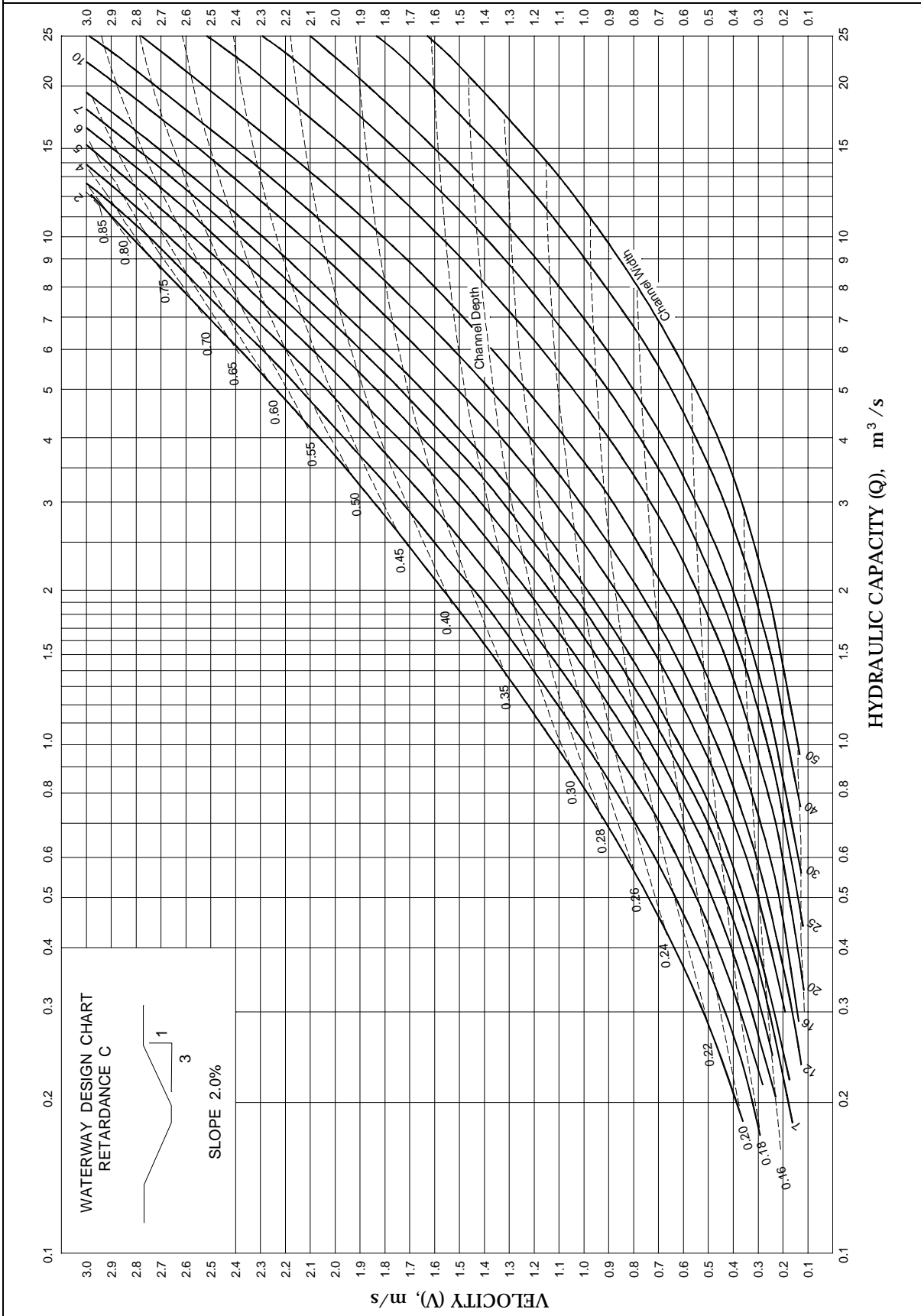
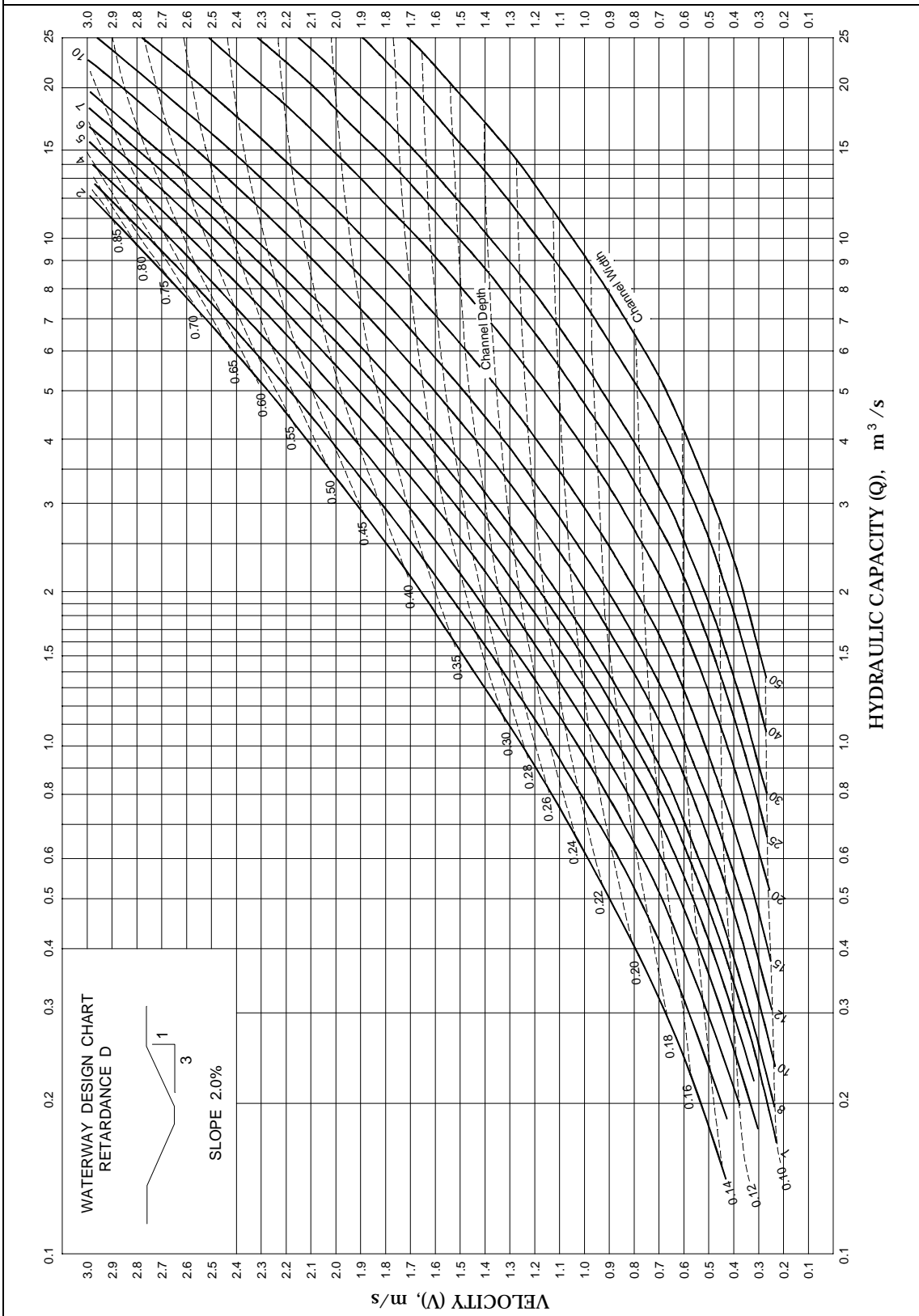


Figure 11.10 Waterway design chart for retardance D and land slope of 2%



The high end of a waterway which carries runoff from only one bank is usually not designed but a minimum top width of about 6 metres (from bank centre to bank centre) is used to enable entry by farm machinery such as mowing equipment.

11.61 Design of a waterway based on one level of retardance

The following steps explain how to design a waterway from first principles for a single retardance value.

A Determine the required cross-sectional area of the waterway

1. Calculate the discharge Q .
2. Estimate a safe design velocity appropriate to the slope, vegetation type and soil erodibility (refer to Table 11.1 *Recommended velocities for consolidated, bare channels and vegetated channels*).
3. Calculate the required cross-sectional area ($A = Q/V$).

B Determine the required hydraulic radius of the waterway

1. Select the level of retardance eg retardance C .
2. Measure the slope at the design point.
3. Using the solution to the Manning formula for the selected retardance, calculate the hydraulic radius for the specified velocity and slope (Figure 8.4 *Solution of the Manning formula for retardance C* or refer to the *Appendix* for other values of retardance. Note that you do not require a value of n to use this graph).

C Select a cross-sectional shape for the waterway

Normal waterway shapes are trapezoidal, parabolic or triangular.

D Determine the appropriate dimensions for the waterway

Use an appropriate chart to determine the dimensions for a specified waterway shape when the cross-sectional area and hydraulic radius are known. Figure 8.4 *Dimensions of trapezoidal channels with 1:3 side channels* is an example of such a chart. Other charts are available in the *Appendix*.

E Calculate constructed bank height

Add 0.15 m to the depth of flow to allow for freeboard. Add an additional amount to account for settlement of the bank after construction. Refer to Table 8.3 and Equation 8.10

F Calculate the Froude number to ensure that the value is less than unity

Refer to Equation 8.6.

Waterway design example 1

Design a trapezoidal shaped waterway with batters of 1:3 (V:H) to accommodate a discharge of $3 \text{ m}^3/\text{s}$ on a land slope of 2%. Assume that the vegetation in the waterway will be maintained at a constant retardance of C and the design velocity is 1.2 m/s. (Note that the following example shows how to design a waterway from first principles. Since the required design is a trapezoidal shape with 1:3 (V:H) batters and a retardance of C , Figure 11.9 can also be used to obtain a solution.)

A Determine the required cross-sectional area of the waterway

$$A = Q/V = 3/1.2 = 2.5 \text{ m}^2$$

B Determine the required hydraulic radius of the waterway

Using the *Solution to the Manning formula for retardance C* (Figure 8.4), calculate the hydraulic radius for the specified velocity of 1.2 m/s.

The value of the hydraulic radius is 0.25.

C Select a cross-sectional shape for the waterway

A trapezoidal shape has been specified.

D Determine the appropriate dimensions for the waterway

Using Figure 8.5 (*Dimensions of trapezoidal channels with 1:3 (V:H) side slopes*) and the values of 0.25 for R and 2.5 for A , determine the required bottom width of 9 m and depth of flow of 0.27 m

E Calculate constructed bank height

Add a value of 0.15m to the depth of flow to account for freeboard

$$0.27 + 0.15 = 0.42$$

Assuming settlement of 30%, calculate constructed height of 0.6 m (Equation 8.10)

F Calculate top width

$$\begin{aligned}\text{Top width} &= \text{Bottom width} + (\text{Batter slope} * (\text{flow depth} + \text{freeboard})) \\ &= 9 + (3 * 0.42) \\ &= 10.3\text{m}\end{aligned}$$

G Calculate the Froude Number

Using equation 8.6 a value of 0.85 is obtained which is acceptable.

11.62 Design of waterways based on two levels of retardance

The above example indicates how to determine the dimensions of a trapezoidal shaped waterway based on a single retardance. To design the same waterway for a higher level of retardance it is necessary to determine the depth required for that retardance. The waterway width will be the same as that calculated for the lower retardance. Velocity will not be a constraint as it will be lower than the permissible velocity used in the design for the low retardance.

Equation 8.8 can be used to determine this depth.

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

The table below gives a guide to determining the values in the above equation.

$$\begin{aligned}Q &= \text{value is known} \\ A &= bd + Zd^2 \\ R &= \frac{bd + Zd^2}{b + 2d \sqrt{Z^2 + 1}} \\ S &= \text{Value is known} \\ n &= 0.030 + 0.00501/VR \text{ (From Figure 8.3, for V} \\ &\quad \text{substitute the value } Q/A)\end{aligned}$$

Where

- b is the width of the waterway calculated for the lower retardance
- d is the depth of flow
- Z is the batter slope 1:Z (V:H)

As depth is the only unknown in the above equation it can be determined using an iterative approach. The velocity at which the flow will be occurring can then be determined from the formula $V = Q/A$.

An alternative to the above approach is to use the waterway design charts as shown in the following example. The computer program RAMWADE can also be used.

Waterway design example 2

Use waterway design charts to determine the specifications for a trapezoidal shaped waterway with batters of 1:3 to accommodate a discharge of 4 m³/s on a land slope of 2% at a maximum velocity of 1.2 m/s. Determine the width of the waterway based on retardance D and the depth based on retardance C.

Solution

1. From Figure 11.10 (*Waterway design chart for Retardance D and land slope of 2.0%*) determine the width of waterway required to accommodate the flow of $4 \text{ m}^3/\text{sec}$ on a 2% slope at a velocity of 1.4 m/s

Answer: Bottom width is 15 metres (the depth of flow is 0.22 m)

2. Assuming a bottom width of 15 metres, determine from Figure 11.9 (*Waterway design chart for Retardance C and land slope of 2.0%*) the depth of flow required to accommodate the $4 \text{ m}^3/\text{sec}$ flow at a retardance of C

Answer: Depth of flow is 0.24m (note that the velocity at the higher retardance would be 1.1 m/s (Note that in this example there is minimal difference in flow depths. There would be a more significant difference if a wider range of retardances was used eg. B and D)

3. Calculate constructed bank height and waterway top width using the procedure in Waterway design example 1.

11.7 Determining the capacity of natural grassed drainage lines

If a natural grassed hollow is to be used instead of a constructed waterway, the capacity should be checked. It may be necessary to check the capacity in several locations if there are changes in the shape or land slope. The procedure is as follows:

- Estimate the retardance value (Table 8.2, Guide to selection of vegetal retardance)
- Measure the slope
- Take measurements to determine the cross-section for the waterway
- Determine the wetted perimeter
- Calculate the area in the waterway cross-section
- Calculate the hydraulic radius
- Determine velocity from a graph showing solutions to Mannings formula for a specified retardance (eg. Figure 8.4 Solution of the Manning formula for retardance C)
- Multiply the velocity by the cross-sectional area to determine the discharge capacity of the drainage line. ■