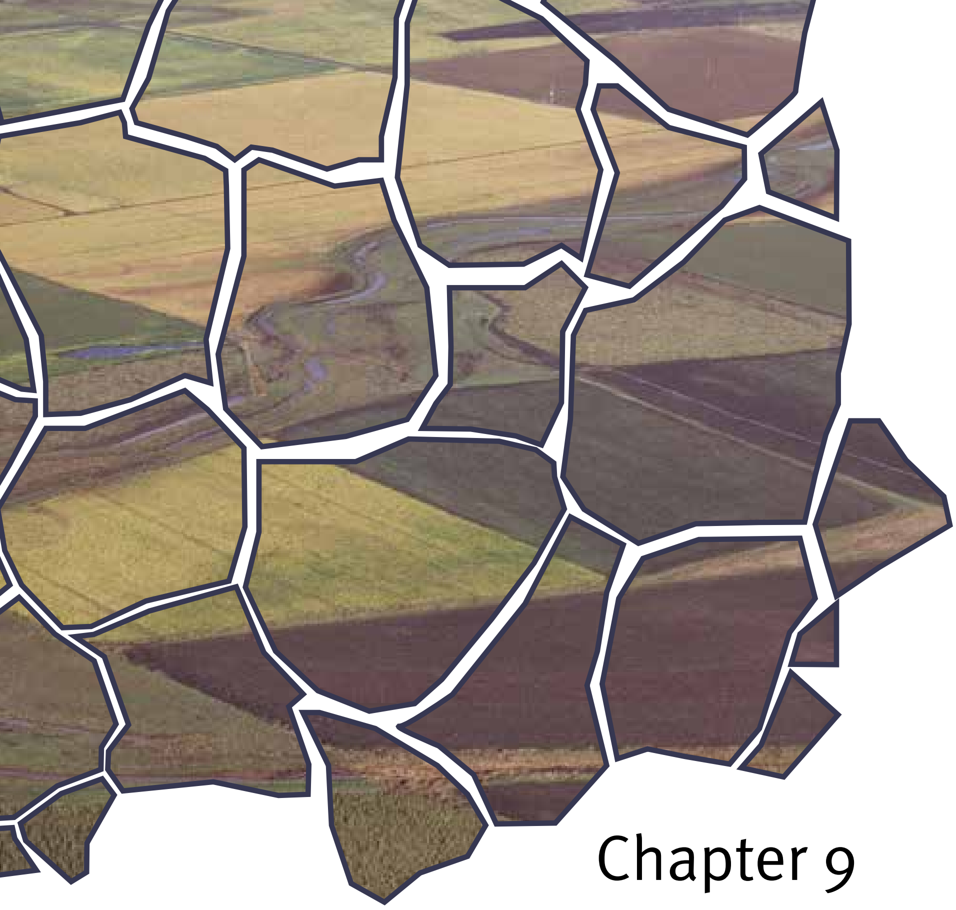

Chapter 9

Waterways

Key points

- Soil conservation waterways collect runoff from contour bank systems and safely convey it to a drainage line or creek system where it can disperse without erosion.
- When designing waterways the objective is to determine the cross-section, slope, and alignment that ensures a velocity that will not cause erosion at the design average recurrence interval (ARI), taking into account the catchment characteristics, vegetation cover, and soil erodibility. Where the failure of a waterway would have serious consequences, its design should be based on a longer than usual ARI (e.g. 50 years).
- Waterways are especially vulnerable to erosion so it is essential that they be well stabilised, either with vegetation (preferably uniform sod forming grasses) or artificial (e.g. concrete) lining before use. Waterways that follow natural drainage lines are less likely to erode.
- Loss of productive land can be a concern for farmers when building waterways. This can cause the waterway design to be compromised. However, waterways actually take up only a small area of land and if well managed they can be grazed.

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Glossary

ARI (average recurrence interval): 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.

cohesive strength: the degree to which soil material is held together.

ferrosols (krasnozems): soils with B2 horizons which are high in free iron oxide, and which lack strong texture contrast between A and B horizons.

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

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.

meander: the natural winding of channels which results from complex geomorphological processes involving streambank erosion and alluvial deposition.

perched waterways: constructed waterways that are elevated in comparison to adjacent natural watercourses.

sodicity: the amount of exchangeable sodium (ESP) in a soil. Excess exchangeable sodium adversely affects soil stability, plant growth, and/or land use. A soil with more than 15% ESP is considered strongly sodic.

sod-forming: vegetation having a dense relatively deep root system will offer the best protection against erosion.

strip cropping: growing crops in rotations in a systematic arrangement of strips at right-angles to the direction of water flow to spread runoff and protect against erosion.

tussocks: the habit of some species of grass to grow in dense tufts that are clearly separated.

waterway: a stable, longitudinally sloping water disposal area of sufficient capacity used to discharge surplus runoff and to allow it to flow to a lower level without causing erosion.

zero tillage: a practice in which the crop is sown directly into a soil not tilled since the harvest of the previous crop. Weeds are controlled using herbicides and stubble is retained for erosion control and to conserve soil organic matter. This contrasts with conventional tillage where a seed-bed is prepared through one or more passes of cultivation equipment (such as disk or tined plough) prior to sowing.

9.1 Introduction

The term ‘waterway’ has a specific meaning in soil conservation terminology that is different 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 they concentrate flows. Waterways need to be carefully designed, constructed, stabilised and maintained to reduce the risk of failure by gullying or by overtopping. Where the failure of a waterway would have serious consequences, its design should be based on a longer than usual Average Recurrence Interval (ARI) (e.g. 50 years).

When designing waterways factors including: the size of the contributing catchment area, soil type, land slope, land use, and expected grass cover in the channel, all need to be taken into account. Waterways used in soil conservation works may be natural or artificial (i.e. constructed with farm dozers, bulldozers, graders or self-loading scrapers). Artificial waterways are usually constructed from the inside.

Landholders can sometimes be concerned about the loss of valuable production land to waterways. This can result in the construction of waterways that are too narrow, increasing velocities and leading to gullying within the waterway. In fact, the area of land occupied by a waterway is much less than what most people imagine. For example, a 1 km long waterway with a 20 m width occupies only 2 ha of land. In addition, waterways can be productive, e.g. for strategic grazing, however stock access to waterways must be managed to ensure that erosion does not occur.

Waterways can be a neglected component of a soil conservation system. The stabilisation and maintenance of waterways often receive insufficient attention. It may take 2 to 3 years for a waterway to grow sufficient grass to safely accept runoff. This can disillusion farmers who are keen to have soil conservation measures in place quickly 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 erosion across the paddock proper is brought under control. However, an eroding waterway can still lead to considerable soil loss within the channel with consequential impacts on water quality downstream. It may also lead to erosion at the outlets of contour banks where they flow 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. Soil fertility and moisture levels are usually more favourable to rapid establishment of stabilising vegetation in natural drainage lines.

Ideally, the alignment of waterways should conform to natural meanders in a drainage line. It is generally not desirable to ‘straighten’ watercourses by removing natural bends. Such action increases construction costs and inhibits the natural inclination for water to flow in a meandering pattern with reduced erosive power. However in many situations, especially in small paddocks, no natural drainage line exists. 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’.

It is generally not recommended that waterways be constructed on floodplains. When installing soil conservation works on floodplains the aim is to ensure that flood flows spread out across the floodplain as they would under natural conditions (rather than concentrating them in a channel). This can be facilitated by strip cropping practices. In some instances small subsurface waterways may be required to accommodate residual flows. However, as subsurface waterways have no above ground banks, they do not divert flood flows —see Chapter 10 for managing runoff on floodplains.

Low intensity rainfall events extending over several days on already saturated catchments may result in prolonged flows in waterways. Such flows will be more pronounced where there are long contour banks and zero tillage farming systems. The cohesive strength of soils is greatly reduced when they are super saturated. Earthen structures (such as banks) that are otherwise 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. Such conditions may also inhibit the growth of vegetation in the waterway.

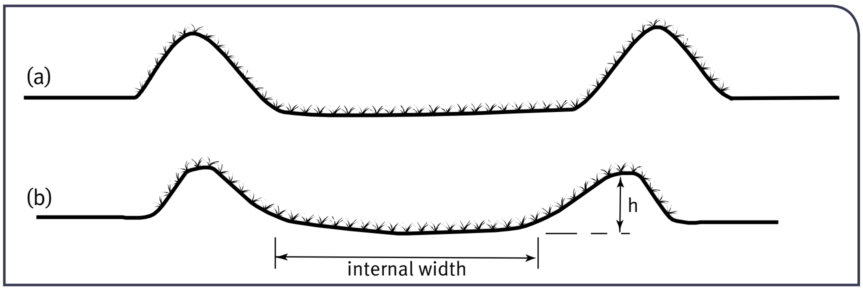
Sub-surface (piped) drainage systems could greatly improve the stability of waterways by minimising the damage resulting from small trickle flows. However, these systems have rarely been implemented in waterways in Queensland

Trees are a feature of natural riparian zones, providing many benefits including stabilising steep creek banks. However, they do not play such a beneficial role in stabilising waterways constructed for soil conservation purposes. Waterways for soil conservation purposes are deliberately constructed with gently sloping banks and channels. Such banks and channels are best stabilized by swards of vegetation such as grasses growing close to the soil surface. Trees can inhibit the establishment and growth of this vegetation by competing for water, nutrients and light. Grazing animals are also attracted to the shade provided by trees and as a result the surface cover in treed areas is often reduced. Clumps and corridors of trees are desirable within and around the edges of cultivated paddocks e.g. to provide habitat for beneficial wildlife, but there are risks in locating them in, or immediately adjacent to, constructed waterways.

9.2 Waterway cross-sections

Waterways for soil conservation purposes are normally constructed to a trapezoidal (Figure 9.1a), parabolic (Figure 9.1b), or a triangular shape.

Figure 9.1: Waterways may be shaped a) trapezoidal, or b) parabolic (or dish-shaped)

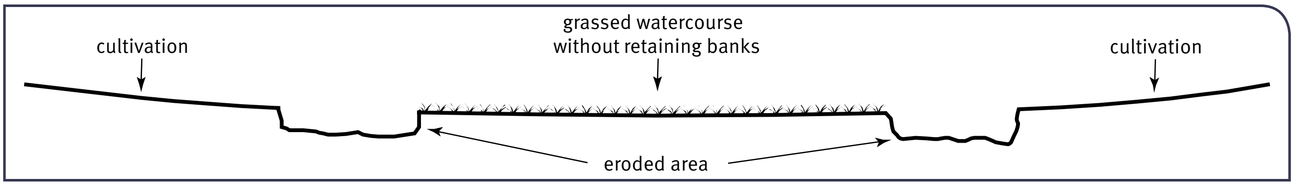


Parabolic cross-sections (or trapezoidal waterways constructed with a slight 'dish') most closely resemble those found in natural waterways. Low flows will meander less in a waterway with a 'dish' profile than they will in a flat-bottomed channel. However, dish shaped waterways are more difficult to construct and trickle flows from the channel bank to the dish bottom can create rills.

If a dish shape waterway is used, the 'dish' is normally constructed to an additional 10 cm, providing the soil is sufficiently deep. A flat-bottomed waterway is recommended on land slopes over 5% where a shallow depth of flow is required to prevent excessive velocities. Triangular shaped channels are generally to be avoided, as they are more likely to erode due to increased velocities in the 'V' of the channel.

Banks that extend above the natural ground level either side of the waterway are essential to ensure that the flow remains in the channel. The only exception is where a waterway is excavated as a subsurface waterway, as in Figure 9.6 (Section 9.2.2). If banks are not constructed for a surface waterway, runoff tends to flow along the furrows in the cultivated areas parallel to and on each side of the grassed drainage line. This will result in gullies forming on one or both sides (Figure 9.2). Retaining banks also define the exact area of land occupied by the waterway. This helps a farmer resist the temptation to gradually extend cultivation into the waterway.

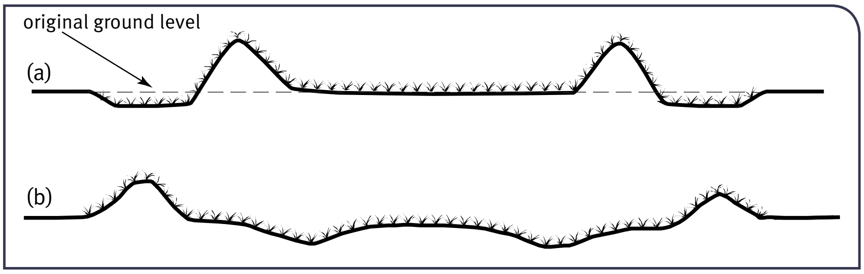
Figure 9.2: Cross-sectional view of a watercourse with erosion in the adjacent cultivation



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 limit the depth and shape of excavation when constructing waterways. A waterway may be difficult to stabilise if surface soils are infertile, or subsoils are unstable. Where subsoils are highly erodible, precautions should be taken to avoid disturbing the area where concentrated flow will occur. In such instances, the waterway can be constructed by excavating the retaining bank from the outside so that the section of the channel across which water flows is left undisturbed (Figure 9.3a).

Figure 9.3: Waterways can be constructed a) with banks built from the outside, or b) with a double-dished bottom



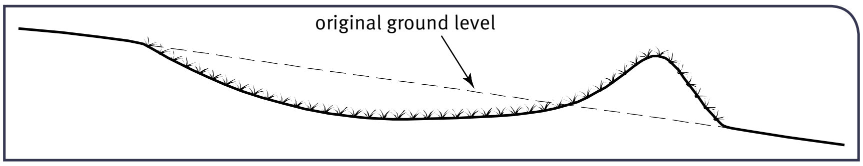
Another approach to addressing this issue on low sloping situations is to obtain soil for use in the banks from a series of excavations in the centre of the waterway (Figure 9.3b). Such an operation requires the use of a scraper. A double-dished bottom can be used in low sloping situations on waterways wider than 30 metres. A 'double-dished' type of construction avoids disturbing the central area of the waterway and reduces the costs of construction and stabilisation.

Whenever possible, topsoil should be spread over excavated channels at completion 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 with successive sections.

9.2.1 Perched waterways

In some paddocks it may not be possible to find a suitable natural depression in which to site a waterway. In such situations the only practical and convenient location for a waterway may be adjacent to a fence. Unless the fence runs directly up and down the slope, waterways constructed in this way will have some degree of side slope. As these waterways are elevated in comparison to any adjacent natural watercourses they are referred to as 'perched' waterways (Figure 9.4).

Figure 9.4: Perched waterway



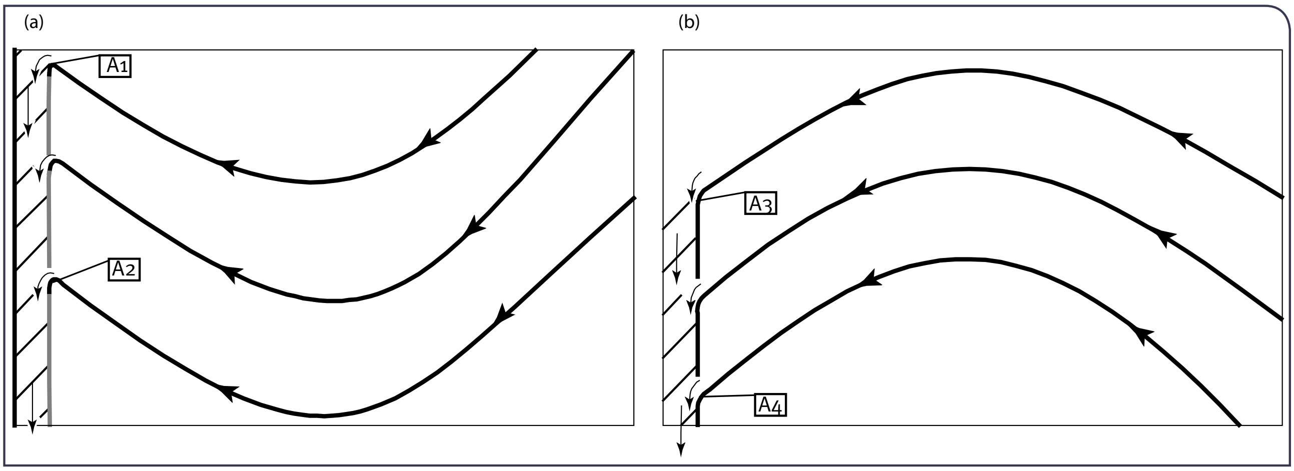
Depending on the amount of side slope involved, perched waterways may require a bank to be constructed only on one side. However, perched waterways generally require a significant amount of excavation across the waterway to produce a relatively flat channel. Such construction requires a higher level of skill than that required for a conventional waterway.

In the event of a perched waterway overflowing, damage to adjacent areas is likely to be greater than with waterways located in natural depressions. Perched waterways should not be constructed where subsoils are highly sodic and inclined to disperse.

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.

Figures 9.5a and 9.5b show plan views of two different arrangements of 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 longer than normal return period. In waterway A3–A4 the tendency is for runoff to flow against the bank furthest from the fence. In this instance particular care is required to ensure that there is adequate capacity at the point where the contour bank enters the waterway (e.g. design points A3 and A4) as this is a point where structures commonly fail through overtopping.

Figure 9.5: Plan view showing perched waterways where the tendency is to flow a) toward the boundary fence and b) away from the fenced boundary

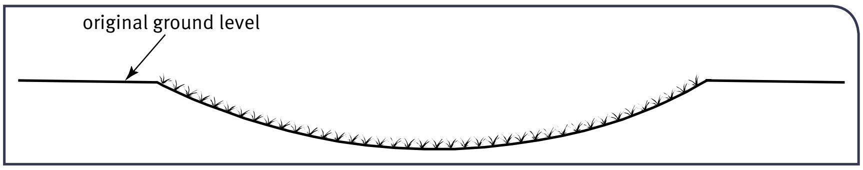


Other examples of perched waterways are provided in Chapter 2.

9.2.2 Subsurface waterways

A subsurface waterway is one constructed by excavating below the natural ground level and with no raised banks (Figure 9.6). The channel of a subsurface waterway is constructed deeper than the channel of adjacent structures so runoff from these structures flows freely into the subsurface channel.

Figure 9.6: Subsurface waterway



Subsurface waterways are often used in horticultural situations and in cane areas because they improve workability in the comparatively confined space of horticulture paddocks by allowing tractors and machinery to readily cross. When crossing subsurface waterways with implements, they must be lifted so that the vegetal lining of the channel is not damaged.

Subsurface waterways are also used in catchment outlets onto floodplains where they may be applied in conjunction with strip cropping.

The depth of excavation to construct a waterway may be specified where the waterway is required for subsurface drainage. An example of such a situation would be where deep furrows discharge directly into a waterway.

It is essential to ensure there is enough depth in the waterway to allow it to accept runoff from inter-row drains which will usually be lower than original ground level. This may provide much greater capacity than that determined by a waterway design. Such waterways need a flat-bottomed or parabolic-shaped channel, stabilised with species such as carpet grass or couch, to safely carry runoff water down the slope. Care should be taken to avoid the use of herbicides that are capable of entering the runoff and killing this grass growth. Waterways should be stabilised with an adequate vegetal cover prior to rows, drains, or banks being discharged into them.

9.3 Design velocity

The maximum velocity recommended for a soil conservation design varies with variation in the nature of the vegetation and soil. Issues to consider when determining design velocity include:

- physical nature of the plants (type and distribution of root growth, seasonality of growth and form of above-ground parts)
- erodibility of soil
- channel shape
- overall extent of vegetation cover and its spatial variability
- slope of the bed.

Table 9.1 provides a guide to maximum recommended permissible velocities for use in design. The table incorporates the effects of waterway slope, fraction of cover, and soil erodibility.

Table 9.1: Recommended maximum velocities for consolidated, bare, and vegetated channels

Channel gradient %	Recommended maximum velocities (m/s) related to percentage of anchored surface cover			
	0% cover (bare surfaces which are consolidated but not cultivated)	50% cover (tussocky species, includes most native grasses)	75% cover (Rhodes grass and creeping species, e.g. couch grass in moderate condition)	100% cover (creeping species, e.g. kikuyu that can be maintained as a permanent dense sod)
Erosion-resistant soils, e.g. ferrosols (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
Erodible soils, e.g. 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 (see Chapter 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 1.0 depending on the degree of erosion resistance provided by the vegetation. Where values exceed 1.0, it would be necessary to ensure that the channel lining had a very high degree of erosion resistance. Table 9.2 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. Table 9.2 shows that where the waterway is deeper than 0.16 m turbulent flow (super-critical) conditions exist. Such conditions are likely to erode the channel, even if it is protected by vegetation.

Table 9.2: Froude number values for a trapezoidal waterway

Flow depth (m)	Velocity (m/s)	Froude number
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 7 m
bed slope 6%
side slopes of 1:3
retardance C

Froude numbers can be reduced by altering the design to reduce the velocity. This can be best achieved by using a cross-section that reduces the depth of flow. If a design is implemented with a Froude number that is greater than 1.0, the vegetation in the waterway would have to be selected and managed to provide a consistently high degree of erosion resistance.

9.4 Waterway stabilisation

Soil conservation waterways usually rely on having a continuous and dense lining of vegetation to prevent erosion. This vegetation protects the channel and banks by reducing the velocity near the bed and by covering and binding the soil together.

9.4.1 Stabilising waterways with vegetation

Uniform sod-forming vegetation, which is characterised by having a dense, relatively deep root system, offers the best protection against erosion of waterways. Kikuyu, couch, African star grass, Rhodes, pangola, Bothriochloa pertusa and Bothriochloa insculpta are all commonly used grasses in Queensland for waterway vegetation. None of these species is native to Queensland but all are widespread and common in agricultural areas throughout the state. Local advice should be sought to confirm that a species proposed to be used for soil conservation works is not known to behave as a weed in the areas where it is proposed to be used. Appendix 4 provides a list of species recommended for use to stabilise soil conservation works in Queensland.

Many of these species are difficult to germinate on cracking clay soils. This is due to the small size of their seeds and the rigid structure of the soil aggregates. Germination failure is a common reason given by farmers for difficulties experienced in stabilising waterways. Sods can be planted as an alternative to planting seed. However, this is highly labour-intensive, suitable planting material may not be readily available, and sods may require watering until they become established.

On Brigalow soils used for cropping, Rhodes grass is generally a good choice for waterway stabilisation.

Most native species grow in tussocks. Tussocks provide less resistance to erosion than the stoloniferous form of the special purpose species normally used in soil conservation works. Native species may still be a good option where suitable stands already exist and where the introduction of exotic species is undesirable. In instances such as this, consideration should be given to constructing waterway banks from the outside to minimise disturbance of the existing native grass sward in the waterway.

Where tussock-forming species are used it is necessary to design for lower recommended maximum velocities and a wider waterway than would be required by sod-forming species to provide adequate bed and bank protection. This is because:

- areas between tussocks are bare of vegetation and exposed to erosion
- tussocks are more variable and create more turbulence
- the root systems of tussock grasses are less dense and uniform and are consequently more prone to be undermined and dislodged.

It is important that vegetation in waterways be maintained. Grass in waterways should be maintained by slashing or by carefully managed grazing. 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.

9.4.2 Stabilising waterways other than with vegetation

Bare-soil waterways have been used on relatively flat irrigation land (‹1% slope) in Coastal Burnett cane-growing areas where waterways are required to fulfil a surface drainage function as well as runoff control. On such low slopes, the design for grassed waterways may require widths so large as to be impractical for farmers. As shown in Table 9.1, velocities as high as 0.5 m/s are permissible where slopes are ‹1% and soils easily erodible, where waterways are bare but consolidated (i.e. not cultivated). Where slopes are less than 1%, experience has shown that design velocities much lower than 0.5 m/s are required. Otherwise the depths required are so great that the waterway would be impractical to construct.

A wide variety of engineering options are used for lining waterways in urban situations. Although more costly than vegetation, engineering solutions offer advantages such as stability under higher velocities and the ability to accept runoff immediately after construction. Also because higher channel velocities can be accommodated by such materials, much narrower widths of channel are acceptable. The following are examples of engineering options for waterway stabilisation:

- **Reinforced turf.** A high level of 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 polyethelene 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.

Such options have rarely been used in agricultural applications. However, they would be worth considering in high-value horticultural applications and for chutes used in stabilising major gully systems—see Chapter 13 of these Guidelines for control of erosion in gullies. If one of these options is to be used, specifications provided by suppliers should be checked to determine recommended maximum velocities for these surfaces

9.5 Waterway freeboard and settlement

Refer to the section on freeboard and settlement in Chapter 6.

9.6 Bends in waterways

Soil conservation layouts occasionally require sharp bends in a waterway, for example a 90° bend, to direct runoff around a corner of a rectangular paddock. Bends in waterways should be designed with a radius as large as possible. In high-risk areas it may be necessary to design for 'super-elevation' flows to ensure the flow is conducted safely through the bend without over-topping the outside bank. As a general guide the outside bank on the curve should be constructed 0.2–0.3 metres higher than the inside bank. An alternative to constructing a bend is to construct a small dam with the spillway coming off at 90° to the inlet waterway.

9.7 Design approach

Equation 9.1

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

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 designing waterways, an important early consideration is to identify critical locations at which specific designs are required. Refer to Section 2.4.1 *Selection of design points* in Chapter 2 for suggestions on how to identify such locations.

The adapted Manning formula (Equation 9.1) (see also Chapter 6) is useful for designing waterways.

It can be difficult to determine the most appropriate retardance level to input into Equation 9.1. The vegetation in a waterway may vary throughout the year, from low levels of cover and retardance (e.g. retardance E) to high levels of cover and retardance (e.g. retardance B), depending on the season and other factors (such as grazing pressure). The rainfall event that leads to the design runoff may also occur at any of a wide range of times throughout the year, when the retardance could be either at its highest, lowest, or in-between.

To determine the design parameters for a waterway, a decision needs to be made of the likely retardance on which to base the calculations. The most conservative way to resolve this dilemma is to base the design on two levels of retardance as follows:

1. when determining the width of the waterway the retardance is assumed to be at its lowest (and velocity hence at its highest), whilst
2. when determining the depth of the waterway the retardance is assumed to be at its highest (and velocity is not a limiting factor but bank height is critical).

Examples of waterway design charts are Figure 9.7 (for a trapezoidal shape, slope of 2% and retardance C) and Figure 9.8 (for a trapezoidal shape, slope of 2% and retardance D). A full set of charts for a range of shapes, retardances and slopes are provided in the Appendices. The computer program RAMWADE (Rational Method Waterway Design) can also be used to design waterways. The program can design for a range of retardances from A to E.

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.

Figure 9.7: Waterway design chart for retardance C and land slope of 2%

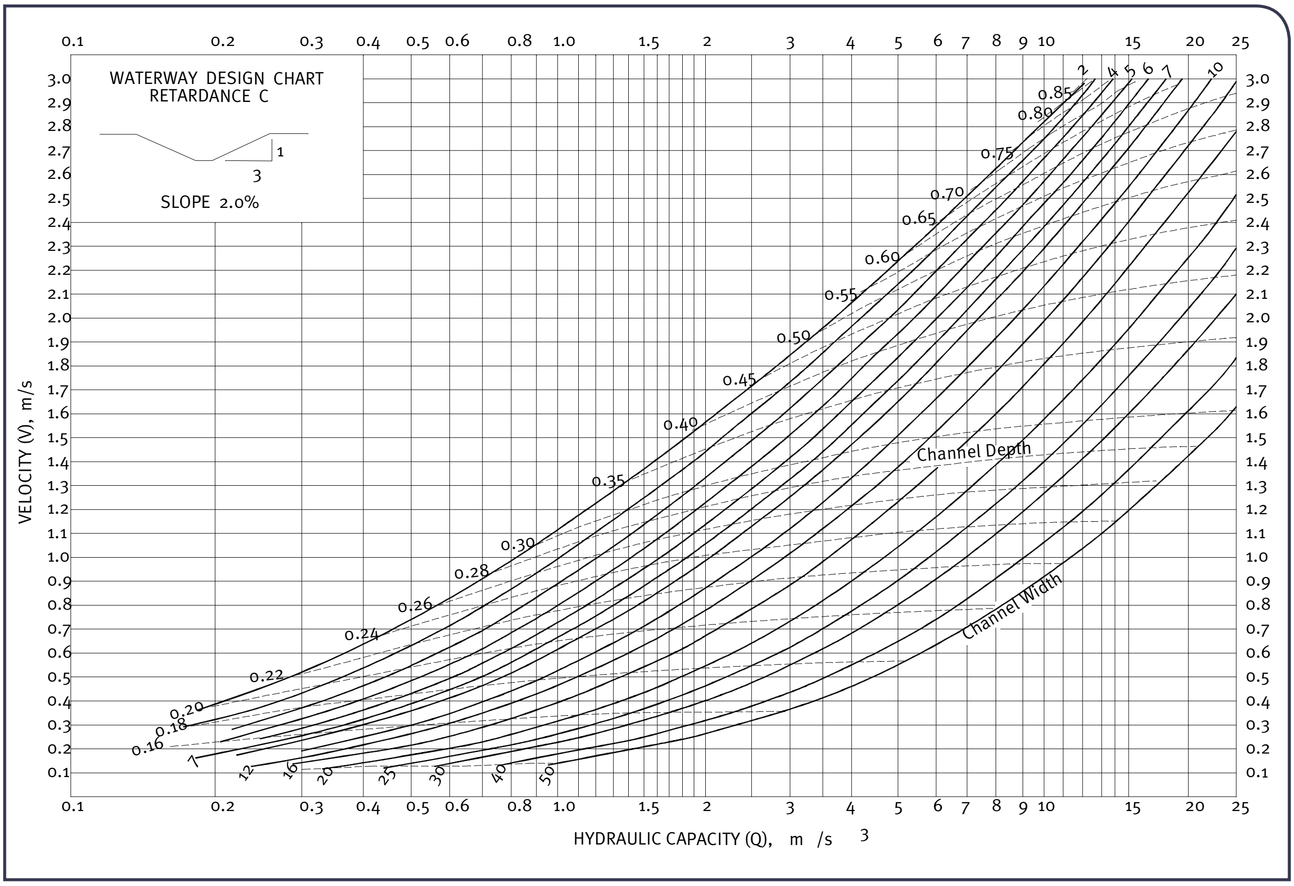
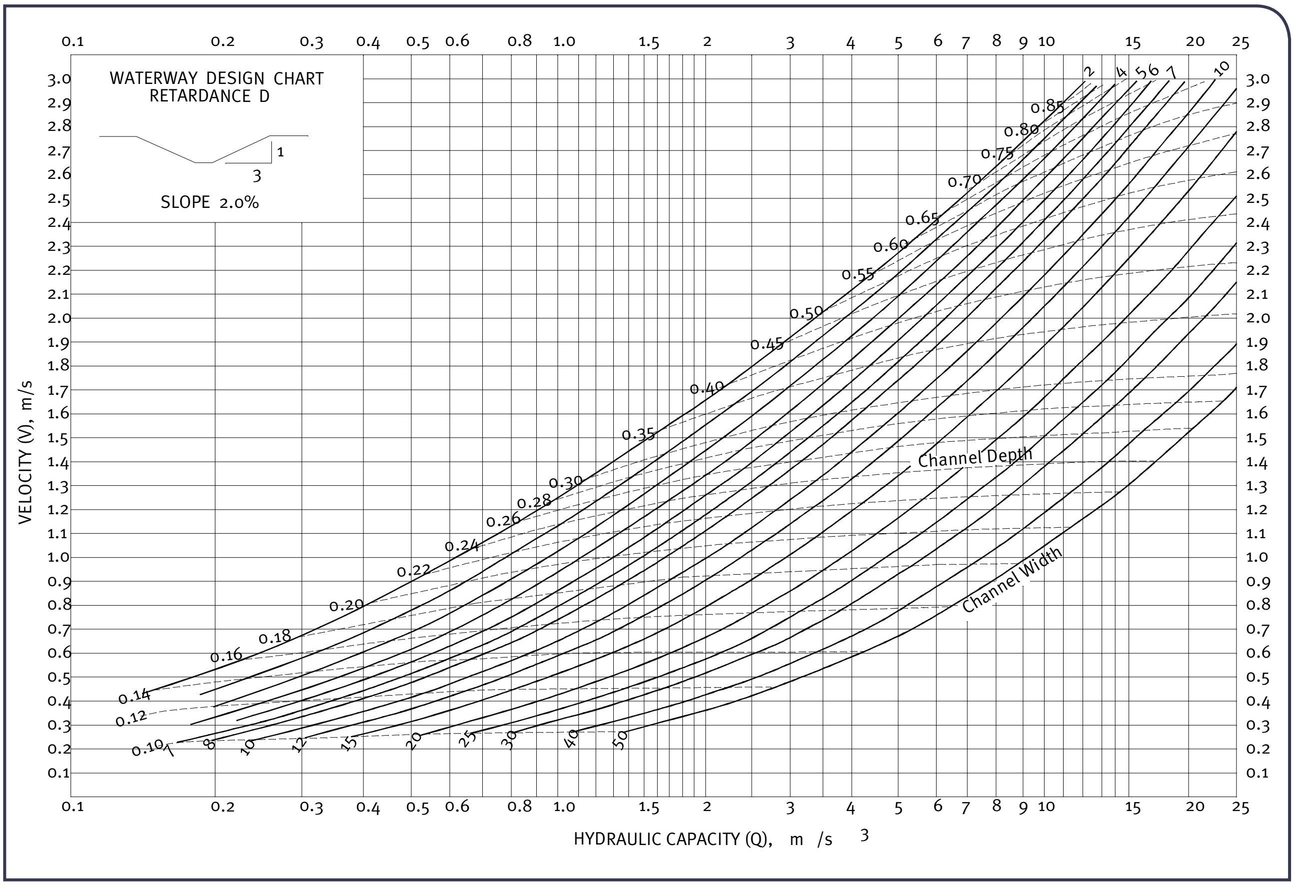


Figure 9.8: Waterway design chart for retardance D and land slope of 2%



Example 1: Designing a waterway from first principles

For a single level of retardance

Design a trapezoidal-shaped waterway with batters of 1:3 (V:H) to accommodate a discharge (Q) of 3m3/s on a land slope (S) of 2%. Assume that the vegetation in the waterway will be maintained at a constant retardance of C and the design velocity (V) is 1.2 m/s.

When designing a waterway based on a single level of retardance, eight steps are required:

Step 1 Determine cross-sectional area of the waterway.
A = Q/V = 3/1.2 = 2.5 m2

Step 2 Determine the required hydraulic radius of the waterway.
Using the solution to the Manning formula for retardance C (Figure 6.4 in Chapter 6), and specified velocity of 1.2 m/s gives a hydraulic radius (r) of 0.25m.

Step 3 Select a cross-sectional shape for the waterway.
A trapezoidal shape has been specified.

Step 4 Determine the appropriate dimensions for the waterway.
Inputting the values of 0.25 for R and 2.5 for A into Figure 6.5 in Chapter 6 gives a required bottom width of 9 m and a depth of flow of 0.27 m.

Step 5 Calculate settled bank height.
From Table 6.3 of Chapter 6 determine that 0.15 m of additional freeboard is required. Add this amount to the depth of flow calculated above (0.27 m) to give a total settled bank height of 0.42 m.

Step 6. Calculate constructed height.
Assuming settlement of 30% (Chapter 6, Equation 6.10) gives a constructed height of 0.6 m.

Step 7 Calculate top width.
Top width = Bottom width + 2(Batter slope x settled height)
= 9 + 2(3*0.42) = 12.5 m

Step 8. Calculate the Froude number.
From Chapter 6, Equation 6.6, a Froude value of 0.77 is determined for these specifications. This is acceptable.

Equation 9.2

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

Where:

Q = 3 m/s
$A = bd + Zd^2$
$R = (bd + Zd^2)/(b + 2d \surd(Z^2 + 1))$
S = 2%

n = 0.030 + 0.00501/VR (from Figure 9.9, for V substitute the value Q/A then assess from Figure 6.3 of Chapter 6)

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)

For a second level of retardance

To design the same waterway used in the example above 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 9.2 can be used to determine the waterway depth.

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.

Example 2: Designing a waterway using charts

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.

To determine the width of the waterway based on retardance D and the depth based on retardance C, follow the following steps:

Step 1 From Figure 9.9, the bottom width of a waterway is determined to be 15 metres required to accommodate the flow of 4 m^3/sec on a 2% slope at a velocity of 1.2 m/s and the depth of flow would be 0.22 m.

Step 2 Given a bottom width of 15 metres, the depth of flow required to accommodate the 4 m^3/sec flow at a retardance of C is determined from Figure 9.7 to be 0.24 m. At this higher retardance the velocity would be 1.1 m/s. (Note that in this example there is minimal difference in flow depths between the two retardances. There would be a more significant difference if the range of retardances used was wider, say from D to B.)

Step 3 Calculate constructed bank height and waterway top width using the same steps as in Example 1.

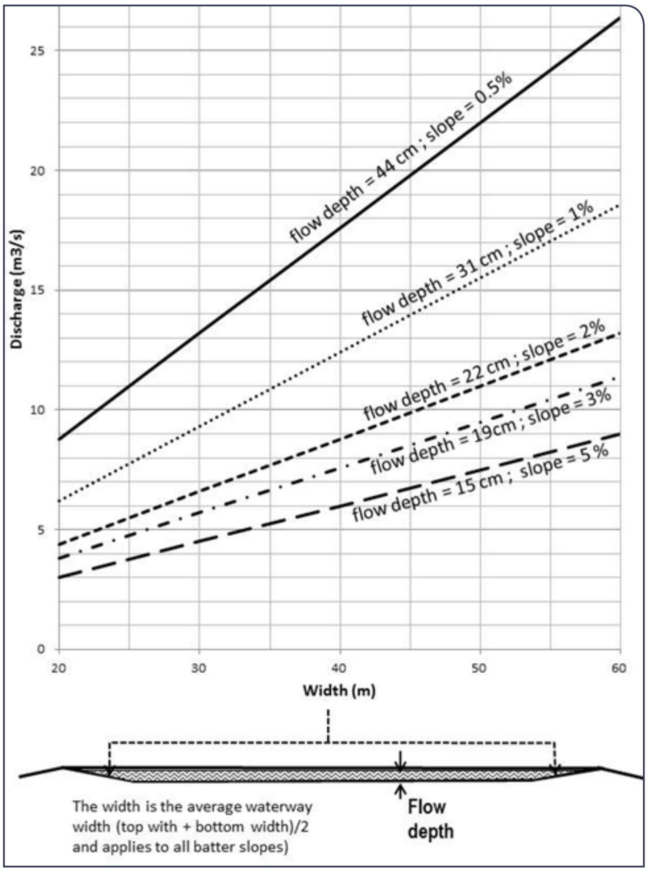
Example 3: Designing wide waterways using charts

When waterways exceed 20 m, the hydraulic radius is almost equal to the depth of flow. This can greatly simplify the design. An example of such a design chart is shown in Figure 9.9. Appendix 3 has four of these charts for the following situations, and they are recommended for use in the extensive cropping lands:

- wide waterway design, retardance C and velocity 1 m/s
- wide waterway design, retardance C and velocity 1.2 m/s
- wide waterway design, retardance D and velocity 1 m/s
- wide waterway design, retardance D and velocity 1.2 m/s.

The following charts are obtained by using the Manning formula. For a given velocity, slope, and retardance, the hydraulic radius is calculated. By assuming that the hydraulic radius equals the depth of flow and by knowing the velocity, it is possible to determine the discharge m^3/s.

Figure 9.9: Design chart for a wide waterway (exceeding 20 m in width)



The width is the average waterway width (top with + bottom width)/2 and applies to all batter slopes)

9.8 Determining the capacity of natural grassed drainage lines

If a natural grassed hollow is to be used in a soil conservation design instead of a constructed waterway, the capacity should be checked to ensure that it is adequate. It may be necessary to check the capacity in several locations if the shape and slope of the land vary. The procedure to check the capacity of a natural grassed drainage line is as follows:

Step 1 Using Table 6.2 of Chapter 6, estimate the retardance value.

Step 2 Measure the slope.

Step 3 Take measurements to determine the cross-section for the waterway.

Step 4 Determine the wetted perimeter.

Step 5 Calculate the area in the waterway cross-section.

Step 6. Calculate the hydraulic radius.

Step 7 Determine the design velocity from a graph showing solutions to Manning's formula for a specified retardance for the calculated cross-section type (e.g. Figure 9.7 if it approximates a trapezoidal shape with 1:3 batters).

Step 8 Multiply the velocity determined in Step 7 by the cross-sectional area to determine the discharge capacity of the drainage line.

Step 9 Compare the discharge capacity calculated in Step 8 with the estimated runoff from the contributing catchment to that point.

9.9 Further information

References

Gregory JM and McCarthy TR (1985) *Maximum allowable velocity prediction for vegetated waterways*, Paper MCR-85-109, American Society of Agricultural Engineers, St Joseph, Michigan.

Other information

DERM fact sheets:

- *Soil conservation waterways—Construction and management*
- *Soil conservation waterways—Plants for stabilisation*
- *Soil conservation waterways—Planning and design*

See Chapter 6 for further detail on design procedures and formulae and Appendix 3 for a full set of design charts.