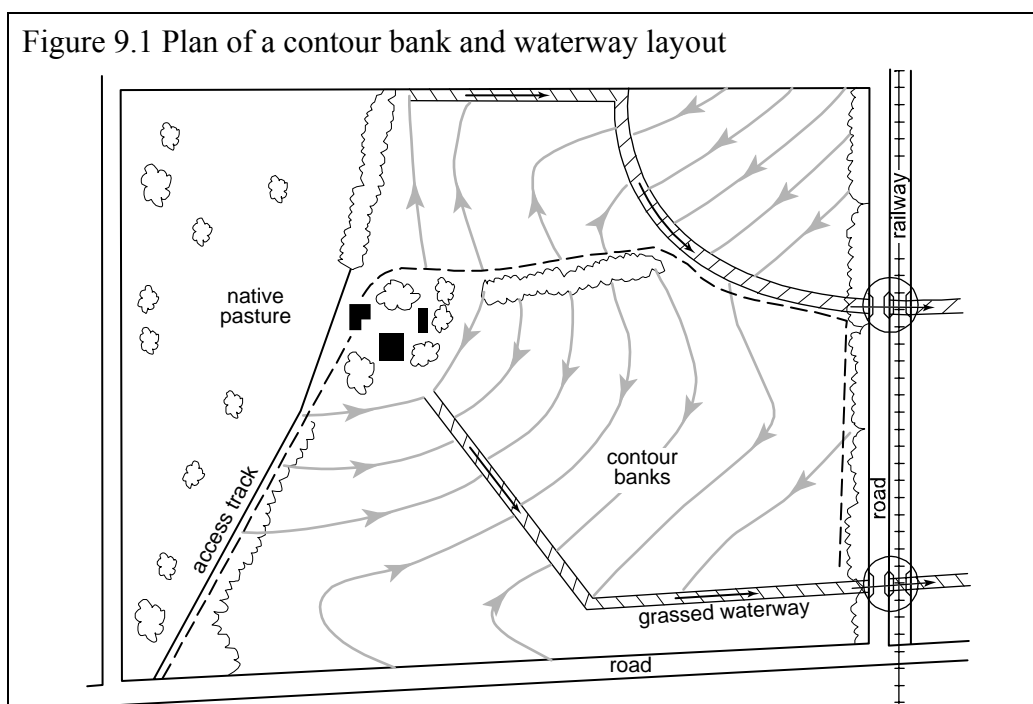


Chapter 9

Contour banks

Contour banks are earthen structures constructed across cultivated slopes, at intervals down the slope. In some countries and other Australian states contour banks are referred to as ‘graded banks’, ‘terraces’ or ‘bunds’. They intercept run-off and safely channel it into stable grassed waterways, natural depressions or grassed areas adjacent to a paddock. Their function is to reduce slope length and to intercept runoff before it concentrates into an erosive force. They also trap much of the sediment from overland flow especially from rills and old gully lines. Any crop or stubble in a contour bank channel acts as a filter as runoff moves slowly along the contour bank channel.



Contour bank layouts require careful planning to ensure the satisfactory coordination of runoff between properties within a catchment and across public utilities such as roads and railway lines (Figure 9.1). More information on this topic is provided in Chapter 2, *Soil conservation planning*.

Contour banks are not strictly ‘on the contour’. They have a low gradient (usually 0.1–0.4%) to minimise the chance of channel flow reaching erosive velocities when the channel is in a bare condition. In some intensive farming situations (eg. horticulture or sugar cane) where pondage must be avoided or where parallel layouts are required, steeper gradients are used for limited distances. If permanent cover is maintained in the channel, much steeper gradients can be utilised. The spacing of contour banks depends mainly on the slope of the land but is also influenced by soil type, cropping practices and previous erosion.

Theoretically, contour banks are usually designed to carry water resulting from a runoff event with a 10 year average recurrence interval. However, the ability of a contour bank to carry the estimated design runoff is very much dependent on the condition of the channel at the time the runoff event occurs. A contour bank with a smooth, bare channel can carry around five times more runoff than one with the channel covered with a close growing crop or dense stubble.

Crop management practices that maintain adequate levels of surface cover will greatly reduce the amount of erosion between contour banks. This will enhance the effectiveness of contour banks and greatly reduce their maintenance costs.

Contour banks play an important role in acting as sediment traps. Up to 80% of the soil moved from a contour bay may be deposited in the contour bank channel (Freebairn and Wockner 1986). Maximum rates of deposition and filtration of nutrients and pesticides are likely to occur when the channel contains a close growing crop or standing stubble.

In intensive cropping areas, as used for the production of horticulture crops or sugar cane, contour banks are usually constructed parallel to each other to facilitate inter-row cultivation, pesticide application, irrigation and harvesting practices. However contour bank layouts in extensive cropping areas are usually not parallel. The long contour banks in such systems provide limited opportunities for parallel layouts because of the irregular nature of the topography.

The introduction of controlled traffic farming has a number of implications for contour bank systems. These are discussed further in the Chapter 13, *Controlled traffic*.

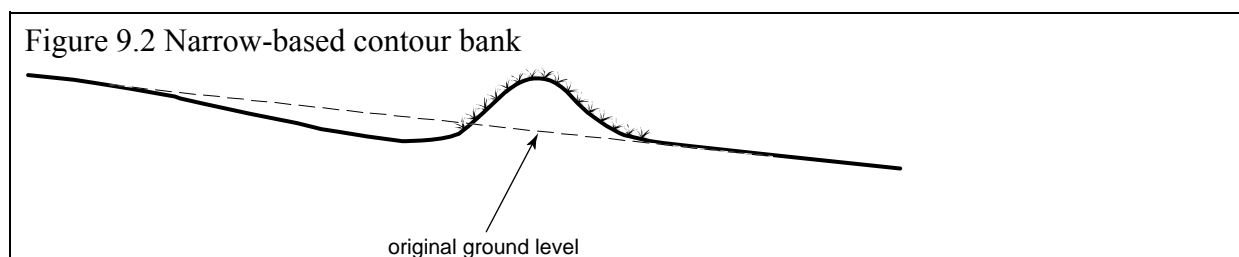
Soils with dispersible subsoils at depths of less than 30 cm are limited in their suitability for bank construction and require special construction techniques. If the subsoils are exposed in the channel, the contour bank will be prone to failure by tunnel erosion.

9.1 Contour bank types

The following types of contour bank cross-sections are used:

- narrow-based
- broad-based
- broad-based top side
- broad-based bottom side.

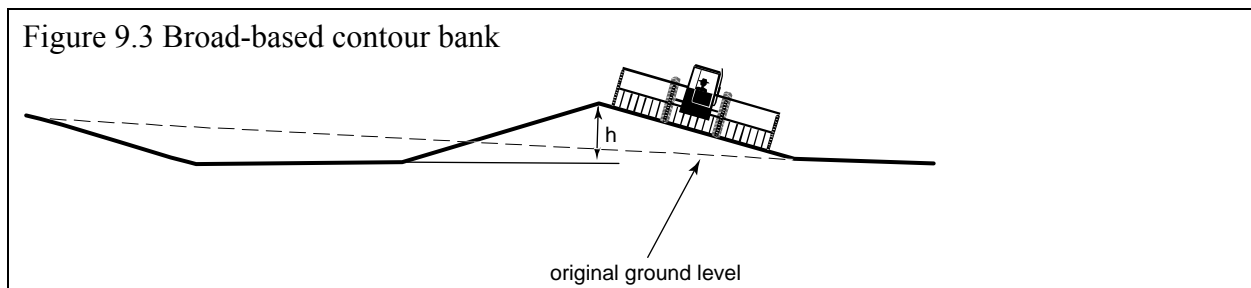
Narrow-based contour banks (Figure 9.2) have batters that are too steep to cultivate. They are normally planted to grass and require weed control especially during the first two years. The channels are usually treated as part of the contour bay, which means that they are cultivated and planted to crop. However some farmers choose to leave the channels grassed. Narrow-based banks may take up to 10% of total cultivated area.



They are commonly used on steeper cultivated slopes of 5–12% or on land that is only occasionally cultivated. They are not suited to cracking clay soils as they may fail following cracking in dry seasons. They are also susceptible to failures resulting from burrowing animals.

Broad-based contour banks (Figure 9.3) are built with batters that can easily be worked with tillage and planting machinery. They allow for the whole of the paddock to be cropped including the channel. Broad-based banks are generally used on deep soils and lower sloping land. They can be

crossed at various angles by farming equipment under a controlled traffic system depending on the slopes of their batters.



Because the batters are cultivated, the risk of failure by cracking is reduced.

Broad-based banks are more costly to build and maintain than narrow-based banks and become impractical to construct as slopes exceed 5%. On steeper slopes on cracking clay soils, *semi-broad-based banks* may be implemented where the up-slope batter of the bank is broadened to suit the width of the most commonly used machinery. Such banks may have a broad base either on the top side (Figure 9.4) or the bottom side (Figure 9.5).

Figure 9.4 Broad-based top side contour bank

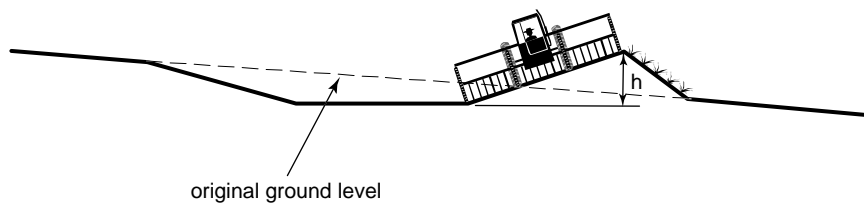
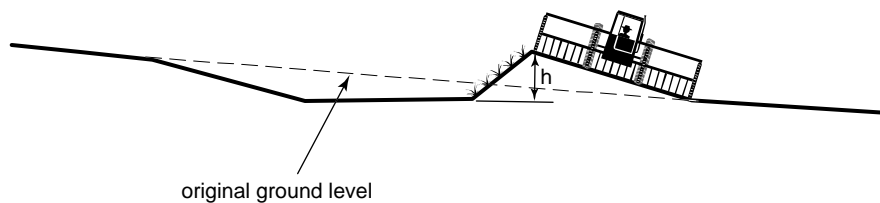


Figure 9.5 Broad-based bottom side contour bank



9.2 Design criteria

Contour banks are normally not individually designed. It is usual to develop specifications for particular situations in a district based on the following parameters:

- gradient
- length
- spacing
- cross-section and depth of flow.

Contour banks are subject to considerable variation in their capacity over time. Settlement will occur after construction. Banks may be worn down by tillage equipment. Sedimentation in the channel will also reduce capacity. Since maintenance of contour banks would normally be carried out on a 5–10 year cycle, it is desirable to carry out construction work so that banks are built or maintained to an above standard specification and then to maintain them once they are below specification.

The dimensions of a newly constructed contour bank are often governed by the construction technique rather than prescribed specifications. For example, contour banks may be constructed with one push of a large bulldozer, creating a structure that greatly exceeds the standard specifications.

9.21 Design velocity

Low velocities are desirable in a contour bank channel to avoid the chance of erosion in the channel and to ensure maximum deposition or trapping of sediment. Low velocities also reduce design peak discharges in waterways by lengthening the time of concentration.

The velocity of flow in a contour bank channel is very much dependent on the condition of the channel at the time that a runoff event occurs. If the channel is in a smooth and bare condition (Mannings n of 0.03) the bank will have maximum potential to discharge runoff. High velocities will occur if there is a significant depth of flow in a major runoff event. The aim of the design should be to keep velocities below 0.4 m/s for easily eroded soils and 0.6 m/s for erosion resistant soils.

However, if channel flow is restricted by a cereal crop such as wheat or standing stubble after harvest (where Mannings n may be 0.15) velocities are not likely to exceed 0.2 m/s. Contour banks must have sufficient capacity to accommodate the design event at these velocities.

In controlled traffic situations, crop direction may sometimes be at right angles to the direction of flow in the channel. Under these circumstances, Mannings n values could be expected to be greater than 0.15. Research is required to determine what Mannings n values are likely to occur under these circumstances.

The variable conditions that occur in a contour bank channel create some complexities in terms of the design. If a contour bank with a bare channel is flowing to capacity, it is likely to be handling an event much greater than that for which it was designed and erosive velocities will occur. This situation must be deliberately risked, as the only alternative is to build a smaller bank or to reduce the gradient. This would lead to regular failure if runoff events occur when the channel is restricted by crop or stubble.

If a design indicates that contour bank velocities will be too high, then the following options should be considered:

- use an alternative channel shape. The use of a flat-bottomed trapezoidal shape will convey flows more safely than a triangular cross-section.
- keep the channel permanently grassed
- use a lower gradient.

The stream power formula (Equation 8.7) may be used to determine the likelihood of erosion occurring in the channel. Table 9.1 provides values of stream power for a typical broad-based contour bank with a trapezoidal shape, a gradient of 0.2% and a Mannings n of 0.03 (bare soil). For cracking clay soils it is recommended that values of stream power be below 3 (W/m^2) (Titmarsh and

Loch 1993). (Values for other soils are not available.) The table indicates that this value will be exceeded for depths of flow of 0.4 metres or greater.

Table 9.1 Stream power values for a typical broad-based contour bank under bare soil conditions			
Depth of flow (m)	Velocity (m/s)	Discharge (m ³ /s)	Stream Power (W/m ²)
0.2	0.4	0.5	1.3
0.3	0.5	1.1	2.3
0.4	0.6	1.8	3.4
0.5	0.7	2.9	4.7
0.6	0.79	4.2	6.0
0.7	0.87	5.8	7.4

Based on the following parameters:

- Trapezoidal shape
- Gradient of 0.2%
- Mannings *n* of 0.3

9.22 Gradients

Contour bank gradients should be chosen to minimise the risk of erosion in the channel when it is in a bare condition but also ensure that the channel has adequate capacity to carry the design runoff when flow in the channel is restricted by crop or standing stubble. Such a compromise can be difficult to achieve in practice because of the five-fold differences that can apply in the values of Mannings *n* (0.03 to 0.15) for these two situations.

High gradients may lead to:

- erosion in the contour bank channel
- high runoff rates in waterways.

Low gradients may lead to:

- poor drainage—an important issue especially for many horticultural crops
- more low points in the bank that will pond runoff until they are filled with sediment
- ‘leakage’ into groundwater systems in locations where this is an issue
- failure by ‘piping’ (linked to tunnel erosion) where there are dispersible subsoils.

The impact of gradient on contour bank velocity and discharge is illustrated in Figures 9.6 and 9.7 respectively.

Figure 9.6 Effect of gradient on contour bank velocity for two flow depths

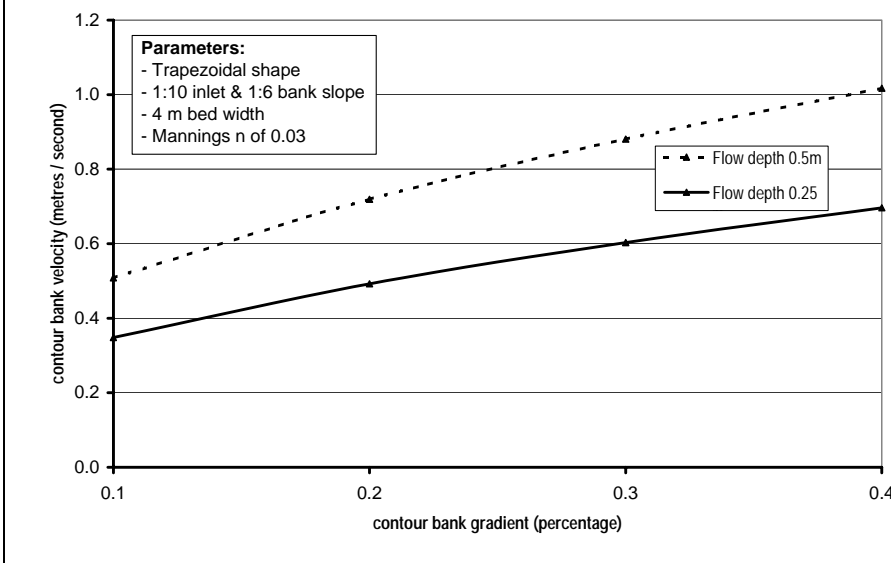
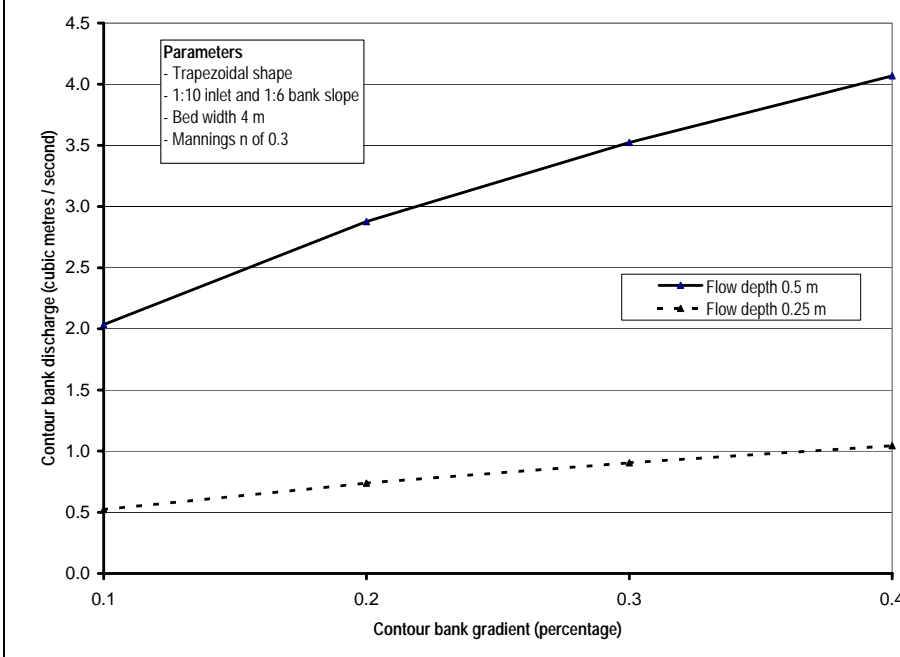


Figure 9.7 Effect of gradient on contour bank discharge for two flow depths



Recommended contour bank gradients are dependent on the steepness of the land and soil erodibility. The capacity of a contour bank of a given height depends on the land slope. The lower the land slope the greater the storage capacity of the bank. There is also a relationship between land slope and bank length. The steeper the landscape, the closer the distance between natural drainage lines. This means that average contour bank lengths on steep slopes are likely to be much shorter than the average bank lengths for low slopes.

Taking the above factors into account, there are good reasons for increasing contour bank gradients as land slope increases. Steeper gradients on higher slopes will compensate for the limited capacity of contour banks on such slopes. However shorter contour banks on steeper slopes means that they

are required to handle less runoff than longer banks—and so there is less likelihood of erosion occurring in the channel.

In horticultural situations, higher gradients can be used where the channel is grassed or where it is bare but not cultivated. If contour banks are used for access and are not cultivated, the risk of erosion in the channel is greatly reduced.

In cane lands gradients as high as 4 % are used where green cane trash blanketing is used on erosion resistant soils eg. krasnozems. Contour bank channels in cane lands are only vulnerable to erosion for a relatively short period when a new crop is planted after the removal of the ratoon crop (every 4 to 8 years). The use of minimum tillage practices or a cover crop can reduce the risk of erosion during the fallow period. Further reference to gradients in cane lands is included in the section *Parallel layouts*.

It is normal practice for a contour bank to be constructed to the same capacity for its entire length. Since the amount of runoff to be carried increases with the length of the contour bank, *variable gradients* can be used along a contour bank channel. This will lengthen the time of concentration and reduce the peak discharge in the waterway.

In contour banks on low land slopes where the maximum gradients are less than 0.2%, there is limited opportunity to use variable gradients. However on steeper land slopes where the maximum gradient is higher, variable gradients as indicated in Table 9.2 can be used eg. for a land slope of 3% to 5%, the gradient in the top 33% of the bank would be 0.2%, changing to 0.25% in the middle 33% followed by 0.3% in the lower (outlet) 33% section of the bank.

Land slope	Appropriate contour bank gradients (%) for average conditions		
	Top section	Middle section	Outlet section
1%	0.1	0.1	0.1
2%	0.1	0.15	0.2
3%–5%	0.2	0.25	0.3
5%–10%	0.3	0.4	0.5

In intensive cropping areas, parallel contour bank systems are often implemented. The implementation of such a system requires some flexibility in contour bank gradients but gradients should be managed to ensure that erosion in the channel is minimised (refer to the section on parallel layouts in this chapter).

Gradients can be modified over short distances to improve workability of the layout. At the high end of a contour bank, it is quite acceptable to improve workability by using a high or low gradient to ensure that the bank meets a fence line at close to a right angle rather than an acute angle.

It is normal practice to ‘split’ contour banks on well-defined ridgelines so that they direct runoff away from the ridge. This ensures that runoff remains in its natural catchment and also provides an ideal position for a road or track to cross over contour banks. The exact location of the ‘split’ should be prominently marked during the surveying process so that the farmer is aware of its location and the significance of this position. The splits on a ridge should be aligned. This may require a readjustment of some levels at the completion of the surveying task to obtain the best alignment.

It should be noted that if contour banks carry runoff across ridge lines that have low slopes or even a saddle, this may result in considerable variation in the contour bank spacing (referred to as the

‘flat ridge syndrome’). This problem can be minimised by modifying the gradient where the bank crosses the ridge. Some zero grade sections in this situation would be acceptable as the low slope ensures maximum contour bank capacity and the convex nature of the topography ensures that there is less likelihood of concentrated flows discharging into this section of the contour bank.

Where contour banks cross ‘sharp’ depressions resulting in a sharp bend in the bank, the gradient can be modified to smooth out the shape of the bank to improve workability. However this will create a low point in the contour bank, which will detain runoff until sufficient sedimentation occurs to remove the pond. If this procedure is adopted, it is essential that the contour bank be given additional capacity where it crosses the drainage line and that such points are checked after construction to ensure they have adequate capacity.

Increased gradients should be considered in situations where contour banks are to be built in land with serious rilling and gullying. However an alternative consideration in such situations is to ensure that the contour bank has additional height where it crosses gully lines, bearing in mind that greater settlement of the bank is likely to occur at these points. The provision of additional height should obviate the need for increased gradient. Ideally, gullies will have been filled in during the construction process. However some form of a depression is likely to remain. This depression will be subject to sedimentation and will disappear over time. Levelling of the land between contour banks (the contour bay) is encouraged to remove the presence of old rill and gully lines. If levelling is not carried out, the rill will continue to concentrate runoff from the adjacent area leading to silt deposition where it meets the contour bank channel.

There is a case for using higher gradients for contour bays where zero tillage is adopted or where contour bank channels are not cultivated. As previously discussed, the highest velocity likely to be achieved in a standard size broad-based contour bank with a wheat crop or standing wheat stubble is 0.2 m/s. The risk associated with this approach is that it is possible that the property could change ownership and the new owner may adopt traditional cropping practices with lower levels of stubble. The preferred option therefore would be to use gradients applicable to a farming system that will have both bare and vegetated channels at different times.

From an hydraulic aspect, level (zero gradient) contour banks, especially on low slopes, could accommodate the runoff they receive, provided they were built to an adequate specification. However they are not recommended because such banks are subject to pondage at regular intervals along the bank. Such ponding can have an adverse effect on crop growth and restrict tillage, planting and harvesting activities.

9.221 Gradients at contour bank outlets

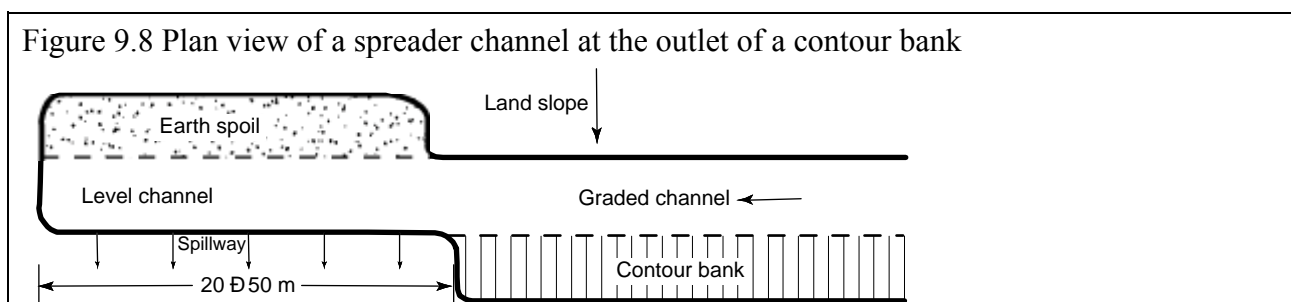
Problems can occur at the point where contour banks discharge into waterways. As well as the gradient in the bed of the contour bank channel, an important consideration is the gradient of the surface of the water in a channel (Stephens 1987). Two different situations may apply—where a bank discharges with a completely free outlet and where the outlet is obstructed in some way.

Examples of where a bank discharges with a completely free outlet include:

- a wide deep hollow
- an adjacent grass paddock
- a subsurface waterway
- an eroding waterway.

In the above cases the gradient of the water surface would be greater than that of the channel, and the velocity would increase. This can be the cause of erosion in bank outlets. In these situations there is no requirement for extra gradient at the bank outlet.

Where contour banks are discharging into a grassed area, it is advisable to construct a spreader channel (Figure 9.8) at the outlet to ensure that discharge occurs over a wide section of the bank. Spreader channels are level channels created by pushing soil uphill rather than downhill as with conventional contour banks. They are used to reduce the concentration of water discharging at the end of a diversion or contour bank into an area of pasture or a watercourse.



A spreader channel would normally involve a level section for the last 20 to 50 metres of a contour bank. The section would have an excavated channel in which soil from the channel is pushed uphill. The use of a hedge incorporating a species such as Monto Vetiver grass along the spreading area would assist in ensuring that runoff exits the sill over the entire length of the spreading area.

Where there is an overfall at a bank outlet, some adjustment to contour bank spacings may be an option in order to find a more stable outlet for a contour bank. Normal gradients or even a level section should be used where there is an overfall. Such overfalls should be stabilised at the outlet by means of a structure such as a rock chute. Where there is instability at a contour bank outlet the last section of contour bank channel should be permanently grassed.

Examples of where the discharge is obstructed in some way include:

- where a bank outlet is too narrow or choked with grass or stubble
- where the bank discharges into a waterway that is flowing at a similar height to the water in the contour bank.

In the above cases the gradient of the water surface will be less than that of the channel bed and the velocity will decrease. This can be the cause of bank overflow near the outlet. Increased gradients will generally be required in these situations. The additional gradient should account for the estimated depth of excavation to construct the contour bank plus the design depth of flow above ground level in the waterway.

In low sloping situations it may not be possible to obtain sufficient additional fall at the bank outlet. In such situations bank height should be increased for at least the last 200 metres of the contour bank. As an additional measure, the contour bank may be constructed to discharge into a secondary waterway running adjacent to the main waterway for about half a contour bay interval.

9.23 Contour bank length

Farmers generally prefer contour banks to be as long as possible to maximise the length of run and to reduce the number of waterways required. However, as bank length increases, so does the risk of failure. The longest bank lengths are implemented on low sloping extensive cropping areas on the Western Downs and the Central Highlands.

On steeper landscapes, the distance between natural drainage lines decreases and normal contour bank lengths become shorter. Shorter contour banks are also associated with the more intensive cropping systems associated with the growing of sugar cane as well as horticulture.

Contour bank capacity is also related to land slope. A bank of a given height will have greater capacity on a low slope than it will on a steeper slope (refer to Figure 9.11 in the section on contour bank cross-sections). This enables the use of longer banks and lower gradients on low slopes.

The amount of runoff discharged from a contour bay will be proportional to the area of the bay. Figure 9.9 shows how the Empirical version of the Rational Method attempts to predict peak discharges for various contour bank lengths on a 2% slope with a 90 metre contour bank spacing at Pittsworth. The graph compares low and high cover farming systems. It shows significantly higher runoff rates under a bare fallow system due to the shorter time of concentration and the selection of a higher C value. However, a contour bank with bare soil in the channel will be able to accommodate considerably more runoff than a bank in which the channel is carrying a crop or standing stubble.

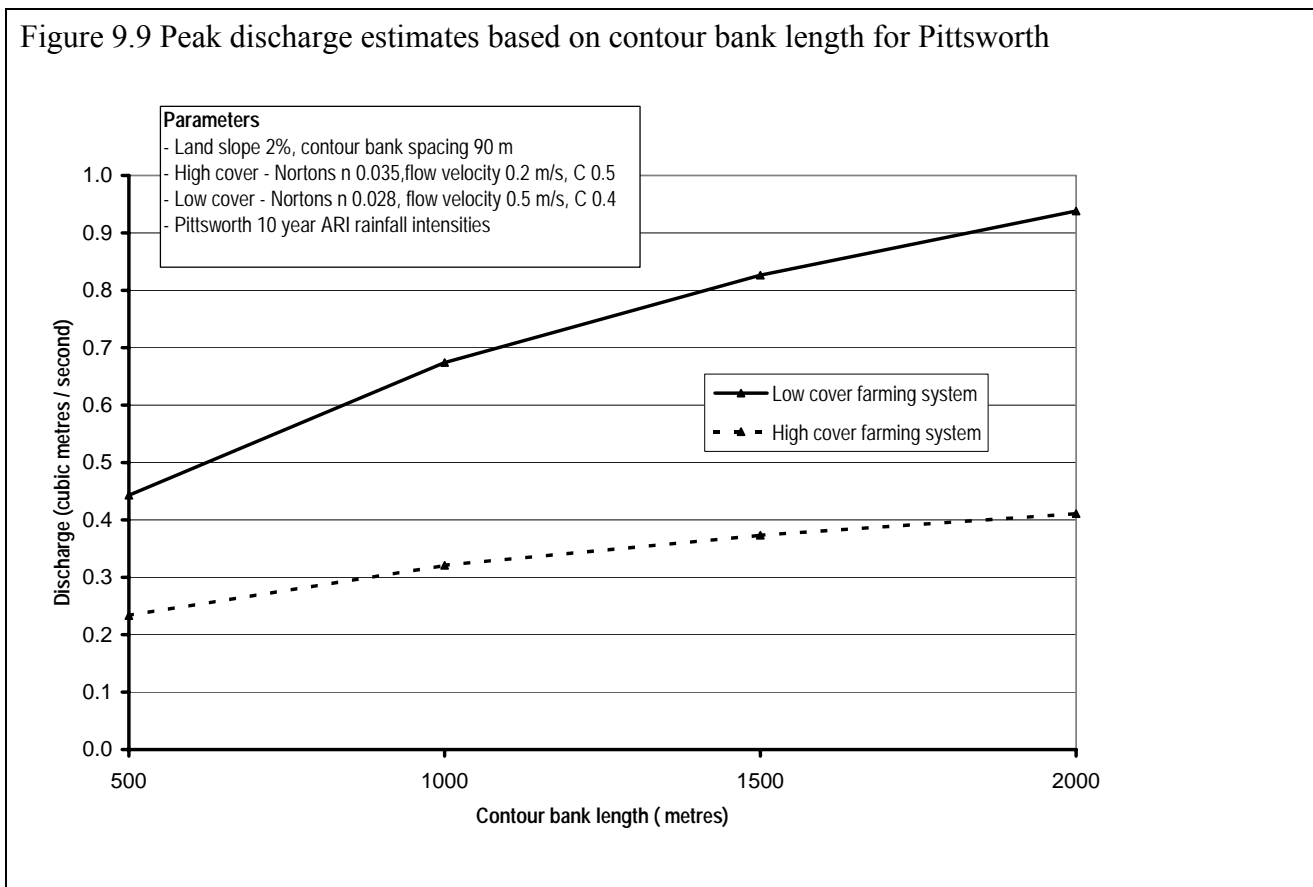


Table 9.3 provides a guide to recommended maximum bank lengths based on land slope. This table is based on contour bank capacities normally maintained by farmers on such slopes and the minimum contour bank spacings normally recommended on such slopes. It also assumes that the runoff is travelling in the one direction in the contour bank channel.

Land slope %	Recommended maximum bank length (metres)
1	2500
1.5	2000
2	1750
3	1500
4	1000
5	750
6	600
7	450
8	400
9	350
10	300

Based on the following parameters:

- Single spaced contour banks
- Use of cropping systems that provide high levels of cover
- High standard of contour bank maintenance

An alternative approach to the design of contour bank length using the KINCON model is provided in Connolly *et al.* 1991. This program is not commercially available.

9.24 Bank spacing

Wide contour bank spacings facilitate the operation of farm machinery and reduce per hectare construction costs. However there are a number of factors that limit the spacing between contour banks:

- the increase in erosion for the wider spacings
- the tendency of overland flows to concentrate, forming gullies between the banks and building up deltas in the channel of the contour bank below
- the practical limit to bank size and the bank's ability to handle runoff.

Various formulae have been proposed for use in determining contour bank spacings based on land slope, soil erodibility, land use and rainfall erosivity. Examination of the Universal Soil Loss Equation has shown that steepness of slope has a much more significant impact on erosion than the length of the slope.

There are no strict rules that determine the 'correct' spacing for a particular situation. A concept of 'single' and 'double' spacings has been used to allow variations in contour bank spacings depending on the average conditions anticipated to be experienced in a paddock. Experience in Queensland has shown that the spacings provided in Table 9.4 are acceptable for most cropping situations.

Average land slope (%)	Single spacing		Double spacing	
	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)	Vertical Interval (VI) (metres)	Horizontal Interval (HI) (metres)
1	0.9	90	1.8	180
2	1.2	60	2.4	120
3	1.5	45	3.0	90
4	1.6	40	3.2	80
5	1.8	36	3.6	72
6	1.9	32	3.8	64
7	2.1	30	4.2	60
8	2.4	30	4.8	60
9	2.7	30	5.4	60
10	3.0	30	6.0	60

‘Single spacings’ should be used where:

- bare fallow cropping systems are likely to be used
- a paddock is suffering from serious erosion
- soils are highly erodible
- contour bank length is close to the recommended maximum length
- farmers are likely to maintain their contour banks to a minimum standard
- parallel contour banks with higher than normal gradients are planned.

‘Double spacings’ may be used where:

- cropping systems that ensure high stubble levels during the fallow phase are used
- minimal erosion has occurred
- farmers are likely to build and maintain contour banks to a high standard.

Spacings between ‘single spaced’ and ‘double spaced’ may be chosen and are used in some districts. An argument against this practice is that the opportunity to later halve the spacing would result in spacings that were unacceptably close for most farmers. However experience has shown that the wider spacings are acceptable provided the conditions listed above are met.

Other factors may determine the spacings required for a particular situation eg. parallel contour banks in irrigated cane have traditionally had a spacing of 40 metres to match the spray width of water winches used for irrigation.

On irregular topography, the distance between banks will vary with the land slope. For this reason it is preferable to measure bank spacing using the vertical interval rather than the horizontal interval. To determine the appropriate vertical interval, a compromise is required. The recommended approach is to use the average VI for the contour bay.

9.25 Parallel layouts

Parallel layouts are a requirement for any situation where inter-row farming operations are practiced or where crops are irrigated. They have traditionally been used in more intensive cropping areas such as for sugar cane or horticulture.

The implementation of parallel layouts requires detailed topographic information and additional inputs are required to implement such systems. They are most readily applied where the topography is even (minimal variation in slope within each of the proposed contour bays). In intensive cropping

areas, contour banks are short allowing for greater opportunities to alter gradients to ensure that the contour bank system is parallel.

The implementation of parallel layouts usually relies on the use of as many natural depressions as possible. This will result in short runs. However the use of subsurface waterways assists trafficability by allowing the tractor operator to lift an implement and travel across the waterway. Above ground waterways would reduce trafficability by requiring the operator to turn around at the waterway.

The use of single spacings in parallel layouts will reduce the amount of runoff that the contour banks need to accommodate and will provide more options for varying gradients to implement the parallel system. The spacing should be modified to match the implement widths or the irrigation system in use on the farm.

Where higher than normal gradients are required, consideration needs to be given to the use of a parabolic or flat bottomed channel rather than a triangular one. The use of a grassed channel may also be necessary. Designs should be carried out to determine if the expected velocities are likely to cause erosion when the channels are in a bare condition.

A steep gradient of say 3–4% will usually be acceptable over a short distance eg. 50 metres at the high end of a contour bank channel because minimal flow is being carried in this section. Table 9.5 (Scarborough *et al.* 1992) provides examples of gradients recommended for use in parallel layouts in the Coastal Burnett. This table applies to situations where contour bank channels are cultivated and could be used as a general guide for the whole of Queensland. If green cane trash blanketing is used and measures are taken to provide erosion protection after the removal of the ratoon crop, (every 4 to 8 years) then higher gradients than that shown in Table 9.5 could be used.

Soil erodibility	Average grade %	Maximum grade for 50 m %
Low	1.5	3.0
Medium	1.0	2.0
High	0.5	1.0

Especially in vineyards but also in trellised tree crops, it is of great advantage if rows are not only parallel to each other but also straight. It is difficult and more expensive to build trellises on curved lines. Water winches used to irrigate sugar cane generally require straight rows to operate effectively.

Some reverse grade sections may be unavoidable in a parallel system. Such sections will result in ponding. Cropping systems and soil types will determine if such ponding can be tolerated. A reverse grade may be avoided by an additional cut in the elevated section of the channel. Another method of correcting the low section leading to a reverse gradient would be to construct this section of the bank from the lower side. This will result in the channel at this point being higher than adjacent sections of the channel.

Parallel layouts have seldom been implemented on broadacre farming systems. The implementation of parallel layouts in such areas would be difficult because there is generally a considerable amount of variation in slopes within contour bays in the rolling landscapes that are a feature of these areas. The lowest slopes are usually found on ridge lines while the maximum slopes occur between the ridge line and the drainage line.

The long contour banks used in broadacre cropping have low gradients and there is limited opportunity to use higher gradients unless the contour bank channel was to be permanently grassed.

The introduction of controlled traffic farming systems requires that land be cultivated in parallel blocks. In broad acre systems this has generally been achieved by cultivating the whole paddock, usually in one direction and passing up and over contour banks (Refer to Chapter 13, *Controlled traffic farming*).

In the South Burnett, some farmers have achieved parallel farming with non-parallel broad-based contour banks by selecting a key bank and working parallel to it. Contour banks above and below the key bank are then crossed at a slight angle. This systems results in furrows that are close to the contour but which drain either into a waterway or a contour bank.

9.26 Contour bank cross-sections

The different types of contour banks were discussed at the beginning of this chapter. While contour banks are often constructed with a trapezoidal shape, the cross-section usually reverts to a triangular shape after a few years of tillage operations.

Two factors with a significant influence on the cross-sectional area of a contour bank are bank height and land slope. Figure 9.10 illustrates the effect of bank height on the cross-sectional area of flow. The data is based on a triangular shaped broad-based contour bank on a 2% land slope and with a bank batter of 1:6. It assumes that the excavated batter conforms to normal land slope.

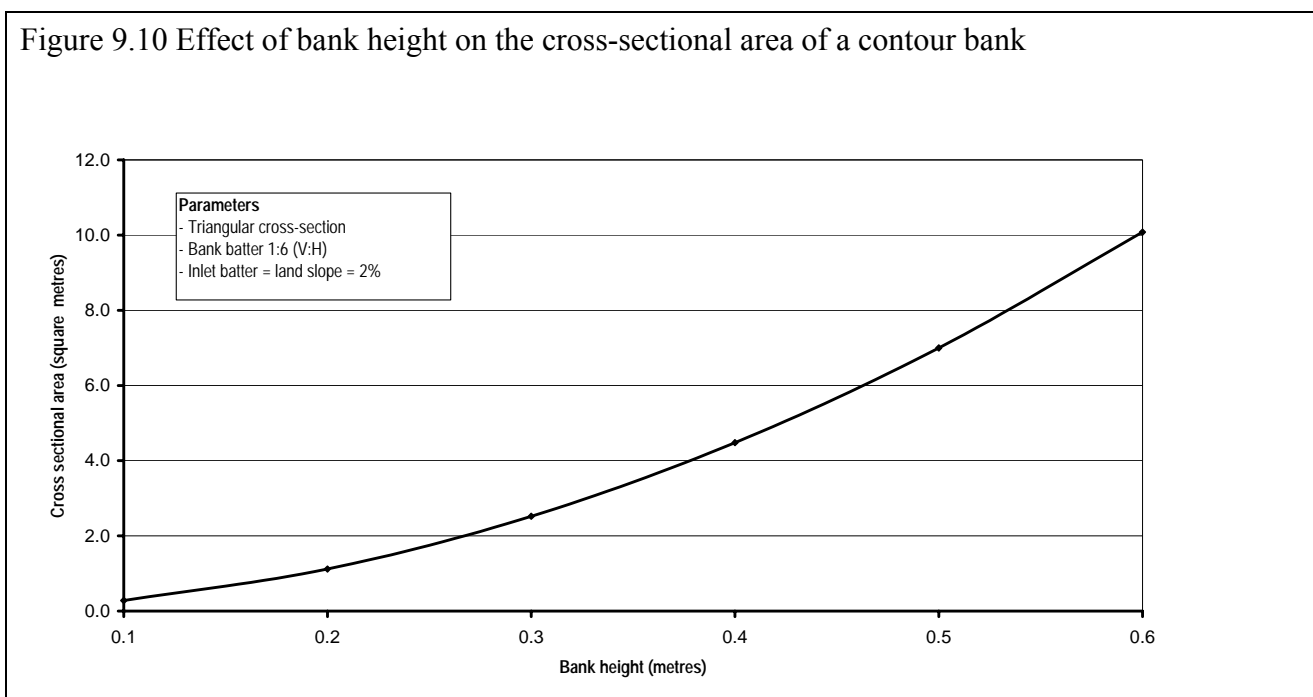
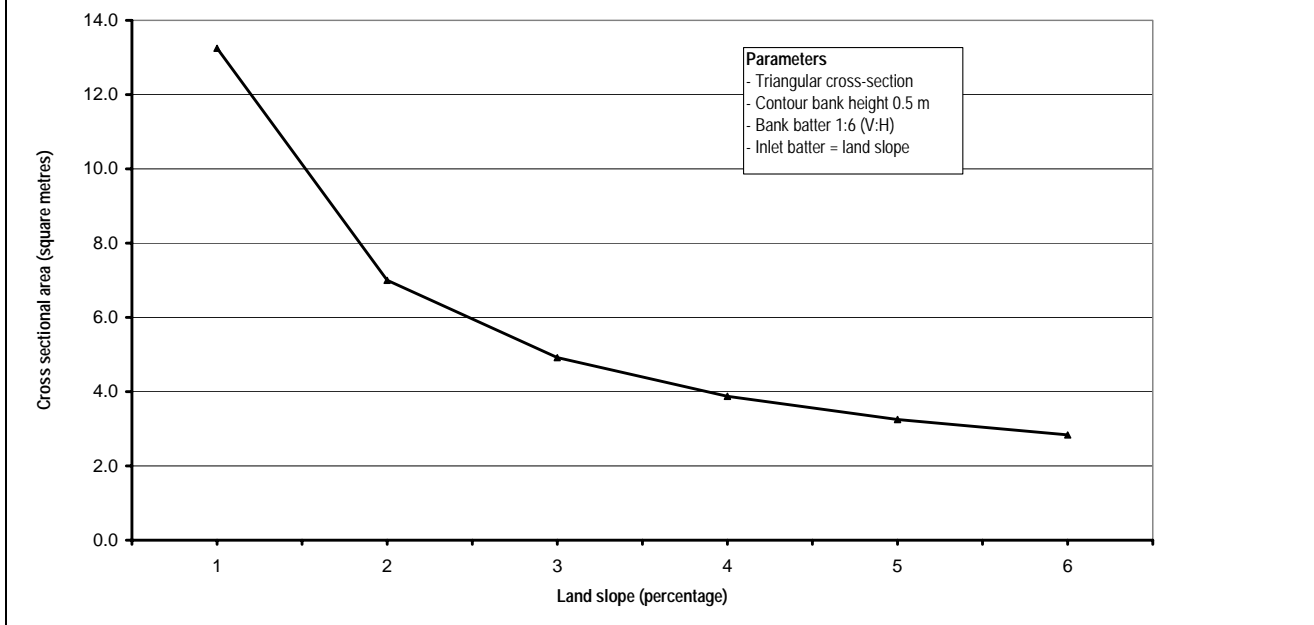


Figure 9.11 illustrates the effect that land slope has on contour bank capacity. The data is based on a triangular shaped broad-based bank with a flow depth of 0.5 metres and a bank batter of 1:6. It also assumes that the excavated batter conforms to normal land slope. On a land slope of 1% where a contour bank interval of 0.9 metres is used, half the contour bay would be under water if there was a flow depth of 0.45 metres. This illustrates the enormous amount of storage that contour banks can have on very low slopes.

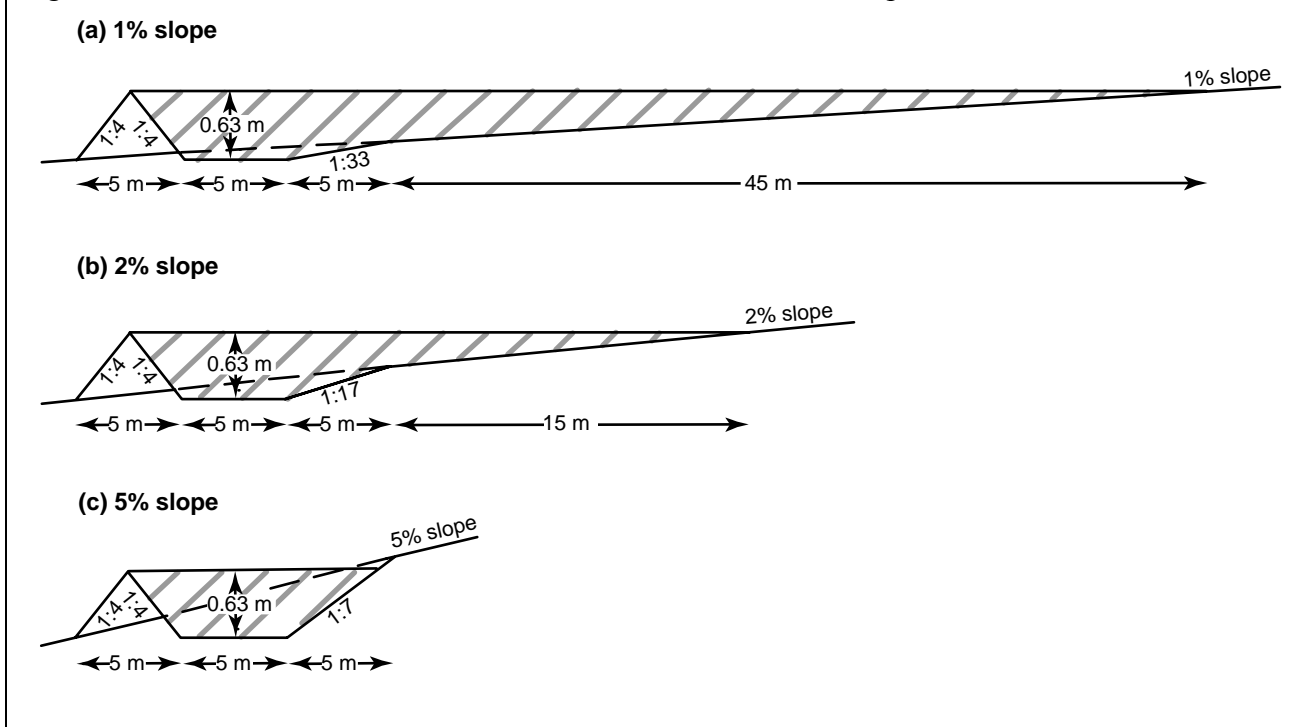
Figure 9.11 Effect of land slope on contour bank cross-sectional area

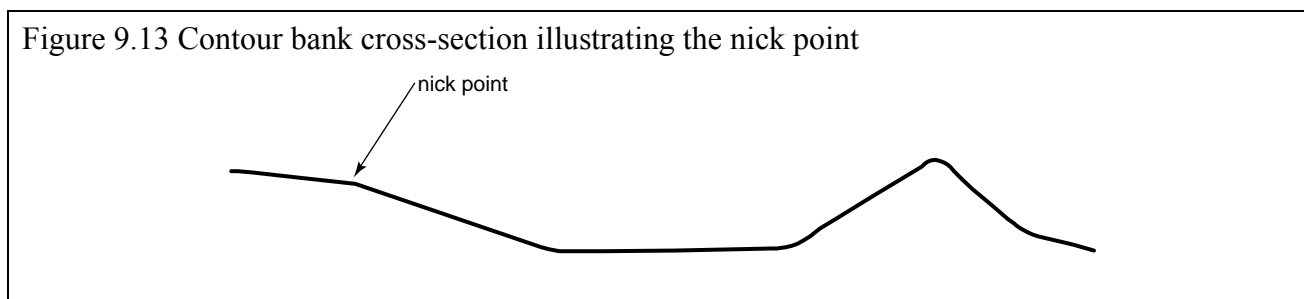


Where land slopes are low, the excavated batter will often conform with the normal land slope after a few years of tillage operations. If the bank has been constructed with a bulldozer using a long length of travel in pushing up the bank then the excavated bank batter will almost conform with normal land slope after construction is complete.

Figure 9.12 also illustrates how land slope impacts on the cross-sectional area of contour banks. It illustrates how 5% is the normally accepted limit for the construction of broad based contour banks with 1:4 batters.

Figure 9.12 Broad based contour banks with 1:4 batters on land slopes of 1%, 2% and 5%





To provide protection against erosion of contour bank channels on steeper slopes, it is best to aim for a flat-bottomed channel (trapezoidal or parabolic). However, on steeper slopes there will be a distinct change in slope where the excavated batter meets the normal land slope. This point is referred to as the 'nick point' (Figure 9.13). It can contribute to rill erosion as overland flows meet the increased slope as they flow into the channel.

Machinery needs must be taken into consideration when determining contour bank cross-sections. The length and grade of the batters of contour banks should be constructed to suit the equipment used to operate on them (especially planting machinery). For cultivated banks, batters flatter than 1:4 (V:H) are recommended. Chapter 13 on *Controlled traffic farming* provides information on contour bank shapes suitable for traversing by machinery.

If a trapezoidal channel is constructed then the base must also conform with machinery needs. Tow paths for travelling irrigators require a trapezoidal shape with at least a 2.0 metre bottom width to help tracking of the irrigator.

9.27 Freeboard and settlement

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

After construction, contour bank capacities need to be checked to ensure they have adequate capacity. Points for special attention are where contour banks cross old gully lines. Additional bank height is required at these locations to ensure the bank has adequate capacity to accommodate the design flow as it crosses the old gully line.

9.3 Design approach

As stated at the beginning of this chapter, contour banks are normally constructed according to general specifications that may apply to a particular situation in a district. Some land management field manuals provide such specifications which have been developed after numerous field observations over many years.

When it is necessary to carry out an individual design for a contour bank or to prepare or modify specifications for use in a district, the following approach is recommended.

In Chapter 8 the concept of combining equations 8.1 ($Q=AV$) and 8.2 (the Manning formula) was discussed. The resulting formula is as follows:

$$\frac{Q}{A} = V = \frac{R^{0.66} S^{0.5}}{n} \dots\dots\dots \text{Equation 9.1}$$

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

Because the channel in a contour bank may have surface conditions varying from a bare condition (Mannings n of 0.03) to a crop or standing stubble (Mannings n of 0.15 in the case of a wheat crop or standing wheat stubble), it is necessary to consider both conditions in the design. This requires the estimation of two design discharges. Figure 9.9 illustrates how the design peak discharge for a contour bank varies considerably for a high and low cover farming system. All paddocks are subject to varying amounts of cover. A low cover farming system refers to the management of the fallow but such a paddock will have a high cover level when it is growing a crop. A paddock where a high level of stubble management is used may have low cover during a period of drought when no crop is planted.

Since crop or standing stubble restricts flows in contour banks it is best to design initially for this condition and then check to see what happens when the design discharge occurs when the channel is bare. A limitation of this method of design, is that it does not take the temporary storage capacity of the contour bank channel into account. The method therefore provides an over-estimation of the actual capacity required. Galletly (1980) refers to the role of contour banks as temporary storage structures. Further research is required to develop a design method that incorporates storage capacity.

From substitution in the above formula the known factors will be the following:

- discharge Q
- gradient s
- roughness coefficient n.

Since we are initially designing for a high level of channel roughness, it can be assumed that the flow will be well below erosive velocities. Therefore we do not need to input a value of V into the above equation. The problem now comes down to finding a depth of flow in the contour bank channel that will give a hydraulic radius R and cross-sectional area A that will accommodate the required value of Q for a given gradient and value of Mannings n . This would require an iterative procedure.

A suitable design can be obtained by preparing a spreadsheet based on the required cross-sectional shape incorporating trial depths of flow and a high and low value of Mannings n . Table 9.6 provides an example of such a table. The table shows how erodible velocities (>0.5 m/s) will occur once the depth of flow in a bare channel exceeds 0.25 m depth of flow. However when the channel is protected by standing stubble, a flow depth of 0.7 m will only be flowing at 0.17m/s.

Table 9.6 Discharges and velocities for a range of flow depths for a trapezoidal shaped contour bank with a gradient of 0.2%

Depth (m)	Cross-sectional area (m ²)	Hydraulic Radius (m)	Mannings $n = 0.15$ eg. standing wheat stubble		Mannings $n = 0.03$ eg. bare cultivated channel	
			Velocity (m/s)	Discharge (m ³ /s)	Velocity (m/s)	Discharge (m ³ /s)
0.10	0.48	0.09	0.06	0.03	0.29	0.14
0.15	0.78	0.12	0.07	0.06	0.37	0.29
0.20	1.12	0.15	0.09	0.10	0.44	0.49
0.25	1.50	0.19	0.10	0.15	0.49	0.74
0.30	1.92	0.22	0.11	0.21	0.54	1.04
0.35	2.38	0.25	0.12	0.28	0.59	1.41
0.40	2.88	0.28	0.13	0.37	0.64	1.83
0.45	3.42	0.30	0.14	0.46	0.68	2.32
0.50	4.00	0.33	0.14	0.58	0.72	2.88
0.55	4.62	0.36	0.15	0.70	0.76	3.50
0.60	5.28	0.39	0.16	0.84	0.80	4.20
0.65	5.98	0.41	0.17	0.99	0.83	4.97
0.70	6.72	0.44	0.17	1.16	0.87	5.82

Shaded area indicates erosive velocities (> 0.5 m/s)

Parameters:

- Trapezoidal cross-section with inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres
- Contour bank gradient of 0.2%

9.31 Example

Determine the constructed height for a contour bank to accommodate discharges of 0.4 m³/sec when a contour bay has a mature wheat crop ($n = 0.15$) and a discharge of 0.9 m³/sec when the contour bay is under bare fallow ($n = 0.03$). The contour bank is to have a trapezoidal cross-section with inlet batters of inlet slope of 1:10, bank slope of 1:6 and bed width of 4 metres and a gradient of 0.2%. Assume that the bank will be built by a bulldozer and that it will settle by 50% after construction.

Solution

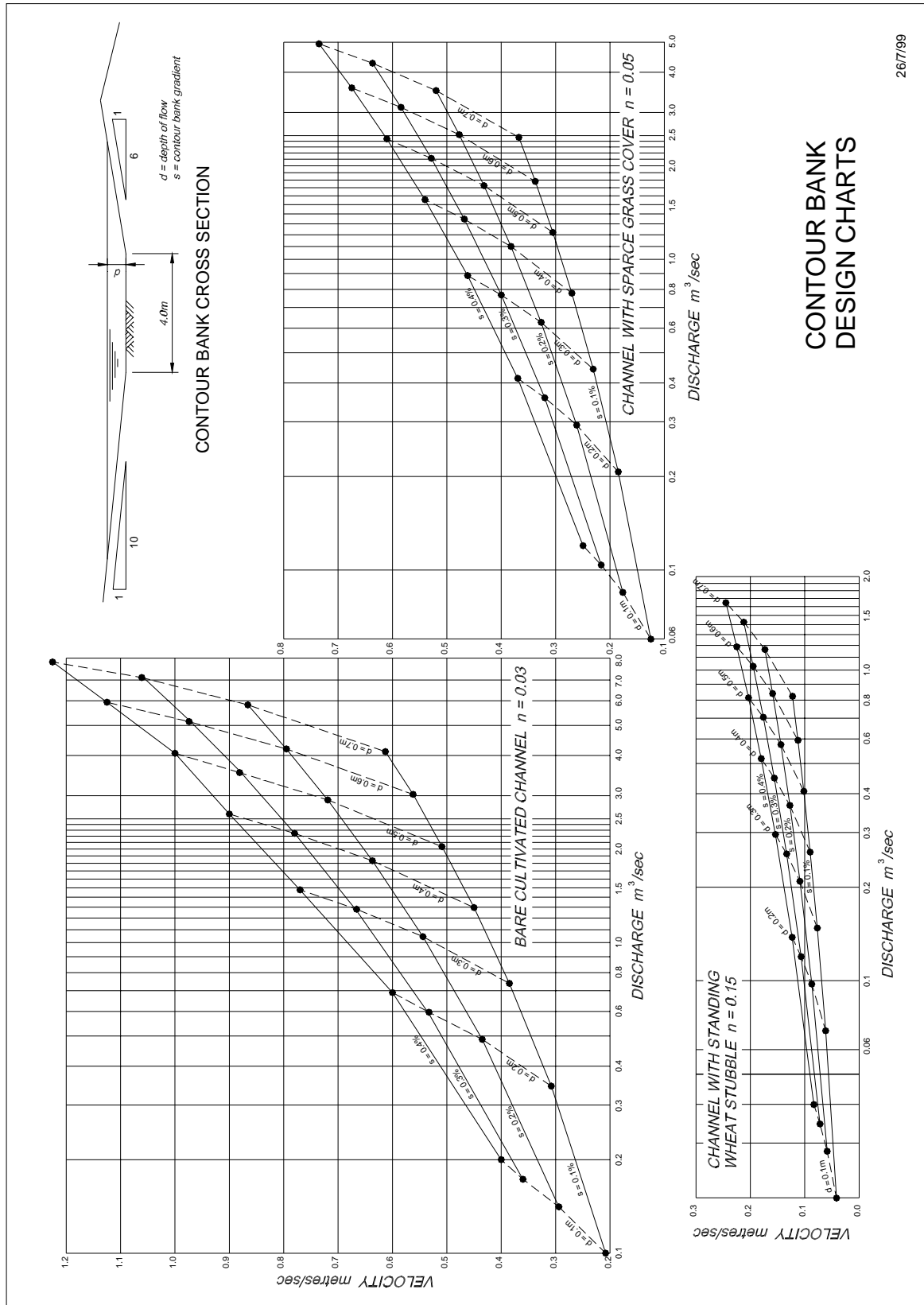
1. Use a spreadsheet to prepare a table similar to Table 9.6 showing velocities and discharges for the two values of n for a range of trial depths and for an acceptable gradient.
2. From Table 9.6 when $n = 0.15$ a flow depth of 0.4 m will have a discharge of 0.37 m³/sec with a velocity of 0.13 m/sec.
3. From Table 9.6 when $n = .03$ a flow depth of 0.3 m will have a discharge of 1.04 m³/sec with a velocity of 0.54 m/sec.
4. The depth of flow obtained in step 1 shows that a depth of flow of 0.4 m would be sufficient to accommodate the required flow. (If an alternative design was required an additional spreadsheet could be prepared based on a different gradient.)
5. An allowance of 0.15 m for freeboard would give a recommended settled bank height of 0.55 metres.
6. An additional 50% should be added to allow for settlement giving a constructed height of 1.1 metres (using equation 8.10).

Note that should the bank carry the design depth of flow of 0.4 m in a bare fallow condition, Table 9.6 shows that it would be carrying a discharge of 1.83 m³/sec at a velocity of 0.64 m/sec. Such a velocity is likely to be erosive but such an event would be rare as it is double the design discharge for bare fallow. Since bare fallow farming systems contribute to high rates of soil erosion in a contour bay, it is most desirable that a high cover farming system is adopted rather than one that has bare fallows.

9.32 Contour bank design charts

Design charts can be prepared to show how contour banks with a specified cross-section perform under a range of values of Mannings n , gradient and flow depth. Figure 9.14 is an example of a contour bank design chart for a broad-based contour bank with a bottom width of 4 metres and batters of 1:6 and 1:10. The three graphs illustrate the dramatic affect that surface roughness in the channel has on both velocity and discharge.

Figure 9.14 Contour bank design chart for a trapezoidal shape and a range of values for Mannings *n*, channel gradient and flow depth



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CONTOUR BANK DESIGN CHARTS

Figure 9.15 shows a graph for the same cross-section as Figure 9.14 but for a constant gradient of 0.2% and three values of Mannings n .

Figure 9.15 Contour bank design chart for a trapezoidal shape and a range of values for Mannings n and flow depth

