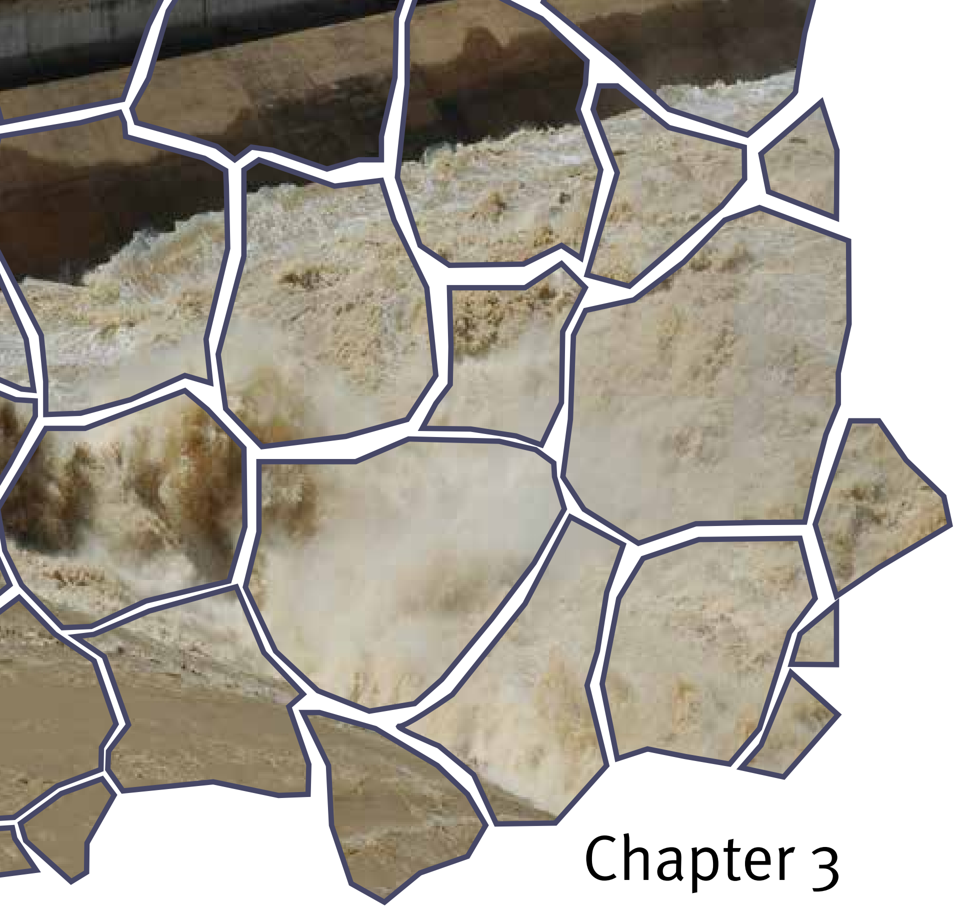
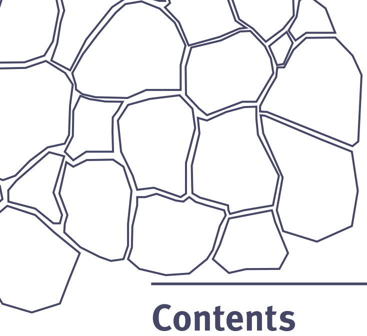


Chapter 3

Peak discharge estimation

Key points

- Soil conservation structures are designed to accommodate a peak discharge. Peak discharge is determined by the area of the catchment above the structure and the rate of runoff expected from that catchment under the conditions for which the structure is designed.
- Runoff is a sporadic occurrence. Most runoff is the result of occasional intense storm events. For any particular locality rainfall events of higher intensity occur less frequently than those of low intensity.
- The frequency with which rainfall events of a particular intensity are predicted to occur (the average recurrence interval or ARI) can be determined for different localities in Queensland from intensity–frequency–duration (IFD) charts available from the Bureau of Meteorology. Soil conservation structures are generally designed for a one-in-ten-year ARI event.
- The rate of runoff is also affected by physical characteristics of the catchment including its shape, landform, soils, and land management.
- A range of modelling approaches have been developed to calculate peak discharge using values for these characteristics as inputs.



Contents

Glossary

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

cracking clay soils: clay soils with shrink-swell properties that exhibit strong cracking when dry.

detention storage structure: a structure used to temporarily hold storm runoff in order to reduce peak flows.

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

infiltration rate: the rate of downward movement of water into the soil. It is largely governed by the structural condition of the soil, the nature of the soil surface and the moisture content of the soil.

intensity–frequency–duration (IFD) curves: graphical representations of the probability that a given average rainfall intensity will occur.

Manning's roughness coefficient: see **retardance**.

melonholes (or gilgais): surface micro-relief associated with some clayey soils, consisting of hummocks and/or hollows of varying size, shape and frequency.

plastic limit: the moisture content of soil at which a narrow, rolled-out thread of soil starts to break apart. An indicator of how the load-bearing qualities of the soil are influenced by wetting.

rainfall erosivity: potential ability of rainfall to cause erosion.

Rational Method: a formula for estimating peak discharge of runoff from a catchment above a specific point. This is calculated using the peak discharge, rainfall intensity for the selected period, runoff coefficient and catchment area.

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

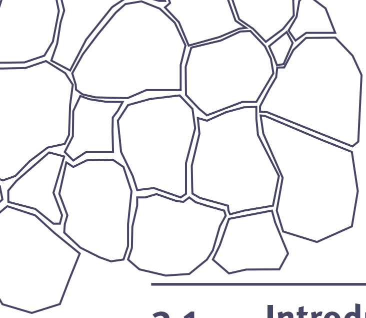
soil permeability: the characteristic of a soil that governs the rate at which water moves through it. This depends largely on soil texture, structure, presence of compacted or impeding layers, and the size and interconnection of pores.

surcharge: temporary increase in the level of water in a channel or storage caused by rapid inflow in excess of spillway capacity.

texture contrast soil (or duplex soil): a soil in which there is a sharp change in texture between the A and B horizon.

tied ridging: a method of controlling erosion where small banks, 15–20 cm high, are constructed on the contour, with an upslope furrow to accommodate runoff from the catchment strip between the ridges and small earthen ties are made within the furrows at 4–5 m intervals to prevent lateral flow.

zero tillage: practice in which a crop is sown directly into a soil not tilled since 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 seedbed is prepared through one or more passes of cultivation equipment (such as disk or tyned plow) prior to sowing.



3.1 Introduction

When designing soil conservation structures it is first necessary to estimate the peak discharge that will occur for a specified average recurrence interval (ARI). Average recurrence interval is the long-term average number of years between the occurrences of a flood as big as or larger than the selected event. Such a discharge is often referred to as a 'design flood'. It should not be confused with the estimate of a flood height resulting from a specific rainfall event over a catchment. Such an estimate is referred to as a 'deterministic' design.

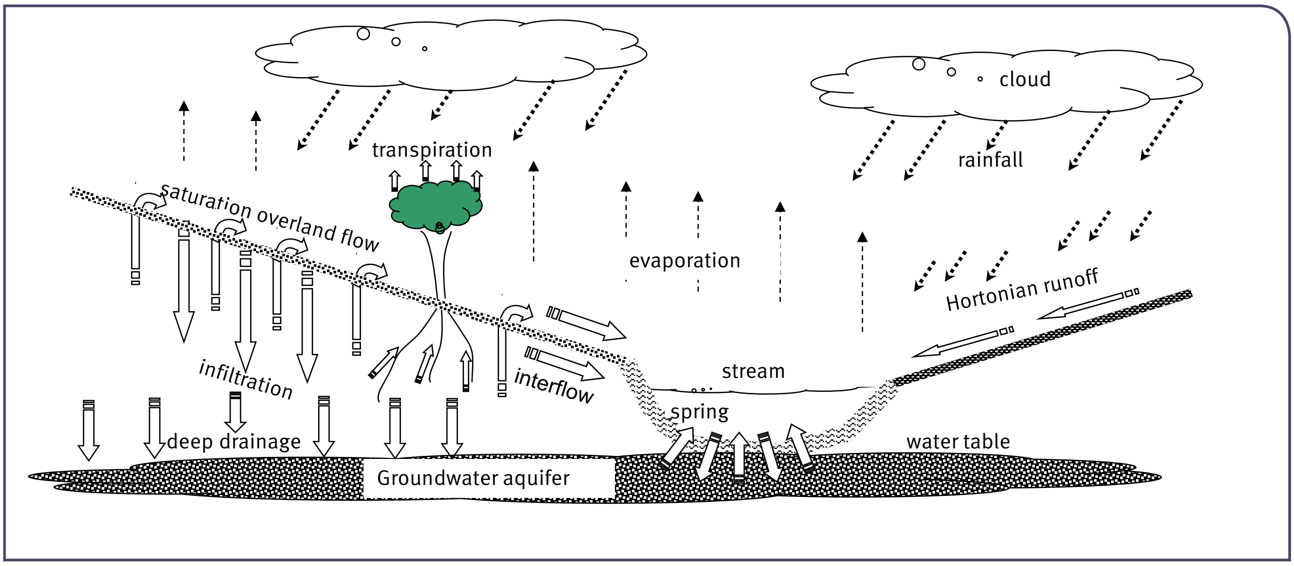
This chapter describes how to estimate peak discharge for small catchments. The majority of designs for soil conservation structures will be for catchments that are smaller than 500 hectares. The methods described in this chapter are satisfactory for catchments up to 2500 hectares in size. For larger catchments an alternative method of runoff estimation should be considered. Information about other methods that might be used is provided in section 3.4 and also can be obtained from *Australian Rainfall and Runoff—A guide to flood estimation* (Pilgrim 1987).

3.2 Factors affecting runoff

As the water (hydrologic) cycle (Figure 3.1) indicates, rain falling on a catchment may return to the atmosphere, be stored above or below the soil surface, or become runoff. Hydrologists refer to rainfall that does not appear as surface flow at the catchment outlet as a 'loss'. Agriculturalists prefer to consider it as a 'gain' as much of this rainfall is stored in the soil for use by crops and pastures.

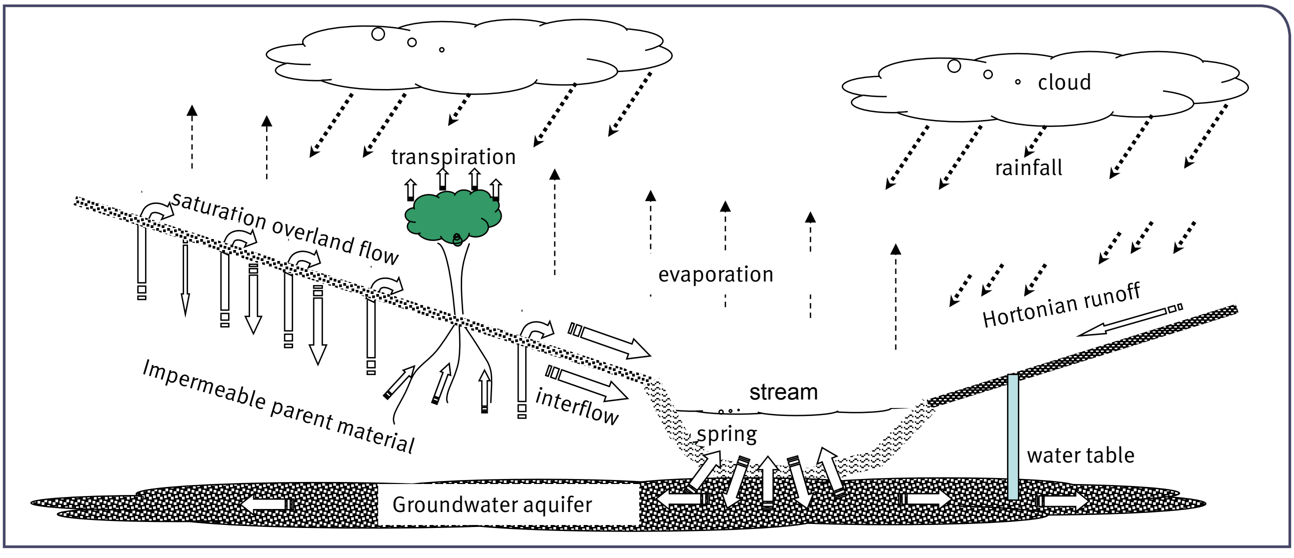
The proportion of annual rainfall that becomes runoff is generally much less than what most people would expect. A study carried out at the Brigalow Research Station in Central Queensland found that under a Brigalow forest the average annual runoff represented only 3% of the total rainfall while the average annual runoff under pasture was 6% (Lawrence and Cowie 1992). Similarly, Freebairn and Silburn (2004) reported that in southern Queensland, runoff occurs at the paddock scale on an average of only five days a year, and significant soil movement only about once every 2–4 years.

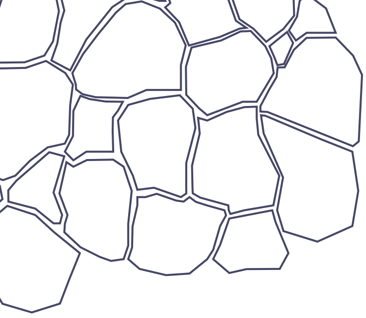
Figure 3.1: Water cycle in a rural landscape



There can be considerable variations in the manner in which the water cycle operates in different catchments. For example Figure 3.2 illustrates the situation that occurs in the Lockyer Valley. Here, the groundwater aquifer is replenished by base flows in Lockyer Creek that may flow for many years after a major flood.

Figure 3.2: A variation on the water cycle in the Lockyer Valley





As illustrated by Figures 3.1 and 3.2, there are two sets of factors affecting the production of runoff:

- rainfall characteristics
- catchment characteristics.

3.2.1 Rainfall characteristics

Characteristics of rainfall that affect the amount and rate of runoff are:

- intensity
- depth
- distribution over an area (spatial)
- distribution over time (temporal).

Intensity

When rain falls with high intensity, runoff is more likely to occur. Very high rainfall intensities can occur in Queensland, especially in areas close to the coast. The highest rates of runoff and soil erosion usually occur during the summer months when intense storm rain occurs. However, significant runoff events may occur in other months, especially in the southern half of the state, where some areas receive between 30% and 40% of their annual average rainfall between April and September.

For any location, there is a general relationship between the duration and intensity of rainfall events. Longer events usually have greater total depths of rainfall but are of lower average intensity than shorter events. Those long events may however also contain short bursts of rain with high intensities.

Frequency distributions can be fitted to rainfall intensity/duration data for any location to estimate the probability of a particular intensity/duration combination occurring. The resultant distributions are termed intensity–frequency–duration (IFD) curves. They are generated in Australia by the Bureau of Meteorology, based on an analysis of rainfall data from *Australian Rainfall and Runoff—A guide to flood estimation* (Pilgrim 1987). Figure 3.3 gives an example of an IFD curve. IFD data can be used to estimate peak rates of runoff for a specified return period.

IFD curves, along with the necessary coefficients used to generate the curves, can be obtained for any location in Australia from the Bureau of Meteorology. These coefficients are required for computer-based programs using IFD data. The formula used to determine the rainfall intensity for a specified return period is shown in equation 3.1.

An example of the coefficients for a selection of return periods for the IFD curves in Figure 3.2 is shown in Table 3.1.

Equation 3.1

$$\ln(i) = a + b(\ln T) + c(\ln T)^2 + d(\ln T)^3 + e(\ln T)^4 + f(\ln T)^5 + g(\ln T)^6$$

Where

ln = natural logarithm

i = intensity in mm/hr

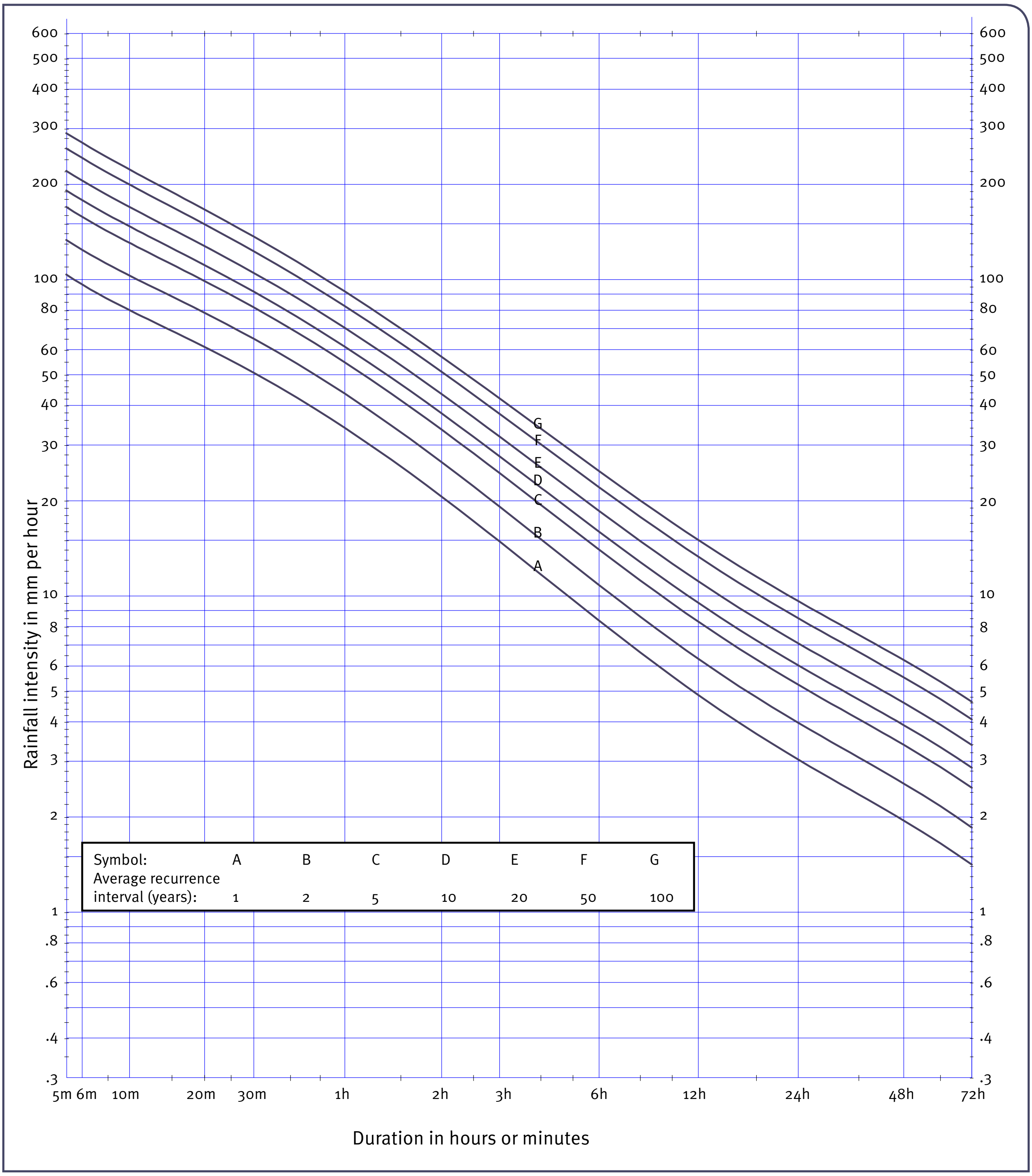
T = time in hours

a, b, c, d, e, f and g are coefficients

Table 3.1 Examples of coefficients for use in calculating rainfall intensities for selected ARIs for Capella (provided by Bureau of Meteorology)

Return period	a	b	c	d	e	f	g
1 year	3.2563	-0.6539	-0.1086	0.00838	0.007905	-0.0003447	-0.0001967
10 years	4.1171	-0.6419	-0.0929	0.00746	0.006617	-0.0002055	-0.0001838
50 years	4.4120	-0.6361	-0.0850	0.00721	0.005956	-0.0001617	-0.0001731

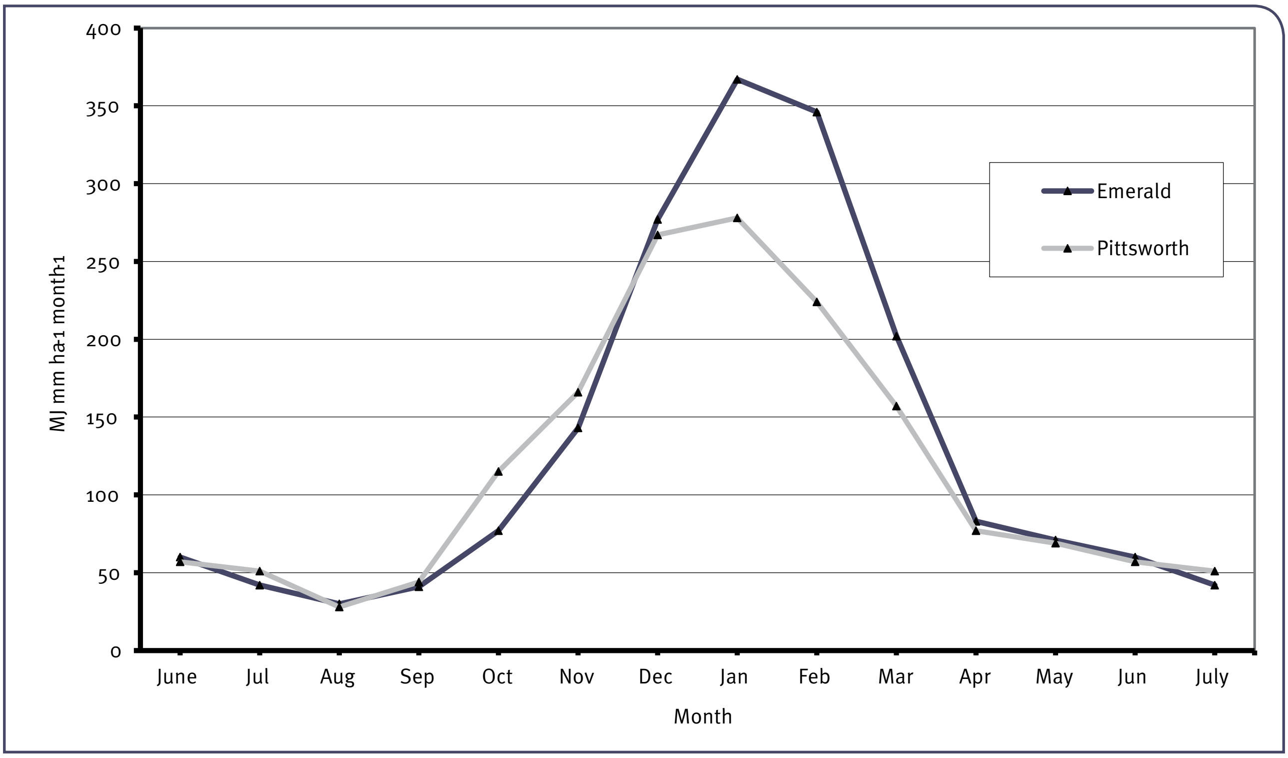
Figure 3.3: Rainfall intensity–frequency–duration curves for the location 23°S, 148°E near Capella (as prepared by the Bureau of Meteorology)



Where there is little variation in average annual rainfall totals throughout a district it would be acceptable to use just one IFD curve for a single location that is representative of the district. However, where average annual rainfall totals vary significantly across a district, then separate charts should be used for different rainfall zones. Areas where changes can occur over a short distance include east to west from the Gold Coast coastal strip to the more elevated hinterland areas and north to south between Cairns and Ingham.

Rainfall intensity is closely related to rainfall erosivity. Rainfall erosivity takes into account the combined effects of the quantity of rain that falls and its kinetic energy. In most areas of Queensland, rainfall erosivity peaks in January–February and is lowest in August–September. Values of rainfall erosivity for specific centres are used in programs such as SOILLOSS (Rosewell 2001) that estimate rates of soil loss based on the Universal Soil Loss Equation (see Chapter 2). Erosivity values for centres throughout Queensland are available in Rosenthal and White (1980). Figure 3.4 provides examples of monthly rainfall erosivity values for Emerald in Central Queensland and for Pittsworth in the south.

Figure 3.4: Monthly rainfall erosivity values for Emerald and Pittsworth



Depth

For rainfall events with the same average intensity, the longer the duration the greater the depth of rainfall. Longer events allow more opportunity for soils to become saturated and for more runoff to be produced. Generally the discharge from a catchment increases progressively as losses are satisfied, until an equilibrium is reached, after which the peak discharge rate remains constant, assuming rainfall intensity is constant. In small catchments, flash floods can occur from high-intensity rainfall over a relatively short period of time. Major floods in large catchments occur after a relatively long duration of rainfall that occurs over the whole of the catchment.

Spatial distribution

The variation of rainfall intensity and depth across a catchment is referred to as the spatial distribution of rainfall. Rain spread evenly across an entire catchment will yield runoff of a different magnitude to that produced if the same volume of rainfall fell in only a small portion of that catchment. Similarly, the runoff produced from a single localised storm within a catchment will vary depending on where that storm occurred. For example, a storm moving up a catchment is likely to produce a lower peak than a comparable storm moving down a catchment. In the former case, runoff produced in the lower part of the catchment will have left the catchment before the runoff from falls higher in the catchment arrives. In the latter case, the runoff rate is compounded because runoff from the top of the catchment may arrive at the same time as the storm has reached the lower catchment.

In some more complex runoff estimation models, allowance can be made for spatial distribution. This is especially important for instance in flood forecasting where lives and properties are at direct risk. However, when carrying out designs for soil conservation structures, it is generally assumed that the rain occurs evenly across the catchment.

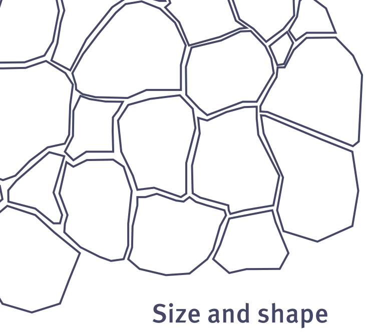
Temporal distribution

Variation in intensity over time during a rainfall event is referred to as temporal distribution. The graphical representation of temporal distribution (measured as rainfall depth over time) is called a hyetograph. A rainfall event with a large proportion of its volume at the start may produce a runoff event of different magnitude than one of the same overall size if the same proportion occurred at the end or some other point during the event.

The Bureau of Meteorology has prepared a set of design temporal patterns from rainfall data for a range of durations (from 10 minutes to 72 hours) and average recurrence intervals (1 to 100 years) (Pilgrim 1998). More complex runoff estimation models use temporal patterns as part of their input data, both in design and flood forecasting exercises. However, the runoff estimation methods described in these Guidelines assume that rainfall intensities are constant for the duration of the event.

3.2.2 Catchment characteristics

The amount and/or rate of runoff generated by a catchment are influenced by a range of physical characteristics. Some of these characteristics vary with the season and the nature of land use and management. For example, paddocks containing soils with high infiltration rates with consistently high levels of surface cover will have lower rates of runoff than paddocks containing soils with low infiltration rates and with low levels of surface cover. The impact of an individual characteristic depends on the size and shape of the catchment. These characteristics should be taken into account when designing a waterway to accommodate the runoff from a paddock. However, when preparing a design for a larger catchment containing a variety of soils and land uses, the effects of different characteristics will be averaged out and some representative parameter values for the whole catchment may be selected when calculating a runoff estimate.



Size and shape

In general, the volume and peak flow rate of runoff increases with catchment size. However, they may also vary with shape. For instance, for the same rainfall event, a long narrow catchment would be expected to have a lower peak rate of runoff than a more compact or circular one of the same size. This is because in the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet and so the flow is spread over a longer time period.

Contour bays represent an unnatural shape for a catchment. They feature a relatively short length of overland flow between banks that act as long detention basins, especially when the channel flow is restricted by a crop or standing stubble. This shape needs to be taken into account when determining the peak discharge from a contour bay.

Topography

Catchments with relatively flat terrain generally have a lower peak rate of runoff than those with steep terrain. This is because runoff flows slower and takes longer to travel over lower sloping surfaces, resulting in the peak discharge being both reduced in height and delayed. However, steep watercourses will often have a higher roughness of the ground surface which may offset any increase in flow velocity due to the higher slope.

Soil conditions

The rate that rainfall infiltrates into the soil affects the amount and rate of runoff. Infiltration rates vary with soil type. Deep sands and friable red soils (ferrosols) have high infiltration rates whilst hard-packed grey clays generally have low infiltration rates. Cracking clay soils have a variable infiltration rate—high when cracks are open and low when cracks are closed. Texture contrast soils often have subsoil layers with low infiltration rates whilst the surface soil can be quite porous. The term soil permeability is also used to express the rate at which water moves through a soil profile. The least permeable layer in the soil controls the rate of water transmission through the soil overall. The Australian Soil and Land Survey Field Handbook (known as the ‘Yellow’ book) (National Committee on Soil and Terrain 2009) classifies permeability into four levels:

- very slowly permeable—less than 5 mm per day
- slowly permeable—5 mm to 50 mm per day
- moderately permeable—50 mm to 500 mm per day
- highly permeable—greater than 500 mm per day.

Soils with abundant biological life generally have high rates of infiltration. Earthworms and termites improve soil aeration and drainage by constructing burrows and termite galleries. Tillage destroys these structures and can reduce permeability. Infiltration rates are also reduced by soil compaction and the formation of surface seals.

The amount of infiltration also depends on the moisture content of the soil. Catchments will absorb more rainfall before runoff commences if they start in a dry condition. Major floods (and severe soil erosion) can occur when heavy rain falls on a catchment that has already been saturated.

Storage

Localised depressions in the land surface can retard surface flows and reduce the amount of runoff. Examples of such features include roughly ploughed paddocks, hoof prints, melon holes (or gilgais), sediment traps, dams, and wetlands. Some cultivation implements, such as tied-ridging implements, are designed to create such storage in an attempt to better utilise rainfall.

Contour banks can provide significant temporary storage. Contour banks of the same height will have much greater capacity on lower slopes than higher slopes because of the greater amounts of runoff stored behind the bank. Contour banks on lower slopes will also have lower gradients, which further increases the period of temporary pondage.

Constructed surface storages can be designed to empty over an extended period of time in order to reduce the flood peak downstream. These are termed detention storage structures.

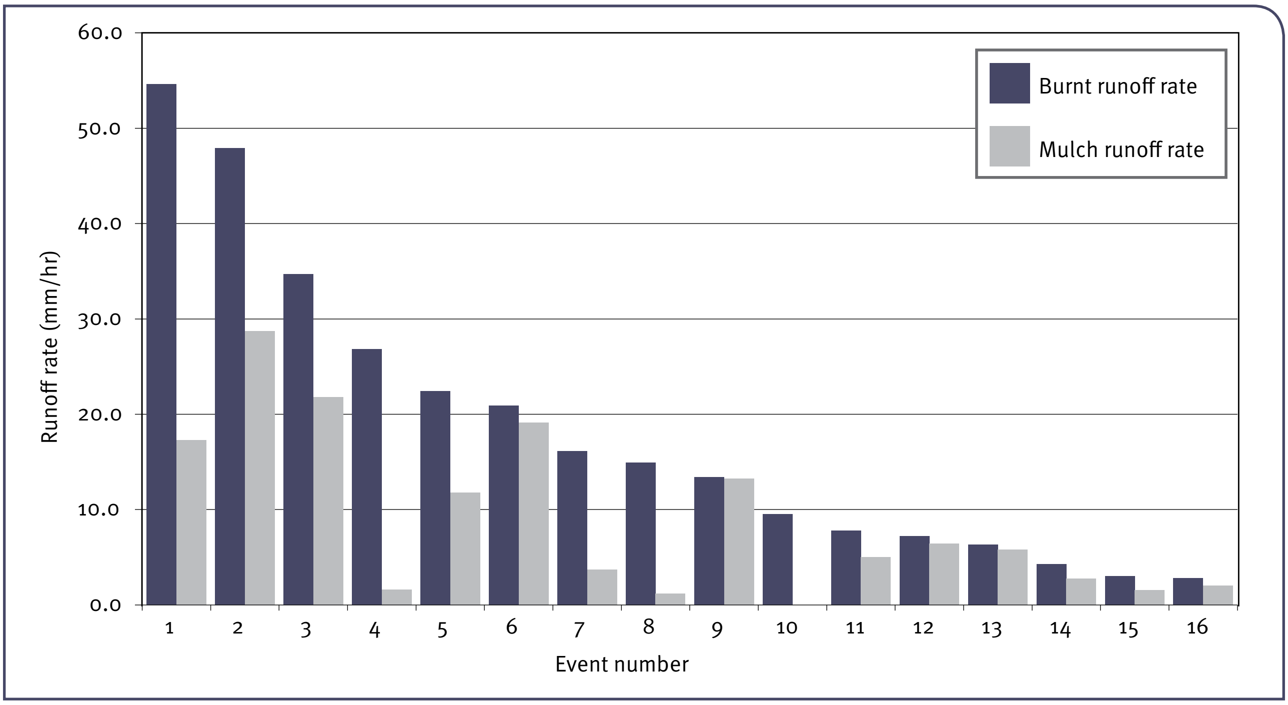
Land use and management

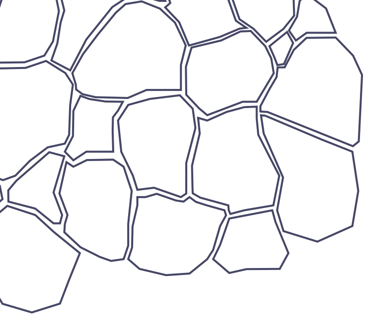
Generally, forested land will produce less runoff than cultivated or pasture land. As an example, Lawrence and Thorburn (1989) found that clearing brigalow forest at Theodore and converting the land to pasture or annual crops more than doubled the mean annual runoff depths. For one catchment, the mean annual runoff increased from 26 mm while under forest, to 56 mm when cultivated, for the time period studied. For another, it increased from 23 mm to 47 mm when the land use changed from forest to pasture.

Management of the soil surface can have an important effect. Higher rates of runoff will usually result from paddocks with low levels of surface cover compared to those with a crop or stubble from the previous crop. Surface vegetation helps increase infiltration rates by reducing soil aggregate breakdown and surface sealing caused by raindrop impact and by impeding overland flows.

The effect of soil surface management on runoff is illustrated in Figure 3.5 which shows peak runoff rates measured from two treatments in a paddock at Greenmount on the Darling Downs between 1976 and 1991. The peak runoff rates from areas where high levels of surface cover remained were significantly lower than the rates from areas with bare fallows in most years. There was a smaller difference in treatment effects when the storm event occurred late in the fallow (e.g. events 6, 9, 12 and 13). Differences in surface cover levels are much higher at the beginning of a fallow than at the end when much of the stubble will have decomposed.

Figure 3.5: Peak runoff rates for the 16 largest events recorded in the Greenmount trial between 1976 and 1991





It is generally accepted that a minimum of 30% stubble cover is required to provide a reasonable level of protection from erosion. Higher levels of cover will increase the protection provided. Particular care needs to be taken to protect the soil surface under drought conditions when crops may fail or not be planted, and cover levels will consequently be reduced. This is more likely to happen in marginal cropping areas where soils have lower moisture-holding capacity and fertility levels. Cover levels are often lower in districts where farmers are struggling to maintain profitability due to their properties being small and their opportunities to adopt new technology limited.

While implementing zero tillage practices reduces soil erosion compared with conventional tillage techniques, sometimes it can result in higher peak runoff rates than stubble mulched plots. This is due to the soil moisture levels being higher and land surfaces being smoother in the absence of cultivation (Sallaway et al. 1990, Freebairn and Wockner 1986).

Soil compaction can also inhibit infiltration. The wheels of tractors, harvesters and implements as well as the traffic of farm animals may cause compaction. Highest rates of compaction occur when soil is sheared or compressed when it is at the critical moisture content known as the ‘plastic limit’. The resultant soil has high strength but reduced porosity.

Severely eroded paddocks have a well-developed system of rills and gullies that rapidly generate runoff and deliver it to the lowest point in the paddock. A paddock protected with a contour bank and waterway system as well as retained stubble will have lower rates of runoff than an actively eroding paddock. Galletly (1980) noted the considerable runoff detention capacity of contour bank channels. Sallaway et al. (1989) found that contour bank systems may store more than half of the runoff from a 50 mm to 70 mm storm. This is especially so when the paddock is under crop or standing stubble which significantly delays the concentration. Under such circumstances, a short storm of high intensity may have ceased before the whole of a contour bay is contributing to the waterway. In urban and homestead areas, runoff volume and rate increases proportionally with the proportion of paved and roofed areas.

3.3 Peak discharge estimation

As discussed in the previous sections, the peak rate of runoff produced by a catchment is dependent on many variables. If peak runoff rates from a catchment have been measured over a long period of time, it would be possible to get a reasonable indication of the magnitude of the peak rates that could be expected for different ARIs from that catchment. However, such records don't exist for the small agricultural catchments that are the subject of most soil conservation designs. For this reason it is necessary to use a method that provides an estimate of the peak rate of flow taking selected catchment characteristics into account.

Methods of estimating runoff vary in complexity depending on the hydraulic processes they attempt to simulate. To fully simulate all runoff generation processes and relationships requires a high degree of expertise as well as sophisticated software and large amounts of data. Such resources are rarely available when designing soil conservation works so the methods used are generally greatly simplified. Ideally, the method used should be developed using data from the catchment for which the design is required or from similar catchments. If this is not possible, the next best approach is to use methods developed elsewhere but incorporating parameter values derived using local data.

There are a number of different methods that can be used to estimate runoff based on local hydrologic data. These include:

- Flood frequency analysis: the flood peak discharge record of a catchment is analysed to provide a direct estimate of the desired design flood for that catchment.
- Regional flood frequency models: these models use relationships developed between runoff data and characteristics of catchments in the region. This approach was used to develop a version of the Rational Method for use in small catchments in the Darling Downs (this model is described in Chapter 5).
- Runoff routing techniques: runoff is followed from its point of origin to the design point using models which represent the runoff processes using storage routing concepts with a series of conceptual storages. The output represents the direct runoff hydrograph at the design point (a hydrograph being a graph showing discharge plotted against time). Examples of runoff routing techniques include:
  - use of a single storage at the outlet, for example, synthetic unit hydrographs as described by Cordery and Webb (1974)
  - use of a network of storages, for example, models such as RORB (Laurenson and Mein 1988) and WBNM (Boyd et al. 1979)
  - use of the continuity and Manning equations as in the ANSWERS model of Beasley et. al. (1980).
- Application of differential equations of unsteady flow such as in the kinematic wave based model, KINCON (Connolly and Barton 1990) (this model is currently not available for commercial use).
- Water balance models: these predict the hydrologic behaviour of a catchment by continuously simulating water movement through the hydrologic cycle.

The great majority of soil conservation designs are for small catchments. a survey by the Department of Primary Industries in 1987 of soil conservation designs in the cropping area of the state (Table 3.2) shows that the majority were for catchments less than 50 ha in area (Stephens 1987). Similarly, Scarborough et al. (1992) found that some 70% to 80% of designs for the Coastal Burnett district are for catchments less than 50 ha in area.

Investment of large amounts of resources in collecting data for calibration and/or the use of sophisticated models is not warranted for such small catchments.

Table 3.2: Proportion of waterway designs carried out in catchments of different sizes in Queensland

Catchment size	0–20 ha	20–50 ha	50–200 ha	200–500 ha	500–1000 ha	>1000 ha
Percentage of designs	33%	30%	25%	9%	2%	1%

In Queensland, the Rational Method of runoff estimation is normally used for the small catchments involved in most soil conservation designs. More sophisticated methods may be occasionally used in the design of soil conservation works in catchments exceeding 1000 ha.

In the following chapters, two versions of the Rational Method are described—the Empirical version and the Darling Downs Flood Frequency (DDFF) version. The Empirical version is considered to be an arbitrary method because it is based on estimated parameters rather than measured hydrologic data. However it is the preferred option for the design of small catchments dominated by paddocks with contour banks. The Darling Downs Flood Frequency version of the Rational Method is considered to have limitations when applied to a contour-banked catchment. These limitations are discussed in detail in Chapter 5.

3.4 Designing for uncertainty

When designing a structure to carry or store runoff, it is necessary to consider how often it will be acceptable for the structure to fail or to surcharge (overtop the bank).

The following terms, which refer to either rainfall or runoff, are used when discussing probability or risk in designing soil conservation works:

- Average Recurrence Interval (ARI), also referred to as average return period, is the average number of years (denoted as y years) within which an event will be equalled or exceeded.
- Frequency is an alternative way of expressing ARI. If an event is described as having a frequency of 1 in y years it means that the event will be equalled or exceeded once in y years on average.
- Probability is the inverse of frequency, that is, 1/y. Probability is often expressed as percentage, this being 100/y %.

If an event has an ARI of 10 years, it means that during a 100 year period, that event will be expected, on average, to be equalled or exceeded 100/10 or 10 times. The frequency of that event is 1 in 10 years, its probability is 0.1 (1/10) and its percentage probability is 10%. This also means that there is a 10% probability of that event being equalled or exceeded in each and every year. Such an event may however occur more than once in any particular year.

It is important to understand that whatever terms are used, they all refer to long-term averages and that the periods between individual events are random. This means that, if an event with an ARI of 10 years occurred last year, the chances of a similar event occurring this year have not lengthened, they remain the same. In other words, there is still a 10% chance (or odds of 10 to 1) of the same event happening again in each successive year. This concept should be fully explained to clients for whom designs are prepared.

In designing soil conservation structures, runoff will be estimated only for very small areas such as a paddock or a small catchment on a farm. It is worth noting that extremely high rainfall events that are ‘off the scale’ of a rainfall intensity chart for that district may still occur in very localised areas. This means that it is likely that in any district, at the paddock scale, rare events such as those with an ARI of 100 years will occur somewhere in a catchment on a much more frequent basis than 1 in 100 years.

It is generally accepted that soil conservation structures should be designed for a runoff event with an ARI of 10 years. However, as discussed later in this chapter, this concept is somewhat theoretical when applied to soil conservation structures since their ability to accommodate runoff varies considerably with the season and the stage in the cropping cycle.

A larger ARI should be used when designing soil conservation structures in situations where failure might threaten public safety or cause severe damage, for example, some diversion banks and perched waterways. The largest ARI used for the design of soil conservation works is seldom more than 50 years. Conversely, on slopes below 1% where surcharging is unlikely to cause significant damage outside a waterway, designs with a lower ARI (e.g. 5 years) may be considered.

Structures should be designed for ‘average’ conditions. Some operators, to provide additional safety margins in their design, will use extreme values of the parameters in runoff estimation models. However, this results in runoff estimates with unknown ARIs and greatly inflates construction costs. If a more conservative design is required, it is better to design for a higher ARI.

3.4.1 Allowing for uncertainty in contour bank and waterway designs

Unlike rigid engineered structures, the physical dimensions of contour banks are constantly changing. Contour bank capacity declines over time as the bank height reduces due to natural settlement and tillage. Capacity is also reduced by deposition of sediment in the channel bottom. For this reason contour banks are normally built to exceed specifications initially so that they will have an effective life of 5 to 10 years before requiring maintenance. In reality, the size of a structure is most commonly determined by the construction technique used by a farmer rather than the theoretical specifications resulting from a design. For example, contour banks in some districts are constructed with one push of a large bulldozer which allows only limited finessing to accommodate details of the design.

For broad-based contour banks (see Chapter 7) 'failure' may involve only overtopping of the bank (surcharging). However, when narrow-based contour banks (see Chapter 7) surcharge, the force of the water may completely remove the bank at the point of failure. Contour banks (especially those that are narrow-based) will be susceptible to failure if conditions have been dry resulting in development of cracks across the bank or if animals have burrowed into and weakened the bank.

Failure of a contour bank may result in serious rill and gully erosion below the breakout and can lead to subsequent failure of lower contour banks. In the event of a failure, banks further downslope will suddenly be required to accommodate amounts of runoff well in excess of what they were designed for. The capacity of these downslope banks will already have been greatly reduced as a result of sediment deposition resulting from the failure of the above bank. The amount of damage that occurs at the time of bank failure is dependent on the amount of protection provided by crops or stubble and the soil tilth in the contour bay at the time of the event.

Runoff that escapes the confines of a waterway may cause erosion as it flows parallel to the waterway or flows away from waterways that are not situated in a natural drainage line.

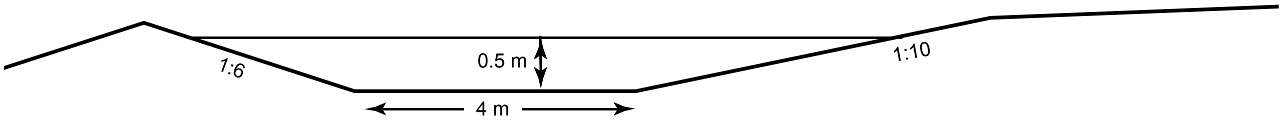
High variation in the condition of the channel of soil conservation structures adds an additional dimension of uncertainty to their design. Unlike structures made of concrete, the degree of 'roughness' in the channel of vegetated structures can vary greatly from time to time depending on the position in the cropping cycle (in the case of contour banks) or the season (in the case of waterways). This means that although a soil conservation structure may be designed to handle a 10 year ARI runoff event, its ability to handle such an event may be considerably impaired depending on the condition of the channel at the time of the event.

Figure 3.6 shows that a typically shaped contour bank with a smooth bare channel (Manning's roughness coefficient, n, of 0.03) can carry five times as much runoff as a channel with a wheat crop or stubble from a previously harvested crop which typically have roughness coefficients of around 0.15. This means that a contour bank designed to meet the required standard with a sparse grass cover will be able to handle well in excess of the design storm when the channel is bare. In other words, a bank will only be able to accommodate a runoff event with a much lower ARI if the channel flow is restricted by a crop or standing stubble whilst if the stubble in a contour bank channel is burnt, the bank will, within minutes, be able to handle an event with a much larger ARI.

Figure 3.6: Broad-based contour bank discharges for three levels of Manning's *n*

Manning's *n*	Predicted velocity m/sec	Predicted capacity m^3/sec
0.03 (bare cultivated channel)	0.72	2.9
0.05 (sparse grass cover)	0.43	1.7
0.15 (standing wheat stubble)	0.14	0.6

Parameters:
Broad-based contour bank with a trapezoidal shape
Bank batter 1:6 (V:H) and excavated batter 1:10 (V:H)
Bottom width of 4 m
Flow depth of 0.5 m
Gradient 0.2%



(Not to scale)

Considering the example in Figure 3.6, it would be reasonable to assume that contour banks should rarely surcharge when the contour bank channel is in a smooth and bare condition. In fact failures are common under these circumstances. Such failures can be attributed to 'weak links' at some points in the length of the contour bank. While a contour bank may have sufficient capacity along the great majority of its length, the flow it can carry is determined by the capacity of the bank at its weakest point.

A common site for contour bank failure is where contour banks cross old gully lines. At these points contour banks require additional height to provide the gully crossing and to account for additional settlement. Such 'crossings' are effectively very small dams that, will in time silt up. Compounding the risk of failure is that these points are likely to have a rill above them which will contribute additional sediment.

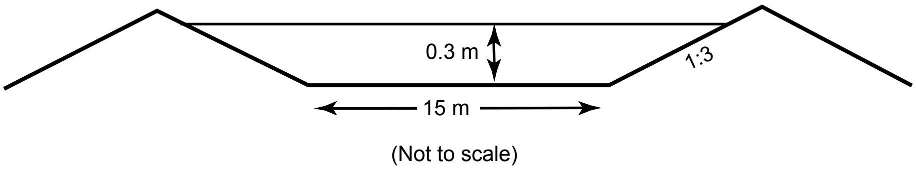
Research into measurement of soil loss in cropping areas has shown that the great majority of soil is lost as a result of a few large events. As contour banks are 'designed to fail' in an event with an ARI in excess of 10 years, it would be reasonable to assume that their effectiveness in reducing soil loss in a paddock must then be questioned. However, the data in Figure 3.6 indicates that well maintained contour banks are most likely to fail when contour bays and channels are under crop or stubble. In such cases, loss of soil from the cultivated area will be reduced by the effects of the cover in the contour bay. Contour bank breakages under bare fallow conditions are only likely if contour banks have been poorly maintained and have fallen below the recommended specifications. In such situations, sediment 'slugs' deposited in bank channels below eroding rills will contribute to contour bank failure.

The ability of a grassed waterway to accommodate runoff will be very dependent on the density and length of grass in the channel. This is illustrated in Figure 3.7. During a good season, grass growth may be prolific and may effectively choke the waterway resulting in reduced velocities and discharges. Conversely, if waterways are heavily grazed or burnt there will be very little retardance to flow from vegetation resulting in high (and erosive) velocities and high discharges. For this reason it is recommended that the permissible velocity used in the design should be based on the seasonal condition when retardance is expected to be least, whilst the design depth of the channel should be based on the expected flow for a higher retardance as expected in good seasons, or where waterways will not be grazed. Vegetative condition is also sensitive to management actions such as slashing or periodic grazing and whether or not fertiliser is used to promote vigorous growth for more effective erosion control.

Figure 3.7: Trapezoidal waterway discharges for three different levels of retardance

Retardance in waterway channel	Manning's *n*	Predicted velocity m/sec	Predicted discharge m^3/sec
High retardance (A) ›75 cm	0.3	0.2	1.0
Moderate retardance (C) 15–25 cm	0.04	1.5	7.3
Very low retardance (E) ‹5 cm	0.025	2.5	11.7

Parameters:
Bottom width of 15 m
Batters (V:H) 1:3
Depth of flow 0.3 m
Slope 2%



3.5 Further information

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Other information

The Bureau of Meteorology (bom.gov.au/water/designRainfalls) provides design rainfall data for nominated locations across Australia in the form of:

- Intensity–Frequency–Duration (IFD) information, which is used in the design of gutters, culverts, bridges and stormwater drains
- Probable Maximum Precipitation (PMP) estimates for the design of large dams and for use in floodplain management.

Technical information on how to interpret and apply this information is contained in:

Carey, Bruce (2014) A study guide on runoff processes. Accessed on Landcare Queensland website landcare.org.au/resources-links/achieving-soil-conservation-in-queensland on 16 August 2014.

Fact sheets on topics covered in this chapter are available from the Queensland Government (qld.gov.au/environment/land/soil).