



Chapter 5

Darling Downs regional flood frequency version of the Rational Method

Key points

- The peak flow resulting from a rainfall event falling in a catchment depends on the characteristics of both the event itself (such as intensity, duration, and location) and of the catchment (such as area, shape, slope, and land surface condition).
- The Rational Method is a set of formulae used to determine the peak flow expected from a soil conservation structure design, such as a contour bank. The Empirical version is a simplification of the full Rational Method which uses parameter values that are based on experience or observation.
- The Darling Downs flood frequency (DDFF) version of the Rational Method has been customised for use in soil conservation design for small non-contour-banked catchments in an area of southern Queensland.
- The application of the DDFF in soil conservation design is limited because it does not allow for different forms of land management and because it is restricted to a comparatively small region.

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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.

catchment response time (also referred to as catchment time of concentration): the shortest time necessary for all points within a catchment to contribute simultaneously to flow past a specified point. Reflects the physiographic characteristics of the catchment (including its shape, size, and landform).

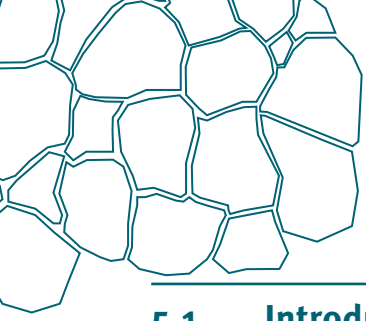
design peak runoff: the maximum flow calculated for a given set of hydrological conditions which is used in the design of a hydrologic structure that can cope with these conditions.

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

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

roughness coefficient: a measure of the retardance to flow in a channel; the greater the retardance, the higher the roughness coefficient. Normally expressed as Manning's n .

runoff coefficient: the C factor in the rational formula which equals the ratio of the rate of runoff to rainfall. It indicates the proportion of the rainfall rate that is actually contributing to the runoff and as such is always less than 1.0.



5.1 Introduction

The Darling Downs Regional Flood Frequency version (DDFF) of the Rational Method has been developed for runoff estimation in small catchments in the Darling Downs region. The DDFF is suitable where contour-banked land represents, at most, a small component of the catchment. However, for catchments dominated by contour banks, the Empirical version of the Rational Method as described in Chapter 4 should be used.

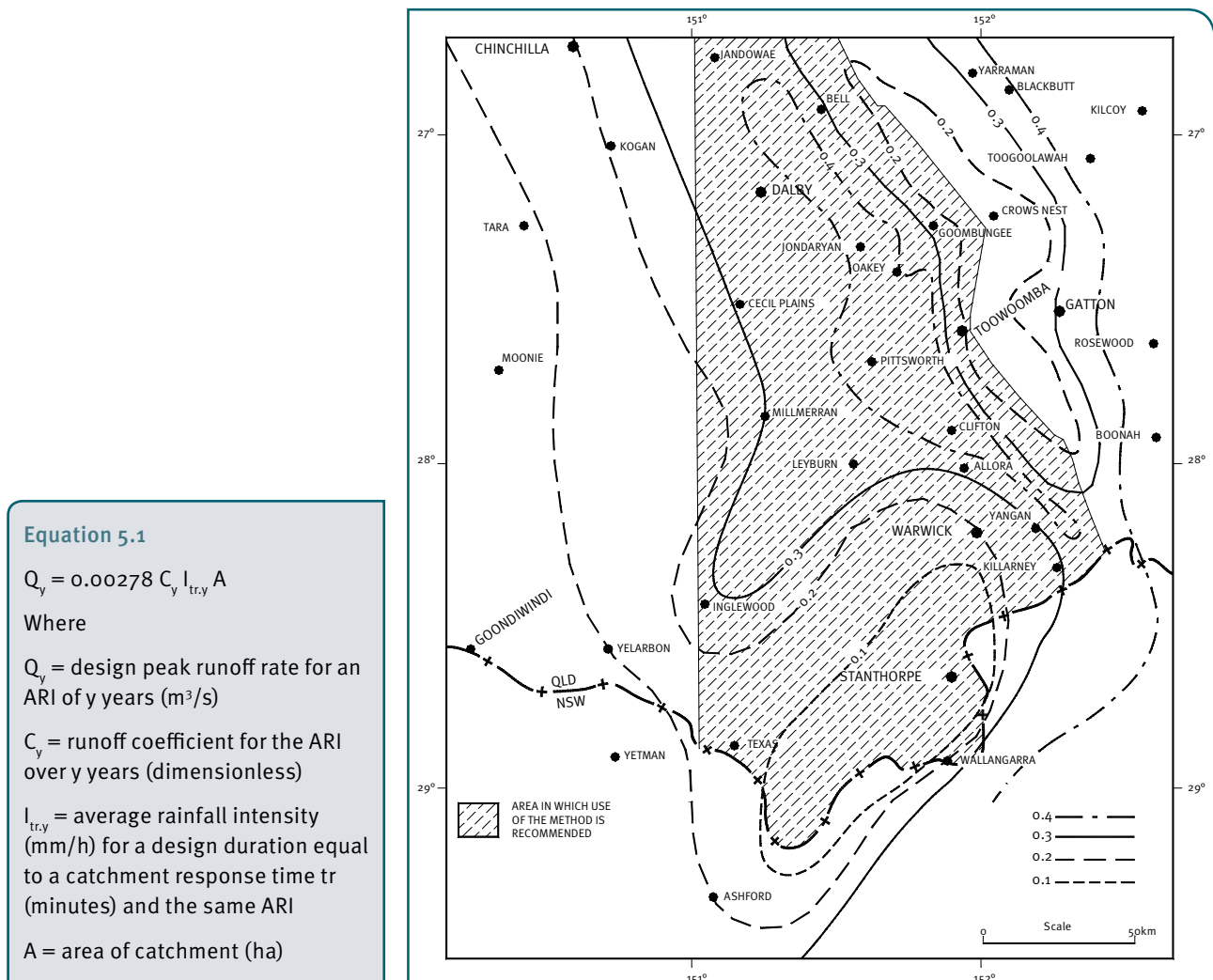
5.2 Description

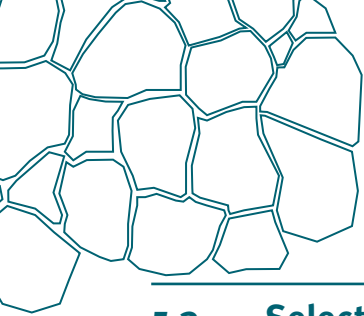
The DDF was developed by Geoff Titmarsh of the (then) Queensland Department of Primary Industries (Titmarsh 1989, 1994) using runoff data collected from calibrated catchments across the region. The DDF applies in an area bounded to the south by the Queensland/New South Wales border, to the west by the 151°E longitude, and to the north and east by the Great Dividing Range (Figure 5.1).

For other parts of Queensland there is insufficient runoff data to develop similar regional versions for small rural catchments. An attempt was made to develop a similar tool for the Burnett and Central Highlands regions around the same time as the DDF, however after all runoff data for catchments in those regions had been collated and examined it was not possible to derive a reliable relationship. This was because there were too few gauging stations, and the records for those that existed did not cover long enough periods of time. Similarly, whilst Weeks (1991) carried out a broadscale study of this type covering most of Queensland the data used in this work were very limited and were mainly captured from large catchments making that version unsuitable for designing soil conservation works.

The formula to calculate design peak runoff using the DDF version of the Rational Method is expressed in Equation 5.1

Figure 5.1: Runoff coefficients for the Darling Downs Flood Frequency version of the Rational Method





5.3 Selection of a runoff coefficient

Equation 5.2

$$C_{10} = 0.22 + 0.004 \Phi$$

Where

C_{10} = runoff coefficient for the 10 year ARI

Φ = percentage of catchment area cultivated.

Values for 10 year runoff coefficients (C_{10}) vary throughout the Darling Downs region as plotted on Figure 5.1. These runoff coefficients were found to also vary with the proportion of the catchment that is cultivated. If the catchment for which peak flows are being calculated using the DDFF contains a proportion of area cultivated, then C_{10} values should be determined using Equation 5.2 and Table 5.1. The higher of the two C_{10} values (from either Table 5.1 or Equation 5.2) should then be used for the design.

Table 5.1: C_{10} runoff coefficients for the DDFF version of the Rational Method based on percentage of cultivation in the catchment

Equation 5.3

$$C_y = FF_y C_{10}$$

Where

C_y = runoff coefficient for an ARI of y years

FF_y = frequency factor for an ARI of y years

C_{10} = runoff coefficient for the 10 year ARI.

Percentage cultivation	DDFF C_{10} value
10	0.3
20	0.3
30	0.3
40	0.4
50	0.4
60	0.5
70	0.5
80	0.5
90	0.6
100	0.6

Runoff coefficient values for ARIs other than 10 years can be estimated using Equation 5.3.

The average frequency factors for ARIs of 1, 2, 5, 10, and 20 years for use in Equation 5.3 are given in Table 5.2.

Table 5.2: Average frequency factors

ARI (years)	Average frequency factors (FF_y)
1	0.5
2	0.6
5	0.8
10	1.0
20	1.2

For example, if the C_{10} runoff coefficient was 0.4 then the C_{20} runoff coefficient would be determined as follows:

$$\begin{aligned} C_{20} &= FF_y C_{10} \\ &= 1.2 \times 0.4 \\ &= 0.48 \end{aligned}$$

5.4 Catchment response time

Titmarsh (1989) examined the influence of the characteristics of Darling Downs catchments on their hydraulic behaviour to derive an objective method of determining flow duration for use with intensity–frequency–duration (IFD) data—refer to Chapter 3 for IFD charts. He found that, for the catchments studied, the average time from the start of the runoff to the time of peak discharge for large events was a good measure of that catchment's response time. Further investigations indicated that the catchment area is the single most reliable indicator in estimating flow duration. Catchment area has the advantage of varying less with changes in map scale than other measurements such as stream length.

Equation 5.4

$$tr = 7.8 A^{0.36} \text{ minutes}$$

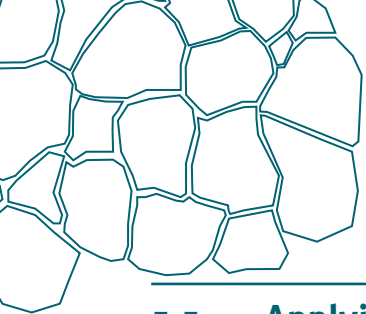
Where

tr = response time (minutes)

A = catchment area (ha)

The relationship used to calculate response time (tr) is expressed in Equation 5.4.

Note that this version of the Rational Method was developed using Pilgrim (1987). No other method of deriving a catchment response time or IFD data should be used with the C10 values shown in Table 5.1.



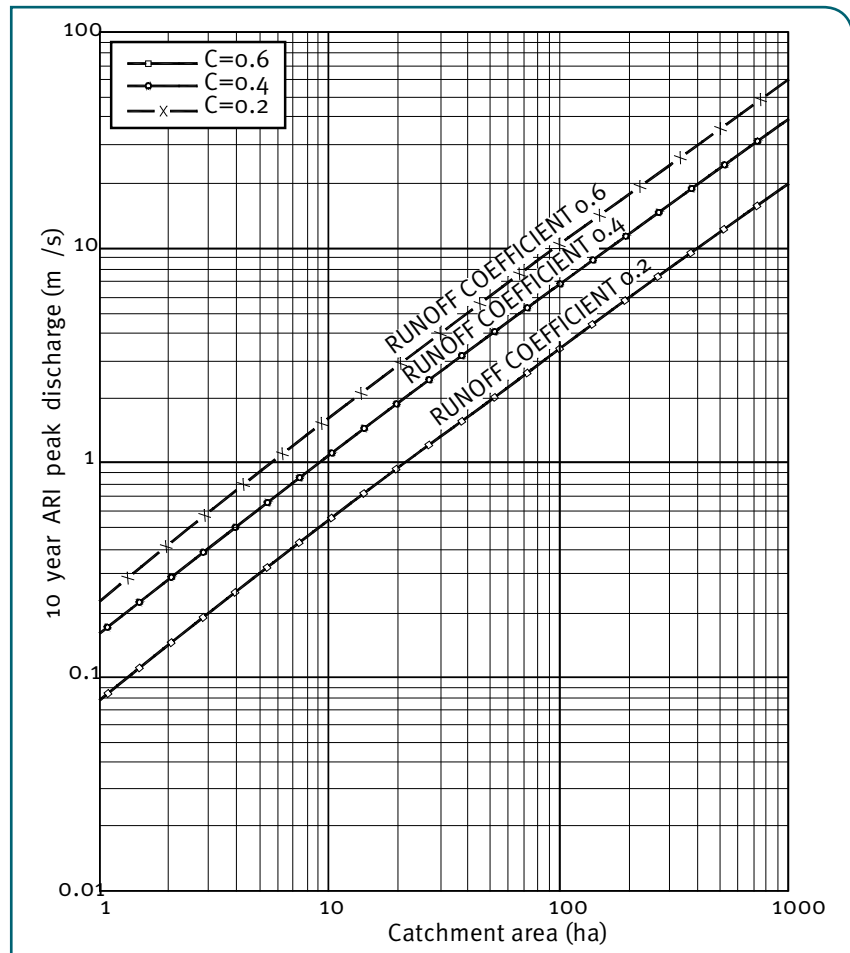
5.5 Applying the Darling Downs flood frequency version

The following procedure is used to determine the design peak discharge at a design point using the DDF:

1. Decide on the design ARI.
2. Measure the area of cultivation and total catchment area to the design point.
3. Calculate the percentage of the catchment that is cultivated.
4. Calculate the catchment response time using Equation 5.4.
5. From the IFD diagram for the district, determine the design rainfall intensity.
6. Determine a C_{10} value from Table 5.1.
7. Calculate C_{10} value using Equation 5.2.
8. Select the higher of the C_{10} values from steps 6 and 7.
9. For ARIs other than 10 years, calculate a C_y value using Equation 5.3 and Table 5.2.
10. Calculate the design peak discharge using Equation 5.1.

A further refinement of this procedure would be to use a district specific chart as shown in Figure 5.2. When using these charts, catchment area and runoff coefficient are the only variables required as inputs when determining the peak rate of runoff for a catchment in a specific district. It is not necessary to determine a rainfall intensity value when using such a chart as rainfall intensity is directly related to response time that is in turn directly related to catchment area.

Figure 5.2: Catchment area–peak discharge relationships for Oakey district



5.6 Worked example using the DDFF to calculate peak discharge

The task is to estimate the 10-year ARI peak discharge for a 120 ha catchment at Oakey assuming that 20 ha of the catchment is cultivated.

Step 1: Calculate a design rainfall duration (t_r) for the catchment using Equation 5.4.

$$\begin{aligned}T_r &= 7.8 A^{0.36} \\ &= 7.8 * 120^{0.36} \\ &= 44 \text{ minutes.}\end{aligned}$$

Step 2: Determine the rainfall intensity for Oakey for a 10 year ARI event of 44 minutes duration.

This is determined with reference to an IFD chart for the Oakey area to be 55 mm/h.

Step 3: Determine a C_{10} value for Oakey.

This is determined with reference to Figure 5.1 to be 0.4.

Step 4: Calculate the percentage of the catchment that is cultivated.

$$\begin{aligned}\Phi &= (20/120) * 100 \\ &= 17\%.\end{aligned}$$

Step 5: Calculate the C_{10} value using Equation 5.2.

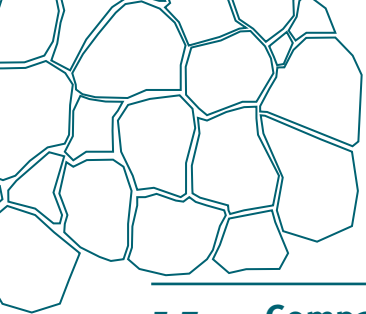
$$\begin{aligned}C_{10} &= 0.22 + 0.004 * 17 \\ &= 0.3.\end{aligned}$$

Step 6: Select the higher of the C_{10} values from steps 3 and 5.

$$C_{10} = 0.4.$$

Step 7: Calculate the design peak discharge using Equation 5.1 and the parameters determined from steps 2 and 6.

$$\begin{aligned}Q_{10} &= 0.00278 * 0.4 * 55 * 120 \\ &= 7.3 \text{ m}^3/\text{s}.\end{aligned}$$



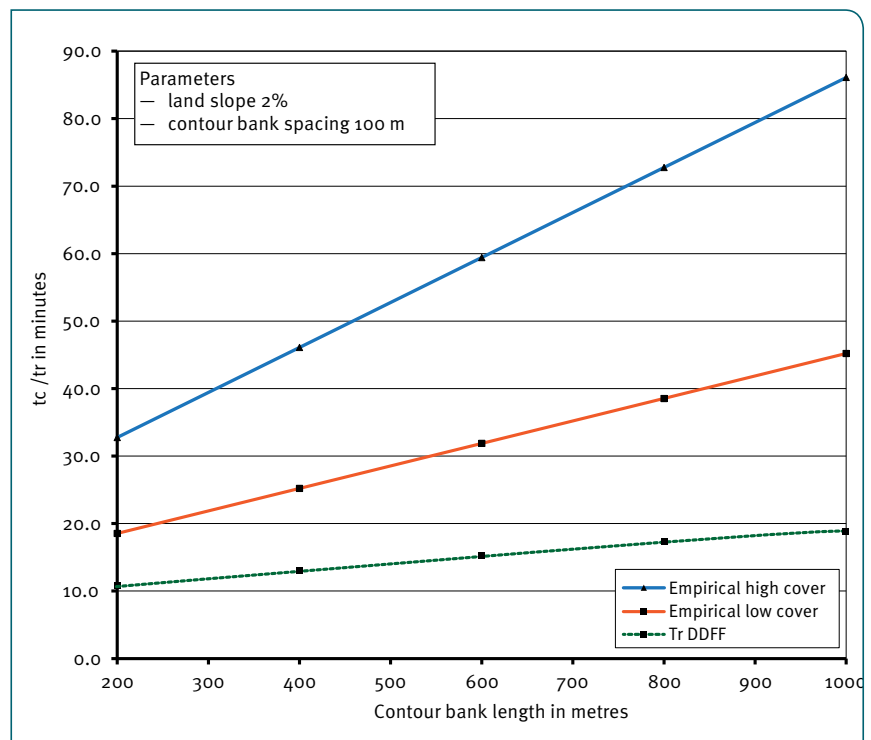
5.7 Comparing DDFF with the Empirical version of the Rational Method

When compared with the Empirical version of the Rational Method, DDFF has been found to consistently overestimate peak discharge for contour bays. Contour bays are an unnatural shape for a catchment. They are narrow and rectangular and are bounded by contour banks which unlike natural catchments have considerable capacity to store runoff. Contour channels also behave unnaturally in that they commonly carry a crop or standing stubble which can greatly retard runoff. The flow velocity of a channel vegetated in this way can be reduced to as little as 1/5th of that of an equivalent unvegetated channel.

Together the effects described in the previous paragraph mean that the discharge from a contour bay is greatly attenuated when compared with a natural catchment. The longer the contour bank, the more influential these effects will be and the greater the behaviour will diverge from that of equivalent natural catchments. When calculating the time of return the DDFF version uses only the gross area of the catchment, assuming that all catchments have similar proportional dimensions. Unlike the Empirical version, DDFF is therefore unable to take into account the effect that the particular shape of contour banks has in retarding flows as discussed above.

The limitations of DDFF are illustrated in Figure 5.3 which compares the time of response calculated using the DDFF method with time of concentration calculated using the Empirical version for a range of contour bank lengths and equivalent slope and bank spacing. The estimates derived using DDFF are consistently lower than those derived using the Empirical method for both high- and low-cover scenarios. It is considered that the time of concentration calculated using the Empirical version gives a better reflection of the effect of contour banks in reducing discharge rates than does the time of response value calculated using the DDFF method.

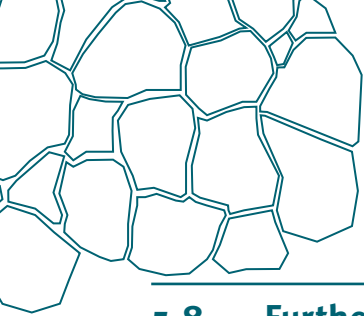
Figure 5.3: Comparison of times of concentration and time of response for a contour bay



Runoff coefficient values derived by inputting observed flood data into the DDFF version show no dependence on paddock characteristics such as soil type, slope or vegetation type and condition. It has been suggested that this is because most data used in estimating runoff is captured from catchments that are much larger than a single paddock. Under these circumstances variations in runoff behaviour between individual paddocks as a result of their different geographic characteristics are averaged out across the catchment. As previously discussed in Chapter 3, land management practices can have a significant effect on peak discharge at the paddock level. Even if the soil profile is saturated, stubble will retard overland flows and especially flow in contour bank channels.

As discussed in Chapter 4, the Empirical version allows for the effect of between-paddock variation in physical characteristics by adjusting the runoff coefficient. If the total area of a paddock is cultivated, as is the case in most soil conservation design tasks, the runoff coefficient used in the DDFF method will be 0.6 irrespective of soil type or land management. By comparison, the runoff coefficient value applied in the Empirical method under these same circumstances will range from 0.3 to 0.6 depending on the runoff potential of the landscape and the cropping system. Such values, whilst still only estimates, are a much better reflection of the actual situation occurring at the paddock level.

For the reasons outlined above, the DDFF version of the Rational Method should only be used when planning soil conservation works in small non-contour-banked catchments in the region indicated in Figure 5.1. DDFF may also give reasonable results for non-contour-banked catchments in other areas of Queensland that have comparable soils, topography, and rainfall intensities; however, the method cannot be recommended for areas outside of the region shown on Figure 5.1 at this time.



5.8 Further information

References

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Other information

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