# Chapter 3

# Runoff processes

To design a soil conservation structure, an estimate must first be made of the amount of runoff it will be required to carry. This requires an estimate of the *peak rate* of discharge usually expressed in cubic metres of runoff per second. An estimate of runoff *volumes* is not required unless a water storage structure such as a dam is being designed. This manual deals with estimates of peak rate of discharge.

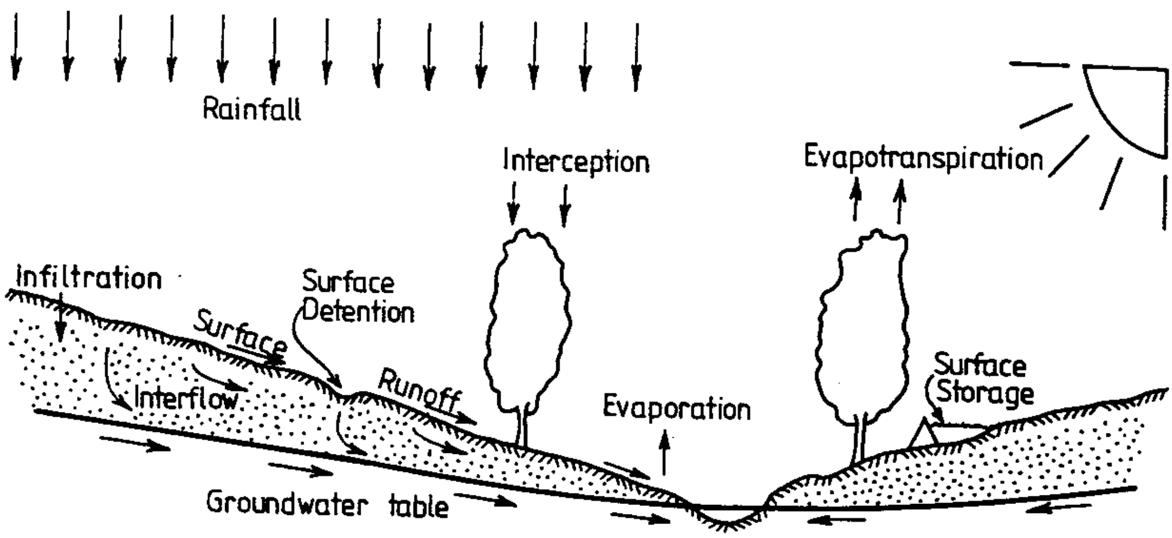
The majority of designs for soil conservation structures will be on catchments with areas less than 500 hectares. The methods described in this manual are satisfactory for catchments up to 2500 hectares in size. For larger catchments an alternative method of runoff estimation should be considered.

## 3.1 Factors affecting runoff

As the 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 it may 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 smaller than most people would expect. A study carried out at the Brigalow Research Station 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). Freebairn and Silburn (2004) reported that in southern Queensland, runoff occurs at the paddock scale on an average of 5 days a year, and significant soil movement about once every 2–4 years.

Figure 3.1 Hydrologic cycle




There are two sets of factors affecting the production of runoff:

- rainfall characteristics
- catchment characteristics.

### 3.11 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).

#### *3.111 Intensity*

With high rainfall intensities there is a greater likelihood for runoff to occur. Very high rainfall intensities can occur in the Queensland environment especially in areas closer to the coast. The highest rates of runoff and soil erosion usually occur during the summer months. 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 also contain short bursts of rain with high intensities.

Frequency distributions can be fitted to rainfall intensity/duration data to give an estimate of the probability of any intensity/duration combination occurring for any location. 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 3.2 gives an example of an IFD curve. Chapters 6 and 7 describe how IFD data is used to estimate peak rates of runoff for a specified return period.

Similar IFD curves can be obtained for any location in Australia. The curves may be purchased from the Bureau of Meteorology along with the necessary coefficients used to generate the curves. 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 as follows:

$$\mathbf{ln(i) = a + b(lnT) + c(lnT)^2 + d(lnT)^3 + e(lnT)^4 + f(lnT)^5 + g(lnT)^6} \quad \text{..............................Equation 3.1}$$

Where

ln = natural logarithm
i = intensity in mm/hr
T = time in hours
a, b, c, d, e, f and g are coefficients

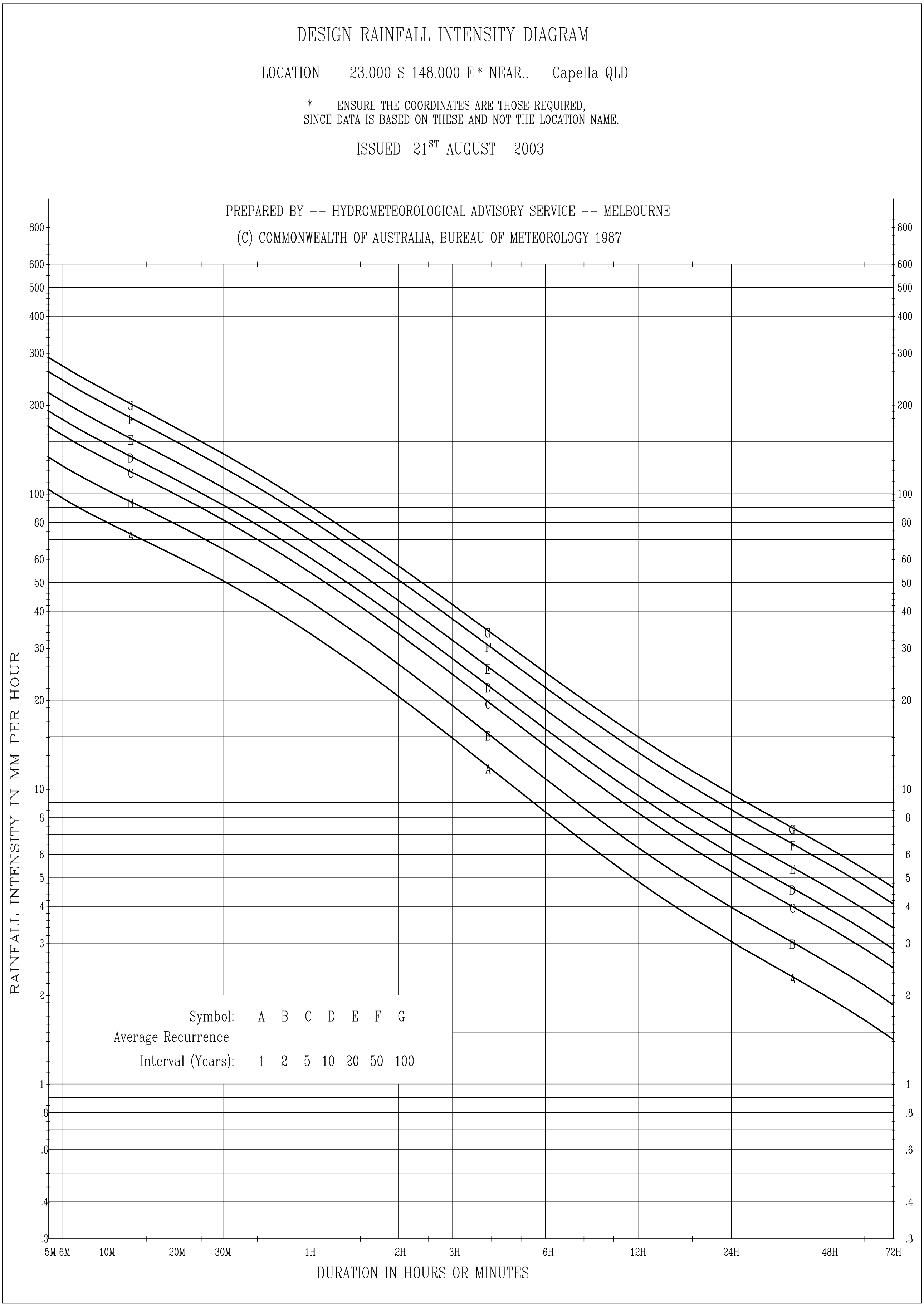
An example of the coefficients for a selection of return periods for the IFD curves in Figure 3.2 is shown in Table 3.1.

Table 3.1 Examples of coefficients for use in calculating rainfall intensities for selected ARI's for Capella

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

Source: Bureau of Meteorology

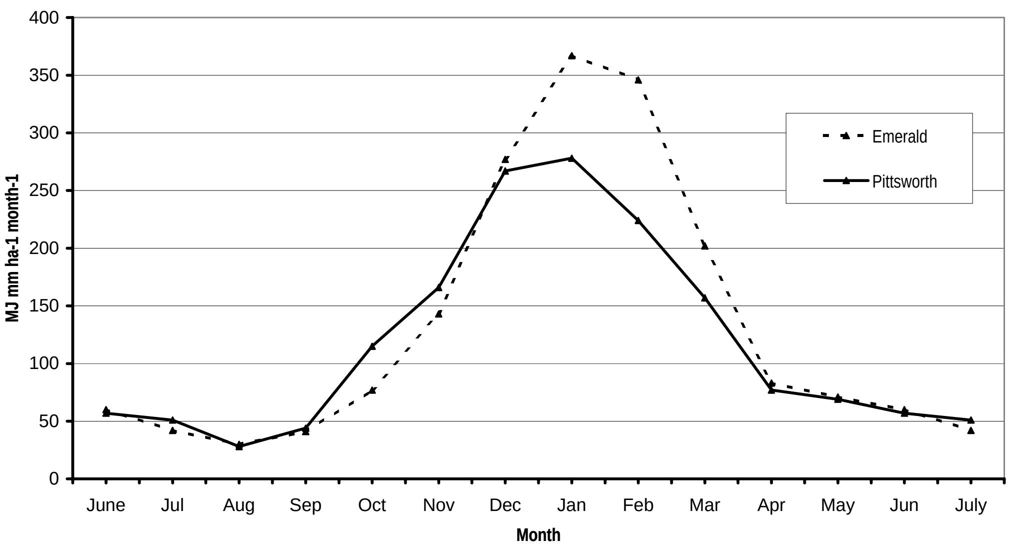
Figure 3.2 Rainfall intensity-frequency-duration curves for the location 23º S, 148º E near Capella as prepared by the Bureau of Meteorology



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 location that is representative of the district. However where average annual rainfall totals change significantly, then separate charts should be used for different rainfall zones. Areas where changes can occur over a short distance include the Gold Coast hinterland and areas between Cairns and Ingham.

Rainfall intensity is closely related to rainfall erosivity, which takes into account the combined effects of rainfall quantity and its kinetic energy. In most areas of Queensland, rainfall erosivity peaks in January–February and reaches a low point in August–September. Values of rainfall erosivity for specific centres are used in programs such as SOILLOSS (Rosewell 2001) which estimate rates of soil loss based on the Universal Soil Loss equation. Erosivity values for centres throughout Queensland are available in Rosenthal and White (1980). Figure 3.3 provides monthly rainfall erosivity values for Emerald and Pittsworth.

Figure 3.3 Monthly rainfall erosivity values for Emerald and Pittsworth




### *3.112 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 losses to be satisfied and more runoff to be produced. The discharge increases as losses are satisfied, until an equilibrium is reached, after which the peak discharge rate remains constant.

### *3.113 Spatial distribution*

The variation of rainfall intensity and depth across a catchment is referred to as *spatial distribution*. A storm spread evenly across an entire catchment will yield runoff of a different magnitude compared to the runoff produced if the same volume of rainfall fell in only parts of that catchment. Similarly, runoff events will differ depending on where storms occur on a catchment. 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 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 of the more complex runoff estimation models, an allowance can be made for spatial distribution. This is especially important in flood forecasting exercises, but when carrying out designs for soil conservation structures, it is generally assumed that the rain occurs evenly across the catchment.

#### *3.114 Temporal distribution*

Variation in intensity over time during a rainfall event is referred to as *temporal distribution*. The graphical representation of rainfall depth over time is called an hyetograph. A rainfall event with a large proportion of its volume at the start may produce a runoff event of different magnitude than if the same proportion occurred at the end or some other part of 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 Interval (ARI's) (1 to 100 years), (Pilgrim 1987). Again, the more complex runoff estimation models use temporal patterns as part of their input data, both in design and flood forecasting exercises. The runoff estimation methods described in this manual assume that rainfall intensities are constant for the duration of the event.

### 3.12 Catchment characteristics

There are a number of physical characteristics of catchments that affect the amount and/or rate of runoff they generate. Some of these characteristics vary with the season and the type of management practices used. The impact of an individual characteristic depends on the size and shape of the catchment. 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. 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.

#### *3.121 Area and shape*

In general, the volume and peak rate of runoff increases with catchment area. However, 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 area. In the longer catchment, it takes more time for the runoff from the most remote part of the catchment to reach the outlet.

Contour bays represent an unnatural shape for a catchment. They have a relatively short length of overland flow with a contour bank that acts as a long detention basin 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.

#### *3.122 Topography*

Catchments with low sloping terrain generally have a lower peak rate of runoff than those with steep terrain. This is because it takes longer for runoff to travel over lower sloping surfaces and the peak discharge will be both reduced and delayed. However, steep watercourses will often have a higher roughness which may offset any increase in flow velocity due to the higher slope.

#### *3.123 Soil conditions*

The rate of infiltration of rainfall into the soil affects the amount and rate of runoff. Infiltration rates vary with soil type. Soils with high infiltration rates include deep sands and ferrosols (krasnozems). 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. 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. Houghton and Charman (1986) describes three permeability rates as follows:

- slowly permeable – less than 10 mm per day
- moderately permeable – 10 mm to 1000 mm per day
- highly permeable – more than 1000 mm per day.

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

The amount of infiltration also depends on the antecedent moisture content of the soil. Catchments in a dry condition can absorb more rainfall then wet catchments before runoff commences. Major flood events (and soil erosion) can occur when heavy rain falls on an already wet catchment.

### *3.124 Storage*

Runoff can be stored in depressions in the land surface, reducing the amount of surface runoff. Examples include roughly ploughed paddocks, hoof prints, melonholes or gilgais, sediment traps, dams, and wetlands. Some implements create storage in an attempt to encourage better utilisation of rainfall eg. tied-ridging implements. 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.

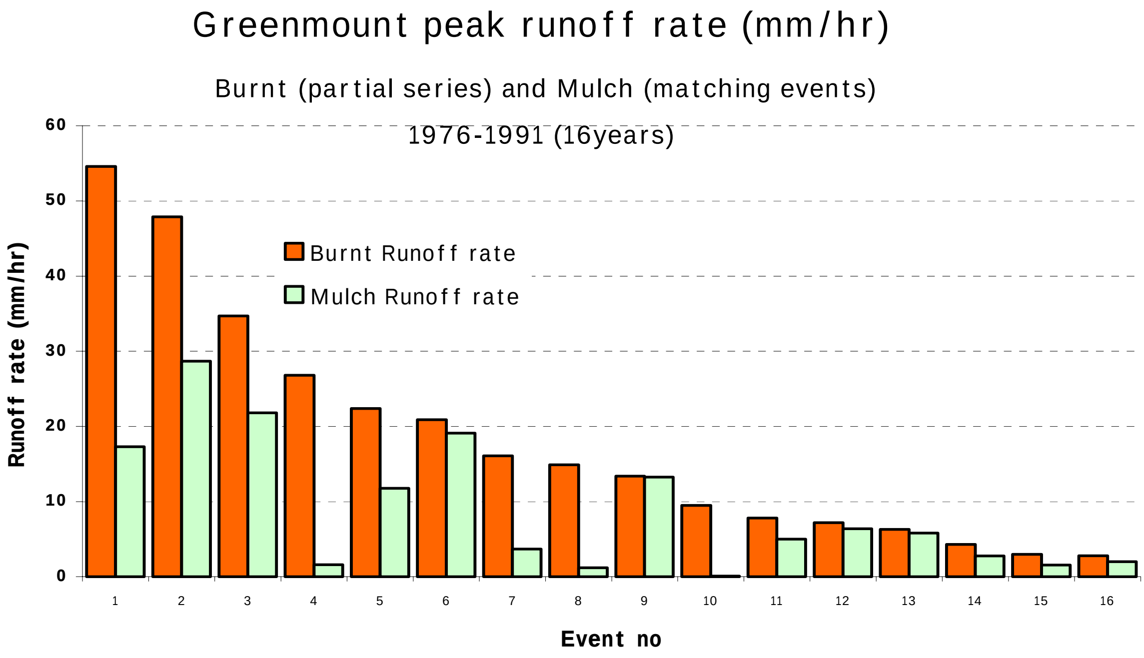
Contour banks can provide significant temporary storage. Contour banks of the same height will have much greater capacity on lower slopes than higher slopes because of the greater amounts of runoff stored behind the bank. Contour banks on lower slopes will also have lower gradients, which further increases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

### *3.125 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 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. The mean annual runoff for another catchment increased from 23 mm to 47 mm when the land use changed from forest to pasture.

The effect of soil surface management is also important. 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 maintain higher infiltration rates by reducing soil aggregate breakdown and surface sealing and it has an impeding effect on overland flows. Figure 3.4 shows peak runoff rates measured from two treatments in a paddock at Greenmount on the Darling Downs from 1976 to 1991. The peak runoff rates from treatments with high levels of surface cover were significantly lower than the rates from treatments with bare fallows in most years. There was a smaller difference in treatment effects when the storm event occurred late in the fallow (eg. 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 3.4 Peak runoff rates for the 16 largest events recorded at the Greenmount trial between 1976 and 1991




It is generally accepted that a minimum level of 30% stubble cover is required to provide a reasonable level of protection from erosion. Higher levels of cover will increase the protection provided. In drought conditions, crops may not be planted and cover levels will be minimal. This is more likely to happen in more 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 because of small properties and limited opportunities to adopt new technology.

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

Soil compaction can also inhibit infiltration. The wheels of tractors, harvesters and implements as well as farm animals may induce compaction. Highest rates of compaction occur when soil is sheared or compressed at the critical moisture content known as the 'plastic limit'. The result is high soil strength and 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 stubble retention practices will have lower rates of runoff than an actively eroding paddock. Contour bank systems may store more than 50% of the runoff from a 50 mm to 70 mm storm (Sallaway *et al.* 1989). Galletly (1980) also referred to the considerable runoff detention capacity of contour bank channels. This is especially so when the paddock is under crop or standing stubble which significantly increase the time of concentration. 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. ■