CHAPTER 2

RAINFALL AND RUNOFF

THE HYDROLOGICAL CYCLE

Precipitation, abstraction, runoff and evaporation comprise basic components of the hydrological cycle. In order to understand the runoff process it is necessary to appreciate the factors affecting it. Precipitation, in the form of rain, snow, hail, or surface condensation does not all find its way into stormwater drains. Much of it either evaporates, is absorbed or is retained on the surface on which it falls. Even then, the rate at which runoff occurs depends not only on the rate of precipitation, but also on the surface configuration, and the depth-discharge relationship.

Rainfall is not as a rule uniform in time. The rate of precipitation varies in time and over a catchment. Wind plays an important effect in bringing in the moisture which has evaporated from exposed waters or transpired from surfaces. Wind causes clouds to travel across the catchment. Precipitation will result if the temperature of the clouds of water vapour drops below dew point. Condensation is followed by precipitation. The cooling action may be caused by rising air; against mountains (orographic precipitation) due to cold fronts (frontal or cyclonic precipitation) or due to thermal currents (convectional precipitation). The latter gives rise to thunderstorms, an intense form of precipitation but often of relatively short duration, i.e. over a few minutes or hours.

Snow, sleet and hail will also give rise to runoff. The necessary surface holding and drainage systems are important, but beyond the scope of this work.

The cycle of evaporation, cloud movement, precipitation and runoff are illustrated in Fig. 2.1.

There are so many variables influencing solar radiation and atmospheric movements that the process can be regarded as somewhat random from the point of view of the engineer. In fact the engineer will never know at design stage what the maximum flow through his storm drains will be. He can only estimate likely flows from an analysis of past data. He does however have an influence on the runoff process, by

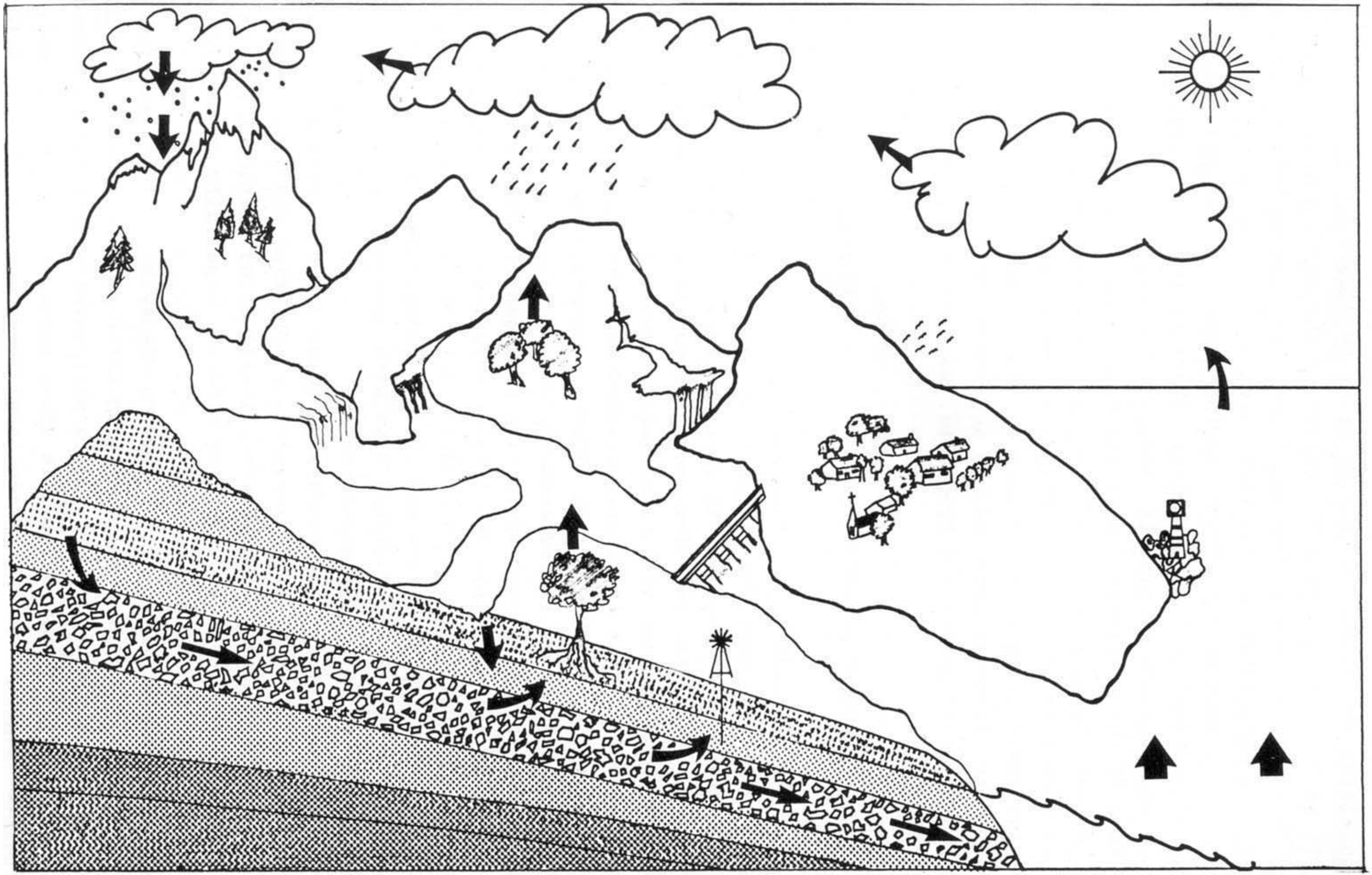


Fig. 2.1 The Hydrological Cycle

channelling the water, by storing it or by diverting it.

If we bear in mind that 71 percent of the earth's surface is covered by water, we realize how easily moisture can be brought inland to result in precipitation. Yet there are forces of nature controlling the system, such as the earth's surface drag on winds and limits to the moisture content in the atmosphere. There is therefore some physical limit to the maximum rainfall intensity one can expect.

Much of the precipitation on the earth's surface infiltrates into the ground. In fact 98% of all the earth's fresh water (excluding ice caps) occurs as groundwater. This water moves slowly through aquifers towards lower lying rivers, lakes or seas, gradually receding in times of drought. It rises again as the aquifer is replenished by rain. Some ground water is abstracted by plants. Most of this is lost by transpiration.

RAINFALL INTENSITY AND DURATION

Historic records of rainfall are seldom as detailed as would be desired by the engineer. He can only use samples to estimate a true rainfall pattern. From the data he must estimate intensity, duration and frequency of storms. Very few countries maintain continuous storm records for the purpose of determining time variation of precipitation during storms. It is frequently assumed that the rate of precipitation is uniform i.e. the hyetograph (graph of rainfall rate versus time) is square-topped. In fact storms may vary in time increasing in intensity starting from a drizzle, and subsequently recede. In such cases it is difficult to define the 'storm' duration or intensity. Storm intensity is given in m/s in S.I. units or more realistically in mm/h. Thus the starting point and end of a storm are subjective as well as the 'intensity'. Thus tabulated data with average rainfall intensities should be used with circumspection.

Theory indicates that rainfall patterns could be affected by urbanization. Radiation from the ground, air pollution and wind speeds are different from rural circumstances. Verification of the effects is hampered by the very causes of the effects, especially in the assessment of radar measurements.

Analysis of storms on a worldwide basis by Bell (1969) has revealed similarities in relationships between total precipitation, storm duration and frequency. He preferred to plot total precipitation over different storm durations rather than storm intensity, as mean intensity is misleading. It varies considerably during a storm. He also selected the partial series rather than annual series in evaluating frequency. That is, some years may contain more than one high storm used in the analysis while other years may have none.

Storm data from the United States, Australia, South Africa and other countries were plotted by Bell. The data covered storm duration between five minutes and two hours, and recurrence intervals from 2 to 100 years. He found the following equation predicted precipitation depth in each case with remarkable accuracy:

$$P_T^t = (0.21\ \ell n\ T+0.52)\ (0.54t^{0.25}-0.50)P_{10}^{60} \tag{2.1}$$

where P_T^t is the rainfall depth over t minutes which is exceeded with a T-year recurrence interval. P_{10}^{60} is the one-hour precipitation for a 10 year recurrence interval. The units of P can be inches or millimetres as long as they are consistent. Thus provided the precipitation over any one duration and recurrence interval are known others can be established. In fact Bell indicated P_{10}^{60} could be evaluated from empirical relationships as follows:

$$P_{10}^{60} = 0.27MN^{0.33}\quad (0<M<50) \qquad \text{and} \tag{2.2a}$$

$$P_{10}^{60} = 0.97M^{0.67}N^{0.33}\quad (50<M<115) \tag{2.2b}$$

where P is the 1-hour, 10-year rainfall in millimetres, M is the mean of the maximum annual observational-day precipitation in millimetres, and N is the mean annual number of rainfall days, $(1<N<80)$.

In general precipitation is more intense the shorter the duration of a storm. Thus short storm rainfall rates as high as 30 mm per minute have been recorded in India, whereas continuous rainfall rates of 30 mm per hour are more typical of European conditions.

Relationships between rainfall intensity and duration are of prime interest to the engineer, who must select a design storm duration if it affects the intensity. The relationship between intensity and duration is usually plotted in the form of Fig. 2.2 on a regional basis for different recurrence intervals. This form may be misleading as intensity implies uniform intensity which may not be the case. Total depth of precipitation (Fig. 2.3) may be a better ordinate.

Frequency analysis is done separately as outlined later, in order to yield intensities for selected frequencies. Yarnall (1935) and others have plotted rainfall intensity maps for a country. Such data can readily be employed to prepare co-axial plots.

The frequency with which precipitation exceeds any particular rate is of concern to the engineer. He will design his drainage system against a certain risk of failure. Rainfall data may be ranked and

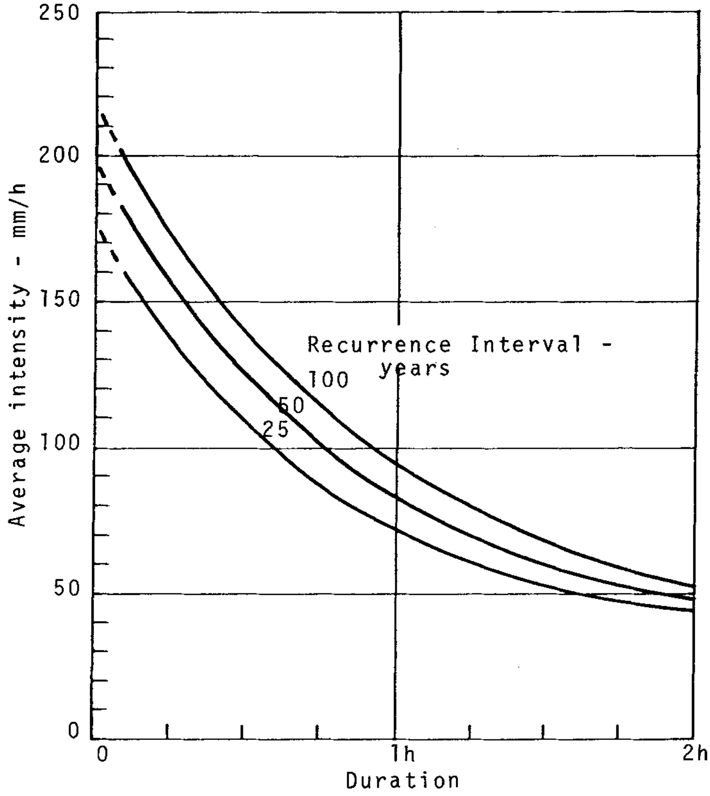


Fig. 2.2 Average Rain Intensity - Duration - Frequency Relationship for Jan Smuts Raingauge

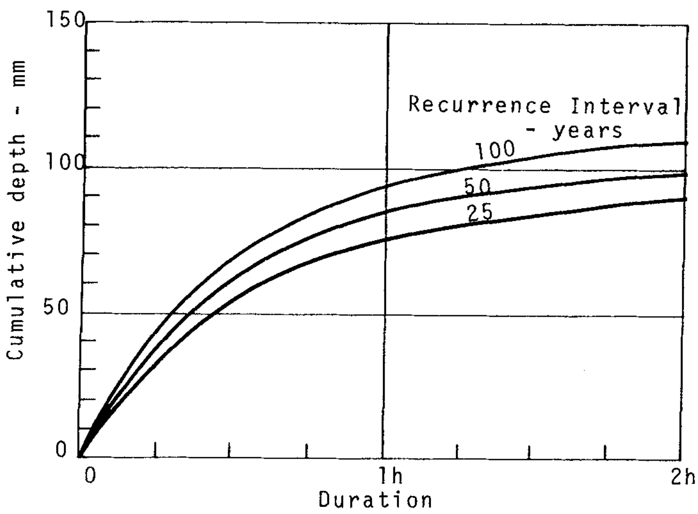


Fig. 2.3 Depth - Duration - Frequency relationship for Jan Smuts Rainguage

the average return period, or recurrence interval, of storms indicated for specific values. Recurrence interval is the average interval between events equal to or greater than the event in question. It is the inverse of the probability of exceedance. The hydrologist may have to rank the data and establish the frequency distribution by interpolation and extrapolation using an assumed probability distribution such as extreme value. Methods of assessing the recurrence interval of storm intensities, and deciding on the risk to take in designing a drainage system, are discussed in a later chapter.

SPATIAL DISTRIBUTION

The intensity of rain varies over a catchment especially in the case of convection-type storms. When studying large catchments it is thus not necessary to assume peak intensity at each point on the surface. Not only may storms have a focus and be represented by contours of equal precipitation (isohyets), but they may also move across a catchment. A numerical analysis of the effect of spatial variation in entensity, and the effect of storm movement, on peak runoff, is presented in the chapter on numerical methods for kinematic flow.

In order to assess the average rainfall over large areas, a weighted average of all the appropriate rain guages in the catchment may be made. Thiessen (1911) proposed the catchment be divided into polygons (Fig. 2.4). Each inner side of a polygon is midway between two rain guages and perpendicular to the line joining them. The polygon thus formed around each guage is taken as the area within which the relevant rain falls.

Another method is to draw isohyets (lines of equal precipitation depth) over the catchment (e.g. Fig. 2.5). Then the areas between isohyets are multiplied by the average rainfall between those isohyets to obtain a total precipitation volume.

For small urban areas e.g. roofs and lots, a uniform intensity may be assumed to fall over the entire catchment, and movement of the storm may be disregarded. For successively larger catchments, a correction may be applied to reduce the average intensity over the catchment when data used are observations from isolated rain guages. Fig. 2.6 was proposed by the Floods Steering Committee for correcting point rain intensity as a function of catchment area and storm duration for England. The factors also vary with climate, season and topography as indicated by Viessman et al. (1972).

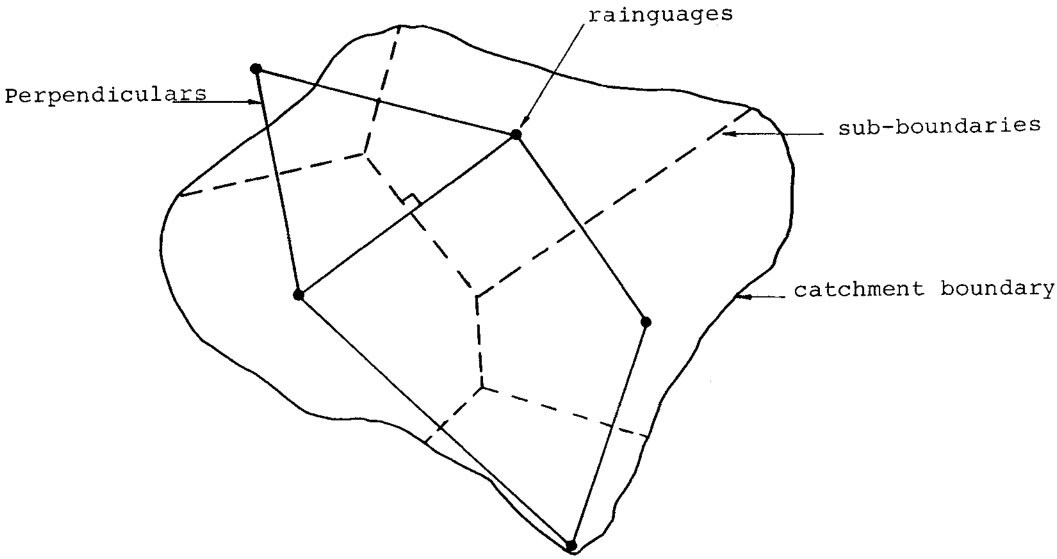


Fig. 2.4 Thiessen Polygons for averaging rainfall over a catchment.

TIME DISTRIBUTION

The assumption of a uniform rate of storm precipitation suffers a number of shortcomings as listed below:

i) Peak runoff from a storm of uniform intensity is likely to be less than that for a storm of the same average intensity but varying in time, especially if it reaches peak towards the end of its duration.

ii) Since there are initial losses, the antecedent rainfall and the rain during the beginning of the storm is likely to be used in filling depression storage and other losses. For this reason too, a storm which peaks at the beginning of its duration is therefore likely to result in a smaller peak runoff than one which peaks later.

iii) Whatever storm intensity-duration relationship is adopted, a different storm duration must be employed in designing storm

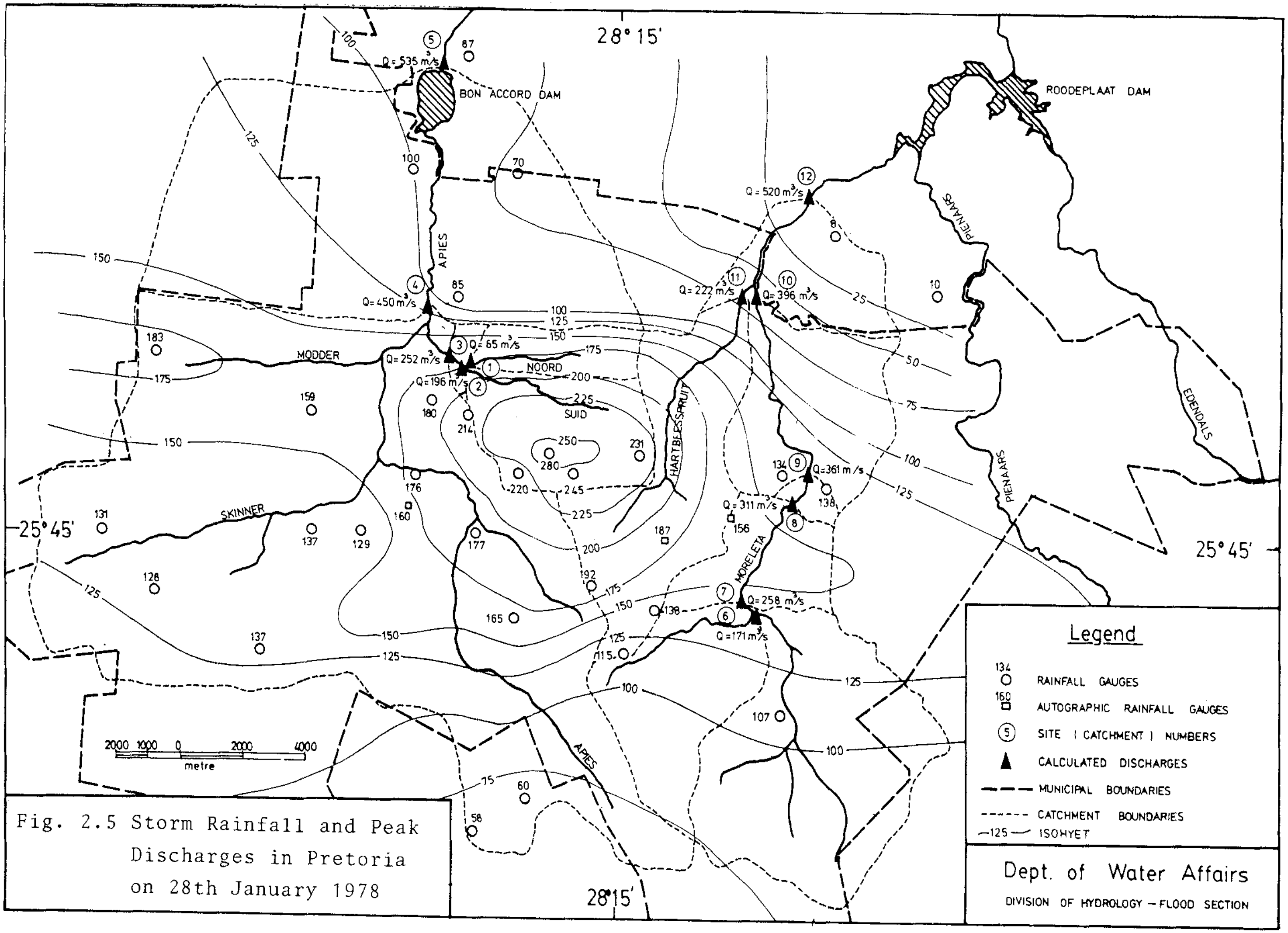
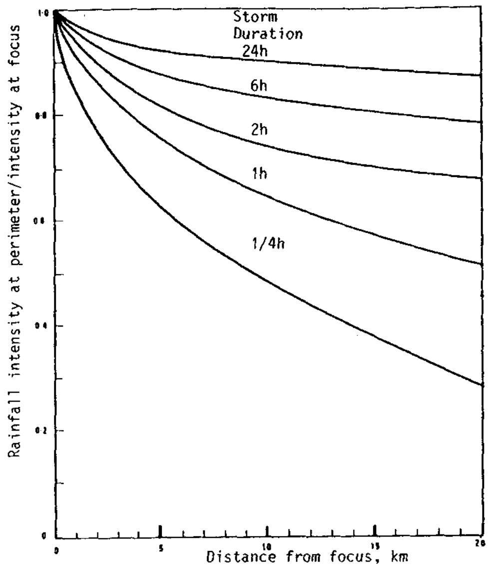
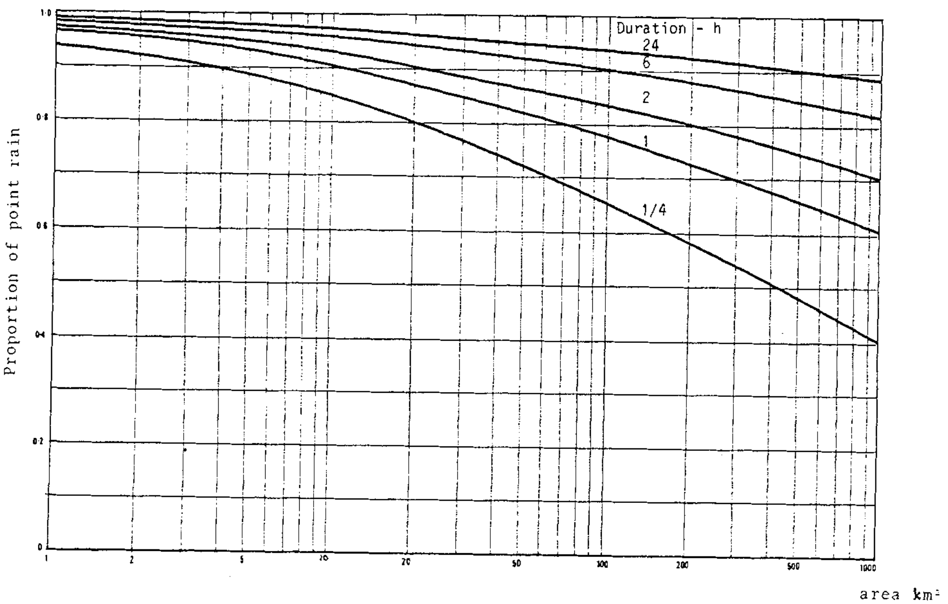


Fig. 2.5 Storm Rainfall and Peak Discharges in Pretoria on 28th January 1978



a. Storm profile across catchment



b. Areal reduction factor

Fig. 2.6 Reduction factors for non-point rainfall drains for each different size catchment. In fact the design storm duration should equal the concentration time of the catchment for uniform storms and maximum runoff for any selected frequency.

Analysis of storm data in the United States by Huff (1976) indicates a high proportion of a storm occurs in the first part of the storm. He categorized storms by the quartile of the duration in which the bulk of the rain fell. Fig. 2.7 indicates the distribution of precipitation for a 'first quartile' storm.

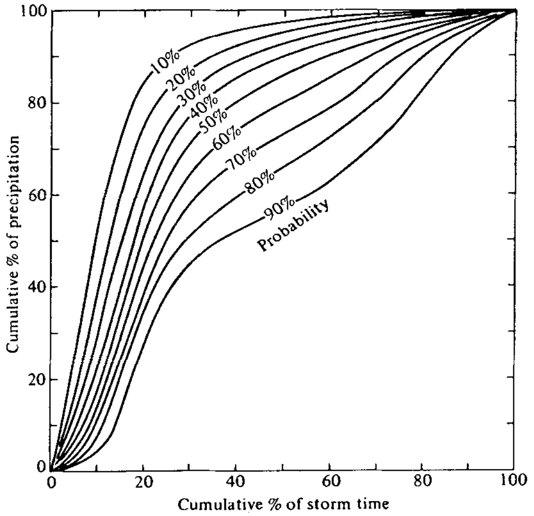


Fig. 2.7: Time distribution of first quartile storms. (After Huff, 1967)

Further analysis indicated storm patterns for differing severity. Thus 90% probability implies that 90% of storms will be more severe than that distribution i.e. will have a greater proportion occuring in the first quartile of the duration.

Chicago-type Synthetic Storm

Keifer and Chu (1957) developed a synthetic hyetograph for stormwater studies in Chicago. They proposed that a hyetograph could be developed which would have the same average intensity as a uniform storm, but it could peak at a chosen time such that the antecedent moisture conditions prior to the peak were such that they result in maximum runoff intensity. The shape of the hyetograph is also such that the average intensity is correct for any storm duration i.e. one hyetograph is sufficient to define any storm.

It is necessary to start with an empirical relationship for average storm intensity versus duration (for any chosen frequency) such as

$$i_a = \frac{a}{(b+t_d)^c} \tag{2.3}$$

where i_a is the average intensity of a storm of duration t_d and a, b and c are constants.
The total precipitation for a storm of duration t_d is:

$$p = i_a t_d = \frac{a t_d}{(b+t_d)^c} \tag{2.4}$$

Hence instantaneous rainfall rate at time t is

$$i = \frac{dp}{dt} = \frac{a[(1-c)t+b]}{(t+b)^{c+1}} \tag{2.5}$$

This is the equation of a hyetograph with the same average rate of rainfall as given by the intensity-duration curve for any storm duration. The peak rain intensity occurs at the start of the storm, however, which may be unrealistic.

The hyetograph is therefore re-adjusted to peak at some proportion r of its duration after the start. Thus if storm duration

$$t = t_b + t_a \tag{2.6}$$

where t_b is the duration of precipitation before the peak and t_a the duration after the peak,

then $$t = \frac{t_b}{r} = \frac{t_a}{1-r} \tag{2.7}$$

so $$i_b = \frac{a[(1-c)t_b/r+b]}{[(t_b/r)+b]^{c+1}} \tag{2.8}$$

and $$i_a = \frac{a[(1-c)t_a/(1-r)+b]}{[t_a/(1-r)+b]^{c+1}} \tag{2.9}$$

One thus has a synthetic hyetograph which peaks at time rt. The hyetograph will have the same average intensity as the intensity-duration curve indicates for any storm duration. Fig. 2.8 illustrates the resulting hyetograph shape. The correct value of r to use must be determined for anticipated local antecedent moisture conditions. A figure for r of 0.375 was found applicable in Chicago.

The value of the technique lies in the fact that only one hyetograph is needed to obtain design flows for any point in a drainage system.

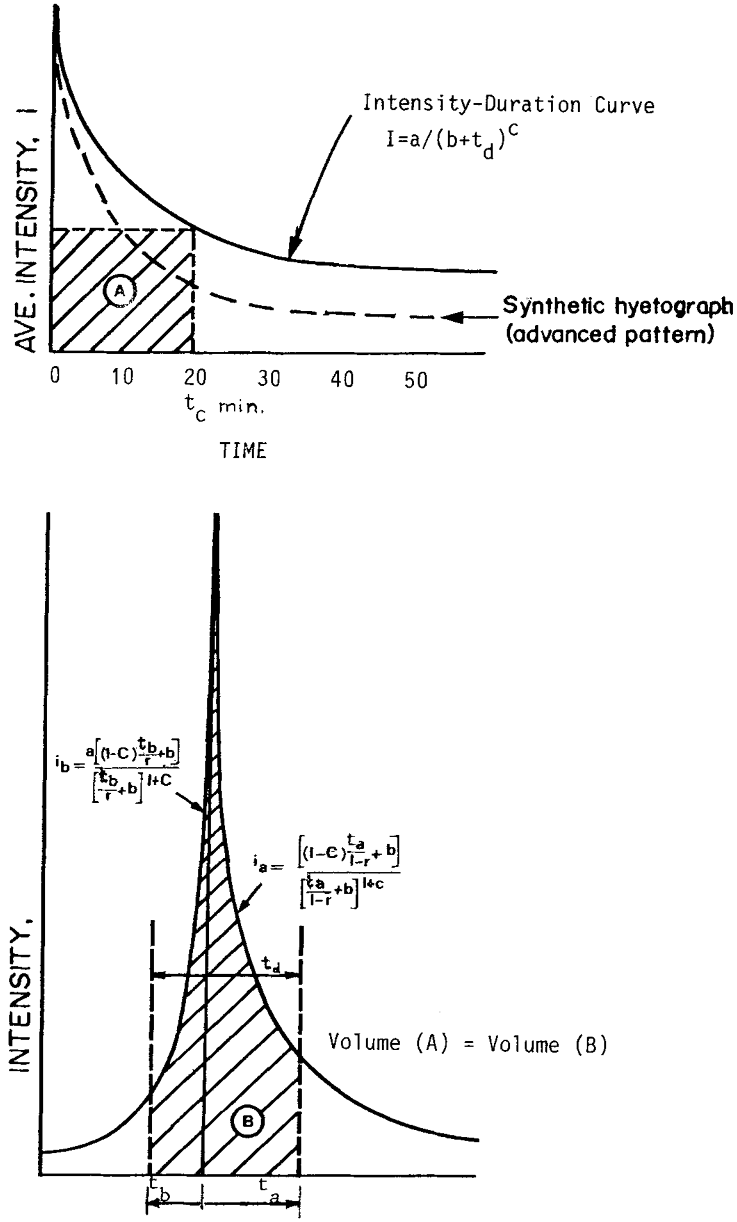


Fig. 2.8 Chicago design storm

Provided one knows the concentration time to the point at which a hydrograph is required, the mean storm intensity is correctly obtained from (2.9). The hyetograph is definitely non-uniform, but whether it represents a real rainfall pattern in all cases is doubtfull.

ABSTRACTIONS AND LOSSES

Much of the water in the form of precipitation which reaches the ground does not run off. It is lost immediately or as it runs off overland and down streams. The water may be lost irretrievably such as by evaporation or transpiration, it may return to the stream, such as groundwater, or it may be stored in depressions or on surfaces. If the complete rainfall-runoff process is to be approximated, the correct abstraction and loss functions must be simulated.

Evaporation and Transpiration

Evaporation involves the vaporization of water and consequently abstraction from surface runoff or pools. The rate of evaporation depends primarily on the exposed surface area, but also on temperature, radiant sunlight, wind, atmospheric pressure and impurities in the water. The mean annual rate of evaporation can vary from 200 mm in cold damp climates to 2000 mm in hot arid areas. The peak rate may be as high as 0.3 mm per hour. The rate of evaporation from any surface depends also on the type and the properties of the surface, e.g. hard pavements, porous ground or leaves. Transpiration losses over an area of catchment are often of the same order of magnitude as evaporation from a free surface with the same overall area.

Although the evaporation rate is small in comparison with precipitation rate, (e.g. a light storm may have a rate exceeding 10 mm/h), evaporation continues after rainfall ceases, so the total loss may be significant for large basins and those with long concentration times.

Care should be taken in interpreting pan evaporation figures. Lake evaporation appears to be only about 65 to 80 percent of the corresponding pan evaporation depth. This is due largely to different radiation effects and depths.

Interception

Portion of storm precipitation will be retained on vegetation and other surface cover. The maximum amount of water which is retained will depend on surface tension effects and the exposed surface area amongst other things. Although the amount intercepted is dependent on storm duration, common practice is to include it in initial abstractions. The total potential interception of trees varies typically from 2 mm to 10 mm.

Depression Storage

The uneven nature of most surfaces will result in some water being trapped. The maximum potential storage is dependent on the surface; thus smooth leveled concrete will retain only a fraction of a millimetre before the balance runs off, while ploughed ground may retain many millimetres of water. Water thus retained may eventually evaporate or seep away. Alternatively the storage ponds may be such that they gradually release water to contribute to the runoff. This is similar to storage routing with a relationship between depth of storage and rate of outflow. The latter form of depression storage is analogous to man-built detention ponds, but on a smaller scale, whereas the permanent storage is analogous to retention storage basins. For short duration storms the retention and detention have the same effect on the peak. In fact it is difficult to distinguish between them in many cases.

Total depression losses up to 10 mm for lawn, or even 25 mm for dense vegetation have been observed. Hicks (1944) reported for general use 5 mm for sand, 4 mm for lawn and 3 mm for clay, but the range is between 1 mm for paved areas and 10 mm for gardens.

Infiltration

Water precipitating on or flowing over porous surfaces seeps in at a rate dictated by the permeability of the surface and the ground porosity. The initial rate of infiltration will depend on the prevailing moisture content. The rate of infiltration will reduce with time during a storm as pores are filled and the water table rises. The decay in infiltration rate can be predicted with Horton's equation (1935):

$$f = f_c + (f_o - f_c)e^{-kt} \tag{2.10}$$

where f is the infiltration rate at time t, k is a decay constant, f_c is the equilibrium capacity and f_o the initial capacity. f_c may be closely approximated by the one-hour infiltration rate, which could vary from 0.2 to 2.0 mm/h for clays, 2 to 10 mm/h for loams and 12 to 25 mm/h for sandy soils. Vegetation can increase these figures many times

(Viessman et al, 1977). Thus 200 mm/h is possible for planted agricultural sandy soil. f_o may vary between 200 mm/h for bare clayey soil to 900 mm/h for planted sandy loam (Wilson, 1974).

A simplified approximation to the decaying infiltration is the constant loss assumption. This may be reasonable for large basins and long duration storms, or for deep porous soils which are unlikely to saturate. The most common nomenclature for the constant rate of infiltration is the ϕ index. It is determined by computing the average loss during a number of storms. For time-varying storm input this may be complicated (Hiemstra et al, 1976). A better approximation is to substract initial losses and then permit a uniform rate of loss.

In reality the relationship between precipitation, losses, basin recharge and return flow are complex. The input hydrograph must be something like that in Fig. 2.9. This represents the hyetograph, or rate of rainfall together with losses. The resulting input is summated over the catchment and routed to result in an output hydrograph, to which must be added groundwater contribution. The theory of hydrographs is taken further later.

SCS METHOD FOR THE EVALUATION OF LOSSES

The amount of retention on the surface and infiltration are primarily functions of soil type and cover. The United States Soil Conservation Service (SCS) (1972) demarcated a wide range of soil types and allocated them curve numbers (CN) on the following basis.

Ground storage gradually increases after the commencement of a storm, until the ground becomes saturated. At that stage rainfall excess (i.e. runoff) rate becomes equal to the precipitation rate (see Fig. 2.10). Thus the runoff proportion of precipitation increases as the storage approaches saturation. If it could be assumed that they increase in proportion, then

$$\frac{Q}{P} = \frac{S}{S_s} \qquad (2.11)$$

where Q is the volume of runoff, P is the volume of precipitation, S is the input volume to ground water storage in the basin and S_s is the input storage at saturation (all in mm or units of depth). Here it is assumed that S occurs in the form of uniform infiltration plus evaporation E plus transpiration T.

$$\text{But } S = P - Q \qquad (2.12)$$

$$\text{Therefore } \frac{Q}{P} = \frac{P - Q}{S_s} \qquad (2.13)$$

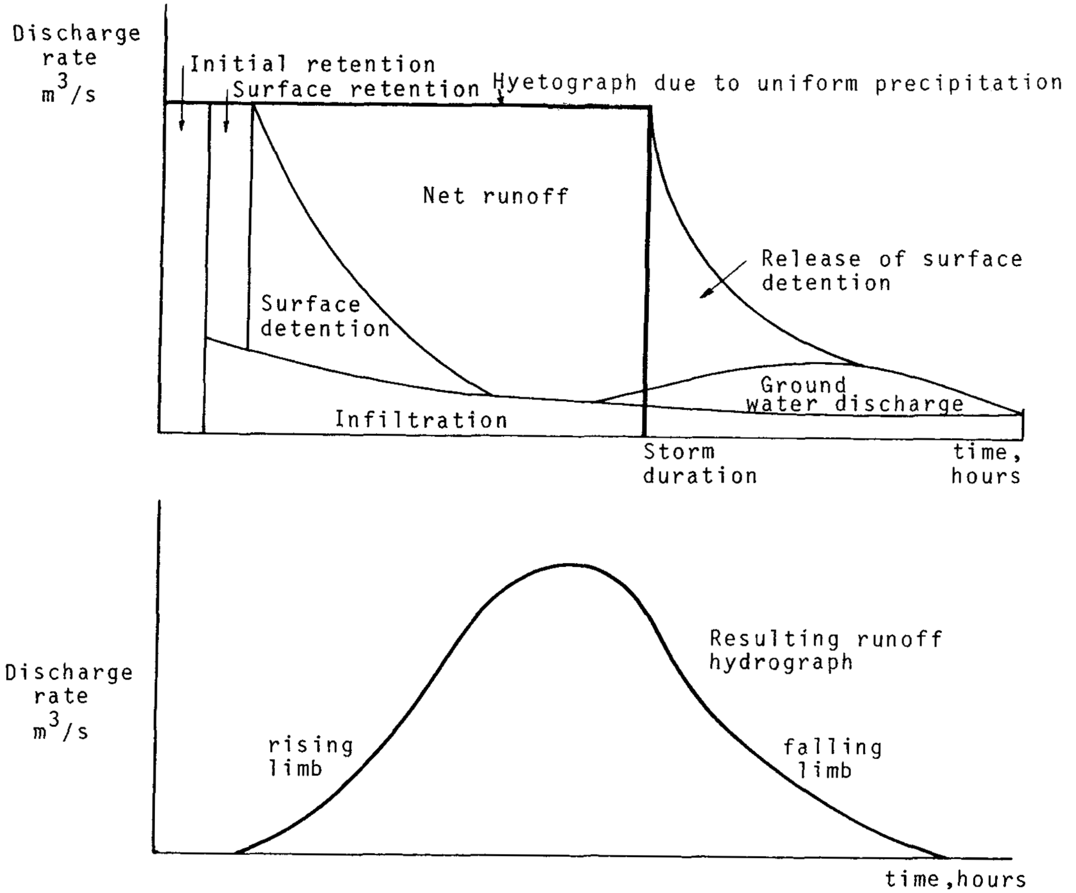


Fig. 2.9 Hydrograph and Hyetograph components.

or $$Q = \frac{P^2}{P + S_s} \tag{2.14}$$

The SCS established from a wide range of soils that the initial abstraction IA was 0.2 S_s. Figures by others, e.g. Schulze and Arnold (1979) indicate values somewhat less than this. However, using the SCS value, then allowing for the initial abstraction one obtains

$$Q = \frac{(P - 0.2\ S_s)^2}{(P + 0.8\ S_s)} \tag{2.15a}$$

and if P is less than 0.2 S_s then

$$Q = 0 \tag{2.15b}$$

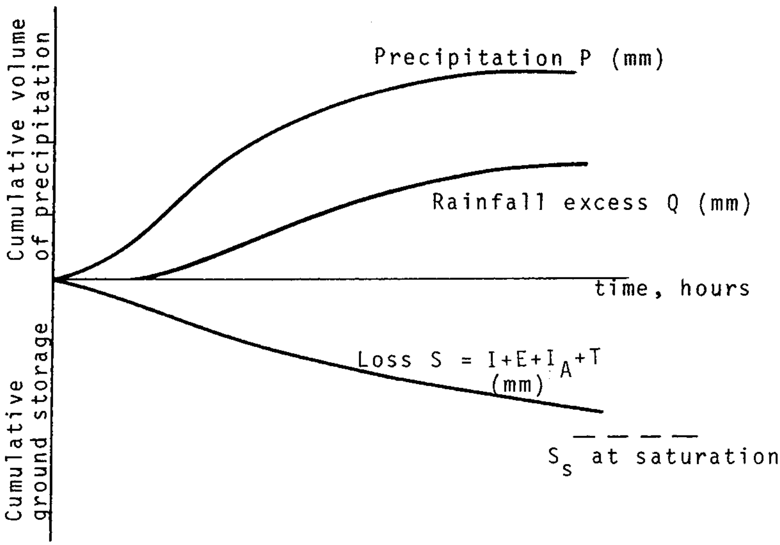


Fig. 2.10 Relationship between precipitation and infiltration losses.

The SCS also established curve numbers (CN) for different soil types, where the maximum soil storage in inches is

$$S_s = (1000/CN) - 10 \tag{2.16}$$

or in mm, $S_s = \frac{25\,400}{CN} - 254$ (2.17)

Hence $CN = \frac{1000}{S_s + 10}$ (S_s in inches) (2.18)

The curve numbers corresponding to different ground curves are tabulated in Table 2.1. There are different numbers for different types of soil, described as groups A, B, C or D, in Table 2.2. There is also an adjustment for antecedent soil moisture (Table 2.3) and for percentage impervious area in the case of urban catchments (Table 2.4). A discussion of the effect of soil moisture on runoff is given by Hawkins (1978).

TABLE 2.1 Runoff Curve Numbers for Selected Land Uses (after Wanielista, 1978) for Antecedent moisture condition 2, and Initial abstraction $0.2S_s$.

Land Use		Hydrologic Soil Group			
		A	B	C	D
Cultivated Land					
Without conservation treatment		72	81	88	91
With conservation treatment		62	71	78	81
Pasture or Range Land					
Poor condition		68	79	86	89
Good condition		39	61	74	80
Meadow					
Good condition		30	58	71	78
Wood or Forest Land					
Thin stand, poor cover, no mulch		45	66	77	83
Good cover		25	55	70	77
Open spaces, Lawns, Parks, Golf Courses, Cemetries, etc.					
Good condition, grass cover on 75% or more of area		39	61	74	80
Fair condition, grass cover on 50% of area		49	69	79	84
Commercial and Business Areas (85% impervious)		89	92	94	95
Industrial Districts (72% impervious)		81	88	91	93
Residential					
Average Lot Size (m^2)	Average % Impervious				
< 500	65	77	85	90	92
1000	40	61	75	83	87
1500	30	57	72	81	86
2000	25	54	70	80	85
4000	20	51	68	79	84
Paved Parking Lots, Roofs, Driveways, etc.		98	98	98	98
Streets and Roads					
Paved with curbs and storm sewers		98	98	98	98
Gravel or paved with swales		76	85	89	91
Dirt		72	82	87	89
Urban Conditions:					
Bare ground		77	86	91	94
Gardens or Row Crop		72	81	88	91
Good Grass (cover greater than 75% of pervious area)		39	61	74	80
Fair grass (cover 50-75% of pervious area)		49	69	79	84
Poor grass (cover less than 50% of pervious area		68	79	86	89
Fair Woods		36	60	73	79

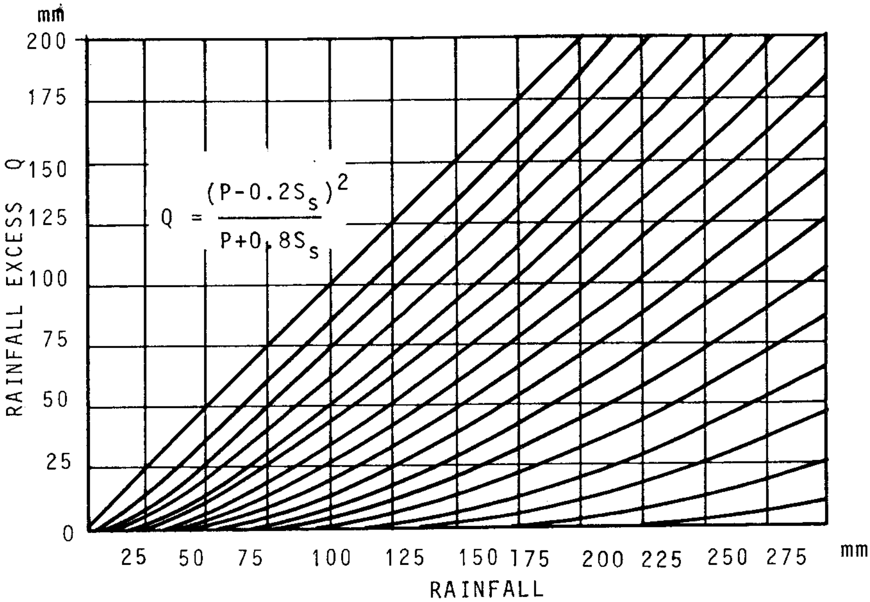


Fig. 2.11 Rainfall excess from curve numbers

TABLE 2.2 SCS Hydrologic Soil Groups

Soil Group	Description
A	Lowest Runoff Potential. Includes deep sands with little silt and clay; also deep, permeable gravel.
B	Moderately low Runoff Potential. Mostly sandy soils less deep and aggregated than A, but group has above average infiltration after wetting.
C	Moderately High Runoff Potential. Shallow soils and soils containing considerable clay and colloids, though less than those of Group D. Group has below-average infiltration after saturation.
D	Highest Runoff Potential. Mostly clays of high swelling percentage, but group also includes some shallow soils with nearly impermeable sub-horizons near surface.

HYDROGRAPHS

Discharge from a catchment following a storm will increase to a peak and then tail off. A plot of flow rate versus time produces a hydrograph. The shape of the hydrograph is a function of many factors, including

TABLE 2.3 CN Adjustments

CN for Moisture Condition 2 (average)	ADJUSTED CNs Condition 1. Soil dry but not at wilting point	Condition 3. When Antecedent Moisture is high
100	100	100
98	87	98
90	78	96
85	70	94
80	63	91
75	57	88
70	51	85
65	45	82
60	40	78
55	35	74
50	31	70
45	26	65
40	22	60
35	18	55
30	15	50

TABLE 2.4 Runoff Curve Numbers for Impervious Areas in Urban Watersheds (Moisture condition 2)

% Impervious Area	Curve No.
100	98
90	97.5
80	97
70	96.5
60	96
55	95
50	94
45	93
40	92.5
35	91
<30	91

storm characteristics and basin topography. The rising limb is a function of the concentration rate of excess precipitation or runoff. Initially there will be retention storage and infiltration losses to subtract from the input. These will diminish if the storm continues until more and more precipitation manifests as runoff. The rate of flow also increases, with the result that initially the hydrograph increases exponentially. At some stage runoff from the furthest parts of the catchment will reach the mouth and a levelling off in runoff is evident.When the input (precipitation) ceases, the hydrograph will start to fall. Runoff will decrease asymptomatically. Continuing surface losses may rapidly reduce outflow to zero. Alternatively the ground water table may rise to such an extent that the aquifer discharges its load downstream to contribute to the total discharge.

Neighbouring catchments may feed into a common downstream river. Then the flows contribute to a single stream. Storage effects due to backwater at junctions is often neglected. In fact it is assumed that contributing hydrographs may be added directly for any point in time to yield a new hydrograph. That hydrograph may then be routed down the river to yield a new discharge hydrograph with the effects of channel storage and the discharge characteristics of the system accounted for.

Hydrograph theory is used to a great extent in the assessment of rural catchment runoff on a regional basis. Implicit behind the development of the theory is that the catchment rainfall-runoff response function is linear. Thus the ordinates of a hydrograph associated with 2 cm of excess rainfall of a certain duration are assumed equal to twice the ordinates of the hydrograph due to 1 cm of excess rain over the same duration. In fact unit hydrographs form the basis for derivation of the hydrographs for any storm in that catchment. Usually the unit hydrograph is prescribed for a storm of unit duration, e.g. 1hr. Then the two-hour unit hydrograph is equal to the sum of the ordinates of two successive unit hydrographs, one lagged one hour relative to the other, and divided by two to reduce it to the hydrograph due to one centimetre of rain instead of two.

By adding successive one-hour hydrographs lagged one hour, one can obtain a massed flow curve for a storm of infinite duration. The resulting curve is referred to as an 'S-curve' (Fig. 2.12).

To obtain a hydrograph for a storm of 'M' hours duration, one subtracts the ordinates the two S-curves, one lagged M hours after the other. The resulting difference should be multiplied by N/M to obtain the hydrograph for a storm of N centimetres depth falling over M hours.

The method is not suitable for small catchments. The critical storm duration is normally less than an hour, and inaccuracies in subtracting the S curves and multiplying by N/M are magnified. Oscillating S curves and even negative hydrograph ordinates may occur. The assumption of linearity is no longer acceptable. In fact the general concept of a unique unit hydrograph for any basin is a gross simplification. In view of the uncertainties and unknowns in rural catchments the techniques are often employed. Application to urban systems can lead to errors, as there is no allowance for the effect of pavements, buildings, canalization or storage.

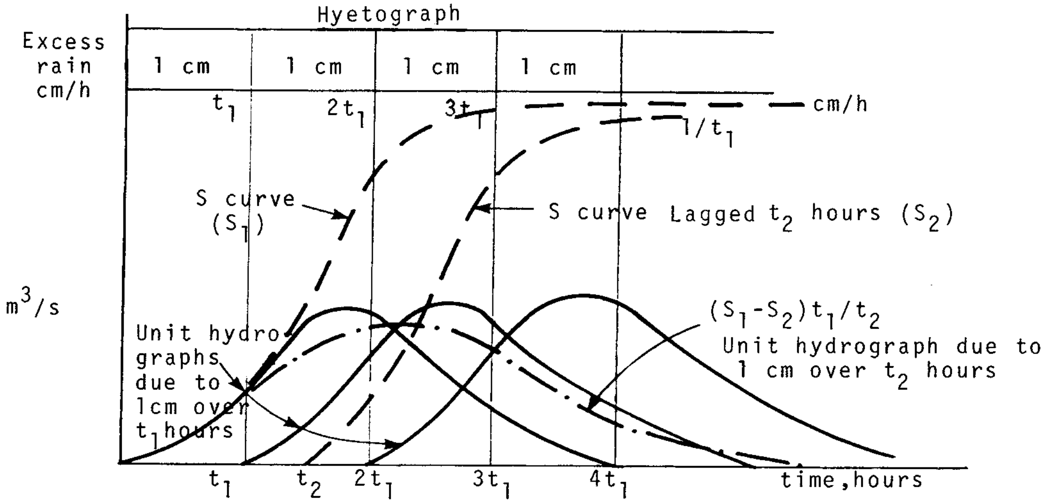


Fig. 2.12 Derivation of S-curve from unit hydrograph

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