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Rainfall-Runoff Analysis of a Compacted Area

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ABSTRACT

Runoff is the total surface flow from a given drainage area. Before runoff can occur, precipitation must satisfy the demands of evaporation, interception, infiltration, surface storage, and surface detention and channel detention. Rainfall duration, intensity and aerial distribution influence the rate and volume of runoff. Total runoff of a storm is clearly related to the precipitation intensity. The amount of runoff from a given drainage area depends on many inter related factors. Watershed characteristics such as slope, shape and size, cover of soil and duration of rainfall have a direct effect on the peak flow and volume of runoff from any area.

INTRODUCTION

The runoff volume during flood event is primarily influencedby precipitation amount before and during the event but certain influence of otherparameters like catchment saturation state before the event is also expected. Someauthors characterise the catchment saturation state by antecedent precipitation index others by antecedent soil moisture condition or by dynamic source area concept. An evapotranspiration ratepameter may also have influence on precipitation-runoff response.The purpose of this study was to analyse the rainfall-runoff relationship.Runoff is generated by rainstorms and its occurrence and quantity are dependent on the characteristics of the rainfall event, i.e. intensity, duration and distribution.

RATIONAL METHOD

The Rational method is based upon the following formula:

$Q_T = C\, i_T\, A$

where:

Q_T = estimate of the peak rate of runoff (cfs) for some recurrence interval, T

C = runoff coefficient; fraction of runoff, expressed as a dimensionless decimal fraction, that appears as surface runoff from the contributing drainage area.

i_T = average rainfall intensity (in/hr) for some recurrence interval, T during that period of time equal to T_c.

A= the contributing tributary drainage area to the point of design in acres which produces the maximum peak rate of runoff

T_c = rainfall intensity averaging time in minutes method is simple and widely used, but there are some inconsistencies

- Rainfall intensity is assumed uniform (temporal and spatial)
- Antecedent catchment condition is not recognised
- Partial area effects may result in larger flows

  Time of concentration, tc
- The runoff travel time from the most remote point of the catchment to the outlet
- It comprises the travel time from roof gutters, open ground, kerb gutter, pipes and channels

Rainfall intensity, I, is dependent on:

- Locality of the catchment
- Recurrence interval used In the design
- Time of concentration or duration of storm Runoff Coefficient, C
- Ratio of runoff to rainfall frequency curves
- Based on the 10I1 storm intensity
- Runoff coefficient is related to the fraction impervious of the catchment

SCS TRIANGULAR HYDROGRAPH METHOD

In this method, peak runoff is determined using the curve number approach. The assumption of uniform rainfall still applies. The hydrograph takes on a triangular shape with equal peak andflow volume as in the rational method. This can be seen below.

Peak runoff rate is calculated by

$q = 0.0021QA/T_p$

where Q = runoff volume in mm depth (from the curve number)

q = runoff rate in m^3/s

A = watershed area in ha.

T_p = time of peak in hours

In this method, the "time to peak" does not equal the time of concentration as in the rational method, in this method time to peak T_p equals

$T_p = D/2 + T_L = D/2 + 0.6T_c$

Where T_p = time to peak (hours)

D = duration of excess rainfall

T_L = time of lag

T_c = time of concentration

It is assumed that the total time of flow is 2.67 Tp and the recession time of the hydrograph is 1.67 Tp.

$T_c = 0.00526\, L^{0.8}(1000/CN – 9)^{0.7}\, S^{-0.5}$

where L = watershed le

S = watershed slope

CN = curve number

Time-Area Method

Time-area methods utilise a convolution of the rainfall excess hyetograph with a time-area diagram representing the progressive area contributions within a catchment in set time increments. Separate hydrographs are generated for the impervious and pervious surfaces within the catchment. These are combined to estimate the total flow inputs to individual sub-catchment entries to the urban drain network.

The time-area method dates from the research of Ross in 1922. Networked urban drainage adoptions of the procedure however only date back to 1963. This computerised program known as the TRRL Method was developed by the UK Transport and Road Research Laboratory (TRRL), described by Watkins (1963). In the U.S., Terstriep and Stall (1974) further developed the method to include pervious runoff. In South Africa Watson (1981) made a number of additional changes particularly to the way infiltration was estimated. Between 1982 and 1986 Watson's model was used through extensive changes, to formulate a computerised package known as ILSAX (O'Loughlin, 1988). The sub-catchment runoff estimating procedure still utilises the basic time-area method to estimate both pervious and impervious portion of runoff.

This method assumes that the outflow hydrograph for any storm is characterised by separable subcatchment translation and storage effects. Pure translation of the direct runoff to the outlet via the drainage network is described using the channel travel time, resulting in an outflow hydrograph that ignores catchment storage effects.

To apply the method, the catchment is first divided into a number of time zones separated by isochrones or lines of equal travel time to the outlet . The areas between isochrones are then determined and plotted against the travel time.

The translated inflow hydrograph ordinates q, for any selected design hyetograph can now be determined. Each block of storm should be applied (after deducting losses) to the entire catchment; the runoff from each sub-area reaches the outflow at lagged intervals defined by the time-area histogram. The simultaneous arrival of the runoff from areas At, A2,...for storms It, I2,...should be determined by properly lagging and adding contributions, or generally:
Qi =Ii-Ai

Non-linear Reservoir Method
In the non-linear reservoir method, the catchment is conceptualised as a very shallow reservoir. The discharge from this hypothetical reservoir is assumed to be a nonlinear function of the depth of water in the reservoir. Computer models such as RAFTS and SWMM can optionally use a non-linear reservoir approach to compute surface runoff hydrographs. The SWMM procedure is described here (Huber and Dickinson, 1988).

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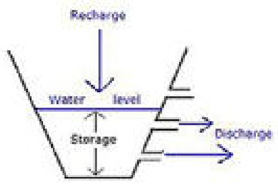

Non-linear reservoir with multiple outlets

Contrary to the linear reservoir, the non linear reservoir has a reaction factor A that is not a constant,[but it is a function of S or Q normally A increases with Q and S because the higher the water level is the higher the discharge capacity becomes. The factor is therefore called Aq instead of A. The non-linear reservoir has no usable unit hydrograph.

During periods without rainfall or recharge, i.e. when R = 0, the runoff equation reduces to

- Q2 = Q1 exp { − Aq (T2 − T1) },

or, using a unit time step (T2 − T1 = 1) and solving for Aq:
Aq = − ln (Q2/Q1)
Hence, the reaction or response factor Aq can be determined from runoff or discharge measurements using unit time steps during dry spells, employing a numerical method. Figure 3 shows the relation between Aq (Alpha) and Q for a small valley (Rogbom) in Sierra Leone.

Figure 4 shows observed and simulated or reconstructed discharge hydrograph of the watercourse at the downstream end of the same valley.

Isochrone Method
The Isochrone Method is a relatively simple way of estimating a runoff hydrograph for an urban catchment. The basis for constructing the hydrograph is a diagram of runoff-time-area and a rainfall hyetograph.The time-area diagram is constructed by dividing the drainage basin into areas of equal time of travel to the point of reference.The time increment used should be the same as that of the design hyetograph. The hydrograph is computed in the manner where i is the excess rainfall (after abstractions) at each time step.

The method provides a hydrograph that reflects the effects of the rainfall distribution; this is more realistic than an assumption of a triangular hydrograph (a method sometimes used with the Rational Method).

The effects of the varying responses from pervious and impervious areas can be included in the method by developing time-area diagrams and excess rainfall hyetographs for each separately. The excess rainfall hyetographs for impervious areas are obtained by subtracting depression storage and allowing for the effects of surface routing. For the pervious-area hyetographs, additional abstractions must be deducted for infiltration using a relationship such as Horton's equation or published or measured values. The individual hydrographs are computed in the manner described above and are then added to give a total hydrograph. This method produces a hydrograph based on a realistic storm pattern which reflects the effects of variations of rainfall abstraction during the storm. The time area diagrams are more easily and reliably computed where a conveyance system exists or has been designed by other methods. It is particularly useful for making preliminary estimates of stormwater storage requirements for urban drainage systems.

isochrone method does not involve complex calculations and can be carried out by hand for small areas where hydrographs are required at one or two locations. The calculations become time consuming for large areas and/or multiple hydrographs.

Deterministic Methods
Deterministic methods quantify runoff from rainfall and/or snowmelt by simulating the effects of the various components of the process. This involves computing the runoff for a number of discrete time steps for the duration of the runoff event. Typically, surface detention storage is first abstracted from the rainfall followed by the abstraction of infiltration on pervious catchments. Infiltration is usually based on a relationship such as Horton's Equation, which relates the soil absorption and infiltration capacities with the current rainfall intensity. Next, the excess runoff is routed overland where additional infiltration may be deducted if the water flows over the pervious surfaces. At an appropriate point the pervious and impervious hydrographs are combined and may be further routed through channels to an inlet point.

Deterministic methods involve large amounts of calculation and are much more suited to computer modelling than to hand calculation. None of the existing computer models discussed in Section 4.6 are purely deterministic although a number of programs are classified as deterministic models. For practical reasons some processes and/or physical characteristics are lumped together and their impact is quantified empirically.

CONCLUSION
Rational method is widely used in all above methods to estimate run off.

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