Effect of Various Parameters on Hydrograph and Rainfall-Runoff Relationship Establishment by using Armfield S-10 Rainfall Hydrograph

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Abstract— Rainfall-runoff process of a watershed is important for water resources planning, flood forecasting, design flood estimation through rainfall runoff process, and many other applications. For a mathematical simulation of this phenomenon, controlled set of experiments were conducted to investigate this process through experimentation on the catchment system placed over a rainfall simulator to obtain runoff hydrograph data. The experiments were carried out over an impermeable plane surface (smooth metal sheet), with a uniform rectangular cross section of dimension one meter wide and two meter long. Laboratory experiments were conducted to know behavior of this phenomenon using rainfall simulator. In this project, stream flow from a single storm, stream flow from multiple storms, stream flows with reservoir storage experiments are performed. Result and conclusion are found out on the basis of experiments performed.

Key words: Hydrograph and Rainfall-Runoff

I. Introduction

A. General

The most important process in the hydrological cycle is the section where rainfall occurs and results in runoff. The runoff is critical to many activities such as designing flood protection works, water supply, agricultural, irrigation purpose. Ensuring safety and minimizing costs are two priorities set by designers. That is why, study of various parameters which affects the hydrograph is essential for this. We have performed series of experiments on Armfield S-10 rainfall hydrograph instrument and have obtained results. Rainfall-runoff process of a watershed is important for water resources planning, and many other applications. For a mathematical simulation of this phenomenon, controlled set of experiments were conducted to investigate this process through experimentation on the catchment system placed over a rainfall simulator to obtain runoff hydrograph data. The experiments were carried out over an impermeable plane surface (smooth metal sheet), with a uniform rectangular cross section of dimension one meter wide and two meter long. Laboratory experiments were conducted to know behavior of this phenomenon using rainfall simulator. In this project, stream flow from single storm, stream flow from multiple storms, stream flows from reservoir storage experiments are performed.

B. Necessity

Rainfall is a natural hydrological phenomenon that plays important role in various natural processes and vital for existence of life on the earth. Variation in rainfall such as in intensity, time duration of rainfall, monsoon breaks, and intermittency in rainfall due to various uncertainties. That's why it is primary to determine the rainfall-runoff relationship. Rainfall-runoff processes of a watershed is important for water resources planning, flood forecasting, design flood estimation through rainfall runoff process, and many other applications.

C. Objectives

1) Establish rainfall runoff relationship by using S -10 Armfield.
2) Study the effect of permeability of hydrograph.
3) Study the effect of reservoir storage on hydrograph.

D. Armfield S-10 Equipment

This apparatus sets out to demonstrate, on a small scale, some of the physical processes found in hydrology. This fall into two related categories: the relationship between rainfall and runoff from catchment areas of variable permeability and the abstraction of ground water by wells, with or without surface recharge from rainfall. Thus it is concerned with that part of the hydrological cycle bounded by the arrival of 'net rainfall' on the ground surface and the catchment runoff by surface streams.

1) Technical Specifications:

Tank dimensions:
Length : 1.2m
Width : 0.6m
Height : 0.2m
Flow meter range : 0.4 - 4.4 liter/min
Runoff collector : 17 x 0.5l compartments

2) Overall Dimensions:

Length : 1.58m
Width : 0.90m
Height : 1.05m

II. Literature review

A. General

Simple rainfall-runoff models, are most widely used so that we can use that information in land-use decision making. In the world different hydrological models are available, with different purpose and complexities. Many researches are performing various experiments in this field. Hydrological model is one of the models used for study and analyzing the impact of different parameters on the hydrograph and to provide brief information.

B. Sherman (1932)

He introduced a new concept of the unit hydrograph which was based on principle of superposition. The unit hydrograph technique got wide acceptance by hydrologist as it was capable of predicting full hydrograph rather than peak discharges and time of concentration for the complex storms. In 20th century Todini (1988) through his research improved outcome of rational method applied to catchments with heterogeneous rainfall and varied basin characteristics.

C. Keith Beven (1980)

As noted in the preface, there are many reasons why we need to model the rainfall–runoff processes of hydrology. The main reason is a result of the limitations of hydrological measurement techniques. We are not able to measure everything we would like to know about hydrological systems. We have, in fact, only a limited range of measurement techniques and a limited range of measurements in space and time. We therefore need a means of extrapolating from those available measurements in both space and time, particularly to ungagged catchments (where measurements are not available) and into the future (where measurements are not possible) to assess the likely impact of future hydrological change.

D. Campbell E. and Bates B. (2001)

Runoff is generated by rainstorm s and its occurrence and quality are dependent on duration and distribution. There are, in addition, other important factors which influence the run off generation processes. When rain falls, the first drops of water are intercepted by the limbs and stems of vegetation's. This is usually refers to as interception storage. As the rain continues water reaching ground surface, infiltrates into soil until reaches to storage where rainfall (intensity) exceeds the infiltration capacity of the soil. Thereafter, surface puddles, ditches, and other depressions are filled (depression storage), after which runoff is generated. The infiltration capacity of the soil depends on its texture and structure, as well as on the antecedent soil moisture content (previous rainfall or dry season). The initial capacity (of a dry soil) is high but, as the storm continues, it decreases until it reaches a steady value termed as final infiltration rate. The process of runoff generation continues as long as the rainfall intensity exceeds the actual infiltration capacity of the soil but it stops as soon as the rate of rainfall drops below the actual rate of infiltration.

III. Methodology

Demonstrations are initiated using a gravel filled tank which incorporates facilities for supplying water to the surface of the gravel and measuring the runoff. The gravel tank is manufactured in stove enameled mild steel supported by a painted mild steel frame. The equipment can be bench mounted or free standing on a laboratory floor. Water is supplied to two overhead square pattern spray nozzles via a flow control valve, flow meter and solenoid valve. Detachable see-through curtains around the tank contain any spray. Runoff is conducted to an outlet at one end of the tank. A collection and measuring unit is located near to the outlet from the tank. This comprises of a traversing vessel divided internally into 17 storage compartments. The collecting vessel is mounted on a plinth incorporating a motor drive and central drainage trough.

A control console is used to control the traversing vessel and the water supplied to the spray heads. The time each compartment is located under the tank outlet can be preselected and the overall time from the start is displayed. Water collected in the vessel provides an immediate histogram of runoff as a function of time. A range of accessories allows demonstrations of surface reservoir retention, depression storage effect and land drainage. Surface runoff and sediment were collected at the end of the soil flume through a metal container placed slightly below the soil surface. The bottom and the side boundaries of the soil flume were impermeable. (Although a bottom drain was set at the end of the soil flume to let the accumulated water out if necessary, it was never used in this study). Although the slope of the flume was adjustable, a fixed slope of 25 was used in this study. The downstream end of the soil flume was shadowed by a shed, such that the rainfall outside the flume was not recorded.

A. Experiment Recording

Runoff samples were collected and measured to compose hydrographs at regular time intervals, depending on the rainfall duration. Each runoff sample was dried by an electric oven to weight dry sediment. Runoff characteristics, including the time of runoff peak and runoff peak, were estimated based upon the hydrograph.

Experiment comprises:

- Two plastic containers for reservoir storage
- Curtains provided on all sides

B. Experimental Procedure

The rainfall scenarios were constructed by considering rainfall intensity, duration, moving direction, rainfall position, and no rainfall interval. All the rainfall scenarios were categorized into three types.

Because of the indoor experimental set-up, raindrops fall vertically, which is different from nature in the case of a moving storm. This could affect the drop impact angle and velocity, which may change the hydrologic response and erosion processes, and subsequently, the experimental results. However, to address the detailed influence of wind on runoff-generation and erosion is beyond the scope of this study

C. Model Development

The rainfall-runoff modeling in the early 19th century was confined mostly to use of empirical formulae or the rational method to transform rainfall into surface runoff. For small scale problems the method based on time of concentration served the purpose but for larger catchments rational methods had to be modified. In due course of time the method of isochrones was introduced. This method was seen as first basic rainfall runoff model.

The development of 'conceptual model' began in 1950's. These models were formulated to apply for long continuous data of rainfall avoiding complexity of storm runoff and base flow separation. With advent of computers 1960s introduced computational models like Stanford watershed model, HEC-1 by Hydrological Engineering Centre, U.S. Army Corps of Engineers, Sacramento River (Burnash et. al,, 1973), TOPMODEL (Beven and Kirkby, 1979).

GIS has been used to estimate the parameters of lumped conceptual models e.g. runoff curve number for drainage basin with widely used SCS model. For distributing lumped state variable, a distributed catchment characteristics as a covariant mean have been used.

D. Setting of Terrain

The sand we have used in the experiment is ideal sand whose size varies from 0.425 mm to 4.75 mm. The catchment was empty at first. We poured down the ideal sand into the catchment in 3 layers and made each layer horizontal. We adjusted the terrain to get a proper slope. In this particular experiment two nozzles were turned on. We are always getting a late graph because after rainfall has started it will take a time to come at the outlet.

IV. RESULTS

A. Stream Flow with Single Storm Using Two Nozzles

The table below contains the values of peak discharges and time of peak for the given ten experiments enlisted below. Intensity of rainfall and rainfall duration are the input that needs to be given with the help of electronic console. The desired values of rainfall intensity and duration can be given. Peak discharge is the highest value of the discharge that we get when experiment is carried out. Time of peak is the time it takes to reach the peak right from the starting of experiment.

Experiments No.	Intensity of Rainfall (mm/hr)	Rainfall duration(min)	Peak discharge $(m^3/sec)\times10^{-6}$ (Q_p)	Time of peak (sec) (T_P)
1	125	3	0.87	300
2	166.67	3	1.24	240
3	208.33	2	1.2	225
4	41.67	2	0.93	240
5	62.5	2	1.73	180
6	83.33	2	6.66	120
7	41.67	2	3.16	30
8	83.33	1.5	2.633	60
9	83.33	1	6.67	180
10	166.67	2	5.267	240

(Readings of single storm using two nozzles)

B. Stream Flow with Single Storm Using One Nozzle

The experimental setup used in this experiment is the same as the previous one except that in place of two nozzle used in the first experiments this time only one nozzle is used. Input is given in the form of rainfall intensity and duration and peak, time of peak is obtained. The data obtained is given in the table below.

Experiment No.	Intensity of rainfall(mm/hr)	Rainfall duration(min)	Peak discharge $(m^3/sec)\times10^{-6}$ (Q_p)	Time of peak (sec) (T_P)
1	125	3	2.8	260
2	166.67	3	2	160
3	208.33	3	2	120
4	229.167	2	2	100
5	125	4	1.4	300
6	166.67	4	2.4	200
7	208.33	4	1.8	220
8	229.167	4	0.8	180
9	125	4	1.6	270
10	166.67	4	1.4	210

(Readings of single storm using one nozzle)

C. Stream Flow with Reservoir Storage

Plastic containers are used as reservoir to store water. Peak discharge and time of peak is affected by this experimental setup. The data is as shown below

Experiment No.	Intensity of rainfall(mm/hr)	Rainfall duration(min)	Peak discharge $(m^3/sec)\times10^{-6}$ (Q_p)	Time of peak (sec) (T_P)
1	83.33	2	4.53	180
2	166.67	3	11.4	160
3	125	4	13.867	210
4	125	3	11.55	135
5	62.5	2	2.46	120
6	166.67	4	11.55	225
7	83.33	6	7.786	225
8	83.33	6	9.688	315

(Readings of stream flow with reservoir)

V. CONCLUSION

A. Effect of Catchment Saturation on Hydrograph

If we compare Experiment 1.1 and 1.2, the time of carriage and rainfall duration is same. So, the parameter that decides the shape of hydrograph is rainfall intensity. Also the catchment in the first case is dry so it takes time for the soil to saturate and therefore peak discharge is further delayed. But as the intensity in the latter case is more the two graphs attains peak almost at the same time.

B. Effect of Rainfall Duration on Hydrograph

By comparing the graph of Experiment 1.6 and 1.8, we can say that when the rainfall duration is longer than the peak of hydrograph shifts towards right side of the graph. The reason for that is the time lag. i.e. the distance between the center of rainfall and peak. The rainfall intensity and the carriage time of two graphs are same and only the variation is due to rainfall duration. In Experiment 1.6 is more than Experiment 1.8, the graph with lesser rainfall duration will reach its peak first.

C. Distribution of Rainfall (single or multiple) on the Shape of Hydrograph

There are two nozzles in the experiment. One is near to the outlet and other is away from outlet. When the nozzle which is near to the outlet is turn on, then we will get peak quickly (Refer Graph No.2.1). We can't vary the intensity during the experiment, so what we get is the single rainfall intensity spread over the whole area which is nothing but single storm only. Hence we have performed experiment by either keeping both the nozzles open and only one of them open

D. Effect of Reservoir Storage on Hydrograph

In the first experiment of reservoir storage with single storm and storage is impermeable. Hence, at starting of the rainfall, there is no ordinate recorded in the graph because of water getting stored initially.

In the second experiment of reservoir storage, reservoir used to be permeable that is recorded initially. The most significant element that we can see in this experiment is the recession limb which is fully developed. We can't see development in other two experiments. The reason is the storage which gets accumulated in the depression get into groundwater and contributes to groundwater flow, which is ultimately empties into the outlet, after the rainfall is long over.

E. Effect of Rainfall Intensity on Hydrograph

Intensity has a direct influence on the peak discharge provided rainfall duration remains the same. Results can be confirmed from the table of experiment 1.4 and 1.5. The peak discharge in the latter case is more because of its high rainfall intensity. The percentage increase in the peak intensity of discharge comes out to be 86.03%.

F. Effect of Carriage Time

When two catchments having same duration and intensity of rainfall, then the shape of hydrograph is affected by time of carriage. More is the carriage time lesser time it will take to reach the peak. It has no significance in actual rainfall scenario. But it has experimental importance. It is not possible to plot hydrograph without carriage.

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