RAINFALL- RUNOFF ANALYSIS OF A COMPACTED AREA

By

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PROJECT REPORT

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DECLARATION

We here by declare that this project report entitled “**Rainfall Runoff Analysis of a Compacted Area**” is a bonafide record of project work done by us during the course of project and the report has not previously formed the basis for the award to us of any degree, diploma, associate ship, fellowship, or other similar title of any other University or Society.

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CERTIFICATE

Certified that this project work entitled **"Rainfall Runoff Analysis for a Compacted Area"** is a record of project work done jointly by Raji, P and Uma, E under my guidance and supervision and that it has no previously formed the basis for the award of any degree, diploma, fellowship, or associate ship to them.

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SYMBOLS AND ABBREVATIONS

◌́	minute
″	seconds
%	percentage
◦	degree
ASAE	American Society of Agricultural Engineers
cm	centimeter(s)
et.al.	and others
Fig.	figure
GI	Galvanised Iron
hr	hour(s)
i.e.	that is
km	kilometer(s)
m	meter(s)
M ha m	million hectare meter
min.	minutes
mm	millimeter(s)
no.	numbers
PVC	Poly Vinyl Chloride
R^2	regression coefficient
Vs	versus
lps	litre per second

INTRODUCTION

Water is essential for all forms of life and is the fundamental resource for human survival and socio economic development as well as for maintaining intact ecosystem. Water resources pose the greatest challenge due to variation in spatial and temporal availability, over exploitation and pollution. Growing water scarcity and competing water demands are expected to widen the gap between water supply and water demand in future.

The total quantity of water in the world is estimated to be about 1386 M km^3. About 96.5% of this water is contained in the oceans as saline water. Some of the water on the land amounting to about 1% of the total water is also saline. Thus only about 35 M km^3 of fresh water is available and 24.4 M km^3 is contained in frozen state as ice in the polar region and on mountaintops and glaciers. About 70% of the fresh water consumed worldwide is used for irrigation. Only 20% of fresh water is being utilized for industrial purposes. But last decade has witnessed a dramatic shift in the priorities of water allocation and development. In the increasing intense competition for water among, agricultural section is using to other sectional water uses. The major reason for the shift is due to the high economic advantage for industrial and urban section.

The United Nation had observed 2003 as the international year of fresh water to drive home the hard water facts that face humanity. 1.1 billion people in over hundred nations suffer without the bare minimum water availability, 2.4 billion without safe sanitation services and over six million easily preventable deaths, mainly of children, occur due to water born disease.

India’s average rainfall is about 119.4 cm, which when considered over the geographical area of 328 M ha amounts to a 400 M ha m. On an average, there are

130 rainy days in a year in the country. It is estimated that out of the average rainfall of 400 M ha m, about 70 M ha m is lost to the atmosphere, of the remaining 330 M ha m about 115 M ha m flows as surface runoff and the rest 215 M ha m soaks in to the ground. As India is one of the focal countries, which need attention on all fronts, the union government as well as the states facing water poverty has been alive to the escalating water riddle.

In Kerala, the mean annual rainfall received is 300 cm. The total number of rainy days in a year is 126. Although rainfall received in Kerala is much above the national average, only very little is utilized for productive purposes. The topography of the state is such that the average width is only 70 km with a length of 700 km. Within this narrow strip of region, we have regions line few meters below mean sea level and peaks with an altitude of 1000 m above mean sea level. This undulating topography is the main reason for water loss to the sea. Over the years Kerala has progressively moved towards a man made water management crisis. A state, which is started off with more than 50,000 M m^3 of fresh water available in its 44 rivers, 900 odd ponds and 300 cm rainfall has water stress in at least one third of its habitation. Worse than this, the 2001 national census figures indicate that only 21% Keralite have access to safe public water supplies. In rural area, 70% or more of the inhabitants depends on well water which is polluted by intestinal coliforms which undoubtedly cross pollutes from the leach pits and deep pits used for disposing human excreta. Tanker water supplies are in to service at an exorbitant cost to the exchequers and have become a small industry, which is difficult to dispense with. Water is turning out to be the limiting factor in the Kerala’s development experience, having potential to over turn many of the social achievements we are proud off.

The water shortage is exacerbated by the synergistic affects of population growth. Today the serious scarcity and more seriously scarcity amidst plenty of syndrome of drinking water converts situation to a crisis. Large-scale abuse of water resources by the modern developmental activities and total neglect of traditional water harvesting structures is responsible for this problem. In these circumstances to mitigate drought, it would be wise to harvest rainfall which would otherwise go as waste and recycle it for stabilizing agricultural production.

Water harvesting is the process of collecting, conveying and storing water from an area that has been treated to increase the runoff. The technologies available are vegetative barriers, contour bunding, contour stonewalls, contour trenching, providing check dam and construction of percolation ponds. The simplest method of water harvesting is to collect and store natural flow from a watershed. Rainwater harvesting is possible in areas with as little as 50-80 mm average annual rainfalls. Quantity of rainwater thus obtained is quite considerable even in drought prone areas. Rainfall is the main source of surface water. The decision whether to store or recharge rainwater depends on the rainfall pattern and runoff.

In places where rainfall throughout the year, one can depends on small domestic sized water tank for storing rainwater. Since the period between two spells of rain is short, on the other hand, in areas where total rainfall occurs only during 1-2 months, the water collected during monsoon has to be stored throughout the year, which requires large volume of storage containers as well as some treatment process. Therefore it is more feasible to use rainwater to recharge ground water aquifers so as to enable to draw water during the rest of the year rather than storing in large containers, which is not always feasible. Hydrological analysis is unavoidable in water harvesting structure design. Information on surface runoff volume is needed for several purposes in soil and water management. It is also needed in the design of soil conservation structures.

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. Runoff will occur only when the rate of precipitation exceeds the rate of infiltration of water in to the soil. Rainfall duration, intensity and aerial distribution influence the rate and volume of runoff. Total runoff of a storm is clearly related to the precipitation for given intensity. Thus a storm of short duration may produce no runoff. 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. As runoff harvesting is going to be the most applicable method for meeting the water demand in the future and hydrological analysis is unavoidable in any water harvesting structure design, a project based on rainfall – runoff analysis was done for a compacted area

The specific objectives of the study are

1. Runoff estimation of a compacted area.
2. Determination of runoff coefficient of the study area.
3. Determination of intensity-duration relationship of rainfall
4. To find out a relation between the rainfall and runoff measured.
5. Derivation of unit hydrograph from the obtained storm hydrograph.

REVIEW OF LITERATURE

Rainfall is the source of water for run off generation over the land surface. During occurrence of rainfall, the vegetations, buildings and other objects, lying over the soil surface, which prevent to reach it over the land surface, intercept a part of it. Lastly the rest of the water amount makes a head over the ground surface, which tends to move from one place to another under the effect of land gradient, and ultimately meets to the streams, channels etc. called as runoff. Runoff is broadly classified in to three types.

Surface runoff, Sub surface runoff and Base flow.

Main factors affecting runoff are climatic factors and physiographic factors.

Climatic factors include rainfall intensity, duration of rainfall, rainfall distribution, direction of prevailing wind.

2.1 Climatological factors

Intensity of rainfall has dominating effect on the runoff yield. If the intensity is greater than the infiltration rate of the soil, then surface runoff is generated rapidly, while in case of low intensity rainfall, there a reverse trend is found.

Fernandez *et.al.*(1994) conducted a study to investigate the impacts of long-term trends and fluctuations in rainfall characteristics as runoff from the Little Washita River watershed. Time series analysis of rainfall and watershed runoff demonstrate that changes in rainfall pattern and amounts can mark the beneficial impacts of flood water retarding structures

Reyes *et.al.* (1993) conducted a study to describe the rainfall intensity distribution. Two measures of rainfall intensity distribution called RIP (Rainfall Intensity Percentage) and WMRIP (Weighted mean Rainfall Intensity Percentage) were described in this study. The kinetic energy calculated from RIP values of 46 events was not significantly different from kinetic energy calculated by the standard break point method. Based on WMRIP value, the rainfall intensity distribution was classified in to low, medium and high intensity periods.

2.2 Physiographic factors

Physiographical factors include size and shape of watershed, form factor, compactness coefficient, slope of watershed, orientation of watershed, land use, soil moisture, soil type and topographical characteristics.

2.2.1 Land use

The land use pattern or land management practices used have great effect on the runoff. For example- an area that is under forest on which a thick layer of mulch of leaves and grasses have been accumulated, the surface runoff becomes too less, as huge rainfall amount is absorbed by the soil due to increase in infiltration rate and formation of resistance in the flow path of the watershed over the ground surface, while in barren lands just reverse trend is found.

Faucet *et.al.* (2004) estimated the amount of runoff, erosion and nutrient losses under simulated rainfall using a variety of compost and mulch material. Results indicated that all of the treatments except for aged poultry litter were effective at reducing total solids loss in the runoff.

Davis *et.al.* (2003) evaluated the effect of five forage species at varying canopy heights on surface runoff and infiltration on 6.1m × 6.1m plots fertilized with poultry litter. The results of this study showed that tall fescue when directly compared to the other forages is more effective at reducing runoff volumes and increasing infiltration, thereby reducing edge of field loss in forage systems.

A series of experiments were conducted by Chandler *et.al.* (1998) in the water catchment of Matalon, Leyte, Philippians to quantify the effect on the rear surface hydrology of land uses common to the steep slopes and thin , calcareous soils. Overland and subsurface runoff collected to compare the surface hydrologic response of tilled, slash/mulch and pasture catchment. The forest site demonstrated the lowest annual runoff response (< 3%), the pasture site demonstrated greatest runoff response (76%).

Gilley *et.al.* (1998) reported the effect of a single application of manure and compost on runoff and erosion under no till and tilled conditions. On the no till sorghum residue treatment, total solids transport represented 5.1% and 3.3% of the applied manure and compost. Total solids transport was 1.3% and 1.4% of the manure applied on the non-tilled wheat residue treatment.

Zhang *et.al.* (1998) evaluated the effects and longevity of soil amendments, tillage and screen cover on runoff and inter rill erosion on a Cecil sandy loam under natural rainfall conditions. Results showed screen cover and tillage temporarily reduced or delayed seal/crust formation, while the effect of gypsum is more persistent. A combination of physical and chemical treatments is the best practice for controlling surface sealing and reducing runoff.

Daniel *et.al.* (1993) assessed the effect of animal manure type, application rate, rain fall intensity and interaction on initial abstraction, run off, total abstraction and curve number for a simulated storm occurring one day after application to plots covered with tall fescue.

A study was conducted by Mcgrefor *et.al.* (1991) for a Greneda silt loam soil to quantify the effect of various rate combination of incorporated and surface applied wheat straw in inter rill runoff and soil loss. Relationship for inter rill runoff and soil loss as a function of weight of surface straw was derived using observed runoff and soil loss combined with observations from closely related laboratory studies.

A dynamic hydrologic model was developed by Borah *et.al.* (1989) ,which simulates space and time distributed rainfall excess and runoff in a small watershed resulting from a single rainfall event. The model parameters were SCS runoff curve number and the Mannings roughness coefficient. The model was simple and easy to apply to watershed where sufficient data were not available. Model validation was demonstrated on the USDA experimental watershed W-5, Mississippi and sensitivities of the model parameters were analyzed.

Yoo *et.al.* (1989) studied the effects of different tillage systems of cotton on runoff volume, runoff as percent of rainfall, peak flow rate and SCS runoff curve number for three years. The runoff parameters were affected by the three tillage systems and these effects varied by the periods. Effects of the storm events on the runoff parameters were higher during the growing period than during the non-growing period.

Onstard and Otterby (1980) conducted a study to find the effect of crop residual on runoff . The study showed a decrease in surface runoff. Runoff reduction and consequent increase in soil water storage was greater in less permeable soils.

Many researchers report that conservation tillage reduces runoff volume (Siemens and Oschwald, 1976). The relative effectiveness of tillage systems in controlling run off is determined by how much it changes runoff velocity, surface storage, conductivity, and soil moisture storage and raindrop impact energy.

2.2.2 Soil moisture

Amount of runoff produced from the catchment area is mainly dependent upon the amount of moisture present in the soil at the time of rain fall. If rain occurs over the land, which has more soil moisture, the water absorbing capacity of the soil becomes too less and thus, resulted more runoff yield.

Evans *et.al.* (1996) assessed the effects of post application irrigation depth and runoff formulation. Results indicated that post application of irrigation can increase the runoff losses for heavy rainfall occurring soon after application.

2.2.3 Soil type

The yield of surface runoff is also dependant upon the types of soil of the catchment area. Absorption of rainwater varies from soil to soil.

A study was conducted by Savabi *et.al*. (2004) to measure storm runoff and soil erosion for the dominant soils in South Miamin- Dade country under different water table regimes. The results indicated that the rainfall runoff relations were similar for the three dominant soil types when tested under a rainfall simulator.

2.3 Runoff estimation

Mc Cool *et.al.* (1995) conducted a study to estimate the runoff using NRCS runoff curve number method. Runoff index values have been calculated using runoff curve number relationships from the Poulose Conservation Field Station near Pullman, Washington. These runoff index values range considerably higher than curve numbers commonly used in hydrologic planning and can be used to improve performance of CN based models in winter conditions of the Pacific Northwest.

2.3.1 Runoff model studies

Several studies were done based on models for analyzing the effect of rainfall and other factors which affect runoff.

King *et.al*.(2004) conducted a laboratory test to compare total loads calculated from time based sampling strategies. Total loads were measured by capturing all the runoff from 2.2 m^2 Bermuda grass sod plots with 5% slope and analyzing for NO_3+ NO_2-N and NH_4-N. Runoff samples were also manually collected on 1-minute interval for overland flow events of 2 hr duration. The results of the study facilitated the selection of time based sampling strategies for plot scale studies.

Tollner *et.al.* (2004) evaluated dynamic version of the sample index and NRCS curve number runoff models currently used in water management for predicting runoff windrow composing operation. The production modified NRCS tended to over predict daily runoff at low production rates, where as the CN modified version of the daily NRCS was more consistent. Both dynamic NRCS tended to over predict monthly run off.

Sajikumar *et.al*. (2002) developed a rain fall run off model using an artificial neural network. The performance of this model in a scarce data scenario was compared with functional series models utilizing the data of river Lee in United

Kingdom and Thuthapuzha river in Kerala. The results confirmed the TPB-NN model as being the most efficient of the black box model tested for calibration period as short as 6 days.

Wanchope *et.al.* (1998) compared GLEAMS, Opus and PRZM-2 model runoff predictions with runoff measured in a precisely controlled field site used for chemical runoff studies. In 1992 and 1993, two 14.5 m x 42.9 m cornfield plots with 3% slope on Teflon loamy sand received six severe artificial rainfall events consisting of a 25mm/hr rainfall for 2hr. Runoff was monitored continuously using a collector and flume. All three models were very sensitive to measurable soil physical properties. Using an initial moisture condition 11 CN of 85, GLEAMS and Opus predicted runoff within 10% overall and produced a pattern of high and low runoff that closely followed the observed.

Montas and Mudramootoo (1996) developed a model named ANSWER to predict runoff and soil loss in southwestern Quebec in two agricultural watersheds. This model under estimated the sediment yield for all events. Runoff prediction with adjusted parameters were better than those with measured parameters.

Zollweg *et.al*.(1996) studied a cell based rainfall runoff model, which was integrated in to the GRASS (Geographic Resources Analysis Support System). The model consists of soil moisture balance and runoff generation/transport sub models. The model results compared favourably with recorded stream flows for 77 rainstorms on the WD-38 watershed in east central Pennsilvania. The 77 storms encompassed a wide variety of rainfall amounts, rainfall intensities and antecedent moisture conditions.

Shiley *et.al.* (1992) evaluated the effect of recession infiltration on run off volume and quantified using the kinematics’ wave model for the case of lateral flow made up of constant rain fall excess during the period of rain fall and constant infiltration after rain fall ends.

Pathak *et.al*. (1989) developed a run off model for small watersheds in the semi axial tropics. A modified SCS run off model and soil moisture accounting procedure were used to simulate run off for small watersheds and validity was tested in small vertisol watersheds at ICRISAT in India.

James and Mohanan (1981) evolved a simple deterministic model for the simulation of monthly rainfall – run off process in the monsoon season for the Chaliyar basin on the Malabar Coast. The monthly rainfall – run off regression model showed non-linear characteristics. The accuracy of the calibration model was also verified using the data for calibration period from the sub basin.

MATERIALS AND METHODS

This chapter describes the materials used and methods adopted for the study.

3.1 Location of study area

The study was undertaken in the KCAET campus Tavanur, Malappuram district. It is situated at 10°52'30" north latitude and 76° east longitude. Total geographical area of the KCAET campus is about 40 ha.

3.2 Climate

Agro climatically the area falls within the boarder line of northern zone, central zone and kole zone. Climatologically the area is in the low rainfall area (1000 – 2000mm). Medium to high rainfall zones are available within 10-15 km of the area. The area receives the rainfall mainly from southwest monsoon and northeast monsoon.

3.3 Experimental details

3.3.1 Description of the study area

A compacted field having 1.23 ha area was selected for the study. This area is the playground of the college. The area has 0.6% slope in the north south direction and has a cross slope of 0.27%. The dimensions of the ground were 175 m x 70 m. Due to the sediment deposition from the upper portion of the study area, the southern and western sides were partially covered by vegetation during the study period. To stabilize the slopping side in the southern boundary of the study area, paving of the slope with stone pitching was adopted.

A cement concrete rectangular channel having average cross section of 0.625 m x 0.16 m and 0.2 % bed slope exists below the stone pitched area. The total length of the channel is 75m. The runoff from the area is conveyed through this channel and is disposed to a percolation pond, which is constructed under the water-harvesting programme implemented in the college during the year 2004-05. The runoff from the area has contributions from the northern and eastern sides and loss from the western sides. So the area requires some modification in order to divert the entire runoff from the area to the outlet.

3.3.2 Modifications of the existing conditions of the study area for the runoff measurement

To divert the outside runoff contribution from the upper areas of the study area and to convey the runoff going outside from the study area to the channel, the following modifications were made in the existing study area.

1 To divert the outside runoff contribution from the upper areas in the northern side an interceptor channel of 40 m length and an average depth of 25cm was made along the northern boundary of the study area. It is shown in Plate 1.

2 The interceptor channel was extended to a length of 128m along the eastern boundary of the study area to intercept and divert the runoff contribution from the eastern side of the study area (Plate 2).

3 An earthen bund of top width 15 cm and side slope 1:1 and total length of 13 m was constructed at northwestern side to make sure that there is no runoff loss from the study area (Plate 3).

4 An earthen bund of 50cm top width with 1:1 side slope and of 44m length was made along the western boundary of the study area to route the runoff to the channel (Plate 4).

5 An earthen bund of 30 cm top width and side slope 1:1 of 2 m length was constructed above the study area in the western side to prevent the entry of runoff from the upper portion to the study area (Plate 5).

6 The ponding depth of channel varied from 9cm to 23cm. The runoff was found to be overflowing in the channel during heavy storms. So there was a need to increase the channel capacity. Providing an extra height of 30 cm on one side increased the discharge capacity of the channel (Plate 6).

7 To prevent the seepage loss from the stone pitched area, cement plastering was done at the worst points (Plate 7).

8 The lower portion of the study area was earth filled and runoff water was ponding over there. To divert the ponding water to the channel, land smoothing was carried at required places and three PVC pipe outlets were provided (Plate 8).

The details of the study area is shown in the Fig.1

Plate.1 Earthen channel at the northern side

Plate. 2 Interceptor drain at the eastern side

Plate. 3 Earthen bund at northwestern side

Plate. 4 Earthen bund at the western side

Plate.5 Earthen bund at then upper northern side

Plate.6 Increased channel height

Plate. 7 Cement plastering at the stone pitched area

Plate. 8 PVC pipe at the cement plastered area

.3.3 Installation of notch

For measuring the runoff generated from the study area, a rectangular notch made of 2 mm thick mild steel with 35 cm crest length and 25 cm height was installed at the end of the channel.

The notch was designed based on the peak runoff rate expecting from the study area. The peak runoff was estimated using rational formula given below

i.e. $$Q = 1/36\ CIA \qquad (1)$$

Where, Q = Peak runoff rate in m^3/s

C = Runoff coefficient

I = Rainfall intensity in cm/hr for duration equal to time of concentration

A = Area in ha

In the above equation assuming C value as 0.3, time of concentration as 15 minute and the maximum 15 minutes rainfall intensity as 8.7 cm/hr, the peak runoff rate from the study area of 1.23 ha was estimated as

$$Q = (0.3 \times 8.7 \times 1.23)/36$$

$$= 0.0891 m^3/s$$

Hence the notch had to carry a maximum peak runoff $0.0891 m^3/s$. The discharge through the notch is obtained by

$$Q=2/3C_d\sqrt{2g}LH^{3/2} \qquad (2)$$

Where,

Q = Discharge rate in m^3/s

C_d = coefficient of discharge of notch

g = acceleration due to gravity in m/s^2

L = Length of crest in m

H = Head over the crest in m.

As the width of the channel is 62.5cm and it is a limiting factor, 35 cm crest length was considered. Substituting L = 35 cm, $Q = 0.0891 m^3/s$ and $C_d = 0.6$ the value of H was obtained and it was 25 cm. The design dimensions of the notch are given in fig.2 and the installed notch is shown in Plate 9.

At the down steam side of the notch to collect the entire flow from the notch to a measuring tank for calibrating the notch, a trapezoidal channel of length 77.5 cm made of GI sheet was installed below the crest. Wooden poles supported the channel section (Plate 9).

A steel rule was fixed in the channel side at a distance of 4H from the crest to measure the depth of flow over the notch such that the zero of the scale was the same level as the crest level of the notch. The smallest division in the scale was 1cm. It was found difficult to measure the head accurately during heavy rainfall due to fluctuations in the water level caused by the falling rainfall. So a hook gauge was installed at the same distance from the crest across the channel. The smallest division in the hook gauge was 1mm (Plate 10).

3.4 Calibration of notch

A cylindrical measuring tank of 220 liter capacity was used to calibrate the notch. The height below the trapezoidal channel was found to be insufficient to place the measuring tank .So required depth of cut was

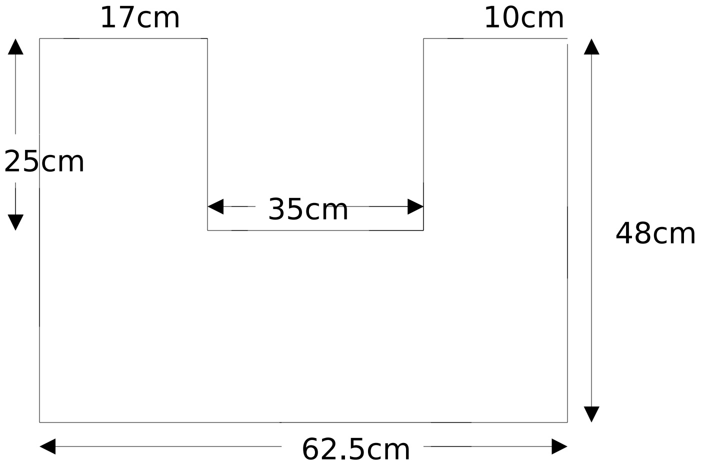


Fig. 2 Dimensions of notch

Plate.9 Galvanised iron sheet below the notch

Plate. 10 Hook gauge at 4H distance from the crest

made to place the tank. It was placed exactly below the end of the trapezoidal channel to collect the runoff from the notch.

The calibration of notch was done during a high intensity storm. The initial depth of flow over the channel was measured using the hook gauge. Simultaneously a stopwatch was started. Discharge from the notch was collected in the measuring tank. The time taken for filling the measuring tank and corresponding depth of flow from the hook gauge was noted. A graph was plotted by taking the average depth of flow along the X-axis and discharge along the Y-axis. A relation connecting discharge and depth of flow was obtained.

3.5 Runoff measurement

For the study year 2005, the SW monsoon season started on June 10. The study area was made ready for runoff measurement by 15th July 2005. So the runoff from the rainfall that occurred between this period could not be accounted. Measurement of runoff from the storms occurring from 6.00 AM to 6.30 PM was only possible as the measurement was carried out manually. Runoff from isolated storms was measured. Rainfalls of short duration and low intensity did not contribute runoff to the measuring point.

The starting time of rainfall was noted using a stopwatch. The time at which runoff just touch the crest level and depth of flow after each 30 second were noted. For very heavy storm it was difficult to measure the depth at every 30 seconds, in that case the depth of flow was noted for every 60 seconds. The procedure was continued till the depth of flow recedes to the crest level of the notch.

3.6 Estimation of runoff volume

The discharge corresponding to the depth of flow taken at an interval of 30 seconds was calculated from the discharge – head relationship. Taking time along the X- axis and discharge along the Y-axis hydrographs for each storms were plotted. The area under the hydrograph gave the direct runoff volume. Runoff volume was estimated by multiplying the sum of the ordinates of storm hydrograph with time interval. A portion of runoff was required for ponding the channel up to the crest level. So the ponded volume should also be considered to get the total runoff volume.

3.7 Rainfall – runoff relationship

The rainfall depth corresponding to the storm was obtained from the rainfall chart. The runoff depth was obtained by dividing the runoff volume with the area. The rainfall – runoff relationship was obtained by plotting rainfall depth as abscissa and runoff depth as ordinate.

3.8 Determination of runoff coefficient

The runoff coefficient is the ratio between runoff and rainfall. The runoff coefficient for various storms was calculated and the average value was taken as the runoff coefficient of the area.

3.9 Derivation of unit hydrograph

Unit hydrograph is defined as the direct runoff hydrograph, produced by a storm of specific duration, resulting from an excess rainfall depth /runoff depth of 1cm which is uniformly distributed over the entire watershed area.

The following steps were used for deriving the unit hydrograph, from a storm hydrograph.

1. A number of isolated storm hydrographs caused by short spells of rainfall excess, each of approximately same duration (0.9 to 1.1D hr) are selected from the study area.

2. The area under each storm hydrograph was evaluated and the ordinates of various storm hydrographs were divided by the respective runoff depth values to obtain the ordinates of unit hydrograph.
3. The runoff depth may be obtained by using the equation as

   Excess rainfall depth = $0.36(\sum 0)\, t/A$ cm.

   Where,

   $\sum 0$ = sum of all storm hydrograph ordinates (cumec).

   t = time interval between successive ordinates in hr.

   A = watershed area in km^2.

   Ordinate of unit hydrograph = (ordinate of storm hydrograph)/(runoff depth).

4. Plot all the hydrograph ordinates and corresponding time.

3.10 Maximum intensity – duration relationship

For calculating the maximum intensity, rainfall chart for the period of 17-06-05 to 19-11-05 were considered. During this period 88 mass curves were obtained. The rainfall chart covers a period of 25hrs. The smallest division of the chart is 15min. The duration selected for finding the maximum intensities were 5min, 10min, 15min, 30min, 1hr, 2hr, 4hr, 6hr and 12hr.

The simple method of finding the maximum intensity for a given duration in any storm is to use a transparent scale with vertical lines drawn on it at a distance equal to the required duration and to measure the maximum vertical intercept of the mass curve by sliding it over the chart. Transparent scales for the required durations were prepared using AutoCAD and were shown in Appendix -2. The procedure was repeated for the 88 charts. From the 88 charts, highest value of maximum rainfall depth for each duration was found out. The maximum intensity was obtained by dividing the highest value of maximum rainfall depth by the corresponding duration.

By plotting maximum intensity along the X- axis and duration along the Y- axis, a relation between them was obtained.

RESULTS AND DISCUSSION

The results of the study conducted are presented in this chapter.

4.1 Calibration of notch

The calibration of notch was done according to the procedure given in 3.4. Table.1 gives the experimental data collected. The highest discharge of 31.43 lps was recorded for the head of 12.20 cm. The Fig.3 shows the plot of discharge (lps) against head (cm)). The R^2 value was found to be 0.98. A power relation was obtained as $Q = 0.7661H^{1.4503}$ which was similar to the Francis formula for computing the discharge of rectangular notch.

Table.1: Measured discharge and head over the notch for calibration

Head (cm)	***Discharge (lps)***	***Head (cm)***	***Discharge (lps)***
4.05	5.50	7.60	14.67
4.50	6.87	8.70	18.33
5.15	7.97	9.80	15.71
5.90	10.00	10.90	25.46
6.70	12.94	11.60	27.50
6.70	12.94	12.20	31.43

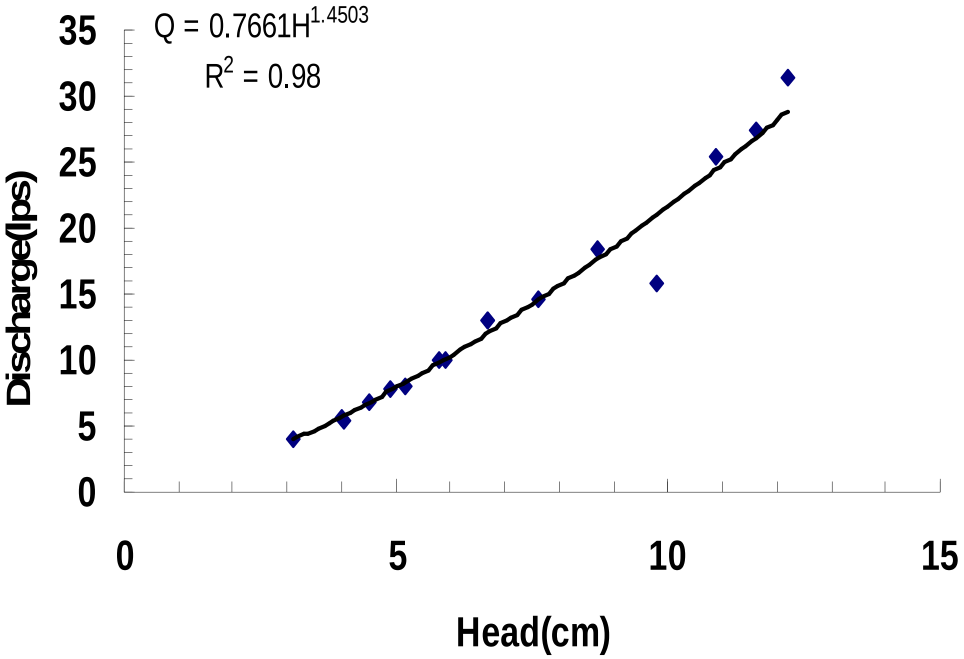


Fig.3. Head – discharge relationship

4.2 Measurement of depth of flow

Measurement of depth flow over the notch for various storms was done as per the procedure in 3.5. The experimental data collected for seven storms were given in Appendix 1.

4.3 Mass curve analysis

Mass curve analysis of each seven storms was done to find duration, amount and intensity of rainfall. The results of the analysis were presented in the following tables. Among the seven storms except the storm $P_{3,}$ all were isolated . For the storm P_3 ,the total rainfall and durations were 45.25mm and 225 min respectively. For the other storms the rainfall depth varied from 7.5mm to 17.5 mm. and rainfall duration ranged from 15 min to 55 min. Maximum intensities of these storms were with the range of 30-89 mm/hr.

Table.2: Mass curve analysis for storm P_1

Time	Duration (min)	Rainfall (mm)	Intensity (mm/hr)
5:00	15	7.5	30

Table.3: Mass curve analysis for storm P_2

Time	Duration	Rainfall (mm)	Intensity (mm/hr)
4:38	0	0	0
4:45	7.0	6	51
4:55	10	2	12
Total	17	8	28.2(avg)

Table.4: Mass curve analysis for storm P_3

Time	Duration (min)	Rainfall (mm)	Intensity (mm/hr)
3:10	0.00	0.00	0.00
3:38	28.00	12.75	27.32
4:00	22.00	2.50	6.80
4:25	25.00	19.00	45.60
4:53	28.00	0.50	1.10
5:00	7.00	3.00	25.70
5:10	10.00	3.00	18.00
5:15	5.00	0.50	6.00
5:30	15.00	0.25	1.00

5:45	15.00	0.25	1.00
5:55	10.00	1.00	6.00
6:25	30.00	2.00	4.00
6:55	30.00	0.50	1.00
Total	225.0	45.25	12.00(avg.)

Table. 5: Mass curve analysis for Storm P_4

Time	Duration (min)	Rainfall (mm)	Intensity (mm/hr)
11:30	0.00	0.00	0.00
11:40	10.00	1.50	9.00
12:00	15.00	6.00	24.00
12:30	30.00	0.50	1.00
Total	55.00	8.00	8.70(avg.)

Table.6: Mass curve analysis for storm P_5

Time	Duration (min)	Rainfall depth (mm)	Intensity (mm/hr)
1:35	0.00	0.00	0.00
1:45	10.00	4.00	24.00
1:50	10.00	2.50	15.00
2:05	15.00	11.00	44.00
Total	35.00	17.50	30.00(avg.)

Table.7: Mass curve analysis for storm P_6

Time	Duration (min)	Rainfall depth (mm)	Intensity (mm/hr)
6:45	0.00	0.00	0.00

6:50	5.00	6.75	89.00
7:00	10.00	1.50	9.00
7:20	20.00	0.50	1.50
Total	35.00	8.75	15.00(avg.)

Table.8: Mass curve analysis for storm P_7

Time	Duration (min)	Rainfall (mm)	Intensity (mm/hr)
7:55	0	0	0
8:00	5	1.25	15
8:08	5	4.75	57
8:15	7.5	2.5	20
8:20	7.5	2.5	20
8:25	5	0.5	6
Total	30	11.5	23.00(avg.)

4.4 Discharge estimation

The discharge corresponding to the depth of flow measured over the notch for various storms was calculated from the equation $Q = 0.7661H^{1.4503}$. The corresponding hydrographs were also plotted.

The discharge calculated for the storm P_1 was given in Table.9 and corresponding hydrograph was shown in fig.4. The maximum discharge estimated was 0.60 lps and the duration of runoff was 9min.

Table.9: Estimated discharge for the storm P_1

Time (cm)	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***
0	0.00	270	0.60
30	0.13	300	0.45
60	0.28	330	0.36
90	0.45	360	0.36
120	0.60	420	0.28
150	0.60	450	0.20
180	0.60	480	0.13
210	0.60	510	0.07
240	**0.60**	540	0.00

The calculated runoff for the storm P_2 was presented in Table.10 and the hydrograph was depicted in fig.5. Maximum discharge for the storm was 2.64lps and the runoff continued for 20.5min.

Table.10: Estimated discharge for the storm P_2

Time (sec)	***ge (lps)***	***Time (sec)***	***ge (lps)***	***Time (sec)***	***e (lps)***	***Time (sec)***	***e (lps)***
0	0.0	720	1.65	420	**2.64**	990	0.55
60	0.36	750	1.58	450	2.40	1020	0.45
120	1.18	780	1.44	480	2.48	1050	0.36
180	1.65	810	1.31	510	2.40	1080	0.28
240	2.09	840	1.18	540	2.32	1110	0.24
300	2.24	870	0.99	570	2.24	1140	0.13
330	2.24	900	0.93	600	2.16	1170	0.07
360	2.40	930	0.82	630	2.01	1200	0.02
390	2.40	960	0.65	660	1.86	1230	0

Table 11 gave the discharge calculated for the storm P_3 and corresponding hydrograph was plotted in Fig.6. This storm produced runoff for 167min.

Table.11: Estimated discharge for the storm P_3

Time (sec)	***arge (lps)***	***Time***	***Dischage***	***Time***	***arge (lps)***	***Time***	***rge (lps)***	***Time (sec)***	***arge (lps)***
0	0.00	1020	12.88	2040	10.80	3120	4.51	4180	17.65
60	1.12	1080	14.51	2100	10.05	3180	4.71	4240	18.54
120	1.79	1140	14.65	2160	9.80	3240	5.31	4300	20.67
180	2.72	1200	14.78	2260	9.19	3300	5.31	4360	21.29
240	3.23	1260	14.78	2340	8.84	3360	8.36	4420	21.92
300	4.13	1320	14.78	2400	9.07	3480	7.00	4540	26.12
360	4.13	1380	14.78	2460	8.25	3520	8.36	4600	27.13
420	5.10	1440	14.51	2520	10.05	3580	8.84	4660	31.43
480	6.03	1500	13.96	2580	7.22	3640	9.31	4720	**28.48**
540	7.00	1560	13.68	2640	7.00	3700	10.80	4780	27.8
600	8.13	1620	13.68	2700	6.78	3760	11.31	4840	26.79
660	9.07	1680	13.41	2760	6.35	3820	11.82	4900	25.13
720	9.80	1740	12.61	2820	6.03	3880	12.61	4960	24.48
780	10.54	1800	12.35	2880	5.82	3940	13.14	5020	23.19
840	11.31	1860	12.08	2940	5.31	4000	14.23	5080	22.55
900	12.08	1920	11.56	3000	5.31	4060	15.06	5140	20.98
960	12.61	1980	11.31	3060	4.81	4120	16.2	5200	20.05

Time	Discharge (lps)	Time	Discharge (lps)	Time	Discharge (lps)	Time	Discharge (lps)
5260	19.14	6520	2.4	7780	5.51	8980	2.32
5320	17.94	6580	2.24	7840	5.61	9040	2.09
5380	17.65	6640	2.09	7960	5.92	9100	1.79
5440	16.49	6700	2.09	8020	5.92	9160	1.65
5500	16.05	6760	2.09	8080	5.92	9220	1.37
5560	15.35	6820	2.16	8140	6.03	9280	1.24
5620	14.65	6880	2.4	8200	6.03	9340	0.87
5680	13.96	6940	2.56	8260	5.72	9400	0.87
5740	13.41	7000	2.72	8320	5.41	9460	0.76
5800	12.88	7060	2.89	8380	5.1	9520	0.55
5860	12.08	7120	2.89	8440	4.61	9580	0.55
5920	12.61	7180	2.89	8500	4.32	9640	0.45
5980	11.05	7240	3.06	8560	4.13	9700	0.41
6040	10.54	7300	3.23	8620	3.76	9760	0.28
6100	9.8	7360	3.4	8680	3.58	9820	0.2
6160	8.84	7420	3.67	8740	3.32	9880	0.16
6220	8.36	7480	3.95	8800	3.23	9940	0.07
6280	7.67	7540	4.13	8880	2.72	1000	0.02
6340	7.11	7600	4.32	8920	2.48	1006	0
6400	6.56	7660	4.81				
6460	6.14	7720	5.00				

The runoff calculated for the storm P_4 is given in Table.12 and the corresponding hydrograph is shown in Fig.7

Table.12: Estimated discharge for the storm P_4

Tim	***Discharge (lps)***	***Time (sec)***	***(lps)***
0	0	450	1.72
30	0.13	480	1.44
60	0.41	510	1.44
90	0.65	540	1.39
120	0.82	570	0.82
150	1.12	600	0.5
180	1.37	630	0.5
210	1.44	660	0.5
240	1.44	690	0.24
270	1.65	720	0.24
300	1.72	750	0.07
330	1.65	780	0.07
360	**1.72**	810	0.02
420	1.72	840	0

The runoff for the storm P_5 was given in Table.13 and the corresponding hydrograph was shown in Fig.8 .The runoff was last for 41min and the highest discharge recorded was 27.80 lps.

Table.13: Estimated discharge for the storm P_5

Time (sec)	Discharge (lps)	Time (sec)	Discharge (lps)	Time (sec)	Discharge (lps)	Time (sec)	Discharge (lps)
0	0	660	26.46	1290	11.31	1890	2.24
30	1.37	690	25.96	1320	10.54	1920	2.09
60	1.94	720	25.46	1350	10.05	1950	1.94
90	3.06	750	24.80	1380	9.31	1980	1.72
120	4.71	780	24.15	1410	8.84	2010	1.31
150	6.35	810	23.19	1440	8.36	2040	1.24
180	8.13	840	23.19	1470	7.79	2070	1.12
210	11.82	870	21.92	1500	7.22	2100	0.87
240	12.88	900	21.60	1530	6.78	2130	0.82
270	14.51	930	20.67	1560	6.24	2160	0.71
300	19.75	960	19.29	1590	5.72	2190	0.55
330	20.98	990	18.54	1620	5.31	2220	0.50
360	22.55	1020	17.95	1650	4.80	2250	0.55
420	24.15	1050	16.92	1680	4.51	2280	0.50
450	25.13	1080	15.91	1710	4.04	2310	0.32
480	25.46	1110	15.35	1740	3.58	2340	0.28
510	26.46	1140	15.2	1770	3.41	2370	0.20
540	**27.80**	1170	13.96	1800	2.97	2400	0.07
570	26.62	1200	13.28	1830	2.89	2430	0.04
600	27.13	1230	11.69	1860	2.4	2470	0
630	26.79	1260	11.82				

The estimated discharge for the storm P_6 was given in Table.14 and the hydrograph is shown in Fig.9. The runoff continued up to 26min and the peak discharge rate was 3.7 lps.

Table.14: Estimated discharge for the storm P$_6$

Time (sec)	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***
0	0	810	2.09	420	3.7	1200	0.76
30	0.36	840	1.94	450	3.67	1230	0.55
60	0.99	870	1.72	480	3.58	1260	0.45
90	1.51	900	1.58	510	3.32	1290	0.45
120	1.79	930	1.51	540	3.14	1320	0.45
150	2.56	960	1.51	570	3.23	1350	0.36
180	2.56	990	1.51	600	2.89	1380	0.2
210	2.8	1020	1.44	630	2.97	1410	0.2
240	3.14	1050	1.31	660	2.8	1440	0.13
270	3.32	1080	1.24	690	2.8	1470	0.04
300	3.32	1110	1.05	720	2.8	1500	0.04
330	3.58	1140	0.87	750	2.4	1530	0.02
360	**3.7**	1170	0.76	780	2.4	1560	0

For the storm P$_7$, Table.15 gave the calculated discharge and the corresponding hydrograph was shown in Fig.10. The runoff occurred for 13min and had a peak discharge rate of 0.71 lps

Table.15: Estimated discharge for the storm P$_7$

Time (sec)	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***
0	0	420	0.65
60	0.2	480	0.45
120	0.41	540	0.28

Time (sec)	***Discharge (lps)***	***Time (sec)***	***Discharge (lps)***
180	0.55	600	0.13
240	**0.71**	660	0.27
300	0.71	720	0.27
360	0.65	780	0

Total runoff volume was obtained by adding the volume from the hydrograph and ponded volume in the channel. The ponded volume of the channel was obtained as 8.94m^3

Fig.4. Hydrograph for the storm P_1

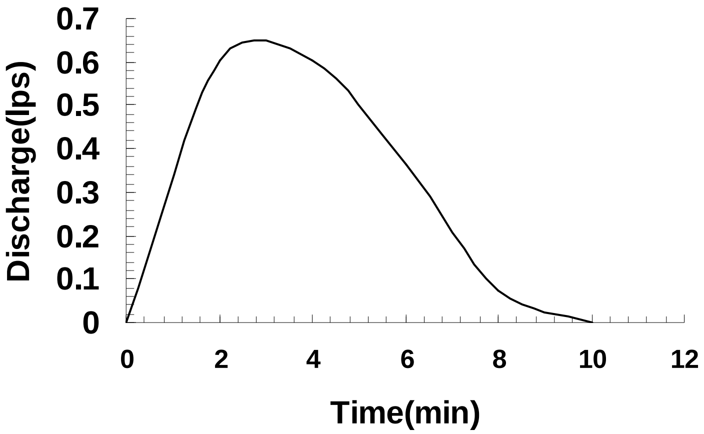
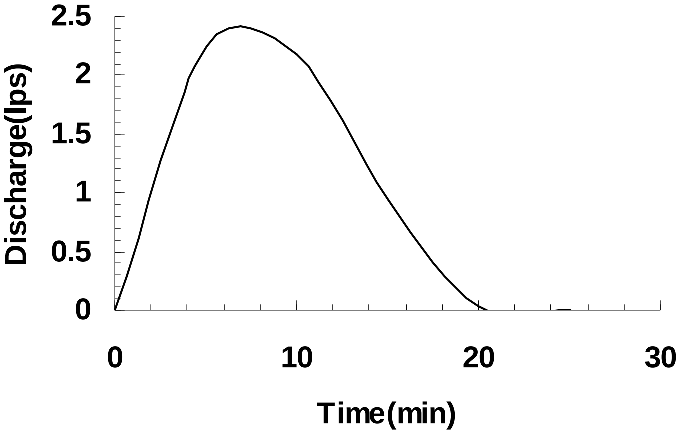


Fig.5.Hydrograph for the storm P_2



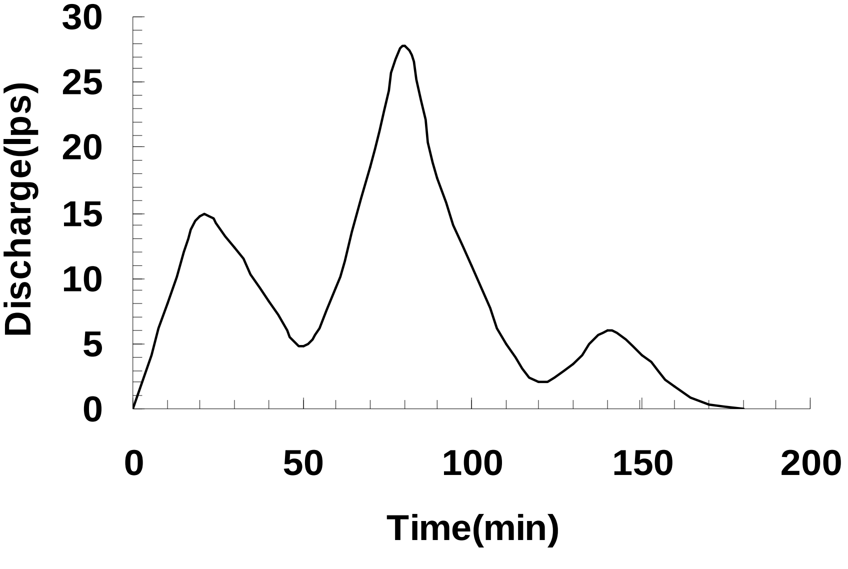


Fig. 6. Hydrograph for the complex storm P_3

Fig. 7.Hydrograph for the storm P_4

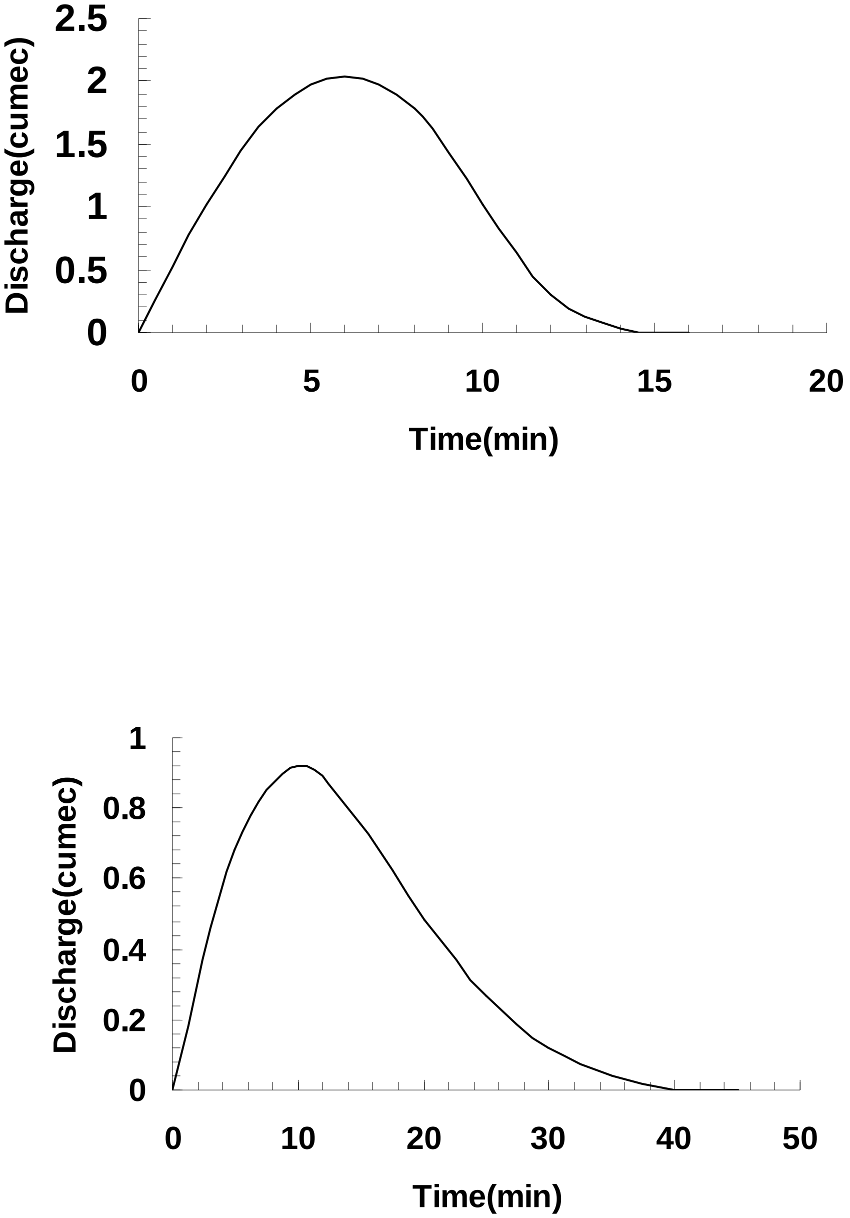


Fig.8. Hydrograph for the storm P_5

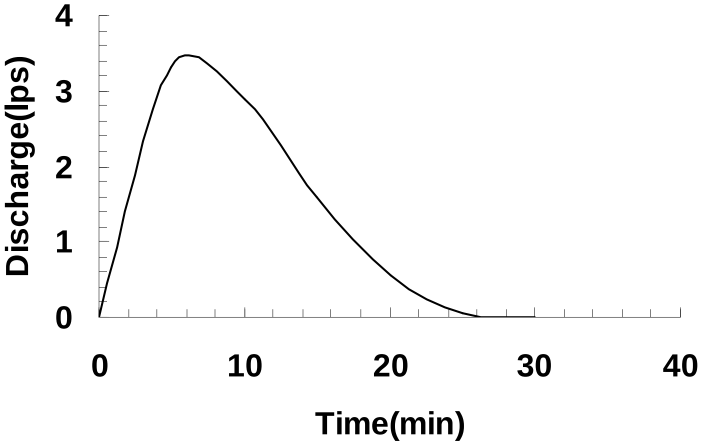


Fig.9.Hydrograph for the storm P6

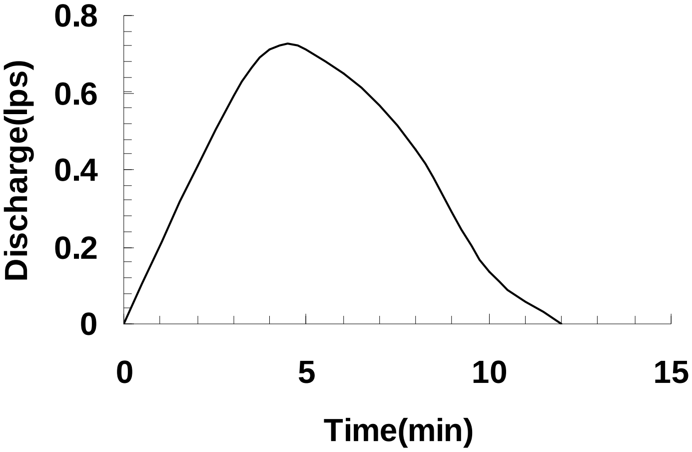


Fig.10. Hydrograph for the storm P7

The results obtained by analyzing mass curves and hydrographs of storms under consideration were summarized in Table.16.

Table.16 Results of analysis of mass curves and hydrographs of various storms

Storm	Rainfall depth (mm)	Duration of Rainfall (min)	Runoff volume (m^3)	Runoff duration (min)	Max. Intensity (mm/hr)	Average intensity (mm/hr)	Peak rate (lps)	Time to peak (min)	Antecedent Rainfall (in 24hr)
P_1	7.50	15.00	9.13	9.00	30.00	30.00	0.61	5.50	10.75
P_2	8.00	17.00	10.55	20.50	48.00	28.20	2.64	7.00	16.25
P_3	**45.25**	**225.00**	**102.01**	**167.00**	45.60	12.01	31.43	**78.00**	33.50
P_4	8.00	55.00	9.71	14.00	24.00	8.70	1.72	5.00	66.00
P_5	17.50	35.00	37.32	41.00	44.00	**30.00**	**27.8**	9.00	73.75
P_6	8.75	35.00	11.45	26.00	**81.00**	15.30	3.70	6.00	36.00
P_7	11.50	30.00	9.22	13.00	57.00	23.00	0.71	4.00	0.00

Maximum runoff volume obtained from the measured storms was 102.01m^3 for the complex storm P_3. The rainfall depth produced that runoff volume was 45.25mm. P3 continued for 225min.

Among the isolated storms the runoff volume was maximum for the storm P_5 ie 37.32m^3 produced by a rainfall depth of 17.5mm. The duration of rainfall was

35min. only, but the runoff continued for 41min. The peak value was also higher for the storm P_5. This may be because a total rainfall depth of 73.75mm was occurred within 24 hr before the commencement of this rainfall. So the field was fully saturated.

The storm P_6 occurred for the same duration as that of P_5 but the runoff volume produced was only 11.45 m^3. This was because the rainfall depth (8.75mm) and average intensity (15mm/hr) was less, even though the maximum intensity was high for the storm.

In the case of storm P_4, the rain occurred for 55min, the runoff was continued only for 14min and the runoff volume was $9.71m^3$. It was because the intensity and rainfall depth was less.

Even though the average intensity, rainfall depth and duration of the storm P_7 was comparable with P_4, P_5 and P_6 runoff volume ($9.22m^3$) and the peak rate (0.71 lps) was less.. The variation was due to the unsaturated condition of the field. There was no rainfall for the past 24 hrs. So the infiltration rate was high and the runoff duration was less.

Comparing storms P_1 and P_2, rainfall depth, duration and average intensities of both were almost same. But the runoff duration and peak runoff for the storm P_2 was more. This was the result of high antecedent rainfall condition before the storm P_2.

From the above discussion it was noticed that the runoff volume and peak runoff were not varying with respect to one factor, but it depended on many factors like rainfall depth, duration, intensity and antecedent moisture condition.

Comparing the hydrographs of isolated storms the rising limb was skewed to the left. The shape of the field more resembles to a fan shaped watershed. Hence the time to peak runoff was less and the rising limb was steeper than the falling limb. Time taken to reach peak for the six isolated storms was between 4 to 9 min. Even though there was wide variation in the runoff duration, the mainly varying part was the falling limb rather than rising limb.

Comparing the hydrographs of P_4 and P_7 with other isolated storm hydrographs the time to peak was more hence the rising limb of P_1 and P_2 was more skewed to the right. In the case of P_4 it was due to less average intensity while in the case of P_7 it was due to less antecedent rainfall condition.

4.5 Rainfall- runoff depth relation

The rainfall and runoff depth were obtained according to the procedure given in 3.7. And were presented in Table.16 and the Fig.11 showed the plot between rainfall and runoff.

The relation obtained can be used for finding out runoff corresponding to any rainfall occurring in the area. For the study area, the relation was found to be linear. The relation obtained was Y= 0.2012X- 0.8467 and the R^2 value was 0.9851

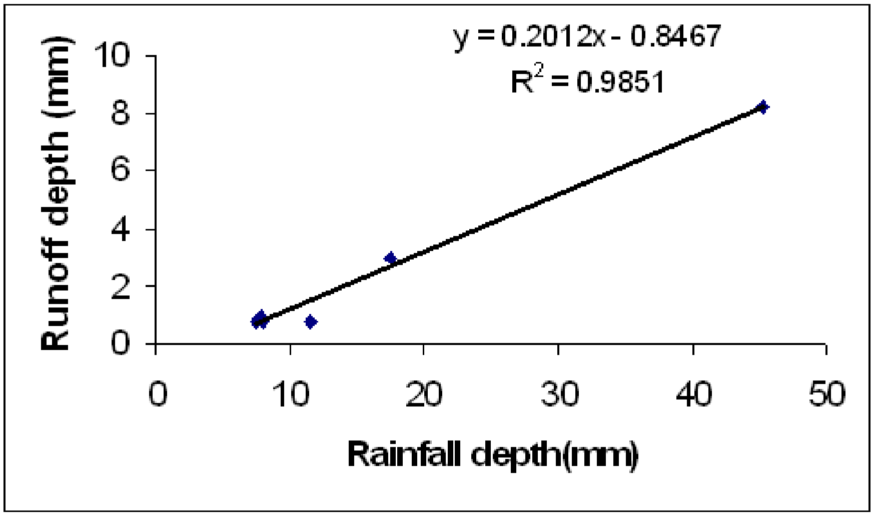


Fig. 11. Rainfall- runoff relation

4.6 Determination of runoff coefficient

The runoff coefficient is the ratio between runoff and rainfall. Runoff coefficient obtained with different storms was given in Table.17.

Table .17: Runoff coefficient for various storms

Storm	Rainfall depth (mm)	Runoff depth (mm)	Runoff coefficient
P_1	7.50	0.738	0.09
P_2	8.00	0.852	0.10
P_3	45.25	8.243	0.18
P_4	8.00	0.785	0.09
P_5	17.50	3.015	0.17
P_6	7.75	0.925	0.11
P_7	11.50	0.745	0.04

Runoff coefficient of the area was obtained as 0.12

The highest runoff coefficient obtained was for the complex storm P_3 followed by the storm P5. For these storms rainfall depth and corresponding runoff depth were more compared to other storms. The next highest rainfall depth was obtained for the storm P_7. But the runoff produced was less due to the less antecedent rainfall condition. So a less value of runoff coefficient was obtained for the storm P_7.

There was percolation loss through the stone pitched area through which the water was conveyed to the channel. As one side of the channel was the stone pitched area, a portion of the runoff was also lost during ponding in the channel. So time taken for concentrating flow was high and time taken to drain the channel was less. As the downstream part of the ground was vegetated more water was infiltrated. The lower part of the study area was level compared to the upper part, hence appreciable amount of water ponded there. These various reasons affected the runoff coefficient obtained.

4.7 Derivation of unit hydrograph

Unit hydrograph from various storm hydrograph were derived as per the procedure 3.9. The unit hydrograph ordinates derived and plot of unit hydrograph is given below.

The data for the unit hydrograph for P_1 is given in Table 18 and the graph is shown in fig.12.

Table.18: Data on unit hydrograph for the storm P_1

Time (min)	0	2	4	6	8	10
Ordinate of unit hydrograph (cumec)	0	2.92	2.92	1.76	0.35	0

The data for the unit hydrograph for P_2 is given in Table 19 and corresponding graph is shown in fig.13.

Table.19: Data for unit hydrograph P_2

Time (min)	0	5	10	15	20	25
Ordinate of unit hydrograph (cumec)	0.00	1.32	1.28	0.55	0.01	0.00

Data for the unit hydrograph for P_4 are given in Table.20 and corresponding graph is given in fig.14

Table.20: Data for unit hydrograph for P_4

Time (sec)	0	2	4	6	8	10	12	14
Ordinate of unit hydrograph (cumec)	0.00	1.01	1.78	2.04	1.78	1.01	0.29	0.03

Data for the storm P_5 are given in Table.21 and the unit hydrograph is shown in fig.15

Table.21: Data for unit hydrograph for the storm P_5

Time (min)	0	5	10	15	20	25	30	35	40
Ordinate of unit	0	0.68	0.91	0.75	0.48	0.28	0.11	0.03	0.00

hydrograph (cumec)									

Data for the unit hydrograph for P_6 is given in Table.22 and the corresponding graph is shown in fig.16

Table.22: Data for unit hydrograph for the storm P_6

Time (min)	0	5	10	15	20	25
Ordinate of unit hydrograph (cumec)	0	1.26	1.09	0.6	0.21	0.01

Data for the unit hydrograph P_7 storms is given in Table 23 and the corresponding graph is shown in the fig.17.

Table .23: Data for unit hydrograph for the storm P_7

Time (min)	0	2	4	6	8	10	12
Ordinate of unit hydrograph (cumec)	0	0.14	0.24	0.22	0.15	0.04	0

The unit hydrograph obtained for six storms were vary in durations. The durations for various unit hydrographs were 9min, 20.5min, 14min, 41min, 26min, and 13min. The duration for the unit hydrograph for the storm P1 and P_7 was found to be nearly equal. So the average of ordinates of these two was taken as the ordinate of representative unit hydrograph for the area. Unit hydrograph obtained for the area can be used for obtaining storm hydrograph for any duration and any rainfall depth. The ordinate of representative unit hydrograph derived was given in Table.24 and corresponding data was given in Fig 17.

Table.24: Ordinates of representative unit hydrograph

Time (min)	0	2	4	6	8	10	12
Ordinate of unit hydrograph (cumec)	0	1.53	1.88	0.99	0.25	0.02	0

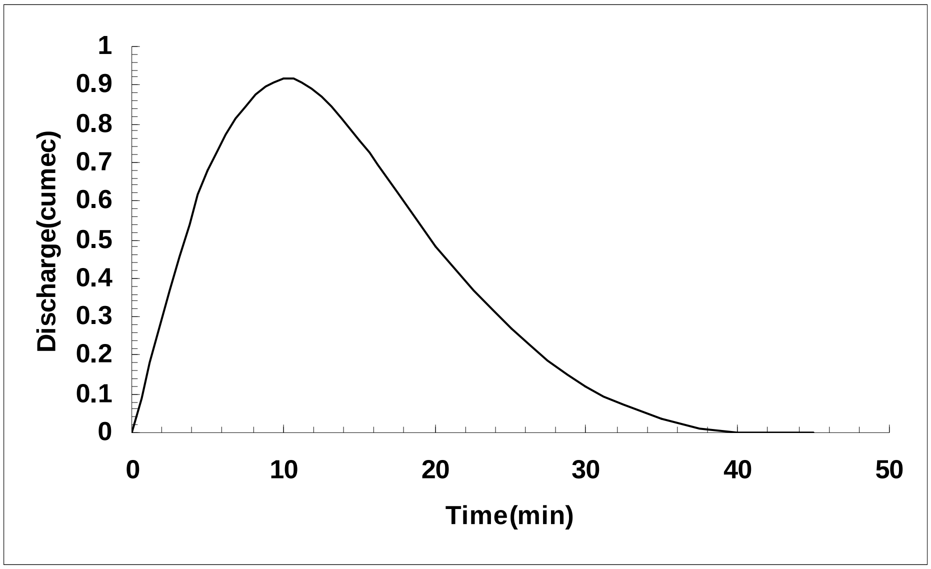


Fig.12. Unit hydrograph for the storm P_1

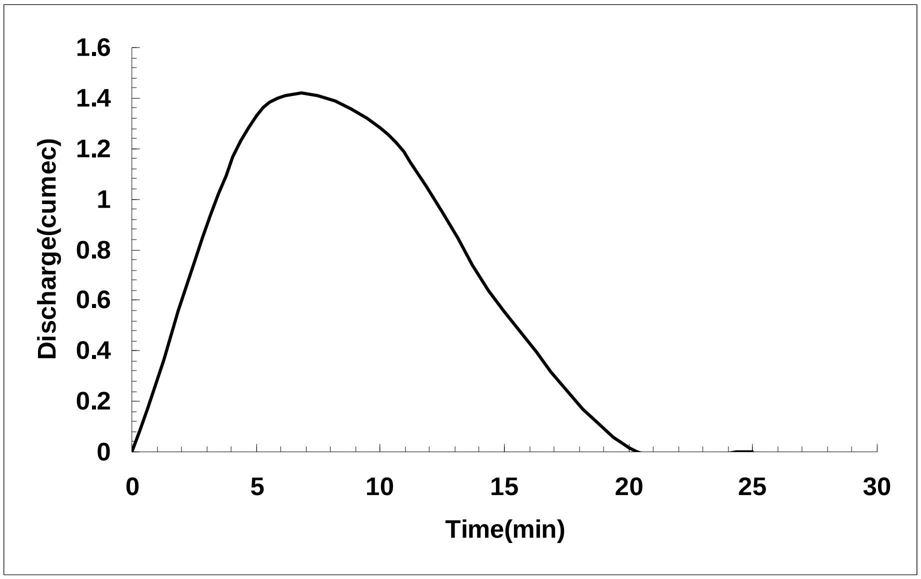


Fig.13. Unit hydrograph for the storm P_2

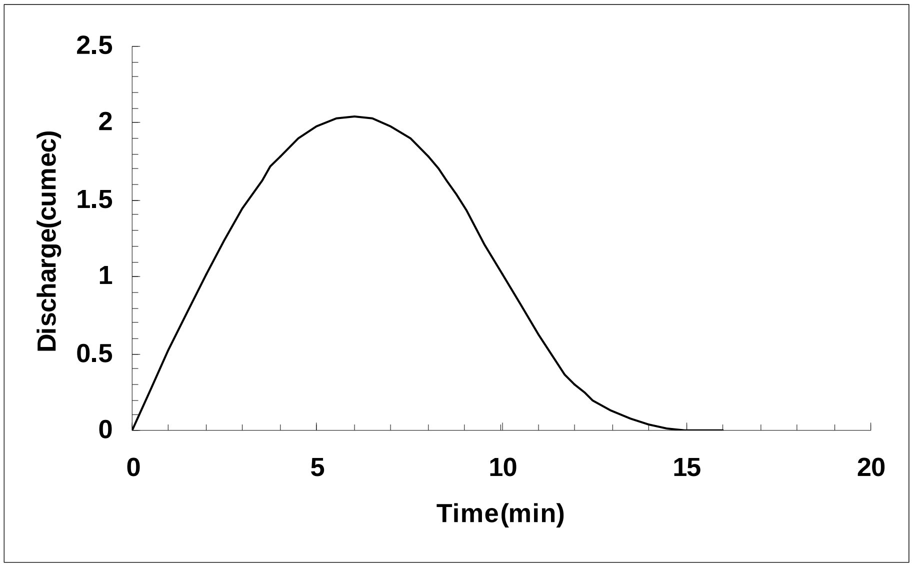


Fig. 14. Unit hydrograph for the storm P_4

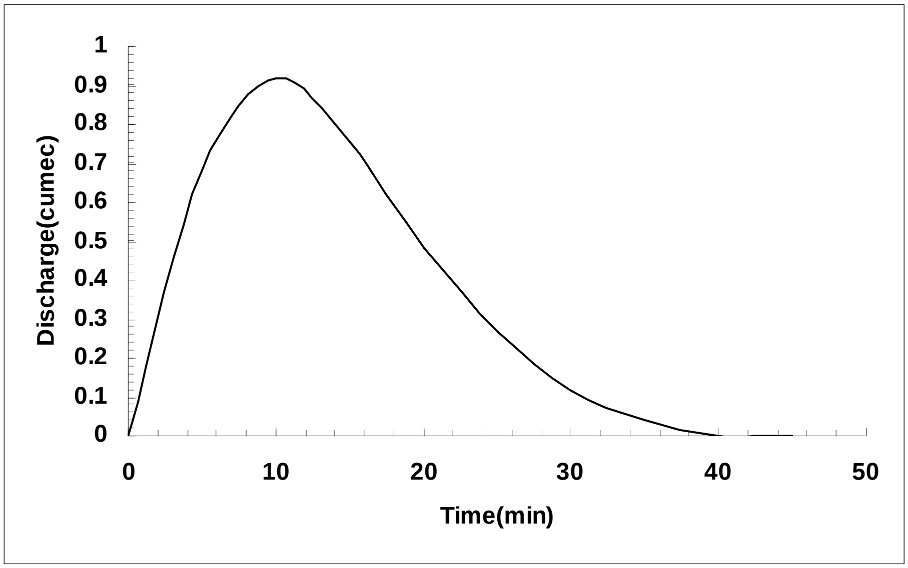


Fig.15. Unit hydrograph for the storm P_5

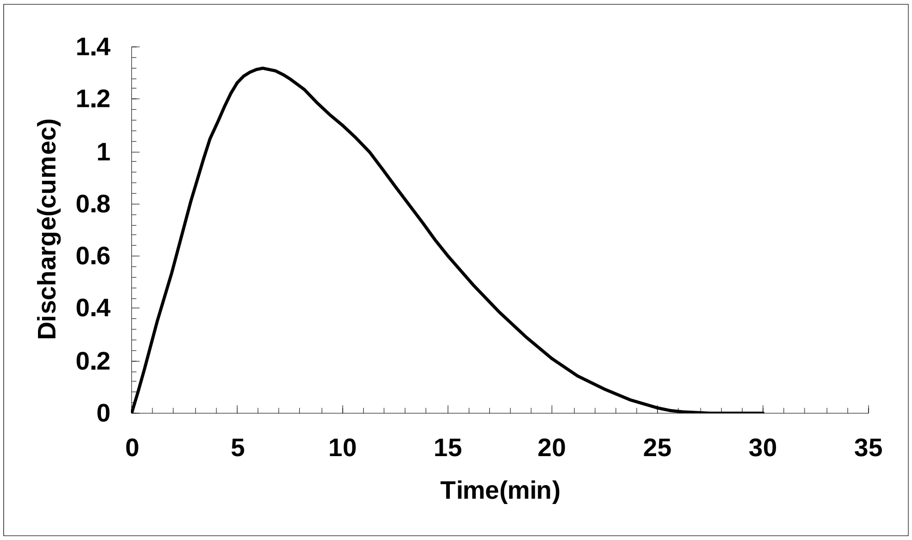


Fig.16. Unit hydrograph for the storm P_6

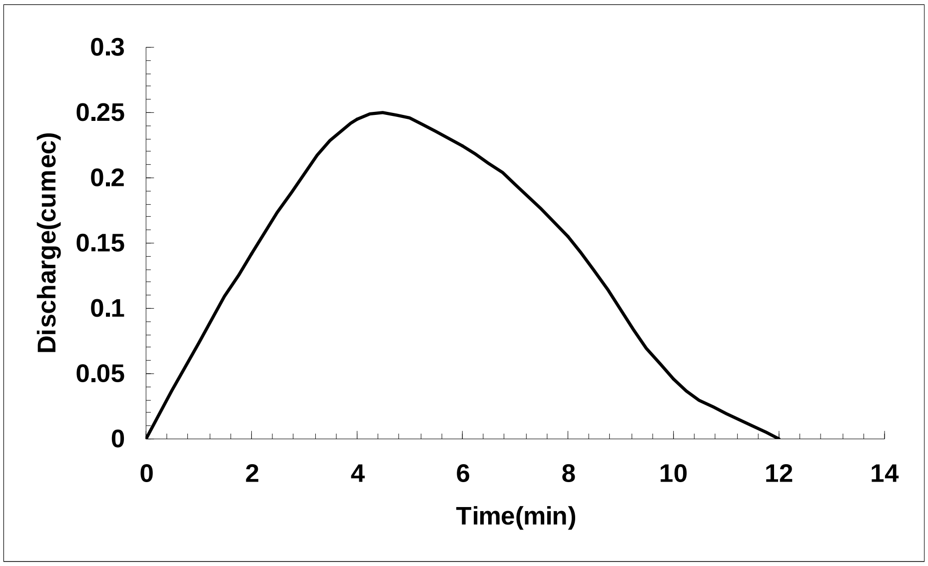


Fig.17. Unit hydrograph for the storm P_7

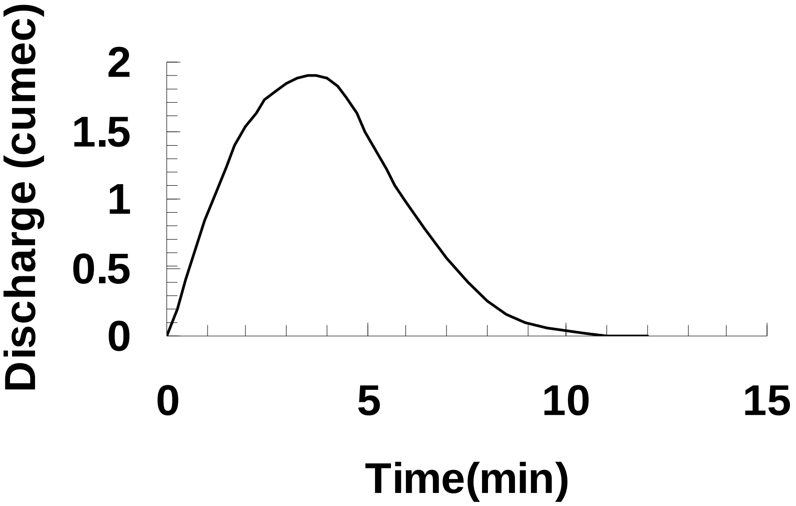


Fig.18. Representative unit hydrograph

4.8 Maximum intensity- Duration relationship

Analysis of rainfall chart was done according to the procedure in the 3.10 and is given in Appendix 3

The maximum intensities obtained for various durations were given in Table 25 and the corresponding graph is shown in fig .19. The obtained relation was $Y = 9.0029 X^{0.6086}$. The R^2 value obtained is 0.9506.

Table .25: Maximum intensities for different duration

Duration	5 min	10 min	15 min	30 min	1 hr	2 hr	4 hr	6 hr	12 hr
Intensity (mm/hr)	120	96	87	70.8	44.4	22.2	11.4	7.2	4.8

Maximum I hr intensity obtained was 44.4mm/hr. An inverse relation was indicated between maximum intensity and duration. The relation gives an idea about the max intensity rain occurring for different durations in the study area. This is essential while designing any rainwater harvesting or soil conservation structures.

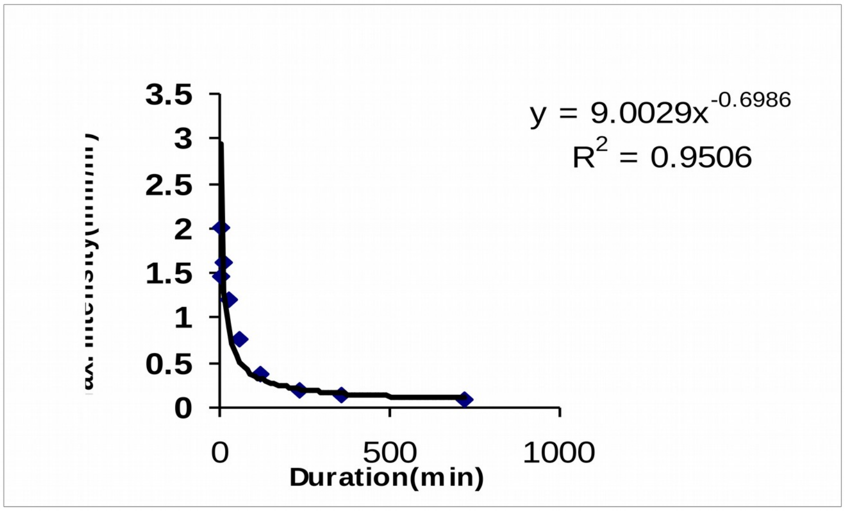


Fig.19. Maximum Intensity –Duration relationship

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SUMMARY

Rainwater harvesting appears to be one of the most promising alternatives for supplying fresh water scarcity and escalating demand. Hydrological analysis is the basic criteria for the design of rainwater harvesting structure.

A study was undertaken to do the rainfall-runoff analysis, KCAET play ground as the study area. The study included runoff estimation from the area, determination of runoff coefficient and to find out a relation between maximum intensity and duration and a relation between rainfall and corresponding runoff.

- Runoff rate from the ground was measured for seven storms. (P_1, P_2, P_3, P_4, P_5, P_6, P_7)

- A relation between head and discharge was obtained for the calibration of notch. The relation was $Q = 0.7661H^{1.4503}$. The R^2 value obtained was 0.98.

- Runoff volume estimated for various storms were $9.13m^3$, $10.55\ m^3$, $102.01\ m^3$, $9.71\ m^3$, $37.32\ m^{3,}$ $11.45\ m^3$ and $9.22\ m^3$respectively.

- A relation between rainfall and runoff was found out as $Y = 0.201X – 0.8467$ and the R^2 value obtained was 0.98.

- Runoff coefficient for the area was obtained as 0.12

- Maximum intensity for durations of 5min, 10min, 15min, 30min, 1hr, 2hr, 4hr, 6hr and 12hr for the monsoon season was found out by the rainfall chart analysis.

- A relation connecting maximum intensity and duration was obtained as $Y = 9.0029X^{-0.6986}$. The R^2 value was 0.9506.

- Unit hydrograph for various storm hydrograph was derived and unit hydrograph with relatively same duration was taken as the representative unit hydrograph of the study area.

The runoff measurement for more number of isolated storms was possible if measuring was done using a stage level recorder. The stone pitched area through which water flowing to the channel was not fully lined. The unit hydrograph obtained form the storm hydrograph can be used as a representative unit hydrograph for the area for future runoff volume and peak runoff rate estimation. The maximum intensity for different duration can be considered for designing any water harvesting structures for the area. A relation between rainfall and runoff can also be taken for future estimation of runoff.

APPENDIX 1

Table.1: Data for the storm P_1

Time (sec)	*Head (cm)*	*Time (sec)*	*Head (cm)*
0	0	270	0.85
30	0.3	300	0.7
60	0.5	330	0.6
90	0.7	360	0.6
120	0.85	420	0.5
150	0.85	450	0.4
180	0.85	480	0.3
210	0.85	510	0.2
240	0.85	540	0

Table.2: Data for the storm P_2

Time (sec)	***Head (cm)***	***Time (sec)***	***Head (cm)***
0	0	720	1.7
60	0.6	750	1.65
120	1.35	780	1.55
180	1.7	810	1.45
240	2	840	1.35
300	2.1	870	1.2
330	2.1	900	1.15
360	2.2	930	1.05
390	2.2	960	0.9
420	2.35	990	0.8
450	2.2	1020	0.7
480	2.25	1050	0.6
510	2.2	1080	0.5
540	2.15	1110	0.45
570	2.1	1140	0.3
600	2.05	1170	0.2
630	1.95	1200	0.1
660	1.85	1230	0
690	1.8	1260	0

Table.3: Data for the storm P_3

Time (sec)	*Head(cm*	*Time (sec)*	*Head(cm*	*Time (sec)*	*Head(cm)*	*Time (sec)*	*Head(cm*
0	0	1260	7.7	2580	4.5	3880	7.1
60	1.3	1320	7.7	2640	4.3	3940	7.5
120	1.8	1380	7.6	2700	4.15	4000	7.8
180	2.4	1440	7.4	2760	4.05	4060	8.2
240	2.7	1500	7.3	2820	3.8	4120	8.7
300	3.2	1560	7.3	2880	3.8	4180	9
360	3.7	1620	7.1	2940	3.55	4240	9.7
420	4.15	1680	6.9	3000	3.4	4300	9.9
480	4.6	1740	6.8	3060	3.5	4360	10.1
540	5.1	1800	6.7	3120	3.8	4420	12
600	5.5	1860	6.5	3180	3.8	4540	11.2
660	5.8	1920	6.4	3240	5.2	4600	11.1
720	6.1	1980	6.2	3300	4.5	4660	10.9
780	6.4	2040	5.9	3360	4.6	4720	10.5
840	6.7	2100	5.8	3480	5.2	4780	10.3
900	6.9	2160	5.4	3520	5.4	4840	9.8
960	7	2260	5.5	3580	5.6	4900	9.5
1020	7.6	2340	5.15	3640	6.2	4960	9.2
1080	7.65	2400	5.9	3700	6.4	5020	8.8
1140	7.7	2460	4.7	3760	6.6	5080	8.7
1200	7.7	2520	4.6	3820	6.9	5140	8.3
Time (sec)	*Head (cm)*	Time *(sec)*	*Head (cm)*	*Time (sec)*	*Head (cm)*	*Time (sec)*	*Head (cm)*
5200	8.3	646	3.00	7660	2.3	8920	4.15
5260	8.15	652	2.7	7720	2.4	8980	4.15
5320	7.9	6580	2.5	7780	2.5	9040	4
5380	7.65	6640	2.3	7840	2.5	9100	3.85
5440	7.4	6700	2.4	7960	2.5	9160	3.7
5500	7.2	6760	2.1	8020	2.6	9220	3.45

5560	7	6820	2	8080	2.7	9280	3.2
5620	6.7	6880	2	8140	2.8	9340	3.2
5680	6.9	6940	2	8200	2.95	9400	3
5740	6.3	7000	2	8260	3.1	9460	2.9
5800	6.1	7060	2	8320	3.2	9520	2.75
5860	5.8	7120	1.9	8380	3.3	9580	2.4
5920	5.4	7180	2	8440	3.55	9640	2.25
5980	5.2	7240	1.8	8500	3.65	9700	2
6040	4.9	7300	1.8	8560	3.9	9760	1.8
6100	4.65	7360	1.9	8620	3.95	9820	1.5
6160	4.4	7420	2	8680	4.05	9880	1.
6220	4.2	7480	2	8740	4.1	9940	0.5
6280	4	7540	2	8800	4.1	1000	0.2
6340	3.6	7600	2.	8880	4.1	1006	0.0
6400	3.4						

Table.4: Data for the storm P_4

Time(sec)	***Head(cm)***	***Time(sec)***	***Head(cm)***
0	0	450	1.75
30	0.3	480	1.75
60	0.65	510	1.55
90	0.9	540	1.55
120	1.05	570	1.5
150	1.3	600	1.35
180	1.5	630	1.05
210	1.55	660	0.75
240	1.55	690	0.75
270	1.7	720	0.45
300	1.75	750	0.45

Time(sec)	***Head(cm)***	***Time(sec)***	***Head(cm)***
330	1.75	780	0.2
360	1.7	810	0.2
420	1.75	840	0.1

Table.5: Data for the storm P_5

Time (sec)	***Head (cm)***	***Time (sec)***	***Head (cm)***	***Time (sec)***	***Head (cm)***	***Time (sec)***	***Head (cm)***
0	0	660	11.7	1290	6.55	1920	2.2
30	1.5	690	11.6	1320	6.6	1950	2.1
60	1.9	720	11.5	1350	6.4	1980	2
90	2.6	750	11.35	1380	6.1	2010	1.9
120	3.5	780	11.2	1410	5.9	2040	1.75
150	4.3	810	11.0	1440	5.6	2070	1.45
180	5.1	840	10.8	1470	5.4	2100	1.4
210	6.6	870	10.5	1500	5.2	2130	1.3
240	7	900	10.5	1530	4.95	2160	1.1
270	7.6	930	10.1	1560	4.7	2190	1.05
300	9.4	960	10.0	1590	4.5	2220	0.95
330	9.8	990	9.7	1620	4.25	2250	0.8
360	10.3	1020	9.25	1650	4	2280	0.75
420	10.8	1050	9.0	1680	3.8	2310	0.55
450	11.1	1080	8.8	1710	3.55	2340	0.5
480	11.2	1110	8.45	1740	3.4	2370	0.4
510	11.5	1140	8.1	1770	3.15	2400	0.2
540	11.55	1170	7.9	1800	2.9	2430	0.15
570	11.8	1200	7.85	1830	2.8	2470	0
600	11.9	1230	7.4	1860	2.55		
630	11.55	1260	7.15	1890	2.5		

Table .6: Data for the storm P_6

Time (sec)	***Head (cm)***	***Time (sec)***	***Head (cm)***	***Time (sec)***	***Head (cm)***	***Time (sec)***	***Head (cm)***
0	0	420	3	810	2.2	1200	1
30	0.6	450	3	840	2	1230	0.8
60	1.2	480	2.95	870	1.9	1260	0.7
90	1.6	510	2.9	900	1.75	1290	0.7
120	1.8	540	2.75	930	1.65	1320	0.7
150	2.3	570	2.65	960	1.6	1350	0.6
180	2.3	600	2.7	990	1.6	1380	0.4
210	2.45	630	2.5	1020	1.55	1410	0.4
240	2.65	660	2.55	1050	1.45	1440	0.3
270	2.75	690	2.45	1080	1.4	1470	0.15
300	2.75	720	2.45	1110	1.25	1500	0.15
330	2.9	750	2.45	1140	1.1	1530	0.1
360	3	780	2.2	1170	1	1560	0

Table .7: Data for the storm P_7

Time (sec)	***Head (cm)***	***Time (sec)***	***Head (cm)***
0	0	420	0.9
60	0.4	480	0.7
120	0.65	540	0.5
180	0.8	600	0.3
240	0.95	660	0.1
300	0.95	720	0.1
360	0.9	780	0

APPENDIX 3

Table .1: Maximum rainfall depth for the month of June

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
17/6/05	4.0	6.0	7.2	12.8	15.6	16.8	18.0	18.2	31.6
18/6/05	4.0	6.4	8.4	14.4	15.6	26.8	34.0	39.6	48.4
19/6/05	2.0	4.0	4.0	5.60	6.40	8.80	8.80	13.4	22.0
20/6/05	6.2	6.4	7.2	9.20	12.4	21.2	25.2	36.0	40.8
22/6/05	2.4	2.8	2.8	3.60	6.00	7.60	9.60	10.4	12.0
24/6/05	1.6	2.0	2.0	2.20	2.20	2.20	3.00	3.20	4.60
25/6/05	5.6	8.0	9.2	12.8	14.0	14.0	14.0	18.4	25.2
27/6/05	2.0	2.6	2.6	2.60	2.60	2.60	2.60	2.60	6.80
28/6/05	2.8	3.6	6.4	9.40	10.2	10.2	10.4	10.4	17.0
29/6/05	1.4	1.6	1.8	1.80	3.20	3.20	5.20	5.20	6.80

Table .2: Maximum rainfall depth for the month of July

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
01/07/05	3.20	6.40	6.80	13.6	16.2	16.8	25.0	26.6	36.0
2/07/05	2.80	4.80	4.80	7.00	7.00	7.60	10.2	11.6	12.0
3/07/05	2.80	4.80	4.80	8.40	12.4	14.4	14.8	16.8	26.4
4/07/05	2.80	5.20	5.60	7.60	10.0	12.4	22.6	25.4	36.4
5/07/05	8.00	8.40	9.20	9.60	10.0	10.0	12.4	12.4	27.2
6/07/05	3.20	4.40	4.40	4.40	4.40	4.40	4.40	4.40	4.40
7/07/05	0.20	0.20	0.20	0.20	0.20	0.20	0.40	0.40	0.40
8/07/05	4.80	7.60	10.0	26.8	32.0	39.2	60.0	98.8	104
9/07/05	6.00	7.20	8.00	15.2	22.0	30.0	48.4	54.8	6.4
10/07/05	5.20	5.60	6.00	8.20	10.0	10.0	10.4	10.4	10.4
11/07/05	2.40	2.40	2.60	2.60	2.60	3.00	3.60	3.60	4.00
13/7/05	1.00	1.50	2.00	2.50	2.50	2.50	2.50	2.50	2.50
14/7/05	0.25	0.50	0.50	1.00	1.50	2.75	2.75	2.75	2.75
16/7/05	1.60	2.00	2.50	5.20	8.00	11.0	12.0	12.0	12.5
17/7/05	2.50	3.00	6.00	8.00	12.25	14.5	15.75	19.5	28.5
18/07/05	5.00	8.00	8.00	8.50	8.50	8.50	8.75	8.75	10.00
19/07/05	2.00	3.00	3.00	4.50	5.00	6.75	7.50	8.00	8.00.

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
20/07/05	1.00	1.50	2.00	3.00	4.00	5.50	5.50	6.00	9.50
21/07/05	0.50	0.75	1.00	1.00	1.00	1.00	1.25	1.25	1.25
22/07/05	4.75	5.75	6.50	6.75	6.75	6.75	6.75	9.00	9.00
23/07/05	2.50	3.25	3.50	3.50	3.50	3.50	3.50	3.50	5.00
24/07/05	4.00	6.00	7.00	7.50	8.75	9.25	9.50	10.5	20.0
25/07/05	0.50	0.75	1.00	1.50	1.50	1.50	1.50	2.00	2.50
26/07/05	4.00	5.00	5.50	6.50	7.75	7.75	7.75	10.25	10.5
27/07/05	5.00	5.50	7.50	7.50	7.50	7.50	7.50	7.50	12.75
28/07/05	4.50	5.00	6.00	8.00	8.50	8.50	14.5	20.5	30.5
29/07/05	4.50	4.50	4.75	5.75	5.75	10.0	10.5	11.25	22.0
30/07/05	4	4.00	10.0	12.5	19.5	23.0	40.0	48.0	59.0

Table .3: Maximum rainfall depth for the month of August

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
1/08/05	5.00	9.5	12.0	16.6	17.6	22.1	31.0	34.0	35.0
2/08/05	3.60	4.04	4.20	6.60	7.80	7.80	10.4	12.0	22.2
4/08/05	1.00	1.00	1.25	1.50	1.75	1.75	2.25	3.50	4.60
5/08/05	1.00	1.90	2.50	3.10	4.00	4.00	5.00	5.00	5.00
8/08/05	2.70	3.00	7.25	10.0	10.0	10.0	10.0	10.0	10.0
9/08/05	2.00	2.00	2.10	2.10	3.60	3.60	3.60	3.60	3.60
10/8/05	2.00	3.00	3.10	4.10	5.60	5.60	5.75	5.75	6.50
11/8/05	0.95	1.00	1.00	1.25	1.45	1.45	1.45	1.50	1.50
13/8/05	7.00	7.00	7.75	13.25	13.25	13.75	28.0	30.25	32.0
14/8/05	3.50	4.00	4.00	6.50	10.0	10.0	12.4	12.4	13.1
15/8/05	8.00	8.00	9.50	18.5	21.0	26.5	38.5	38.5	45.25

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
16/8/05	3.00	6.00	6.50	9.00	9.00	9.00	9.00	9.00	9.00
17/8/05	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50
18/8/05	6.50	9.00	10.0	11.5	11.5	11.5	11.5	11.5	11.5
24/8/05	0.55	0.55	0.55	1.05	1.55	2.00	2.50	2.50	2.50
31/8/05	2.75	3.05	3.25	4.30	6.50	7.85	8.50	8.50	13.0

Table.4: Maximum rainfall depth for the month of September

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
03/9/05	1.50	1.50	2.50	3.10	5.00	10.0	15.0	17.0	23.0
05/9/05	1.50	1.60	1.60	2.00	2.75	5.00	7.00	7.00	7.00
6/09/05	1.00	1.50	3.00	5.00	7.50	13.5	27.0	31.0	36.5
7/09/05	2.50	2.50	7.50	10.5	17.0	25.0	40.0	40.1	50.5
8/09/05	2.00	3.50	4.50	7.50	12.0	13.5	14.5	15.5	30.0

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
9/09/05	2.25	2.50	5.25	5.50	6.60	6.75	8.00	9.25	11.5
10/9/05	5.00	7.00	10.0	15.0	27.0	52.5	63.5	71.5	103.5
11/9/05	5.50	8.50	8.60	10.55	13.5	21.0	34.5	35.0	36.5
20/9/05	5.00	5.50	5.75	7.50	9.00	11.6	20.75	20.75	21.5
21/9/05	3.10	4.40	4.40	5.10	5.15	5.15	6.50	7.50	7.50

Table .5: Maximum rainfall depth for the month of October

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
8/10/05	5.00	8.50	9.00	15.5	20.0	21.6	21.6	21.6	21.6
9/10/05	10.0	14.5	24.0	35.5	40.5	43.75	46.5	46.5	49.0
10/10/05	0.25	1.00	1.00	1.45	2.00	2.50	2.50	2.50	2.50
11/10/05	6.50	12.0	12.5	15.0	27.0	42.0	47.5	48.75	48.75
12/10/05	00.5	1.00	1.50	2.15	2.60	3.00	3.00	3.00	3.00
13/10/05	0.60	1.40	1.50	2.50	4.00	5.75	7.50	7.50	7.50
14/10/05	0.25	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.40
16/10/05	1.05	1.25	1.50	1.50	1.50	1.50	1.50	1.50	1.50
19/10/05	0.75	0.95	1.00	1.45	1.90	3.40	4.00	6.00	6.00
20/10/05	6.00	8.00	8.00	16.0	17.0	18.0	18.0	18.0	18.0

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
22/10/05	1.75	3.00	4.00	4.50	7.00	8.10	9.40	9.40	9.40
23/10/05	0.50	.9.00	0.90	1.00	1.10	1.10	1.10	1.10	1.10
24/10/05	0.50	1.00	1.05	1.25	1.75	2.50	2.75	7.00	7.00
26/10/05	2.65	3.75	3.75	4.25	5.25	6.50	9.75	9.75	9.75
28/10/05	1.00	1.60	1.60	3.25	3.25	3.60	3.60	3.60	4.00
30/10/05	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	9.50
31/10/05	9.00	9.00	9.50	14.5	23.5	31.0	31.0	40.0	40.0

Table.6: Maximum rainfall depth for the month of November

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
2/11/05	3.00	3.60	4.25	7.50	11.5	11.75	15.6	15.6	15.6

	Rainfall depth in mm								
Date	***5 min***	***10 min***	***15 min***	***30 min***	***1 hr***	***2 hr***	***4 hr***	***6 hr***	***12 hr***
6/11/05	.5.00	1.50	2.00	4.00	4.55	7.50	9.50	9.50	9.50
8/11/05	0.10	0.15	0.25	0.50	0.85	1.00	1.00	1.00	1.00
9/11/05	0.25	0.45	0.50	0.50	0.50	0.50	0.60	0.60	0.60
12/11/05	10.0	25.0	30.0	32.0	44.6	44.6	44.6	44.6	44.6
13/11/05	5.50	8.00	9.50	9.75	12.5	17.0	17.8	17.8	17.8

ABSTRACT

Rainwater harvesting is going to be the most applicable method for eliminating water scarcity and to meet the escalating demand. Hydrological analysis is unavoidable in any water harvesting structural designing. A study was done at KCAET, Tavanur to analyze the rainfall-runoff characteristics by selecting the college playground as the study area. Runoff for seven storms was measured and the runoff volume obtained was 9.13m^3, 10.55 m^3, 102.01 m^3, 9.71 m^3, 37.32 m^{3,} 11.45 m^3 and 9.22 m^3 respectively. A relation between discharge and corresponding head for the notch was calculated as

$Q = 0.7661H^{1.4503}$.The R^2 value obtained was 0.98. The runoff coefficient for the compacted study area was 0.12. Unit hydrograph from various storm hydrograph were derived and the unit hydrograph for the storm on P_1 and P_7 was considered for the derivation of representative unit hydrograph. A relation between rainfall and runoff was found out as $Y = 0.201X – 0.8467$ and the R^2 value was 0.98. From rainfall chart analysis, a relation between maximum intensity and duration was obtained as $Y = 9.0029X^{–0.6986}$. The R^2 value was 0.9506.