Stormwater Assessment Studies for Selected Urban and Rural Sub-Watersheds

A Thesis Submitted to

THAPAR UNIVERSITY

in the partial fulfillment for the award of the

Degree of

MASTER OF TECHNOLOGY

in

(ENVIRONMENTAL SCIENCE AND TECHNOLOGY)

Submitted by

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PATIALA (PUNJAB)-147004July 2013

CERTIFICATE

This is to certify that the work done in this thesis report entitled **"Stormwater Assessment Studies for Selected Urban and Rural Sub-Watersheds"** submitted by Megha Bedi in partial fulfillment of requirement for the award of the **Master degree in Environmental science and Technology** in **"School of Energy and Environment"**, Thapar University, Patiala, is a record of the student's own work carried out by her under my supervision and guidance. The report has not been submitted for the award of any degree or certificate in this or any other university or institution.

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CANDIDATE'S DECLARATION

I hereby declare that the work presented in this dissertation entitled "**Stormwater Assessment Studies for Selected Urban and Rural Sub-Watersheds**" in partial fulfillment of requirement for the award of the **Master degree in Environmental Science and Technology** in the School of Energy and Environment, Thapar University, Patiala, in July 2013, is an authentic record of my own work carried out by me, under the guidance of Dr. A.S. Reddy, Head of Department, School of Energy and Environment , Thapar University, Patiala.

The matter embodied in this report has not been submitted in any other university or institute for the award of any degree.

(Megha Bedi)

Date:

Place:

This is to certify that above declaration made by student concerned is correct to the best of my knowledge & belief.

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ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to my guide **Dr. A. S. Reddy**, Head of Department and Associate Professor, School of Energy and Environment, Thapar University, Patiala, for his exemplary guidance, monitoring and constant encouragement for the successful completion of this seminar. The blessing, help and guidance given by him time to time shall carry me a long way in the journey of life on which I am about to embark.

I am obliged to **Mr. Amarpreet Singh Arora, Mr. Siddarath Sharma** for the valuable information provided by them in their respective fields. I am grateful for their cooperation during the period of my assignment.

I am also indebted to my friends **Arshdeep Boparai, Kamna Srivastava, Gurprinder Kaur, Harkrishan Singh** for their help and support.

Finally, I would like to express my deepest gratitude to my **parents and family,** without whom I am nothing , to provide me great opportunities, everlasting support, big encouragement and lots of love.

Last, but not least, I thank God for giving me strength to overcome difficulties encountered.

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Stormwater Assessment Studies for Selected Urban and Rural Sub-Watersheds

ABSTRACT

Stormwater has become a major issue both in urban and rural human settlements. Storm water runoff estimations have been ignored ever since. The objective of this study is to estimate the quantity of surface runoff from different sub-catchments within Punjab, India and formulate relationships between runoff rates and catchment characteristics. Five urban sub-watersheds of the Patiala city and two rural sub-watersheds, Chappa village, Sangrur district, Punjab have been selected for the stormwater estimation. The catchment characteristics and the rainfall characteristics required in the estimations have been obtained. The hydrological methods and models available for the quantification were reviewed, and the method most appropriate for the present stormwater runoff estimations was articulated. Using the method, stormwater runoff estimations for the selected catchments has been done. Details of the catchments, the rainfall, and the runoff estimates are presented in this paper.

Keywords: Runoff Estimation, Stormwater Quantification, Stormwater Management, Model Development.

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CHAPTER-1

INTRODUCTION

1.1) BACKGROUND INFORMATION

Stormwater is rain, melted snow or any other form of precipitation that has come into contact with the ground or any other surface. This water seeps into the ground, is absorbed by vegetation, evaporates or flows over land or impervious surfaces contributing to the stormwater runoff. The addition of roads, driveways, parking lots, rooftops and other surfaces that prevent water from soaking into the ground, greatly increase the runoff volume created during storms. The runoff from a drainage area/ watershed/ catchment i.e the area of land contributes runoff generated from a precipitation event to a single outlet point from where it is usually carried to a river, lake, reservoir, wetland or ocean.

Stormwater must be managed for two key reasons:

Water cycle: Our atmosphere absorbs water from the earth, it falls back down as precipitation where it is absorbed by the soil and used by vegetation to grow. The water eventually evaporates back into the atmosphere and the cycle continues. But because of the human interference with this cycle, precipitation can't reach the soil through the impervious surfaces such as roads and buildings, thus altering the normal functioning of the water cycle.

Pollution: As stormwater flows toward sewer systems it can pick up toxic debris and chemicals such as fertilizers, oil and grease, pesticides, dirt, animal and bird fecal matter, other pollutants and litter. While there is some attenuation of these pollutants before entering the receiving waters, the quantity of human activity results in large enough quantities of pollutants to impair these receiving waters.

The ultimate goal of urban stormwater management is to achieve effective control of pollutants in stormwater runoff and reduce the volume and rate of runoff to control downstream impacts from flooding and stream-channel erosion**.**

To reduce the impacts of runoff on urban streams, EPA expanded the Clean Water Act in 1987 to require municipalities to obtain permits for discharges of stormwater runoff. As a result, many communities have adopted regulations requiring developers to install stormwater management practices that reduce the rate and/or volume and remove pollutants from runoff generated on their development sites (*Centre for Watershed Protection*, Watershed 101).

1.2) OBJECTIVES OF THE STUDY

The key objectives of the work are:

- Computing volume of runoff generated by precipitation events for urban and rural sub-watersheds.
- Developing Direct Runoff Hydrograph (Flow Rate as a function of time) for the urban catchments

1.3) SIGNIFICANCE OF WORK

The Stormwater management strategy comprises of the following stages:

- Collection of stormwater runoff
- Treatment of collected stormwater runoff
- Reuse or Recycling of treated stormwater
- Ground water recharging

For management of stormwater runoff generated from a precipitation event over a watershed / drainage area, the estimation of runoff quantities becomes an utmost requirement. Prior to proposing any management scheme for the discharge from a watershed/ catchment, quantification of runoff is an indispensable component.

In the present study, selected sub-watersheds of Punjab, both urban and rural, were studied and required watershed characteristics were collected. Ultimately the study will yield volume of stormwater generated by storm events and direct runoff hydrographs for the catchments. The Runoff hydrograph can be used in future for assessing runoff rate or discharge at any duration of storm.

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CHAPTER-2

REVIEW OF LITERATURE

Review of literature has been carried out on the following aspects:

1. Storm Water Management
2. Modeling of Watershed Hydrology

The literature review was carried out from sources like research papers published in peer reviewed journals, technical reports, working papers of sponsored projects, proceedings of international conferences and technical manuals published by various national and international agencies, like, USEPA, Global Water Partnership (GWP), Center for Watershed Protection (CWP) etc.

2.1) STORMWATER MANAGEMENT

Stormwater runoff occurs when precipitation from rain or snowmelt flows over the land surface. The addition of roads, driveways, parking lots, rooftops and other surfaces that prevent water from soaking into the ground to the landscape greatly increases the runoff volume created during storms. This runoff is swiftly carried to the local streams, lakes, wetlands and rivers and can cause flooding and erosion, and wash away important habitat for critters that live in the stream. Stormwater runoff also picks up and carries with it many different pollutants that are found on paved surfaces such as sediment, nitrogen, phosphorus, bacteria, oil and grease, trash, pesticides and metals. Thus, stormwater is of concern for two main issues: One related to the volume and timing of runoff water (flood control and water supplies) and the other related to potential contaminants that the water is carrying, i.e. water pollution.

To reduce the impacts of runoff on urban streams, EPA expanded the Clean Water Act in 1987 to require municipalities to obtain permits for discharges of stormwater runoff. As a result, many communities have adopted regulations requiring developers to install stormwater management practices that reduce the rate and/or volume and remove pollutants from runoff generated on their development sites (*Centre for Watershed Protection*, Watershed 101).

In context of this, **Vermont Stormwater Management Manual** (2002) by Vermont Agency of Natural Resources provides regulatory requirements for the management of stormwater and technical guidance for the design of stormwater treatment practices. It sets forth required stormwater treatment standards, and design criteria for water quality, groundwater recharge, channel protection, overbank flood protection and extreme flood control. Besides these, it comprehends the stormwater treatment practices (which can be used either alone or in combination) acceptable to meet the treatment standards.

Stormwater must be managed for two key reasons:

Water cycle: Our atmosphere absorbs water from the earth, it falls back down as precipitation where it is absorbed by the soil and used by vegetation to grow. The water eventually evaporates back into the atmosphere and the cycle continues. But because of the human interference with this cycle, precipitation can't reach the soil through the impervious surfaces such as roads and buildings. An **Industry report on Water Sensitive Urban Design** (2002) by Cooperative Research Centre for Catchment Hydrology, Melbourne Water Corporation addresses key issues of stormwater management in the context of an integrated urban water cycle.

Pollution: As stormwater flows toward sewer systems it can pick up toxic debris and chemicals such as fertilizers, oil and grease, pesticides, dirt, animal and bird fecal matter, other pollutants and litter. While there is some attenuation of these pollutants before entering the receiving waters, the quantity of human activity results in large enough quantities of pollutants to impair these receiving waters. **Center for Watershed Protection (CWP) Manual** (2005) suggests methods to assess sub-watershed pollution sources in order to develop and target education and enforcement efforts that can prevent or reduce polluting behaviors and operations.

The ultimate goal of urban stormwater management is to achieve effective control of pollutants in stormwater runoff and reduce the volume and rate of runoff to control downstream impacts from flooding and stream-channel erosion**. Best management practices (BMPs)** that mirror the natural process of infiltration found in undeveloped watersheds can effectively increase the volume of water returned to the soil and reduce the volume of direct runoff to streams and sewers (Iowa Stormwater Management Manual, 2009).**The Stormwater Management Manual for Western Washington** (2005) states that minimization of stormwater flows, prevention of soil erosion, capture of water-borne sediment that has been unavoidably released from exposed soils, and protection of water quality from on-site pollutant sources, all can readily be achieved when proper **Best Management Practices (BMPs**) are planned, installed, and properly maintained.

Stormwater management includes the following aspects:

- Managing stormwater to control flooding and erosion.
- Managing and controlling hazardous materials to prevent release of pollutants into the environment (source control).
- Planning and constructing stormwater systems so contaminants are removed before they pollute surface waters or groundwater resources.
- Acquiring and protecting natural waterways where they still exist or can be rehabilitated.
- Building structures such as ponds, swales or wetlands or newer Green Infrastructure solutions to work with existing drainage structures, such as pipes and concrete channels.
- Revising current stormwater regulations to address comprehensive stormwater needs.
- Developing long-term asset management programs to repair and replace aging infrastructure.
- Enhancing and enforcing existing ordinances to make sure property owners consider the effects of stormwater before, during and after development of their land.
- Educating a community about how its actions affect water quality, and about what it can do to improve water quality.

Approaches to Stormwater Management

Low-Impact Development (LID) is a stormwater management approach that seeks to manage runoff using distributed and decentralized micro-scale controls. LID's goal is to mimic a site's pre-development hydrology by using design techniques that infiltrate, filter, store, evaporate, and detain runoff close to its source. Instead of conveying and treating stormwater solely in large end-of-pipe facilities located at the bottom of drainage areas, LID addresses stormwater through small-scale landscape practices and design approaches that preserve natural drainage features and patterns.

Green Infrastructure refers to natural systems that capture, cleanse and reduce stormwater runoff using plants, soils and microbes. On the regional scale, green infrastructure consists of the interconnected network of open spaces and natural areas (such as forested areas, floodplains and wetlands) that improve water quality while providing recreational opportunities, wildlife habitat, air quality and urban heat island benefits, and other community benefits. At the site scale, green infrastructure consists of site-specific management practices (such as interconnected natural areas) that are designed to maintain natural hydrologic functions by absorbing and infiltrating precipitation where it falls.

Environmental Site Design (ESD), also referred to as Better Site Design (BSD), is an effort to mimic natural systems along the whole stormwater flow path through combined application of a series of design principles throughout the development site. The objective is to replicate forest or natural hydrology and water quality. ESD practices are considered at the earliest stages of design, implemented during construction and sustained in the future as a low maintenance natural system. Each ESD practice incrementally reduces the volume of stormwater on its way to the stream, thereby reducing the amount of conventional stormwater infrastructure required. Example practices include preserving natural areas, minimizing and disconnecting impervious cover, minimizing land disturbance, conservation (or cluster) design, using vegetated channels and areas to treat stormwater, and incorporating transit, shared parking, and bicycle facilities to allow lower parking ratios.

Storm Water Management And Best Management Practices, Hydrology Design Manual, **Texas Department Of Transportation** (2011) includes certain structural and non-structural measures such as erosion control to minimize erosion and sediment transport, storm water detention and retention systems to reduce peak runoff rates and improve water quality, sedimentation and filtration systems remove debris, suspended solids, and insoluble pollutants, vegetation buffers to reduce transport of pollutants. Measures intended to mitigate storm water quantity and quality problems are termed “best management practices” (BMPs). These measures include detention and retention ponds which delay storm water flow and trap sediment, rock filter dams for the same reasons, silt fences to trap sediment, various filter materials in socks or tubes, and vegetation to retard flow and trap sediment.

2.2) MODELING OF WATERSHED HYDROLOGY

Hydrologic analysis provides estimates of flood magnitudes as a result of precipitation. These estimates consider processes in a watershed that transform precipitation to runoff and that transport water through the system to a project's location **(Hydrology Design Manual, Texas Department Of Transportation, 2011)**. In the design of facilities such as storm drain systems, culverts, and bridges, floods are usually considered in terms of peak runoff or discharge in cubic feet per second or cubic meters per second. For systems that are designed to control the volume of runoff, such as detention storage facilities, or where flood routing through culverts is used, the discharge per time will be of interest. Thus, the hydrology study may provide:

1. Peak flow rate/ peak runoff rate
2. Volume of runoff expected with a specified storm duration,
3. Hydrograph (flow rate as a function of time)

For quantification of runoff generated during a storm event within a watershed various methods and hydrological models may be used. Each such model demands data in the form of watershed and rainfall based parameters.

Rational and modified rational methods have been the most commonly used methods due to the ease in formulations and lesser parameter requirements. The **New Jersey Stormwater Best Management Practices Manual** discusses the fundamentals of computing stormwater runoff rates and volumes from rainfall through the use of various mathematical methods. It provides guidelines for the use to NRCS, Rational and Modified rational methods.

These two methods require **runoff coefficient** for the catchments i.e. the ratio of fraction of total rainfall that appears as total runoff volume (Runoff= K. Rainfall) or the percentage of precipitation that appears as runoff. The runoff coefficient depends upon physical chacrcteristics of the catchments like vegetation, depression, disturbances, etc. Its value increases with increasing rainfall depth (Hydrology Design Manual, TxDOT). watersheds with more impervious surfaces tend to have a higher runoff coefficient and vice- versa.

The Rational and Modified rational methods use the assumption that duration of strom equals to the **Time of Concentration (TOC)** which is the time required for a drop of water to travel from the most hydrologically remote point in the subcatchment to the point of collection **(HydroCAD Stormwater Modeling, 1986)** or the time required for the entire watershed to contribute to runoff at the outlet point. When runoff is computed using the rational method, *tc* is the appropriate storm duration and in turn determines the appropriate precipitation intensity for use in the rational method equation **(Hydraulic Design Manual. TxDOT).** For storm duration more than the time of concentration, the peak flow rate continues. when using the Modified Rational Method to compute a stormwater quality design storm hydrograph, the entire storm duration at an average intensity can be used.

Various methods are available for calculating the TOC for a watershed**. Fang et al. (2008)**, estimated Tc for 96 Texas watersheds using five empirical equations: **Williams, Kirpich, Johnstone–Cross, Haktanir–Sezen, and Simas–Hawkins methods**. The drainage areas of watersheds studied are approximately 0.88 – 440.3 km^2. Average relative differences of Tc estimated using different empirical equations with the same set of watershed parameters range from -38 to 207% , absolute average differences range from -3.0 to 2.8 hand are much larger than differences estimated using three sets of watershed parameters. **Kirpich and Haktanir–Sezen methods provide reliable estimates of mean values of Tc variations.**

Akan (2002) gave a simple method is presented to size infiltration structures like infiltration basins and trenches to control storm water runoff. The runoff hydrograph is assumed to be trapezoidal in shape with a peak runoff rate calculated using the **rational formula**. Given the watershed time of concentration and the allowable runoff rate, the method determines the required size of the infiltration structure. Rational method was also used **by Chena et al. (2007)**, for estimating the maximum discharge of a landslide-induced debris flow. The results show that the peak debris velocity was between 2.4 and 4.7 m s− 1 and the peak debris discharge was between 6.7 and 35.7 m3 s− 1. The peak discharge initially increased at the upper portion of the channel, then decreased at the lower portion, indicating that the upper channel experienced erosion but the lower channel experienced deposition. The location with the maximum debris flow discharge corresponds to the point where the volume of the debris flow started to decrease.

Another very commonly used method is **US-SCS** method, now known as the **NRCS method**.

The US-SCS CN Method uses Curve Number (CN) of the catchment as a representation of impervious area. The runoff curve number is based on the area's hydrologic soil group (A, B, C and D), land use, treatment and hydrologic condition (based upon level of grazing) and antecedent moisture condition. Its range varies between $100 \geq CN \geq 0$, where, 100 represents condition of zero retention (impervious catchment) and 0 represents full retention (pervious catchment).

The **Soil conservation service curve number (SCS-CN) methodology by Water Science & Technology Library** is aimed at presenting an up-to-date account of the SCS-CN method and clarify its potential for practical applications, and especially those other than originally intended. It provides introduction of rainfall-runoff modeling and elements of catchment, precipitation, interception, surface detention and depression storage, evaporation, infiltration, runoff, and the runoff hydrograph, the factors affecting the curve number (CN), the determination of CN, the use of NEH-4 tables, sensitivity analysis, advantages and limitations of the SCS-CN method, and application to distributed watershed modeling, etc.

Mishra and Singh (2004), Presented a critical review of daily flow simulation models based on the Soil Conservation Service curve number (SCS-CN). A more versatile model based on the modified SCS-CN method was introduced which specializes into seven cases. The proposed model was applied to the Hemavati watershed (area = 600 km2) in India and was found to yield satisfactory results in both calibration and validation. The model conserved monthly and annual runoff volumes satisfactorily. Similar work was done by **Millhollon, et al. (2009)**, where they used NRCS runoff curve number method to estimate runoff from the watershed in its natural, forested state and in its current state of cultivated crop land and pasture.

The NRCS method has many methodologies most commonly used among them in the TR-55. **Paul Schiariti** demonstrated a comparison between **Tr-55 and MRM(**modified rational method) stating that, rational / MRM Peak Flow Rates are reasonably close to TR-55 for larger drainage areas; runoff Volumes are significantly different for the two methods, (Rational / MRM volumes can be 3 to 4 times less then TR-55 volumes); the Time to Peak is significantly different for both methods; rational / MRM Peak Flow Rates can be significantly different from TR-55 for smaller drainage areas.

The low impact development (LID) approach has been recommended as an alternative to traditional stormwater design. Research on individual LID practices such as bioretention, pervious pavements, and grassed swales has increased in recent years. Bioretention cells have been effective in retaining large volumes of runoff and pollutants on site, and consistently reduced concentrations ofcertain pollutants such as metals (**Michael E. Dietz, 2007**).

Some researchers have also used new techniques and modified the existing ones.
Guo (2006), presented a theoretical derivation of a dimensionless unit hydrograph using the **kinematic wave approach (KHUH)**. To verify the applicability of the KWUH derived in this study, a set of hypothetical rectangular watersheds ranging from 20 to 200 acres was investigated. The predicted 100-year peak flow rates from these five hypothetical rectangular watersheds are compared with the Soil Conservation Service dimensionless unit graph Method (SCSUH) and the Colorado Unit Hydrograph Procedures (CUHP). In general, the KWUH produces good agreement with the CUHP when the catchment has an area between 60 and 120 acres. Based on the study of hypothetical rectangular watersheds, it is recommended that the KWUH be applicable to urban catchments with a drainage area of up to 120 acres. He also **in 2012** the **expanded the rational method into the rational hydrograph method** in which the time of concentration is considered as the system memory and the contributing rainfall depth to the present runoff rate is defined as the accumulated precipitation over the past up to the time of concentration. In doing so, the complete runoff hydrograph can be generated under a continuous non uniform hyetograph. The event-averaged time of concentration and runoff coefficient can be derived by the **least-square method**.

Apart from the above methods, the **synthetic unit hydrograph method** is an upcoming new technology which has emerged because of the unavailability of rainfall and watershed data. Such a method uses synthetic data rather than the natural. **Fang et al**., Texas, reevaluated dimensionless unit hydrograph by using several examples to develop **synthetic unit hydrographs**. It was found that it is necessary to change the shape of dimensionless hydrograph if different peak rate factors (PRF) are used. Regional regression equations have been developed for basin-mean time to peak Tp and peak discharge Qp of Gamma unit hydrographs with respect to watershed parameters: drainage area, main channel slope and length. A procedure has been established for development of synthetic unit hydrographs for Texas watersheds. The study found that mean peak rate factor for Texas watersheds is 370, which is lower than standard NRCS PRF of 484.

Models and computer softwares are also being used for the purpose of modeling. These softwares are based upon the methodology of an existing method. the following softwares are readily available online and can be used further in the calculations:

- HydroCAD storm water modeling system(based upon SCS-NRCS)
- NRCS WinTR-55
- The EPA Storm Water Management Model (SWMM)
- HEC-HMS(based upon NRCS)

Storm Water Management Model (SWMM) user manual provide detailed information on the EPA Storm Water Management Model (SWMM), a comprehensive mathematical model for simulation of urban runoff quantity and quality in storm and combined sewer systems. It attempts to provide adequate information in this manual for most users so that they can conceptualize a stormwater problem and simulate it using SWMM. Similar to this online tutorials and user guides are readily available for all the softwares.

Apart from these models many others have also been used by researchers for quantification.

Lowe et al. (2003) used the **EPA's BASINS** (Better Assessment Science Integrating Point and Nonpoint Sources) software to create a HSPF watershed model of the Mamaroneck River, located in lower Westchester County, New York. . The model was successfully calibrated and verified using 20 years of flow data. . Land use, river reach and topographic data supplied with BASINS were compared to local county data and some discrepancies were noted, particularly with the reach data.

Ghnanapala (2006), assessed the probable impact of urbanization upon the magnitude of flood peaks used the Basic **Model HEC-l** that has been used to estimate Runoff and HEC-RAS model that has been used to establish the Rating Curve. Two urban watersheds were gauged mathematically and modeled using the HEC model to identify the behavior for urban watersheds in Colombo and also to identify parameters applicable to these. Land cover of the watersheds showed that in the urbanized areas the pervious extent was approximately 62% while in less urbanized areas the previous extent was about 76%. Average Curve Numbers for the urbanized areas were 95 and 70 for impervious and pervious areas respectively. The HEC rainfall-runoff model developed for both watersheds produced very good peak discharge matching and hence these models could be used for drainage environment improvement projects in urban areas.

Lemonds et al. (2007), developed a calibrated hydrologic model called **SWAT** (Soil and Water Assessment Tool) for the Blue River watershed (867 km2) in Summit County, Colorado. Comparison of simulated and observed stream flow hydrographs at two U.S. Geological Survey gaging stations resulted in good fits to average monthly values.

Schoener and Gerhard (2010) compared **AHYMO (the Arid-Lands Hydrologic Model) and HEC-HMS** for Runoff Modeling in New Mexico Urban Watersheds and concluded that, for all sub-basin sizes modeled in this study, HEC-HMS peak flow rates were significantly higher for scenarios with low imperviousness. Scenarios with high imperviousness and small sub-basins resulted in significantly higher AHYMO peak flows. Differences between the two models can be reduced by adjusting the storage coefficient R in HEC-HMS.

Models using more mathematical terms in the flow-governing equations are more physically based and expected to be more accurate than models using approximations, however, are more complex due to more intensive but approximate numerical schemes (inefficient). Models using approximate equations with analytical solutions may provide a balance between complexity and accuracy. Other factors such as data intensiveness, user friendliness, and resource requirements are also important considerations (**Borah,** 2011).

CHAPTER-3

METHODLOGY

3.1) ***Reviewing hydrological models available for the estimation of runoff and articulation of the model best suited for the selected sub-watersheds.***

The main focus of the work was to quantify runoff from small sub-watersheds both in urban and rural areas. For this purpose articulation of a hydrological model was needed. The model should be able to help in developing a stormwater hydrograph for a rainfall event with return period of 6 months, one year or two years.

Various hydrological methods and models were reviewed from hand books (Engineering Hydrology, third Edition by Subramanya, K), hydrology manuals (Iowa Stormwater management Manual, Hydraulic Design Manual; TxDOT, Storm Sewer Design Manual), review articles and research papers.

3.1.1) Computing runoff coefficient and calculating the runoff volume

The US-SCS CN Method was used for computing runoff coefficient and calculating runoff volume. This method requires Curve Number, daily precipitation/ rainfall and drainage area of the sub-watersheds.

For the urban catchments, the Curve Number was found by using the software NRCS WIN TR.55 SMALL WATERSHED HYDROLOGY. For rural catchments, the weighted CN was obtained by using individual CN corresponding to the respective land use.

A range of daily rainfall was considered to relate the volume of runoff with the rainfall depth. The runoff generated from a rainfall event was used to calculate runoff coefficient (runoff/ rainfall). The weighted runoff coefficient was compared with the one obtained from US- SCS CN Method. The Runoff Coefficients were plotted against the rainfall depths to obtain a graph that was further used to obtain runoff coefficient at any desired rainfall depth.

3.1.2) Calculating the Time of Concentration

The following methods were used for calculating the time of concentration for each catchment, all suitable for small catchments:

- Rational Method

- Kirpich Method
- Kerby- Hathwey Equation
- Morgali & Lisely Method
- Adhoc Method
- Johnstone Cross Method

Average time of concentration was calculated by ignoring extremes values as given by Rational Method (minimum) and Morgali and Lisely method (maximum). The Time of Concentration was further used to develop the runoff hydrograph by the modified rational method.

3.2.3) Generating the Direct Runoff Hydrograph

The Modified Rational was used to generate direct runoff hydrograph for the urban catchments. When using this method, the entire storm duration at an average intensity of rainfall is used. Using the average rainfall intensity, runoff coefficient and drainage area of the watershed peak flow rate was computed for duration of 30 mins. each till rain stops (210 min.). This peak flow rate was plotted against time (mins.) keeping time to rise equal to time to recede equal to time of concentration which gave rise to trapezoidal hydrographs each having duration equal to 30 min. plus time of concentration. All such trapezoidal hydrographs were added to develop the runoff hydrograph for the rainfall event.

3.2) ***Collection of background information for the selected sub-watershed areas.***

3.2.1) Collecting sub-watershed characteristics

- The sub-watershed boundaries were demarcated and detailed study was done on the selected sub-watersheds and their characteristics. Drainage area, channel length, channel slope, land use details and soil type were worked upon.
- For information collection on the characteristics, physical survey of the catchments, interviews with local people, maps available on net (Google maps, Encarta maps, etc.) were used. Patiala municipal council and Department of Town and Country planning, Punjab were also been depended on for the information.

3.2.2) Collecting rainfall data

- Data on storm/rainfall events was obtained from Indian Meteorological Department.
- Variation of rainfall was studied over past 5 years for Patiala (daily average) and Sangrur (monthly average).
- 90, 80,70,60,50 percentile rainfall events were calculated for the collected rainfall data.
- Rainfall hyetograph, mass curve and maximum depth- maximum intensity- duration curves were generated.

3.3) ***Quantification of run-off for the catchments using the hydrological model so selected.***

Quantification of runoff has been done for 7 catchments located in Punjab; 5 Urban and 2 rural. The Urban catchments located in Patiala city, Punjab are Civil Lines, Model Town, Manjit Nagar, Preet Nagar and Bus Stand. Two sub-watersheds were selected from Village Chhapa, District Sangrur. Each of the catchment has a pond where the runoff resulting from precipitation events ultimately reaches out.

The following flowchart (Fig. 3.1) shows the scheme for runoff estimation followed for the urban sub-watershed:

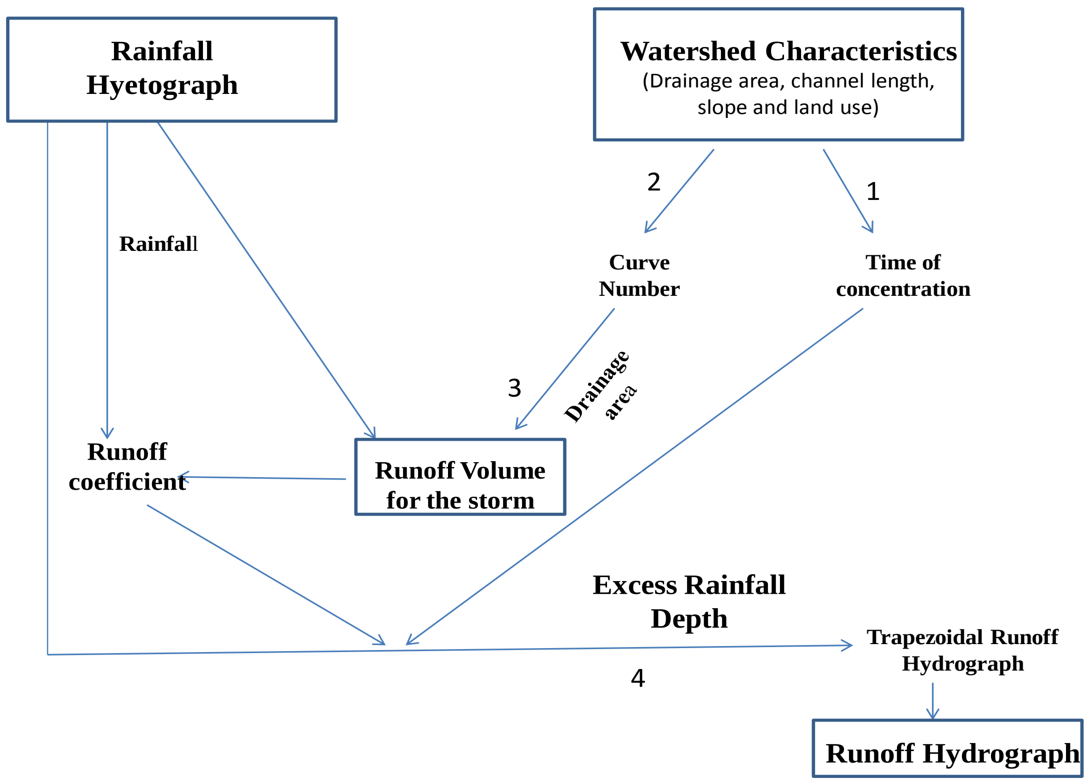

Fig. – (3.1) Flow Chart for Stormwater Assessment for Urban Sub-Watersheds

Shown in the flow chart above, 1, 2, 3, and 4 are the Hydrological methods/ models used:

1. For calculating Tc the following have been used
   a. Rational Method
   b. Kirpich Method
   c. Kerby- Hathwey Equation
   d. Morgali & Lisely Method
   e. Adhoc Method
   f. Johnstone Cross Method
2. NRCS WIN TR.55 Small Watershed Hydrology Software.
3. US- SCS CN (NRCS) Method
4. Modified Rational Method

The two rural sub-watersheds have a pond each, where the runoff collects. Based upon the maximum holding capacity of pond, groundwater recharge rate was calculated.

Shown below is the flow chart (Fig. 3.2) for estimating groundwater recharge rate for the rural sub-watersheds:

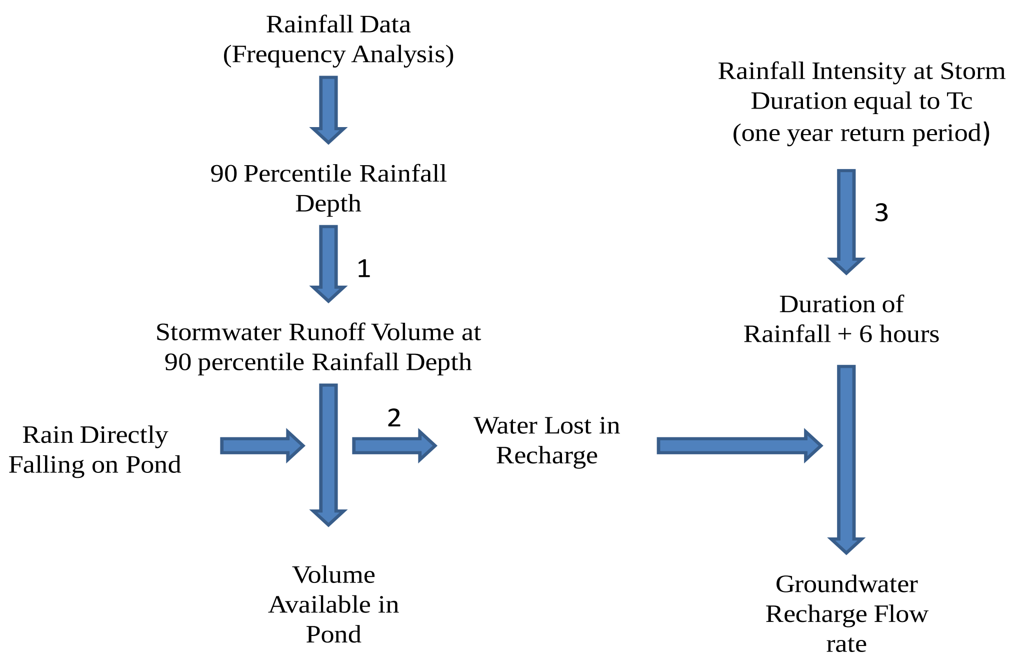

Fig.- (3.2) Flow Chart for Calculating Groundwater Recharge Rate for Rural Sub-Watersheds

Shown in the flow chart above, 1, 2, 3 signify the following:

1. US- SCS CN (NRCS) Method was used for calculating the rainfall volume.
2. The available volume in pond plus the water lost in recharge should compensate the stormwater runoff and rain directly falling on pond.
3. Rainfall intensity at duration equal to time of concentration was found using IDF Curve for return period of 1 year.

The following (Table-3.1) and (Table-3.2) summarize the formulae of the hydrological methods used:

METHOD	**FORMULA**	**NOMENCLATURE**	**UNITS**
US-SCS/ NRCS CN METHOD	1. $s = \frac{25400}{CN} - 254$ 2. $Q = \frac{(P-I_a)^2}{P-I_a+S}$ 3. V = Q* A	S = Potential Maximum Retention in Soil CN = Curve Number Q = Daily Runoff from Catchment P = Daily Rainfall/ Precipitation Ia= Initial Abstraction	Ia - 0.2 S P - mm A - m^2 V - m^3
MODIFIED RATIONAL METHOD	$Q = \frac{CIA}{Z}$	Q = Peak Runoff Rate I = Rainfall Intensity A = Drain Age Area Z = Conversion Factor	Q - m^3/s I - mm/hour A - km^2 Z – Conversion factor value .277 for the above unit, and 1 when, Q - $feet^3/s$ I - inch/ hour A- acres

(Table- 3.1) Hydrological Methods and Formulae

METHOD	FORMULAE USED (t_c = time of concentration in minutes)
Rational Method	$t_C = 0.76\,A^{0.38}$ A= Area in km^2
Kirpich Method	$t_C = 0.0078\left(\frac{L^{0.77}}{S^{0.385}}\right)$ L = length of flow (feet) S= slope
Kerby-Hathwey Equation	$t_C = \left(\frac{0.67nL}{S^{0.5}}\right)^{0.467}$ N= manning's roughness factor
Morgali & Lisely Method	$t_C = \left(\frac{0.94n^{0.6}L^{0.6}}{I^{0.4}S^{0.3}}\right)$ I= rainfall intensity (inch/ hour)
Adhoc Method	$t_c = \sqrt{drainage\ area}$ Area in square miles tc = hours
Johnstone – cross	$t_c = 3.258\left(\frac{L}{S}\right)^{0.5}$ L= km

(Table-3.2) Methods and Formulae for Tc Calculations

CHAPTER-4

RESULTS AND DISCUSSIONS

The results and discussions have been summarized as shown below:

1. **Characteristics of the selected sub- watersheds**
2. **Rainfall data for the selected areas**
    a. Rainfall hyetograph
    b. Mass curve
    c. Maximum depth- duration curve
    d. Maximum intensity duration curve
3. **Run-off for the Sub- watersheds**

    3.1). Runoff coefficient

    3.2). Time of concentration

    3.3). Runoff volume (By US-SCS CN Method)

        3.3.1). Curve Number

        3.3.2). Volume of runoff generated

4. **Direct Runoff Hydrograph (By Modified Rational Method)**

4.1) CHARACTERISTICS OF SELECTED SUB-WATERSHEDS

Patiala, princely city of state of Punjab, doesn't have provisions for the stormwater drainage as a result even modest rainfall events produce severe flooding in many parts of the city. Before any planning or any practical steps to control the quality of urban runoff, it is necessary to first specify the quantity of the urban surface runoff generated. In this concern, five Sub- watersheds were selected from Patiala city namely *Civil Lines, Model Town, Manjit Nagar, Preet Nagar and Bus stand* depicting urban characteristics. Demarcation of these sub-watersheds was done with the help of Google Earth Pro software.

SUBWATERSHED 1: Civil lines

This catchment within the city Patiala is a Residential area having high intensity of urbanization. It is marked by the presence of houses, school and parks. This area faces problems of open defecation, open urination, MSW dumping and stormwater. The stormwater in this area collects in an arbitrary outlet which is formed by sloping the roads toward it. Few underground sewers or tanks are created for passage of stormwater but are not well managed and often remain blocked.

Fig. –(4.1) ***Civil Lines Sub-Watershed***

SUBWATERSHED 2: Model Town

This catchment within the city Patiala is a commercial area having high intensity of urbanization. It is marked by the presence of houses, workshops, theater (Tagore) and government offices. This area faces problems of open urination, MSW dumping and stormwater. The stormwater in this area collects in the pits on roads where it stagnates and is lost through percolation and evaporation. No underground sewers or tanks are created for passage of stormwater.

Fig. –(4.2) Model Town Sub-Watershed

SUBWATERSHED 3: Manjit Nagar

This catchment within the city Patiala is an agricultural area having low intensity of urbanization consequently having large proportions of grass over, natural plants and landscaping. It is marked by the presence of houses, workshops, animal farms, agricultural farms, and slums. This area faces problems of open defecation, open urination, MSW dumping and stormwater. The stormwater from this area goes to nearby depression or toba. No underground sewers or tanks are created for passage of stormwater.

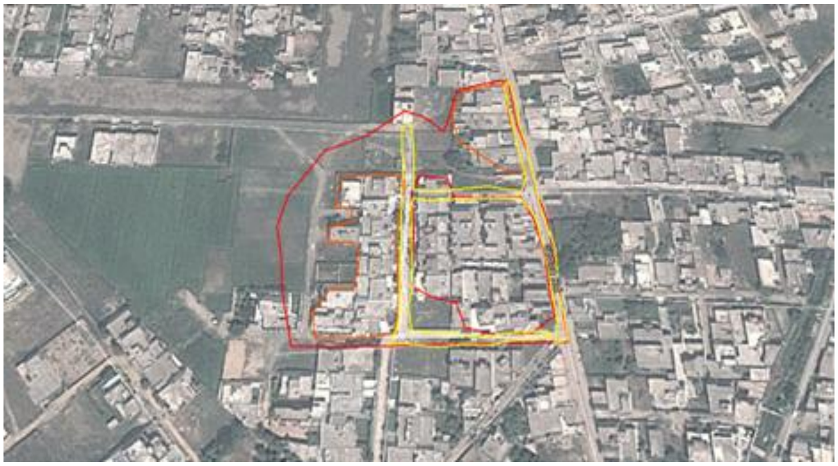

Fig. – (4.3) Manjit Nagar Sub- Watershed

SUBWATERSHED 4: Preet Nagar

This catchment within the city Patiala is a developed area having high intensity of urbanization consequently maximum impervious cover. It is marked by the presence of houses, shops and park. This area faces problems of open urination, construction waste dump, MSW dumping and stormwater. The stormwater in this area collects in the pits on roads where it stagnates and is lost through percolation and evaporation. At some places localized pits or underground tanks are created for passage of rain water.

Fig. – (4.4) Preet Nagar Sub-Watershed

SUBWATERSHED 5: Bus Stand

This catchment within the city Patiala is a commercial area having high intensity of urbanization consequently maximum impervious cover and almost negligible tree canopy and bare soil. It is marked by the presence of railway station, bus stand, workshops, shops and street hawkers. This area faces problems of open urination, MSW dumping, municipal sewage flooding, overflowing sewer manholes, open discharge of sewage and stormwater. The stormwater in this area collects in the pits on roads where it stagnates and is lost through percolation and evaporation. Even a single rain causes water to flood over roads due to poor stormwater conveyance systems.

Fig. – (4.5) Bus Stand Sub-Watershed

The rural areas within Punjab severely lack facilities for storwmwater drainage. The concept of stormwater management has not even reached out to most of the villages in Punjab. Two sub-watersheds have been selected from Chappa village, District Barwala. Chappa has two ponds located with the village where the runoff from rainfall event ultimately reaches out. These ponds receive open urination, open defecation, MSW dumping, municipal sewage flooding, open discharge of sewage and stormwater runoff.

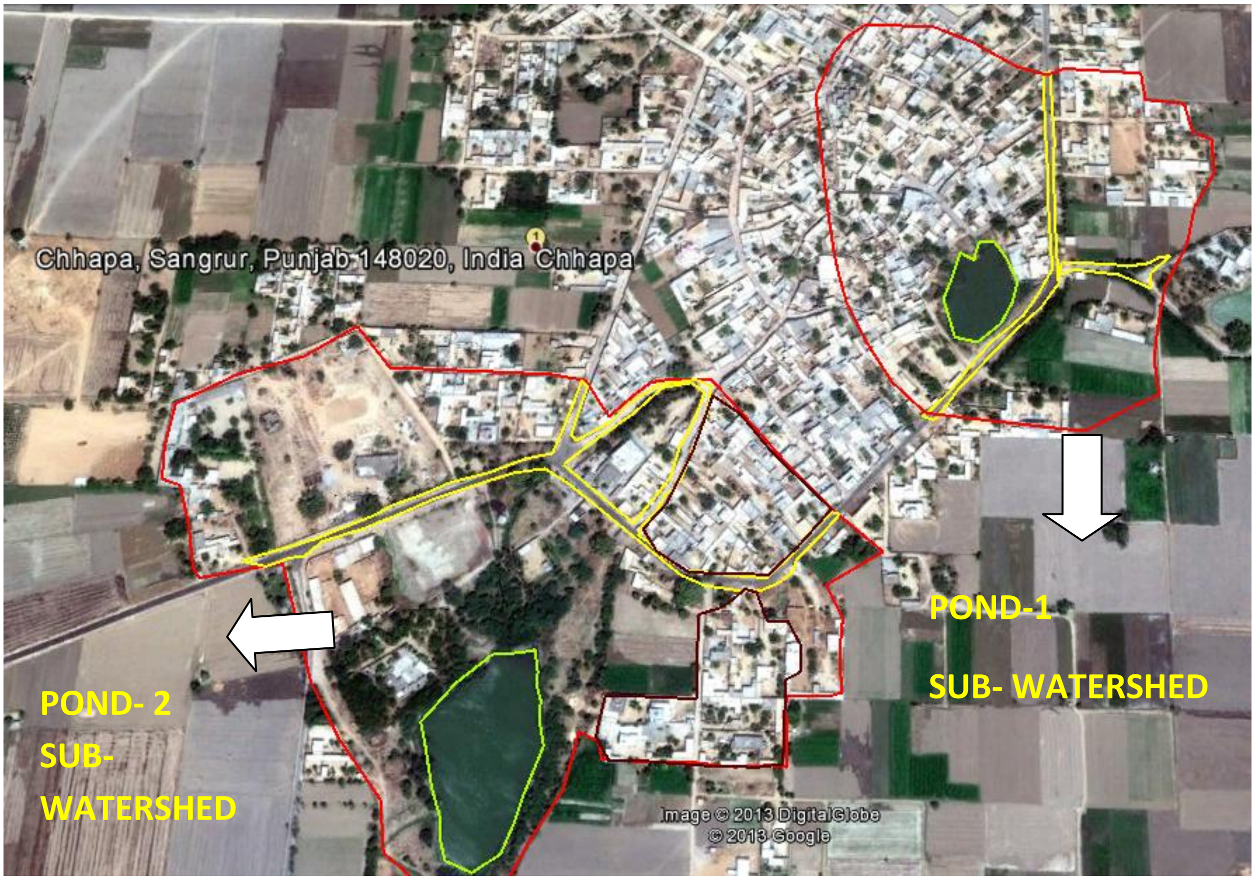

Fig. – (4.6) Rural Sub-Watersheds

The following watershed characteristics were studied for the sub-watersheds:

- Catchment size/ drainage area
- Channel length
- Channel Slope
- Soil type (hydrological soil type A, B, C, D)
- Land use

    1. Impervious area (Roods and Roof top)
    2. Grass cover
    3. Tress canopy
    4. Bare soil
    5. Fallow land
    6. Pasture (Hydrological condition based upon extent of grazing)
    7. Farmsteads

The following Table (4.1) depicts the watershed characteristics namely Drainage area, Channel length and slope for the selected sub-watersheds:

SUB-WATERSHED	**AREA Acres (m^2)**	**CHANNEL LENGTH Feet (m)**	**SLOPE**
URBAN SUB-WATERSHEDS			
Civil Lines	8 (31733)	800 (244)	0.0125
Model Town	2 (8501)	246 (75)	0.02
Manjit Nagar	3.84 (15672)	462 (141)	0.015
Preet Nagar	1.5 (6124)	342 (104.2)	0.0051
Bus Stand	9.8 (39950)	580 (177)	0.0147
RURAL SUB-WATERSHEDS			
Pond- 1	23.17 (93765)	720 (219.45)	0.002
Pond-2	37.34 (151110)	1181 (360)	0.013

(Table 4.1) Sub-Watershed Details

The land use details for the sub-watersheds are shown below through pie chart (Fig. 4.7)

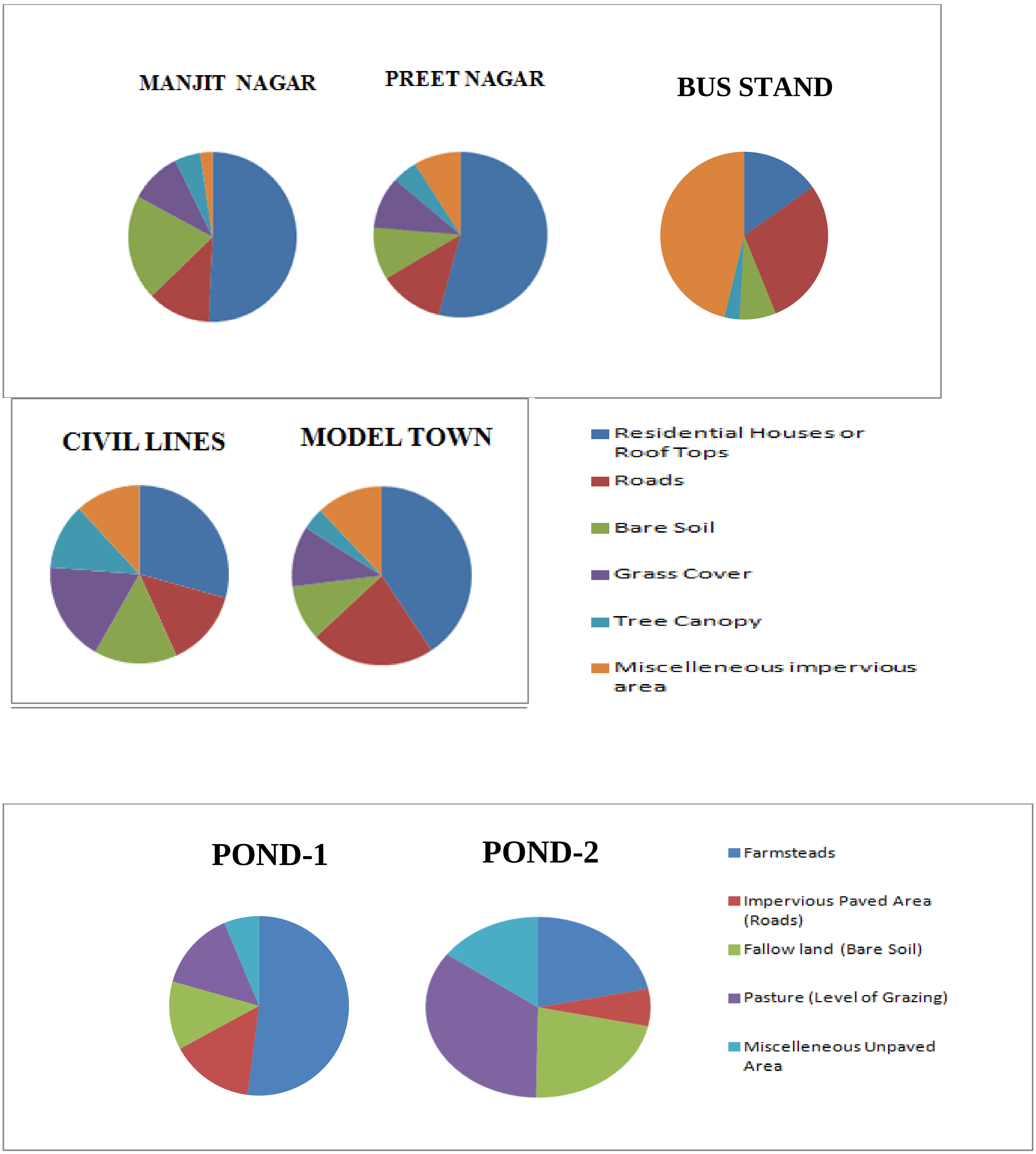

Fig.- (4.7) Land Use Details for the Sub-Watersheds

4.2) RAINFALL DATA FOR THE SUB- WATERSHED AREAS.

URBAN WATERSHED

Daily average rainfall data was compiled for all the watersheds over a period of six years (2006-2011). The source of this data is the Indian Meteorological Department online website.

The following graph (Fig-4.8) shows the variation of rainfall over these catchments from the year 2006- 2011.

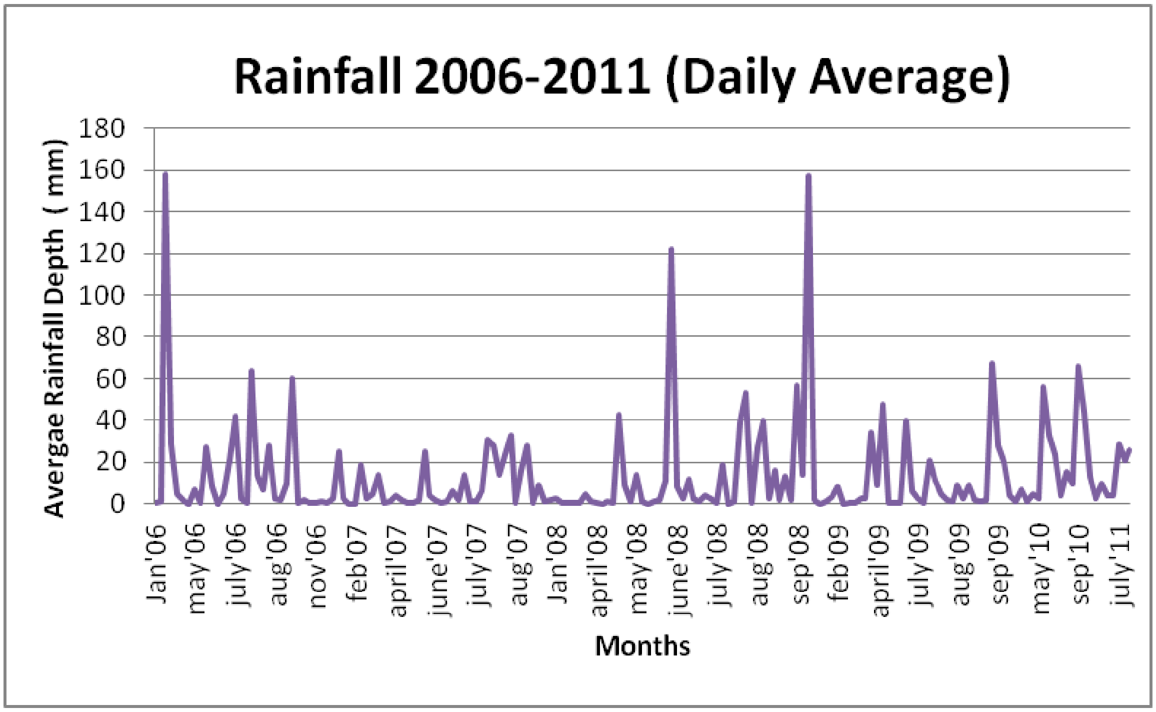

Fig. - (4.8) Variation of Rainfall (2006-2011) for Patiala

RURAL SUB-WATERSHEDS

Rainfall data was obtained from Indian Meteorological Department for the five years (2008-2012). The data so obtained is the arithmetic average of the rainfall (mm) of the stations under the district Sangrur, Punjab).

The following graph (Fig-4.9) shows the variation of average monthly rainfall over these catchments from the year 2008- 2012. Monthly average rainfall for Patiala and Sangrur can b seen from Appendix 1 and 2.

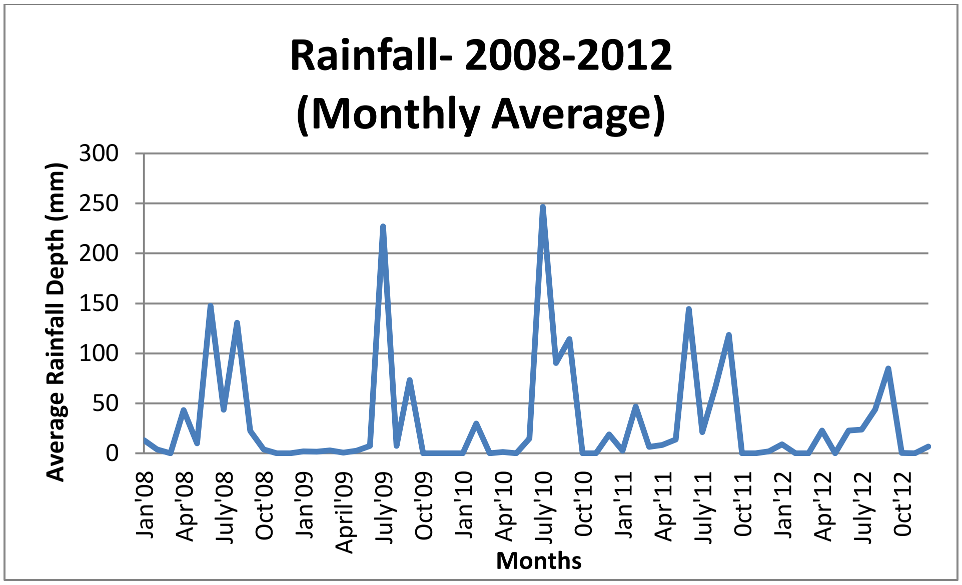

Fig. - (4.9) Variation of Rainfall (2006-2011) for Sangrur District

For the urban catchments, the following Bar Chart (Fig-4.10) shows 90, 80, 70, 60, and 50 percentile values for average precipitation depths.

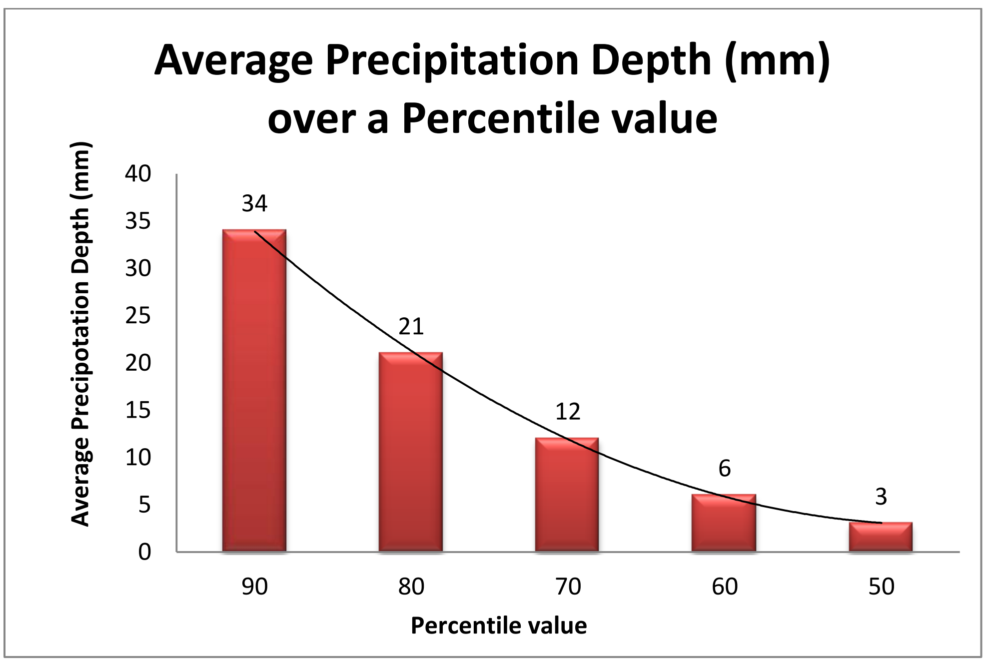

Fig. – (4.10) Average Precipitation Depths at Different Percentile Values

For e.g. 90 percentile value ‘34mm’ signifies that the probability for a rainfall event to have 34 mm or lesser depth of precipitation , is 90 percent or that 90 percent of the rainfall events will have an average precipitation equal to or less than 34 mm.

For the purpose of quantification, a range of rainfall intensities (12mm, 21mm, 34mm, 64mm, 122mm, 157mm) were selected to show the variations in the volume of runoff. Rainfall depths 6 mm and 3 mm were omitted from calculations since these do not fulfill the criteria" P $\geq$ 0.2 S", as per US-SCS CN Method. For depicting the rainfall characteristics over these catchments, rainfall event occurred on **4-September-2012***(wunderground.com)* was used as an example. An average of **35 mm** rain had occurred on this particular date which is near about the 90 percentile value so calculated. The total duration of rainfall considered was **210 minutes**.

a) **Hyetograph (Rainfall Intensity V/S Time) of the Storm**:

The following table (Table-4.2) shows the distribution of rainfall over the catchment and the corresponding rainfall intensity (mm/hour) for the precipitation event.

Time (min)	Rainfall (mm)	Cumulative Rainfall (mm)	Intensity (mm/hour)
0	0	0	0
30	4	4	8
60	8	12	16
90	2	14	4
120	9	23	18
150	7	30	14
180	3	33	6
210	2	35	4

(Table 4.2) Rainfall Distribution over Duration of Storm

The following bar chart (Fig-4.12) depicts the Hyetograph of the storm for 35mm average rainfall depth that was derived by the mass curve (Fig-11.) of the rainfall that is a plot of accumulated precipitation against time, plotted in chronological order.

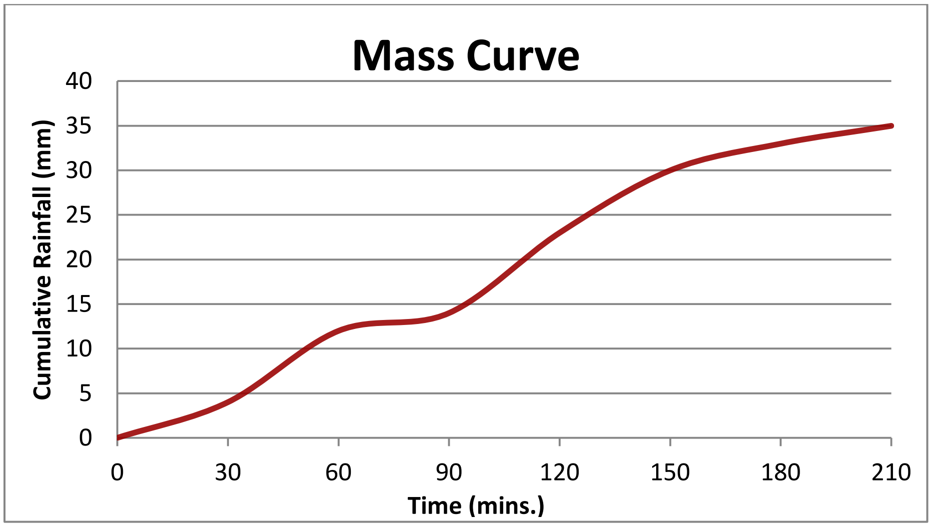

Fig. – (4.11) Mass Curve of the Rainfall Event

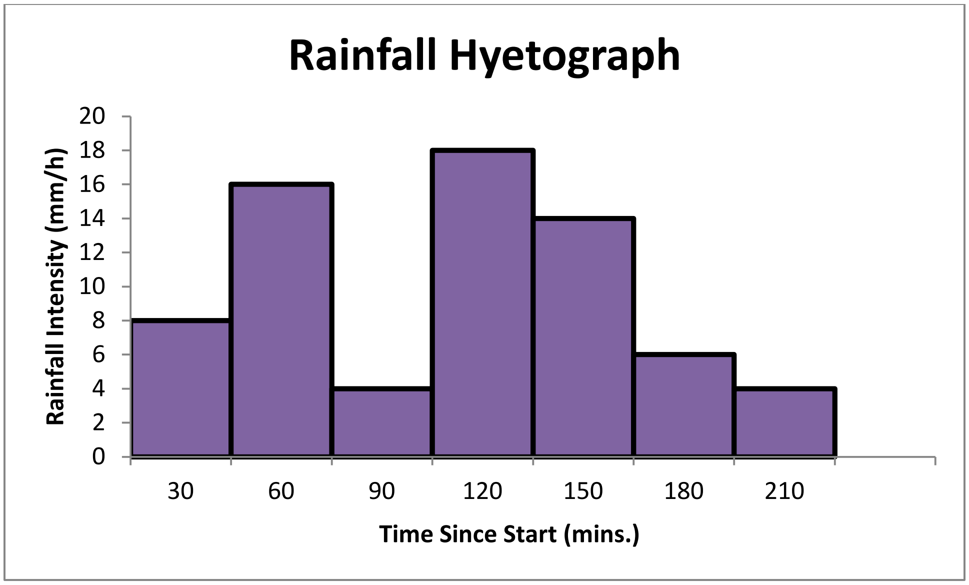

Fig. – (4.12) Hyetograph of the Rainfall Event

b) Maximum Intensity- Maximum Depth- Duration Relation

i. Maximum Intensity- Duration relationship

If the mass curve is divided into N segments of time interval Δt such that the total duration of storm D= N Δt, then the intensity of storm for various sub-durations can be calculated.

For each such duration, the intensity will have a maximum value and this is analyzed to obtain *a relationship for variation of the maximum intensity with duration for the storm*.

ii. Maximum Depth- Duration relationship

It is used to relate the maximum Depth of precipitation in the duration t, to the duration D.

The following (Table-4.3) shows the maximum depth marked in bold for the different duration calculated by cumulative rainfall. The maximum depths are encircled. The maximum depth and the corresponding maximum intensity are shown in (Table-4.4).

Time (min)	Cumulative Rainfall (mm)	30	60	90	120	150	180	210
0	0							
30	4	4						
60	12	8	12					
90	14	2	10	14				
120	23	9	11	19	23			
150	30	7	16	18	26	30		
180	33	3	10	19	21	29	33	
210	35	2	5	12	21	23	31	35

(TABLE-4.3) Maximum Rainfall Intensities at Different Storm Durations

Time (mins.)	30	60	90	120	150	180	210
Maximum Depth(mm)	9	16	19	26	30	33	35
Maximum Intensity (mm/h)	18	16	12.67	13	12	11	10

(TABLE-4.4) Maximum Intensity- Maximum Depth- Duration Relation

The data obtained from the above analysis was plotted as maximum depth v/s duration and maximum intensity v/s duration as shown in (Fig-4.13).

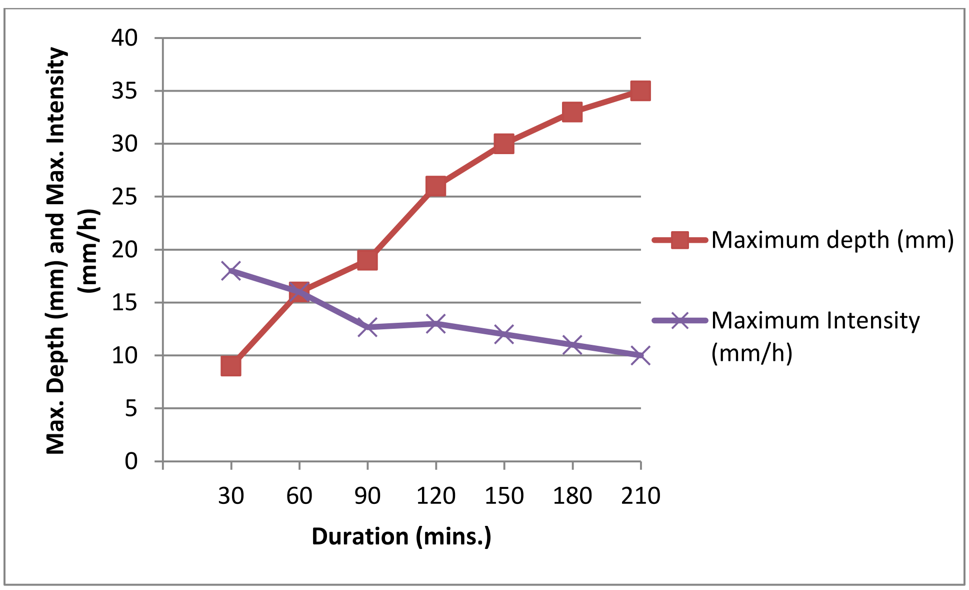

Fig. – (4.13) Maximum Intensity- Maximum Depth- Duration Curves for the Rainfall Event

4.3) *RUN-OFF FOR THE SUB- WATERSHEDS*

4.3.1). Runoff Coefficient

For the urban sub-watersheds:

The runoff coefficient (K) was calculated based upon individual coefficients for the sub-areas within the catchment and then weighted runoff coefficient was calculated. The following K values where considered **(Table-4.5)** depending upon the land-use:

LAND USE	K
Roof Tops	0.85
Paved Area (Roads/ Driveways/ Courtyards)	0.65
Unpaved Area (Grass Cover/ Bare Soil)	0.25

(Table- 4.5) Runoff Coefficient for Rational Method having return period 2 years

Source: Literature survey

For Rural sub-watershed:

Runoff coefficients for rural catchments were calculated by taking the following (Table-4.6) as a basis:

Watershed characteristic	Extreme	High	Normal	Low
Relief - C_r	0.28-0.35 Steep, rugged terrain with average slopes above 30%	0.20-0.28 Hilly, with average slopes of 10-30%	0.14-0.20 Rolling, with average slopes of 5-10%	0.08-0.14 Relatively flat land, with average slopes of 0-5%
Soil infiltration - C_i	0.12-0.16 No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	0.08-0.12 Slow to take up water, clay or shallow loam soils of low infiltration capacity or poorly drained	0.06-0.08 Normal; well drained light or medium textured soils, sandy loams	0.04-0.06 Deep sand or other soil that takes up water readily; very light, well-drained soils
Vegetal cover - C_v	0.12-0.16 No effective plant cover, bare or very sparse cover	0.08-0.12 Poor to fair; clean cultivation, crops or poor natural cover, less than 20% of drainage area has good cover	0.06-0.08 Fair to good; about 50% of area in good grassland or woodland, not more than 50% of area in cultivated crops	0.04-0.06 Good to excellent; about 90% of drainage area in good grassland, woodland, or equivalent cover
Surface Storage - C_s	0.10-0.12 Negligible; surface depressions few and shallow, drainageways steep and small, no marshes	0.08-0.10 Well-defined system of small drainageways, no ponds or marshes	0.06-0.08 Normal; considerable surface depression, e.g., storage lakes and ponds and marshes	0.04-0.06 Much surface storage, drainage system not sharply defined; large floodplain storage, large number of ponds or marshes

(Table-4.6) Runoff Coefficients for Rural Sub- Watersheds

Source: Hydraulic Design Manual TxDOT, (2011) The runoff coefficient for rural watersheds is given by:

$$C = C_r + C_i + C_v + C_s$$

Runoff coefficients for the catchments were also calculated as the ratio of runoff (mm) to rainfall (mm) generated as calculated by US-SCS CN Method.

The following (Table- 4.7) show mean runoff coefficient, weighted runoff coeffiecint and runoff coefficient for 90 percentile rainfall value (34mm) for the sub-watersheds.

SUB-WATER SHEDS	CIVIL LINES		MODEL TOWN		MANJIT NAGAR		PREET NAGAR		BUS STAND		POND-1		POND-2	
Rainfall	**Runoff**	**K**	**Runoff**	**K**	**Runoff**	**K**	**Runoff**	**K**	**Runoff**	**K**	**Runoff**	**K**	**Runoff**	**K**
12	0.458	0.0381	1.51	0.125	0.1	0.0025	1.16	0.0966	2.45	0.2041				
21	3.5	0.1666	6.21	0.295	2.15	0.0577	5.41	0.2576	8.12	0.3866	0.415	0.019	0.288	0.06010
34	10.83	0.3185	15.52	0.456	8.14	0.1670	14.21	0.4179	18.47	0.5432	3.74	0.11	3.28	0.19044
64	33.72	0.5268	41.35	0.646	28.73	0.3660	39.33	0.6145	45.66	0.7134	19.11	0.298	17.94	0.39897
122	85.9	0.7040	96.29	0.789	78.5	0.5740	93.64	0.7675	101.72	0.8337	62.46	0.511	60.3	0.60198
157	119.14	0.7588	130.42	0.830	110.9	0.6452	127.56	0.8124	136.18	0.8673	92.397	0.588	89.88	0.67011
	Mean	0.413	**Mean**	0.51	**Mean**	0.3021	**Mean**	0.4944	**Mean**	0.5914	**Mean**	0.305	**Mean**	0.38432
	weighted	0.566	**Weighted**	0.647	**Weighted**	0.611	**Weighted**	0.658	**Weighted**	0.63	**Weighted**	0.38	**Weighted**	0.34

(Table 4.7) Runoff Coefficients for the Sub-Watershed Calculated by US-SCS CN Method

The value of runoff coefficients for a range of rainfall depths as expected was found to increase with increasing rainfall depth (Fig. 4.14).

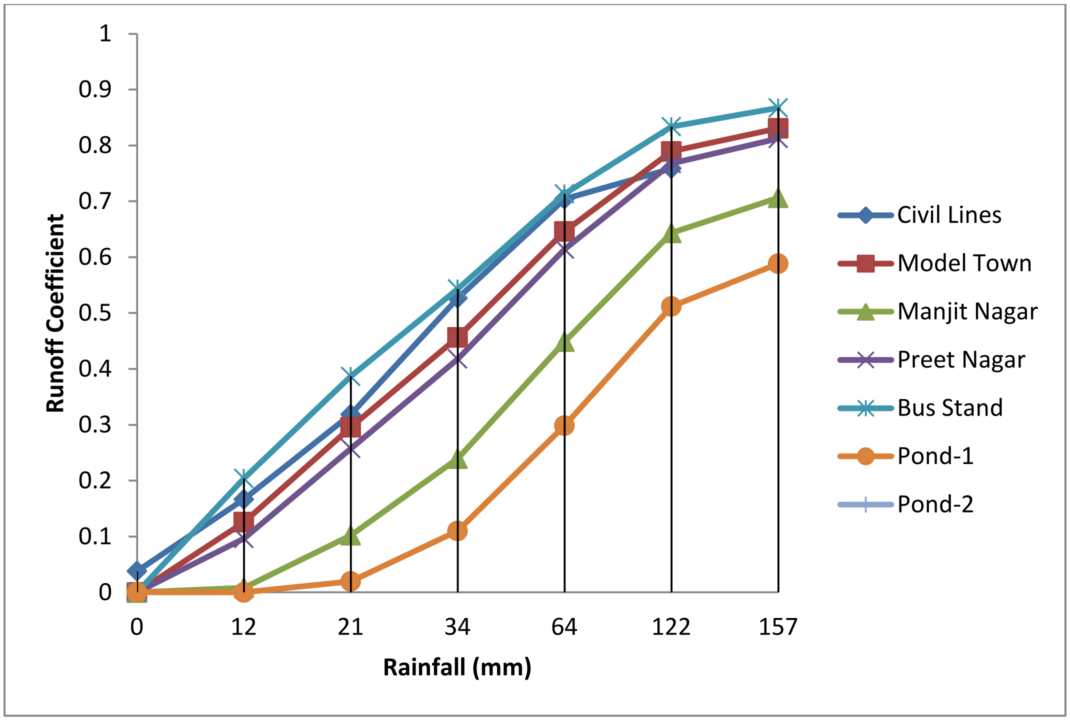

Fig. – (4.14) Rainfall- Runoff Coefficient Relationship for the Sub- Watersheds

- ✓ Weighted runoff coefficients have higher value for all the catchments since the runoff coefficients used for individual areas are given for rational method for a return period of 2 years whereas our assumption is 6 months return period.
- ✓ Since the Bus Stand catchment has maximum area under impervious cover as compared to all other catchments, as evident from above, has the highest runoff coefficient at 90 percentile rainfall value i.e. Bus Stand will witness maximum percentage (approx. 55 %) of rainfall resulting into runoff.
- ✓ Pond- 2 catchment has the lowest impervious area and hence has lowest runoff coefficient out of all catchments i.e. it will witness minimum percentage (approx. 9 %) of rainfall resulting into runoff.

4.3.2). Time of Concentration (Tc)

The following **(Table-4.8)** shows the Tc for different sub-watersheds.

SUB-WATERSHED	**Rational Method Tc (min)**	**Kirpich Method Tc (min)**	**Kerby-hathwey Equation Tc (min)**	**Morgali & Lisely Method Tc(min)**	**Adhoc Method Tc (min)**	**Johnstone cross method Tc (min)**
Civil Lines	0.2	7	18	29	7	14
Model Town	0.12	2.5	9	12	3.5	6
Manjit Nagar	0.15	4.5	18	30	4.6	9.5
Preet Nagar	0.22	3.5	11.5	16	3	8.5
Bus Stand	0.10	8	9	12	7.5	19
Pond-1 Sub-watershed	0.30	13	14	72	36	34
Pond-2 Sub-watershed	0.37	15	7	55	29	17

(Table- 4.8) Tc Calculations for Selected Sub- Watersheds

Rational Method and Morgali Lisely method yield extreme values of Tc (minimum and maximum respectively). Hence ignoring the extremes the following (Table-4.9) shows the average Tc values for the different sub-watersheds.

Sub-Watershed	**Civil Lines**	**Model Town**	**Manjit Nagar**	**Preet Nagar**	**Bus Stand**	**Pond-1 Sub-Watershed**	**Pond-2 Sub-Watershed**
Tc (Minutes)	12	6	10	7	11	24	18

(Table-4.9) Tc for the Selected Sub- Watersheds

- ✓ The urban sub-watersheds have almost equal time of concentration irrespective of the varying drainage areas due to the fact that these have almost similar slopes i.e. the elevation difference between the outlet and most remote point of the catchment and distance between the two.
- ✓ Among the rural sub-watersheds, Pond-1 catchment has lower Tc irrespective of its smaller drainage area as compared to Pond-2 catchment due to the fact that the catchment slope is much less than that of Pond-2 catchment.

4.3.3). Runoff Volume (By US-SCS CN Method)

4.3.3.1). Curve Number (CN)

For urban sub-watersheds:

The Curve Number for the catchments was assessed with the help of hydrologic model WIN TR-55 Small Watershed Hydrology software. Both individual and weighted CN where found out.

The following figures (4.15-4.19) show interface of the software and the calculated CN.

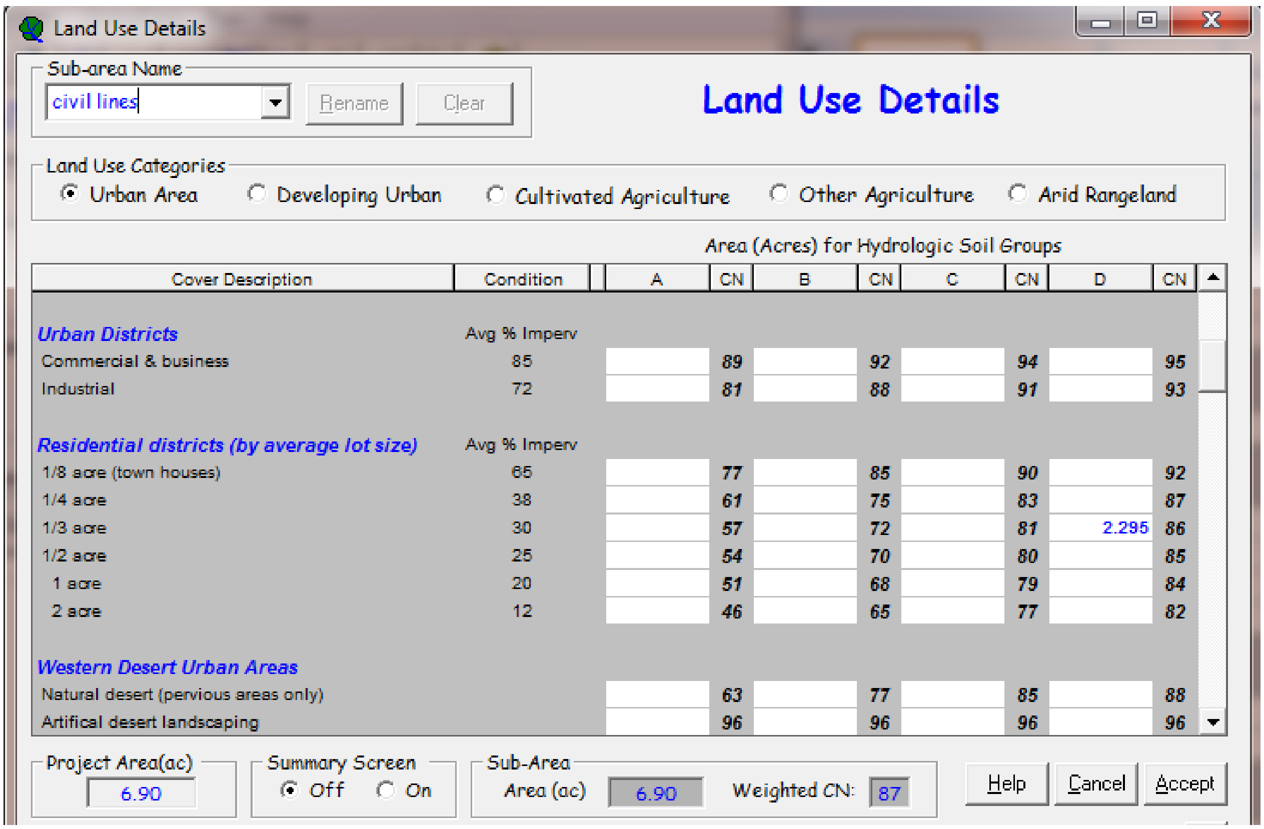

Fig. – (4.15) Weighted CN Calculations for Civil Lines

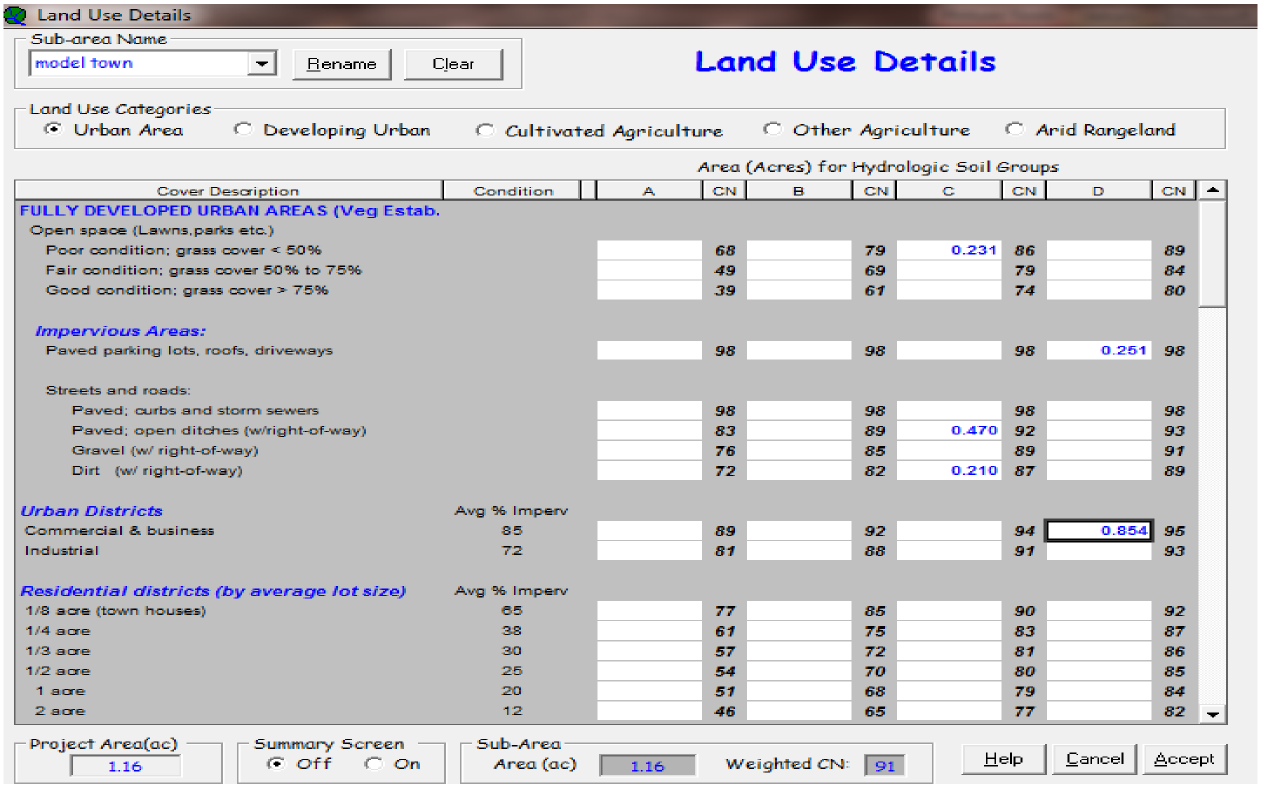

Fig. – (4.16) Weighted CN Calculations for Model Town

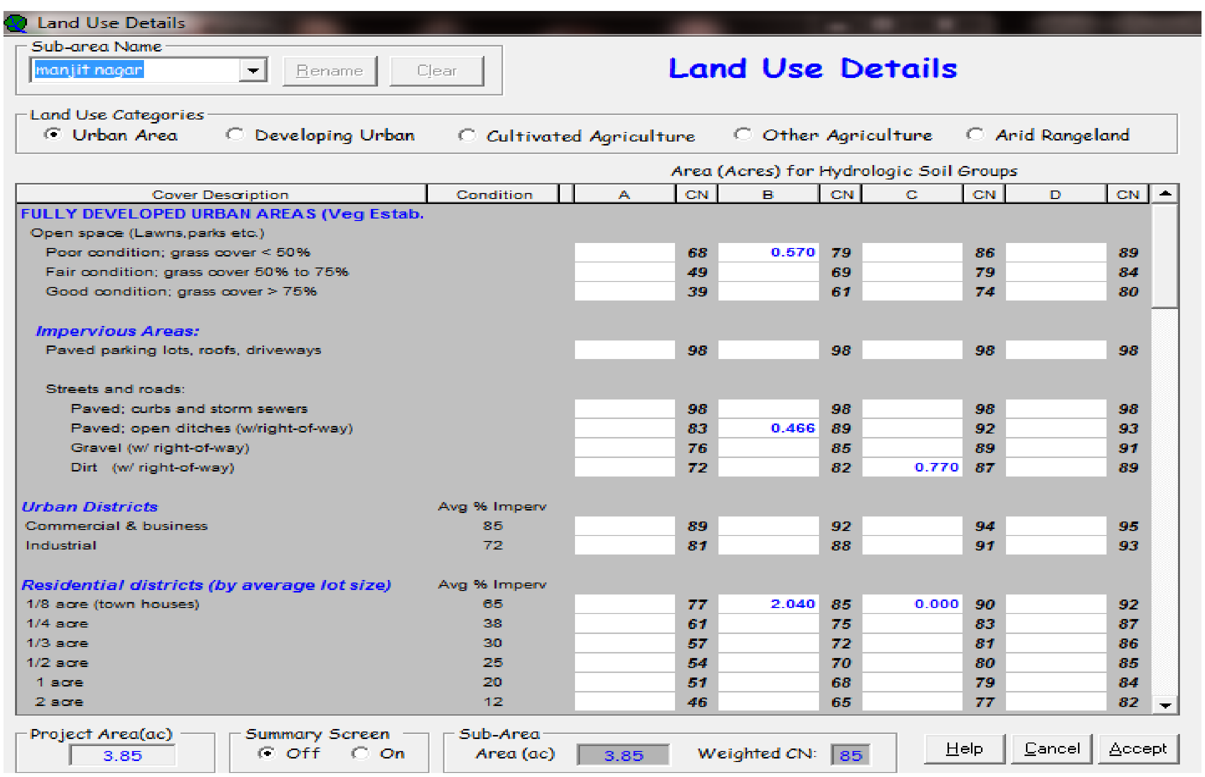

Fig. – (4.17) Weighted CN Calculations for Manjit Nagar

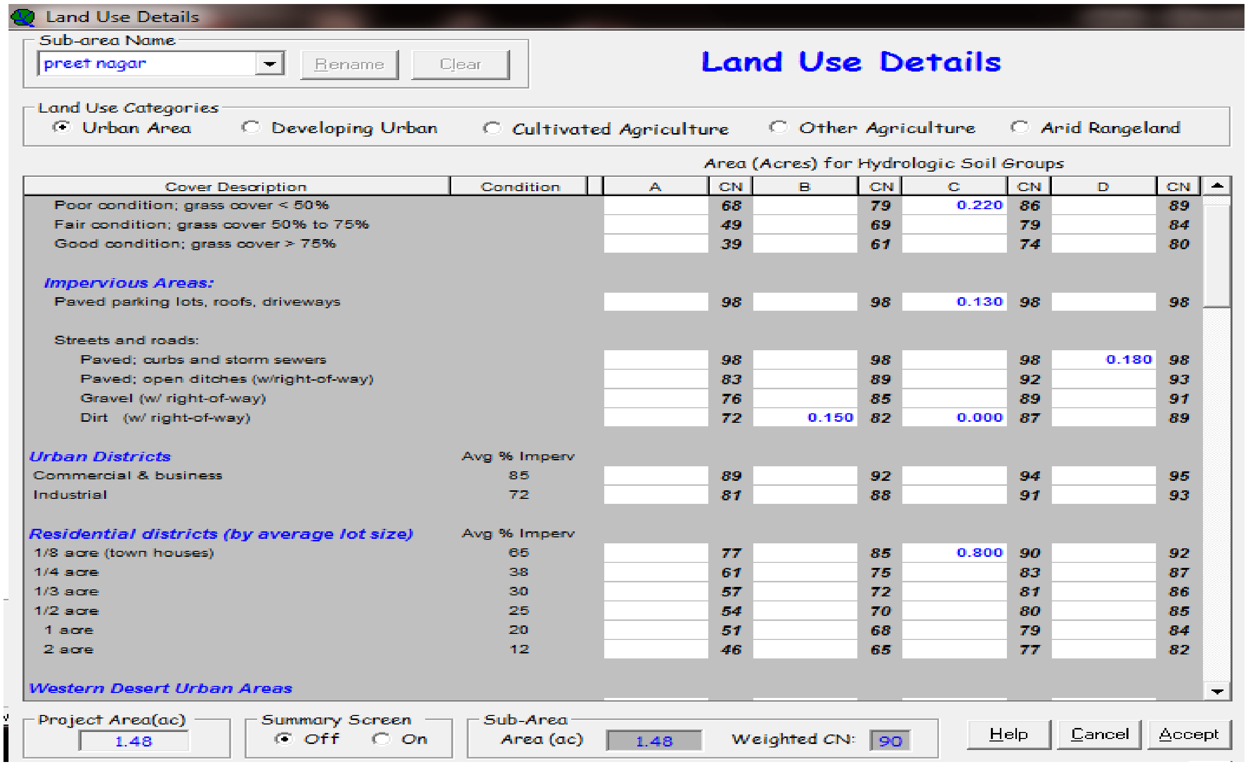

Fig. – (4.18) Weighted CN Calculations for Preet Nagar

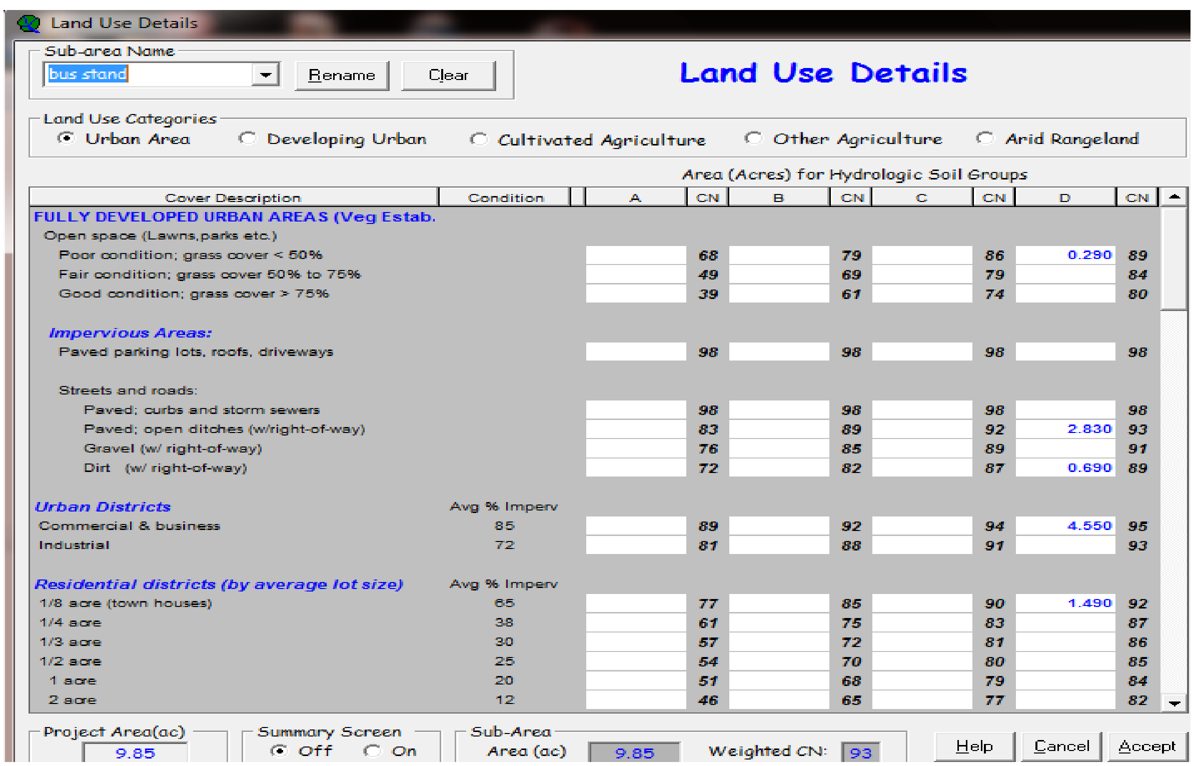

Fig. – (4.16) Weighted CN Calculations for Bus Stand

CN for rural sub-watersheds:

The following (Table- 4.10) has been used as a basis for calculation CN for rural catchments.

LAND USE	***SOIL GROUP A***	***SOIL GROUP B***	***SOIL GROUP C***	***SOIL GROUP D***
Fallow	77	86	91	94
Pasture				
Poor	68	76	86	89
Fair	49	69	79	80
Good	39	61	74	80
Urban (Impervious)	*72*	*79*	*85*	*88*
Farmsteads	59	74	82	86

(Table- 4.10) CN for Rural Sub- Watersheds

Source: US Department of Agriculture, Soil Conservation Service (1976)

The following (Table- 4.11) shows the calculated Curve Number for all the 7 catchments:

SUB-WATERSHED	**WEIGHTED CURVE NUMBER**
Civil Lines	*87*
Model Town	*91*
Manjit Nagar	*84*
Preet Nagar	*90*
Bus Stand	*93*
Pond-1	*77*
Pond-2	*76*

(Table- 4.11) Weighted CN for the Selected Sub- Watersheds

- ✓ CN on a higher side for Model Town, Preet Nagar and Bus Stand can be attributed to the higher impervious fractions in these catchments as shown above in the pie charts.

- ✓ Manjit Nagar has the lowest CN out of all the urban catchments due to largest portion of this area contributing to bare soil, tree canopy and grass cover.
- ✓ A lower CN has been found for Pond-2 catchment since it has larger proportion of land under bare soil and pasture compared to Pond-1 catchment.

4.3.3.2). Volume of Runoff

FOR URBAN CATCHMENTS

The following (Table- 4.12) shows calculated volume of runoff (m^3/s) generated for the selected urban sub-watersheds corresponding precipitation events of 12mm (70 percentile), 21mm (80 percentile), 34mm (90 percentile), 64mm, 122mm, 157mm.

PRECIPITATION (mm)	URBAN CATCHMENTS Run off Volume (m^3) Approx.				
	Civil Lines	Model Town	Manjit Nagar	Preet Nagar	Bus Stand
12	12	13	3	8	98
21	111	53	34	34	325
34	343	132	128	87	738
64	1070	352	450	240	1825
122	2726	820	1230	574	4065
157	3780	1110	1740	780	5440

(Table- 4.12) Volume of Runoff for Urban Sub- Watersheds

- ✓ The maximum volume of runoff is being generated in the sub-watershed Bus Stand because of the largest drainage area among all the catchments and highest Curve Number.
- ✓ For all the rainfall events Preet Nagar records lowest runoff volume because of the smallest catchment area.

- ✓ Civil Lines and Bus Stand don't differ much in drainage area but still there is huge variation in the runoff volume. This is attributed to the lower Curve Number for Civil Lines catchment.
- ✓ The lowest Curve Number is of Manjit Nagar due to largest pervious area however its larger drainage area doesn't allow lowest volume of runoff.

FOR RURAL CATCHMENTS

Similar range of precipitation events has been considered for the rural catchments since this is the most probable range. The following (TABLE-4.13), shows the volume of runoff generated in the two selected rural catchments; Pond 1 sub-watershed and Pond-2 sub-watershed.

PRECIPITATION (mm)	**RURAL CATCHMENTS** Run off Volume (m^3) Approx.	
	Pond-1 Sub- Watershed	**Pond-2 Sub- Watershed**
21	40	44
34	350	500
64	1792	2712
122	5856	9112
157	8664	13575

(Table- 4.13) Volume of Runoff for Urban Sub- Watersheds

- ✓ As observed above Pond-2 Sub-Watershed has higher runoff volume due to larger drainage area contributing to the run off.

Thus from the above tables we can see how rainfall intensity effects the volume of runoff. Higher the precipitation larger is the runoff volume resulting from the catchments. The following (Fig. 4.20) shows this relation for all the catchments.

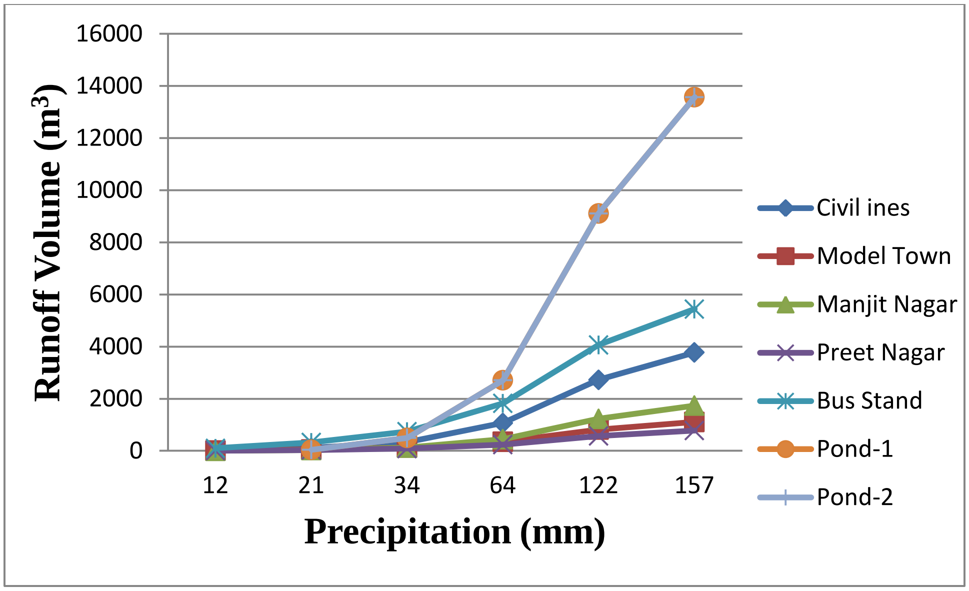

Fig. - (4.20) Precipitation- Volume of Runoff Relationship

4.4) DIRECT RUNOFF HYDROGRAPH (BY MODIFIED RATIONAL METHOD) FOR URBAN CATCHMENTS

Direct runoff hydrograph was developed using the modified rational method. Peak flow rates were computed for duration of 30 minutes each for complete storm duration of 210 minute. For each such rainfall individual trapezoidal hydrographs were plotted such that each hydrograph lags the former by 30 minutes. For each individual hydrograph the time of rise equals time of recede equals time for concentration.

The direct runoff hydrograph resulted from a storm of duration 210 minutes and rainfall depth 35mm (4-Sep-2012) was constructed by adding individual trapezoidal hydrographs.

Shown below are the (Tables -4.14-4.18) for the calculated peak flow rates and volumes of runoff. Fig. (4.20-4.29) show trapezoidal hydrographs and final direct runoff hydrographs for the sub-watersheds respectively.

CIVIL LINES								
Duration (mins.)	**Rainfall (mm)**	**Cumulative Rainfall**	**Runoff Coefficient**	**Intensity (inch/h)**	**Drainage Area (acres)**	**Peak Flow Rate(cfs)**	**Runoff Volume (cu. ft)**	**Cumulative volume (cfs)**
0-30	4	4	0.012	0.314	8	0.030144	54.2592	54.2592
30-60	8	12	0.03816	0.62	8	0.189274	340.6925	394.9517
60-90	2	14	0.108	0.15	8	0.1296	233.28	628.2317
90-120	9	23	0.22	0.7	8	1.232	2217.6	2845.832
120-150	7	30	0.28	0.55	8	1.232	2217.6	5063.432
150-180	3	33	0.3	0.354	8	0.8496	1529.28	6592.712
180-210	2	35	0.32	0.15	8	0.384	691.2	7283.912

(Table-4.14) Peak Runoff Rate and Volume of Runoff for Civil Lines

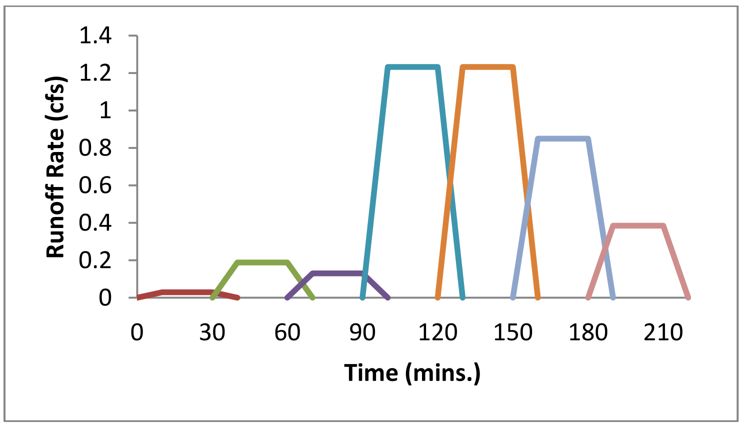

Fig. – (4.21) Trapezoidal Runoff Hydrograph for Civil Lines

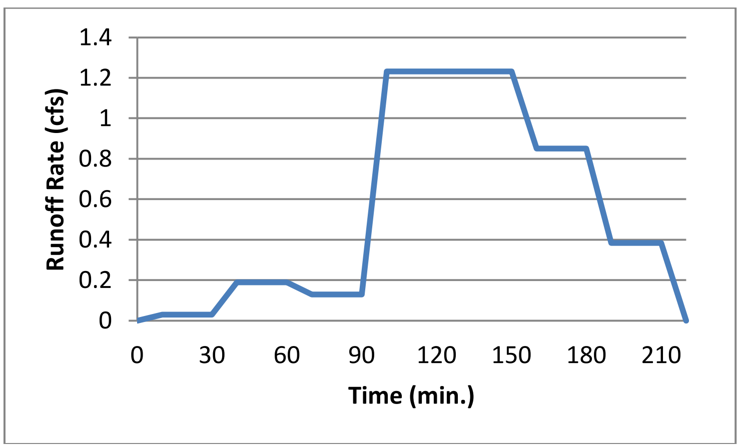

Fig. – (4.22) Direct Runoff Hydrograph for Civil Lines

MODEL TOWN								
Duration (mins.)	Rainfall (mm)	Cumulative Rainfall (mm)	Runoff Coefficient	Intensity (inch/h)	Drainage Area (acres)	Peak Flow Rate (cfs)	Runoff Volume (cu. ft.)	Cumulative volume (cu. ft.)
0-30	4	4	0.04	0.314	2	0.02512	45.216	45.216
30-60	8	12	0.12	0.62	2	0.1488	267.84	313.056
60-90	2	14	0.17	0.15	2	0.051	91.8	404.856
90-120	9	23	0.25	0.7	2	0.35	630	1034.856
120-150	7	30	0.33	0.55	2	0.363	653.4	1688.256
150-180	3	33	0.42	0.354	2	0.29736	535.248	2223.504
180-210	2	35	0.47	0.15	2	0.141	253.8	2477.304

(Table-4.15) Peak Runoff Rate and Volume of Runoff for Model Town

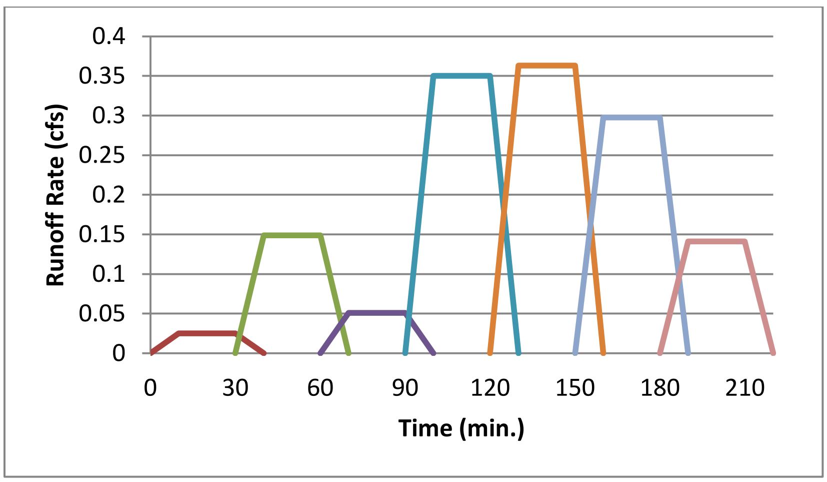

Fig. – (4.23) Trapezoidal Runoff Hydrograph for Model Town

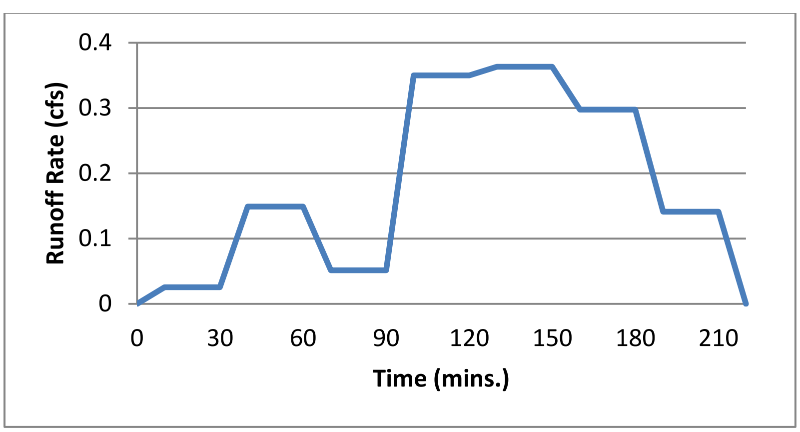

Fig. – (4.24) Direct Runoff Hydrograph for Model Town

MANJIT NAGAR								
Duration (mins.)	**Rainfall (mm)**	**Cumulative Rainfall (mm)**	**Intensity (inch/h)**	**Runoff Coefficeint**	**Drainage Area (acres)**	**Peak Flow Rate (cfs)**	**Runoff Volume (cu. ft.)**	**Cumulative volume (cu. ft.)**
0-30	4	4	0.314	0.0022	3.84	0.002653	4.77481	4.77481
30-60	8	12	0.62	0.008	3.84	0.019046	34.28352	39.05833
60-90	2	14	0.15	0.05	3.84	0.0288	51.84	90.89833
90-120	9	23	0.7	0.11	3.84	0.29568	532.224	623.1223
120-150	7	30	0.55	0.17	3.84	0.35904	646.272	1269.394
150-180	3	33	0.354	0.21	3.84	0.285466	513.8381	1783.232
180-210	2	35	0.15	0.24	3.84	0.13824	248.832	2032.064

(Table- 4.16) Peak Runoff Rate and Volume of Runoff for Manjit Nagar

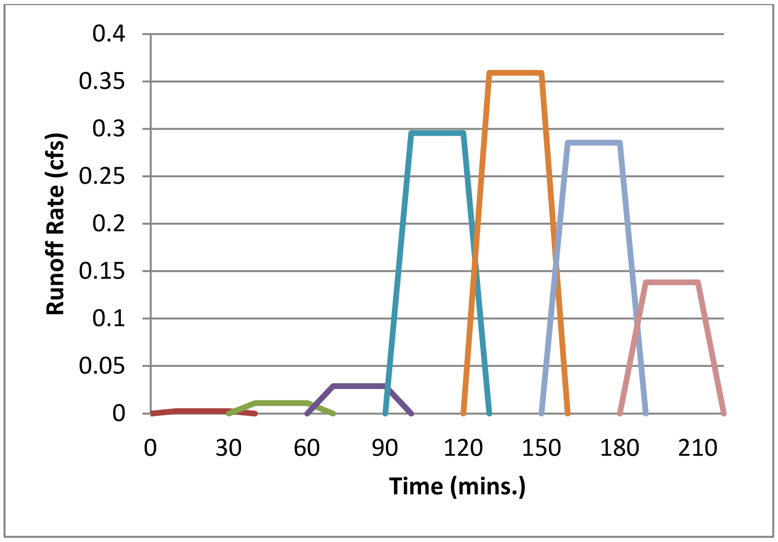

Fig. – (4.25) Trapezoidal Runoff Hydrograph for Manjit Nagar

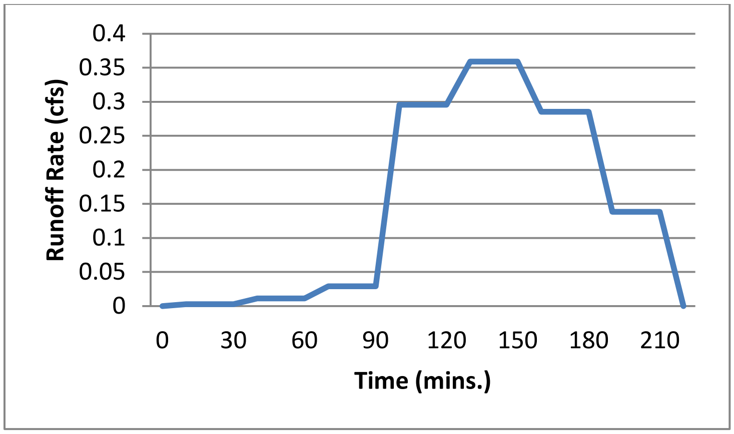

Fig. – (4.26) Direct Runoff Hydrograph for Manjit Nagar

PREET NAGAR								
Duration (mins.)	Rainfall (mm)	Cumulative Rainfall (mm)	Intensity (inch/h)	Drainage Area (acres)	Runoff Coefficient	Peak Flow Rate (cfs)	Runoff Volume (cu. ft.)	Cumulative volume (cu. ft.)
0-30	4	0.314	0.033	1.5	0.015543	0.015543	27.9774	27.9774
30-60	8	0.62	0.096667	1.5	0.0899	0.0899	161.8206	189.798
60-90	2	0.15	0.15	1.5	0.03375	0.03375	60.75	250.548
90-120	9	0.7	0.22	1.5	0.231	0.231	415.8	666.348
120-150	7	0.55	0.32	1.5	0.264	0.264	475.2	1141.548
150-180	3	0.354	0.38	1.5	0.20178	0.20178	363.204	1504.752
180-210	2	0.15	0.42	1.5	0.0945	0.0945	170.1	1674.852

(Table- 4.17) Peak Runoff Rate and Volume of Runoff for Preet Nagar

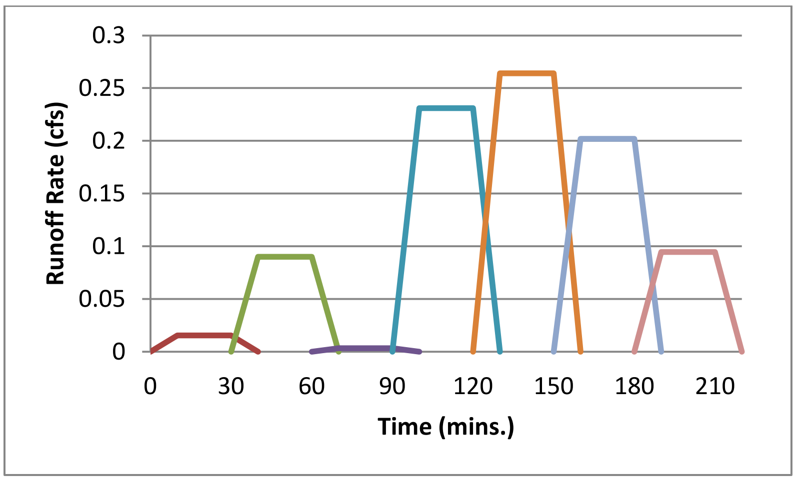

Fig. – (4.27) Trapezoidal Runoff Hydrograph for Preet Nagar

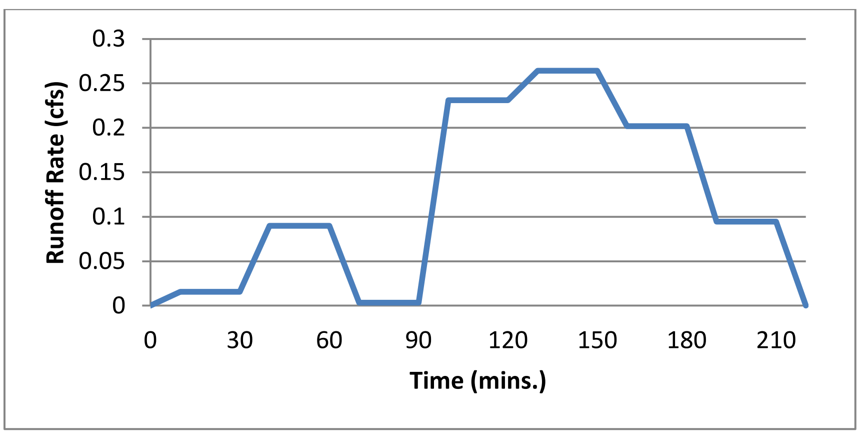

Fig. – (4.28) Direct Runoff Hydrograph for Preet Nagar

BUS STAND								
Duration (mins.)	**Rainfall (mm)**	**Cumulative Rainfall (mm)**	**Intensity (inch/h)**	**Runoff Coefficient**	**Drainage Area (acres)**	**Peak Flow Rate (cfs)**	**Runoff Volume (cu. ft.)**	**Cumulative volume (cu. ft.)**
0-30	4	4	0.314	0.1	9.8	0.30772	553.896	3007.655
30-60	8	12	0.62	0.204167	9.8	1.240519	2232.934	5240.589
60-90	2	14	0.15	0.2789	9.8	0.409983	737.9694	5978.558
90-120	9	23	0.7	0.395	9.8	2.7097	4877.46	10856.02
120-150	7	30	0.55	0.442	9.8	2.38238	4288.284	15144.3
150-180	3	33	0.354	0.5223	9.8	1.811963	3261.534	18405.84
180-210	2	35	0.15	0.5532	9.8	0.813204	1463.767	19869.6

(Table- 4.18) Peak Runoff Rate and Volume of Runoff for Bus Stand

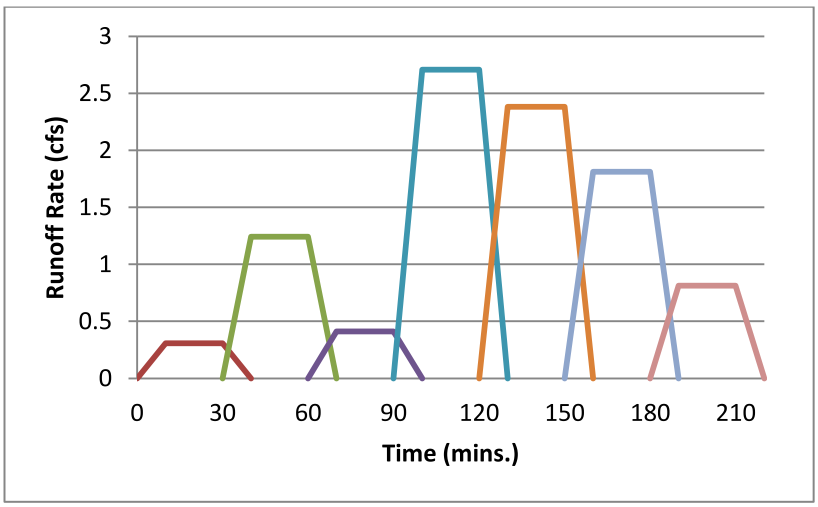

Fig.- (4.29) Trapezoidal Runoff Hydrograph for Bus Stand

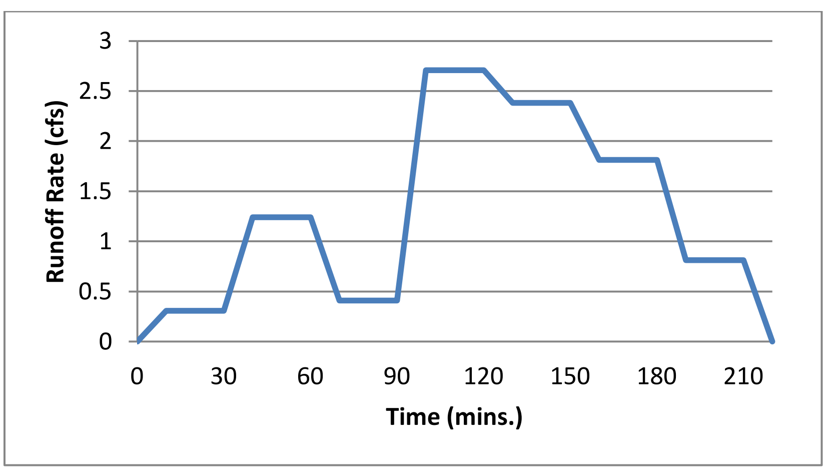

Fig. – (4.30) Direct Runoff Hydrograph for Bus Stand

FOR RURAL CATCHMENTS

For stormwater management in rural areas where large natural storage is available, maximum volume that can be stored carried by it is of more interest rather than the runoff hydrograph. Parallel research is being carried out in the School of Energy and Environment, Patiala, on groundwater recharge systems for stormwater disposal in rural sub-watersheds. Recharge was done for the entire stormwater volume getting into the pond.

For calculating the rate of groundwater recharge, duration of storm was calculated from the rainfall intensity at duration equal to time of concentration with a return period of 1 year. The minimum time gap between two individual storm events was considered as 6 hours.

The following (Table- 4.19) shows the recharge rate for the two ponds.

Pond	**Tc**	**Pond Area (hectares)**	**Intensity (mm/h)**	**Groundwater recharge**	**Storm Duration (min.)**	**Recharge time (hour)**	**Rate (m^3/h)**
Pond- 1	24	1.2	50	350	40.8	6.68	52.395
Pond- 2	18	1.6	60	500	34	6.566	76.149

(Table- 4.19) Groundwater Recharge Rate

CHAPTER-4

CONCLUSIONS

The hydrological model articulated for assessing stormwater was found suitable for small urban and rural catchments.

Direct runoff hydrographs were constructed for the urban sub-watersheds and maximum volume of runoff was seen for Bus Stand catchment.

For the rural sub-watersheds, keeping in mind the maximum volume that the ponds store, groundwater recharge rates of 52.395 m3/h and 76.149 m^3/h for Pond-1 and Pond-2 were suggested.

The study conducted on the selected sub-watersheds from urban and rural areas suggests that even moderate rainfall events generate huge amounts of stormwater which contributes to public nuisance and damaging of roads.

The drains in rural catchments often remain full and hence the Tc calculated may be on a higher side. The CN for the catchments has been calculated using data that is not specifically for Indian conditions.

ANNEXURE-1

INDIA METEOROLOGICAL DEPARTMENT
DISTRICT RAINFALL (MM.) FOR LAST FIVE YEARS

District : PATIALA

Note : (1) The District Rainfall(mm.)(R/F) shown below are the arithmatic averages of Rainfall of Stations under the District.
(2) % Dep. are the Departures of rainfall from the long period averages of rainfall for the District.
(3) Blank Spaces show non-availability of Data.

YEAR	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.
2008	14.9	-48	2.8	-90	0.0	-100	19.5	95	176.8	922	481.1	944	101.8	-49	255.5	35	255.6	123	10.6	-44	1.7	-56	0.1	-99
2009	9.3	-67	10.1	-63	23.0	13	38.7	287	9.7	-44	14.3	-69	125.9	-36	118.0	-37	163.3	43	3.8	-80	0.4	-90	0.0	-100
2010	4.9	-83	6.2	-77	0.0	-100	0.4	-96	1.3	-92	120.0	160	363.0	83	75.8	-60	188.8	65	7.2	-62	0.0	-100	30.4	111
2011	5.1	-81	21.3	-14	7.7	-63	4.1	-56	10.4	-32	197.2	259	147.3	-38	142.5	-32	138.9	20	0.0	-100	0.0	-100	5.4	-63
2012	10.4	-61	0.1	-100	0.3	-99	17.9	92	3.7	-76	18.3	-67	127.4	-46	110.2	-47	74.1	-36	0.5	-98	0.9	-79	7.8	-46

APPEXURE-2

INDIA METEOROLOGICAL DEPARTMENT
DISTRICT RAINFALL (MM.) FOR LAST FIVE YEARS

District : SANGRUR

Note : (1) The District Rainfall(mm.)(R/F) shown below are the arithmatic averages of Rainfall of Stations under the District.
(2) % Dep. are the Departures of rainfall from the long period averages of rainfall for the District.
(3) Blank Spaces show non-availability of Data.

YEAR	JANUARY		FEBRUARY		MARCH		APRIL		MAY		JUNE		JULY		AUGUST		SEPTEMBER		OCTOBER		NOVEMBER		DECEMBER	
	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.	R/F	%DEP.
2008	13.0	-35	4.0	-79	0.0	-100	43.3	287	10.0	-45	147.7	240	43.5	-76	130.5	-16	22.5	-78	4.0	-83	0.0	-100	0.0	-100
2009	1.8	-91	1.5	-92	2.8	-86	0.6	-95	2.6	-86	7.5	-83	226.9	26	7.5	-95	73.3	-29	0.0	-100	0.0	-100	0.0	-100
2010	0.0	-100	29.8	58	0.0	-100	1.3	-88	0.0	-100	14.6	-66	246.5	37	90.3	-42	114.3	10	0.0	-100	0.0	-100	19.0	35
2011	2.7	-85	46.8	142	6.5	-59	8.3	-20	13.8	-26	144.5	223	21.2	-87	66.3	-55	118.4	38	0.0	-100	0.0	-100	1.9	-85
2012	8.9	-51	0.0	-100	0.0	-100	22.8	119	0.0	-100	22.7	-49	23.8	-85	43.9	-70	85.0	-1	0.4	-98	0.0	-100	6.9	-47

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