CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Evaluation of Limitations of Rational Method for Runoff Calculation for Urban Areas of Islamabad

by

Hamid Ali Shah

A project report submitted in partial fulfillment for the degree of Master of Science

in the

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This research work is dedicated to my parents, respected teachers and all those friends who have supported me since the beginning of the research.

CERTIFICATE OF APPROVAL

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Abstract

Rational Method is generally used for estimation of peak discharges. Different authors mentioned different catchment area limitations for use of rational method with respect to different locations due to variation in precipitation rate and variation of ground characteristics. Mostly, the researchers stated that the results from this method could be acceptable upto area limitations of 200 acres. However, there is need to evaluate the applicability of rational method with respect to catchment area for Islamabad region to check the application and catchment limitations for the design of storm drainage system in future. Digital Elevation Modeling (DEM) along with other helping tools like Global Mapper, Sam-Sam water harvesting have been used to estimate runoff by rational method. Different points of interest developed with drainage areas of 663.8 acres, 805.4 acres, 1056.9 acres and 1529.0 acres. Then, corresponding value of runoff coefficient "C" is calculated with respect to type of drainage area. Discharge from rational method was estimated for all points of interest. Then, the results were compared with Soil Conservation Service (SCS) Curve Number method applied to same catchments. The results obtained from comparison showed that Rational Method approach could be applicable for larger areas with respect to characteristics of the ground and type of the area i.e. for developed areas. Readers will be able to evaluate the applicability of Rational Method approach after going through this research work.

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Abbreviations

C	Runoff Coefficient
CDA	Capital Development Authority
CN	Curve Number
Cusecs	Cubic Foot per second
DEM	Digital Elevation Modelling
ft.	Foot
GIS	Geographic Information System
hr.	Hour
in.	Inch
i	Average Intensity of Rainfall
IDF	Intensity Duration Frequency Curve
km	Kilometers
m	Meters
mm	Millimeters
PCT	Percentage
PMD	Pakistan Meteorological Department
Q	Discharge
SCS	Soil Conservation Service
Tc	Time of Concentration
$\mathbf{t_{ch}}$	Channel Time of Concentration
TxDOT	Texas Department of Transportation

Chapter 1

Introduction

1.1 Background

Portion of precipitation that makes its way towards streams, lakes or oceans after infiltration process into the ground as surface or sub-surface flow is known as Runoff. It can be further divided into two portions:-

a) Surface runoff: It is the flowing water above the land and which finally discharges its water into the sea.

b) Sub surface run off: This is the water which infiltrated into porous soil mass and makes its way towards rivers and lakes.

When land is developed, clearing removes the vegetation that intercepts, and causing increase in runoff rate due to absence of shrubs, vegetation etc. The construction and development of buildings, infrastructures, parking lots and other surfaces that are non-porous to rainwater further reduces infiltration and increases runoff. Depending on the degree of changes to the land surface, the total runoff can increase dramatically. These changes can also quicken the rate at which runoff flows through the land. This effect is further exacerbated by drainage systems such as gutters, storm sewers and lined channels that are designed to quickly carry runoff to rivers and streams.

In the hydrologic analysis of a development site, there are a number of variable factors that affect the nature of stormwater runoff from the site. Some of the factors that need to be considered include:-

- Rainfall amount and storm distribution
- Drainage area size, shape and orientation
- Ground cover and soil type
- Watershed development potential

So, it is difficult to estimate exact runoff volume. Estimation of peak runoff provide the basis for all planning, design, and construction of drainage facilities. Erroneous hydrology results in infrastructure that is either undersized, oversized, or can cause great unbalancing. At the same time, it is significant to realize that the result of the runoff analysis is an approximation. There are different methods used for estimation of runoff, majorly used methods are as below:-

- Rational formula
- Curve Number method
- Hydrograph method
- Use of remote sensing and GIS

1.2 Research Motivation

Different methods can be used to estimate stormwater runoff and for the design of storm drainage system; but there is need to verify the catchment limitations for these methods. So that the authentic statement regarding the limitations of these methods i.e. rational method in Pakistan can be a guide for the hydraulic design engineer to follow the catchment limitations for storm drainage network design.

Different authors mentioned different catchment area limitations for use of rational method for different locations. As for different locations, different catchment area limitation exists due to variation in precipitation rate and variation of ground characteristics. So, there is need to evaluate the applicability of rational method with respect to catchment area for the selected region so that it can be used for design of storm drainage network in the future.

1.3 Problem Statement

"Flooding in the streams is one of the major concerns for the hydraulic design engineer; due to this phenomenon many urban areas became affected. There are different methods for estimating runoff and for the design of drainage network i.e. culvert design, storm water drainage design; but the rational method is the simplest method to be adopted for design purpose. For applying rational method there should be a reliable guideline regarding catchment area limitation for the urban areas of Islamabad, Pakistan so that it can be followed by design engineers as an authentic guideline in the future".

The determination of the magnitudes and frequencies of discharges in sewers and in natural catchments drained by open streams by consideration of the amounts and frequencies of rainfall over the area has been the subject of many publications in the past half-century. In all research work conducted in past, specific area is considered; but there is no research conducted on this selected area. Therefore, there is need to check the validity in the selected region.

1.4 Research Objectives

Main objective is to evaluate the validity of rational method for the drainage design by addressing assumptions available in the literature. The key objective of this study is to check the validity of rational method approach with respect to catchment area limitation for the selected region of Pakistan. Aim is to find out cut off value upto which this method can be applicable and addressing assumptions. Then comparison of results obtained from rational method with SCS curve number method is also elaborated.

1.5 Limitations of the Study

The conducted study has following limitations:

1. This study is limited to an urban area having catchment area of 1529.00 acres out of which 34.59% of area is developed as per actual site as well as according to site plan.
2. Global Mapper has limitation of defining streams as experienced for stream no. 4. In such case, while calculating time of concentration (Tc) by Izzard method, flow length by using Mockus (USDA 1973) relationship given by equation (4.1).

1.6 Organization of Research Project

The layout of research project comprises of main five chapters. These are:

Chapter 1: It is titled as introduction. It explains the background of runoff estimation, research motivation, problem statement, research objectives, limitations of study and organization of research project.

Chapter 2: It explains the literature review related to previous researches on limitations of rational method. It consists of background, history of research on limitations of rational method, history of methods used for runoff and summary of this chapter.

Chapter 3: It is named as methodology and it consists of introduction to rational method, data selection, study area, curve number method for runoff calculation and summary of this chapter.

Chapter 4: It is named as results and discussions which covers calculation of runoff using rational method approach, calculation of runoff using curve number method, comparison between both methods and summary of Chapter 4.

Chapter 5: It consists of conclusion, results from the study and future recommendations.

Chapter 2

Literature Review

2.1 Background

Different authors published their articles in which different catchment area limitations are mentioned, similarly a number of manuals and books are available in which catchment area limitation is mentioned with respect to the study area and topographical characteristics of the area. Most engineering offices in the United States continue to use this method originally introduced in 1889. Even though this method has frequently come under academic criticism for its simplicity, no other practical drainage design method has evolved to such a level of general acceptance by the practicing engineer. The Rational Method properly understood and applied, can produce satisfactory results for urban storm drain design for sizing of street inlets and storm drains.

2.2 Research History on Limitations of Rational Method

Dhakal et al. (2011) stated that for areas of US state of Albama rational method can be used for watersheds with drainage areas less than 200 acres because rational method is a simple procedure, and cannot be applicable to a complex watershed with more drainage area.

W.M.D. Wijesinghe and N.T.S. Wijesekera (2011) applied rational method for Srilanka region and observed that rational method in general are intended for smaller catchment areas less than about 6177.63 acres and stated reason behind this limitation is that only the peak discharge can be calculated using rational equation and in that equation the peak discharge is directly proportional to the runoff coefficient, when the other parameters are kept constant.

Moreover, Ahsan et al. (2016) researched on Indus and Jhelum River basins, Pakistan region and stated that the rational method is used in cases where the catchment area is 40 acres or less.

Salamia et al. (2017) considered area of 483 km^2 for research work but results were not acceptable and stated that rational method approach is not acceptable for this huge area.

Atlanta Regional Commission, Georgia (2001) mentioned in Georgia Stormwater Management Manual that maximum drainage area that should be used with the Rational Method is 25 acres and stated that the rational method should not be used for storage design or any other application where a more detailed routing procedure is required.

New Jersey Department of Environmental Protection, U.S state of New Jersey (2004) stated that rational method is limited to drainage areas less than 20 acres because it cannot predict total runoff volumes.

Department of Irrigation and Drainage Malaysia (2006) said that it was realised that this procedure overestimates the peak discharge for large catchments over 200 acres because it does not take into account a real and temporal variation in storm rainfall, and detention storage present in surface depressions, gutters, and channels.

Fauzi Bin Baharudin (2007) carried out a study on rainfall-runoff characteristics of urban catchment of Sungai Kerayong, Malaysia and concluded that the method can be considered as the most reliable approach in estimating the design storm peak runoff, experience has shown that it only provides satisfactory results on small catchments of up to 80 hectares only (197.684 acres) because for larger catchments, storage and timing effects become significant, so hydrograph method is needed.

Similarly, North Carolina Department of Environment and Natural Resources (2007) stated that rational method is most applicable to drainage areas approximately 20 acres or less due to its simplicity.

Urban Drainage and Flood Control District, Colorado USA (2007) indicated that for urban catchments that are not complex and are generally 160 acres or less in size, it is acceptable that the design storm runoff be analyzed by the rational method. Further stated, that the greatest drawback to the rational method is that it normally provides only one point on the runoff hydrograph. When the areas become complex and where sub-catchments come together, the rational method will tend to overestimate the actual flow, which results in oversizing of drainage facilities. The rational method provides no direct information needed to route hydrographs through the drainage facilities. One reason the rational method is limited to small areas is that good design practice requires the routing of hydrographs for larger catchments to achieve an economic design.

Planning & Development Department Infrastructure Division, South Carolina, U.S. (2010) elaborated that the rational method is acceptable for sizing individual culverts or storm drains that are not part of a pipe network or system and do not have a contributing drainage area greater than 20 acres.

Board of County Commissioners, Arapahoe, State of Colorado, America (2011) published that rational method may be used for watershed sizes from 5 to 160 acres.

Texas Department of Transportation, U.S state of Texas (2016) highlighted that rational method can be appropriate for estimating peak discharges for small drainages upto 200 acres area and elaborated that it is applicable on only those areas for which Tc is less than the duration of the rainfall.

Urban Drainage and Flood Control District, Colorado USA (2017) revised their statement and said that for urban catchments that are not complex and are generally 90 acres or less in size rational method can be adoptable. One reason the rational method is limited to small areas is that good design practice requires the routing of hydrographs for larger catchments to achieve an economically sound design. Rational method so provides no means or methodology to generate and route hydrographs through drainage facilities.

2.3 Summary

It is clear from above history that in literature different values are mentioned regarding catchment area limitations of rational method corresponding to different research locations. According to researchers rational method can be applied to different areas depending upon the characteristics of the ground and variation in precipitation rate.

Researchers have their own opinion regarding catchment area limitations for this method ranging from minimum of 5 acres to a maximum of 6177.63 acres. So, there is dire need to validate the assumptions available in the literature for this selected urban region of Pakistan so that this method can be adoptable for design purpose.

Chapter 3

Methodology

3.1 General

The work is carried out in different phases. Firstly, the data is collected from actual site regarding drainage of the area and topography of the site. Then analyzing of the collected data in which useful data is segregated from the available data. In addition to this catchments & streams data is generated through the use of DEM for Terrain's surface modeling and by using Global Mapper.

After selection of location, data of all streams is compiled which includes stream details, corresponding drainage area, slope of the stream etc. Moreover, different points of interest developed and corresponding drainage area is calculated using Google Earth, Global Mapper and AutoCAD.

C-weighted is then calculated by distributing area into developed and un-developed zone. Rainfall intensity is taken maximum as per CDA guidelines. Runoff is then calculated by using Rational Method. Results obtained from rational method are then compared with the SCS Curve Number Method to check the validity of rational method.

3.2 Site Selection and Data Collection

To evaluate the validity of rational method by addressing assumptions available in the literature a site has been selected in Islamabad known as "EMAAR Housing Society" near Islamabad Expressway, DHA Phase-II Extension Islamabad having minimum elevation of 487.00 and maximum elevation of 537.00.

FIGURE 3.1: Aerial view of site selected-EMAAR Pakistan.

The site is selected due to the reason that both types of area i.e. developed as well as non-developed area is present here also data regarding road network plan, contour plan was easy to obtain.

Useful data is then collected from site for research work i.e. master plan, contour plan, grading points showing elevation of all points, etc.

3.2.1 Master Plan of Selected Location

Master plan of selected location is collected from Shahzaman Pvt. Ltd. working as a contractor at Infrastructure development of EMAAR, Pakistan. The percentage of residential area as well as of green area is tabulated in Table 3.1.

TABLE 3.1: Area distribution of location.

Sr. No.	Description	Percentage of Area
1	Roof / Houses	58.33%
2	Parks / Green Areas	5.07%
3	Paved Area	36.60%

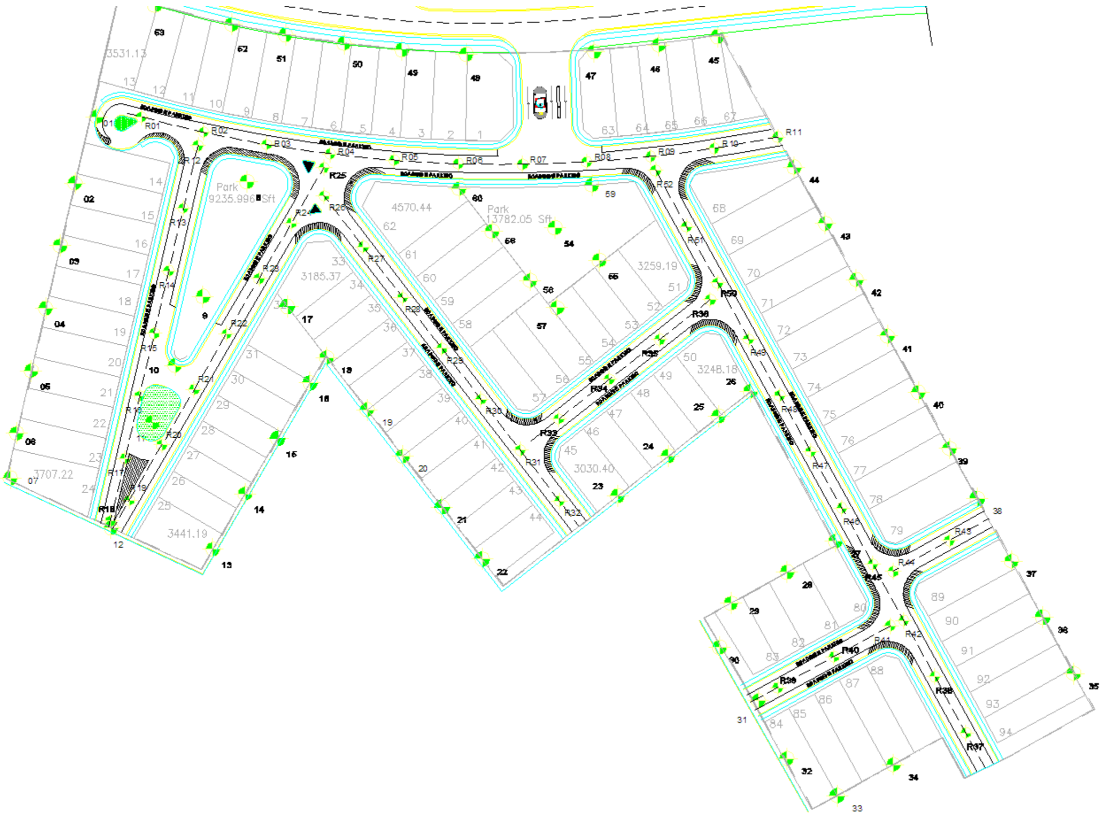

FIGURE 3.2: Master Plan of EMAAR Housing Society - a view.

3.2.2 Contour Plan of Selected Location

Contour plan of all area is then collected from Shahzaman Pvt. Ltd. working as a contractor at Infrastructure development of EMAAR, Pakistan.

Grading point data showing levels of each point is also shown in tables below. The elevation points of the site ranging from minimum of 487.00m and maximum elevation of 537.00m, which shows that the natural slope of the area is steep. Detail of grading points along with their level is mentioned in Table A1 and Table A2 of Appendix-A.

After collecting contour plan, elevation and leveling detail of actual site, water-course i.e. Nullah passing through the selected area is also enlarged and shown in Figure 3.4.

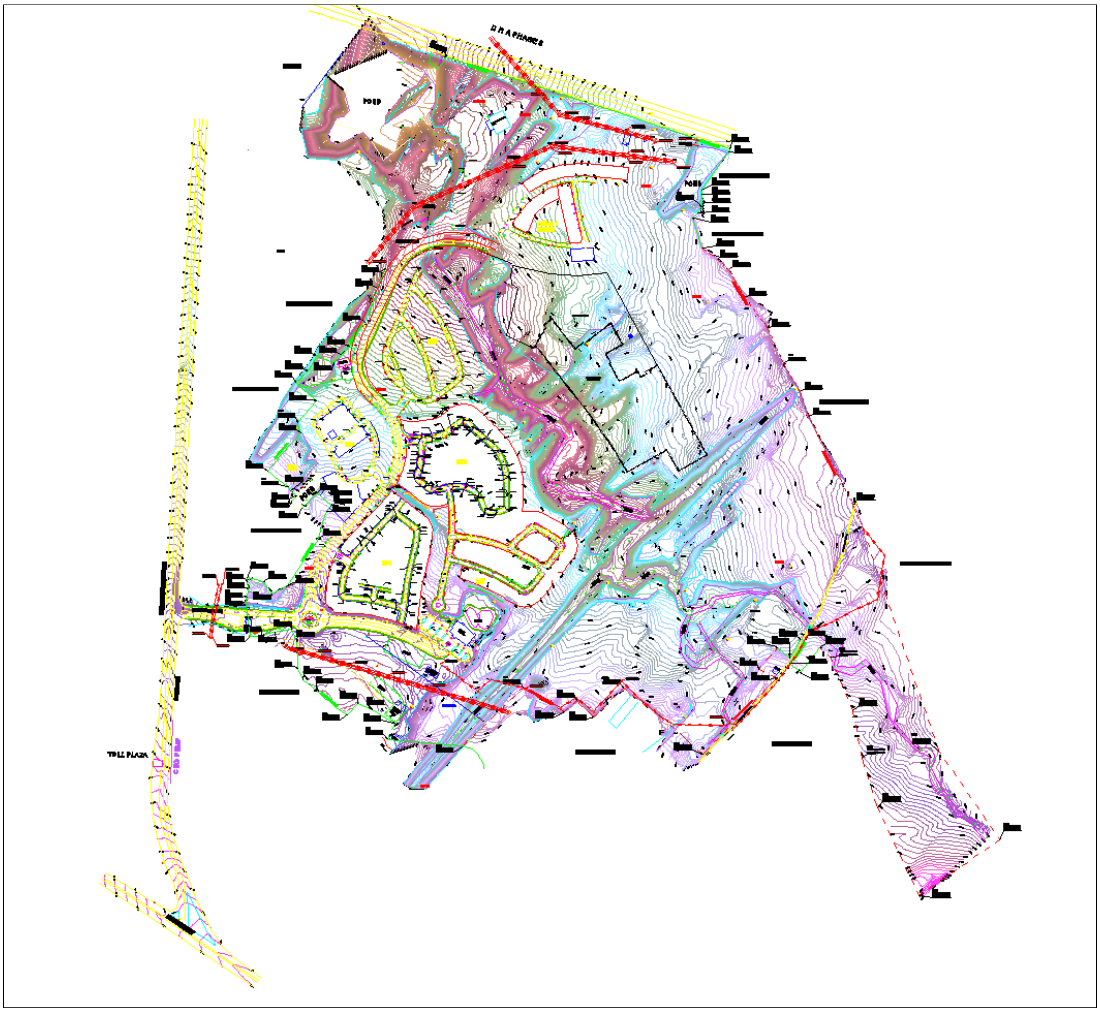

FIGURE 3.3: Contour plan of Selected Site.

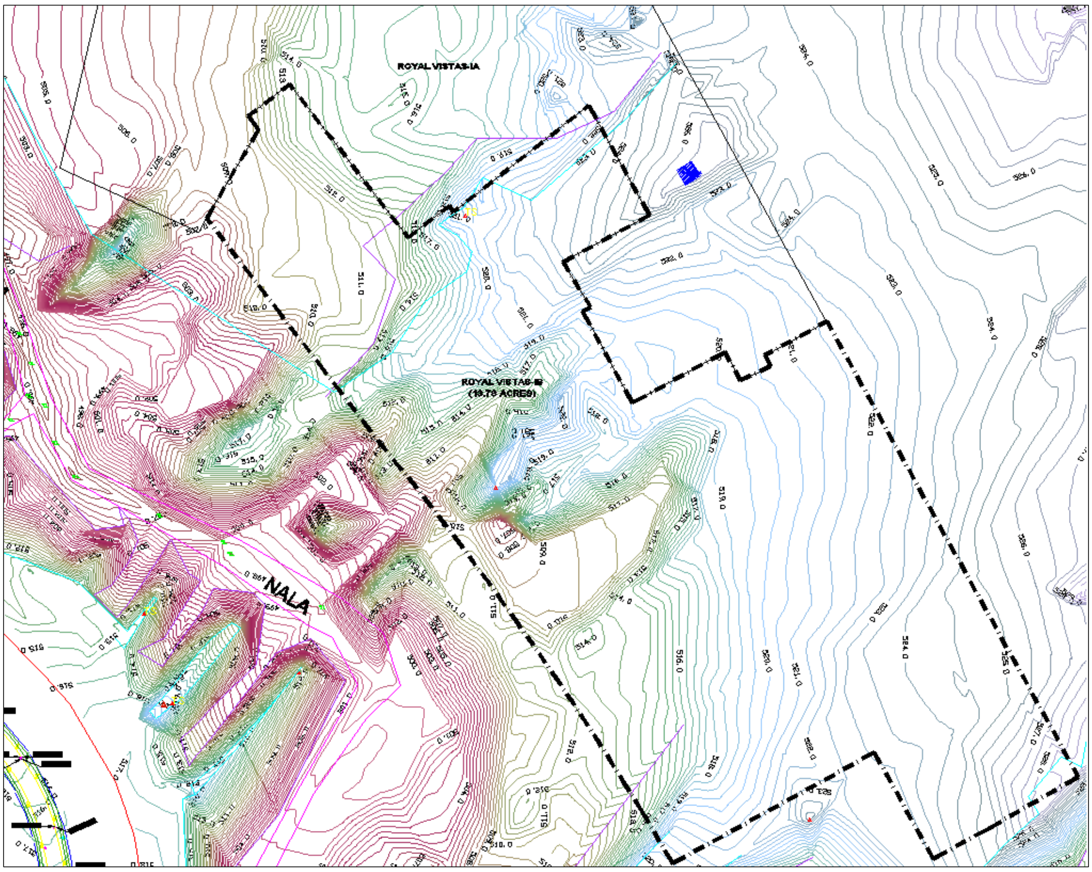

FIGURE 3.4: Enlarged view of Watercourse (Nullah).

3.2.3 Rainfall Data from Meteorological Department

Available rainfall data from international airport Islamabad and from Pakistan Meteorological department office at H8 for the year 1982, 1992, 1997 and 2001 is taken and shown in Figures 3.5 and 3.6.

3.3 Rational Method

The Rational Method is widely used for determining design flow rate i.e. surface runoff in storm sewer design using equation (3.1). The Rational Equation, and estimation of its parameters to calculate Q, plays a key role in hydraulic design of storm sewers.

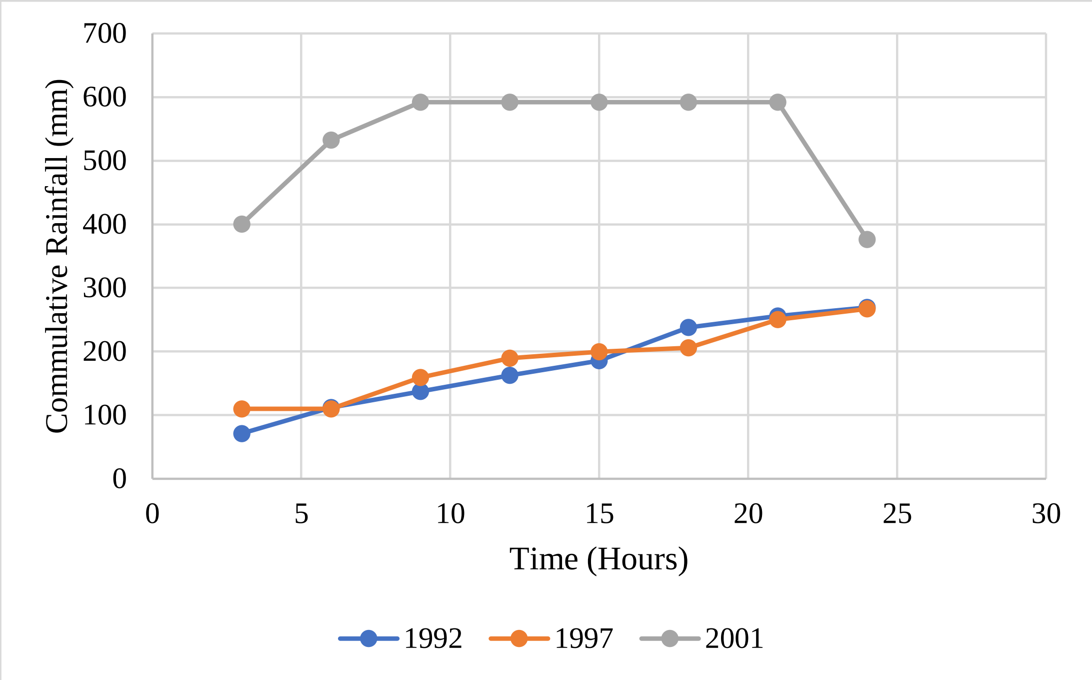

Figure 3.5: Rainfall record at Islamabad Airport.

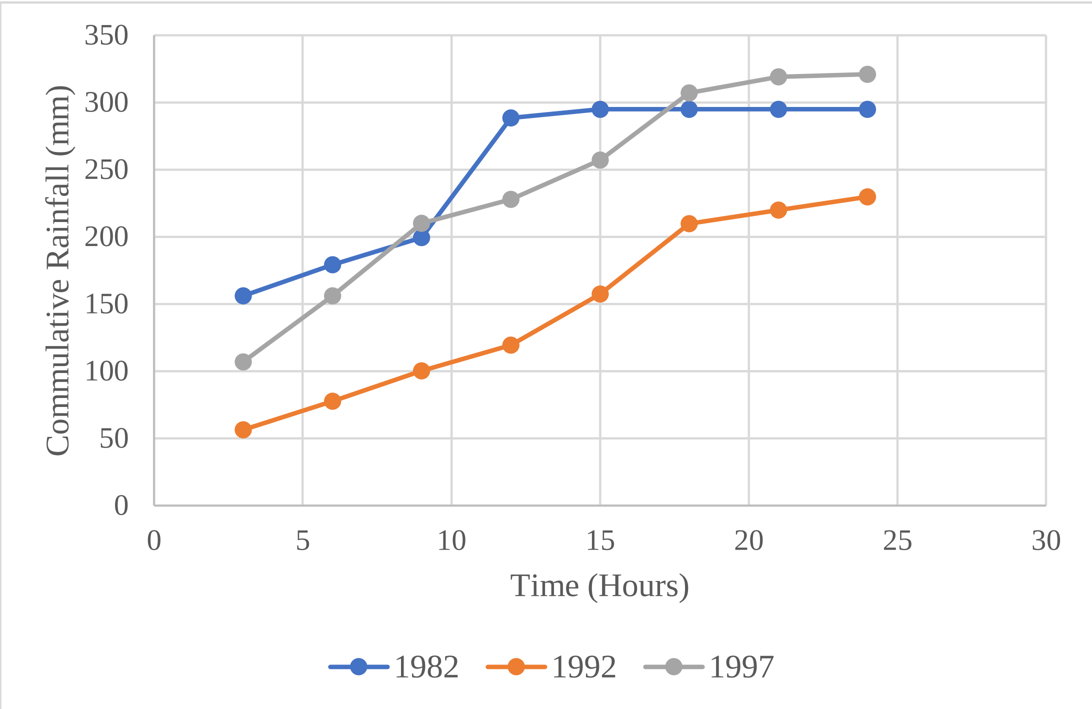

Figure 3.6: Rainfall record at PMD office, H-8.

$$Q = CiA \tag{3.1}$$

Where,

Q = Maximum rate of runoff (ft^3/sec or m^3/sec)

C = Runoff coefficient

i = Average rainfall intensity (in. / hr. or mm/hr.)

A = Drainage area (ac or ha)

The Rational Method can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm drain pipes, culverts and small ditches. The rational method is a tool for estimating peak (maximum) discharge from relatively small drainage areas (Mulvaney, 1850; Kuichling, 1889). So there is need to evaluate the limitations of the method so that it can be used as a guide for hydraulic design engineers to apply this method accordingly.

It was noted that different authors mentioned different area limitation for the use of rational method but no one provided the justification behind that limitation. So it is required to verify the correct statement regarding the limitation of the rational method for Islamabad region.

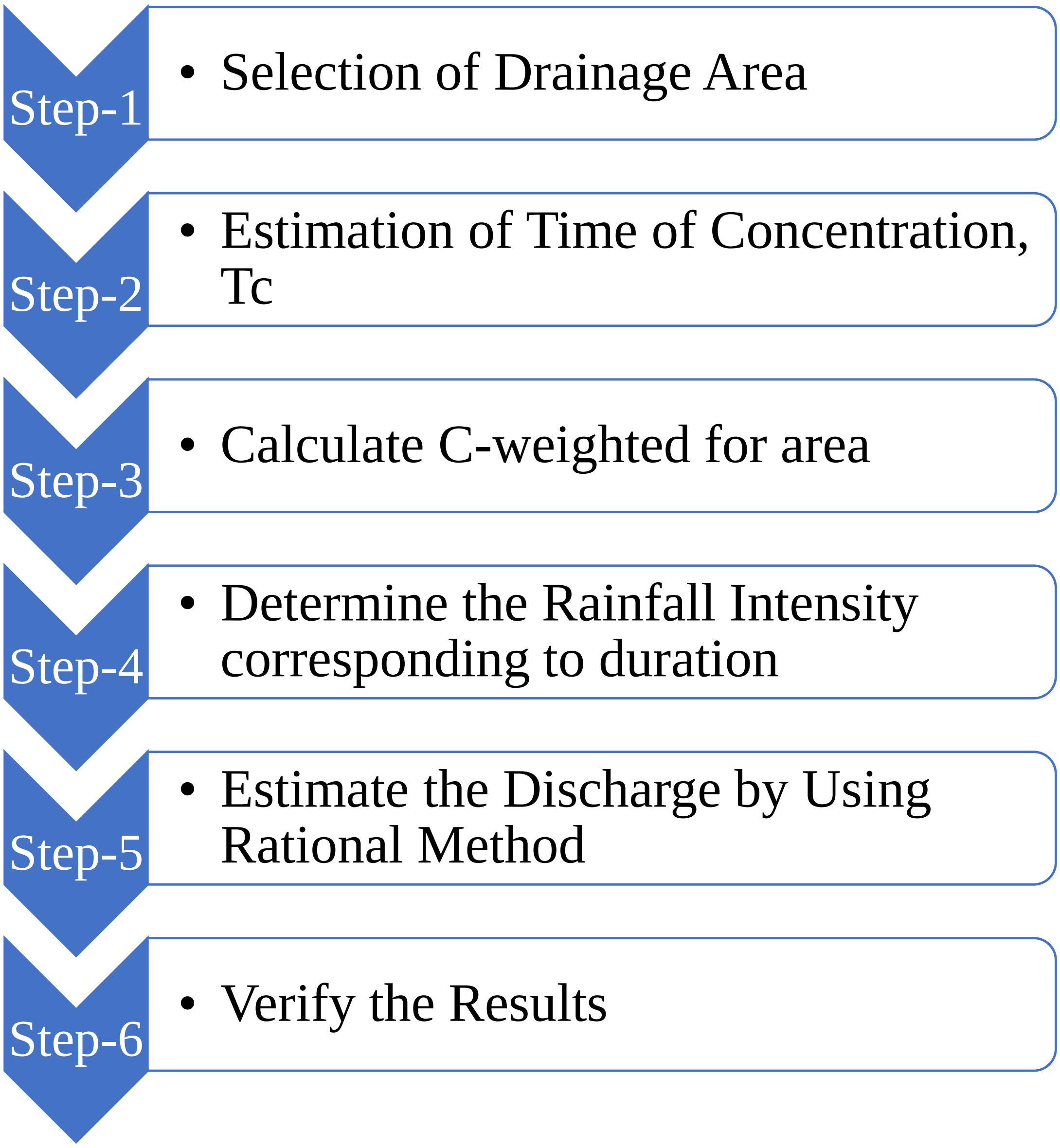

FIGURE 3.7: Steps involved in Rational Method procedure.

3.3.1 Drainage Area "A"

The drainage area is the catchment area under observation and from which runoff is generated and needs to be estimated. Area can be in acres or hectares.

Drainage area majorly classified in following sub categories:-

- Residential Area

- Industrial Area
- Business Area
- Unimproved Area
- Lawns
- Streets

3.3.2 Time of Concentration "Tc"

Time of concentration (Tc) is the time needed for runoff to move from the hydraulically farthest point in the catchment to the outlet. The most remote point is that point which has lengthiest travel time to the watershed outlet, and not essentially the point with the longest flow distance to the outlet.

Time of concentration is usually functional to only surface runoff and may be calculated using different methods. It will differ based on slope and character of the catchment and the flow path.

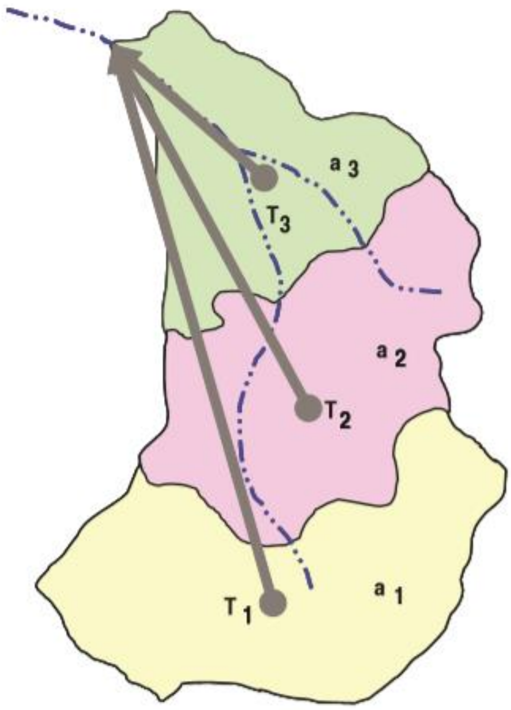

FIGURE 3.8: Conceptual watershed illustrating travel time.

Time of concentration is further sub divided into two categories depending upon nature of flow and calculated by different methods:-

i. Channel Flow by Kirpich Method

ii. Overland Flow by Izzard Method

3.3.2.1 Channel Flow by Kirpich Method

For channel flow through any stream or water path, Kirpich method is used; as illustrated below:-

$$t_{ch} = \frac{KL^{0.770}}{S^{0.385}} \tag{3.2}$$

Where,

t_{ch} = Channel time of concentration in minutes

K = A unit conversion factor, in which K = 0.0078 for traditional units and K = 0.0195 for SI units

L = Channel flow length in ft or in m

S = Dimensionless channel slope

3.3.2.2 Overland Flow by Izzard Method

Izzard (1946) proposed the relationship for the Time of concentration for roads and turf surfaces:-

$$t_c = \frac{41L^{1/3}}{i^{2/3}} \times \left[\frac{0.0007i + c_r}{S^{1/3}}\right] \tag{3.3}$$

Where,

t_c = Overland time of concentration in minutes

L = Overland flow distance in ft or m

i = Average rainfall intensity in in. /hr. or mm/hr.

S = Dimensionless slope

c_r = Retardance factor ranging from 0.007 for smooth pavement to 0.012 for concrete and to 0.06 for dense turf

3.3.3 Runoff Coefficient "C"

"C", also known as runoff coefficient is a dimensionless ratio used to specify the amount of runoff generated by a catchment area.

TxDOT suggests ranges of C values for urban watersheds for numerous combinations of land use and soil surface type. Table A3 of appendix-A is used for runoff coefficient values:-

Different areas have different value of coefficient with respect to the characteristics of the area. Following are the characteristics of the area on which value of coefficient depends:-

- Developed area or Non-developed area
- Type of soil in the area, i.e. sandy or rock, etc.
- Slope of the area
- Type of pavement in the area
- Nature or purpose of the area, i.e. residential, industrial etc.

3.3.3.1 C-weighted

If there are mixture of land in the selected area; then the "C" value will be a composite of all types of land.

$$C_w = \frac{\sum_{j=1}^{n} C_j A_j}{\sum_{j=1}^{n} A_j} \tag{3.4}$$

Where,

C_w = Weighted runoff coefficient

C_j = Runoff coefficient for area j

A_j = Area for land cover j

n = Number of distinct land uses

3.3.4 Rainfall Intensity "i"

The rainfall intensity (i) is the mean precipitation rate in inch /hour or in millimeters/hour for definite rainfall duration and a selected frequency. The time duration of the rainfall should be greater than the Tc for that area.

For relating duration of rainfall with the intensity, curves are used which are known as intensity-duration-frequency (IDF) curves. So, from recorded data, IDF curves can be established. Figure 3.9 illustrating the IDF curves for return period of 2.33 years, 5 years, 10 years, 25 years, 50 years and 100 years respectively.

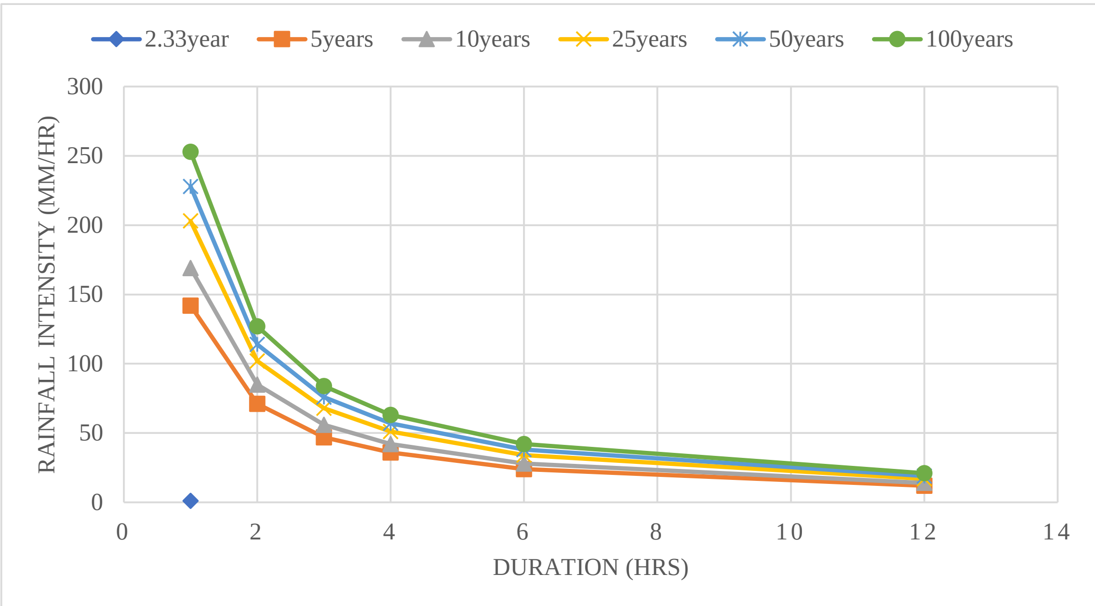

FIGURE 3.9: Rainfall Intensity Duration Frequency (IDF) Curve.

3.4 SCS CN Method

The SCS method (SCS, 1985; NRCS, 1986) is an alternative method for estimating the volume of storm water runoff that is produced from a given amount of rainfall.

The basic equation is:

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{3.5}$$

Where, Q is the runoff depth (to get volume, multiply by the watershed area), P is the rainfall depth, I_a is the initial abstraction and S is the potential maximum retention after rainfall begins.

All units are depth, either inches or mm. I_a is hypothesized as the amount of rain that falls before runoff is started; this is typically grossly assumed to be 0.2S. So equation (3.5) is usually written as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{3.6}$$

The S term is determined indirectly from tables relating qualitative land use information to a runoff index called the Curve Number (CN). The CN is related to S with:

$$S = \frac{1000}{\mathrm{CN}} - 10 \tag{3.7}$$

Where, CN is the curve number, unit-less.

The required runoff volume is determined by multiplying the runoff depth (Q*) by the drainage area.

3.4.1 Steps Involved in Using SCS CN Method

Following are the steps involved in applying this methodology:

i. Firstly depending upon the characteristics of the soil, hydrologic soil group is selected from Table A4 of appendix-A, i.e. group "A", "B", "C", or "D".

ii. Then based on cover type of existing site, any cover description is selected from Table A5 of appendix-A, i.e. residential area or paved streets.

iii. By using details mentioned in above both points, CN value is picked up from Table A4 of Appendix-A.

iv. Based on the amount of rainfall at the subject location, Rainfall-Runoff tables for selected runoff Curve Numbers are used to get runoff value from rainfall quantity.

v. The Natural Resources Conservation Service's National Engineering Handbook, Part 630, Hydrology, chapter 10, published appendix "A" for direct conversion of rainfall depth into runoff depth. This appendix was developed using MS Excel spreadsheets. The tables in that appendix show runoff amounts from rainfall quantities up to 40 inches and for runoff curve numbers 50 to 98.

vi. Selected drainage area of site is then multiplied with runoff value obtained from appendix "A" to get discharge value.

3.5 Stream Generation Using Global Mapper & DEM

Terrain's surface modeling is carried out by using DEM and then Global Mapper is used for establishing catchments & streams.

A Digital Elevation Model (DEM) is a dedicated database that indicates the relief of a surface between points of known elevation. A digital elevation model (DEM) is a 3D sketch / graphic of topography's surface created from a terrain's elevation data. Method of creating DEMs often consists of interpolating digital contour maps that may be produced by direct survey of the land surface.

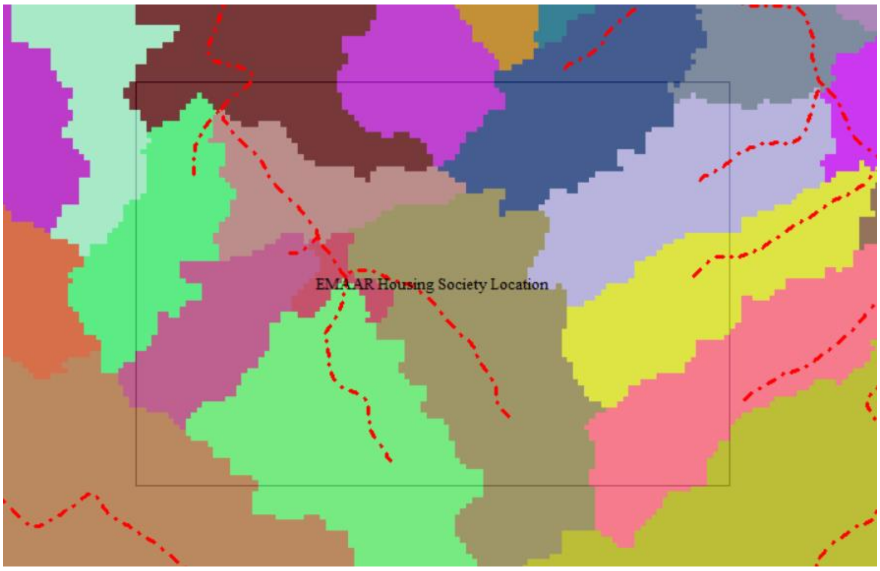

FIGURE 3.10: Generation of streams using Global Mapper.

3.6 Stream Numbers for all Points of Interest Use of Global Mapper

Different stream numbers are assigned for further correspondence in research work. There are eight numbers of streams of 1^{st}, 2^{nd}, 3^{rd} and 4^{th} order respectively. Stream no. 1 and 2 combines to form stream no. 3, which is 1^{st} point of interest for runoff calculations. Then stream no. 4 joins with stream no. 3 that is 2^{nd} point of interest for calculation work. From this stream no. 5 continues its way to meet stream no. 6 at its path that is 3^{rd} point of interest.

Stream no. 5 & 6 combines to form stream no. 7 that further joins at the end with stream no. 8 and constitute 4^{th} point of interest for the calculation of whole work. Detail is as below:-

TABLE 3.2: Stream numbers assigned.

Sr. No.	Stream No. Assigned	Previous Stream(s)	Point of Interest
1	Stream No. 1	-	-
2	Stream No. 2	-	-
3	Stream No. 3	Stream No. 1 & 2	1st Point of interest
4	Stream No. 4	-	-
5	Stream No. 5	Stream No. 3 & 4	2nd Point of interest
6	Stream No. 6	-	-
7	Stream No. 7	Stream No. 5 & 6	3rd Point of interest
8	Stream No. 8	-	-
9	-	Stream No. 7 & 8	4th Point of interest

The pictorial view of drainage network of the selected study area after assigning numbers to all streams and developing four different points of interest is shown in Figure 3.11. The whole network consists of four numbers of interest points and eight numbers of streams.

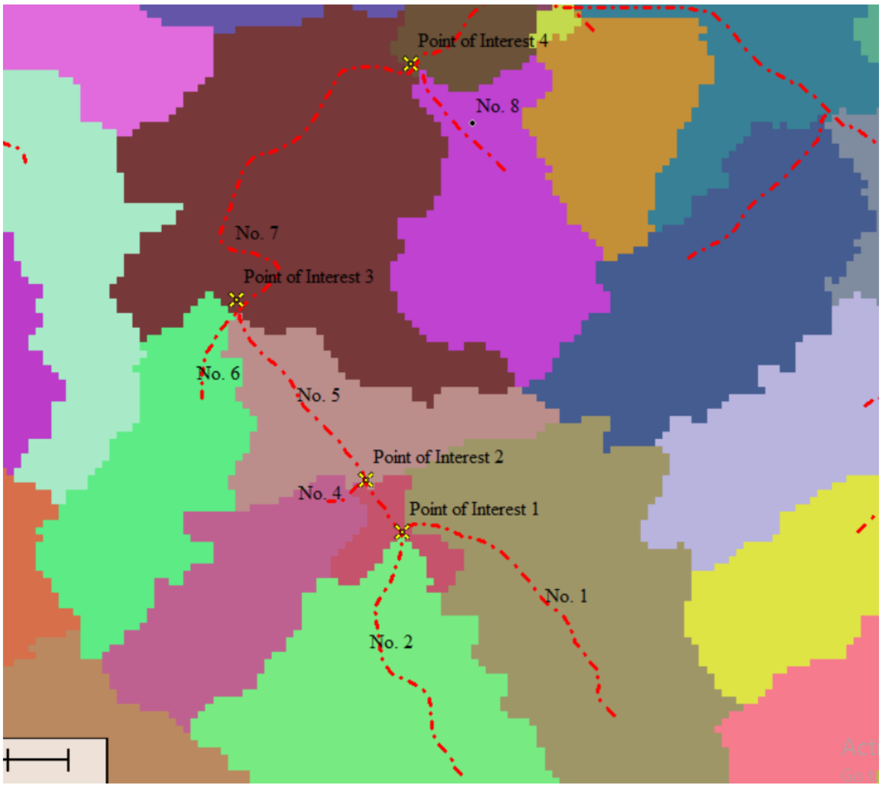

FIGURE 3.11: Complete drainage network plan - Global Mapper.

3.7 Corresponding Streams Data – Verification by Google Earth Tool

Necessary data required for further processing of research work is then calculated. Length of each stream along with elevation at starting and ending point of each stream is then find out along with corresponding drainage area using Global Mapper. Detail of each stream, its length, its slope and corresponding drainage area in km^2 and in acres is tabulated in Table A6 of Appendix-A.

Then to check the validity of drainage area estimated by Global Mapper, all network along with area characteristics is imported to Google Earth for cross-checking. Area corresponding to stream no. 3 is plotted on Google Earth for verification of value, as shown in Fig. 3.12

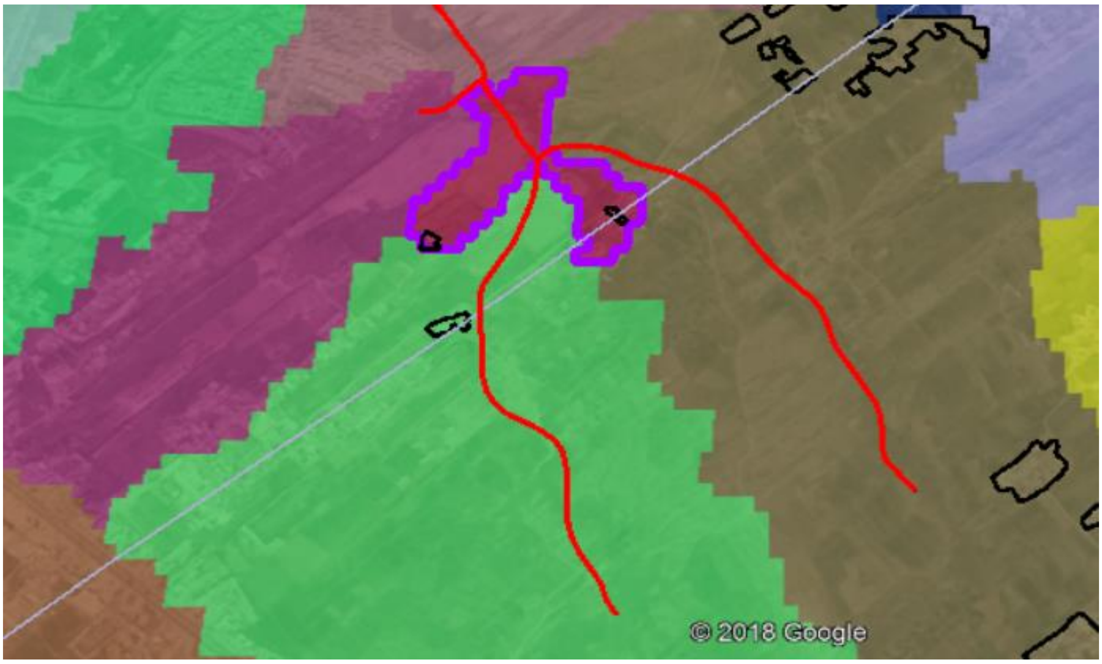

FIGURE 3.12: Import of Global Mapper Network to Google Earth.

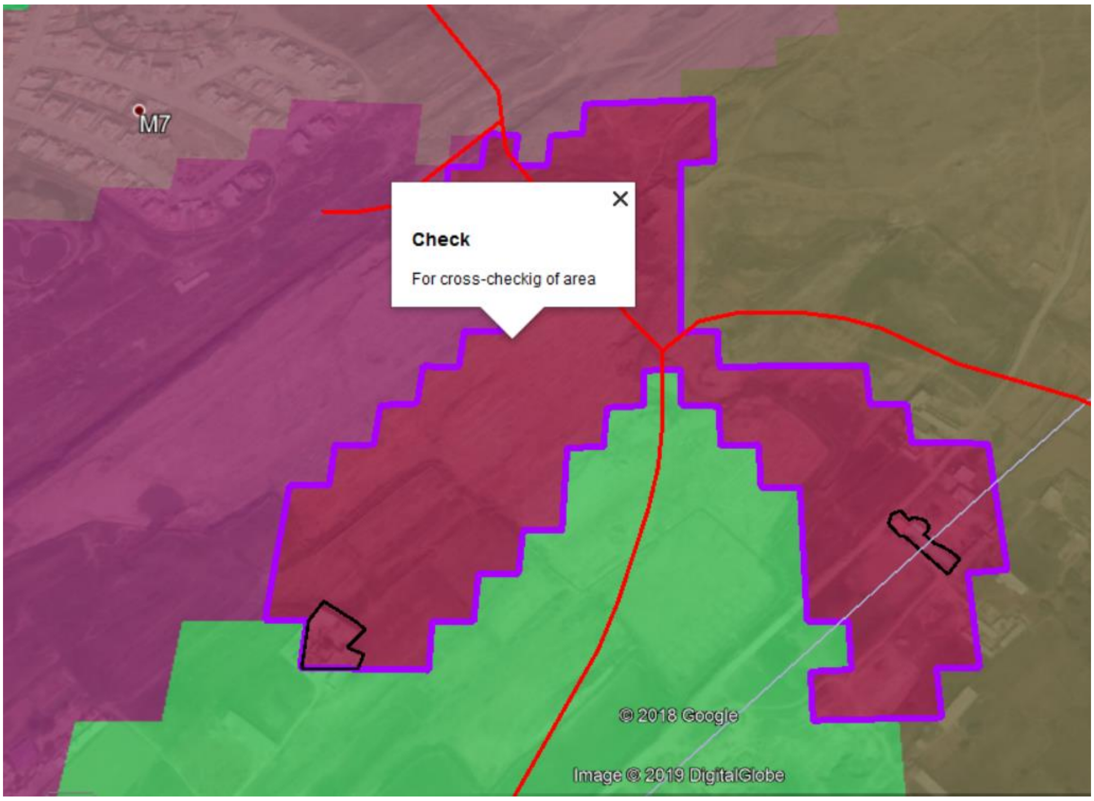

FIGURE 3.13: Cross-checking of drainage area.

Drainage area is then calculated and cross-checked by creating area boundary corresponding to individual stream no. 3 and results are detailed below:

Drainage Area Results from Global Mapper:-

Drainage area of stream no. 3 as mentioned in Table A6 of Appendix-A = 687.76 – 350.43 – 313.36 = 23.9 acres.

Drainage Area Results from Google Earth:-

Drainage area of stream no. 3 = 23.5 acres as circled in Figure 3.14 which is nearly equals to that of obtained from Global Mapper. Difference can be due to rounding off in conversion factor from km^2 to acres.

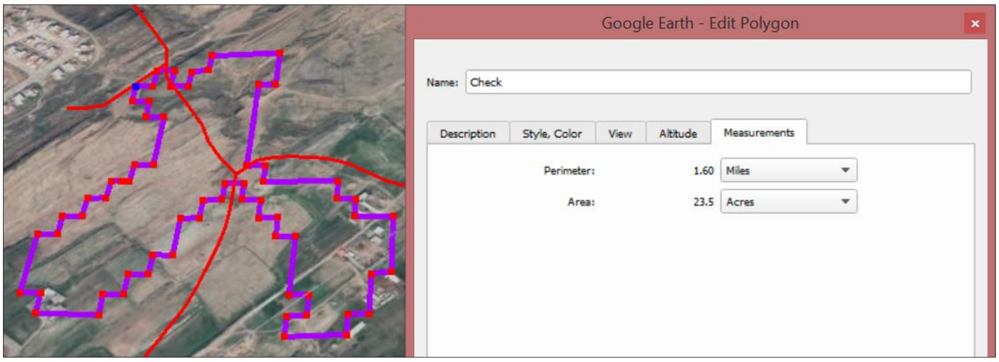

FIGURE 3.14: Drainage area from Google Earth.

3.8 Average Rainfall for Selected Site – Using SamSam Model

As the rational method is only applicable to those areas, for which rainfall characteristics are uniform throughout the area.

In view of this, five different locations are selected within the selected area and by using SamSam Model average precipitation on each location is estimated.

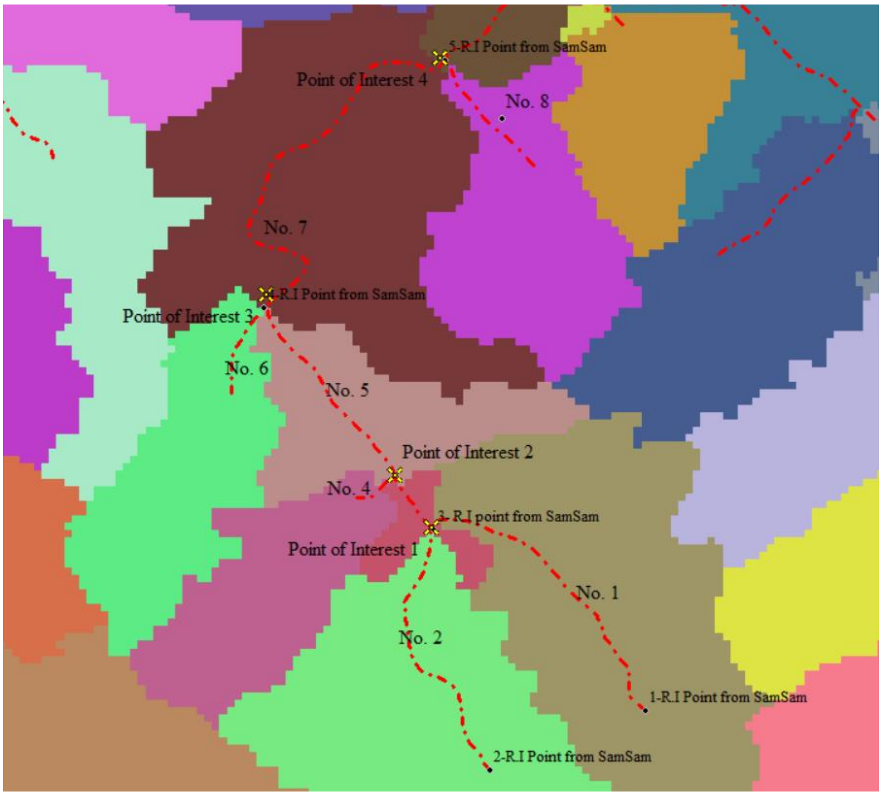

FIGURE 3.15: Selected locations for checking rainfall characteristics.

Detail of rainfall characteristics for all selected locations obtained from SamSam Model is same. It means that rainfall characteristics for all points are same throughout the year. Hence, rational method approach is valid for this selected area as there is no change in yearly rainfall amount at all remote points within the selected area. Detail characteristics of rainfall for selected points are mentioned in next part:

Location No. 1:

Name of location: Location No. 1

Latitude: 33.5097 (decimal degrees)

Longitude: 73.1995 (decimal degrees)

Average precipitation (in mm or liter per m^2) for the selected location is listed in Table A7 of Appendix-A

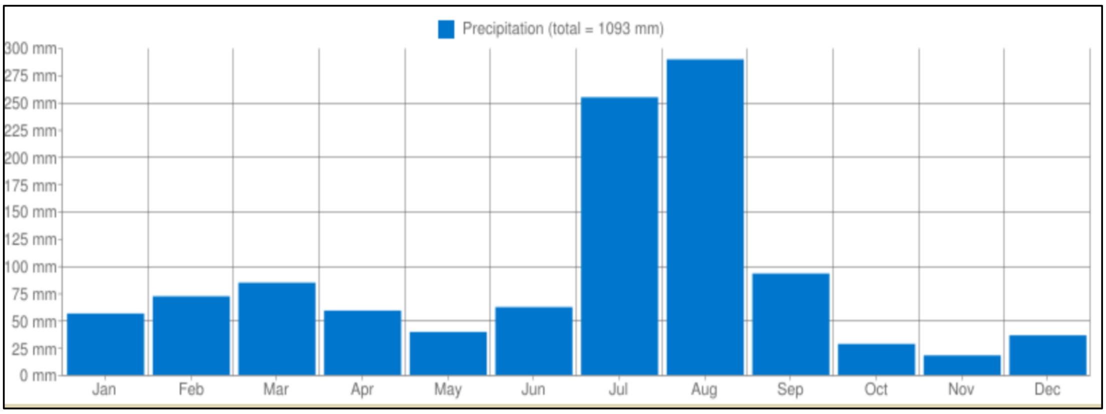

FIGURE 3.16: Rainfall chart - for Location 1.

Location No. 2:

Name of location: Location No. 2

Latitude: 33.5075 (decimal degrees)

Longitude: 73.1935 (decimal degrees)

Average precipitation (in mm or liter per m^2) for this location is also same as Location No. 1.

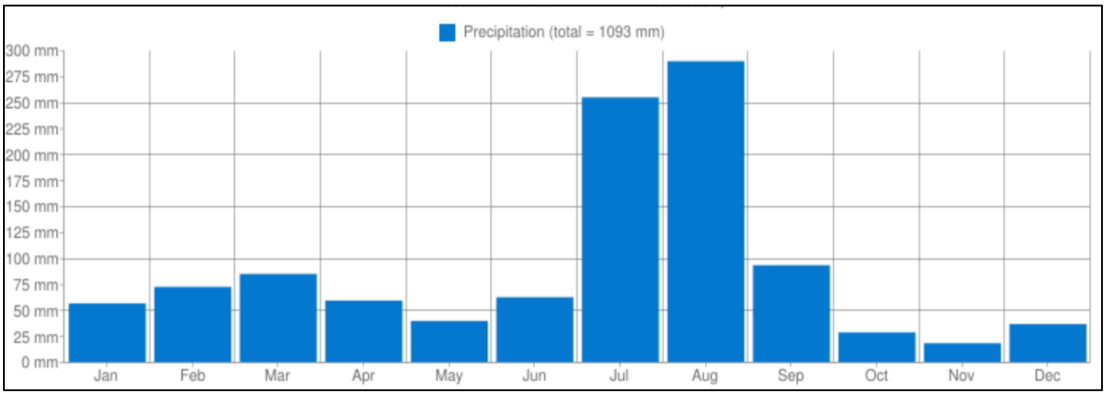

FIGURE 3.17: Rainfall chart - for Location 2.

Location No. 3, 4 and 5:

Similarly, as per results for location no. 1 & 2, annual rainfall for location no. 3, 4 and 5 is also same. Annual rainfall for the whole region is 1093 mm. So the characteristics of rainfall for the selected site are favorable for use of rational method.

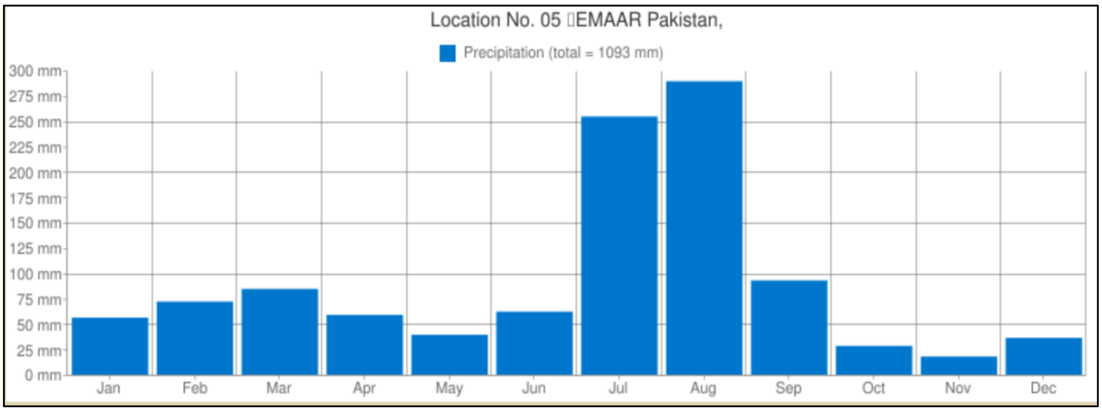

FIGURE 3.18: Rainfall Chart - for Location 3, 4 and 5.

3.9 Summary

The site selection, data collection is completed. Data required for application of rational method and SCS CN method is collected in all respect and summarized. Rational method can be applied to those areas where the rainfall remain uniform all over the catchment area, so SamSam Model is used to verify the uniformity of rainfall on this complete catchment area. Streams are generated using DEM and

Global Mapper. Relevant data corresponding to each stream is then calculated. The network generated on Global Mapper is then imported to Google Earth and cross-checked the data. It is observed that elevation of all points from contour plan is also synchronized with that of visualize from google earth.

Chapter 4

Results and Analysis

4.1 General

The analysis work is further divide in two parts. First part is the discharge calculations using rational method approach and the other part is the calculation of discharge by using SCS CN method. The results from both methods are compared to check the validity of rational method for urban areas with respect to limitations of catchment area.

4.2 Discharge Calculations Using Rational Method

The calculation work is divided into different phases as mentioned below:

- Drainage Area Selection
- Estimation of Tc
- Calculation for C-weighted
- Rainfall intensity determination

- Discharge Calculations

4.2.1 Drainage Area Selection

Whole area is further sub-divide into four different areas for calculation work. Four points of interest have been developed with respect to drainage area and location of the site.

4.2.1.1 Drainage Area No. 1 - 1st Point of Interest

The drainage area firstly considered for estimation of discharge is comprised of two numbers of streams joined at a location which is named as 1st point of interest. Details of area along with location snap are shown in Figure 4.1, Figure 4.2 and in Table 4.1.

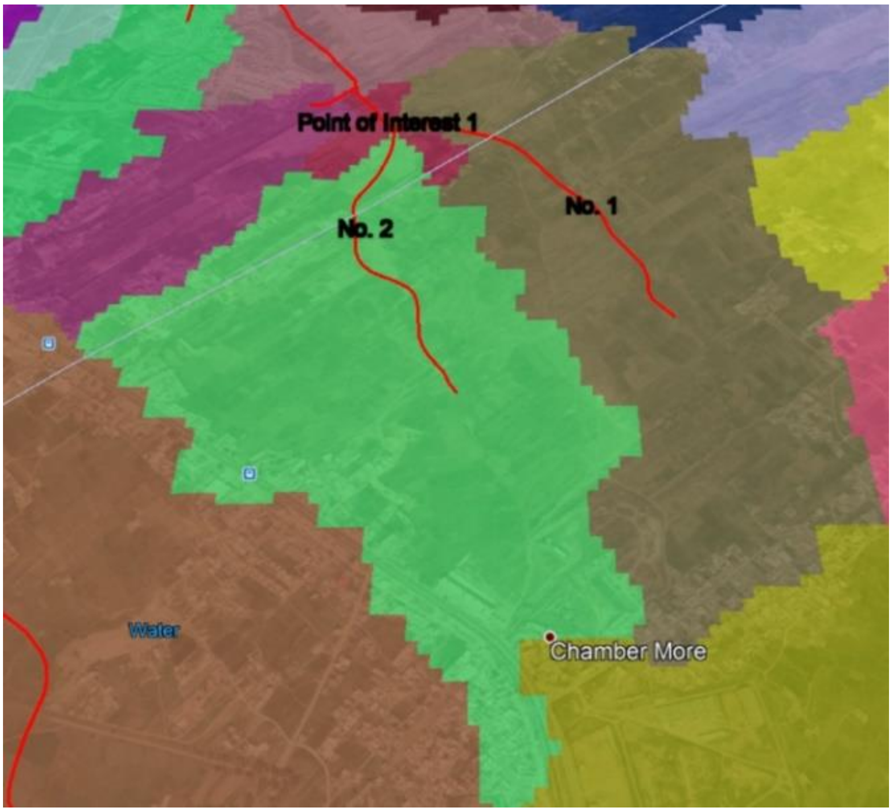

FIGURE 4.1: 1st Point of Interest- Google Earth.

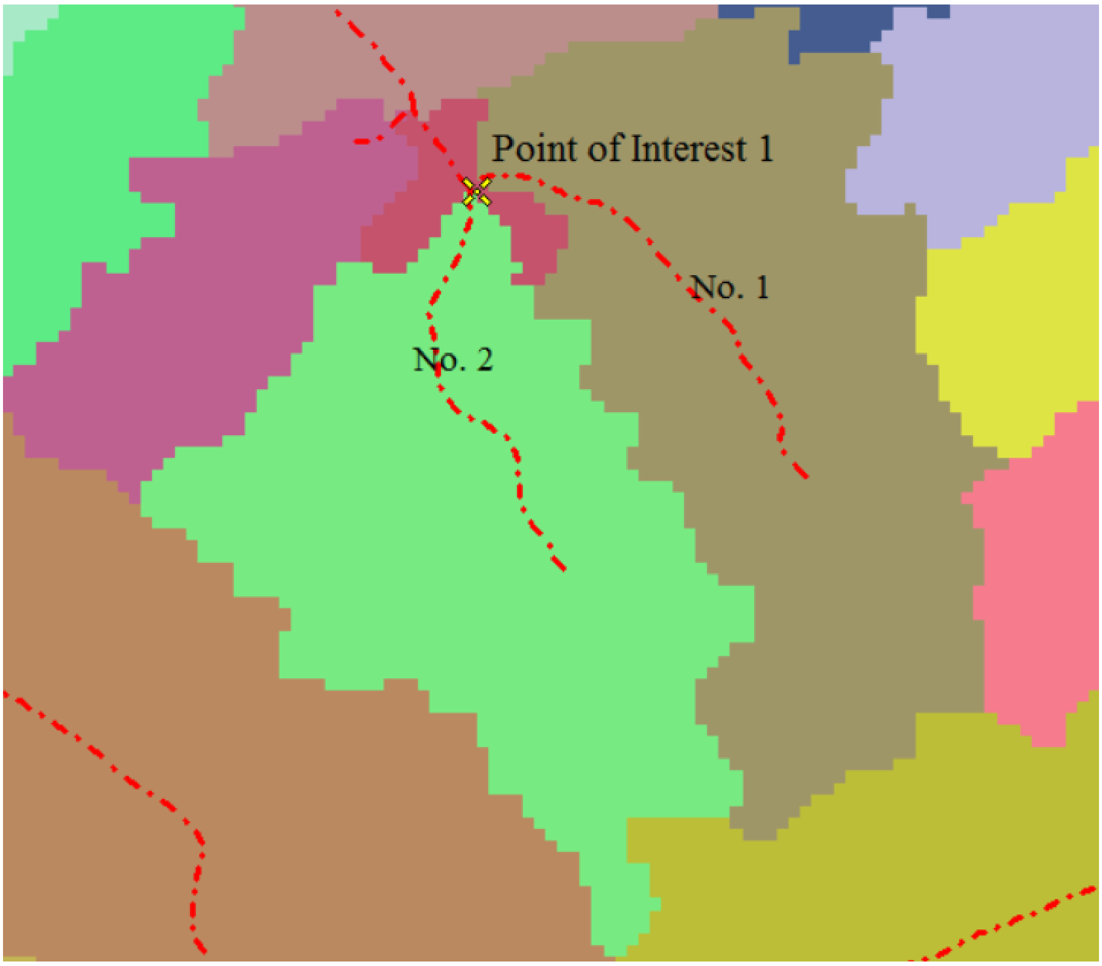

FIGURE 4.2: 1st Point of Interest - Global Mapper.

TABLE 4.1: Drainage Area - 1st Point of Interest.

Sr. No.	Description	Values	Remarks
1	No. of Streams Contributing	02	Stream No. 1 & No. 2
2	Drainage Area of Stream No. 1	350.43	acres
3	Drainage Area of Stream No. 2	313.36	acres
4	Total Drainage area for 1st Point of interest	663.79	acres

4.2.1.2 Drainage Area No. 2 - 2nd Point of Interest

The drainage area next considered for estimation of discharge is comprised of one streams of 1st order i.e. stream no. 4 and other stream is stream no. 3 which also carrying drainage water from 1st point of interest respectively. These streams joined at a location which is named as 2nd point of interest. Details of area along with location snap are shown in Table 4.2, Figure 4.3 and Figure 4.4.

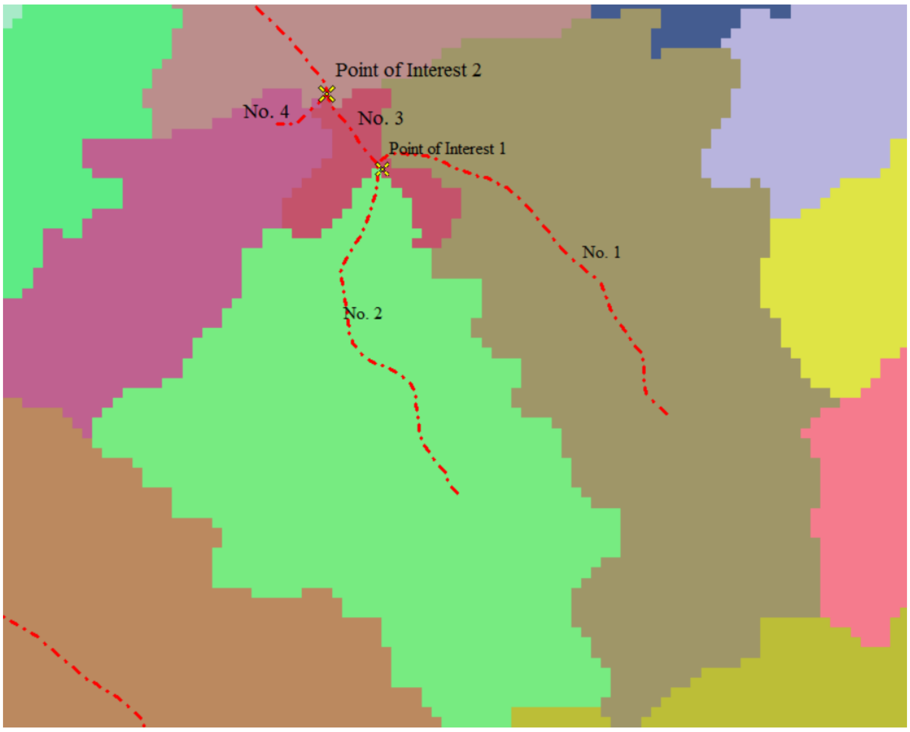

FIGURE 4.3: 2nd Point of Interest- Global Mapper.

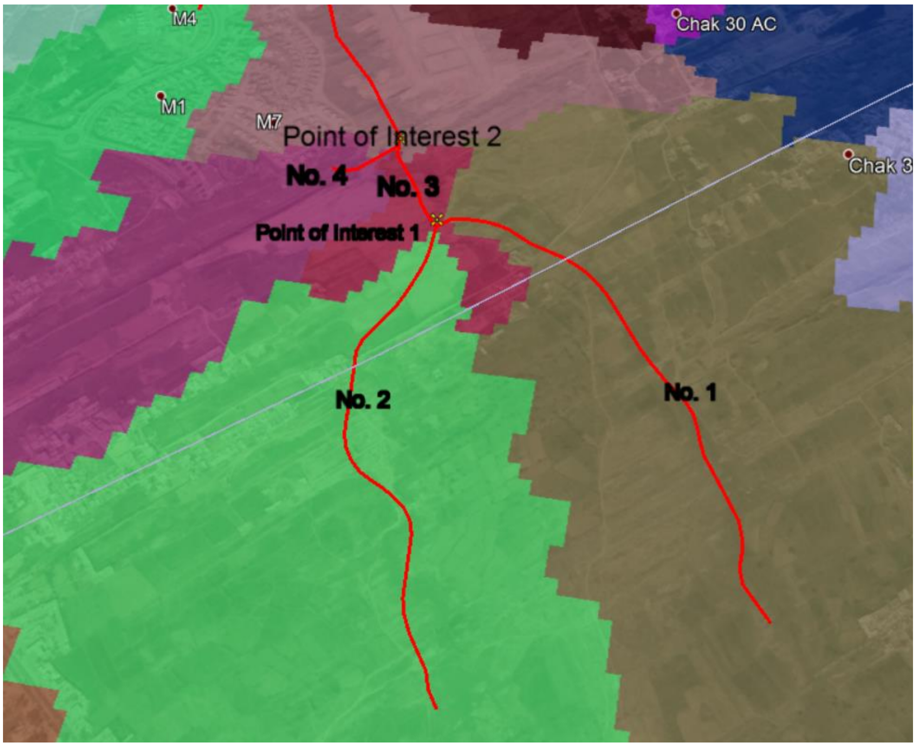

FIGURE 4.4: 2nd Point of Interest - Google Earth.

Table 4.2: Drainage Area - 2^{nd} Point of Interest.

Sr. No.	Description	Values	Remarks
1	No. of Streams Contributing	02	Stream No. 3 & No. 4
2	Drainage Area of Stream No. 3	687.76	acres (Area corresponding to stream no. 1 & no. 2 is also included)
3	Drainage Area of Stream No. 4	117.63	acres
4	Total Drainage area for 2^{nd} Point of interest	805.39	acres

4.2.1.3 Drainage Area No. 3 - 3^{rd} Point of Interest

Similarly, the drainage area next considered for estimation of discharge is comprised of one streams of 1^{st} order i.e. stream no. 6 and other stream is stream no. 5 which also carrying drainage water from 2^{nd} point of interest respectively. These streams joined at a location which is named as 3^{rd} point of interest. Details of area along with location snap are shown below:

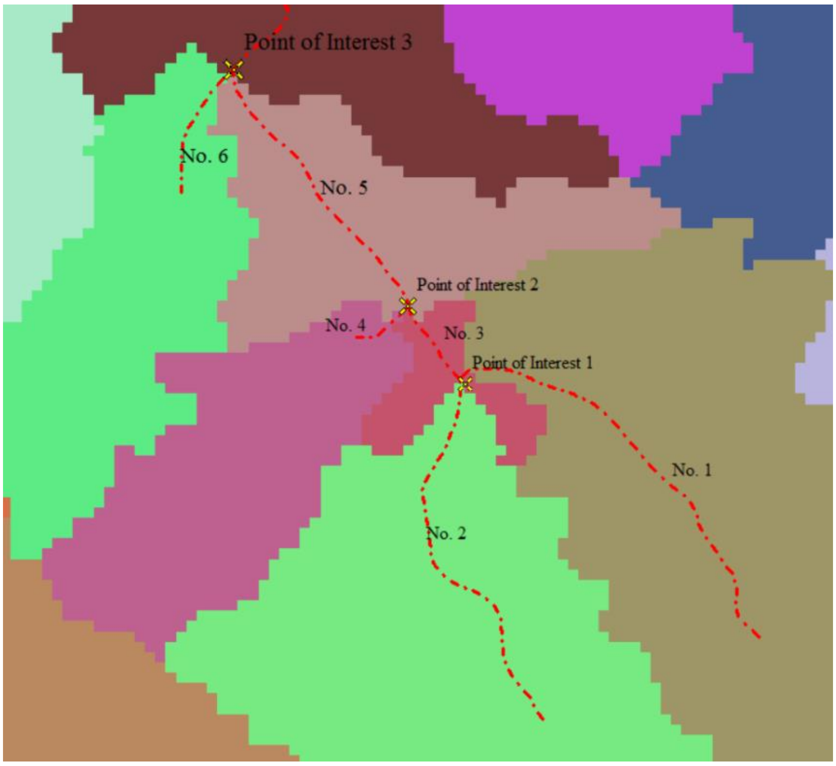

Figure 4.5: 3^{rd} Point of Interest- Global Mapper.

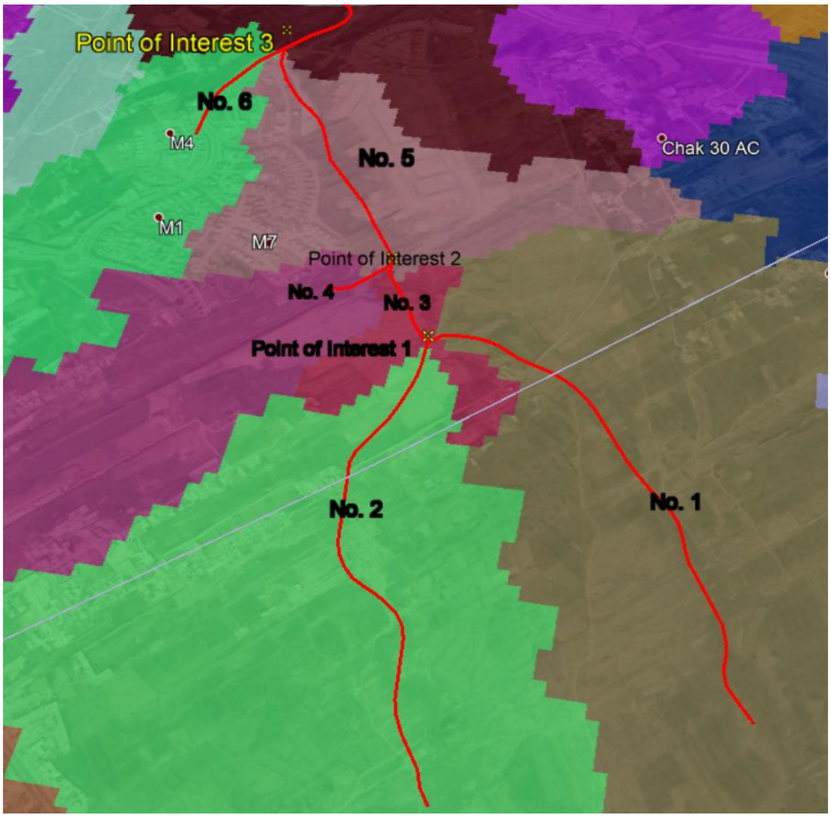

FIGURE 4.6: 3rd Point of Interest- Google Earth.

TABLE 4.3: Drainage Area - 3rd Point of Interest.

Sr. No.	Description	Values	Remarks
1	No. of Streams Contributing	02	Stream No. 5 & No. 6
2	Drainage Area of Stream No. 5	915.6	acres (Area corresponding to stream no. 3 & no. 4 is also included)
3	Drainage Area of Stream No. 6	141.364.4	acres
4	Total Drainage area for 3rd Point of interest	1056.97	acres

4.2.1.4 Drainage Area No. 4 - 4th Point of Interest

In addition to above, the drainage area next considered for estimation of discharge is comprised of one streams of 1st order i.e. stream no. 8 and other stream is stream no. 7 which also carrying drainage water from 3rd point of interest respectively. These streams joined at a location which is named as 4^{th} point of interest. Detail of location snap on global mapper and google earth is shown in Figure 4.7 and Figure 4.8. Whereas, corresponding data for 4th point of interest is tabulated in Table 4.4.

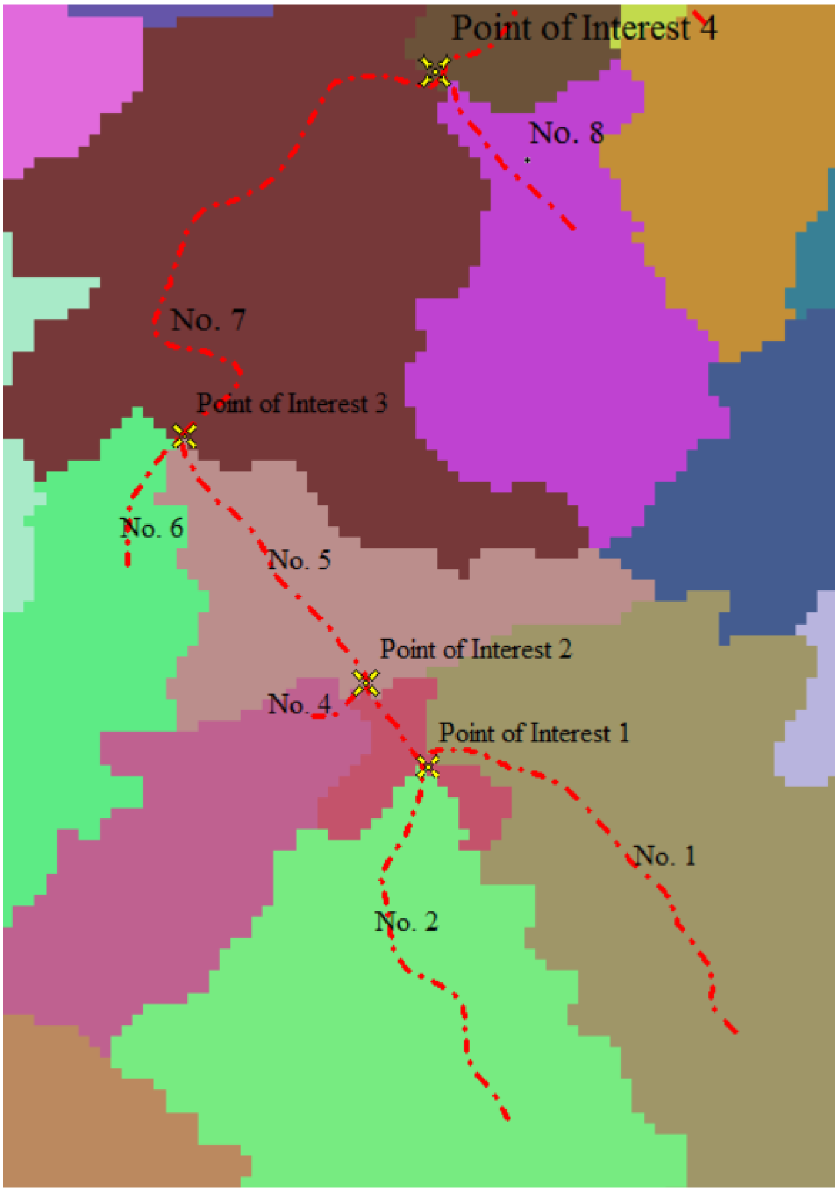

FIGURE 4.7: 4th Point of Interest- Global Mapper.

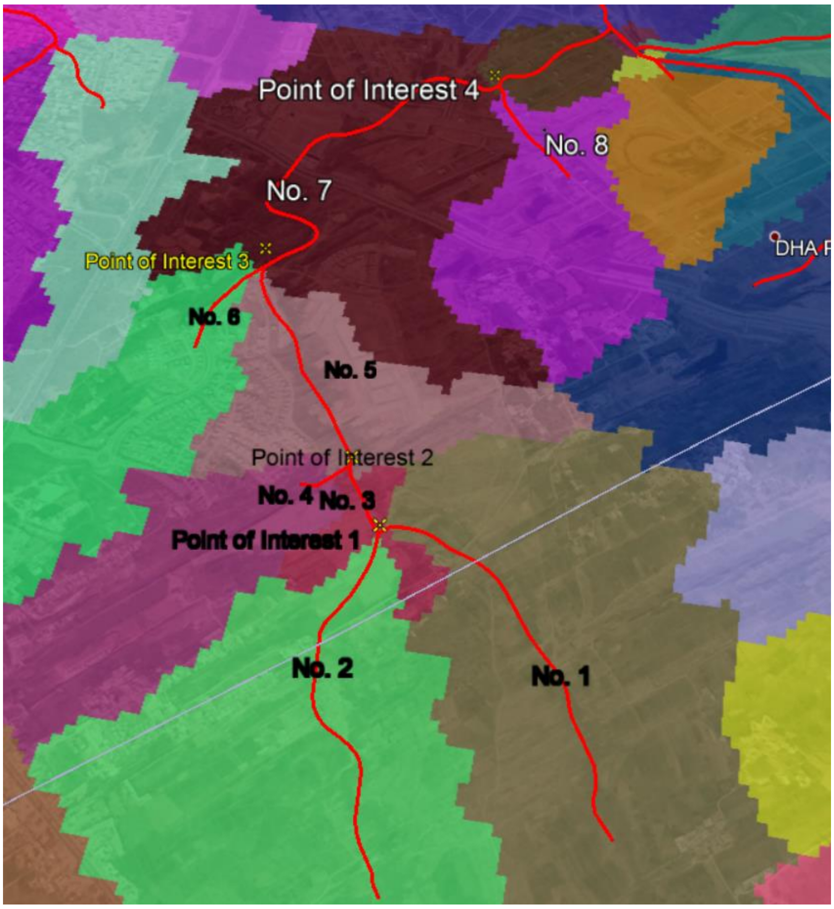

FIGURE 4.8: 4^{th} Point of Interest- Google Earth.

TABLE 4.4: Drainage Area - 4^{th} Point of Interest.

Sr. No.	Description	Values	Remarks
1	No. of Streams Contributing	02	Stream No. 7 & No. 8
2	Drainage Area of Stream No. 7	1378.5	acres (Area corresponding to stream no. 5 & no. 6 is also included)
3	Drainage Area of Stream No. 8	150.50	acres
4	Total Drainage area for 4^{th} Point of interest	1528.99	acres

4.2.2 Estimation of Time of Concentration, Tc

For estimating Tc, two different methods are used as narrated in section 3.3.2:-

i. Channel Flow by Kirpich Method

ii. Overland Flow by Izzard Method

4.2.2.1 Channel Flow by Kirpich Method

For channel flow through any stream or water path, Kirpich method is used. Detail of this method is mentioned in section 3.3.2.1. Time of concentration for channel flow is estimated using equation (3.2).

TABLE 4.5: Channel Flow by Kirpich Method.

Sr. No.	**Name Assigned to Streams**	**Length of stream /channel**	**Length of stream / channel**	**Elevation (m) from Global Mapper**		**Average Slope**	**Coefficient, "K"**	**tch from Kirpich Method**
		(Km)	(m)	At start	At end	Pct. (%)		(minutes)
1	No. 1	1.20	1200.0	543.8	518	2.15	0.0195	20.09
2	No. 2	1.14	1140.0	544.8	518	2.35	0.0195	18.66
3	No. 3	0.25	254.0	518	511.4	2.61	0.0195	5.64
4	No. 4	0.17	168.0	515	511.4	2.16	0.0195	4.41
5	No. 5	0.85	850.0	511.4	491	2.40	0.0195	14.78
6	No. 6	0.41	405.0	505.9	491	3.69	0.0195	7.07
7	No. 7	1.62	1616.0	491	461.4	1.83	0.0195	26.87
8	No. 8	0.54	537.4	487	461.4	4.76	0.0195	7.97

4.2.2.2 Overland Flow by Izzard Method

Izzard (1946) proposed the relationship for the time of concentration for roads and turf surfaces as narrated in section 3.3.2.2. So, overland time of concentration is then calculated by using equation (3.3).

TABLE 4.6: Overland Flow by Izzard Method.

Sr. No.	Name Assigned to Streams	Drainage Area	Flow Path - Longest Path	Elevation (m) from Global Mapper & Google Earth		Average Slope	Average Rainfall Intensity	Coefficient, "Cr"	Tc from Izzard Method
		(Acres)	(ft)	At start	At end	Pct. (%)	(in./hr.)		(minutes)
1	No. 1	350.430	7029.21	577.8	543.8	3.47	3.00	0.046	55.68
2	No. 2	313.36	6573.13	556.8	540.1	1.60	3.00	0.046	70.51
3	No. 3	23.97	1405.93	534.9	513.3	5.95	3.00	0.046	27.21
4	No. 4	117.63	3651.44	550.1	513.6	3.14%	3.00	0.046	46.27
5	No. 5	110.22	3511.57	539.8	507.2	3.08%	3.00	0.046	45.99
6	No. 6	141.36	4076.98	539.2	503.2	2.25%	3.00	0.046	53.61
7	No. 7	321.52	6675.24	534.6	482.2	3.74%	3.00	0.046	53.38
8	No. 8	150.50	4233.22	536.1	487.3	9.07%	3.00	0.046	34.13

Whereas, in the Watershed lag method of computing time of concentration, flow length is defined as the longest path along which water flows from the watershed divide to the outlet. Flow length can be measured using aerial photographs, quadrangle sheets, or GIS techniques. Mockus (USDA 1973) developed an empirical relationship between flow length and drainage area using data from Agricultural Research Service (ARS) watersheds. This relationship is:

$$l = 209A^{0.6} \tag{4.1}$$

Where;

l = Flow length, ft

A = Drainage area, acres

4.2.2.3 Calculated Tc for all Points of Interest

After calculation of channel flow and overland flow for all streams; time of concentration for each point of interest is then tabulated for further correspondence.

TABLE 4.7: Time of Concentration, Tc - 1st Point of Interest.

Description	**Values**	**Remarks**
No. of Streams Contributing	2.0	(No. 1 & No. 2)
Catchment / Drainage Area	2.68	(Km^2)
-do-	663.79	(acres)
Tc of Stream 1, Overflow	55.67	(minutes)
Tc of Stream 1, Channel flow	20.09	(minutes)
Tc, upto previous point; of Stream 1 (Max. of flow)	-	-
Tc of Stream 2, Overflow	70.51	(minutes)
Tc of Stream 2, Channel flow	18.66	(minutes)
Tc, upto previous point; of Stream 2 (Max. of flow)	-	-
Tc for Point of Interest-1	*70.51*	*(minutes)*

Time of concentration for 1st point of interest is the maximum from flow corresponding to stream no. 1 and stream no. 2. So, the calculated time of concentration is 70.509 minutes for 1st point of interest.

Similarly for calculating Tc for 2nd point of interest, previous time will be added to obtain cumulative time for whole catchment area under consideration.

TABLE 4.8: Time of Concentration, Tc - 2nd Point of Interest.

Description	**Values**	**Remarks**
No. of Streams Contributing	4.0	(No. 1,2,3 & 4)
Catchment / Drainage Area	3.26	(Km^2)
-do-	805.39	(acres)
Tc of Stream 3, Overflow	27.21	(minutes)
Tc of Stream 3, Channel flow	5.64	(minutes)
Tc, upto previous point; of stream 3 (Max. of flow)	*70.51*	*(minutes)*
Tc of Stream 4, Overflow	46.26	(minutes)
Tc of Stream 4, Channel flow	4.41	(minutes)
Tc, upto previous point; of stream 4 (Max. of flow)	-	-
Tc for Point of Interest-2	76.15	(minutes)

Similarly, time of concentration for 2nd point of interest is the maximum from flow corresponding to stream no. 3 and stream no. 4 along with addition of previously calculated time of concentration for earlier point of interest. So, the calculated time of concentration is 76.15 minutes for 2nd point of interest.

Furthermore, for calculating Tc for 3rd point of interest, previous time will be added to obtain commulative time for whole catchment area under consideration.

Table 4.9: Time of Concentration, Tc - 3rd Point of Interest.

Description	**Values**	**Remarks**
No. of Streams Contributing	6.0	(No. 1,2,3,4,5 & 6)
Catchment / Drainage Area	4.27	(Km^2)
-do-	1056.97	(Acres)
Tc of Stream 5, Overflow	45.99	(minutes)
Tc of Stream 5, Channel flow	14.77	(minutes)
Tc, upto previous point; of stream 5 (Max. of flow)	*76.15*	*(minutes)*
Tc of Stream 6, Overflow	53.61	(minutes)
Tc of Stream 6, Channel flow	7.07	(minutes)
Tc, upto previous point; of stream 6 (Max. of flow)	-	-
Tc for Point of Interest-3	90.93	(minutes)

Correspondingly, time of concentration for 3rd point of interest is the maximum from flow corresponding to stream no. 5 and stream no. 6 along with addition of previously calculated time of concentration for preceding point of interest. So, the calculated time of concentration is 90.926 minutes for 3rd point of interest.

Moreover, for calculating Tc for 4th point of interest, previous time will be added to obtain commulative time for whole catchment area under consideration.

Table 4.10: Time of Concentration, Tc - 4th Point of Interest.

Description	**Values**	**Remarks**
No. of Streams Contributing	8.0	(No. 1,2,3,4, 5,6,7&8)
Catchment / Drainage Area	6.187	(Km^2)
-do-	1528.990	(acres)
Tc of Stream 7, Overflow	53.384	(minutes)
Tc of Stream 7, Channel flow	26.874	(minutes)
Tc, upto previous point; of stream 7 (Max. of flow)	*90.926*	*(minutes)*
Tc of Stream 8, Overflow	34.130	(minutes)
Tc of Stream 8, Channel flow	7.969	(minutes)
Tc, upto previous point; of stream 8 (Max. of flow)	-	-
Tc for Point of Interest-4	117.800	(minutes)

So, the final time of concentration for the whole catchment area is 117.8 minute. Therefore, duration of rainfall should be greater than time of concentration, Tc i.e. 117.8 minute; so that rational method can be applied to this area.

4.2.3 Calculation for C-weighted

If there are mixture of land in the selected area; then the "C" value will be a composite of all types of land as elaborated in section 3.3.3.1. So the value of "C" can be calculated by using equation (3.4) and Table A3 of Appendix-A.

4.2.3.1 C-weighted for Developed Area - Royal Vistas Housing Society

C-weighted of developed area is then divided further into two areas according to percentage of developed area. Total distribution of residential area, parks, green areas and roads is calculated from society's layout map. Royal Vistas is a developed hosing society within the selected site; whose all detail layout drawings ware available with Engineering branch. Stream no. 5 and stream no. 6 is draining water from this society, so the C-weighted calculated for this area will be used for both streams respectively. Then average value of C is used for calculating c-weighted value for all area. Detail calculation is illustrated below:-

TABLE 4.11: C-weighted for Developed Area - Other Housing Societies.

Description	**Area**	**Unit**	**Min C-Value**	**Max C-Value**	**Avg. C- Value**	**(A × C)**
Total Area of Houses / Roof	61493.49	Sqm	0.75	0.95	0.85	52269.47
Total Area of Parks / Green Area	6252.75	Sqm	0.1	0.25	0.175	1094.23
Total Area of Roads	30189.93	Sqm	0.85	0.95	0.9	27170.94
$\sum$A	97936.17				$\sum$(A × C)	80534.63
$C_{weighted}$ = (A × C) / A				= 0.822		

4.2.3.2 C-weighted for Developed Area - Other Societies

Similarly, total distribution of residential area, parks, green areas and roads in other housing societies calculated according to CDA standards. Total 100000-Sqm area is considered for calculations. Then average value of C is used for calculating c-weighted value for all area. Detail calculation is demonstrated in Table 4.12:

TABLE 4.12: C-weighted for Developed Area - Royal Vistas Housing Society.

Description	**Area in %**	**Area in Sqm**	**Min C-Value**	**Max C-Value**	**Avg. C Value**	**(A × C)**
Residential	55	55000	0.75	0.95	0.85	46750.00
Total Area of Parks / Green Area	8	8000	0.1	0.25	0.175	1400.00
Streets/Roads	26	26000	0.85	0.95	0.9	23400.00
Graveyards	2	2000	0.15	0.2	0.175	350.00
Commercial & Parking	5	5000	0.70	0.95	0.83	4125.00
Public Buildings	4	4000	0.3	0.7	0.5	2000.00
$\sum$A	100000.00				**$\sum$(A × C)**	78025.00
$C_{weighted}$ = (A × C) / A				= 0.780		

4.2.3.3 Overall Developed Area

Total developed area corresponding to each stream is calculated by using Google Earth. Developed areas according to actual conditions are marked and value with respect to each is calculated. As shown in Figure 4.9, developed area for each stream is marked and value is calculated and tabulated values are narrated in tables in next section.

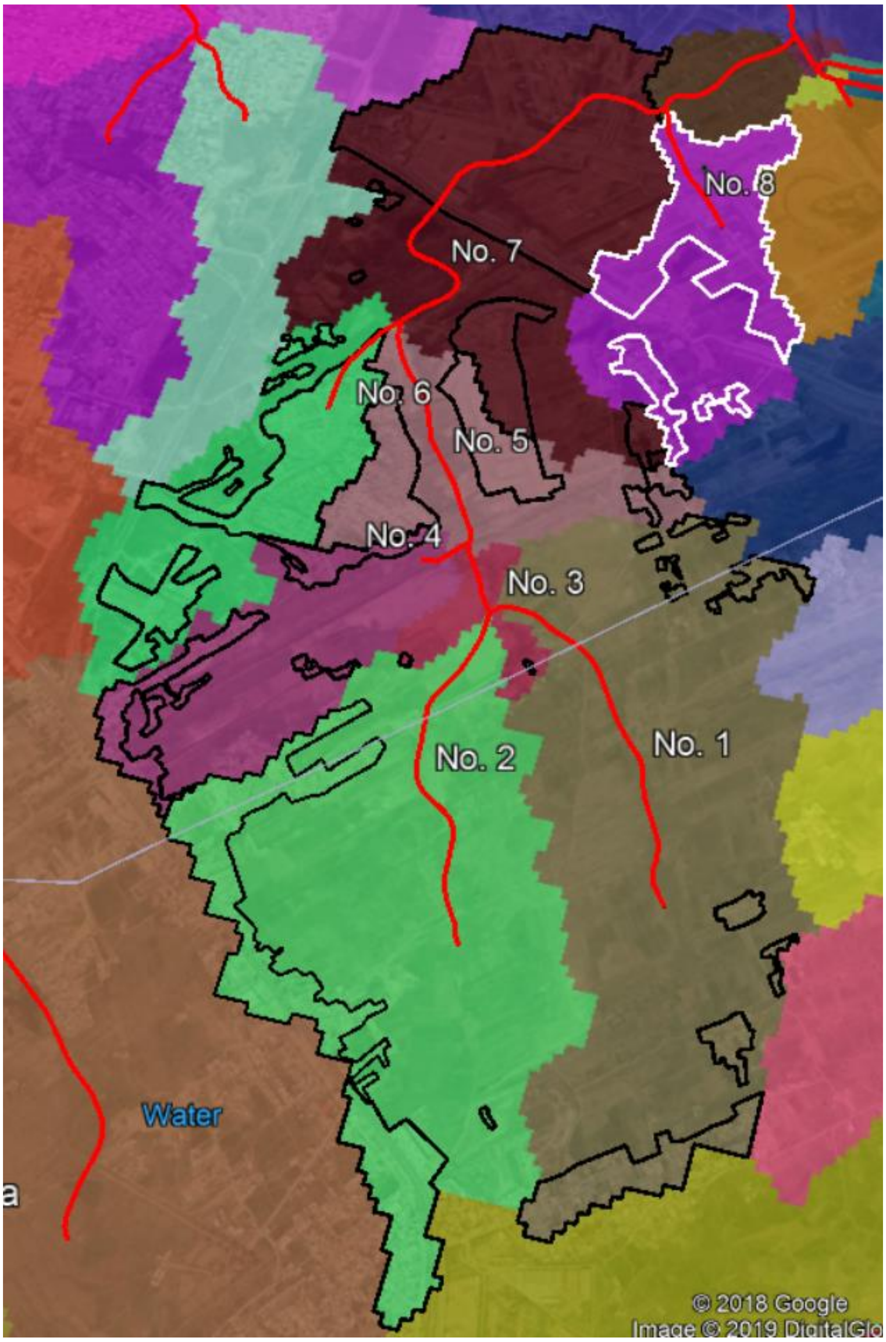

FIGURE 4.9: Developed area marked using Google Earth Tool.

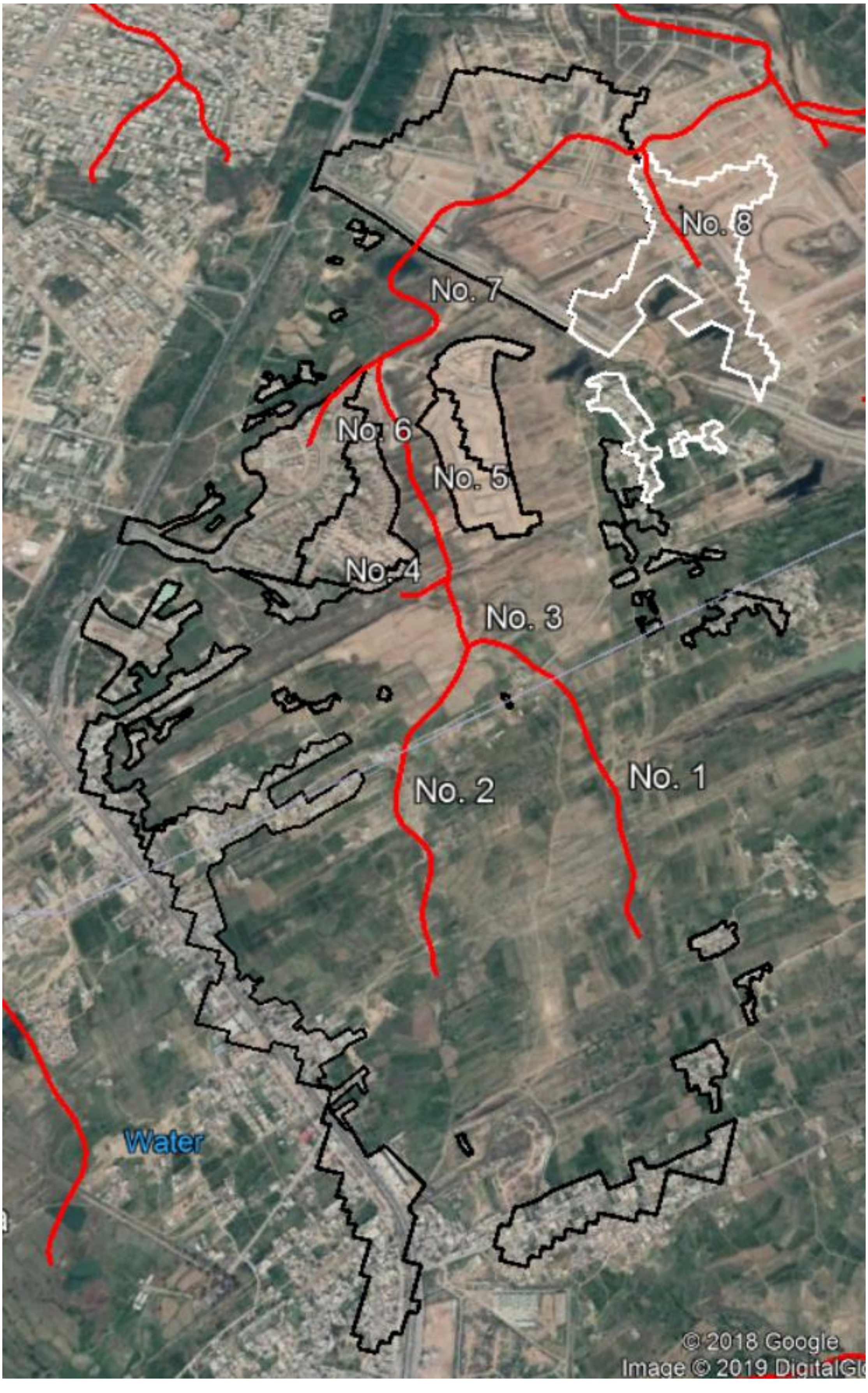

FIGURE 4.10: Another view for developed area marked using Google Earth Tool.

Each Polygon area is then selected for calculating each area and then area for each stream is estimated. As shown below area with respect to stream no. 2 is denoted by "A1" and value is 22.6 Acres.

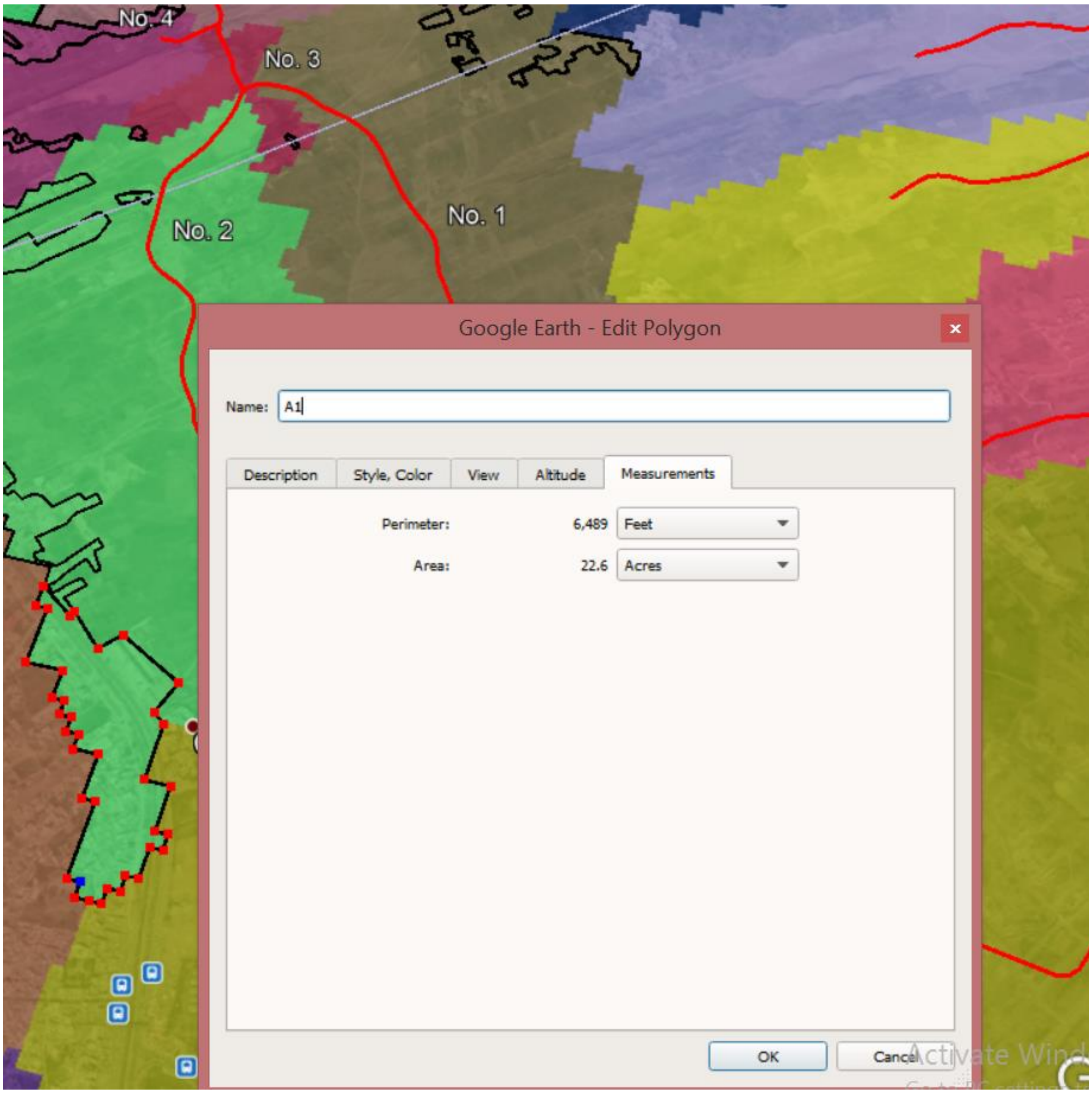

FIGURE 4.11: A view of developed area calculations- Google Earth.

Similarly, calculations for all area are done and tabulated results are mentioned for further runoff estimation process.

Table 4.13: Developed area w.r.t stream no. 1.

Sr. No.	Name Assigned to Area	Details	Developed Area	
			(ft^2)	(Acres)
1	A-7	Area-A7 for Stream No. 1	788730.00	18.11
2	A-8	Area-A8 for Stream No. 1	164210.00	3.77
3	A-9	Area-A9 for Stream No. 1	100665.00	2.31
4	A-10	Area-A10 for Stream No. 1	51509.00	1.18
5	A-11	Area-A11 for Stream No. 1	206644.00	4.74
6	A-12	Area-A12 for Stream No. 1	87222.00	2.00
7	A-13	Area-A13 for Stream No. 1	25429.00	0.58
8	A-14	Area-A14 for Stream No. 1	22449.00	0.52
9	A-15	Area-A15 for Stream No. 1	32478.00	0.75
(Sum of Values)			1479336.00	33.96

Table 4.14: Developed area w.r.t stream no. 2.

Sr. No.	Name Assigned to Area	Details	Developed Area	
			(ft^2)	(Acres)
1	A-1	Area-A1 for Stream No. 2	984653.00	22.60
2	A-4	Area-A4 for Stream No. 2	1920379.00	44.09
3	A-5	Area-A5 for Stream No. 2	11445.00	0.26
4	A-6	Area-A6 for Stream No. 2	23710.00	0.54
(Sum of Values)			2940187.00	67.50

Table 4.15: Developed area w.r.t stream no. 3.

Sr. No.	Name Assigned to Area	Details	Developed Area	
			(ft^2)	(Acres)
1	A-16	Area-A16 for 3	12293.00	0.28
2	A-17	Area-A17 for 3	7068.00	0.16
(Sum of Values)			19361.00	0.44

TABLE 4.16: Developed area w.r.t stream no. 4.

Sr. No.	**Name Assigned to Area**	**Details**	**Developed Area**	
			(ft^2)	(Acres)
1	A-19	Area-A19 for 4	667936.00	15.33
2	A-20	Area-A20 for 4	63837.00	1.47
3	A-22	Area-A22 for 4	370218.00	8.50
(Sum of Values)			1101991.00	25.30

TABLE 4.17: Developed area w.r.t stream no. 5.

Sr. No.	**Name Assigned to Area**	**Details**	**Developed Area**	
			(ft^2)	(Acres)
1	A-23	Area-A23 for 5	1121181.00	25.74
2	A-24	Area-A24 for 5	829697.00	19.05
3	A-25	Area-A25 for 5	178946.00	4.11
(Sum of Values)			2129824.00	48.89

TABLE 4.18: Developed area w.r.t stream no. 6.

Sr. No.	**Name Assigned to Area**	**Details**	**Developed Area**	
			(ft^2)	(Acres)
1	A-26	Area-A26 for 6	2131875.00	48.94
2	A-27	Area-A27 for 6	11821.00	0.27
3	A-28	Area A-28 for 6	96729.00	2.22
4	A-29	Area A-29 for 6	48789.00	1.12
5	A-30	Area-A30 for 6	595900.00	13.68
(Sum of Values)			2885114.00	66.23

Table 4.19: Developed area w.r.t stream no. 7.

Sr. No.	**Name Assigned to Area**	**Details**	**Developed Area**	
			(ft^2)	(Acres)
1	A-31	Area-A31 for 7	876974.00	20.13
2	A-32	Area-A32 for 7	206184.00	4.73
3	A-33	Area-A33 for 7	16033.00	0.37
4	A-34	Area-A34 for 7	8424.00	0.19
5	A-35	Area-A35 for 7	55352.00	1.27
6	A-36	Area-A36 for 7	7835410.00	179.88
(Sum of Values)			8998377.00	206.57

Table 4.20: Developed area w.r.t stream no. 8.

Sr. No.	**Name Assigned to Area**	**Details**	**Developed Area**	
			(ft^2)	(Acres)
1	A-37	Area-A37 for 8	376078.00	8.63
2	A-38	Area-A38 for 8	92939.00	2.13
3	A-39	Area-A39 for 8	3016244.00	69.24
(Sum of Values)			3485261.00	80.01

4.2.3.4 Distribution of Complete Catchment Area and "C" Values Used

As tabulated in previous tables, developed area corresponding to each stream is calculated to separate both areas i.e. developed and undeveloped; so that different "C" value can be used accordingly. Table 4.21 shows the total drainage area corresponding to each stream as well as developed area within that catchment area along with undeveloped area respectively.

Table 4.21: Distribution of complete catchment in Developed and Undeveloped areas.

Sr. No.	Name Assigned to Streams	Length of stream / channel	Corresponding Total Drainage Area		Developed Area		Remaining Undeveloped Area	
		(Km)	(Km^2)	(Acres)	(Km^2)	(Acres)	(Km^2)	(Acres)
1	No. 1	1.200	1.418	350.43	0.14	33.96	1.28	316.47
2	No. 2	1.140	1.268	313.36	0.27	67.50	0.99	245.86
3	No. 3	0.254	0.097	23.97	0.0018	0.44	0.10	23.53
4	No. 4	0.168	0.476	117.63	0.10	25.30	0.37	92.34
5	No. 5	0.85	0.446	110.22	0.20	48.89	0.25	61.33
6	No. 6	0.405	0.572	141.36	0.27	66.23	0.30	75.12
7	No. 7	1.616	1.301	321.52	0.84	206.57	0.47	114.94
8	No. 8	0.537	0.609	150.50	0.32	80.01	0.29	70.49
(Sum of Values) in Acres				1528.99		528.91		1000.08

In Table 4.22; "C" values used for each stream area is mentioned along with number of reference tables from which values have selected or calculated. Different values corresponding to developed and undeveloped areas are also detailed for further correspondence during calculation work.

Table 4.22: "C" values used corresponding to each stream.

Sr. No.	Stream No's	"C" value used for Developed Area	"C" value used for Undeveloped Area	Remarks	
				(Developed Area)	(Undeveloped Area)
1	Stream No. 1	0.78	0.70	As calculated in Table 4.12	Value for Drainage area type "Steep grassed slope" from Table A3
2	Stream No. 2	0.78	0.70	-do-	-do-
3	Stream No. 3	0.78	0.70	-do-	-do-
4	Stream No. 4	0.78	0.70	-do-	-do-
5	Stream No. 5	0.82	0.70	As calculated in Table 4.11	-do-
6	Stream No. 6	0.82	0.70	As calculated in Table 4.11	-do-
7	Stream No. 7	0.78	0.70	As calculated in Table 4.12	-do-
8	Stream No. 8	0.78	0.70	-do-	-do-

4.2.4 Rainfall Intensity Determination

The duration of the rainfall should be greater than the Tc for applying rational method approach as discussed in Section 3.3.4.

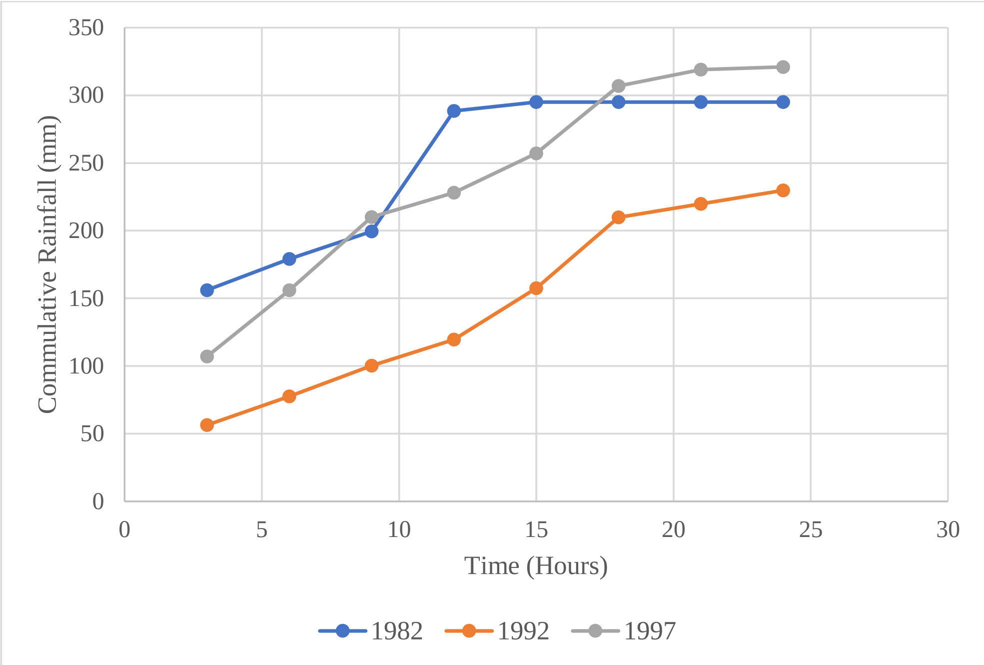

FIGURE 4.12: Rainfall Record at Islamabad Airport.

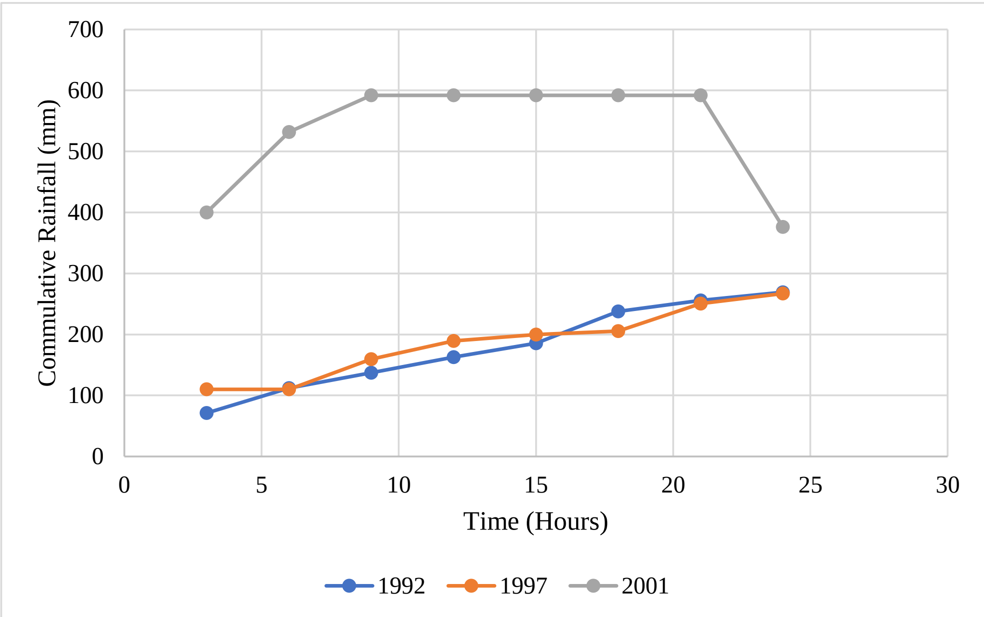

FIGURE 4.13: Rainfall Record at Met Office H-8.

For relating duration of rainfall with the intensity, curves are used which are known as intensity-duration-frequency (IDF) curves. So, from recorded data, IDF curves can be established.

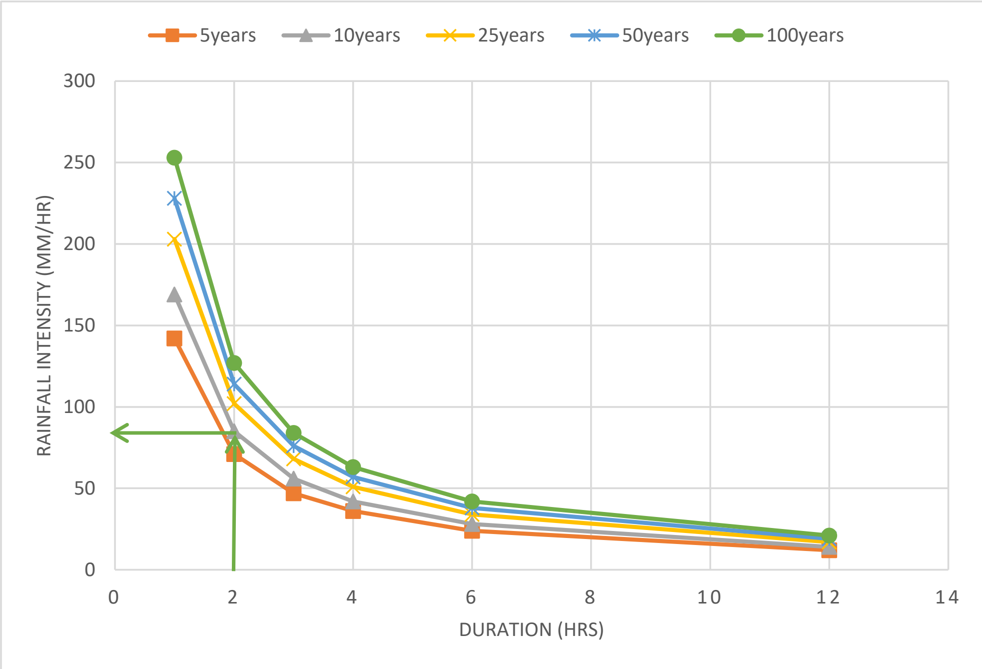

FIGURE 4.14: IDF curves for Rainfall Intensity.

The selected rainfall duration is 2 hours i.e. 120 minutes because the final time of concentration for the whole catchment area is 117.8 minute as calculated in Table 4.10 and the return period is taken as 10 years i.e. for culvert design. Therefore, duration of rainfall should be greater than the time of concentration, Tc i.e. 117.8 minute; so that rational method can be applied to this area.

Rainfall intensity with respect to 2 hours duration is approximately 80 mm/hr.

$$\text{Rainfall intensity} = 3.15 \text{ in/hr.}$$

Whereas, by laws and modalities of Capital Development Authority, Islamabad stated rainfall intensity for Islamabad region is 3.0 in/hr. This is nearly equal to value obtained from IDF curves.

So, rainfall intensity, "i" = 3.0 in/hr.

4.2.5 Discharge Calculations

As in the previous sections all values have been calculated and mentioned clearly. So, now discharge is calculated by using rational method approach and each is detailed below.

Discharge corresponding to following points of interest is calculated and tabulated below:-

- Discharge corresponding to 1st Point of Interest
- Discharge corresponding to 2nd Point of Interest
- Discharge corresponding to 3rd point of interest
- Discharge corresponding to 4th Point of Interest

Table 4.23: Discharge corresponding to 1st Point of Interest.

Point of Interest No. 1									
Sr. No.	**Streams Contributing in Drainage / Discharge**	**"A" Corresponding Drainage Area**		**"A" Commulative Drainage Area**	**"C" Coefficient Value**	**"i" Average Rainfall Intensity**	**Individual Area Discharge**	**Commulative Area Discharge**	**Commulative Area Discharge**
		(Km^2)	(Acres)	(Acres)		(in. / hr.)		(Cfs)	(Cfs)
1	Stream No. 1 (Developed)	0.14	33.96	350.43	0.78	3.00	79.49	744.07	1418.38
2	Stream No. 1 (Un Developed)	1.28	316.47		0.70		664.58		
3	Stream No. 2 (Developed)	0.27	67.49	313.36	0.78	3.00	157.99	674.30	
4	Stream No. 2 (Un Developed)	0.99	245.86		0.70		516.31		

Table 4.24: Discharge corresponding to 2nd Point of Interest.

<table>
<tr><td colspan="10">Point of Interest No. 2</td></tr>
<tr><th rowspan="2">Sr. No.</th><th rowspan="2">Streams Contributing in Drainage / Discharge</th><th colspan="2">"A" Corresponding Drainage Area</th><th>"A" Commulative Drainage Area</th><th>"C" Coefficient Value</th><th>"i" Average Rainfall Intensity</th><th>Individual Area Discharge</th><th>Commulative Area Discharge</th><th>Commulative Area Discharge</th></tr>
<tr><td>(Km^2)</td><td>(Acres)</td><td>(Acres)</td><td></td><td>(in. / hr.)</td><td></td><td>(Cfs)</td><td>(Cfs)</td></tr>
<tr><td>1</td><td>Stream No. 3 (Developed)</td><td>0.0018</td><td>0.44</td><td rowspan="2">23.97</td><td>0.78</td><td rowspan="2">3.00</td><td>1.04</td><td rowspan="2">1468.83 (*+Previous Discharge)</td><td rowspan="4">1721.95</td></tr>
<tr><td>2</td><td>Stream No. 3 (Un Developed)</td><td>0.10</td><td>23.53</td><td>0.70</td><td>49.41</td></tr>
<tr><td>3</td><td>Stream No. 4 (Developed)</td><td>0.10</td><td>25.30</td><td rowspan="2">117.63</td><td>0.78</td><td rowspan="2">3.00</td><td>59.22</td><td rowspan="2">253.12</td></tr>
<tr><td>4</td><td>Stream No. 4 (Un Developed)</td><td>0.37</td><td>92.34</td><td>0.70</td><td>193.90</td></tr>
</table>

Table 4.25: Discharge corresponding to 3rd Point of Interest.

Point of Interest No. 3									
Sr. No.	**Streams Contributing in Drainage / Discharge**	**"A" Corresponding Drainage Area**		**"A" Commulative Drainage Area**	**"C" Coefficient Value**	**"i" Average Rainfall Intensity**	**Individual Area Discharge**	**Commulative Area Discharge**	**Commulative Area Discharge**
		(Km^2)	(Acres)	(Acres)		(in. / hr.)		(Cfs)	(Cfs)
1	Stream No. 5 (Developed)	0.198	48.89	110.22	0.822	3.00	120.62	1971.36 (*+Previous Discharge)	2292.51
2	Stream No. 5 (Un Developed)	0.25	61.33		0.700		128.78		
3	Stream No. 6 (Developed)	0.27	66.23	141.36	0.822	3.00	163.39	321.16	
4	Stream No. 6 (Un Developed)	0.30	75.12		0.700		157.76		

Table 4.26: Discharge corresponding to 4th Point of Interest.

Point of Interest No. 4									
Sr. No.	**Streams Contributing in Drainage / Discharge**	**"A" Corresponding Drainage Area**		**"A" Commulative Drainage Area**	**"C" Coefficient Value**	**"i" Average Rainfall Intensity**	**Individual Area Discharge**	**Commulative Area Discharge**	**Commulative Area Discharge**
		(Km^2)	(Acres)	(Acres)		(in. / hr.)		(Cfs)	(Cfs)
1	Stream No. 7 (Developed)	0.84	206.57	321.52	0.78	3.00	483.54	3017.43 (*+Previous Discharge)	3352.74
2	Stream No. 7 (Un Developed)	0.47	114.94		0.70		241.38		
3	Stream No. 8 (Developed)	0.32	80.01	150.50	0.78	3.00	187.28	335.32	
4	Stream No. 8 (Un Developed)	0.29	70.49		0.70		148.03		

Summary of discharge calculated by rational method is tabulated below. In the next section results obtained from this method will be compared with other method i.e. NCRS CN method to check the validity of rational method approach.

TABLE 4.27: Discharge calculations using Rational Method-Summary of Results.

Sr. No.	**Description**	**Drainage Area (acres)**	**Discharge by Rational Method (Cfs)**
1	1^{st} Point of Interest	663.79	1418.38
2	2^{nd} Point of Interest	805.39	1721.95
3	3^{rd} Point of Interest	1056.97	2292.51
4	4^{th} Point of Interest	1528.99	3352.74

4.3 Verification of Results using SCS Curve Number Method

Hydrology National Engineering Handbook developed and stated "Runoff curve numbers for urban areas" in Hydrologic Soil-Cover Complexes, chapter 9. Depending upon the characteristics of natural ground, CN value is selected for further calculations.

Steps involved in applying this methodology are briefed in Section 3.4.1.

4.3.1 Hydrologic Soil Groups

Soil groups are further classified into four categories ranging from low runoff to high runoff as detailed in Table A4 of Appendix-A.

Selected study area has two type of distributions with respect to area i.e. developed and undeveloped area. So, developed area has moderately high runoff potential as per site conditions which lie in Group-C. Similarly, undeveloped area has obstructions like weeds, bushes, grass etc. which make runoff potential moderately low comparatively; hence lies in Group-B.

4.3.2 Cover Type and Hydrologic Conditions

According to cover type and depending upon the hydrological conditions, soil cover type is majorly divided into many types and detail classification is enlisted in Table A5 of Appendix-A. The soil type of selected catchment area is of three types as detailed below:-

i. For Developed area - Residential districts by average lot size 1/8 acre or less (town houses) is applicable.

ii. For undeveloped area - Natural desert landscaping (pervious areas only) is selected.

iii. For under construction undeveloped area - Newly graded areas (pervious areas only, no vegetation) is chosen.

4.3.3 Rainfall

Average rainfall for the catchment area is calculated from Table A7 of Appendix-A. Average rainfall value is 91 mm which is equal to 3.58 inch. So this value will be used for calculating discharge using curve number approach.

4.3.4 Curve Numbers (CN) Used

According to soil cover and hydrologic conditions, three values of curve numbers are related. For complete developed area; curve no. 90 is applicable. Whereas undeveloped area is further categorized into two types, complete undeveloped area and near future developing area.

Curve number (CN) values shown in Table 4.28 are taken from the corresponding curve number available in tables of Natural Resources Conservation Service's National Engineering Handbook, Part 630 (appendix-A), Hydrology, for estimating runoff corresponding to rainfall. The applicable parts of that Appendix-A are

Table 4.28: Curve Numbers (CN) used.

Description	**Soil Cover and Hydrologic Conditions**	**Hydrologic Soil Group**	**CN**	**Remarks**
Developed area	Residential districts by average lot size 1/8 acre or less (town houses)	Group - C	90	Complete developed area
Undeveloped area	Natural desert landscaping (pervious areas only)	Group - B	77	Complete undeveloped area
	Newly graded areas (pervious areas only, no vegetation)	Group - B	86	Near future developing area

reproduced as Table B1 through B3 of Appendix-B. The boxed values in each of these tables indicate runoff w.r.t 3.58 inch of rainfall explained in section 4.3.3.

Table 4.29: Discharge for 1st Point of Interest using CN Method.

Point of Interest No. 1										
Sr. No.	**Streams contributing in Drainage / Discharge**	**CN for Hydrologic Soil Group**	**Rainfall (in)**	**Runoff "Q" (in)**	**Corresponding Drainage Area**		**"Q" Individual Discharge**	**"Q" Stream Discharge**	**"Q" Comm. Discharge**
		(Table 4.28)	(Table A7)	(Table B1-B3)	(Km^2)	(Acres)	(Cusecs)	(Cusecs)	(Cusecs)
1	Stream No. 1 (Developed)	90	3.58	2.52	0.14	33.96	85.65	555.92	1091.50
2	Stream No. 1 (Un Developed)	77	3.58	1.49	1.28	316.47	470.27		
3	Stream No. 2 (Developed)	90	3.58	2.52	0.27	67.50	170.23	535.58	
4	Stream No. 2 (Un Developed)	77	3.58	1.49	0.99	245.86	365.35		

Table 4.30: Discharge for 2nd Point of Interest using CN Method.

Point of Interest No. 2									
Sr. No.	**Streams contributing in Drainage / Discharge**	**CN for Hydrologic Soil Group**	**Rainfall (in)**	**Runoff "Q" (in)**	**Corresponding Drainage Area**		**"Q" Individual Discharge**	**"Q" Stream Discharge**	**"Q" Comm. Discharge**
		(Table 4.28)	(Table A7)	(Table B1-B3)	(Km^2)	(Acres)	(Cusecs)	(Cusecs)	(Cusecs)
1	Stream No. 3 (Developed)	90	3.58	2.52	0.00180	0.44	1.12	1127.58 (*+Previous Q)	1328.59
2	Stream No. 3 (Un Developed)	77	3.58	1.49	0.095	23.53	34.96		
3	Stream No. 4 (Developed)	90	3.58	2.52	0.10	25.30	63.80	201.01	
4	Stream No. 4 (Un Developed)	77	3.58	1.49	0.37	92.34	137.21		

Table 4.31: Discharge for 3rd Point of Interest using CN Method.

Point of Interest No. 3									
Sr. No.	**Streams contributing in Drainage / Discharge**	**CN for Hydrologic Soil Group**	**Rainfall (in)**	**Runoff "Q" (in)**	**Corresponding Drainage Area**		**"Q" Individual Discharge**	**"Q" Stream Discharge**	**"Q" Comm. Discharge**
		(Table 4.28)	(Table A7)	(Table B1-B3)	(Km^2)	(Acres)	(Cusecs)	(Cusecs)	(Cusecs)
1	Stream No. 5 (Developed)	90	3.58	2.52	0.198	48.89	123.31	1543.04 (*+ Previous Q)	1821.71
2	Stream No. 5 (Un Developed)	77	3.58	1.49	0.248	61.33	91.13		
3	Stream No. 6 (Developed)	90	3.58	2.52	0.268	66.23	167.04	278.68	
4	Stream No. 6 (Un Developed)	77	3.58	1.49	0.304	75.12	111.64		

TABLE 4.32: Discharge for 4th Point of Interest using CN Method.

Point of Interest No. 4									
Sr. No.	**Streams contributing in Drainage / Discharge**	**CN for Hydrologic Soil Group**	**Rainfall (in)**	**Runoff "Q" (in)**	**Corresponding Drainage Area**		**"Q" Individual Discharge**	**"Q" Stream Discharge**	**"Q" Comm. Discharge**
		(Table 4.28)	(Table A7)	(Table B1-B3)	(Km^2)	(Acres)	(Cusecs)	(Cusecs)	(Cusecs)
1	Stream No. 7 (Developed)	90	3.58	2.52	0.836	206.57	520.98	2592.35 (*+ Previous Q)	2947.24
2	Stream No. 7 (Un Developed)	86	3.58	2.17	0.465	114.94	249.65		
3	Stream No. 8 (Developed)	90	3.58	2.52	0.324	80.01	201.79	354.89	
4	Stream No. 8 (Un Developed)	86	3.58	2.17	0.285	70.49	153.11		

4.4 Summary

Discharge is calculated from both methods corresponding to each point of interest. Rational method and SCS CN method both are applied to same catchment area to visualize the results and to check the validity of rational method.

It is observed from calculations that Rational Method approach estimate high value of discharge as compared to CN method.

Comparison of results for 1st point of interest is tabulated in Table 4.33:

TABLE 4.33: Comparison of Results for 1st Point of Interest.

Point of Interest No. 1							
Sr. No.	**Streams contributing in Drainage / Discharge**	**Corresponding Drainage Area**		**Commulative Drainage Area**	**Discharge from Rational Method**	**Discharge from CN Method**	**Percentage by which Rational Method value higher from CN approach**
		(Km^2)	(acres)	(acres)	(Cfs)	(Cfs)	(%)
1	Stream No. 1	1.418	350.43	663.79	1418.38	1091.50	29.95
2	Stream No. 2	1.268	313.36				

It is shown from above calculations that for area of 663.79 acres, discharge value from Rational Method is 29.95% higher than that of SCS CN Method.

Table 4.34: Comparison of Results for 2nd Point of Interest.

Point of Interest No. 2								
Sr. No.	**Streams contributing in Drainage / Discharge**	**Corresponding Drainage Area**		**Commulative Drainage Area**	**Discharge from Rational Method**	**Discharge from CN Method**	**Percentage by which Rational Method value higher from CN approach**
		(Km^2)	(acres)	(acres)	(Cfs)	(Cfs)	(%)
1	Stream No. 3	2.783	687.76	805.40	1721.95	1328.60	29.61
2	Stream No. 4	0.476	117.63				

It is shown from above calculations that for area of 805.40 acres, discharge value from Rational Method is 29.61% higher than that of SCS CN Method.

Table 4.35: Comparison of Results for 3rd Point of Interest.

Point of Interest No. 3							
Sr. No.	**Streams contributing in Drainage / Discharge**	**Corresponding Drainage Area**		**Commulative Drainage Area**	**Discharge from Rational Method**	**Discharge from CN Method**	**Percentage by which Rational Method value higher from CN approach**
		(Km^2)	(acres)	(acres)	(Cfs)	(Cfs)	(%)
1	Stream No. 5	3.705	915.61	1056.97	2292.51	1821.71	25.84
2	Stream No. 6	0.572	141.36				

It is revealed from Table 4.35 that for area of 1056.97 acres, discharge value from Rational Method is 25.84% higher than that of SCS CN Method.

Table 4.36: Comparison of Results for 4th Point of Interest.

Point of Interest No. 4								
Sr. No.	**Streams contributing in Drainage / Discharge**	**Corresponding Drainage Area**		**Commulative Drainage Area**	**Discharge from Rational Method**	**Discharge from CN Method**	**Percentage by which Rational Method value higher from CN approach**
		(Km^2)	(acres)	(acres)	(Cfs)	(Cfs)	(%)
1	Stream No. 7	5.578	1378.49	1528.99	3352.74	2947.24	13.76
2	Stream No. 8	0.609	150.50				

It is exposed from Table 4.36 that for area of 1528.99 acres, discharge value from Rational Method is 13.76% higher than that of SCS CN Method.

Chapter 5

Conclusions and Recommendations

5.1 Conclusions

Different researchers mentioned different catchment area limitation for use of rational method, but from the calculations it is observed that as area increases results seems more reliable. But there is need to clear that either for all type of areas results of rational method be applicable to larger areas, for addressing this percentage of developed and undeveloped area is calculated for all points of interest.

It is observed that results of rational method will be more acceptable if more developed area is present. Detail of calculations is tabulated in Table 5.1.

In literature, different authors mentioned that rational method is not applicable to catchment area of larger value but the comparison showed that as the area value goes on higher side, results are more acceptable. It means that it can be applicable to large areas depends upon type of catchment area. So assumptions available in the literature are not valid for all locations.

Table 5.1: Developed Area Percentage Related with Results.

Percentage Difference w.r.t Area Distribution						
Description	**Developed Area**	**Total Catchment Area**	**Percentage of Developed Area**	**Discharge from Rational Method**	**Discharge from CN Method**	**Percentage by which Rational Method value higher from CN approach**
	(acres)	(acres)	(%)	(Cfs)	(Cfs)	(%)
1st Point of Interest	101.46	663.79	15.28	1418.38	1091.50	29.95
2nd Point of Interest	127.20	805.40	15.79	1721.95	1328.60	29.61
3rd Point of Interest	242.33	1056.97	22.93	2292.51	1821.71	25.84
4th Point of Interest	528.91	1528.99	34.59	3352.74	2947.24	13.76

5.2 Recommendations

As different authors mentioned different catchment area limitations for use of rational method, for different locations due to variation in precipitation rate and variation of ground characteristics.

So, the limitations for use of rational method for any catchment area will be needed to verify first depending upon the ground characteristics and type of the area i.e. developed or undeveloped.

If there is all developed area in the selected catchment then rational method can be applicable even if there is larger area. Urban areas of Islamabad included mostly the developed areas so rational method can be adopted for design of storm drainage system. This is a simple method which can be easy to find out discharge value for any catchment area.

Correct application of either method needs another study including hydrograph method or any other technique.

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Appendix A

Table A1: 1st set of Grading Points.

GRADING POINT			
Point #	**Elevation**	**Northing**	**Easting**
13	507.49	1039450.86	3224449.91
14	508.20	1039468.12	3224460.01
15	509.10	1039485.39	3224470.10
16	509.90	1039502.66	3224480.19
17	512.90	1039526.41	3224473.10
18	510.50	1039510.57	3224485.32
19	514.60	1039494.28	3224497.88
20	516.00	1039479.80	3224509.04
21	516.40	1039463.96	3224521.26
22	517.00	1039447.79	3224533.74
23	516.80	1039467.48	3224575.90
24	517.99	1039479.85	3224591.62
25	518.70	1039492.21	3224607.35
26	519.00	1039500.06	3224617.34
27	522.00	1039453.38	3224643.83
28	520.17	1039443.72	3224628.73
29	520.50	1039434.06	3224611.22
30	523.00	1039420.28	3224607.72
31	521.80	1039403.65	3224619.70

32	521.15	1039385.69	3224628.55
33	521.37	1039374.13	3224644.27
34	520.17	1039383.80	3224661.79
35	520.50	1039412.16	3224717.91
36	521.15	1039429.67	3224708.24
37	521.96	1039447.18	3224698.58
38	522.50	1039466.60	3224687.86
53	520.62	1039396.20	3224726.72
54	520.76	1039377.50	3224737.03
55	520.92	1039356.35	3224748.71
56	521.07	1039343.14	3224755.99
57	521.58	1039327.45	3224764.65
58	522.18	1039308.77	3224774.96
59	522.78	1039290.08	3224785.27
60	523.34	1039271.04	3224794.94
61	523.99	1039252.71	3224805.89
62	524.59	1039234.03	3224816.20
63	525.18	1039215.77	3224826.28
64	525.37	1039199.32	3224820.09
65	525.25	1039192.63	3224808.51
66	525.21	1039184.14	3224791.67
67	524.86	1039196.12	3224793.35
68	524.30	1039209.78	3224785.81

TABLE A2: 2nd set of Grading Points.

GRADING POINT			
Point #	**Elevation**	**Northing**	**Easting**
69	523.57	1039227.29	3224776.14
70	522.83	1039244.80	3224766.48
71	522.09	1039262.31	3224756.82

72	521.35	1039279.82	3224747.16
73	520.62	1039297.33	3224737.49
74	519.73	1039314.84	3224727.83
75	519.48	1039332.35	3224718.17
76	519.27	1039349.87	3224708.50
77	519.57	1039367.38	3224698.84
78	520.01	1039382.76	3224690.35
79	518.96	1039359.59	3224680.30
80	518.26	1039349.92	3224662.79
81	517.55	1039340.26	3224645.27
82	516.84	1039330.60	3224627.76
83	516.04	1039320.93	3224610.25
84	517.35	1039347.68	3224596.39
85	517.74	1039356.51	3224612.40
86	519.33	1039365.34	3224628.40
87	519.59	1039398.02	3224608.26
88	518.86	1039388.35	3224590.75
89	518.13	1039378.69	3224573.24
90	517.61	1039369.39	3224556.40
91	518.10	1039397.28	3224572.69
92	517.54	1039408.09	3224564.35
93	517.06	1039422.56	3224553.19
94	516.88	1039437.04	3224542.03
95	517.26	1039450.00	3224570.05
96	517.85	1039434.17	3224582.27
97	518.56	1039418.09	3224594.15
98	519.07	1039461.56	3224605.20
99	511.81	1039469.39	3224479.84
100	512.84	1039453.57	3224492.07
101	513.86	1039437.38	3224503.83

102	514.88	1039421.56	3224516.06
103	515.91	1039405.74	3224528.29
104	516.87	1039389.91	3224540.53
105	517.58	1039350.56	3224571.37
106	517.00	1039334.84	3224583.73
107	516.18	1039318.93	3224595.85
108	515.58	1039302.84	3224607.72
109	515.42	1039286.57	3224619.36
110	515.77	1039270.13	3224630.75

TABLE A3: Runoff coefficient "C" values.

Type of drainage area	**Runoff coefficient**
Business:	
Downtown areas	0.70-0.95
Neighborhood areas	0.30-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.35-0.40
Apartment dwelling areas	0.30-0.70
Industrial:	
Light areas	0.30-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
Sand or sandy loam soil, 0-3%	0.15-0.20
Sand or sandy loam soil, 3-5%	0.20-0.25

Black or loessial soil, 0-3%	0.18-0.25
Black or loessial soil, 3-5%	0.25-0.30
Black or loessial soil, >5%	0.70-0.80
Deep sand area	0.05-0.15
Steep grassed slopes	0.7
Lawns:	
Sandy soil, flat 2%	0.05-0.10
Sandy soil, average 2-7%	0.10-0.15
Sandy soil, steep 7%	0.15-0.20
Heavy soil, flat 2%	0.13-0.17
Heavy soil, average 2-7%	0.18-0.22
Heavy soil, steep 7%	0.25-0.35
Streets:	
Asphaltic	0.85-0.95
Concrete	0.90-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

TABLE A4: Hydrologic Soil Groups as Defined by the SCS (1986).

Soil Group	**Description**
Group A	A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr). The textures of these soils are typically sand, loamy sand, or sandy loam.

Group B	B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr). The textures of these soils are typically silt loam or loam.
Group C	C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in-/hr). The texture of these soils is typically sandy clay loam.
Group D	D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr). The textures of these soils are typically clay loam, silty clay loam, sandy clay, silty clay, or clay.

Table A5: CN for different hydrologic soil group defined by the SCS (1986).

Cover description, cover type and htdrologic condition	**Average percent impervious area**	**CN for hydrologic group**			
		A	**B**	**C**	**D**
Fully developed urban areas (vegetation established): Open space (lawns, parks, golf courses, cemeteries, etc.)					

Poor condition (grass cover < 50%)	68	79	86	89
Fair condition (grass cover 50% to 75%)	49	69	79	84
Good condition (grass cover > 75%)	39	61	74	80
Impervious area:				
Paved parking lots, roofs, driveways, etc. (excluding right-of-ways)	98	98	98	98
Streets and roads:				
Paved; curbs and storm sewers (excluding right-of-way)	98	98	98	98
Paved; open ditches (including right-of-way)	83	89	92	93
Gravel (including right-of-way)	76	85	89	91
Dirt (including right-of-way)	72	82	87	89
Western desert urban areas:				
Natural desert landscaping (pervious areas only)	63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shurb with 1 to 2-inch sand or gravel mulch and basin borders)	96	96	96	96
Urban districts:				

Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
Developing urban areas:					
Newly graded areas (pervious areas only, no vegetation)		77	86	91	94

TABLE A6: Drainage network data-Stream's details.

S. No.	Name Assigned to Stream	Length of stream / channel	Elevation (m) from Global Mapper		Slope	Corresponding Drainage Area from Global Mapper		Previous Channel
		(Km)	At start	At end	PCT (%)	(Km^2)	(Acres)	
1	No. 1	1.2	543.8	518	2.15	1.418	350.43	-
2	No. 2	1.14	544.8	518	2.35	1.268	313.36	-
3	No. 3	0.254	518	511.37	2.61	2.783	687.76	No.1, No. 2
4	No. 4	0.168	515	511.37	2.16	0.476	117.63	-
5	No. 5	0.85	511.37	491	2.40	3.705	915.61	No. 3, No. 4
6	No. 6	0.405	505.94	491	3.69	0.572	141.36	-
7	No. 7	1.616	491	461.4	1.83	5.578	1378.49	No. 5, No. 6
8	No. 8	0.537	487	461.4	4.76	0.609	150.50	-

TABLE A7: Yearly rainfall from SamSam Model - for Location 1.

Month	**Rainfall (mm)**
January	56
February	72
March	85
April	59
May	39
June	62
July	255
August	289
September	93
October	28
November	18
December	36
Year	**1093**

Appendix B

Table B1: Runoff from rainfall data- Curve no. 77.

Runoff for inches of rainfall- Curve no. 77										
Inches	**Tenths**									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03
1	0.05	0.07	0.10	0.13	0.17	0.21	0.25	0.30	0.34	0.39
2	0.45	0.50	0.56	0.62	0.68	0.74	0.80	0.87	0.93	1.00
3	1.07	1.14	1.21	1.28	1.36	1.43	1.50	1.58	1.66	0.73
4	1.81	1.89	1.97	2.05	2.13	2.21	2.29	2.37	2.46	2.54
5	2.62	2.71	2.79	2.87	2.96	3.04	3.13	3.22	3.30	3.39
6	3.48	3.56	3.65	3.74	3.83	3.92	4.01	4.10	4.18	4.27
7	4.36	4.45	4.54	4.63	4.73	4.82	4.91	5.00	5.09	5.18
8	5.27	5.36	5.46	5.55	5.64	5.73	5.83	5.92	6.01	6.10
9	6.20	6.29	6.38	6.48	6.57	6.66	6.76	6.85	6.95	7.04
10	7.13	7.23	7.32	7.42	7.51	7.61	7.70	7.79	7.89	7.98
11	8.08	8.17	8.27	8.36	8.46	8.56	8.65	8.75	8.84	8.94
12	9.03	9.13	9.22	9.32	9.42	9.51	9.61	9.70	9.80	9.90
13	9.99	10.09	10.19	10.28	10.38	10.47	10.57	10.67	10.76	10.86
14	10.96	11.05	11.15	11.25	II.34	11.44	11.54	11.64	11.73	11.83
15	11.93	12.02	12.12	12.22	12.31	12.41	12.51	12.61	12.70	12.80
16	12.90	13.00	13.09	13.19	13.29	13.39	13.48	13.58	13.68	13.78
17	13.87	13.97	14.07	14.17	14.26	14.36	14.46	14.56	14.65	14.75
18	14.85	14.95	15.05	15.14	15.24	15.34	15.44	15.54	15.63	15.73
19	15.83	15.93	16.03	16.12	16.22	16.32	16.42	16.52	16.61	16.71
20	16.81	16.91	17.01	17.11	17.20	17.30	17.40	17.50	17.60	17.70
21	17.79	17.89	17.99	18.09	18.19	18.29	18.38	18.48	18.58	18.68
22	18.78	18.88	18.98	19.07	19.17	19.27	19.37	19.47	19.57	19.67
23	19.76	19.86	19.96	20.06	20.16	20.26	20.36	20.45	20.55	20.65

24	20.75	20.85	20.95	21.05	21.15	21.24	21.34	21.44	21.54	21.64
25	21.74	21.84	21.94	22.03	22.13	22.23	22.33	22.43	22.53	22.63
26	22.73	22.83	22.92	23.02	23.12	23.22	23.32	23.42	23.52	23.62
27	23.72	23.82	23.91	24.01	24.11	24.21	24.31	24.41	24.51	24.61
28	24.71	24.81	24.90	25.00	25.10	25.20	25.30	25.40	25.50	25.60
29	25.70	25.80	25.89	25.99	26.09	26.19	26.29	26.39	26.49	26.59
30	26.69	26.79	26.89	26.99	27.08	27.18	27.28	27.38	27.48	27.58
31	27.68	27.78	27.88	27.98	28.08	28.18	28.28	28.37	28.47	28.57
32	28.6-7	28.77	28.87	28.97	29.07	29.17	29.27	29.37	29.47	29.57
33	29.66	29.76	29.86	29.96	30.06	30.16	30.26	30.36	30.46	30.56
34	30.66	30.76	30.86	30.96	31.05	31.15	31.25	31.35	31.45	31.55
35	31.65	31.75	31.85	31.95	32.05	32.15	32.25	32.35	32.45	32.55
36	32.64	32.74	32.84	32.94	33.04	33.14	33.24	33.34	33.44	33.54
37	33.64	33.74	33.84	33.94	34.04	34.14	34.24	34.33	34.43	34.53
38	34.63	341.73	34.83	34.93	35.03	35.13	35.23	35.33	35.43	35.53
39	35.63	35.73	35.83	35.93	36.03	36.1.3	36.22	36.32	36.42	36.52
40	36.62	36.72	36.82	36.92	37.02	37.12	37.22	37.32	37.42	37.52

Note: Runoff value determined by equation $Q = \dfrac{(P - 0.2S)^2}{P + 0.8S}$

Table B2: Runoff from rainfall data- Curve no. 86.

Runoff for inches of rainfall- Curve no. 86										
Inches	**Tenths**									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0	0.00	0.00	0.00	0.00	0.00	0.02	0.04	0.07	0.11	0.15
1	0.20	0.25	0.31	0.36	0.43	0.49	0.56	0.63	0.70	0.77
2	0.85	0.92	1.00	1.08	1.16	1.24	1.32	1.41	1.49	1.58
3	1.66	1.75	1.83	1.92	2.01	2.10	2.19	2.27	2.36	2.45
4	2.54	2.64	2.73	2.82	2.91	3.00	3.09	3.19	3.28	3.37
5	3.47	3.56	3.65	3.75	3.84	3.93	4.03	4.12	4.22	4.31
6	4.41	4.50	4.60	4.69	4.79	4.88	4.98	5.08	5.17	5.27
7	5.36	5.46	5.56	5.65	5.75	5.85	5.94	6.04	6.14	6.23
8	6.33	6.43	6.52	6.62	6.72	6.82	6.91	7.01	7.11	7.20
9	7.30	7.40	7.50	7.59	7.69	7.79	7.89	7.99	8.08	8.18
10	8.28	8.38	8.47	8.57	8.67	8.77	8.87	8.97	9.06	9.16
11	9.26	9.36	9.46	9.55	9.65	9.75	9.85	9.95	10.05	10.15

12	10.24	10.34	10.44	10.54	10.64	10.74	10.84	10.93	11.03	11.13
13	11.23	11.33	11.43	11.53	II.62	11.72	11.82	11.92	12.02	12.12
14	12.22	12.32	12.42	12.51	12.61	12.71	12.81	12.91	13.01	13.11
15	13.21	13.31	13.40	13.50	13.60	13.70	13.80	13.90	14.00	14.10
16	14.20	14.30	14.40	14.49	14.59	14.69	14.79	14.89	14.99	15.09
17	15.19	15.29	15.39	15.49	15.59	15.69	15.78	15.88	15.98	16.08
18	16.18	16.28	16.38	16.48	16.58	16.68	16.78	16.88	16.98	17.08
19	17.17	17.27	17.37	17.47	17.57	17.67	17.77	17.87	17.97	18.07
20	18.17	18.27	18.37	18.47	18.57	18.67	18.77	18.86	18.96	19.06
21	19.16	19.26	19.36	19.46	19.56	19.66	19.76	19.86	19.96	20.06
22	20.16	20.26	20.36	20.46	20.56	20.66	20.76	20.85	20.95	21.05
23	21.15	21.25	21.35	21.45	21.55	21.65	21.75	21.85	21.95	22.05
24	22.15	22.25	22.35	22.45	22.55	22.65	22.75	22.85	22.95	23.05
25	23.15	23.24	23.34	23.44	23.54	23.64	23.74	23.84	23.94	24.04
26	24.14	24.24	24.34	24.44	24.54	24.64	24.74	24.84	24.94	25.04
27	25.14	25.24	25.34	25.44	25.54	25.64	25.74	25.84	25.94	26.03
28	26.13	26.23	26.33	26.43	26.53	26.63	26.73	26.83	26.93	27.03
29	27.13	27.23	27.33	27.43	27.53	27.63	27.73	27.83	27.93	28.03
30	28.13	28.23	28.33	28.43	28.53	28.63	28.73	28.83	28.93	29.03
31	29.13	29.23	29.33	29.43	29.53	29.62	29.72	29.82	29.92	30.02
32	30.12	30.22	30.32	30.42	30.52	30.62	30.72	30.82	30.92	31.02
33	31.12	31.22	31.32	31.42	31.52	31.62	31.72	31.82	31.92	32.02
34	32.12	32.22	32.32	32.42	32.52	32.62	32.72	32.82	32.92	33.02
35	33.12	33.22	33.32	33.42	33.52	33.62	33.72	33.82	33.92	34.02
36	34.12	34.22	34.31	34.41	34.51	34.61	34.71	34.81	34.91	35.01
37	35.II	35.21	35.31	35.41	35.51	35.61	35.71	35.81	35.91	36.01
38	36.11	36.21	36.31	36.41	36.51	36.61	36.71	36.81	36.91	37.01
39	37.11	37.21	37.31	37.41	37.51	37.61	37.71	37.81	37.91	38.01
40	38.11	38.21	38.31	38.41	38.51	38.61	38.71	38.81	38.91	39.01

Note: Runoff value determined by equation $Q = \dfrac{(P - 0.2S)^2}{P + 0.8S}$

Table B3: Runoff from rainfall data- Curve no. 90.

Runoff for inches of rainfall- Curve no. 90										
Inches	**Tenths**									
	0	**0.1**	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**
0	0.00	0.00	0.00	0.01	0.02	0.06	0.10	0.14	0.20	0.26
1	0.32	0.39	0.46	0.53	0.61	0.68	0.76	0.84	0.93	1.01
2	1.09	1.18	1.27	1.35	1.44	1.53	1.62	1.71	1.80	1.89
3	1.98	2.08	2.17	2.26	2.36	2.45	2.54	2.64	2.73	2.83
4	2.92	3.02	3.11	3.21	3.30	3.40	3.49	3.59	3.68	3.78
5	3.88	3.97	4.07	4.17	4.26	4.36	4.46	4.56	4.65	4.75
6	4.85	4.94	5.04	5.14	5.24	5.33	5.43	5.53	5.63	5.73
7	5.82	5.92	6.02	6.12	6.22	6.31	6.41	6.51	6.61	6.71
8	6.81	6.91	7.00	7.10	7.20	7.30	7.40	7.50	7.60	7.69
9	7.79	7.89	7.99	8.09	8.19	8.29	8.39	8.48	8.58	8.68
10	8.78	8.88	8.98	9.08	9.18	9.28	9.38	9.47	9.57	9.67
11	9.77	9.87	9.97	10.07	10.17	10.27	10.37	10.47	10.57	10.66
12	10.76	10.86	10.96	11.06	11.16	11.26	11.36	11.46	11.56	11.66
13	11.76	11.86	11.96	12.05	12.15	12.25	12.35	12.45	12.55	12.65
14	12.75	12.85	12.95	13.05	13.15	13.25	13.35	13.45	13.55	13.65
15	13.75	13.85	13.94	14.04	14.14	14.24	14.34	14.44	14.54	14.64
16	14.74	14.84	14.94	15.04	15.14	15.24	15.34	15.44	15.54	15.64
17	15.74	15.84	15.94	16.04	16.14	16.24	16.33	16.43	16.53	16.63
18	16.73	16.83	16.93	17.03	17.13	17.23	17.33	17.43	17.53	17.63
19	17.73	17.83	17.93	18.03	18.13	18.23	18.33	18.43	18.53	18.63
20	18.73	18.83	18.93	19.03	19.13	19.23	19.33	19.43	19.52	19.62
21	19.72	19.82	19.92	20.02	20.12	20.22	20.32	20.42	20.52	20.62
22	20.72	20.82	20.92	21.02	21.12	21.22	21.32	21.42	21.52	21.62
23	21.72	21.82	21.92	22.02	22.12	22.22	22.32	22.42	22.52	22.62
24	22.72	22.82	22.92	23.02	23.12	23.22	23.32	23.42	23.52	23.62
25	23.72	23.82	23.92	24.02	24.11	24.21	24.31	24.41	24.51	24.61
26	24.71	24.81	24.91	25.01	25.11	25.21	25.31	25.41	25.51	25.61
27	25.71	25.81	25.91	26.01	26.11	26.21	26.31	26.41	26.51	26.61
28	26.71	26.81	26.91	27.01	27.11	27.21	27.31	27.41	27.51	27.61
29	27.71	27.81	27.91	28.01	28.11	28.21	28.31	28.41	28.51	28.61
30	28.71	28.81	28.91	29.01	29.11	29.21	29.31	29.41	29.51	29.61
31	29.71	29.81	29.91	30.01	30.11	30.21	3.31	30.41	30.51	30.61
32	30.71	30.81	30.91	31.01	31.11	31.20	31.30	31.40	31.50	31.60

33	31.70	31.80	31.90	32.00	32.10	32.20	32.30	32.40	32.50	32.60
34	32.70	32.80	32.90	33.00	33.10	33.20	33.30	33.40	33.50	33.60
35	33.70	33.80	33.90	34.00	34.10	34.20	34.30	34.40	34.50	34.60
36	34.70	34.80	34.90	35.00	35.10	35.20	35.30	35.40	35.50	35.60
37	35.70	35.80	35.90	36.00	36.10	36.20	36.30	36.40	36.50	36.60
38	36.70	36.80	36.90	37.00	37.10	37.20	37.30	37.40	37.50	37.60
39	37.70	37.80	37.90	38.00	38.10	38.20	38.30	38.40	38.50	38.60
40	38.70	38.80	38.90	39.00	39.10	39.20	39.30	39.40	39.50	39.60

Note: Runoff value determined by equation $Q = \dfrac{(P - 0.2S)^2}{P + 0.8S}$