Modelling of Urban Storm Water Runoff Using SWMM

by

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A Thesis Submitted to the Academic Faculty in Partial Fulfillment of the Requirements for the Degree of

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DECLARATION OF CANDIDATE

We hereby declare that the undergraduate research work reported in this thesis has been performed by us under the supervision of Assistant Professor Tajkia Syeed Tofaand this work has not been submitted elsewhere for any purpose.

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DEDICATION

We would like to dedicate our works to our respective parents. Their hard work and dedication inspires us in life and everything we do.

We also pay our respect and gratitude to our supervisor Assistant Professor Tajkia Syeed Tofa. We would like to express our utmost gratitude to each and every individual for their support throughout the work.

Acknowledgement

"In the name of Allah, Most Gracious, Most Merciful"

All praise to Almighty Allah who enabled us to complete this thesis paper very efficiently and successfully. Without His kind blessing and guidance, we could never make it possible.

We are greatly indebted to our supervisor Assistant Professor Tajkia Syeed Tofa for her tremendous assistance, encouragement and valuable instructions needed for the thesis. Every steps regarding the thesis were monitored by her sincerely and thus we could complete the thesis very smoothly.

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Last but not the least, our deepest and heartiest sincerity to our parents who encouraged us from the very beginning and made us even better day by day by their advices and life experience.

Abstract

Water logging is one of the major nuisances faced in Dhaka. Moderate to severe rainfall intensity, during the monsoon season, causes severe inundation in the prime locations of the city. The primary causes of water logging are inadequate drainage sections, conventional drainage systems with low capacity and gravity, natural siltation, lack of inlets and outlets, indefinite drainage outlets, improper maintenance of existing drainage systems, and over and above disposal of solid waste into drains and drainage paths. Water logging is also sometimes caused by the topography of the city area. The residents of Dhaka City are burdened by the water logging, which has negative social, physical, economic, and environmental consequences. Urbanization is one of the reasons of increasing impervious area, disturbing the natural catchment and creating a demand for efficient drainage system. Mirpur 10, Begum Rokeya Sarani is one of the areas where flooding in quite inevitable during the rainy season. In this study, the storm water modelling of the mentioned area was conducted involving EPA SWMM and ArcGIS software to access the surface runoff and flooding using IDF curve for different return periods. The rainfall data of Dhaka city from 2010 to 2019 was collected from Bangladesh Meteorological Department (BMD) and the hydraulic data was collected from DWASA. Moreover, node flooding of the existing hydraulic structure, due to severe rainfall events, was also analyzed. To see how far Low Impact development practices could reduce urban flooding, one of them (Rain barrel) was tested on the catchment area, and the node flooding volumes were compared with or without Low Impact Development techniques. The results of the modeling show that there is a significant risk of node flooding, particularly in the event of extreme rainfall. However, after the LIDs were implemented, the flood peak value, surface runoff and flooding were significantly reduced.

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Chapter 1: Introduction

1.1. Introduction

The importance and necessity of stormwater modeling is gradually increasing because of global events like; urbanization, population growth and climate change. While increasing urbanization and population growth triggers a rapid growth of cities, they also affects the growing population with growing pollution of environment. These effects will only be amplified due to climate change in future and cause catastrophic weather occurrences.

Stormwater is water that forms on the ground surface as a result of precipitation or melting ice and snow (Prakash et al., n.d.). It is more relevant in urban areas where conveyance system is used. Conveyance systems are usually developed around a 10-minute rainfall event with a two-year return period. Thus, urban floods are usual, causing material damage in the tens of millions of euros (Tikkanen, n.d.).

Stormwater is also important in terms of the urban water balance, despite flooding. Larger stormwater runoff levels and peak flows are associated with increased impervious land cover, which decreases other components of the hydrologic cycle such as infiltration and evapotranspiration. Furthermore, stormwater carries hazardous contaminants from urban surfaces directly into downstream waterways (Scalenghe & Ajmone Marsan, 2009).

There is a well-documented loss in biodiversity and water quality in urban streams around the world. Increases in impervious surfaces such as roofs and roads, development of hydraulically functional drainage systems, compaction of soils, and changes to vegetation are usually correlated with urbanisation. This leads to increased flood flows and stream erosion, as well as the possibility of reduced baseflow. Water pollution from suspended sediments, heavy metals, hydrocarbons, nutrients, and diseases is also a result of urbanization (Elliott & Trowsdale, 2007).

1.2. Background

Dhaka, the capital of Bangladesh, is one of the most densely populated city where urbanization took place very rapidly. As a result, many inconsiderate development projects were undertaken by both private and state owned land developers. These projects increased the built up area, increasing the imperviousness of the land, hampering the natural drainage patterns and a reduction in retention basins, all of which resulted in a reduction in runoff concentration time and an increase in peak flow. Dhaka now falls victim to flooding at the slightest hint of rainfall and the streets of Dhaka remains inundated for hours after each heavy rainfall.

Stormwater flooding causing water logging, has been a concern in Dhaka city for the past few years, causing major infrastructure issues as well as a significant economic loss in development as well as significant damage to existing property and objects. These floods are primarily caused by insufficient drainage channels and their inappropriate operation and management. Furthermore, the city's natural environment is broken, and pathogens spread, causing significant inconvenience to its occupants (ISlam, 2013).

1.2.1. Effects of urban flooding

Even with minimal rainfall, Dhaka becomes a stagnant city during the monsoon. For example, on June 13, 2017, the city received 28 mm of rain, inundating many areas of the city and causing inconvenience to residents. Water logging has a wide range of consequences, from disruption of daily life to serious resource destruction (Subrina & Chowdhury, 2018). The consequences of urban flooding are discussed here;

a) Damage to Infrastructure

Land heave, subsidence, dampness, and other property damage are all caused by flooding by rainfall. Substructures in low laying areas gets damaged by water and brick foundations losses it’s longevity due to it. Temporary or weak structures in slums and low earning zones gets affected by the flooding severely. Often the occupants of these areas has to relocate. The roads, service utilities damaged by flooding hampers the day to day life of citizens as well as costs an enormous amount to fix and repair.

Figure 1:roads damged by flooding ; source: *(*Waterlogging Damages Zahir Raihan Road*, 2015)*

b) Decrement of income opportunity

Urban flooding has a number of negative consequences, including direct financial costs and a lack of revenue opportunities in different forms. Commercial operations in Dhaka have nearly come to a halt due to the flooding crisis. Shopping malls, restaurants, and even banks have exceptionally low consumer traffic and transaction rates. The income of day to day labors such as hawkers, street vendors, rickshaw pullers, day labors etc. suffers the most because of it as they do not have a savings to support their families in case of hazardous climate. Urban flooding obstructs traffic flows, posing a barrier to communication and timely delivery of goods, resulting in lost time, decreased productivity, and financial damage.

*Figure 2: economic losses because of flooding; (*Dhaka Street Vendors' Eid Sales Waterlogged*, 2015)*

c) Contamination of water sources and spread of water borne diseases

Strom water is often polluted by waste from hospitals, factories, overflowing latrines, and trash in the streets and drains. Ground water and receiving water sources such as canals, ponds, and detention areas are contaminated by this polluted storm water runoff. Urban runoff combines with sewage from overflowing latrines and sewers in poorly drained areas, thus creating waste and a wide range of problems associated with waterborne diseases.

d) Destruction of vegetation

The ecosystem of flora and fauna is harmed by stagnant water and constant wastewater release. By polluting the soil and water sources, contaminated storm water disrupts the habitat's ecosystem. This results in a decline in the number of trees, aquatic plants, and animals. The flow from drainage causes streams to scour deepening and widening the channels, negatively affecting the habitats of the ecosystem. Sediments flowing downstream ends up damaging aquatic habitats.

e) Disturbance of normal life

Urban flooding disrupts the day to day life of people of every aspects. The school going kids can’t go to school, street side stalls loose business, heavy traffic kills valuable time of passengers of vehicles and passerby can’t cross road. The shops and markets gets closed, supplies of products gets hampered, stored foods and goods gets rotten, all in all it is a nightmare come true whenever it rains in the city of Dhaka.

Figure 3: students affected by flooding ; (Boat Service on Dhaka Streets, *2017)*

1.3. Objectives

The main goal of this paper is to determine the extent of water logging in the Mirpur region. The study's ultimate aim is to improve the drainage condition of the Mirpur region in order to reduce the area's water logging problem. Thus the main aims and objective of the study are following;

- The aim of this study is to determine the effects of urban water runoff on drainage networks through SWMM simulations.
- To assign boundary conditions for the catchments and define the sewer network.
- To create a dynamic rainfall-runoff model to investigate runoff volume.
- To use LID techniques to assess the effects on the stormwater drainage system and determine the feasibility of two LID techniques.

1.4. Study Area

We've selected Begum Rokeya Sharani of Kazipara, Mirpur, Dhaka as our location of study to model in SWMM.

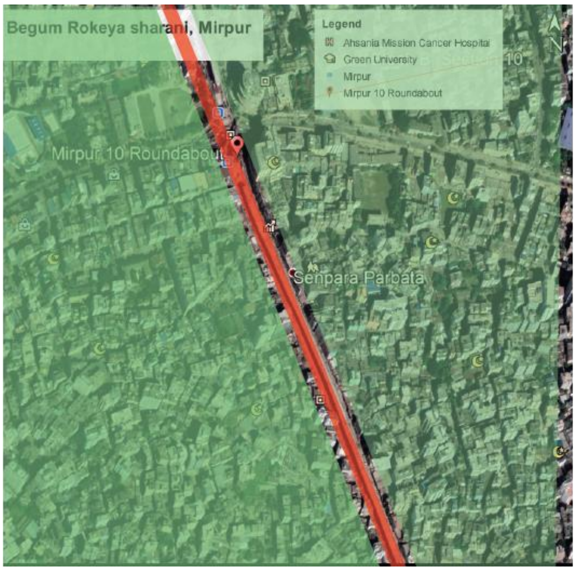


Figure 4: kazipara, Mirpur; source: google map

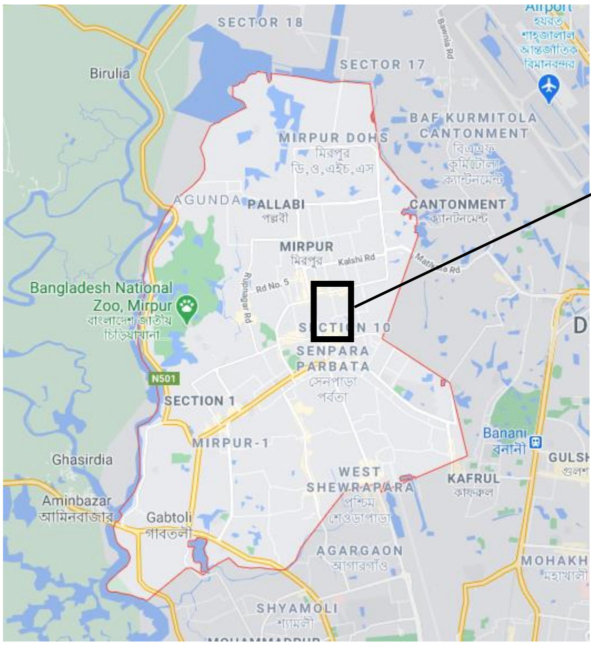


Figure 5: Map of mirpur; source: google map

Catchment

Road

The area covers 0.4645 km^2 of kazipara situated in the north-east of Dhaka, locating 23.8042°N 90.3667°E.

Mirpur is one of Dhaka's most well-known neighborhoods. It was established in 1962 and is located in the city's north-east corner. If it rains for many hours, the view of Dhaka city shifts - most of the busy roads, such as Mirpur-10, become impassable. Since the city's primary drainage system, the canals, are blocked and unable to carry the massive amount of storm water, Kazi para, Shewra para, and streets become flooded. Water logging is an issue that has negative social, physical, economic, and environmental consequences in Dhaka (Islam et al., n.d.).

Chapter 2: Literature Review

2.1. Urban flooding

2.1.1. Introduction

Historically, different viewpoints have been taken on urban drainage schemes. Urban drainage has been viewed as an essential natural resource, a convenient cleansing tool, an effective waste transport medium, a flooding hazard, a nuisance wastewater, and a disease transmitter at various times and in various locations. Climate, topography, geology, scientific expertise, engineering and construction skills, social traditions, religious beliefs, and other factors have all affected how urban drainage is viewed locally. These factors have driven and restricted the creation of urban drainage solutions for as long as humans have been building cities. Many fascinating and unusual urban drainage methods can be seen in historical accounts (Asfaw, 2016).

Mismanagement of drainage facility of an area can be the main cause of urban flooding, among many other causes. Heavy rainfall can lead to failure of drainage canals and sewage systems. Rain water can stand still on streets, roads, catchments and cause flooding. Water can enter the sewage system in one location and then be deposited on city streets in another.

2.1.2. Drainage networks

The purpose of drainage systems are to transport surface water or ground water. The drainage system should also protect the substructure from deterioration, soddenness, and loss of load-bearing capacity and strength. Another important goal of storm sewers is to protect public health and safety, the environment, sustainable development, and health and safety.

A drainage system would contain all of the components necessary to ensure that the substructure is adequately drained, including:

- Open ditches,
- Closed ditches with pipe drains,
- Drainage by stormwater drainage pipes, and
- Channels and culverts (Asfaw, 2016).

New urban water management methods have been established in the last two decades to enhance environmental, economic, social, and cultural outcomes. Such an approach is referred to as LID (low impact development), but other acronyms include SUDS (sustainable urban drainage systems), WSUD (water sensitive urban design), and LIUDD (low impact urban design and development, as used in New Zealand) (Elliott & Trowsdale, 2007).

2.2. Using Arc GIS for Georeferencing and DEM

ArcGIS is a geographic information system (GIS) that allows you to create, analyze, manage, edit, and visualize geographic information. It can be used to summarize the watershed's landscape and hydrological characteristics as feedback to a model. GIS experts may examine land use, topography, population density, and hydrological and environmental analysis with the right data. GIS manages information from all over the world by layers, functions, and attributes. Raster data models may be used to model continuously changing data over a surface, such as elevation, temperature, rainfall, and noise levels. Surfaces have numerical values, such as temperature, slope, and rainfall, which can be measured at any point on the earth's surface.

A DEM is a raster portrayal of a continuous surface, most commonly the earth's surface. The resolution is the most important factor in determining the accuracy of this data (the distance between sample points). The data type (integer or floating point) and the exact measurement of the surface when making the initial DEM are two other variables that affect accuracy. DEM errors are usually known as sinks or peaks. A sink, also known as a depression or hole, is a region surrounded by higher elevation values. This is an internal drainage area (*Exploring Digital Elevation Models—Help | ArcGIS Desktop*, n.d.).

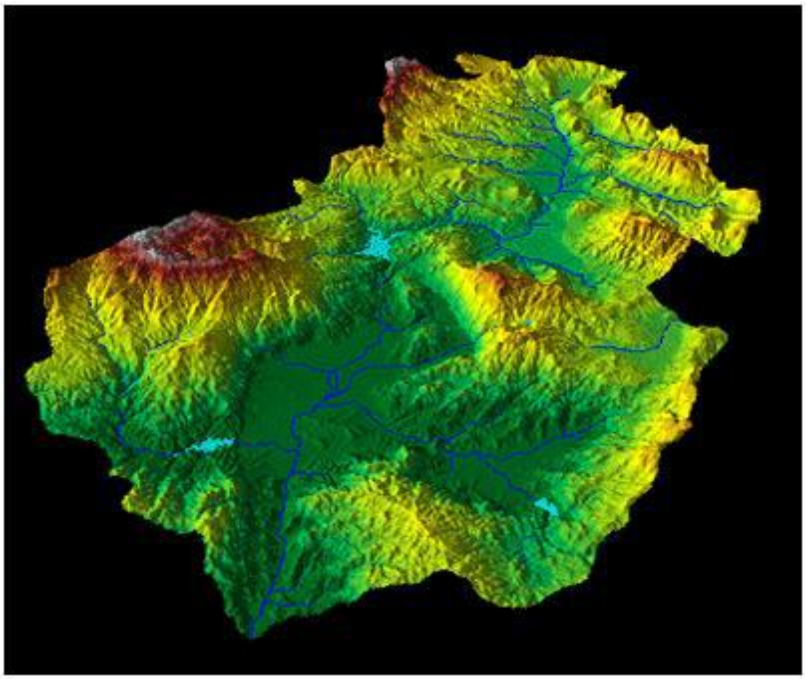


*Figure 6: Visualization of a raster DEM surface, (*Exploring Digital Elevation Models—Help | ArcGIS Desktop*, n.d.)*

2.3. SWMM

The EPA Storm Water Management Model (SWMM) is a complex rainfall-runoff simulation model that can be used for singular or long-term (continuous) simulations of runoff quantity and quality in urban areas. SWMM's runoff portion works with a series of subcatchment areas that receive precipitation and produce runoff and pollutant loads. SWMM's routing component transports runoff through a network of pipes, channels, storage/treatment systems, pumps, and regulators. During a simulation cycle comprised of multiple time phases, SWMM monitors the quantity and quality of runoff produced within each subcatchment, as well as the flow rate, flow depth, and quality of water in each pipe and channel (Rossman, n.d.).

Starting with version 5.0.19, the SWMM5 program includes an additional calculation module that allows users to account for different forms of LID activities, such as infiltration trenches, vegetative swales, and bio-retention cells, in the catchment model. Both direct rainfall and runoff collected from nearby areas are stored, infiltrated, and evaporated by them. SWMM conducts a moisture balance during a simulation to keep track of how much water passes between and is deposited within each LID sheet. The following layers make up the general scheme of LID controls in

SWMM5: surface layer, soil (substrate) layer, storage layer, and underdrains. A series of verification tests were carried out to assess the accuracy of the SWMM program in terms of modeling storm water runoff from green roofs, using the results of measurements provided in the ‘Monitoring on experimental sites' portion (Burszta-Adamiak & Mrowiec, 2013).

2.4. LID Techniques

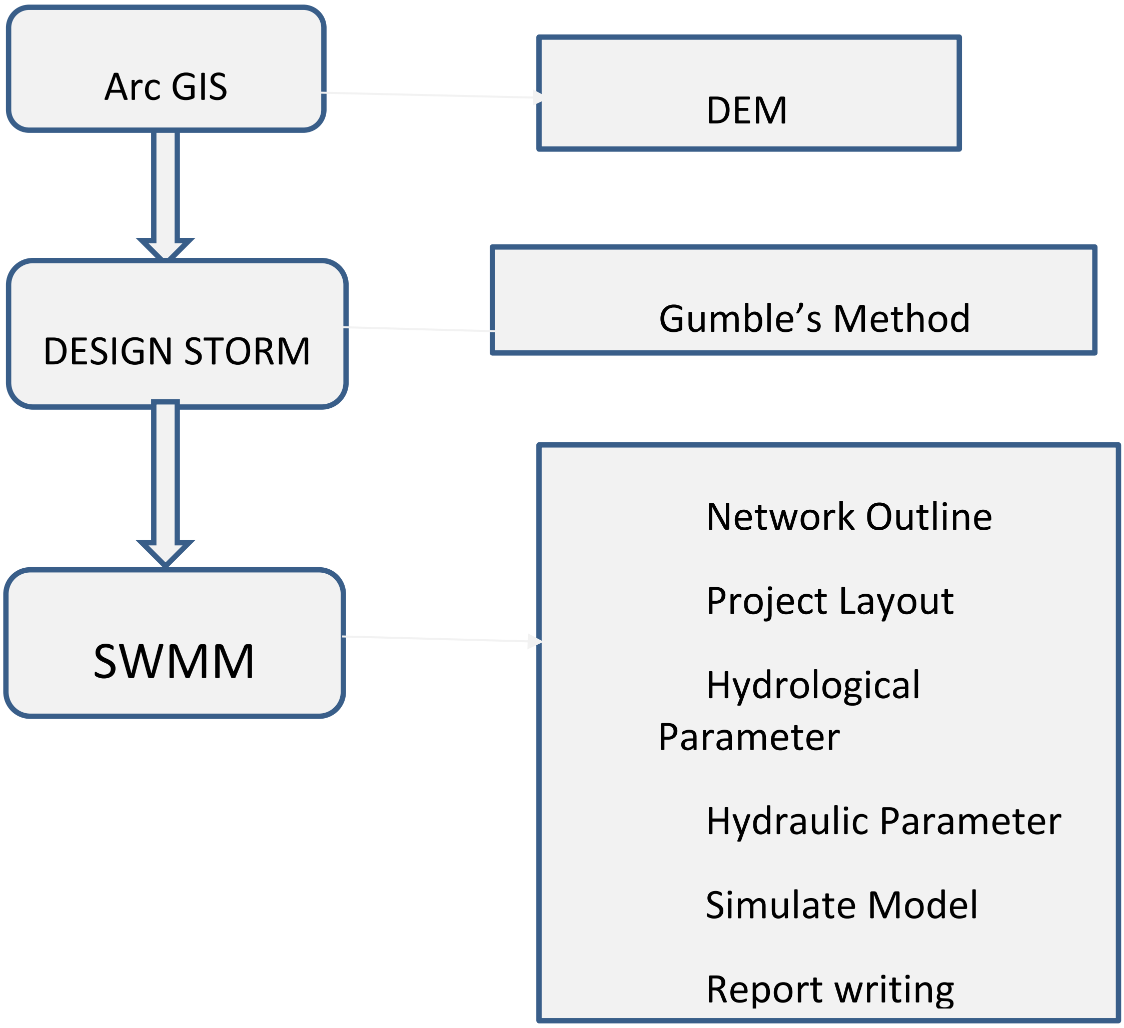
LID Controls are low-impact development practices that catch runoff and treat it with a combination of detention, infiltration, and evapotranspiration. They are viewed similarly to aquifers and snow packs in that they are considered products of a specific subcatchment. SWMM can model eight different types of LID controls explicitly:

- Bio-retention Cells
- Rain Gardens
- Green Roofs
- Infiltration Trenches
- Continuous Permeable Pavement
- Rain Barrels (or Cisterns)
- Rooftop Disconnection
- Vegetative Swales

Optional drain systems may be installed in the gravel storage beds of bio-retention cells, infiltration trenches, and permeable pavement systems to transport excess collected runoff away from the site and avoid flooding. They may also have an impermeable floor or liner to avoid penetration into the surrounding soil. Clogging can cause a decrease in hydraulic conductivity in infiltration trenches and permeable pavement systems over time (Rossman, n.d.).

Chapter 3: Methodology

The following flowchart was followed to obtain data from SWMM software. This flowchart basically indicates different performing methods and results obtained from them.



SWMM requires a set of data of parameters related to catchment characteristics. Model accuracy depends mostly on the reliability of the parameters. Data collection process might be difficult, expensive, labor intensive. Again from ArcGIS , we can obtain different data for the catchment area.

Again some data will be collected from field with practical experience. Again the data which are extremely difficult to obtain or impossible to get from these sources, they will be obtained from the tables of SWMM manual which was provided by EPA itself.

3.1 Data Collection

Required Data	Data type	Source	Remarks
Precipitation Data	Secondary	BMD	10yr 3hr rainfall 2010-2019
Study Area (DEM)	Primary	Arc GIS, Google Earth	
Impervious percentage			
Slope			
Sewer Network Data	Secondary	WASA	2013
LID Control Data	Secondary	swmm5.org	

Figure 7: Data collection

Precipitation Data:

The data was collected from Bangladesh Meteorological Department for the years 2010-2019. It’s a secondary type data as information has been collected by government department. 10years 3hour daily rainfall data set was provided by BMD.

Digital Elevation Model:

Nodes, Junctions, sub catchments were drawn in analog map with the ArcGIS software and then was imported to SWMM. The analog map was collected from Google Earth, a screen shot was taken of the study area. Nodes and junctions were drawn as per the map. This will be primary data sets.

Impervious Percent and Slope:

Slope data was collected using the slope tool on actual DEM. Average slope for each catchment was added as an attribute to sub catchment shape file.

By using imperviousness raster, average imperviousness was calculated for individual sub catchment. We got all these data directly from ArcGIS software, so all these data are primary data.

Sewer Network Data:

Sewer data was collected from WASA. The data was for the year 2013. This basically provides us data for the whole sewage network of the area, the conduit length, manhole positions, slope data and outfall of that region. As the data has been collected, so it will fall under secondary type data.

LID Control Data:

LID data was collected directly from the tables of swmm manual. So these will be secondary data.

3.2 ArcGIS

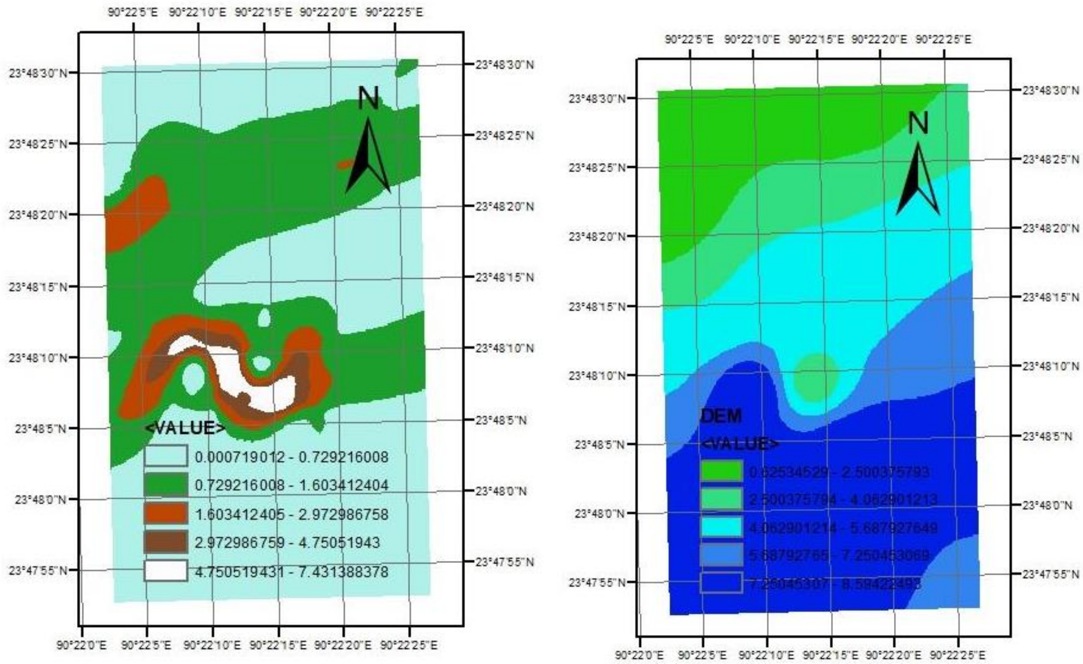


Figure 8: Digital Elevation Model from ArcGIS software

ArcGIS software basically uses different unique locations of the actual ground system. It is a computer system that displays geographically referenced information. The information we have about earth is always attached with a location: like Where was rock layer found? Where are the coal mines? etc.

Georeferencing is the process to relate the internal coordinate system of a digital map to a ground system of geographical coordinates. Georeferenced map is directly related to Earth Coordinate system, so any location in actual ground can be easily determined by such type of maps. The transforms within the map is usually stored as an image file. After georeferencing, the digital file can be used for further analysis, determining the coordinates of a point or any distance measurement.

A Digital Elevation Model (DEM) is a raster representation of a continuous surface, referencing the surface of the earth. From DEM we achieved different values that was further used in SWMM software:

- Slope, Elevation data from digital map.
- Location confirmation of different points.
- Conduit length measurement.
- Catchment area measurement.

These data sets were gathered from ArcGIS software to further analyze the SWMM software.

Nodes	Latitude	Longitude
J1	23.808778	90.370845
J2	23.807931	90.370986
J3	23.806802	90.371445
J4	23.805990	90.371656
J5	23.804720	90.372221
J6	23.803202	90.372962
J7	23.801896	90.373527
J8	23.799416	90.374445

Table 1: nodes, latitude, longitude

These coordinates were taken as input in an excel file for the ArcGIS software. These coordinates were georeferenced in the software and a digital elevation map was generated. The following conversions were used:

Projection : Traverse_Mercator

False_Easting : 500000.0

False_Northing: -2000000.0

Central_meridian: 90.0

Scale_Factor : 0.9996

Latitude_Of_Origin : 0.0

Linear Unit : Meter (1.0)

So all the coordinates were thus georeferenced and the digital elevation model was developed which is shown in the fig 1.1.

3.3 Storm Design

From Bangladesh Meteorological Department, 10 years (2010-2019) daily rainfall data was collected and an IDF curve was developed. Gumbel's Distribution was used for developing the curve for 5,10,25,50,100 years return period. IDF curve was then plotted in time series in SWMM to determine the intensity of the rainfall.

Frequency Analysis provides a systematic approach for using historical data to relate the magnitude of a naturally occurring event (e.g. rainfall, water level etc.) to the probability of its occurring in a given time period or to its recurrence interval. The objective of frequency analysis in a hydrologic context is to infer the probability that various size events will be exceeded or not exceeded from a given sample of recorded events. The frequency distribution technique is based on the distributional assumptions that is made of the mean, variance and for some distribution coefficient.

The magnitude X of a hydrologic event can be represented as the mean plus the departure of the event from the mean.

$$\boldsymbol{X = \bar{X} + K_T\, \sigma}$$

Where, X is the event of specified probability, X is the mean of the event series, σx is the standard deviation of the series and K is the frequency factor defined by the specific distribution and T is the return period.

Frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. Gumbel Distribution or Extreme Value Type I (EV 1) Distribution is one of them. In Bangladesh, Gumbel method is generally used.

Gumbel's distribution is designed to use the existing data record to tell how large an event (flood) with a return period of Tr will be.

Use the data record to find the mean X, and standard deviation, σ_x of the maximum annual floods.

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} \bar{x}$$

$$\sigma_x{}^2 = \frac{1}{n-1}\sum_{i=1}^{n} (x_i - \bar{X})^2$$

Select the return period, Tr you wish and then solve the Gumbel expression for K.

$$K = -0.78(\,0.577 + ln\, ln\,(ln\, ln\, \frac{\square\square}{\square\square\ -1}))$$

Frequency factor equation:

$$\boldsymbol{X = \bar{X} + K_T\, \sigma}$$

Here, x̄, σ and K_T are mean, standard deviation and frequency factor.

These are the equations that were involved in storm design. The IDF curve was developed accordingly.

3.4 IDF Curve

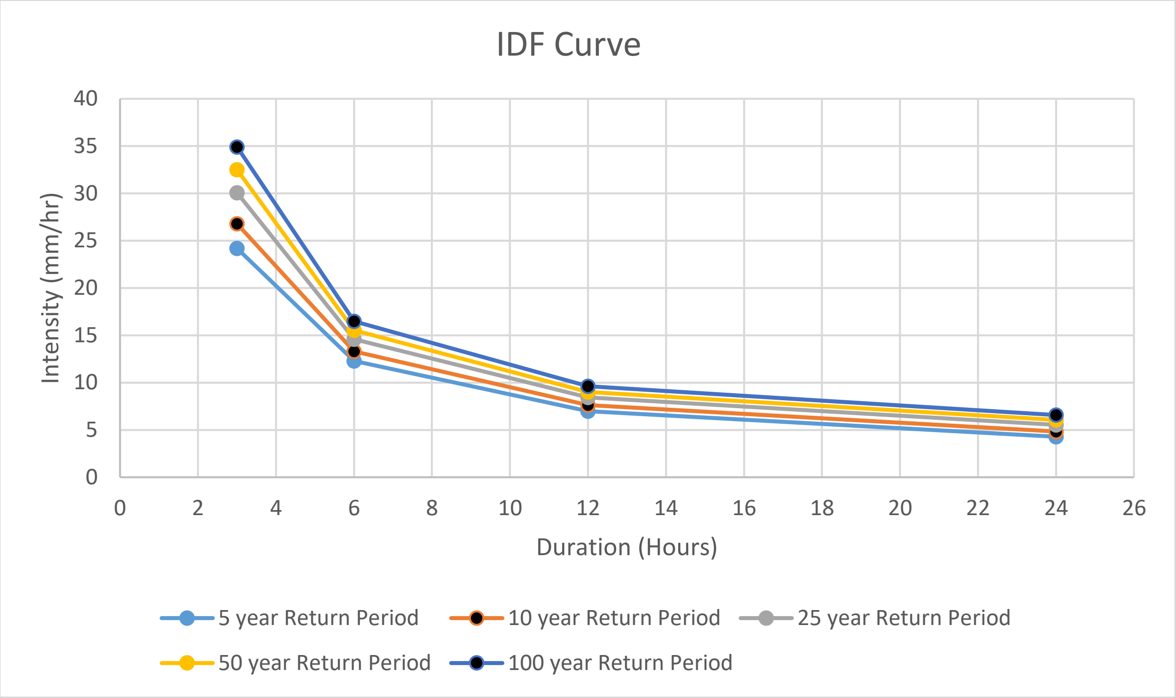


Figure 9: Intensity-Density-Frequency curve by Gumbel's Distribution for different return periods.

From the IDF curve we get the following data,

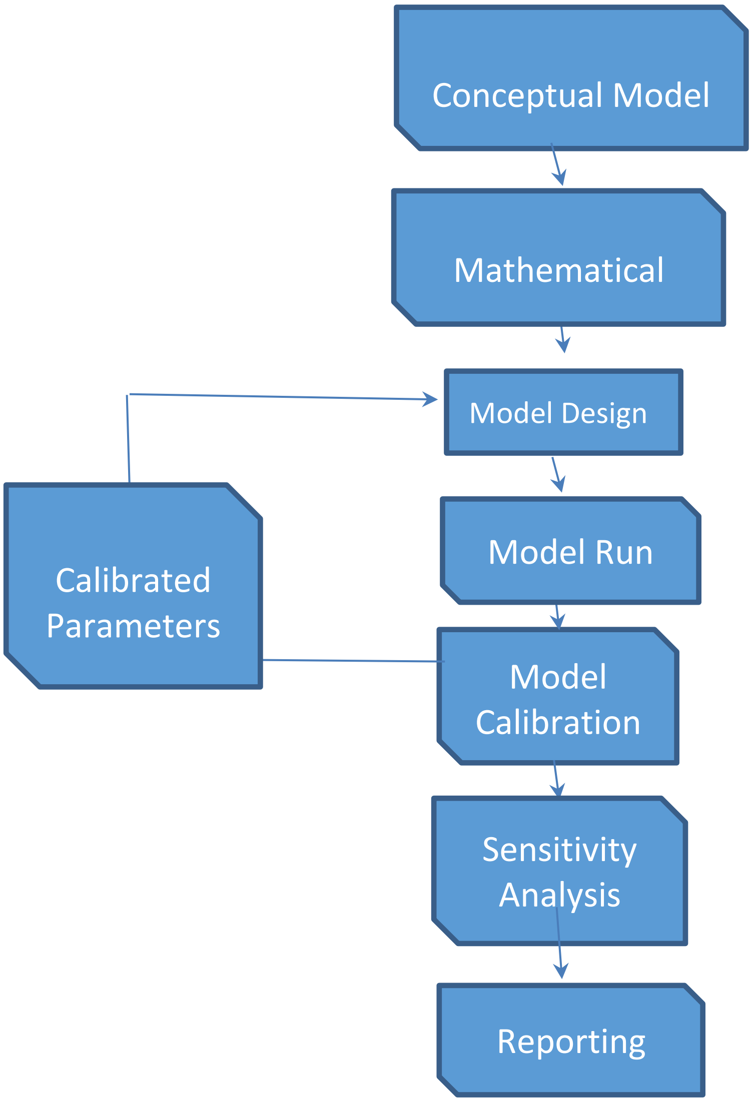
5 Year 3 hours rainfall intensity= 24.1937 mm/hr.

10 Year 3 hour rainfall intensity= 26.7905 mm/hr.

25 Year 3 hour rainfall intensity= 30.0715 mm/hr.

50 Year 3hour rainfall intensity= 32.5056 mm/hr.

100 Year 3hour rainfall intensity= 34.9217 mm/hr.


Conceptual Model
Mathematical
Model Design
Calibrated Parameters
Model Run
Model Calibration
Sensitivity Analysis
Reporting

4.1 Conceptual Model

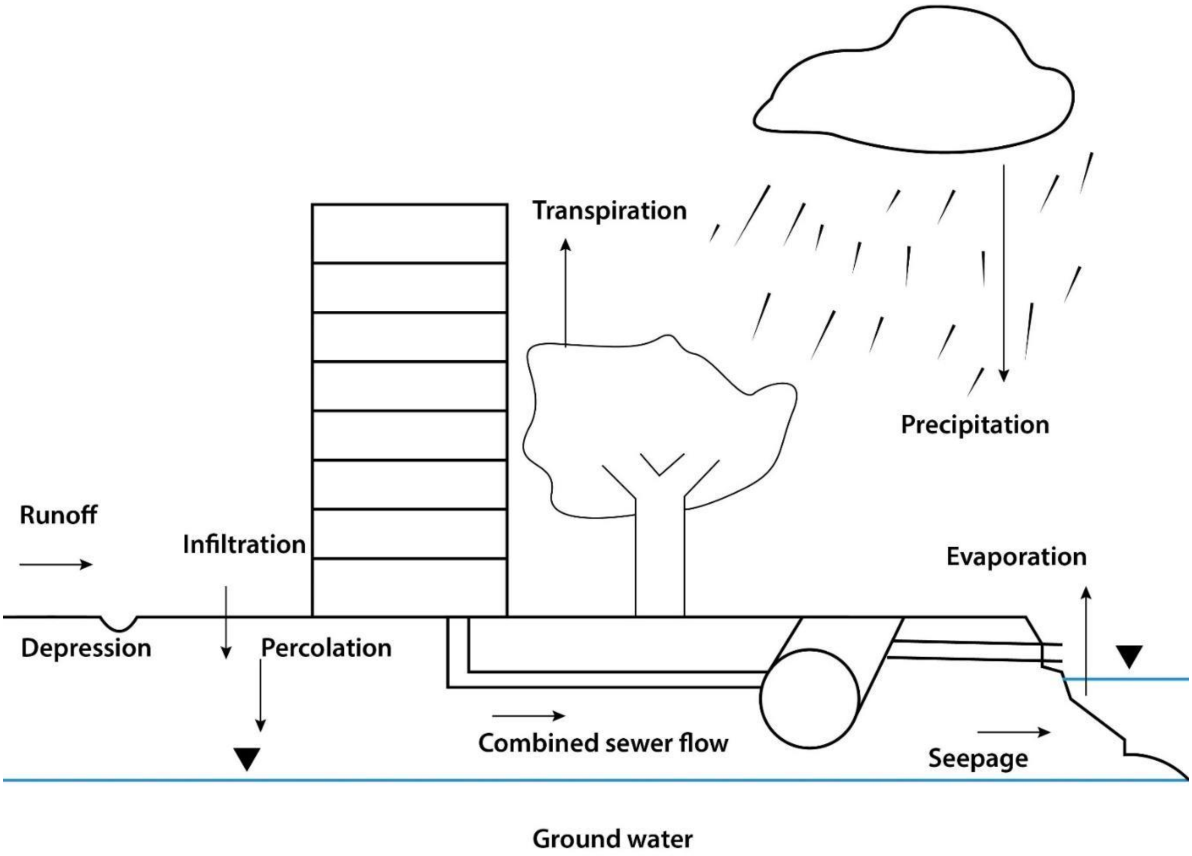


Figure 10: conceptual model

There are basically several major processes in this conceptual model:

Evaporation, condensation, precipitation, interception, infiltration, percolation, transpiration, runoff and storage.

All it starts from the evaporation process from outlet zone. Evaporation is the major project of this conceptual model. By evaporation, the water in liquid state is transferred to gaseous state and then turns into water vapour. Once these water vapours attain enough kinetic energy, they go upwards. Factors affecting evaporation process are temperature, humidity, wind speed and solar radiation. Transpiration is also another evaporation process which basically includes the evaporation through small pores of the leaves of plants. In practical field, this evaporation and transpiration are combined together and called evapotranspiration.

While at a certain temperature, the air contains more vapour than it receives from free water surface, that is called condensation.by condensation, water vapour is released into atmosphere as form of precipitation.

Precipitation that reaches Earth surface is distributed in many manners: a portion will be again evaporated and returned to atmosphere, a portion will be intercepted by vegetation, some will be percolated into the soil by infiltration and the rest flows as surface runoff into the outlet. A certain amount of precipitation will be infiltrated first and percolated into the streams as groundwater flow. Again most precipitation will go back to the environment as surface runoff. Sometimes this surface runoff will be stored in depression storage if there is any depression in the zone.

Groundwater is mostly derived from precipitation that has been percolated through soil. The flow of ground water is relatively very slow considering the surface runoff flow. Groundwater flows through soil layers and then finally discharges into a stream. This movement of ground water is basically called seepage. So the infiltration water can reach the stream either by surface runoff or through seepage. The amount of groundwater flow may vary from few millimeters to a few meters a day. It means the movement is very slow.

From the structures, the used water or sewage water will be discharged into combined sewer system and the whole system is discharged through an outlet into the streams. This combined sewer system can be harmful for the hydrological cycle if there is any leakage in it, the discharge can pollute the ground water system. If the ground water gets polluted somehow, it will be very difficult to rectify that. So extra precaution has to be taken for sewer systems.

4.2 Mathematical Model

The second step of SWMM modelling is to build a mathematical model. This model is basically the mathematical version of previous conceptual model. Mathematical model gives explanation and direction for problem solution. Comparing with reality such model is developed and calibrated accordingly.

In our case we have used a very basic equation for the actual scenario. Runoff has been calculated for the study area. Runoff is basically the portion of precipitation that reaches the stream. We have considered the following equation for SWMM modelling:

$$R = P - (D + I_N)$$

Here,

R= Surface Runoff

P= Precipitation

D= Depression

I_N= Infiltration

So this fundamental equation was developed for the modelling purpose.

4.3 Model Design

After understanding the conceptual model and the mathematical model the next step is designing our model. Our model design has been designed using the EPA SWMM 5.1 software. While designing the model it was given the utmost priority that the design reflects the real life scenarios. Necessary data for designing the model were collected from GIS, WASA, BMD (Bangladesh Meteorological Department) etc.

4.3.1 Setting up project defaults

Before we start drawing our model and input different values for different parameters we need to set up our project defaults. These project defaults ultimately control how our model will behave and which flow units we will be getting our results in.

Firstly, we have labeled different elements of the model so while constructing the model we know exactly which is which. This makes our model more orderly and helps us navigate through the model construction process easily.

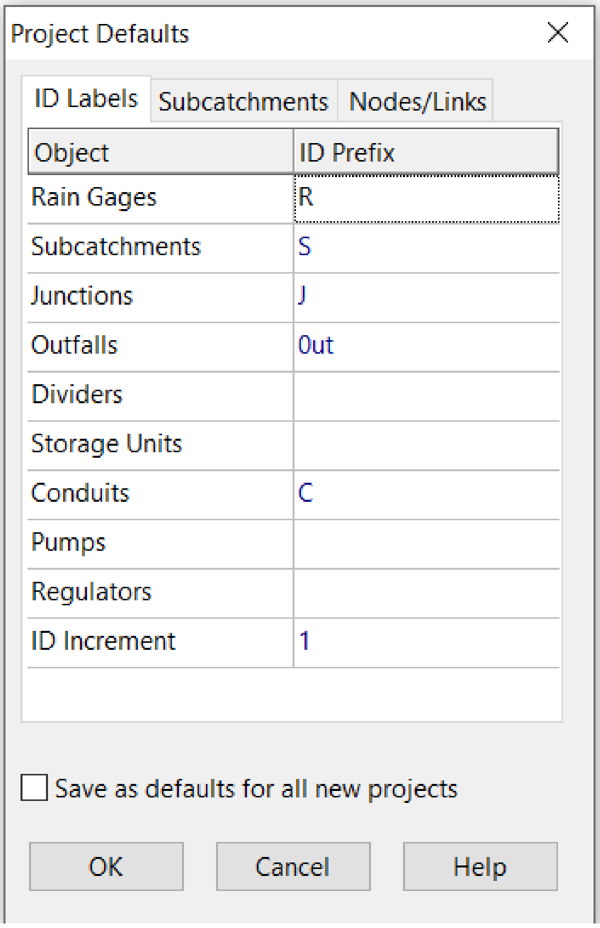


Figure 11 Prject Defaults: ID labelling

Here we see that rain gage is labelled as R and sub catchments, junctions, outfalls and conduits are represented by S, J, Out and C consecutively. Here we also see that the id increment is 1 which means that all the elements labelling will increase by 1 that means if the first conduit is represented by C1 then the second conduit will be represented by C2 which is an increment by 1 and onward like this.

After the project labelling is done then we have to input the parameters of sub catchments. These will essentially determine how a sub catchment will behave in our model.

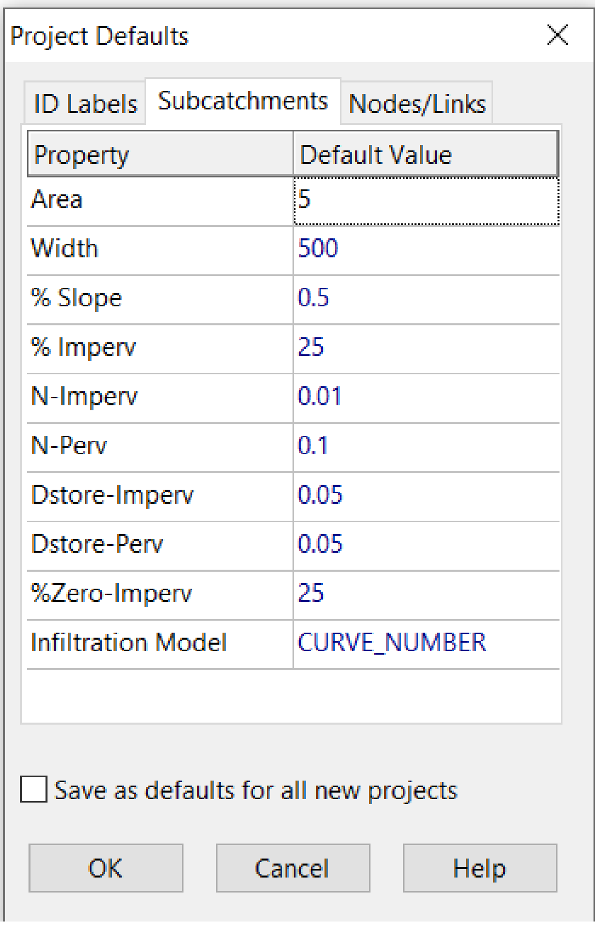


Figure 12 Project defaults: Sub catchment defaults setting

Here we see that the main parameters for a sub catchment is

Area – The total area of a sub catchment in hectare. This variable's data was taken from GIS.

Width – It is the maximum length water has to travel to reach the outlet. From map we calculated the width for different sub catchments.

%Slope – It is the slope of the area, every land has their own natural slope and this slope helps in the runoff of water.

N – This is manning's N and for different parts of the sub catchments N is also different. N in impervious and impervious area differs a lot. The value of this part was taken by looking at the satellite picture and determining the land profile from pictures then comparing them with the defaults value set in the SWMM software.

Infiltration Model – In SWMM different infiltration model can be put in like Horton's model or Curve Number etc. For our model we have chosen curve model to be the infiltration process. This decision was taken by taking the simplicity into account. For Horton's infiltration model there are a lot of parameter that need to be put in for the model the work, to get the result of these parameters many tests needed to be done but in the case of curve number model the curve number decides how the infiltration will occur. And in SWMM itself there is a list about the relation between soil profile and curve number. So if we know the soil or land profile then we can easily find its curve number. As we did not do any laboratory test and are heavily relying on satellite pictures, curve number model is the one that we went for.

Lastly we have to specify every nodes or links specifications. Nodes and links can be of different types.

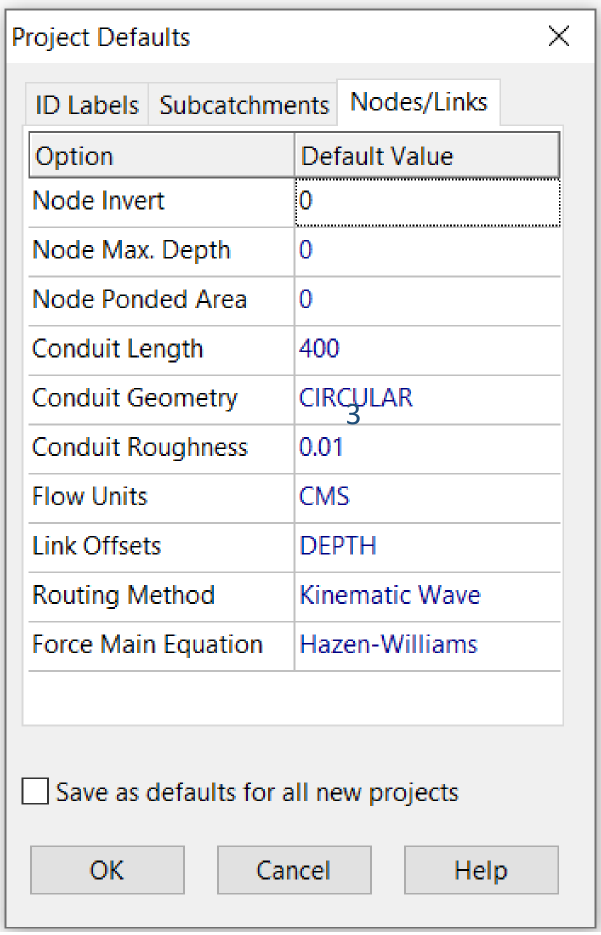


Figure 13 Project defaults: Node defaults setting.

Here the main things to look for is that the ponded area is set as 0 so there won't be any water stored surrounding the node but there will be water inside the node according to specifications.

Conduit geometry is selected circular as we have seen on the site. We got our hydraulic data from WASA (2013).

Conduit Roughness was selected as 0.013 because the conduits are made of concrete and we know that conduits Manning's N is about 0.013.

Then the Flow unit is selected to be CMS meaning we will get our flow unit in cubic meter per second.

Routing method we have selected to be kinematic wave model because we are working here with open channel flow and this can be well represented by the kinematic wave.

4.3.2 Rain gage placement

After we have finished setting up the project defaults then we can place our rain gage on our model. Rain gage can be placed anywhere on the model and this single rain gage will simulate rainfall for the whole area.

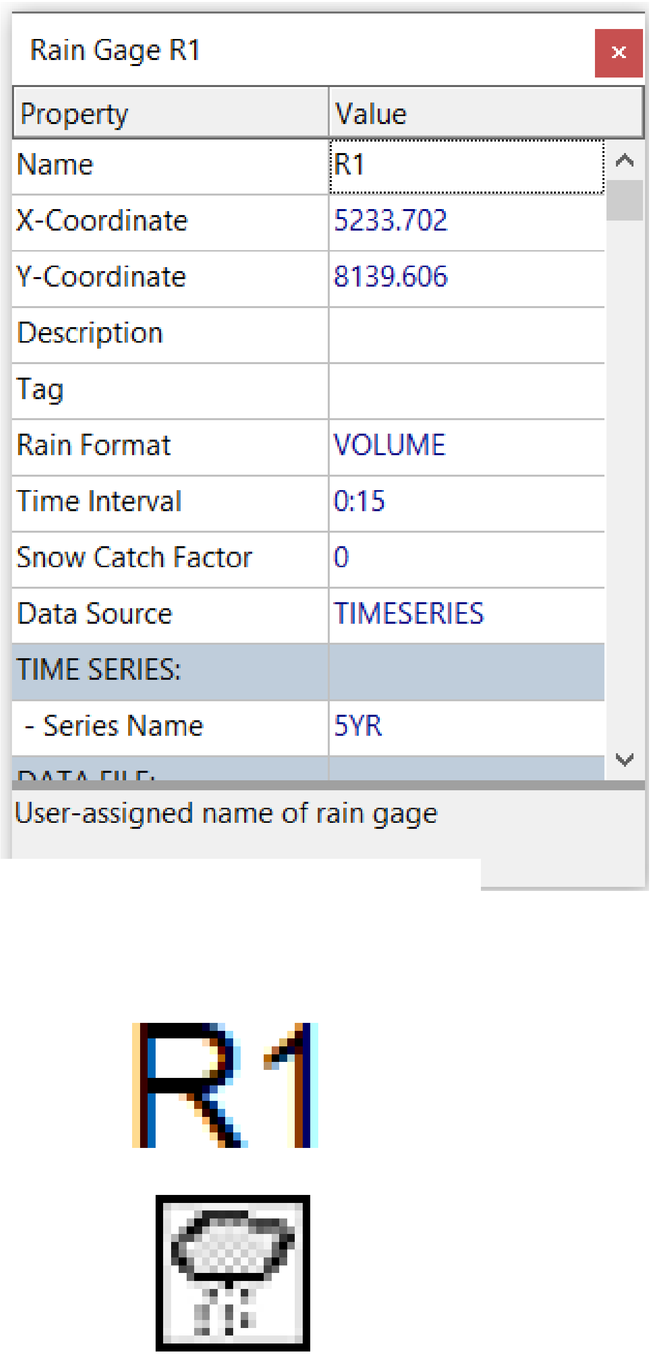


Figure 14 Rain gage parameters and placement

Here in the rain gage parameters the important things are the rain format, time interval, data source, series name.

Rain format – Rain format is selected as volume here. It can also be selected as intensity. In case of volume the input of the rainfall is given in the total amount of rainfall occurred in a specific amount of time. This rainfall amount is in mm as we already selected CMS as our flow unit. One of the most important thing is that we will be working with 3hr rainfall.

Time interval – Here time interval is 15 minutes as we have chosen. The less the time interval the more accurate a model will be. We will also get to know the results in a 15 min interval. This 15 min time interval means we have to input rainfall for every 15 min in the form of volume and the unit of the rainfall will be in mm.

Data source – Data source here we have chosen time series. This is the rainfall amount for a particular event. We will be manually inputting the rainfall data with respect to time that is why it is given in time series.

Series name – Here we see the series is 5YR this means the rainfall is that we are working for this particular event has a return period of 5YR. From our storm design we have gotten the 3hr 5-year rainfall to be 24.1937 mm/hr. so the total rainfall is 72.5811 mm in 3hr. From this rainfall amount we actually made a hyetograph of 3hr rainfall. For making the hyetograph triangular method was used where initially the rainfall is low then as time passes intensity increases and after a certain time it decreases gradually.

Time Minutes	Rainfall 5yr	Rainfall 10yr	Rainfall 25yr
15	2	3	4
30	3	3.5	6
45	3.5	4	8
60	6	6	9
75	10	10	14.2145
90	12	13	15
105	13.5811	15.3715	10
120	8	8	8
135	6	7	6
150	3.5	5.5	4
165	3	3	3
180	2	2	3

Table 2 Different return period's rainfall time series

Here is the hyetograph for 5yr return period and 3hr rainfall. If we add all the rainfall amount, then we get 72.5811 mm of total rain fall for the whole of the duration.

4.3.3 Junction and Outfall placement

Now that we have placed our rain gage now it’s time to place our junctions and outfalls. What we see in this case is that the pipeline is a very long one and we are working with only a portion of that pipeline so in theory there are no outfall existing in our area. So what we’ve done is taken the last junction as our outfall because at the end all the water actually is going to leave the area flowing through that junction.

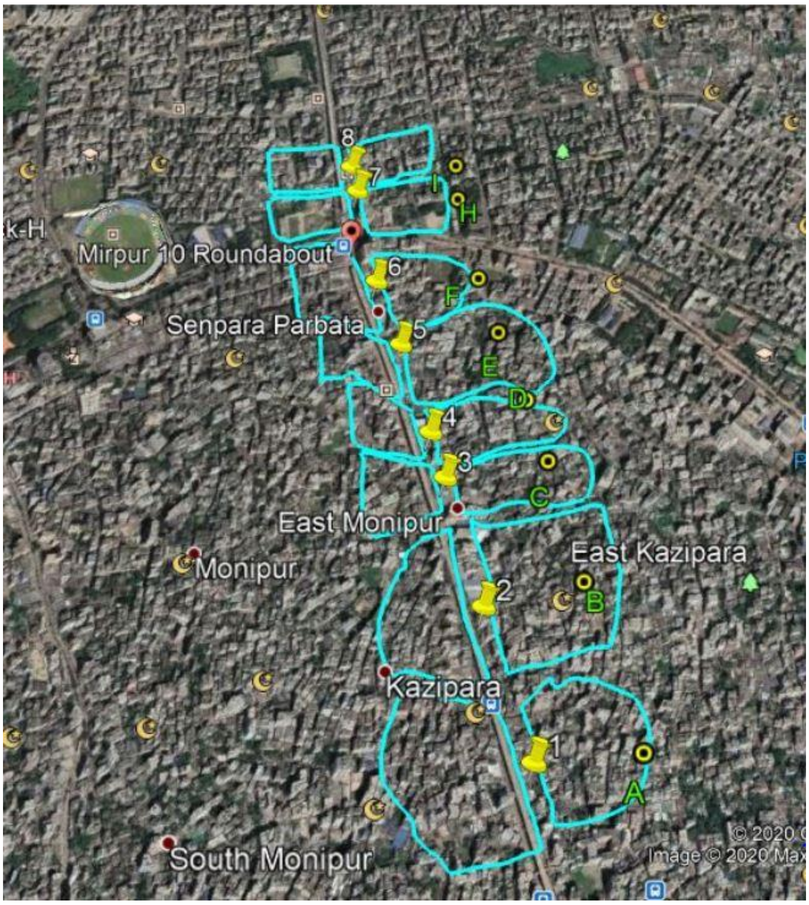


Figure 15 Backdrop for SWMM

From WASA we got the co-ordinates of the junctions and these co-ordinates were in BTM (Bangladesh Transverse Mercator), Then with the help of GIS we converted the co-ordinates to UTM (Universal Transverse Mercator). After getting the co-ordinates we put those down and pinpointed the exact location of the junctions on the map. The yellow pushpins in the pictures represent every junction in the real world.

After that we took a picture of the map with the position of the junctions and used that picture as the backdrop in SWMM for drawing our model. From that picture we placed the junctions in SWMM on top of our backdrop. This way we ensured that our model looked as accurate as possible.

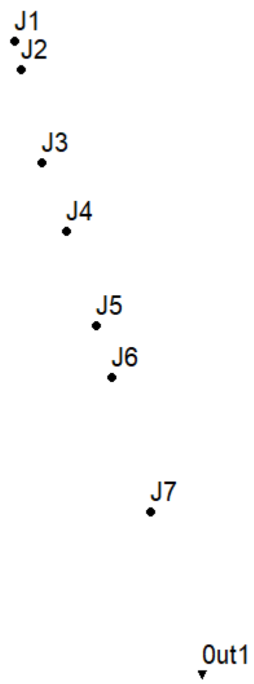
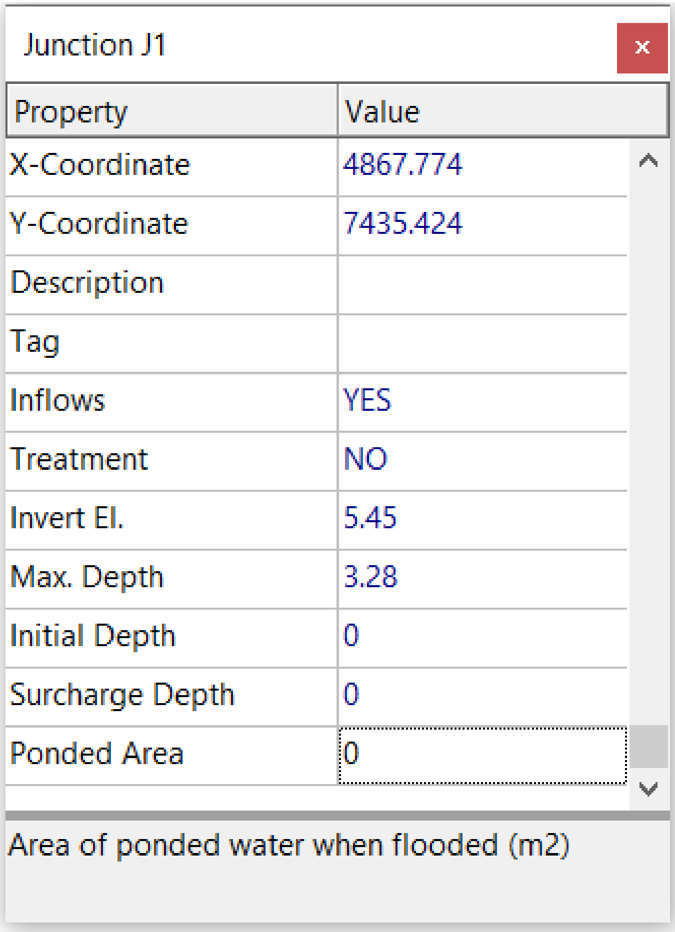


Figure 16 Junction placement

After positioning the junction, we had to put different parameters for all of the junctions.



Junction J1

Property	Value
X-Coordinate	4867.774
Y-Coordinate	7435.424
Description	
Tag	
Inflows	YES
Treatment	NO
Invert El.	5.45
Max. Depth	3.28
Initial Depth	0
Surcharge Depth	0
Ponded Area	0

Area of ponded water when flooded (m2)

Figure 17 Junction parameters

For junction the main parameter we had to look for was Inflows, Invert Elevation, Max Depth.

Inflows – Here we see that the inflow box is given yes because the pipeline we are working with is a combined sewer system and it not only accommodates storm water but also sewer water from adjacent areas. So even if there is no rainfall even then there will be flow inside of the pipe system. Here is how we calculated the different inflow of different junctions.

To know the sewage inflow first, we had to calculate the population and then multiply that population by the average waste water generation amount. This is the fundamental way we got our sewage inflow.

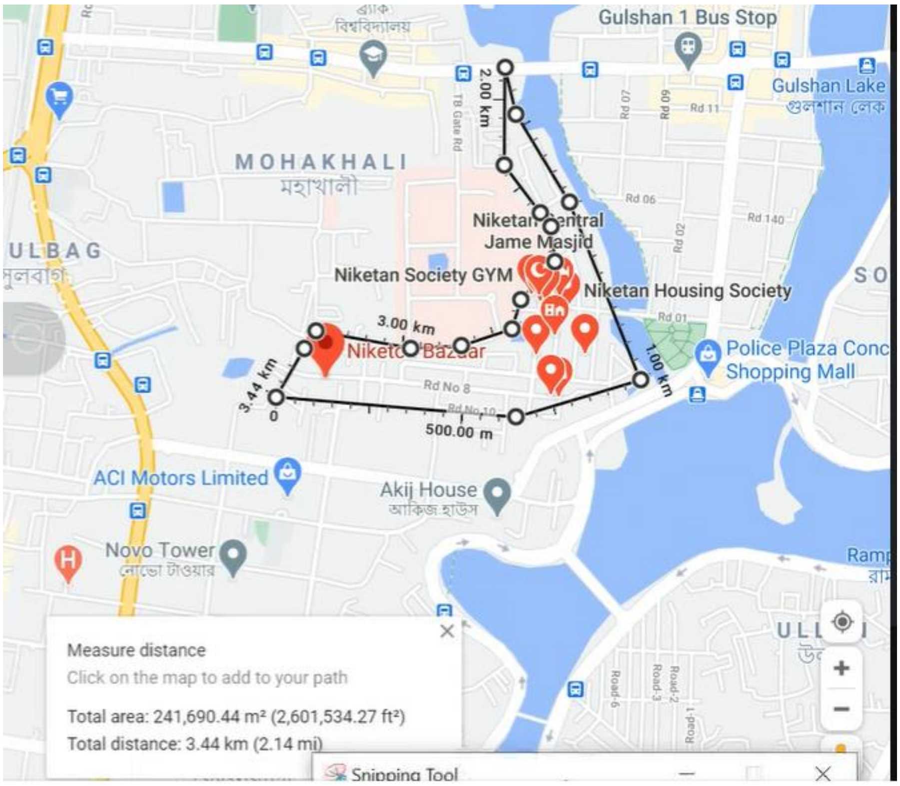


Figure 18 Niketon area calculation

To get the population we first had to know the area and the density. We searched for a similar area Niketon and found that there are about 150 thousand people living in there (The Daily Star). From there we calculated the area of Niketon from google

Area hectare	Density per hectare	population	Per Capita Water per day	water use lpd	Peak factor	water use m3/s	Waste water production	Junction inflow	Junction
7.7699	6206	48219.9994	150	6750799.916	2.5	0.078134258	70%	0.123712	7
4.5324	6206	28128.0744	150	3937930.416	2.5	0.045577898	70%	a	
3.4195	6206	21221.417	150	2970998.38	2.5	0.034386555	70%	0.058275	6
2.3755	6206	14742.353	150	2063929.42	2.5	0.023888072	70%	a	
3.0917	6206	19187.0902	150	2686192.628	2.5	0.031090192	70%	0.050746	5
1.9546	6206	12130.2476	150	1698234.664	2.5	0.019655494	70%	a	
5.9893	6206	37169.5958	150	5203743.412	2.5	0.060228512	70%	0.081186	4
2.0841	6206	12933.9246	150	1810749.444	2.5	0.020957748	70%	a	
3.0998	6206	19237.3588	150	2693230.232	2.5	0.031171646	70%	0.064134	3
3.2779	6206	20342.6474	150	2847970.636	2.5	0.032962623	70%	a	
2.6425	6206	16399.355	150	2295909.7	2.5	0.026573029	70%	0.045862	2
1.9182	6206	11904.3492	150	1666608.888	2.5	0.019289455	70%	a	
2.2783	6206	14139.1298	150	1979478.172	2.5	0.022910627	70%	0.043258	1
2.0234	6206	12557.2204	150	1758010.856	2.5	0.020347348	70%	a	

Table 3 Inflow calculation in junctions

earth and found that it is 241690.44m^2. This is how we got the density. For average water consumption we looked to BNBC 2015 and found that it was 150lpcd. We assumed the most chunk of the area was residential so about 70% of that water was being wasted and finally ending up on sewer system.

Here we see the area of the sub catchments which we will discuss later in this paper.

Invert Elevation – The data of the invert elevation for each of the junction we got from WASA.

Max Depth – This is the distance from the invert to the ground surface and data was collected from WASA.

Those were all the parameters of the junction now we setup the outfall

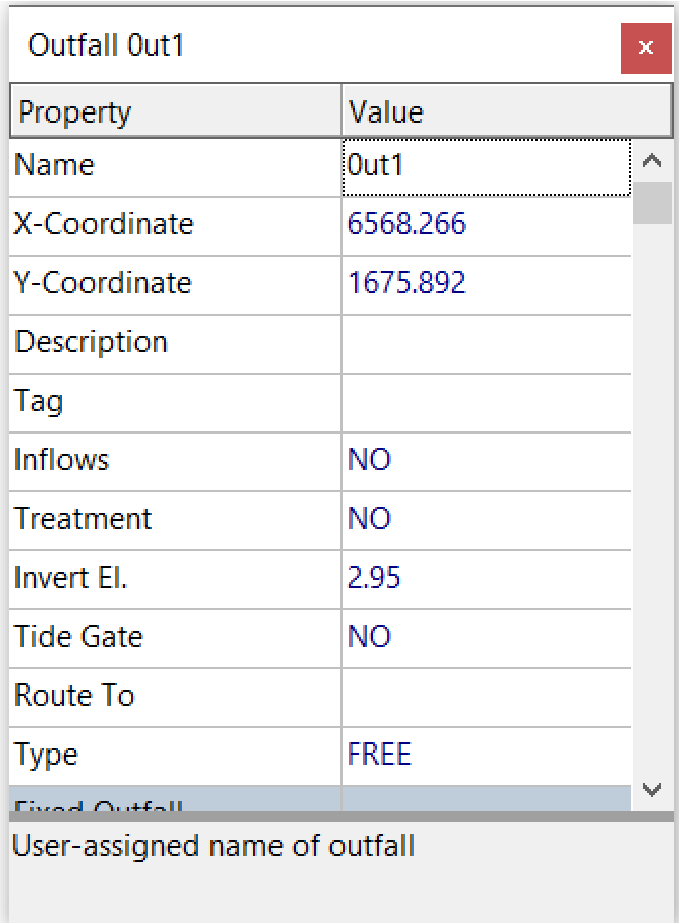


Figure 19 Outfall parameters

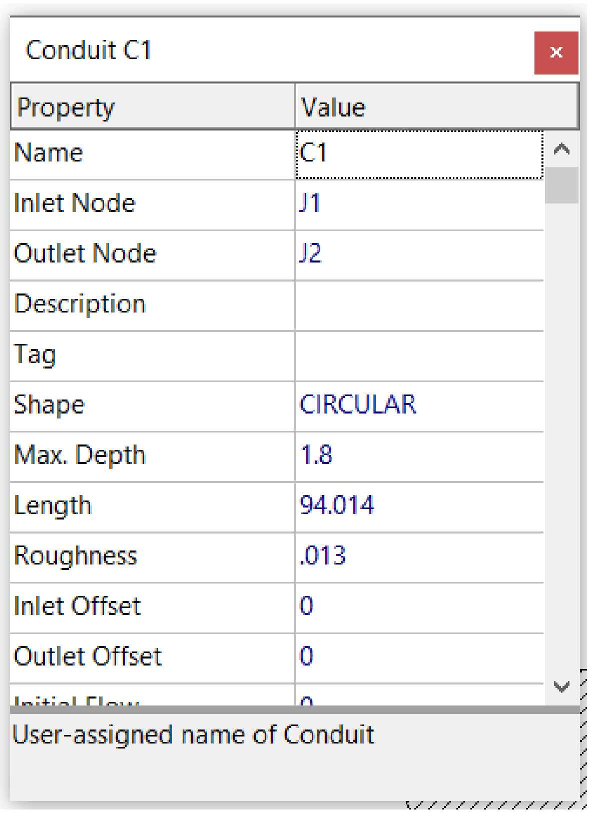
For the outfall the only parameter we input was invert elevation. From before we know that it is actually not an outfall but a junction which we've considered as an outfall for the sake of our model. So for our model we will get water from the adjacent area and those water will be accumulating from J1 to J7 and finally be disposed from the outfall.

Junction	Invert Elevation	Max. Depth
J1	5.45	3.28
J2	5.35	3.2
J3	5.29	3.15
J4	5.24	3.2
J5	4.28	3.35
J6	3.28	3.45
J7	3.14	3.5
Outfall	2.95	

Table 4 Junction parameter's values

4.3.4 Conduits placement

For the conduit placement part, we need to add junction by a conduit. So we connected J1 with J2 by a pipe J2 with J3 and so on.



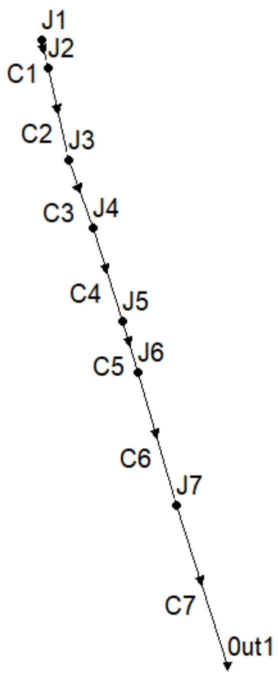


Figure 20: Conduit parameters and placement

For a conduit we have three parameters that we had to put in mainly.

Shape – The shape of our conduit is circular and we got that data from WASA

Max. depth – Max depth is the diameter of the pipeline for our case and because we are dealing with combined sewer system the diameter is more than average pipelines.

Length – We measured the length of each conduit by measuring the distance between two consecutive junctions by using GIS.

Roughness – This is manning's N and because our pipeline is made of concrete the manning's N in this case is 0.013.

Inlet and outlet offset – For our case both the offsets are 0 as seen from our data from WASA because the invert elevation of one end of a pipe and the junction that side is attached to has the same invert elevation.

Conduit	Shape	Max. Depth	Length m	Roughness
C1	Circular	1.8	94.014	0.013
C2	Circular	1.8	154.341	0.013
C3	Circular	1.8	66.916	0.013
C4	Circular	1.8	149.99	0.013
C5	Circular	1.8	193.226	0.013
C6	Circular	1.8	143.73	0.013
C7	Circular	1.8	283.959	0.013

Table 5 Conduit parameter's values

4.3.5 Sub catchment placement

After we've placed our conduits now it was time for us to place sub catchments. While placing the sub catchments we took a general approach. There were in total 7 junctions in our model. Keeping in line with that we placed two sub catchments on either side of all the junction. So in total we had fourteen sub catchments S3-S16.

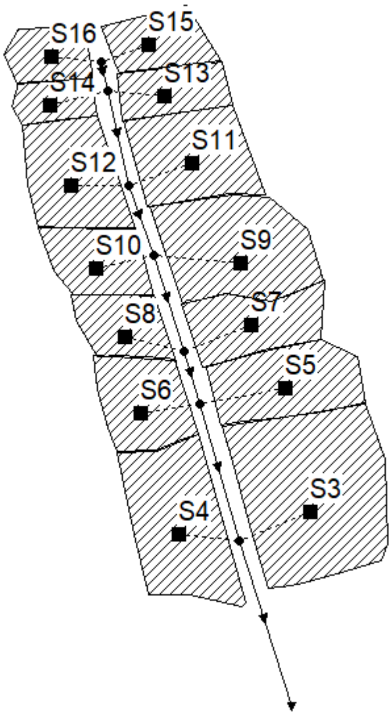


Figure 21 Sub catchment Placement

Then we put different parameters for each of the sub catchments.

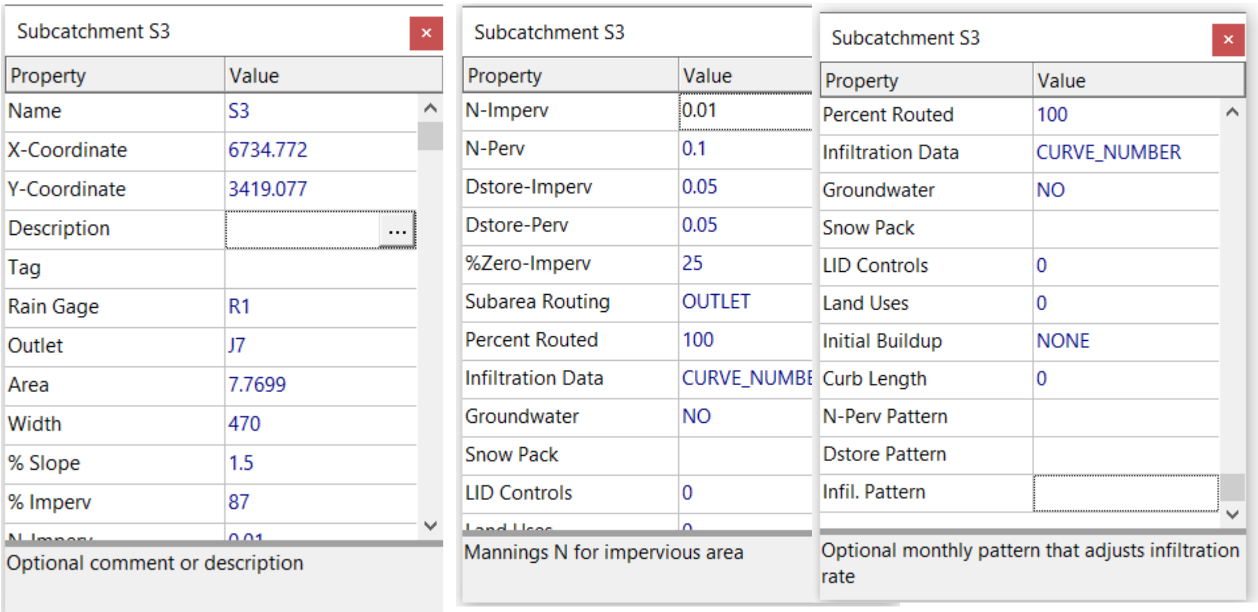


Figure 22 Sub catchment parameters

The main parameters that we had to look for are as follows:

Rain gage – So sub catchment will receive precipitation and it needs to be specified what that precipitation amount and pattern will be. In our case all the sub catchments get this precipitation data form rain gage 1 or R1.

Outlet – When precipitation occurs then surface runoff will also occur. Where these water will be disposed of is specified in this parameter. For our case we have chosen that every junction will act as the outlet for two of its surrounding catchments one on the left of the junction and other on the right of the junction.

Area – Area of a sub catchment is crucial. We assumed an area where the water will contribute to the outfall. Form that using GIS we calculated the area in hectares.

Width – Width was calculated by dividing the area with the maximum flow length for each sub catchment.

%Slope – We got the data of the slope from GIS for each of the sub catchment.

%Impervious – The percentage of impervious was obtained using GIS and analyzing satellite picture. We looked at the area and divided the area into various squares. Then decided by watching at the picture which area was impervious and which was pervious. Form there counting the square which are impervious we got the impervious percentage for that sub catchment.

N-imp, N-perv, Dstore-imperv, Dstore-perv – All these values were taken from the list of value set in the SWMM software for different soil profile.

LID Control – Initially there were no Lid control on the sub catchments which would give us the flood data on the scene. Later Lid control was added to see the effect of it.

Curve Number – In the project default we already specified that we will be using curve number for our infiltration model.

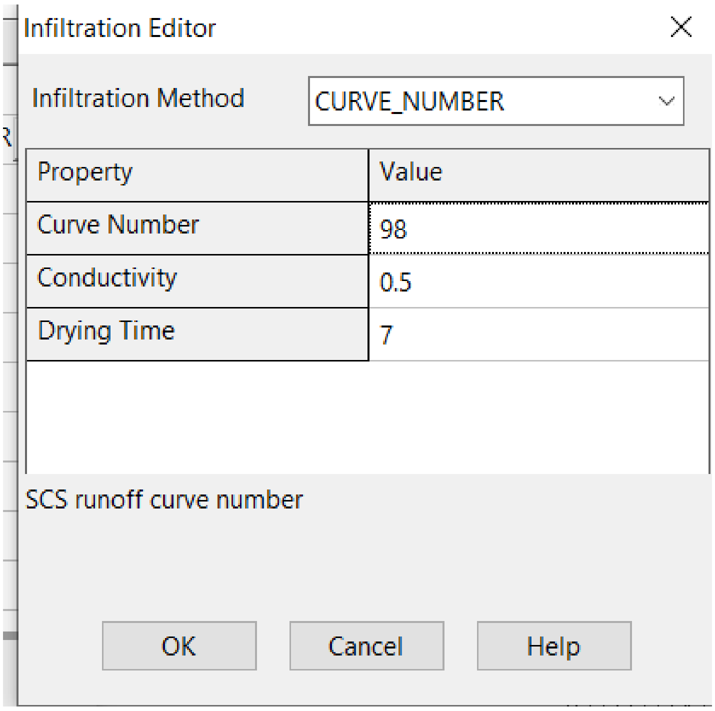


Figure 23 Sub catchment infiltration parameters

Here we mostly chose 98 curve number for our infiltration simulation because in our sub catchment it was mostly roofs and pavements which corresponds to the curve number 98. We also used 7 days as drying time as default.

Sub catchment	Area	Width	%Slope	%Imperviousness
S3	5.54	420	1.4	82
S4	3.532	475	1.4	84
S5	3.132	480	2.5	81
S6	2.01	74	1.4	78
S7	2.7854	64	1.4	80
S8	1.458	85	1.4	80
S9	4.8987	110	1.6	80
S10	1.8754	102	1.6	74
S11	2.758	100	0.5	80
S12	2.6587	98	0.6	75
S13	2.0145	75	3	82
S14	1.545	80	0.5	75
S15	1.975	70	0.4	76
S16	1.56	74	0.6	78

Table 6: Sub catchment parameter's values

Putting in all these parameters our model design is done.

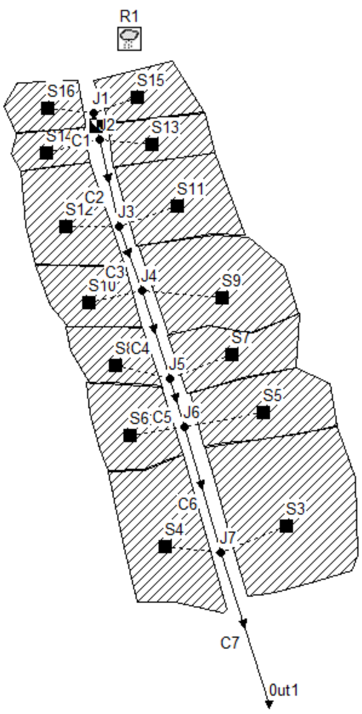


Figure 24: Final model

Chapter 5: Model Run

After the model designing is done we run the model and when we run the model then we get result of flood.

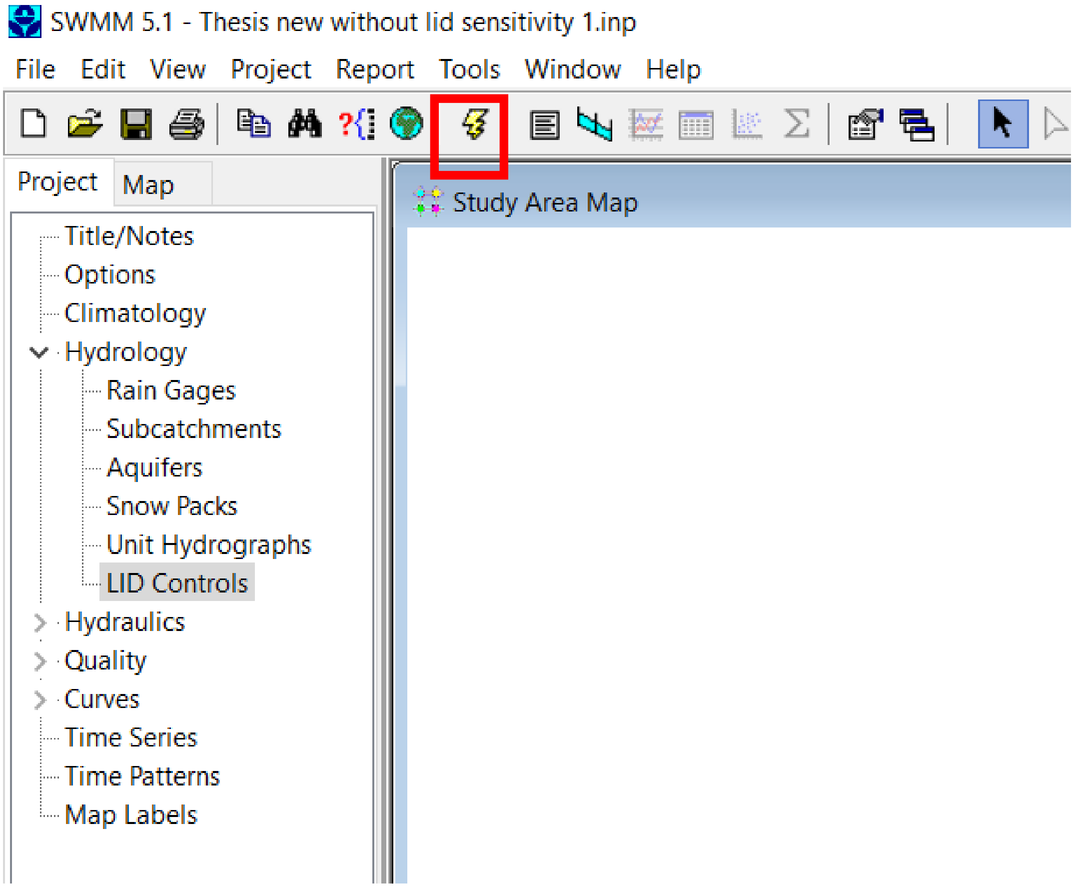


Figure 25: Model Run

But in our case when we ran the model we hardly got any flooding. But from practical experience we knew that this was not right. So at this point we needed to calibrate our model to get accurate results.

Chapter 6: Model Calibration

For the calibration of our model we chose the event of 31st may 2018 when a 3hr rainfall of 82mm was observed. Due to this rain fall what was seen is that J2, J3, J6, J7 were flooded for quite a bit of time which we got to know from The Daily Star. Taking this event into account we put in the same amount of rainfall and by the process of trial and error kept changing the parameters until we got a similar outcome from that rainfall as in real life.

For calibration we chose 4 parameters Area, Width, Slope, Imperviousness (Choi & Ball, 2002).

Following are the data after we calibrated those parameters:

	After Calibration			
Subcatchment	Area	width	Slope	Imperv
S3	7.7699	470	1.5	87
S4	4.5324	530	1.5	89
S5	3.4195	500	3	78
S6	2.3755	85	1.4	82
S7	3.0917	70	1.6	85
S8	1.9546	90	14	85
S9	5.9893	130	2	85
S10	2.0841	110	2	80
S11	3.0998	110	0.5	85
S12	3.2779	120	0.8	85
S13	2.6425	86.5	4	87
S14	1.9182	80	0.7	80
S15	2.2783	75	0.4	85
S16	2.0234	80	1	80

Table 7: Parameter's value after calibration

After calibration we found that our model was running as it we saw in real life. Flood was occurring in J2, J3, J6 and J7 and duration and intensity was also the same as seen in real life.

Chapter 7: Results:

After modelling by SWMM node flooding, system flooding and system runoff has been analyzed for with and without LID technique. Moreover, changes for using different return periods has also been considered and reviewed for detail understanding.

7.1 Node flooding

From table 8 to table 13, it is noticeable that node flooding volume and hour has been decreased significantly after using rain barrel as LID technique. It is also noticeable that in junction J7, hour of maximum flooding has been reduced by 14 minutes. For 25 yr. return period, it is about 20 minutes.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.27	0.134	0	02:00	0.081
J3	0.27	0.205	0	02:00	0.133
J6	1.23	2.528	0	02:00	5.833
J7	2.03	2.589	0	02:00	11.064

Table 8: Node Flooding for 5 yr. return period without LID

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.13	0.109	0	02:01	0.026
J3	0.14	0.168	0	02:04	0.052
J6	0.90	2.358	0	02:01	3.193
J7	1.72	2.681	0	01:46	8.874

Table 9: Node Flooding for 5 yr. return period with LID

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.42	0.303	0	02:00	0.244
J3	0.42	0.424	0	02:00	0.363
J6	1.40	2.989	0	01:59	6.893
J7	2.27	2.832	0	02:00	12.757

Table 10: Node Flooding for 10 yr. return period without LID

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.25	0.303	0	02:00	0.164
J3	0.26	0.421	0	02:00	0.242
J6	1.09	2.886	0	02:00	4.464
J7	1.78	2.833	0	02:00	10.502

Table 11: Node Flooding for 10 yr. return period with LID

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.49	0.280	0	01:45	0.307
J3	0.52	0.401	0	01:45	0.463
J6	1.68	2.960	0	01:45	8.358
J7	2.71	2.785	0	01:45	15.024

Table 12: Node Flooding for 25 yr. return period without LID

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr
J2	0.31	0.280	0	01:45	0.188
J3	0.34	0.396	0	01:45	0.300
J6	1.22	2.850	0	01:45	5.805
J7	2.26	2.886	0	01:25	11.823

Table 13: Node Flooding for 25 yr. return period with LID

7.2 System Flooding

Here in figure 1 and figure 2, we can see a reduction of flooding time and peak flooding has been reduced to 5 CMS after using rain barrel. Similar results have also been found in other return periods.

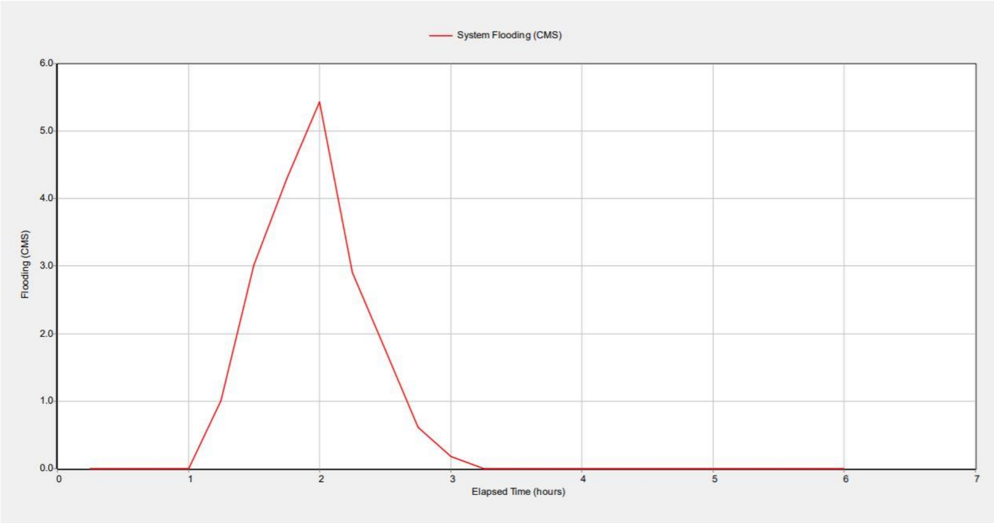


Figure 26: System flooding for 5yr return period without LID

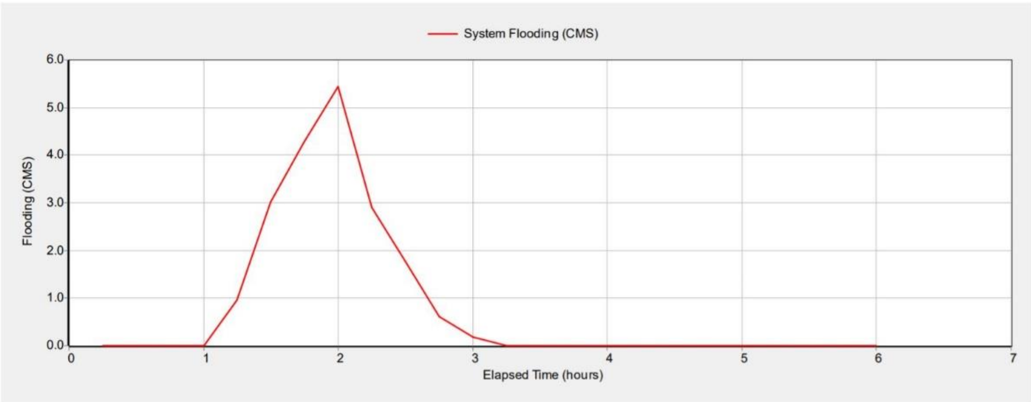


Figure 27: System flooding for 5yr return period with LID

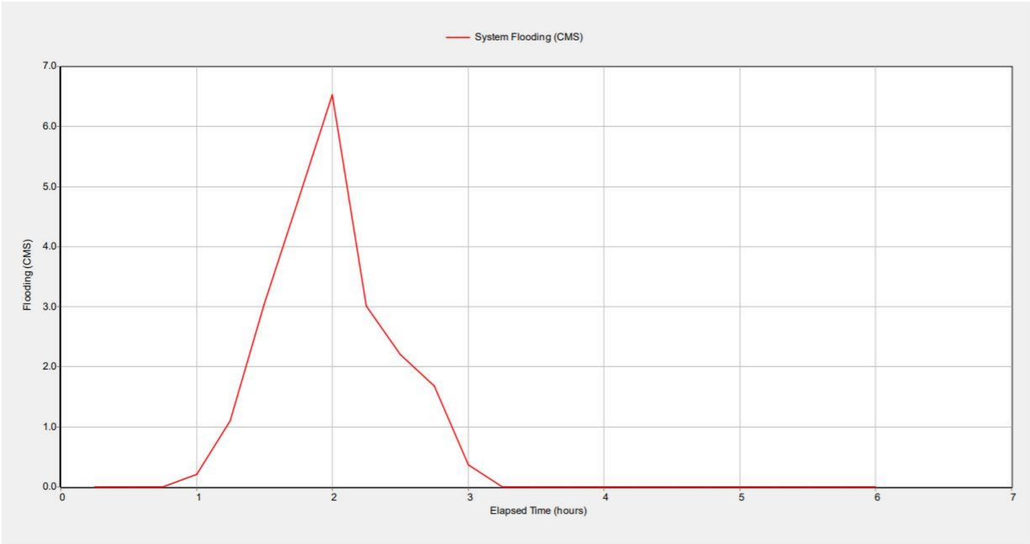


Figure 28: System flooding for 10yr return period without LID

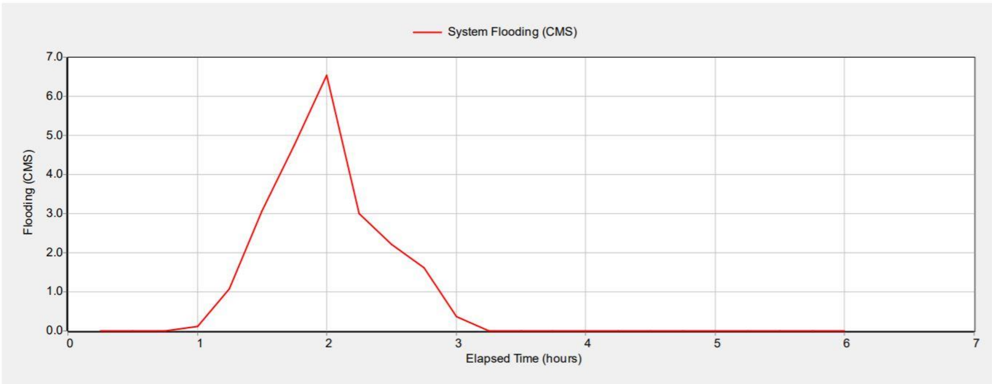


Figure 29: System flooding for 10yr return period with LID

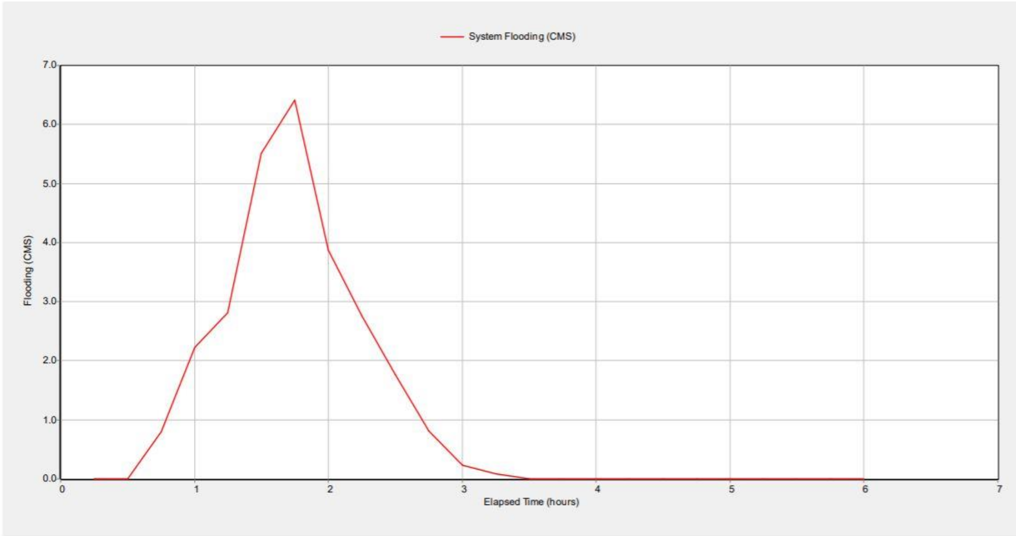


Figure 30: Node Flooding for 25 yr. return period without LID

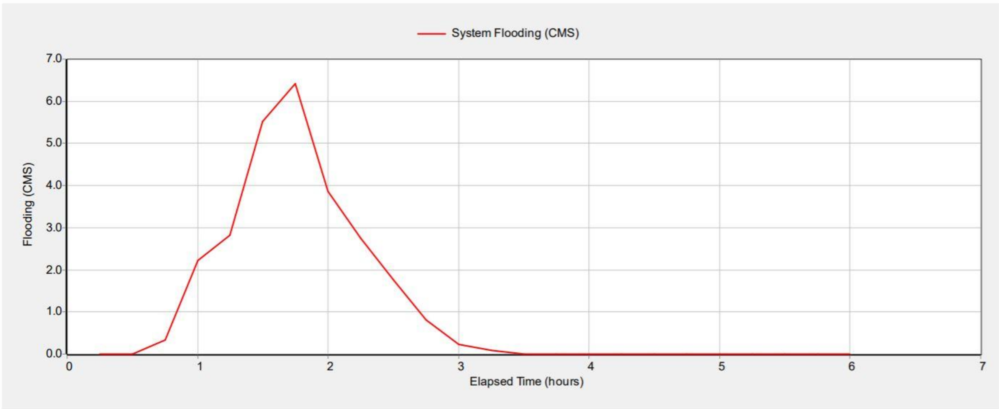


Figure 31: System flooding for 25yr return period with LID

7.3 System Runoff

It is observed that during the time of 0 to 1hr, there is a reduction of runoff after using LID (Rain Barrel). It is because the rain barrel stored some amount of rainfall and thus reduced runoff. The amount of runoff can be more reduced if rain barrel height, time delay, area covered by LID, area of each rain barrel can be increased.

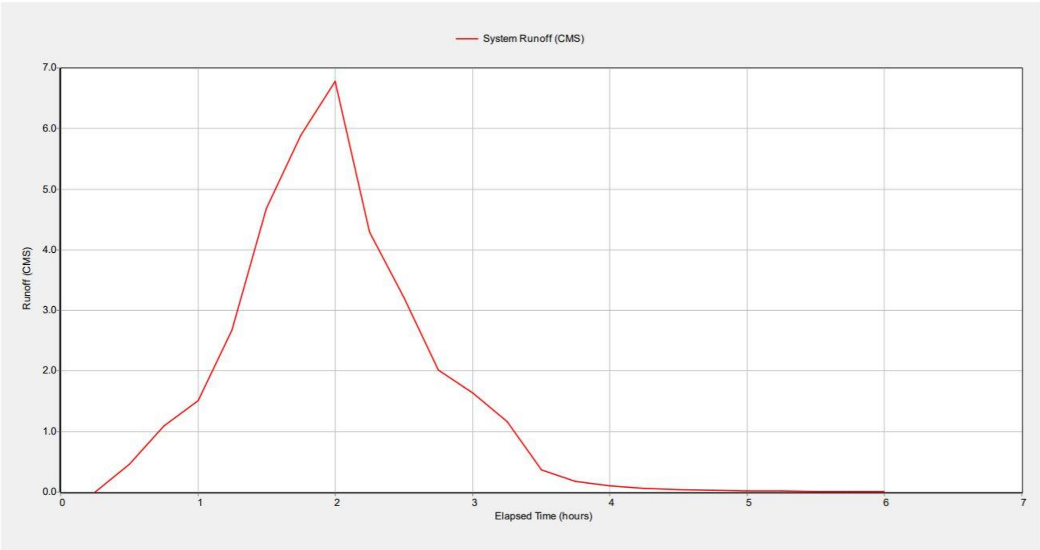


Figure 32: System Runoff for 5yr. return period without LID

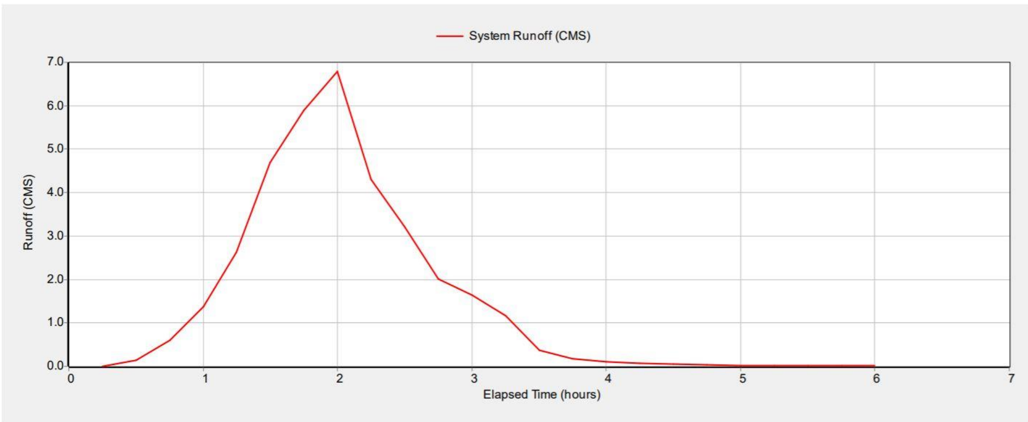


Figure 33: System Runoff for 5yr. return period with LID

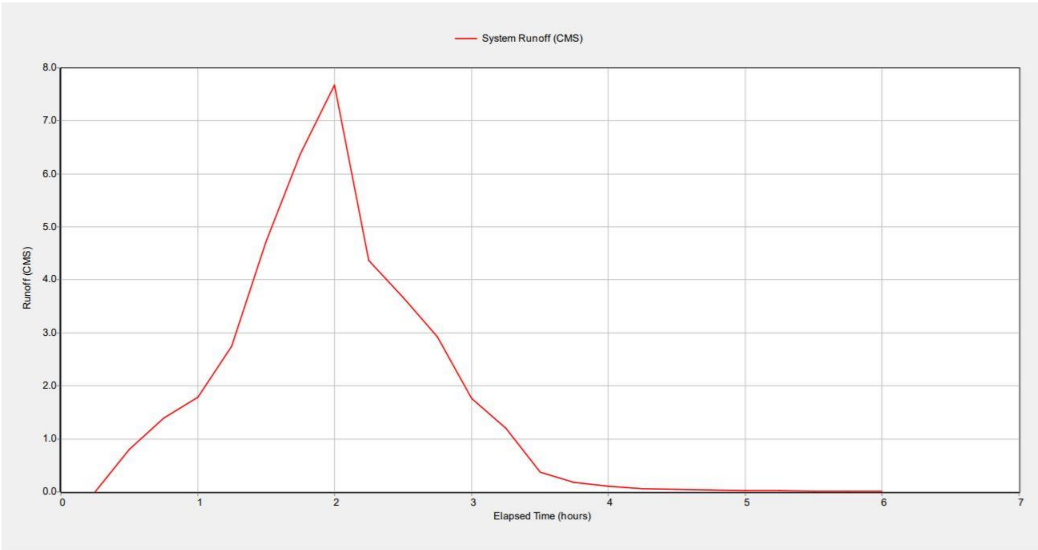


Figure 34: System Runoff for 10yr. return period without LID

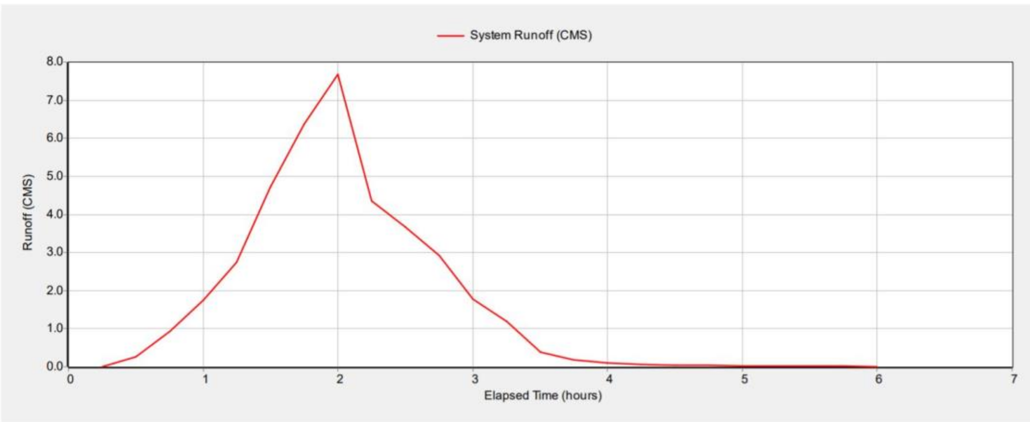


Figure 35: System Runoff for 10yr. return period with LID

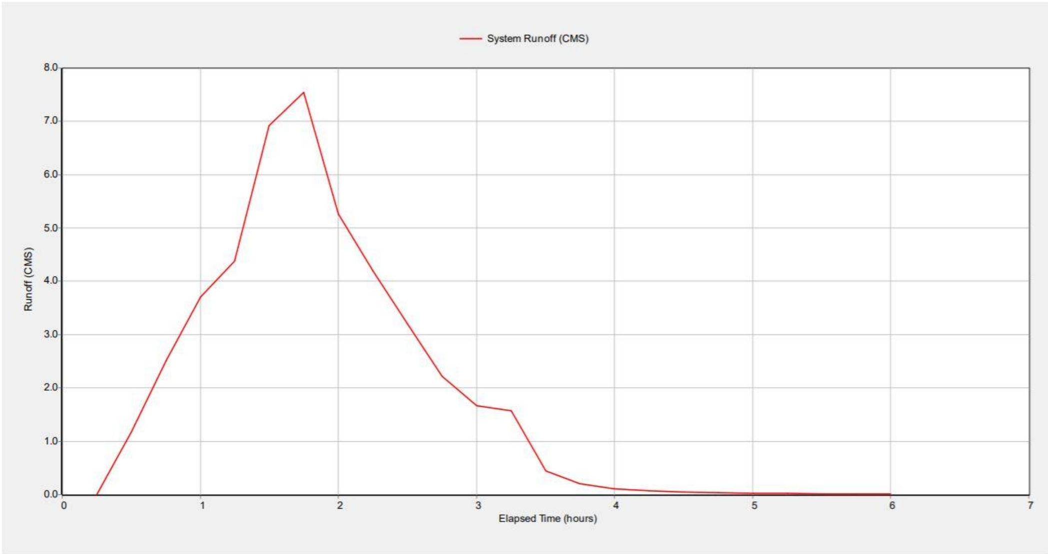


Figure 36: System Runoff for 25yr. return period without LID

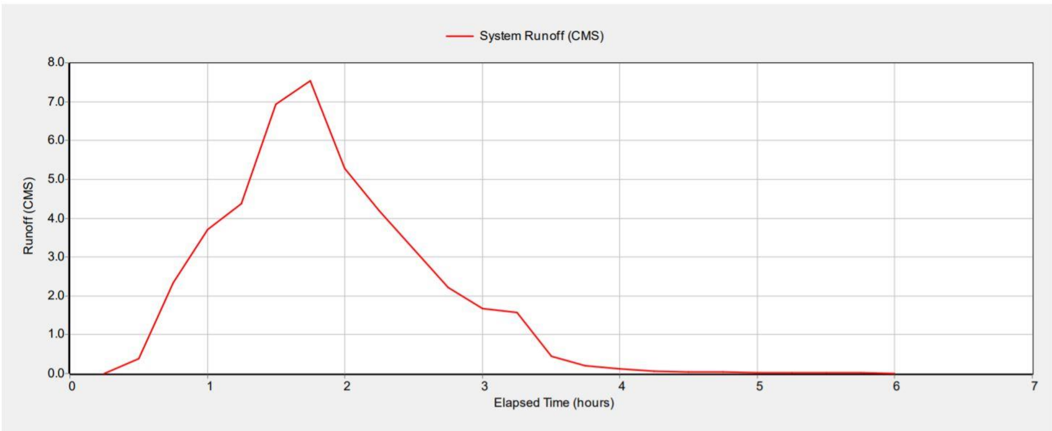


Figure 37: System Runoff for 25yr. return period with LID

Chapter 8: Discussions and Comparisons

It is obvious that application of LID (Rain Barrel) technique can be an excellent remedy measure to reduce flood volume and surface runoff. Moreover, flood hours has been reduced significantly due to the use of rain barrel. One of the main reasons to choose rain barrel is that it is more convenient to implement in the study area and it is more accessible. Flood hour and surface runoff can be more controlled if barrel height, area covered by LID can be increased. Increasing the time of drain delay in the LID technique can be an efficient way to reduce flood volume, time and runoff.

5 yr 3hr Return Period	10 yr 3hr Return Period	25 yr 3hr Return Period
Total flood volume 10^6 liter	Total flood volume 10^6 liter	Total flood volume 10^6 liter
12.145	15.372	18.116
Flooded Junction	Flooded junction	Flooded junction
J2, J3, J6, J7	J2, J3, J6, J7	J2, J3, J6, J7

Table 14: Comparison of flood volumes of synthetic rainfall events without LID

Return Period	Flood Volume (without LID) 10^6 ltr	Flood Volume (with LID) 10^6 ltr	Flood Volume Reduction Due To LID 10^6 ltr	Flooded Junction
5 year 3hr	17.166	12.145	5.021	J2,J3,J6, J7
10 year 3hr	20.257	15.372	4.885	J2, J3, J6, J7
25 year 3hr	24.152	18.116	6.036	J2, J3, J6, J7

Table 15: Comparison of flood volumes of synthetic rainfall events with LID

5 yr 3hr Return Period	10 yr 3hr Return Period	25 yr 3hr Return Period
Total flood volume 10^6 liter	Total flood volume 10^6 liter	Total flood volume 10^6 liter
17.166	20.257	24.152
Flooded Junction	Flooded junction	Flooded junction
J2, J3, J6, J7	J2, J3, J6, J7	J2, J3, J6, J7

Table 16: Comparison of flood volumes of synthetic rainfall events with or without LID

Chapter 9: Conclusions and Recommendations

This study basically focuses on storm water (rainfall-runoff) modelling on Begum Rokeya Sarani, Mirpur 10 via SWMM and the impact of LID (sustainable urban drainage structure) in the drainage system.

ArcGIS was used to determine some of the model parameters and IDF curve was prepared to use the rainfall data in the simulation. There were several limitations while conducting the study. For instance, although hydrological data was able to be collected, some hydraulics data were missing to the calibration part of the modelling.

The study depicts that the study area catchments are exposed to remarkable urban flooding in case of high rainfall events and mitigation measures are needed for the remedy.

Urban flooding and surface runoff are serious adverse impacts of urbanization. Bangladesh as a flood prone country faces so many natural disasters related to rainfall and urbanization causes extra problems for instance water logging, degradation of water quality, drainage problem, disease spreading etc. The SWMM modelling found significant amount of flooding and surface runoff for different return periods in the study area and LID technique (Rain Barrel) was used to reduce the negative impact of urbanization. As a result, significant amount of flooding, flooding time and runoff were reduced. So, rain barrel can be suggested to minimize the flood amount and frequency.

In future, other LID techniques can be implemented and analyzed the results. Also, actual hydraulic data can be used to calibrate and verify the outcomes. Moreover, sewer system modification can be implemented to mitigate the urban flooding.

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