Flood Assessment on Addis Ababa Light Rail Transit System (LRT)

(Meshualekiya – Gotera)

Masters of Science Thesis

By

Fisha Hailemichael

<u>Research Advisor</u>

Dr. Ing. Dereje Hailu

A thesis submitted to the school of graduates of Addis Ababa University in partial fulfillment of requirements for Master of Science degree in Railway Engineering at the Addis Ababa University, Institute of Technology, Addis Ababa, Ethiopia

Addis Ababa University

October, 2015

Declaration and copy right

Fisha Hailemichael declares that this thesis is my original work and that it has not been presented and will not presented by me to any other university for similar or any other degree award.

Signature …………….

Flood Assessment on Addis Ababa Light Rail Transit System (LRT)

(Meshualekiya – Gotera)

Thesis Submitted to Addis Ababa Institute of Technology, School of Graduate Studies in partial fulfillment of the requirements for the Degree of Masters of Science in Civil Engineering with Railway Engineering.

Date defended___________________________

Members of Examining Board

______________________ ___________________

(Chairman) (Signature)

______________________ ____________________

(Advisor) (Signature)

______________________ ____________________

(Internal examiner) (Signature)

______________________ ____________________

(External examiner) (Signature

Abstract

Addis Ababa has a pronounced rainfall peak during the summer (July to August).Flooding is a major problem for Addis Ababa city roads. Therefore, the study was carried out to assess the flood risk on Meshualekiya-Gotera corridor due to rainfall intensities of for different years of return periods.

This research paper assesses flooding condition due to the integration of Roads and Light Rail Transit drainage Systems of Addis Ababa with the help of ArcGIS and EPA SWMM modeling software.

The urban rainfall-runoff modeling was done for 15 minutes of intensity from IDF curves of Addis Ababa observatory for return periods of 2, 5, 10, 25, 50 and 100 years. The peak discharge values from Modeling software EPA SWMM for inlet manholes compared with rational method (rational formula) and nearly the same result were found.

The result showed that some of the left side (From Meshualekiya to Gotera) of road drainage manholes encountered flooding. The flooding time ranges from 10 minutes to the maximum of 20 minutes. For 2, 5, 10, 25 and 50 years of return period, no any flooding encountered in the railway line. But when it checked extremely within 100 years of return period, flooding occured on the railway track system for durations of 10.2 minutes only in one manhole location. So, the drainage system networks of the road previously designed and implemented have sizing problems.

As a recommendation by making simulation, pipe diameters of 1.06meter and 1.22 meter were recommended to link each other for flooded manhole areas. For Manholes (MH-L-433, MH-L-439, MH-L-440, MH-L-440’) section double piping (2 pipes with diameter of 0.75 meter) is best applicable solution to avoid the flooding near that area.

Key Words: Rational method, ARCGIS, EPA SWMM, Flood risk locations

Acknowledgements

First of all I would like to thank the almighty GOD for his unspeakable gift, help and protection. I would like to express my genuine gratitude and appreciation to Dr. Dereje Hailu, whose guidance and support to finalizing the thesis paper work.

Also, I am deeply grateful to my classmates, those who supported me throughout the master program

TABLE OF CONTENTS

List of Abbreviations

AACRA	Addis Ababa City Road Authority
AMSL	Above Mean Sea Level
DEM	Digital Elevation Model service
EPA SWMM	Environmental Protection Agency Storm Water Management Model
GIS	Geographic Information System
IDF	Intensity-Duration-Frequency

List of Figures

List of Tables

Chapter One

Introduction

1.0 Introduction

1.1 General

Appropriate drainage is essential in the design of highways and railways since it affects the road serviceability and usable life. The drainage designs involves providing facilities that collect, transport and remove the water that comes from rainfall from the roads and from their neighbors.

Urban areas which are close to artificial drainage systems, or located at the bottom of hill slopes, in valley bottoms and hollows, may be more prone to surface water flooding. This may especially be the case in areas that are down slope of land that has a high runoff potential including impermeable areas and compacted ground.

Surface water flooding can occur in rural and urban areas, but usually causes more damage and disruption in the latter. Flood pathways include the land and water features over which floodwater flows. These pathways can include drainage channels, rail and road cuttings. Developments that include significant impermeable surfaces, such as roads and car parks may increase the volume and rate of surface water runoff.

This study seeks to take the analysis of the annual occurrences of floods in Addis Ababa (Meshualekiya-Gotera) by analyzing its hydrological and drainage systems of Addis Ababa Light Rail Transit Systems and the roads. The main reason for this paper is to check the integration of railway drainage systems with the previously constructed drainage networks of the road.

The analysis of were done using ARCGIS 10.0, EPA SWMM 5.1, and Excel spread sheets. Drainage networks peak flood determination for the 2, 5, 10, 25, 50 and 100 years of return period based on AACRA (Addis Ababa City Road Authority) Drainage Design Manual and other data's were used for the hydraulic analysis.

1.2 Study Area

The study area is located in South of Addis Ababa, the road from Meskel-Square to Kality road (Debrezeit Road), specifically between Meshualekiya to Gotera road corridor and including wide area of right and left sides. The drainage systems previously constructed only for the pavement road but now integrated with the new railway line drainage systems also. The area is covered with commercial and residential buildings. The soil type in the area is mainly clayey and most section is covered by expansive soil. The elevation of the study area ranges from 2310 to 2362 amsl.

Figure 1.1: The study area location

1.3. Statement of the Problem

Ethiopia, like many countries, is prone to a range of environmental and natural disasters including floods. The nature and severity of such disasters depend on geographical conditions and preparedness of the local population. The occurrences of floods have had major impact on the standard of living of peoples and also infrastructures in the country, especially in the urban areas like Addis Ababa.

In rainy season, most of Addis Ababa city roads are congested with high floods and most of movements on the road and surroundings totally stop until the rain stops. Low investments in urban drainage facilities, Increase in peak and flood frequency due to inadequate drainage management and Design, lack of a reliable garbage collection and disposal, lack of street cleaning or its low frequency, lack of control in construction sites, non-existence of drainage master plan and lack of efficient and effective maintenance of drainage scheme. Due to one or more of these reasons, one of the main roads of Addis Ababa, from Meskel square to Kality road near Global hotel, the roads and surroundings has been flooded at the time of high rainfall intensity.due to this, traffic jam encountered until the flood ends up.

The newly railway constructed from North- south and from East to west doesn’t have its own drainage system design, the system uses the previously constructed drainage systems of road. Due to this the whole drainage systems of the areas may not be enough to accommodate the changes applied.

1.4. Objective of the Study

The main and specific objectives of the thesis work as follows:-

1.4.1. General Objective

Assessing flooding risk locations due to the integration of railway drainage systems with the previously constructed drainage networks of the road based on the actual data’s of drainage networks and catchment areas from GIS on a specific segment of the AA LRT system. The study area is around 2 km length starting from Mesualekiya to Gotera,one part of North-South railway corridor.

1.4.2. Specific Objectives

The specific objectives are listed below:-

- To identify locations that faces flooding for return periods of 2, 5,10,25,50 years.
- To determine the hours of flooding time and volume of flooding
- To estimate the catchment areas Peak discharge comparison using two methods
- To produce profile output for flooded Manholes (nodes)

Chapter Two

Literature Review

2.0 Introduction

This Chapter discusses about what meant by flooding? The nature or forms of flooding in Ethiopia urban context, Flood risks and flood risk assessments with the needs of urban drainage systems. And also the advantages of urban drainage modeling for the sake of flood mitigation measures.

2.1 Concepts of Flooding

A flood is an excess of water or water mixed with mud on land that's normally dry and is a phenomenon which is caused by high flow of water, or overflow of water in an established watercourse, such as a river, stream, or drainage ditches; or ponding of water at or near the point where the rain fell.

Flooding occurs when channels are filled with water beyond their capacity and results in excess water pouring out of the channel into the adjacent floodplain. Flooding can be the result of any of the following processes: excess rainfall, increased runoff, steep slopes, dam failure, and urban development. The majority of floods are connected with precipitation (High rainfall). At the time of rainfall, some of the water infiltrates, or sinks into the ground. Some evaporates directly into the atmosphere. The rest of the water becomes surface runoff, flowing downhill over the surface under the influence of gravity into the stream (Alemayehu, 2007).

2.2 Urban drainage components

Urban drainage systems are needed in developed urban areas because of the interaction between human activity and the natural water circulation. The urban drainage systems can be completely artificial, or combination of manmade sewer facilities and natural watercourses. The system can be represented as a network consisting of catchments and sub catchments, nodes, links and outlet. The components of the system are defined below :((Linmei Nie, 2003).

Catchment: - A catchment is the area collecting water from nearby higher terrain surface, which is delineated by topographic contour lines. A catchment is usually described by its parameters (catchment area, the percentage of impervious area, average slope, the longest flow length and approximate shape).

Nodes: - are junctions to link the sewers. They also provide storm water transition between surface and subsurface systems. Typical examples of nodes are manholes. Manholes should be provided at intersections of storm water drains, junctions between different size of storm water drains, where a storm water drain changes direction/gradient and on long straight lengths.

Links: - transport flow in the system, and are often open channels or closed sewers with regular or irregular cross sections.

Outlet: - The most downstream component of the urban drainage system, which discharges the sewage from the system to receiving waters.

2.2.1Drainage Inlets

The hydraulic capacity of a storm drain inlet depends upon its geometry as well as the characteristics of the gutter flow. Inappropriate inlet size (capacity) or poor inlet location may cause flooding on the road resulting in a hazard to the travelling public. Storm drain inlets are used to collect runoff and discharge it to an underground storm drainage system. Inlets used for the drainage of road surfaces can be divided into the following four classes :(ERA MANUAL, 2013)

1. Grate inlets: - Grate inlets consist of an opening in the gutter or ditch covered by a grate. The principal advantage of grate inlets is that they are installed along the road where the water is flowing.

2. Curb-opening inlets: - These inlets are vertical openings in the curb covered by a top slab. The inlets are most effective on flatter slopes, in sags, and with flows which typically carry significant amounts of floating debris

3. Slotted inlets:-These inlets consist of a slotted opening with bars perpendicular to the opening. Their principal advantage is their ability to intercept flow over a wide section

4. Combination inlets: - Various types of combination inlets are in use. Curb opening and grate combinations are common. This combination results in a high capacity inlet which offers the advantages of both grate and curb-opening inlets.

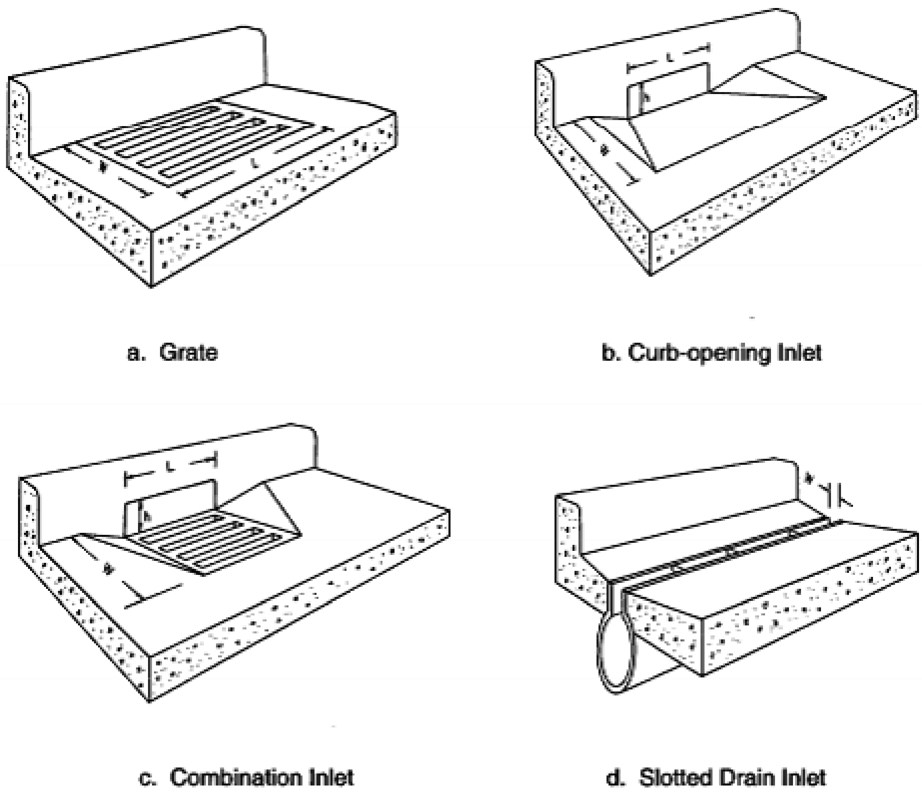


Figure 2.1: Storm Drain Inlets (ERA MANUAL, 2013)

2.3 Types of Track Drainage

Adequate drainage must be installed in new or upgraded track. Without adequate track drainage, track formation may become saturated leading to weakening and subsequent failure. Track drainage systems consists of two types :-(Railcorp Engineering Manual,2009)

- Surface drainage
- Subsurface drainage

2.3.1 Surface Drainage

Surface drainage removes surface runoff before it enters the track structure, as well as collecting water percolating out of the track structure.

Basic grading of the ground on either side of the track is a form of surface drainage, and allows water flowing out of the track structure to be removed.

Shoulder grading may be used in very flat areas where it is difficult to get sufficient fall for either surface or subsurface drains.

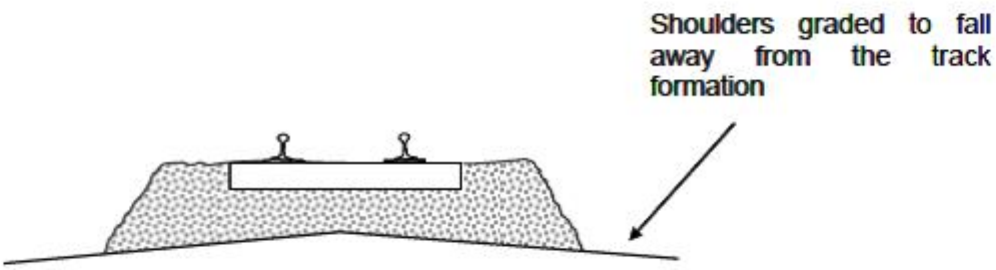


Figure 2.2: Typical Track Formation

2.3.2 Subsurface Drainage

Subsurface drainage is necessary for maintaining the integrity of the track formation and ensuring the stability of earth slopes. Subsurface drainage is used for:

- Drainage of the track structure
- Controlling of ground water
- The draining of slopes

Subsurface drainage shall be provided in locations where the water table is at or near earthworks level.

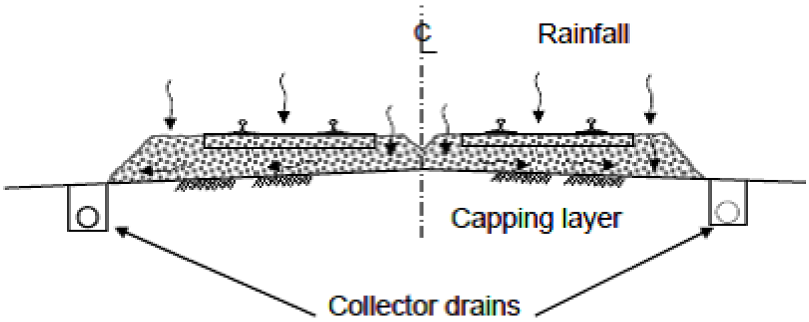


Figure 2.3: Collector of water seeping in to the ballast structure

2.4 Flooding on railways

The purpose of Track Drainage is to remove water from the Track Support System. The main sources of water that can affect the Track Support System are:-

- precipitation on the track;
- run off from areas adjacent to the track including Catchments external to Network Rail boundaries;

- Groundwater from underlying permeable layers, perched water tables and infiltration through the ballast and Ditches.

Proper surface water control and discharge from railway property is critical to maintaining the stability of railway embankments. Without this, track is at risk of flooding and becoming structurally unsafe. Any blockage of ditches and drains can allow flooding of track and adjacent land.

Figure 2.4: Railway track flooding (Thiruvananthapuram, India)

2.5 Forms of Floods in Ethiopia

Flooding can be classified into several types. Out of those river floods and urban floods are the most common in Ethiopia. The flood types are explained below.

2.5.1 River floods

River floods can be further classified by the rapidity of flooding or by the magnitude of flooding. In the first classification; a flood can either be a flash flood or a normal flood. Flash floods occur in mountainous areas or in urban cities founded near mountains, with high slopes and shallow soil depths and are caused by high intense of rainfall. In the case of normal flood, the river rises gradually and gives time for the people before arrival of the flood (Senarathne, 2002).

2.5.2 Urban floods

Flooding in urban areas occurs when the capacity of drainage system does not have enough space to take though them. Floods vary considerably in size and duration. Field-scale flooding is usually due to intense local storms where water and soil can flow straight off the land surface. With prolonged rain falling over wide areas rivers are fed by a network of ditches, streams and flows build up to the point where the normal channel is overcome and water floods onto surrounding areas (Daniel, 2007).

Urban drainage systems are needed in all urban areas because of their interaction between human daily activity and the natural water circulation. This interaction has two main forms: the removal of wastewater after using human daily activities, institutions' activities, and the consumption of industrial and commercial products; and secondly, systematically avoiding unwanted rainwater from the covering lands of impermeable surface areas away from existing natural areas. When these two forms of interaction not satisfied with the capacity of urban drainage systems, Flooding will occur (Linmei Nie, 2003).

2.6 Causal Factors of Flooding in Ethiopia

The causes of floods can be broadly divided into physical, such as natural forces (climate factors), and human influences such as deforestation and urban development’s. The most common causes of floods are climate related, mostly High rainfall. Long duration of rainfall or high intensity of rainfall events are the most common cause of flooding in Ethiopia urban cities. These events are usually associated with several days, weeks or months of continuous rainfall. Urbanization in particular has a direct impact on the magnitude and behavior of floods (Nott, 2006).

2.6.1 Causes of Flooding In Addis Ababa

At this time urbanization increases in Addis Ababa, means that new infrastructures are built ongoing (Buildings, asphalt paved roads, Railroads).when urbanization increases, impermeability increases with the increase in impervious surfaces (i.e. residential houses, commercial buildings, paved roads, parking lots, railway slab track, ballasted railway with paved sub ballast etc.), drainage pattern changes, overland flow gets faster, flooding and environmental problems such as land degradation increases. It is a crucial problem facing the existing and future environmental conditions of urban centers like Addis Ababa (Dagnachew, 2009).

Addis Ababa has only few formal drainage systems Installed. The provider of urban drainage infrastructure is the Addis Ababa City Roads Authority (AACRA).ACCRA has no responsibility on maintenance of drainage structures at the time of damage, discharge rates or the quality of surface runoff. The larger hydrological catchment is less emphasized in the design of roadside drains. Surface sealing resulting from urbanization generates more surface runoff, the risk of flooding (Backhaus, 2014).

2.7 Flooding in Ethiopia

Floods are relatively common in Ethiopia during the rainy season between June and September when heavy rains from the highlands flow into the low lands. On 6 August 2006, the Dechatu River burst its banks in the city of Dire Dawa near Somalia. Home to about 400,000 people, it is Ethiopia’s sixth-largest city, about 525 kilometers east of the capital Addis Ababa. Entire buildings were destroyed in some cases and sweeping away homes, trees and fences. More than 650 people are dead by flash floods. Altogether, the devastating floods left close to 20,000 people homeless in eastern Ethiopia (World watch institute, 2006). The Omo River, which flows into Kenya’s Lake Turkana, burst its banks between 8 and 13 August 2006. Extensive flooding occurred in one district of south Omo zone with heavy loss of lives and property. Around 14 villages are flooded and cut off. 364 people are dead (WFP, 2006).on 22 Apr 2013, Heavy rains over the past two weeks continue to cause flooding in Ethiopia. More than 9,000 households were affected in Somali region, and an additional 1,300 households were affected across Oromiya and the Southern Nations, Nationalities and People’s Region (SNNPR) (ReliefWeb, 2013). On 7 August 2014, different sub cities of Addis Ababa flooded. In Bole sub city woreda 13 in Sunrise building property of 700 thousands birr damaged as a result of flood. In the same way the same day as a result of flood has entered in 7 residencies property of 65 thousands birr has been damaged in Kirkos sub-city woreda 15 around Kera behind the Mosque and also around Olompia heavy flood brought passengers and vehicles to stay for a long time (Ethiopian Opinion, 2014).

2.8 The concepts of flood risk

Flood risk captures the impact flooding has on society. The concept of flood risk, which is function of the probability that a flood event will occur and the consequences damage for human health, the environment, infrastructures associated with a flood event. Practically, flood risk is made up of four major building blocks: the probability of flooding, the exposure of the receptors-at-risk to a flood with certain characteristics, the value of these receptors-at-risk and the exposure of these receptors-at-risk. The combination of the first two components gives the flood hazard while the combination of the latter three elements constitutes the consequence of flooding (Messner and Meyer, 2005).

2.9 Flood Risk Assessment

Flood Risk Assessment can be defined as:-

"A flood risk assessment is the identification, quantification and communication of flood risk using the source-pathway-receptor model. It examines the sources of flooding and the pathways by which floodwaters might reach receptors, such as people, property and the environment to determine the likelihood of them being affected by flooding. It also examines the flood hazards that are likely to arise and the vulnerability of receptors to such hazards" (OPW, 2009).

In the assessments of flood risk, the source-pathway-receptor model means that:-

Source:-where the source of water to create the flood comes from (i.e. rainfall, river…)

Pathway:-the way and the integrations of drainage systems where the flooded water passes through.

Receptor:-the final destination where the flooded water affects (i.e. Infrastructures and peoples)

2.10 Rainfall-based Flood estimation methods

Flood prediction and modeling generally involve approximate descriptions of the rainfall-runoff transformation processes. Some of rainfall based flood estimation methods (SCS method, Unit hydrograph, rational method) are discussed below.

2.10.1 SCS Method

Soil conservation Service (SCS) model has been applied for the estimation of flood discharge from small watershed. In catchments where agricultural lands are prevailing, American Soil Conservation Service (SCS) Runoff Curve Number Method is widely used for planning the structures aimed at water storage and, erosion and flood control. The method requires numeric catchment characteristics which are the basis of catchment runoff determination. The objective of the method is to determine the right curve number of the catchment of interest that defines the runoff potential. Hydrologic soil group number, land use type, vegetation cover, soil conservation measures, antecedent soil moisture conditions are the basic catchment characteristics used for curve number calculations. For that reason, the most important step in the calculation of flood discharge is to determine and calculate these characteristics accurately. During the planning of water storage structures, the most commonly used method for determining land use, vegetation cover and soil classes of a catchment (Tekeli et.al, 2007)

2.10.2 Unit Hydrograph

The unit hydrograph approach uses for design flood estimation. The theory of unit hydrograph refers to the relationship between net rainfall and direct runoff. The catchment is treated as a black box with the net rainfall as input and the direct runoff as response. If the input is a uniform net rainfall with a duration t_{dur} and a unit depth, the response is the t_{dur} -unit hydrograph. The direct runoff due to any net rainfall with different depths for successive increments of t_{dur} is obtained by linear superposition of the responses of the various net rainfall depths at each increment of t_{dur}.The direct runoff is added to the base-flow to give the total runoff. Application of the Unit Hydrograph Method requires :(GHKSAR, 2000)

- Loss Model: methods of determining the net rainfall hyetograph from the rainfall hyetograph
- Unit Hydrograph: The unit hydrograph for a catchment can be derived from rainfall-runoff monitoring.

2.10.3 Rational method

The Rational Method is used for flood estimation and also can be used to estimate stormwater runoff peak flows for the design of gutter flows, drainage inlets, storm drain pipe, culverts and small ditches. It is most applicable to small and highly impervious areas. The main considerations of the Rational Method are as follows :(GMDID, 2010)

- The peak runoff rate is a function of the average rainfall rate during the time of concentration;
- Rainfall intensity is constant during rainfall and
- The runoff coefficient (C) is constant during the storm event.

The probabilistic Rational Method has been developed with the runoff coefficient for different return periods. A return period (recurrence interval) is an estimate of the likelihood of an event such as flood to occur. It is a statistical measurement typically based on historic data denoting the average recurrence interval over an extended period of time, and is usually used for risk analysis.

2.11 Design of storm sewers

Hydrology will be defined as the study of rainfall events and runoff as related to the engineering design of conveyance features such as ditches and culverts. These conveyance features are typically designed to a particular storm event or storm frequency.

Generally, storm sewers are designed to provide safe passage of vehicles, and to collect, convey and discharge for frequently occurring, low-return-period storms. A design frequency is selected to match the facility's cost, amount of traffic, potential flood hazard to property, expected level of service, political considerations, and budgetary constraints, considering the magnitude and risk associated with damages from larger flood events.

We assign a certain amount of risk because of cost and feasibility. The greater the conveyances of failure, the higher risk, and therefore the storm return period. Here are a couple of examples (AREMA Manual, 2003)

Table 2.1: Designed Return periods for different structures

Conveyance Feature	Design Frequency
Culverts	50 yr
Ditches	50 yr
Storm Sewer	10 yr

Most agencies typically assess damage based upon the 100-year storm event; the designer should always check or test the system against the 100-year storm to evaluate how the system performs under those conditions. If, for instance, the tracks are well above the 100-year storm elevation, then the designer has completed his design. However if the storm overtops the tracks, the designer may reconsider designing the size of the culvert.

2.12 Modeling urban flooding

There are different steps and processes of surcharged drainage system and urban flooding.

Simulation models for flood risk analysis are required to accurately describe the hydraulic phenomena of surcharged and flooded drainage systems, some of them are listed below:-

(Schmitt T.G. et al., 2004)

- Identify the current capacity of the various drainage systems.
- The transition from free surface flow to pressure flow in the sewer pipes
- The rise of water level above ground level with water escaping from the drainage systems and
- The occurrence of surface flow during surface flooding

Different software's are available for the design and analysis of urban drainage systems. Some of them are:

- HEC-HMS (U.S. Army Corps of Engineers)
- MIKE 11 model(Danish Hydraulic Institute)
- ISIS(Halcrow)
- HY-8(FHWA)
- Storm Water Management Model (SWMM)
- MOUSE (Danish Hydraulic Institute)

2.12.1 HEC-HMS

HEC-HMS is software developed by the U.S. Army Corps of Engineering´s Hydrologic Engineering Center for the modeling of rainfall-runoff process. The software includes a graphical user interface for the management and analysis of the model data. The software enables the user to perform hydrological modeling based on a wide selection of common mathematical models used in hydrology. The models included in the software can thus be categorized as follows: (Valentin Heimhuber, 2013)

- **Loss Method:** A model to compute the runoff volume is often referred to as the loss method since it accounts for the losses that occur during a rainfall event as a result of infiltration and evapotranspiration. For each time interval in the modeling process, the loss method calculates the amount of water that contributes to the runoff in the river (effective rainfall).
- **Transform Method:** Models of direct runoff are also called transform method, since they convert the effective rainfall over a watershed into a hydrograph at the outlet of the watershed. These models account for the surface roughness and geometry of the watershed.
- **Baseflow Method:** Baseflow models are used to simulate the fraction of the runoff contributed by groundwater.
- **Routing Method:** If the analyzed watershed is divided into sub-watersheds, the flow at the outlet of a certain upstream watershed has to be routed through the river channel in the downstream watershed. The models used to simulate this routing process are therefore called routing methods. They account for the geometry and roughness of the relevant river channel.

2.12.2 MIKE 11 model

MIKE 11 is developed by Danish Hydraulic Institute (DHI) water and environment used to simulate surface-runoff flow, sediment transport and water quality in rivers, flood plains,channels.MIKE 11 is based on an effective numerical solution of the complete non-linear St-Venant equation for 1-D flows. Flood level and discharges as a function of time are calculated at specific points along the branches to describe the passage of flood flows through the model.it is designed for flood risk analysis, real-time flood forcasting,hydraulic analysis/design of structures and others.DHI's MIKE 11 software package is a very versatile and modular engineering tool for modeling conditions in rivers, lakes/reserviours,irrigation canals and other inland water system.it is designed for:(Singh S.K.,2004)

- Flood risk analysis and mapping
- Design of flood alleviation systems
- Real-time flood forcasting
- Hydraulic analysis/design of structures including bridges

- Drainage and irrigation studies
- Optimization of river and reserviour operations
- Dam break analysis
- Water quality issues
- Integrated groundwater and surface water analysis

2.12.3 ISIS model

ISIS can be used to model flows and water levels in open channels and floodplains. A wide range of structures, including bridges,culverts, pumps and weirs can also be modeled. An ISIS model is constructed using a number of different hydraulic units, which can be thought of as building blocks that are connected together. In most cases, an ISIS model must have the following three types of unit as a minimum :(Halcrow, 2009)

- Upstream boundary: to represent the flow entering the model.
- Downstream boundary: to represent the downstream water level.
- At least 2 river/routing/conduit sections: to represent the river channel.

Each unit contains model data appropriate to the unit type, e.g. a River Section unit contains crosssection geometry and roughness data for the river. Units also contain one or more node labels in order to be able to identify the unit and to be able to define the connectivity with other units in the model.

Units with the same label are automatically connected. River Section and Conduit units are connected together in the order in which they appear within the Network Properties Window, from the beginning to the end of the particular channel reach.

2.12.4 HY-8

HY-8 automates culvert hydraulic computations. HY-8 enables users to analyze :(FHWA, 2014)

- The performance of culverts
- Multiple culvert barrels at a single crossing as well as multiple crossings
- Roadway overtopping at the crossing and
- Develop report documentation in the form of performance tables, graphs, and key information regarding the input variables

HY-8 is the ability to define multiple crossings within a single project. A crossing is defined by 1 to 6 culverts, where each culvert may consist of multiple barrels.

2.12.5 MOUSE

MOUSE (Danish Hydraulic Institute, 1988) stands for Modelling Of Urban SEwers and is a hydrologic-hydraulic model applicable only for modelling of urban catchments. This model is used extensively for sewerage design in Australia compared to the design of stormwater drainage networks.The hydrologic part of the model deals with simulation of runoff using two methods: a simple method based on time-area diagram and a complex method based on kinematic wave theory and continuity equation.The hydraulic part of the model simulates flow routing in closed conduits or open channels. Three options are available in MOUSE to compute depth and velocity of flow. The first is the kinematic wave method, which is mostly applied to part full flow conditions. The second is the diffusive wave method, which considers backwater and surcharge in the systems. The last is the dynamic wave method, which provides a full hydrodynamic solution. MOUSE, like SWMM, is well-suited for analysing the hydraulic performance of complex looped sewer systems including overflows, storage basins and pumping stations. Water quality modelling and prediction is also included in the MOUSE model. (S.T.Dayaratne, 2000)

2.12.6 The Storm Water Management Model (SWMM)

The SWMM allows the simulation of flows of urban runoff as well as their carriage through the combined sewer system. This is for single rainfall events and for long periods of time. It presents several options to simulate the build-up and wash-off of the pollutants in the catchment area, and different conditions in the combined sewer system too. This software uses kinematic wave methods. The kinematic wave approach derives from the one-dimensional continuity and momentum equations (St. Venant equations) that describe the physical processes of the movement of water. The kinematic wave equation results when the inertial terms and the pressure terms have minimal influence on the transmission of water.

The concept of kinematic wave approach for surface runoff computation is based on the kinematic wave computation. This means that the surface runoff is computed as flow in an open channel, taking the gravitational and friction forces only. The runoff amount is controlled by the various hydrological losses and the size of the actually contributing area.

The shape of the runoff hydrograph is controlled by the catchment parameters length, slope and roughness of the catchment surface. These parameters form a base for the kinematic wave computation (Manning equation).(Temprano et.al, 2006)

2.13 Model Selection

EPA SWMM is selected for this study due to the following reasons:-

- is public domain software and freely copied
- primarily developed for drainage systems of urban areas
- Combined hydrologic and hydraulics software.
- simplicity and understand easily

Chapter Three

Materials and Methodology

3.0 Introduction

The methodology involved in developing a Storm Water Management Model (SWMM) for the Study area and for rational method of discharge calculation. The development stages are discussed in detail in the next sections.

3.1 Data Collection

3.1.1 Meteorological data

Daily rainfall data's for 33 years (observatory station) are available from National Meteorology Agency (NMA) of Ethiopia. The maximum daily precipitation selected and used as an input for further hydro-simulation works.

3.1.2 Digital Elevation Model (DEM) of the study area

A DEM is a grid of square cell; and each cell value represents the elevation of the land surface. DEM is important to know the existing ground surface area flow of water, direction of flow and to identifying and selecting catchment locations. There are different techniques to get DEM data's for study locations, for this study From USGS 30x30 meter Addis Ababa DEM data, clipping my study area location using ArcGIS 10.0 data management tools.

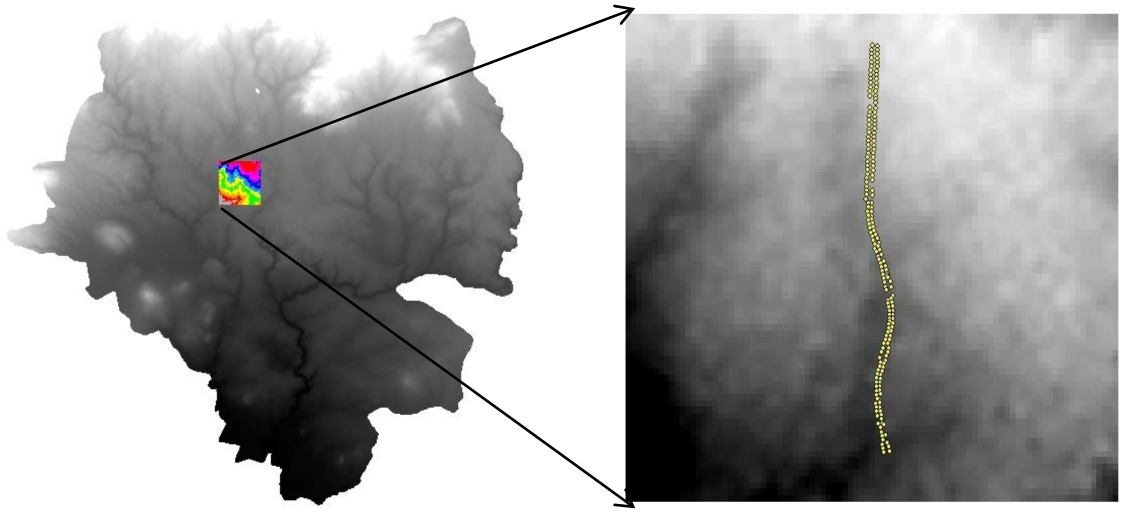


Figure 3.1: Clipped DEM for the study area

3.1.3 Drainage System Network

The drainage system network data for the study area were collected from Addis Ababa City Road Authority (AACRA) and Ethiopian Railway Corporation (ERC).The following information on storm drain/pipe systems were collected:

- Inlet size, type, location
- Location, size, slope, and shape of pipes
- Manholes

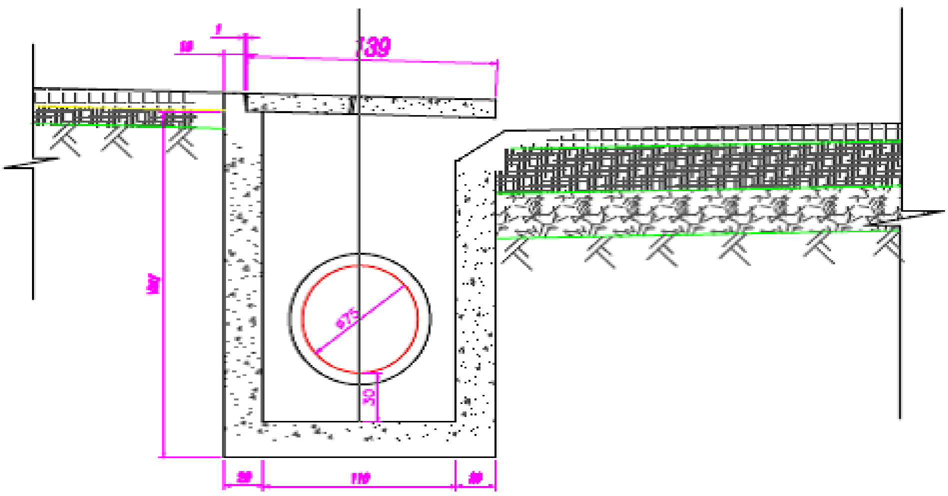
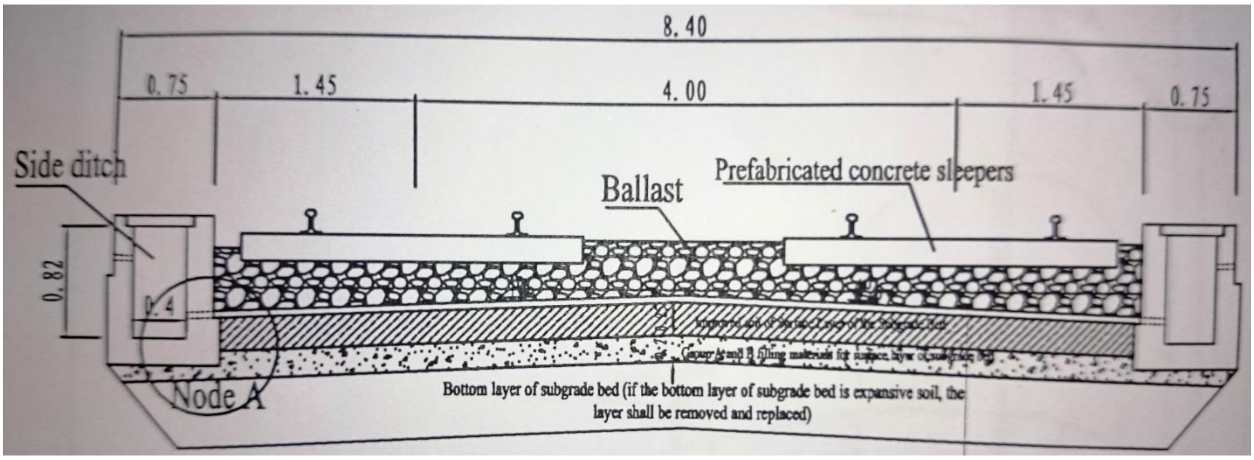


Figure 3.2: Manhole sizes and pipe diameters



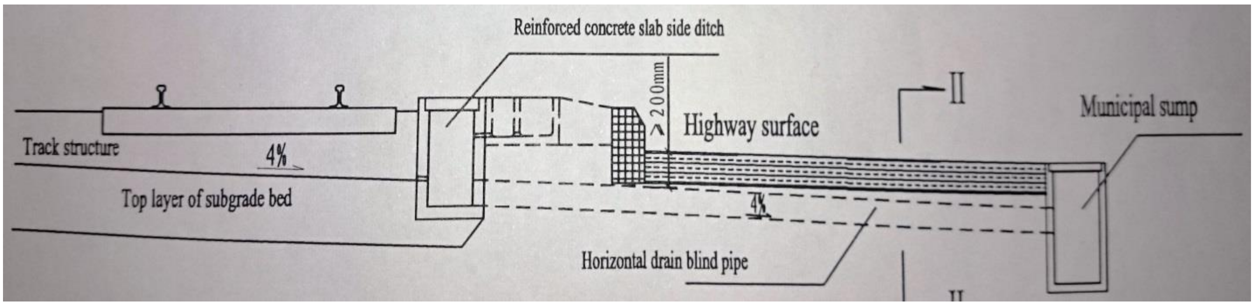


Figure 3.3: The drainage systems of the railway track and pipe connections with AACRA manholes

3.2 Analysis Methods

3.2.1 Intensity-Duration-Frequency (IDF) Curves

The IDF relationships are used when designing drainage works for any engineering project, and allow the engineer to design safe and economical flood control measures. The original design source from Meskel-square to Kality used the Gumble method for the preparation of IDF curves. The Gumbel method calculates the 2, 5, 10, 25, 50 and 100-year return intervals for each duration period and requires several calculations. In this method, from the raw data of Addis Ababa to compute the maximum precipitation (P) and the statistical variables (arithmetic average and standard deviation) for durations (5, 10, 15, 20, 30, 60, 90,120 minutes) were computed using equation 3.1, based on studies of large number of gauges in east Africa.

$$RRt=t/24[(b+24)^n/(b+t)^n] \qquad (3.1)$$

Where:

RRt=rainfall ratio=Rt: R24

Rt= rainfall in given duration"t"in hour

R24=rainfall in 24 hour

t=time in hour

n=0.9($0.78 \leq n \leq 1.09$)

b=0.3(based on studies of large number of gauges in east Africa)

Using the above formula the following rainfall ratio (RRt) for different minutes of durations computed in table 3.1

Table 3.1: Rainfall ratio (RRt) computation sheet

	5 min	10 min	15min	20min	30 min	60 min	90 min	120 min
t(hr)	0.08333	0.16666	0.25	0.33333	0.5	1	1.5	2
b+24	24.3	24.3	24.3	24.3	24.3	24.3	24.3	24.3
$(b+24)^n$	17.6622	17.6622	17.6622	17.6622	17.6622	17.6622	17.6622	17.6622
b+t	0.38333	0.46666	0.55	0.63333	0.8	1.3	1.8	2.3
$(b+t)^n$	0.4219058	0.50362	0.58388	0.66293	0.81805	1.26634	1.69725	2.11619
RRt	0.1453517	0.24354	0.3151	0.37003	0.4498	0.58115	0.6504	0.69552

Then using the correlation(Rt=RRt*R24),for each years of record of 24hr rainfall(mm) result changed to 5,10,15,20,30,60,90 and 120 minutes rainfall results.

Frequency precipitation PT (in mm) for durations with a specified return period T (in year) is given by the following equation (Lamia Abdul, 2012)

PT = Pav + KT * S ………………………………………………………………….. (3.2)

Where: PT= frequency precipitation for each duration with a specified return period T.

Pav = average of the maximum precipitation corresponding to a specific duration.

S = standard deviation of the series.

$$S=\sqrt{\frac{(Pt-Pav)^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3.3)$$

$K_T = -\sqrt{6}\{0.5772 + \ln(-\ln\left(1-\frac{1}{T}\right)\}/\pi$ …………………………………………..… (3.4)

Where: Pt= Maximum Precipitation Depth corresponding to a specific duration.

n = number of years of record.

KT = the frequency factor

Using the above steps, IDF curves for observatory station (33 years of records of 24 hr rainfall data's) were created on Figure 3.4

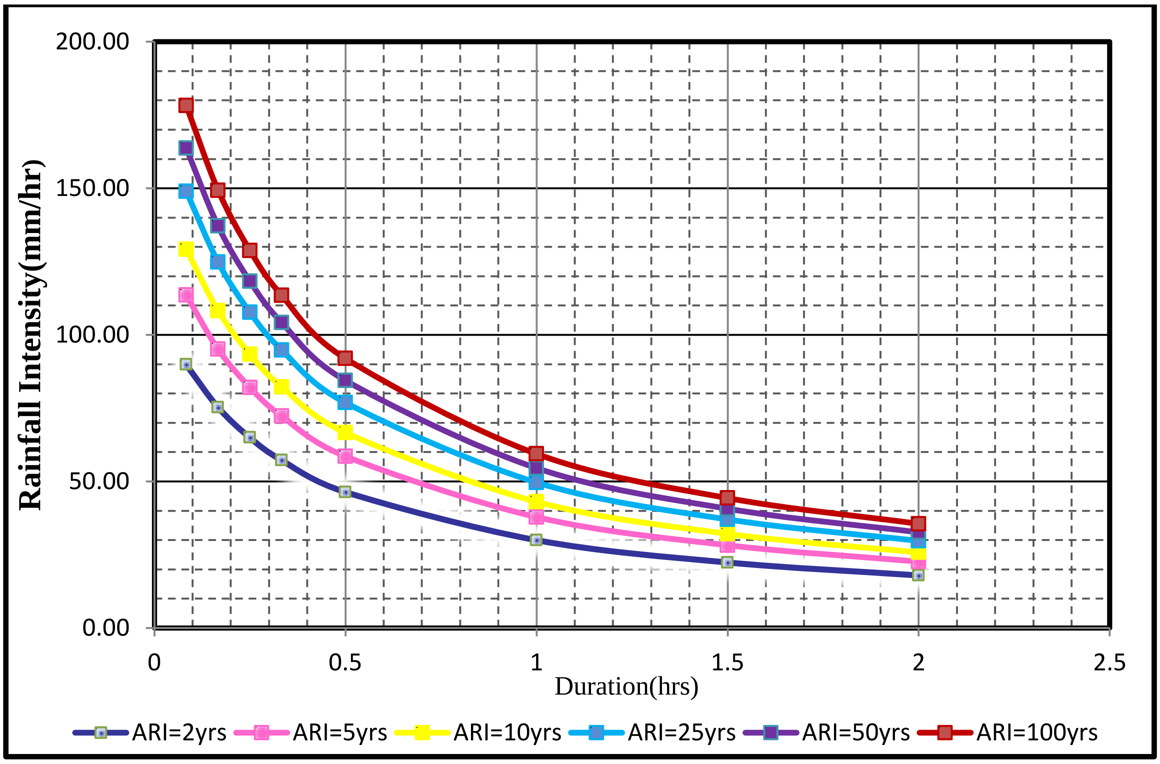


Figure 3.4: Intensity-duration-frequency (IDF) curves Observatory Station (33 years of data)

For the study area, the nearest station is Addis Ababa observatory (near Tikur Anbessa Hospital) and the IDF curve available on AACRA design manual. For preparation of the IDF curves on AACRA Manual, annual maximum precipitation data of 10, 20, 30 and 60 minutes duration were collected with records of 26 years. And by computation of mean and standard deviation for each duration of precipitation records and by application of Gumbel's Extreme Value Type I (EVI) distribution. Then IDF curves of Figure 3.5 created.

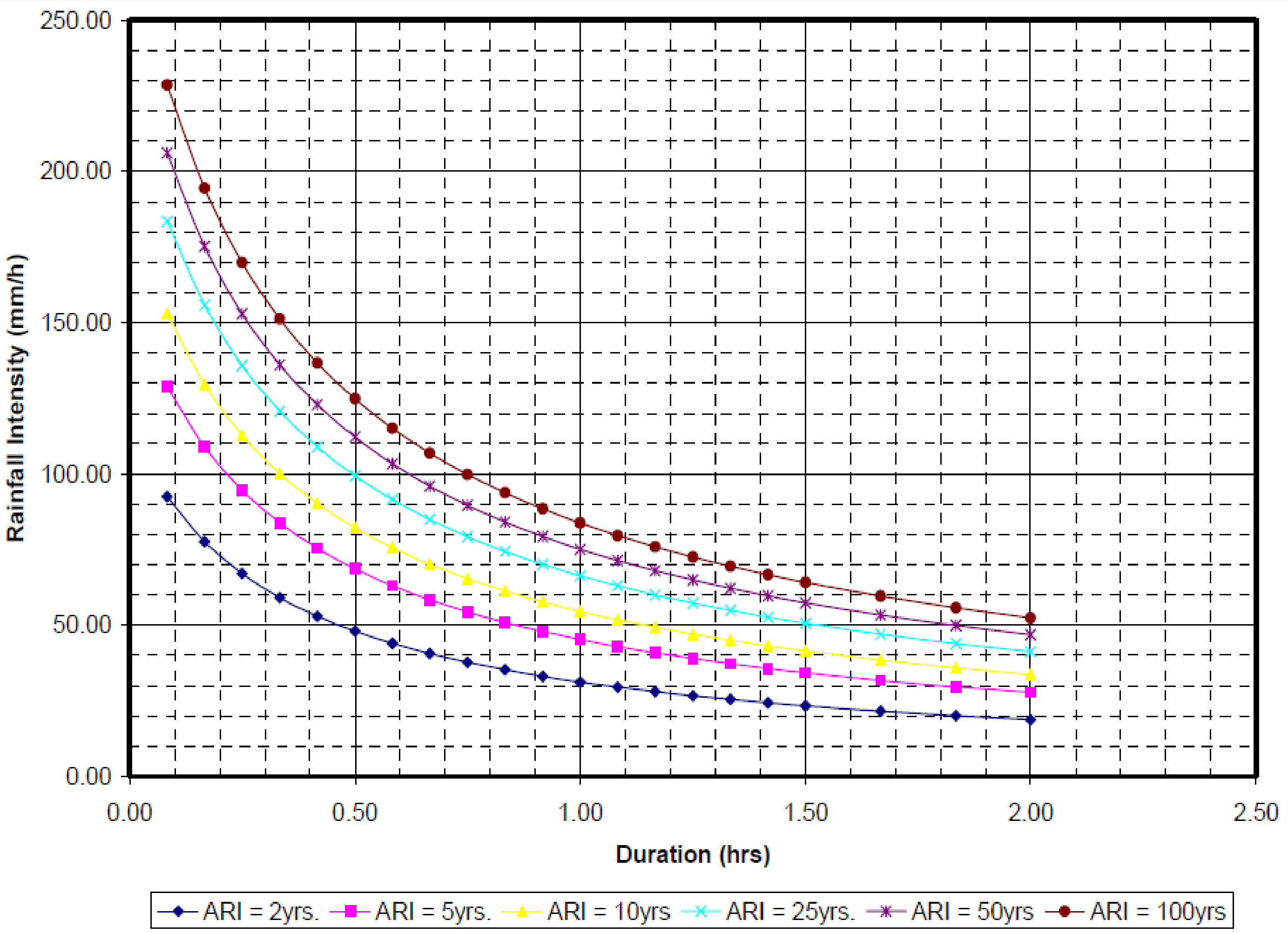


Figure 3.5: Intensity-duration-frequency (IDF) curve (Addis Ababa, Observatory)

(AACRA, 2003)

The above two IDF curves are compared as below table and shows that, the minimum percentage difference is 0.44% for 2 years return period on 120 minutes of duration whereas the maximum percentage difference is 30.75% for the 100 years of return period on 90 minutes of duration.

Table 3.2: percentage differences of IDF curves of Obs. (26 years) vs. IDF (33 years)

	Return period (years)								
	2			5			10		
Duration(min)	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference
5	89.89	92	2.29	113.56	128	11.28	129.22	152	14.99
10	75.31	78	3.45	95.13	108	11.92	108.25	128	15.43
15	64.96	68	4.47	82.06	95	13.62	93.38	112	16.63
20	57.21	60	4.65	72.27	84	13.96	82.24	100	17.76
30	46.36	48	3.42	58.57	70	16.33	66.65	82	18.72
60	29.95	30	0.17	37.83	45	15.93	43.05	54	20.28
90	22.35	24	6.87	28.23	35	19.34	32.12	40	19.70
120	17.92	18	0.44	22.64	28	19.14	25.76	34	24.24
	Return period (years)								
	25			50			100		
Duration(min)	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference	IDF(33 yrs)	IDF Obs.(26 yrs)	% difference
5	149.01	184	19.02	163.69	206	20.54	178.27	228	21.81
10	124.83	155	19.46	137.13	175	21.64	149.35	195	23.41
15	107.68	135	20.24	118.29	152	22.18	128.82	170	24.22
20	94.84	120	20.97	104.18	136	23.40	113.46	150	24.36
30	76.85	100	23.15	84.43	112	24.62	91.95	125	26.44
60	49.65	66	24.77	54.54	75	27.28	59.4	84	29.29
90	37.04	50	25.92	40.69	58	29.84	44.32	64	30.75
120	29.71	42	29.26	32.64	46	29.04	35.54	50	28.92

For further hydrological and hydraulics analysis/process IDF curves from AACRA manual taken due to annual maximum precipitation data of 10, 20, 30 and 60 minutes duration were used specifically rather than 24 hr rainfall data's for IDF curve preparation.

3.2.1.1 Alternating Block Method

This method used to develop a design storm hyetograph from an IDF curve to input in SWMM 5 modeling software.

The steps to get the design storm hyetograph as follows: - (chow, 1988)

- Select the design return period,
- Read the intensity from the IDF curve for each of the durations,
- Calculate the corresponding precipitation depth as the product of the intensity and duration.

  $P = iT_d$………………………………………………………………….. (3.5)

  Where: P=rainfall depth (mm)

  i=intensity from IDF curve (mm/hr)

  Td=duration time (hr)
- Differences between successive precipitation depth values give the amount of precipitation to be added for each additional unit of time

- These increments are recorded into a time sequence with the maximum intensity occurring at the center of the required duration
- And the remaining arranged in descending order alternately to the right and left of the central to form the design hyetograph.

The overall calculation process is described in Table 3.3 for 15 minutes of storm design

Table 3.3: Alternating block method calculation sheet

Return Period	**Duration (min)**	**Intensity (mm/hr)**	**Rainfall (mm)**	**Increment of rainfall(mm)**	**Ordinated Block**
2	5	92.00	7.67	7.67	4.00
	10	78.00	13.00	5.33	7.67
	15	68.00	17.00	4.00	5.33
5	5	128.00	10.67	10.67	5.75
	10	108.00	18.00	7.33	10.67
	15	95.00	23.75	5.75	7.33
10	5	152.00	12.67	12.67	6.83
	10	130.00	21.67	9.00	12.67
	15	114.00	28.50	6.83	9.00
25	5	182.00	15.17	15.17	8.17
	10	155.00	25.83	10.67	15.17
	15	136.00	34.00	8.17	10.67
50	5	206.00	17.17	17.17	9.08
	10	175.00	29.17	12.00	17.17
	15	153.00	38.25	9.08	12.00
100	5	228.00	19.00	19.00	10.17
	10	194.00	32.33	13.33	19.00
	15	170.00	42.50	10.17	13.33

Then the hyetograph plotted using Table 3.3 ordinated block results in Figure 3.6 for return periods of 2, 5,10,25,50 and 100 years.

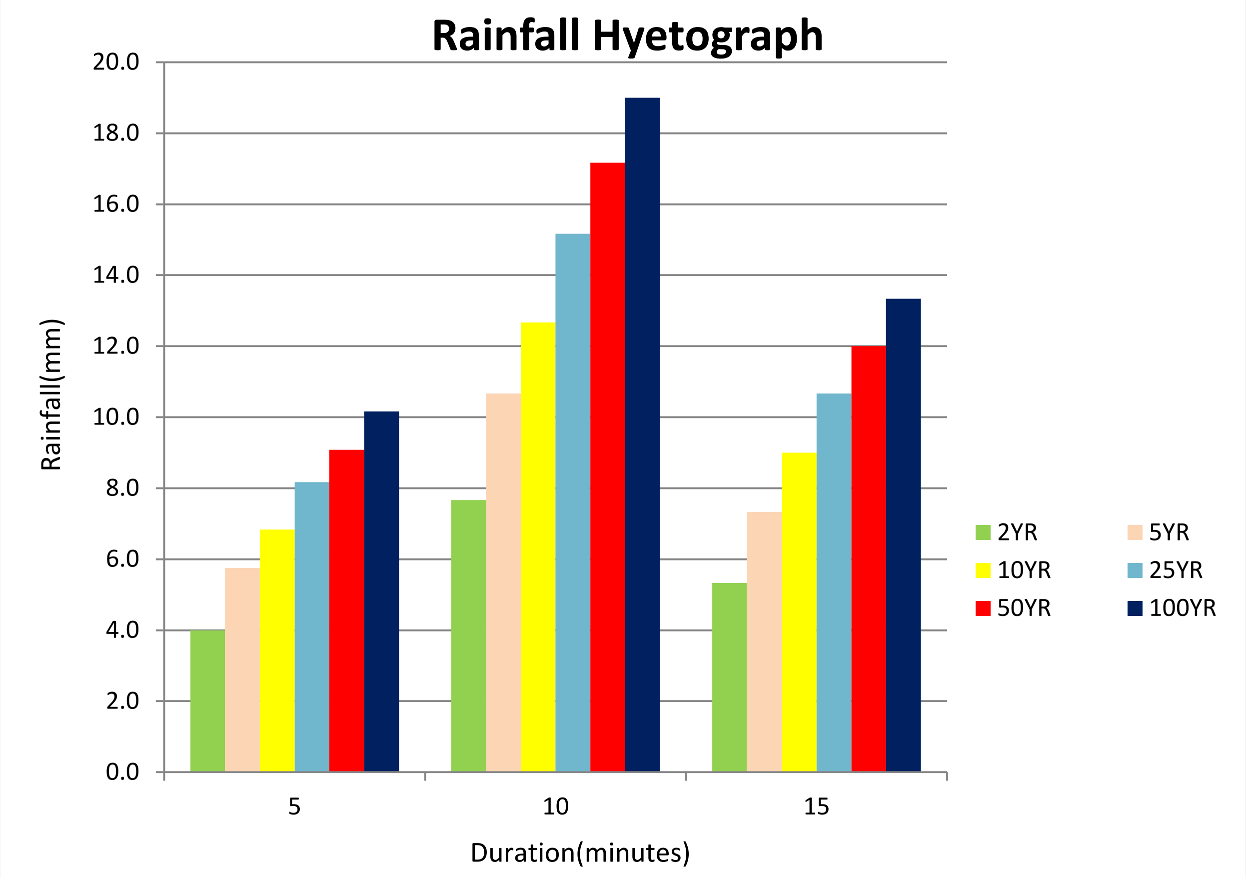


Figure 3.6: Intensity Hyetograph for 15 minutes of storm design period for different return periods

3.2.2 Catchment Area Delineation

The hydrologic modeling tools in the ArcGIS Spatial Analyst extension toolbox provide methods for describing the physical components of a surface or Digital elevation models. The hydrologic tools allow identifying sinks, determining flow direction, calculating flow accumulation, delineating watersheds, and catchment area selection.

All spatial analyst tools that are used for delineating stream network and watershed boundaries are available in ArcToolbox. Hydrology tools can be found by selecting Spatial Analyst Tools. Delineating catchment areas using the following steps as follows: - (Parmenter and Melcher, 2012)

- **Flow Direction:** Based my study area (Clipped DEM) – this will compute for every cell the direction that water would flow through it.
- **Sink:** from the Flow Direction grid to identify sinks in the clipped DEM. These are areas surrounded by higher areas, so that there is no external drainage.

- **Fill:** This step will fill the sinks of clipped DEM.
- **A new Flow Direction:** based on the Filled (Depression-less) DEM.
- **Flow Accumulation:** based on the new filled Flow Direction grid, this step calculates for each cell in the filled DEM array, the number of cells flowing into it. Areas of higher values are where water collects and drains. The Flow Accumulation grid will allow the software to determine the area draining to any specified point on the DEM.
- **Snap Pour Point:** The Snap Pour Point command snaps the stream gage point to the nearest area of high flow accumulation.
- **Watershed**: This command performs the watershed delineation based on the snapped stream gage pour point.

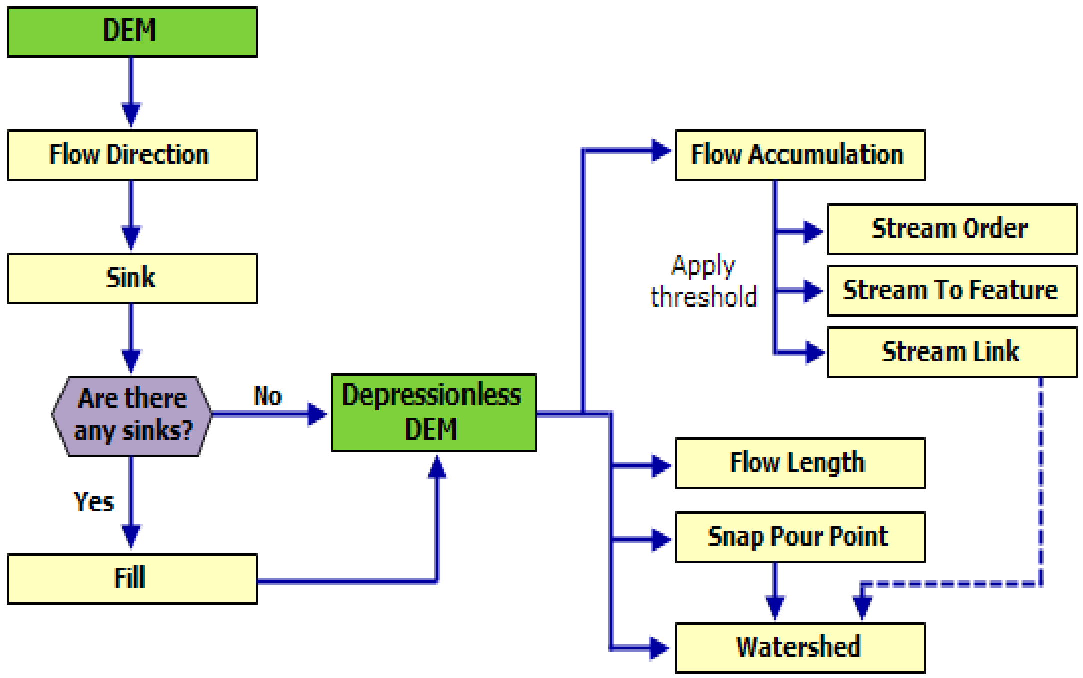
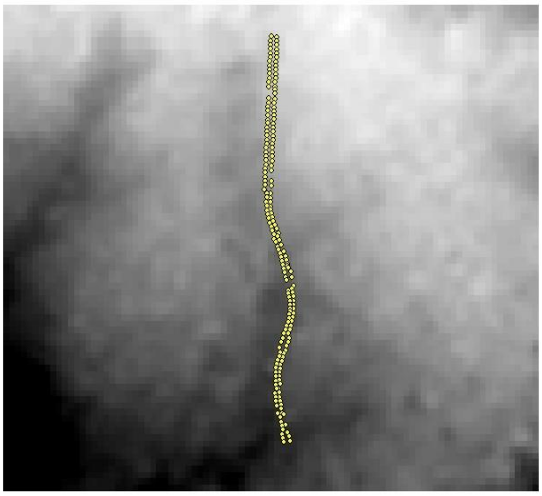


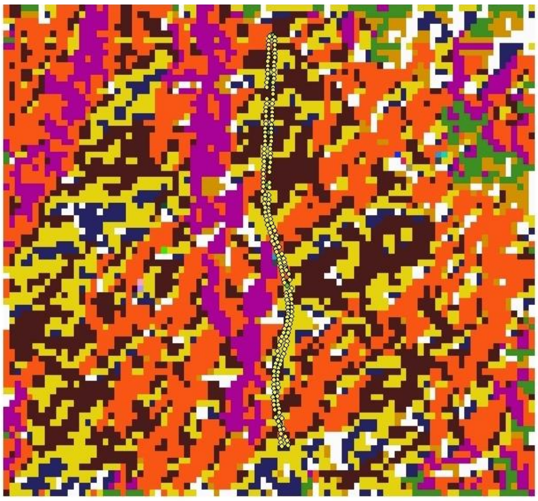
Figure 3.7: Hydrological modeling flowchart

Source: http://resources.arcgis.com

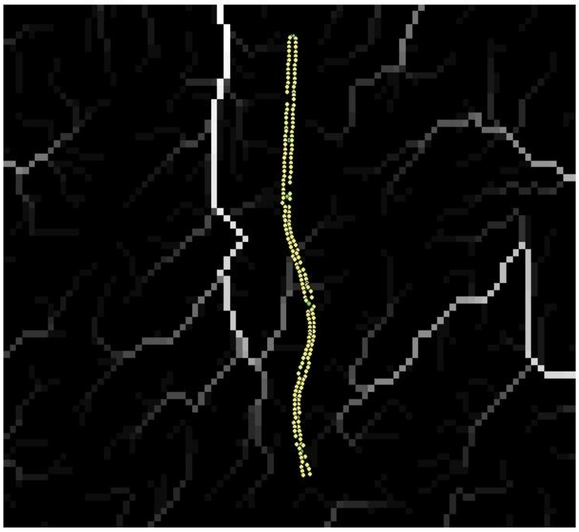
Using the above steps in ArcGIS, the following catchment areas are created for all manholes by considering all the manholes as a pour point.



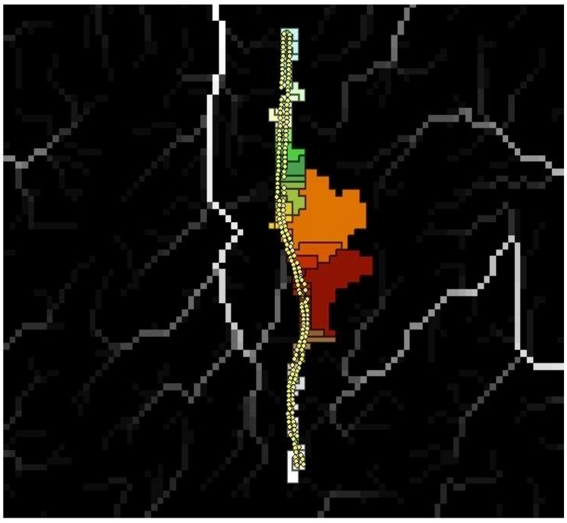
Clipped DEM with Manholes



Flow Direction



Flow Accumulation



Catchment polygon processing

(Catchment areas for each inlet manholes)

Figure 3.8: Catchment area delineation process using spatial analyst tools

Totally 202 sub-catchments are created and 11 of them are the railway track system sub-catchments. The maximum widest sub-catchment areas are 8.95 ha and 6.43 ha.

3.3 The Rational Method

A popular approach for determining the peak runoff rates from small catchment areas less than 80 hectares is the Rational Formula. The Rational Method considers the entire drainage area as a single unit and estimates the peak discharge at the most downstream point of that area.

The Rational Method is expressed in Equation 3.6 and also explanation of each variable in the rational method equation. (AACRA Manual, 2003)

$$Q = \frac{CIA}{360} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.6)}$$

Where:

Q = Peak flow in m3/s

C = Dimensionless runoff coefficient assumed to be a function of the watershed and often the frequency of the flood being estimated

I = rainfall intensity for the design storm (mm/hr)

A = drainage area (hectares)

Higher intensity storms will require modification of the coefficient because infiltration and other losses have a proportionally smaller effect on runoff. The adjustment of the Rational Method for use with major storms can be made by multiplying the right side of the rational formula by a frequency factor C_f. The rational formula now becomes: (ERA MANUAL, 2002)

$$\mathrm{Q} = \frac{\mathrm{CfCIA}}{360} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(3.7)}$$

Cf values are listed below. The product of C_f times C shall not exceed 1.0.

Table 3.4: Frequency factors for rational formula (ERA MANUAL, 2002)

Recurrence Interval(years)	C_f
5	1.0
10	1.0
25	1.1
50	1.2
100	1.25

3.3.1Runoff Coefficient

The runoff coefficient (C) is the variable of the Rational Method least susceptible to precise determination and requires judgment and understanding on the part of the design engineer. This variable represents the ratio of runoff to rainfall.it represents the interaction of many factors, including the storage of water in surface depressions,infiltration,antecedent moisture, ground cover, ground slopes and soil types.

When the catchment area contains varying amount of different covers, a weighted runoff coefficient can be determines as:

$$C_w = \frac{\sum C_i A_i}{A} \qquad (3.8)$$

Where, C_w=weighted runoff coefficient

$C_{i,}$ A_i =runoff coefficient and area respectively for cover type i

A=total drainage area

Table 3.5: Runoff coefficients for rational formula (AACRA MANUAL, 2003)

Type of Drainage Area	C
Business:	
Commercial area	0.70-0.95
Neighbourhood areas	0.50-0.70
Residential:	
Single-family areas	0.30-0.50
Multi-units, detached	0.40-0.60
Multi-units, attached	0.60-0.75
Suburban	0.25-0.40
Apartment dwelling areas	0.50-0.70
Industrial:	
Light areas	0.50-0.80
Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.20-0.40
Railroad yard areas	0.20-0.40
Unimproved areas	0.10-0.30
Lawns:	
Sandy soil, flat, < 2%	0.05-0.10
Sandy soil, average, 2 to 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 to 7%	0.18-0.22
Heavy soil, steep, > 7%	0.25-0.35
Streets:	
Asphaltic	0.70-0.95
Concrete	0.80-0.95
Brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95

3.3.2 Rainfall Intensity

The rainfall intensity (I) is the average rainfall rate in mm/hr for a selected return period that is based on a duration equal to the time of concentration (Tc). Once a particular return period has been selected for design and a time of concentration has been calculated for the drainage area, the rainfall intensity can be determined from intensity-duration-frequency curves from Figure 3.5 As above mention before. Calculation of Tc is discussed in detail in the next section.

3.3.3 Time of Concentration (T_c)

Use of the Rational Method requires calculating the time of concentration (tc) for each design point within the drainage basin. The duration of rainfall is then set equal to the time of concentration and is used to estimate the design average rainfall intensity (I). The basin time of concentration is defined as the time required for water to flow from the most remote part of the drainage area to the point of interest for discharge calculations. The time of concentration is computed as a summation of travel times within each flow path.

Using the below two methods calculating time of concentration for rational formulas (AACRA Manual, 2003)

3.3.3.1 Sheet flow travel time

Sheet flow is a shallow mass of runoff on a plane surface with the depth uniform across the sloping surface. Calculate time of concentration using the following variation of kinematic wave equation:

$$Tc = \frac{5.476}{{P_2}^{0.5}} \left\lfloor \frac{nL}{\sqrt{S}} \right\rfloor^{0.8} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots. (3.9)$$

Where: Tc=Time of concentration (minutes)

n=manning's roughness coefficient

S=slope of the surface (m/m)

L=flow length

P_2=2-year, 24 hour rainfall depth (mm)

Values of manning's roughness coefficient n can be obtained from Table 3.6

Table 3.6: manning's roughness coefficient (n) for overland and sheet flow

N	Surface	n	Surface
0.011	Smooth asphalt	**Cultivated Soils**	
0.012	Smooth concrete	0.06	Residue cover □ 20%
0.013	Concrete lining	0.17	Residue cover > 20%
0.014	Good wood	0.13	Range (natural)
0.014	Brick with cement mortar	**Grass**	
0.015	Vitrified clay	0.15	Short grass prairie
0.015	Cast iron	0.24	Dense grasses
0.024	Corrugated metal pipe	0.41	Bermudagrass
0.024	Cement rubble surface	**Woods***	
0.05	Fallow (no residue)	0.40	Light underbrush
		0.80	Dense underbrush

3.3.3.2 Velocity Method

The velocity method is applicable to sheet flow, shallow concentrated flow, pipe flow, or channel flow.

$$T_t = \frac{L}{60V} \quad \text{.. (3.10)}$$

Where T_t=Travel time (minutes)

L=length of flow (m)

V=velocity (m/s)

Using manning's equation we can estimate average velocity in pipes and open channels:

$$V = \frac{R^{\frac{2}{3}} S^{\frac{1}{2}}}{n} \quad \text{.. (3.11)}$$

Where: R=the hydraulic radius (m) $=\frac{A}{P}$

A=crossectional flow area (m^2)

P=wetted perimeter (m)

3.4 Modeling Using EPA SWMM 5.1

3.4.1 Model Description

The Environmental Protection Agency Storm Water Management Model (EPA SWMM) is a dynamic rainfall-runoff simulation model used for single event or long-term (continuous) simulation for urban area drainage network systems. The runoff component of SWMM operates on a collection of sub-catchment areas that receive precipitation (rainfall) and generate runoff. The routing portion of SWMM transports this runoff through a system of pipes, channels and storage. SWMM tracks the quantity runoff generated within each sub-catchment, and the flow rate, flow depth, and quantity of water in each pipe and channel during a simulation period (Lewis A. Rossman, 2010)

3.4.2 Steps in Using EPA SWMM 5.1

The following steps generally used for selected study area :-(Lewis A. Rossman, 2010)

1. Specify a default set of options and object properties to use

   - Default Id labels for Nodes, Links
   - Default sub-catchments properties like area,slope,width
   - Default Node/link properties(node invert, conduit length, routing method)

2. Draw a network representation of the physical components of the study area

   - Adding a Rain Gage(rainfall intensity for the study area)
   - Adding a Sub-catchment (from delineated watershed catchments)
   - Adding a Node (Manholes of study area)
   - Adding a Link(pipes connecting Manholes of study area)

3. Edit the properties of the objects that make up the system

4. Select a set of analysis options

5. Run a simulation.

6. View the results of the simulation

3.5 Data entry

3.5.1 Rational formula

Following is the application of the rational method to estimate peak discharges for each inlets (manholes):

1. Site data:-for each inlet of manhole, the catchment area, slope, longest path is known from ArcGIS results

2. Land use type:-the catchment area divided in to three groups. These are pavement (asphaltic), paved and unpaved (commercial areas) from actual site visit and Google earth.

3. Runoff coefficient(C):-from above Table for streets pavement (asphaltic) =0.95, for drives and walks paved=0.85.for the remaining catchment areas out of the main road (commercial and residential area) the following two methods are used:-

- Site visit:-the roads, out of the main road of the study area, included in the catchment areas are more likely impervious. Only little areas are not covered by impervious material. The impervious areas are covered by roofs, asphaltic road, cobble stones and concrete.

A.Asphaltic roads

B.Cobble stone roads C.Concrete road

Figure 3.9: Study area catchment areas with different impervious materials.

- Google Earth Pro:-by overlaying ArcGis catchment areas with Google Earth Pro,calculating averege weighted (Cw).for pervious area C=0.3(for green areas), for roads and residential/commercial roofs C=0.95

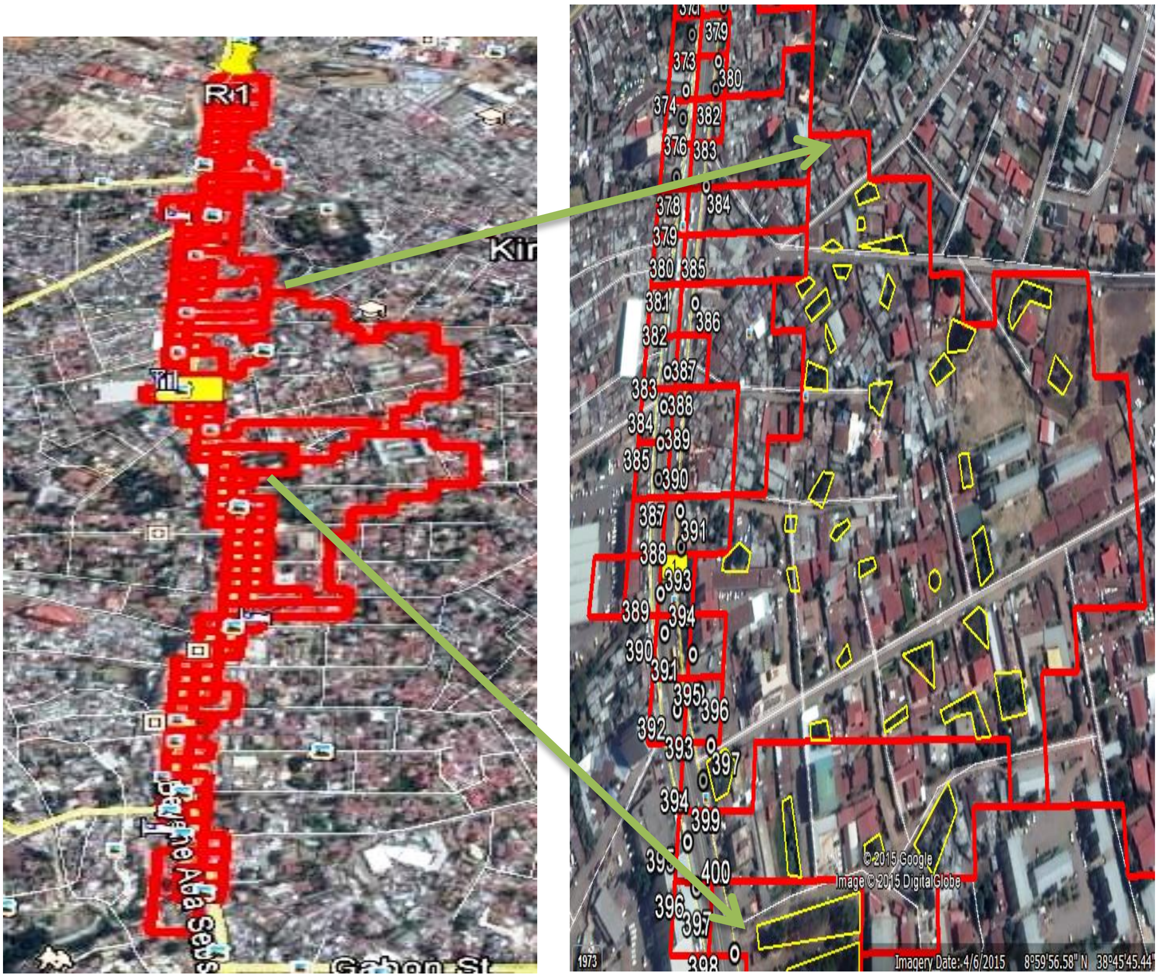


Figure 3.10: Overlaying ArcGis Catchement area on Google Earth Pro and measuring Pervious area

4. Time of concentration (Tc):-using equation for each manhole. For T_c less than 5 min use 5 min.

5. Determine Rainfall Intensity:-from calculated Tc reading from IDF curves for the needed design return periods.

6. Determine peak Discharge (Q):-using equation calculating the discharges for each manhole for different return periods.

The overall process shows as below Table excel sheet as an example for 5 manholes

Table 3.7: Rational Formula inlet Discharge computation sheet

LOCATION		**CATCHMENT**			**GUTTER DISCHARGE Design Frequency 10years**						
IN-LET NO	**INLET MANHOLE**	**LAND-USE TYPE**	**FLOW LENGTH**	**SLOPE (m/m)**	**DRAIN AREA "A" (ha)**	**RUN-OFF COEF "C"**	**CA (ha)**	**TIME OF CONC "t_c" (min)**	**TOTAL TIME OF CONC "t_c (min)**	**Rainfall Intensity "I" (mm/h)**	**Q= 0.002 78 CIA (m^3/s)**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
1	486	Pavement	30.00	0.020	0.029	0.95	0.027	1.39	5.00	152.00	0.090
		Paved	15.00	0.030	0.015	0.85	0.013	0.68			
		Residential and commercial area	70.65	0.030	0.214	0.81	**0.174**	2.34			
						0.83	0.213	4.40			
2	487.0	Pavement	30.00	0.020	0.029	0.95	0.027	1.39	5.00	152.00	0.025
		Paved	15.000	0.030	0.015	0.85	0.013	0.68			
		Residential and commercial area	9.57	0.040	0.030	0.62	**0.019**	0.42			
						0.79	0.059	2.49			
3	488.0	Pavement	30.00	0.020	0.014	0.95	0.014	1.39	5.00	152.00	0.050
		Paved	15.00	0.030	0.008	0.85	0.006	0.68			
		Residential and commercial area	93.370	0.040	0.110	0.89	**0.098**	2.61			
						0.89	0.118	4.67			
4	489.0	Pavement	30.00	0.020	0.014	0.95	0.014	1.72	5.24	150.94	0.049
		Paved	15.000	0.030	0.008	0.85	0.006	0.84			
		Residential and commercial area	74.000	0.040	0.110	0.89	**0.098**	2.68			
						0.89	0.118	5.24			
5	490.0	Pavement	30.00	0.020	0.029	0.95	0.027	1.72	5.00	152.00	0.029
		Paved	15.000	0.030	0.015	0.85	0.013	0.84			
		Residential and commercial area	12.030	0.050	0.038	0.73	**0.028**	0.57			
						0.83	0.068	3.13			

3.5.2 EPA SWMM 5.1

From Mesualekiya to Gotera (2km) it consists of 202 sub-catchments, 199 junctions (nodes) and 199 conduits (pipes) in the whole drainage network. Figure 3.11 shows the arrangement of drainage network.

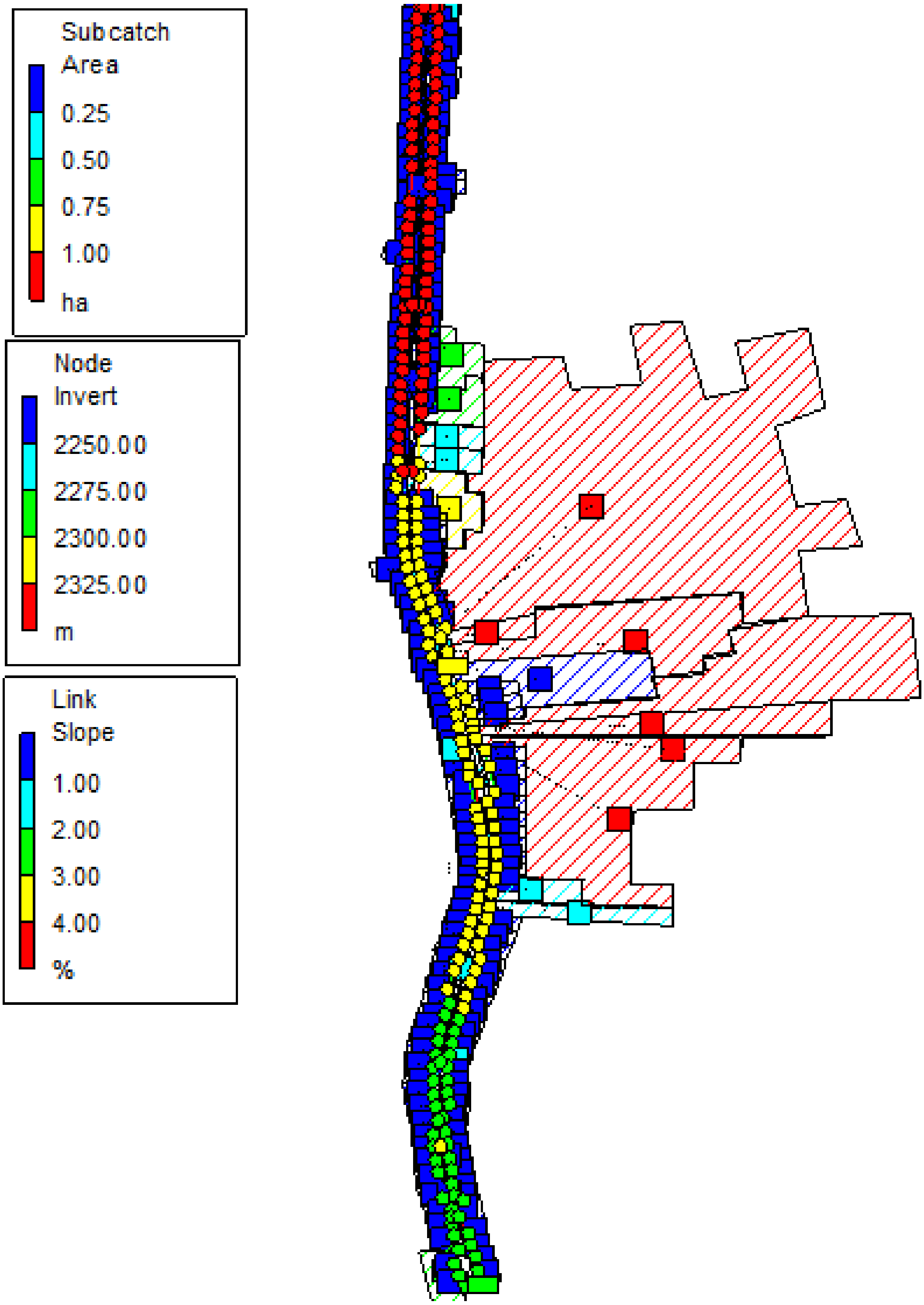


Figure 3.11: Meshualekiya-Gotera Road subcatchments, manholes and conduits.

Sub-catchment data: - for all sub-catchments inputting the following data's

-Area in hectare

-Width (meter), calculated as the ratio of the area to the longest flow path in the watershed.

-Slope in percent

-Percentage of imperviousness (by dividing impervious area to the total area of catchment)

-Rainfall intensity for 2, 5, 10, 25, 50 and 100 years of return periods. Input 15 minute intensity in a hyetograph form.

Subcatchment SC-LS-47

Property	Value
Name	SC-LS-47
X-Coordinate	473815.453
Y-Coordinate	994628.143
Description	
Tag	
Rain Gage	R-25
Outlet	MH-L-399
Area	1.520
Width	60.87
% Slope	4.61
% Imperv	88

Figure 3.12: Sub-catchment data input Box

-infiltration, Horton's infiltration method applies. The following infiltration parameters suggested from Water Quality Capture Optimization and Statistics Model (2011)

Horton's initial infiltration rate:-the nature of the study area soil type is most likely clayey soil and also no vegetation since it is commercial areas.so from below table 25.4mm/hr is taken.

Table 3.8: Horton's initial infiltration by soil type (WQ-COSM, 2011)

Soil Type	(in/hr)	(mm/hr)
Dry sandy soils with little or no vegetation	5.0	127
Dry loam soils with little or no vegetation	3.0	76.2
Dry clay soils with little or no vegetation	1.0	25.4
Dry sandy soils with dense vegetation	10.0	254
Dry loam soils with dense vegetation	6.0	152
Dry clay soils with dense vegetation	2.0	51
Moist sandy soils with little or no vegetation	1.7	43
Moist loam soils with little or no vegetation	1.0	25
Moist clay soils with little or no vegetation	0.3	7.6
Moist sandy soils with dense vegetation	3.3	84
Moist loam soils with dense vegetation	2.0	5.1
Moist clay soils with dense or no vegetation	0.7	18

Horton's Infiltration Decay Rate: - most reported values in use by modelers range from 2 to 6/hr.an average value 4/hr is taken.

Horton's Final Infiltration Rate:-the study area is clayey soil type.so from below table 1.3mm/hr is selected

Table 3.9: Horton's Final Infiltration Rate by Soil Type (WQ-COSM, 2011)

	Final Infiltration Rate	
Soil Type	(in/hr)	(mm/hr)
Clay loam, silty clay loam, sandy clay, silty clay, clay	0.00 - 0.05	0.00 - 1.3
Sandy clay loam	0.05 - 0.15	1.3 - 3.8
Silt loam, loam	0.15 - 0.30	3.8 – 7.6
Sand, loamy sand, sandy loam	0.30 - 0.45	7.6 – 11.4

Drying Time:-used by modelers typically varies from 1 to 14 day depending on local climate during the rainfall seasons.in Addis Ababa rainy season condition as an assumption 4days taken. But, this factor is most important for continues simulation. For this study don't have any affect the result since the simulation is done for 15 minutes of rainfall intensity.

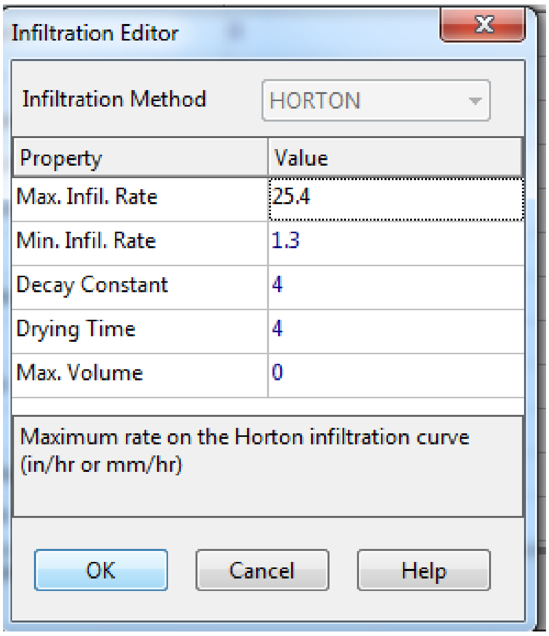


Figure 3.13: Infiltration editor Box

Manholes (joints) data: -invert elevation, Maximum depth

The invert elevation corresponds to the elevation of the corresponding junction. The maximum depth is the distance from the bottom of the junction to the ground surface. Both data's taken from raw data of the road alignment. The maximum depth is 2.0 meter for all manholes. The minimum nodal surface area is $1.21m^2$(1.1mX1.1m).

Conduit Pipe Data:-Shape, Diameter, Length

The shape of conduit pipe is circular with diameter of 30cm, 75cm and 85cm.the total length of the pipes differs from one location to another according to the distances of manholes which they are going to links.

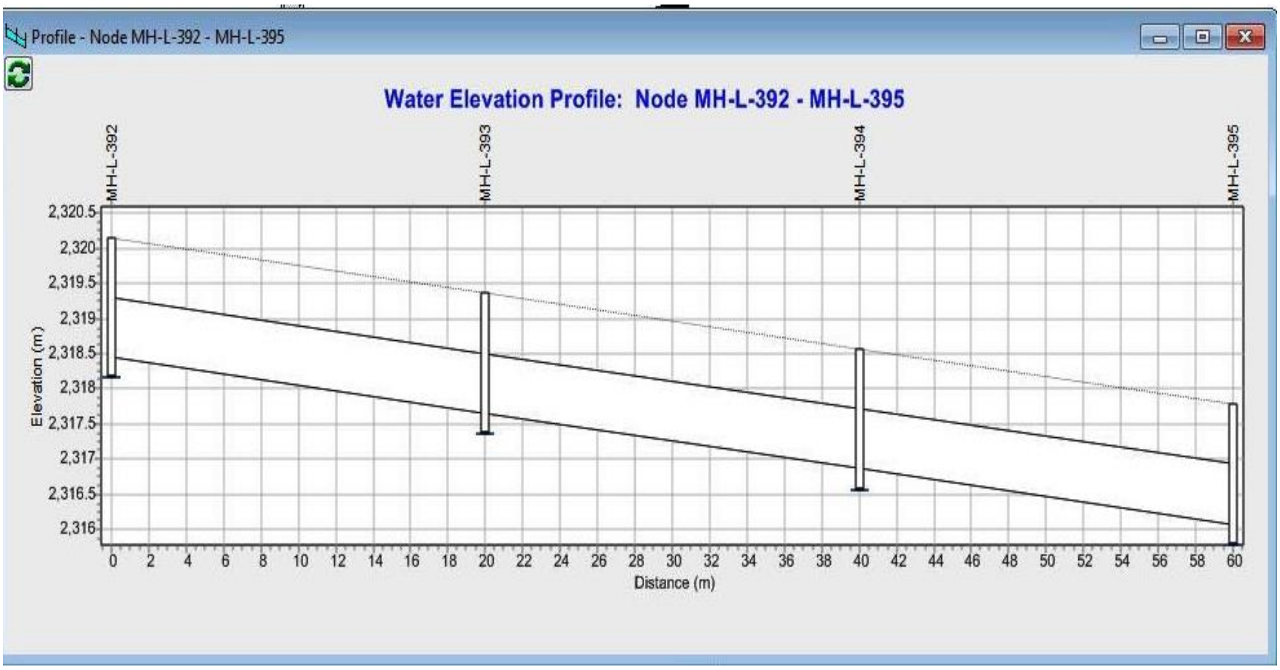


Figure 3.14: The characteristics of joints (manholes) and Conduits

Chapter Four

Results and Discussion

4.0 Introduction

This chapter compares the peak discharges outputs from rational method and with the modeling software. Identify the locations of flooding zones including the volume and time.

4.1 Peak Discharge Results comparison

Using rational Method(Rational formula) and EPA SWMM 5.1 modeling software for different years of return period, the results of peak discharge for all intake manholes calculated and the result shows nearly the same peak discharge rates. Table 4.1 showed the results of peak discharges by the two methods separately for the right side of the road and the left side of the road.

Table 4.1: Left & Right side inlet manholes Discharge comparison (10 years of return period)

Node(Manhole) Left Side	Inlet Discharge(CMS)		Node(Manhole) Right Side	Inlet Discharge(CMS)	
	Epa Swmm 5.1	Rational Formula		Epa Swmm 5.1	Rational Formula
MH-L-486	0.103	0.090	**MH-R-486**	0.033	0.030
MH-L-487	0.031	0.025	**MH-R-487**	0.031	0.029
MH-L-488	0.053	0.050	**MH-R-488**	0.016	0.015
MH-L-489	0.054	0.050	**MH-R-489**	0.016	0.015
MH-L-490	0.034	0.029	**MH-R-490**	0.028	0.025
MH-L-456	0.035	0.032	**MH-R-443**	0.013	0.012
MH-L-457	0.035	0.032	**MH-R-444**	0.013	0.012
MH-L-458	0.038	0.035	**MH-R-445**	0.024	0.022
MH-L-459	0.02	0.018	**MH-R-446**	0.012	0.010
MH-L-460	0.02	0.018	**MH-R-447**	0.011	0.010
MH-L-461	0.021	0.019	**MH-R-448**	0.021	0.019
MH-L-462	0.021	0.020	**MH-R-449**	0.01	0.009
MH-L-463	0.043	0.040	**MH-R-450**	0.009	0.009
MH-L-464	0.092	0.092	**MH-R-360**	0.016	0.015
MH-L-465	0.094	0.093	**MH-R-361**	0.014	0.011
MH-L-367	0.085	0.078	**MH-R-362**	0.014	0.011
MH-L-368	0.048	0.044	**MH-R-363**	0.039	0.037
MH-L-369	0.05	0.046	**MH-R-364**	0.048	0.044

MH-L-370	0.05	0.046	**MH-R-365**	0.024	0.023
MH-L-371	0.089	0.084	**MH-R-366**	0.024	0.023
MH-L-372	0.007	0.008	**MH-R-367**	0.047	0.044
MH-L-373	0.008	0.008	**MH-R-368**	0.023	0.022
MH-L-374	0.016	0.017	**MH-R-369**	0.023	0.021
MH-L-375	0.046	0.040	**MH-R-370**	0.022	0.018
MH-L-376	0.046	0.041	**MH-R-371**	0.021	0.017
MH-L-377	0.242	0.235	**MH-R-372**	0.041	0.033
MH-L-378	0.01	0.009	**MH-R-373**	0.02	0.019
MH-L-379	0.011	0.010	**MH-R-374**	0.02	0.018
MH-L-380	0.011	0.011	**MH-R-375**	0.038	0.035
MH-L-381	0.012	0.011	**MH-R-376**	0.018	0.017
MH-L-382	0.025	0.023	**MH-R-377**	0.018	0.016
MH-L-383	0.278	0.270	**MH-R-378**	0.034	0.032
MH-L-384	0.142	0.135	**MH-R-379**	0.016	0.015
MH-L-385	0.144	0.136	**MH-R-380**	0.016	0.015
MH-L-386	0.322	0.322	**MH-R-381**	0.031	0.029
MH-L-387	0.034	0.032	**MH-R-382**	0.015	0.014
MH-L-388	0.05	0.046	**MH-R-383**	0.022	0.020
MH-L-389	0.05	0.046	**MH-R-384**	0.041	0.039
MH-L-390	0.05	0.046	**MH-R-385**	0.021	0.019
MH-L-391	0.071	0.065	**MH-R-386**	0.021	0.020
MH-L-392	0.008	0.013	**MH-R-387**	0.045	0.042
MH-L-393	0.002	0.010	**MH-R-388**	0.088	0.083
MH-L-394	0.014	0.013	**MH-R-389**	0.016	0.014
MH-L-395	0.045	0.042	**MH-R-390**	0.024	0.022
MH-L-396	0.034	0.032	**MH-R-391**	0.016	0.015
MH-L-397	1.25	1.251	**MH-R-392**	0.022	0.020
MH-L-398	1.243	1.241	**MH-R-393**	0.016	0.013
MH-L-399	0.529	0.539	**MH-R-394**	0.008	0.006
MH-L-402	0.011	0.014	**MH-R-395**	0.012	0.011
MH-L-403	0.007	0.013	**MH-R-397**	0.023	0.021
MH-L-404	0.047	0.044	**MH-R-398**	0.008	0.007
MH-L-405	0.675	0.691	**MH-R-399**	0.012	0.011
MH-AL-01	0.613	0.619	**MH-R-400**	0.03	0.028
MH-L-406	0.612	0.611	**MH-R-401**	0.018	0.016
MH-L-407	0.056	0.051	**MH-R-402**	0.02	0.019
MH-L-408	0.049	0.044	**MH-R-403**	0.046	0.043
MH-L-409	0.02	0.018	**MH-R-404**	0.05	0.047
MH-L-410	0.025	0.023	**MH-R-405**	0.016	0.013
MH-L-411	0.045	0.042	**MH-R-406**	0.014	0.013
MH-L-412	0.02	0.018	**MH-R-407**	0.016	0.015

MH-L-413	0.018	0.017	**MH-R-408**	0.018	0.017
MH-L-414	0.036	0.030	**MH-R-409**	0.02	0.018
MH-L-415	0.016	0.017	**MH-R-410**	0.04	0.035
MH-L-416	0.018	0.017	**MH-R-411**	0.02	0.019
MH-L-417	0.117	0.112	**MH-R-412'**	0.019	0.018
MH-L-418	0.192	0.186	**MH-R-413**	0.016	0.016
MH-L-419	0.015	0.013	**MH-R-414**	0.014	0.013
MH-L-420	0.031	0.029	**MH-R-415**	0.01	0.009
MH-L-421	0.035	0.033	**MH-R-416**	0.05	0.047
MH-L-422	0.027	0.025	**MH-R-417**	0.021	0.020
MH-L-423	0.018	0.017	**MH-R-418**	0.017	0.016
MH-L-424	0.022	0.021	**MH-R-419**	0.024	0.023
MH-L-425	0.016	0.014	**MH-R-420**	0.051	0.048
MH-L-426	0.014	0.013	**MH-R-421**	0.017	0.015
MH-L-427	0.015	0.014	**MH-R-422**	0.047	0.044
MH-L-428	0.019	0.018	**MH-R-423**	0.019	0.018
MH-L-429	0.023	0.021	**MH-R-424**	0.016	0.015
MH-L-430	0.125	0.120	**MH-R-425**	0.027	0.025
MH-L-431	0.025	0.021	**MH-R-426**	0.012	0.011
MH-L-432	0.024	0.021	**MH-R-427**	0.012	0.011
MH-L-433	0.014	0.012	**MH-R-428**	0.025	0.023
MH-L-434	0.049	0.046	**MH-R-429**	0.014	0.013
MH-L-435	0.021	0.019	**MH-R-430**	0.016	0.015
MH-L-436	0.017	0.015	**MH-R-431**	0.021	0.020
MH-L-437	0.014	0.012	**MH-R-432**	0.012	0.011
MH-L-438	0.048	0.046	**MH-R-433**	0.014	0.013
MH-L-439	0.044	0.038	**MH-R-434**	0.032	0.030
MH-L-440	0.013	0.011	**MH-R-435**	0.039	0.037
MH-L-440'	0.012	0.010	**MH-R-436**	0.019	0.017
MH-L-441	0.012	0.010	**MH-R-437**	0.011	0.010
MH-L-442	0.05	0.047	**MH-R-438**	0.014	0.013
MH-L-443	0.036	0.034	**MH-R-439**	0.259	0.263
MH-L-444	0.029	0.026	**MH-R-440**	0.027	0.025
MH-L-445	0.024	0.022	**MH-R-441**	0.033	0.031
MH-YDK-L1	0.017	0.015	**MH-YDK-R1**	0.017	0.015
MH-YDK-L2	0.054	0.052	**MH-YDK-R2**	0.054	0.052
MH-YDK-L3	0.046	0.042	**MH-YDK-R3**	0.046	0.042
MH-YDK-L4	0.105	0.105	**MH-YDK-R4**	0.073	0.070
MH-YDK-L5	0.054	0.051	**MH-YDK-R5**	0.076	0.074
			MH-YDK-R6	0.037	0.035

4.2 Design (original) data review

The inlet discharge amount results for manholes from Eng. Zewdie Eskindir & CO.PLC have differences from results indicated above, due to the following reasons:-

- **IDF Curves: -** Since my location is nearest to Observatory station, I take the IDF curves of observatory from AACRA.but they use Bole IDF curves from AACRA for their design. The intensity values of Observatory station are greater than Bole station values.
- **Catchment Areas: -**The catchment areas for each manhole are delineated from ARCGIS. These areas are the paved road area including with their surrounding areas. But the original design source considers only the paved road area as a catchment area.

4.3 Flooding Results

Using 15 minutes duration, rainfall amount of 17mm, 23.75mm, 28.5mm, 34mm,38.25 mm and 42.5 mm for 2, 5, 10, 25,50 and 100 years of return periods respectively, the following flooding occurred mainly on the left side of the road. The total volume of flooding and hours of flooding for flooded manholes for different return periods defined as Table 4.2 and Table 4.3.

Table 4.2: flooded manholes for 10years and 25 years of return periods

10 Years Return Period				**25 Years Return Period**			
Flooded Node	**Hours Flooded**	**Maximum Rate (CMS)**	**Total Flooded volume(10^6 liter)**	**Flooded Node**	**Hours Flooded**	**Maximum Rate (CMS)**	**Total Flooded volume(10^6 liter)**
MH-L-397	0.25	0.567	0.34	**MH-L-397**	0.25	1.314	0.788
MH-L-398	0.25	1.371	0.823	**MH-L-398**	0.25	1.664	0.999
MH-L-406	0.25	0.582	0.349	**MH-L-406**	0.25	1.03	0.618
MH-L-412	0.25	0.404	0.242	**MH-L-412**	0.25	0.446	0.268
MH-L-413	0.25	0.016	0.009	**MH-L-413**	0.25	0.019	0.011
MH-L-414	0.25	0.038	0.023	**MH-L-414**	0.25	0.047	0.028
MH-L-415	0.25	0.036	0.022	**MH-L-415**	0.25	0.044	0.027
MH-L-424	0.25	0.488	0.293	**MH-L-424**	0.25	0.581	0.349
MH-L-432	0.25	0.125	0.075	**MH-L-432**	0.25	0.204	0.122
MH-L-433	0.25	0.012	0.007	**MH-L-433**	0.25	0.014	0.008
MH-L-440'	0.33	0.32	0.194	**MH-L-439**	0.17	0.025	0.015
				MH-L-440	0.17	0.024	0.014
				MH-L-440'	0.33	0.348	0.244

Table 4.3: flooded manholes for 50 years and 100 years of return periods

50 Years Return Period				100 Years Return Period			
Flooded Node	**Hours Flooded**	**Maximum Rate (CMS)**	**Total Flooded volume(10^6 liter)**	**Flooded Node**	**Hours Flooded**	**Maximum Rate (CMS)**	**Total Flooded volume(10^6 liter)**
MH-L-385	0.17	0.035	0.021	**MH-L-383**	0.17	0.033	0.019
MH-L-395	0.17	0.067	0.04	**MH-L-384**	0.17	0.105	0.063
MH-L-396	0.17	0.028	0.017	**MH-L-385**	0.17	0.161	0.096
MH-L-397	0.25	1.823	1.094	**MH-L-393**	0.17	0.001	0.001
MH-L-398	0.25	1.898	1.139	**MH-L-394**	0.17	0.002	0.001
MH-AL-01	0.17	0.078	0.047	**MH-L-395**	0.25	0.131	0.079
MH-L-406	0.25	1.311	0.786	**MH-L-396**	0.17	0.072	0.043
MH-L-412	0.25	0.481	0.288	**MH-L-397**	0.25	2.116	1.27
MH-L-413	0.25	0.021	0.013	**MH-L-398**	0.25	2.128	1.277
MH-L-414	0.25	0.057	0.034	**MH-AL-01**	0.25	0.308	0.185
MH-L-415	0.17	0.052	0.031	**MH-L-406**	0.25	1.427	0.856
MH-L-424	0.33	0.628	0.389	**MH-L-411**	0.17	0.017	0.01
MH-L-432	0.25	0.265	0.159	**MH-L-412**	0.25	0.504	0.302
MH-L-433	0.25	0.016	0.009	**MH-L-413**	0.25	0.024	0.014
MH-L-439	0.17	0.055	0.033	**MH-L-414**	0.25	0.064	0.038
MH-L-440	0.17	0.06	0.036	**MH-L-415**	0.25	0.038	0.023
MH-L-440'	0.33	0.347	0.281	**MH-L-423**	0.17	0.047	0.028
MH-R-439	0.17	0.012	0.007	**MH-L-424**	0.33	0.698	0.453
				MH-L-431	0.17	0.027	0.016
				MH-L-432	0.25	0.31	0.186
				MH-L-433	0.25	0.017	0.01
				MH-L-437	0.17	0.009	0.006
				MH-L-438	0.17	0.006	0.003
				MH-L-439	0.25	0.082	0.049
				MH-L-440	0.25	0.02	0.012
				MH-L-440'	0.33	0.362	0.272
				MH-R-439	0.25	0.133	0.08
				MH-YDK-L4	0.17	0.001	0.001

As we seen in Table 4.3, MH-YDK-L4 is assigned as railway manhole and only flooded at the time of 100 years of return period. Figure 4.1 shows when MH-L-431 fully occupied, the water comes from rail track (MH-YDK-L4) been full and flooding starts on the rail track system for 10.2 minutes of duration.

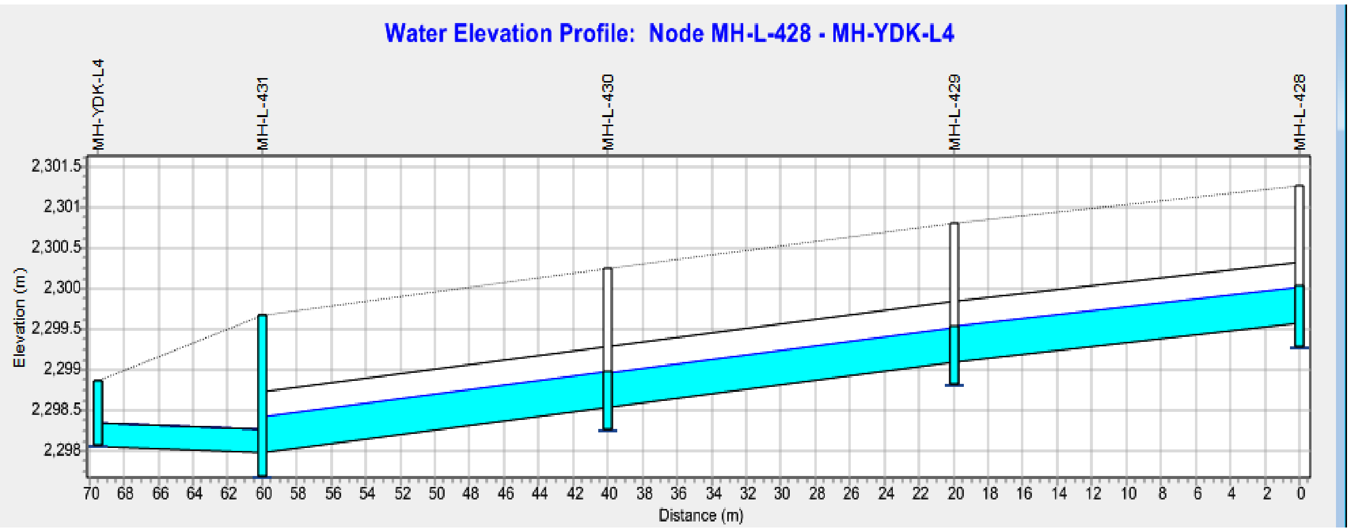


Figure 4.1:100 years of return period flooded manholes (MH-YDK-L4 and MH-L-431)

MH-L-428 location is 100 meter far from Global Hotel or in front of United Bank head office.

The EPA SWMM 5.1 rainfall-runoff simulation software gives the following outputs of manhole flooded as a profile for 2, 5, 10, 25,50 and 100 years of return periods. The following below figures shows some of flooded manholes with their specific location.

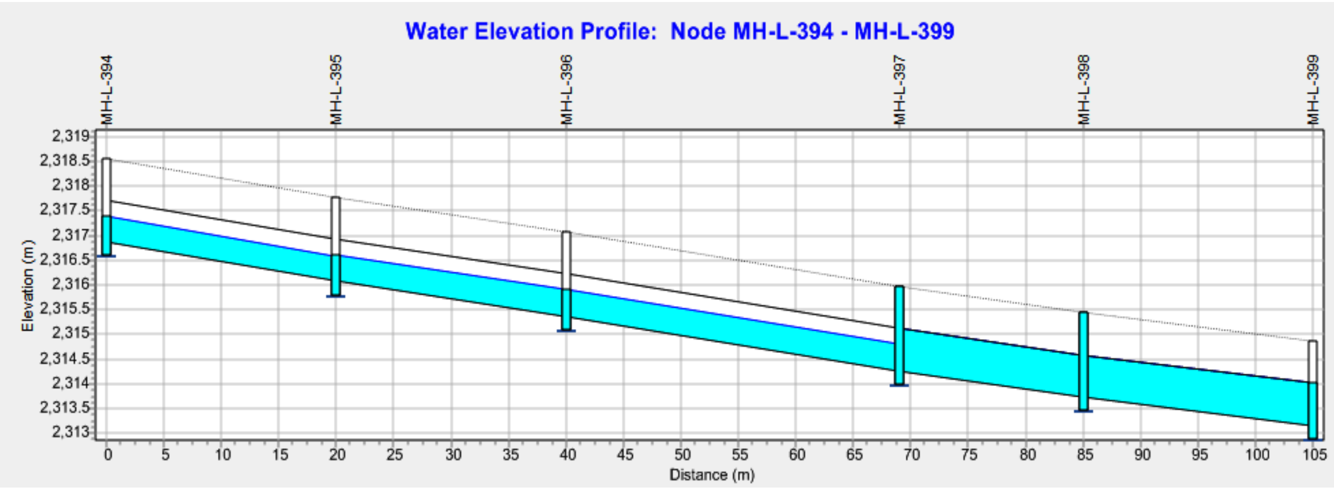


Figure 4.2:-10years of return period flooded manholes (MH-L-397 and MH-L-398)

The locations of MH-L-397 and MH-L-398 are infront of Mujib Towers near NOC fuel station, 1.08 km from mesualekiya.

Including the above flooding results that comes from design problem, an additional volume of flooding expected due to construction problems as I seen from site visit.

A.Manhole opening depth less than 5 cm

B. Manhole opening closed with muds/Garbage

C. Manhole cover misplaced and partly closed the opening

Figure 4.3: Construction problems on the study area locations

4.4 Remedial Measures

According to the results seen, when the design checked by 25 years of return period rainfall, 12 numbers of manholes (MH-L-397, MH-L-398, MH-L-406, MH-L-412, MH-L-413, MH-L-415, MH-L-424, MH-L-432, MH-L-433, MH-L-439, MH-L-440, MH-L-440') are flooded. By simulating by different inputs, the following recommendations are given:-

- Increase the sizes and numbers of conduits to stop flooding of manholes.

  <u>For Manhole MH-L-397</u>

  Change the diameter of PIPE-L-44(MH-L-396 to MH-L-397) from 0.85 meter to 1.06 meter.

  <u>For Manhole MH-L-398</u>

  Change the diameter of PIPE-L-45(MH-L-397 to MH-L-398) from 0.85 meter to 1.22meter.

  <u>For Manholes (MH-L-406, MH-L-412, MH-L-413, MH-L-415)</u>

  Change the diameter of 17 pipes (PIPE-L52 to PIPE-L70) from 0.75 meter to 1.06 meter.

  <u>For Manholes (MH-L-424 and MH-L-432)</u>

  Change the diameter of 11 pipes (PIPE-L71 to PIPE-L82) from 0.75 meter to 1.22 meter.

  <u>For Manholes (MH-L-433, MH-L-439, MH-L-440, MH-L-440')</u>

  Change the single pipe diameter to double piping for 10 pipes (PIPE-L83 to PIPE-L93) from diameter 0.85 meter to 1.5 meter (double piping of 0.75 meter and the numbers will be 20 pipes) and increase the manhole width to install the two pipes together.

Chapter Five

Conclusion and Recommendation

5.1 Conclusion

This study presents a systematic approach in the identification of flooded manhole locations with the application of flow models EPA SWMM 5.1 and ARCGIS. Using ARCGIS 10.0 extracting my study area digital elevation model (DEM) from addis ababa 30 x30 meter DEM.Then by using spatial analyst tools on ARCGIS, delineating catchment areas for each manholes of the study area.Intensity-Duration-Frequency (IDF) curve taken from Addis Ababa City Road Authority (AACRA) manual, the Observatory station IDF curves nearest to my study area. Using EPA SWMM 5.1 software and rational formula methods; inputting all data's that needed for rainfall-runoff processing for different return periods of rainfall.to determine percentage of imperviousness and runoff coefficients of the catchment areas, by applying two methods. The one is by visiting the study area catchment locations and the other one, by overlaying catchment outputs of ARCGIS with Google Earth Pro. The outputs of inlet discharge to manholes from both methods nearly the same results.

As seen from the modeling results, flooding occurs on the left side (from Meshualekiya to Gotera) of road starting from 2 years of return period of rainfall with flooding time takes a minimum of 10.2 minutes to the maximum of 19.8 minutes.in the railway path, flooding occurs only in one manhole, at the time of 100 years of return period rainfall with flooding time of 10.2 minutes but in the others return periods of 2, 5,10,25,50 years no any flooding manholes encountered.

Due to the flooding the following situation will be seen on the flooded location:-

- Traffic jam for the specified flooding time.
- Infrastructure damages(road, drainage structures)
- damage to private property, including homes and businesses

5.2 Recommendations

For future studies related with urban flooding and urban drainage designs, EPA SWMM software is recommended. Regarding catchment area selections, designers should take not only the paved catchment areas, should include the catchment areas from neighbor sides of the road. For precision and good results of drainage design, specific time (5min, 10min, 15 min…) recording data’s of rainfall are more important than 24 hours of rainfall data’s and IDF curves. If IDF curves of stations are taken, should be nearest to the study area locations.

References

Addis Ababa City Roads Authority (AACRA - 2003). Drainage Design Manual, Ethiopia

Alemayehu Z. (2007). Modeling of Flood hazard management for forecasting and emergency response of 'Koka' area within Awash River basin using remote sensing and GIS method, Msc. Thesis.Addis ababa university,faculity of science

AREMA(2003). Practical Guide to Railway Engineering

Barbara P. and Jack M. (2012). Watershed and Drainage Delineation by Pour Point in Arc Map 10, Tutorial

Backhaus.A et.al (2014). Water Resilient Green Cities in Africa, Work package 2.Ethiopia,addis ababa.

Chow.V. T. (1964). Handbook of Applied Hydrology, McGraw-Hill, New York.

Dagnachew A. (2009). Study of the urban Drainage System in Addis Ababa, Yeka Sub-City,Msc. thesis,Addis ababa university,faculity of technology

Daniel, A. (2007). Assessment of flood risk in Dire DawaTown, EasternEthiopia, Using GIS.Msc. Thesis,Addis ababa university,technology faculty.

Ethiopian Opinion (2014). Around 765 thousands birr damaged due to heavy flood in Addis Ababa, available at https://ethiopiantimes.wordpress.com/tag/addis-abeba/ , last assessed July 18,2015

Federal Highway Administration(2014).HY-8 User Manual (v7.3), Pennsylvania State University

Government of the Hong Kong Special Administrative Region (2000). Storm water drainage manual (Planning, Design and Management).Hong Kong.

Government of Malaysia department of irrigation and drainage (2010).Rational method of flood estimation for rural catchments in Peninsular Malaysia.Malaysia.

Halcrow(2009).ISIS Free & ISIS Professional Quick Start Guide.United Kingdom

Nott J. (2006). Extreme Events: A Physical Reconstruction and Risk Assessment. Cambridge University Press. New York.

Janet B. et.al (2008). Automatic Calibration of the U.S. EPA SWMM Model for a Large Urban Catchment,Journal of Hydraulic Engineering. Journal of Hydraulic Engineering, Vol. 134, No. 4,April 1, 2008. ©ASCE,

Lamia Abdul (2012). Developing Rainfall Intensity-Duration-Frequency Relationship For Basrah City. Basrah University, Iraq

Lewis A. Rossman(2010). Storm Water Management Model User's Manual,United states environmental protection agency.

Linmei Nie(2004). Flooding Analysis of Urban Drainage Systems, Dissertation paper.Trondheim, Norway

OPW (2009). The Planning System and Flood Risk Management,Guidelines for Planning Authorities.Ireland.

RailCorp Engineering Manual(2009) Track Drainage, Version 1.2.NSW Government

Railnews.co.in (2013), Thiruvananthapuram, available at http://www.railnews.co.in/thiruvananthapuram-flooding-mayor-railways-trade-charges-for-flooding/ last assessed July 21, 2015

ReliefWeb (2013). Ethiopia: Floods (as of 29 Apr 2013), available at http://reliefweb.int/map/ethiopia/ethiopia-floods-29-apr-2013-location-map , last assessed July 18, 2015

Schmitt T.G. et al. (2004).Analysis and modeling of flooding in urban drainage systems,Journal of Hydrology. Kaiserslautern, Germany

Senarathne P.C. (2006) Learning to live with Floods,Natural Hazards and Disasters, Sri Lankan-German Development Cooperation.Sri Lanka

Singh S.K. (2004). Analysis of uncertainties in Digital Elevation Models in Flood(Hydraulic) Modeling

Tekeli et.al (2007). Estimation of flood discharge for small watershed using SCS curve number and geographic information system, International Congress on river basin management.

Urban Watersheds Research Institute Water (2011).Quality Capture Optimization and Statistics Model (WQ-COSM). UrbanWatersheds Research Institute, Inc.,Denver, CO, USA.

Valentin Heimhuber(2013).GIS Based Flood Modeling as Part of an Integrated Development Strategy for Informal Settlements

World Food Programme(WFP)(2006). Extensive flooding in Ethiopia, available at https://www.wfp.org/stories/extensive-flooding-ethiopia-wfp-update ,last assessed July 25,2015

World watch institute (2006). Ethiopia Hit by Flooding in North, South and East, available at http://www.worldwatch.org/node/4591 , last assessed July 26,2015

ANNEXES

Appendix A: Sub-catchment summary

Table A1: Sub-catchment summary

Name	Area(ha)	Width(m)	%Imperv	%Slope	Outlet
SC-LS-1	0.26	34.07	83.00	2.8900	MH-L-486
SC-LS-2	0.07	50.60	79.00	3.0200	MH-L-487
SC-LS-3	0.13	13.38	93.00	3.7300	MH-L-488
SC-LS-4	0.13	16.66	93.00	3.7300	MH-L-489
SC-LS-5	0.08	48.01	84.00	3.5900	MH-L-490
SC-LS-6	0.08	17.32	96.00	3.1500	MH-L-456
SC-LS-7	0.08	16.86	96.00	3.1500	MH-L-457
SC-LS-8	0.09	45.17	97.00	3.7100	MH-L-458
SC-LS-9	0.05	22.60	96.00	3.2300	MH-L-459
SC-LS-10	0.05	21.67	96.00	3.2300	MH-L-460
SC-LS-11	0.05	21.69	96.00	3.8200	MH-L-461
SC-LS-12	0.05	21.81	97.00	3.8700	MH-L-462
SC-LS-13	0.10	42.07	99.00	3.8700	MH-L-463
SC-LS-14	0.24	17.49	97.00	3.1200	MH-L-464
SC-LS-15	0.24	20.05	97.00	3.1200	MH-L-465
SC-LS-16	0.20	35.54	94.00	3.6500	MH-L-367
SC-LS-17	0.11	40.83	97.00	3.3700	MH-L-368
SC-LS-18	0.12	40.86	97.00	3.3900	MH-L-369
SC-LS-19	0.12	39.83	98.00	3.3900	MH-L-370
SC-LS-20	0.22	27.67	96.00	3.6700	MH-L-371

SC-LS-21	0.02	17.22	100.00	1.4700	MH-L-372
SC-LS-22	0.02	18.59	100.00	1.9600	MH-L-373
SC-LS-23	0.04	40.02	100.00	1.9600	MH-L-374
SC-LS-24	0.11	17.13	85.00	4.0900	MH-L-375
SC-LS-25	0.12	13.16	85.00	4.0900	MH-L-376
SC-LS-26	0.60	46.62	96.00	5.2100	MH-L-377
SC-LS-27	0.02	25.54	100.00	2.6200	MH-L-378
SC-LS-28	0.03	27.27	100.00	2.7700	MH-L-379
SC-LS-29	0.03	28.38	100.00	3.0500	MH-L-380
SC-LS-30	0.03	29.80	100.00	3.1900	MH-L-381
SC-LS-31	0.06	62.25	100.00	3.3100	MH-L-382
SC-LS-32	0.71	40.95	93.00	5.9100	MH-L-383
SC-LS-33	0.34	33.33	97.00	6.1200	MH-L-384
SC-LS-34	0.35	33.32	94.00	6.6900	MH-L-385
SC-LS-35	0.82	48.52	99.00	6.5200	MH-L-386
SC-LS-36	0.08	47.78	100.00	3.5600	MH-L-387
SC-LS-37	0.12	25.07	93.00	4.4600	MH-L-388
SC-LS-38	0.12	24.92	93.00	4.4600	MH-L-389
SC-LS-39	0.12	25.14	93.00	4.4600	MH-L-390
SC-LS-40	0.17	36.69	94.00	5.8000	MH-L-391
SC-LS-41	0.02	15.38	100.00	3.5800	MH-L-392
SC-LS-42	0.00	4.54	100.00	2.8800	MH-L-393
SC-LS-43	0.03	33.39	100.00	2.1600	MH-L-394
SC-LS-44	0.11	40.81	100.00	3.9200	MH-L-395
SC-LS-45	0.08	44.87	100.00	3.1000	MH-L-396

SC-LS-46	4.45	105.25	88.00	2.8400	MH-L-397
SC-LS-47	1.52	60.87	88.00	4.6100	MH-L-399
SC-LS-49	0.03	27.75	100.00	3.0200	MH-L-402
SC-LS-50	0.02	18.27	100.00	3.9100	MH-L-403
SC-LS-51	0.11	40.75	100.00	4.5800	MH-L-404
SC-LS-52	2.15	57.93	84.00	5.9400	MH-L-405
SC-LS-53	0.13	38.58	96.00	3.1700	MH-L-407
SC-LS-54	0.12	40.23	95.00	4.6300	MH-L-408
SC-LS-55	0.05	22.11	95.00	4.3000	MH-L-409
SC-LS-56	0.06	20.01	97.00	4.6700	MH-L-410
SC-LS-57	0.11	41.28	98.00	5.1000	MH-L-411
SC-LS-58	0.05	21.68	97.00	3.6400	MH-L-412
SC-LS-59	0.04	22.61	95.00	5.2100	MH-L-413
SC-LS-60	0.08	46.42	98.00	6.1100	MH-L-414
SC-LS-61	0.04	21.00	100.00	3.1100	MH-L-415
SC-LS-62	0.04	20.91	100.00	3.2800	MH-L-416
SC-LS-63	0.28	33.42	100.00	7.6900	MH-L-417
SC-LS-64	0.48	31.92	95.00	6.2200	MH-L-418
SC-LS-65	0.04	37.56	100.00	2.0700	MH-L-419
SC-LS-66	0.07	18.88	100.00	3.5100	MH-L-420
SC-LS-67	0.08	18.23	100.00	3.5700	MH-L-421
SC-LS-68	0.06	56.21	100.00	3.2100	MH-L-422
SC-LS-69	0.04	23.31	100.00	2.6600	MH-L-423
SC-LS-70	0.05	21.06	100.00	2.7300	MH-L-424
SC-LS-71	0.04	38.44	100.00	2.1000	MH-L-425

SC-LS-72	0.03	35.11	100.00	3.2700	MH-L-426
SC-LS-73	0.04	24.65	100.00	3.3900	MH-L-427
SC-LS-74	0.05	21.97	100.00	4.2800	MH-L-428
SC-LS-75	0.05	20.73	100.00	4.5200	MH-L-429
SC-LS-76	0.30	39.57	97.00	3.4800	MH-L-430
SC-LS-77	0.06	19.00	82.00	2.7600	MH-L-431
SC-LS-78	0.06	18.44	82.00	2.7600	MH-L-432
SC-LS-79	0.03	33.96	100.00	1.8200	MH-L-433
SC-LS-80	0.12	39.37	100.00	2.7600	MH-L-434
SC-LS-81	0.05	52.27	100.00	2.4300	MH-L-435
SC-LS-82	0.04	43.05	100.00	2.2100	MH-L-436
SC-LS-83	0.03	34.02	100.00	1.8200	MH-L-437
SC-LS-84	0.12	40.50	100.00	3.3700	MH-L-438
SC-LS-85	0.11	41.57	85.00	3.3200	MH-L-439
SC-LS-86	0.03	14.30	80.00	3.2600	MH-L-440
SC-LS-87	0.03	15.05	78.00	2.6800	MH-L-440'
SC-LS-88	0.03	31.55	78.00	2.6800	MH-L-441
SC-LS-89	0.12	39.98	100.00	2.7600	MH-L-442
SC-LS-90	0.09	43.79	100.00	3.1600	MH-L-443
SC-LS-91	0.07	48.96	93.00	2.9700	MH-L-444
SC-LS-92	0.06	62.80	100.00	2.7200	MH-L-445
SC-RS-93	0.08	48.99	100.00	2.6300	MH-R-486
SC-RS-94	0.07	50.46	100.00	2.6200	MH-R-487
SC-RS-95	0.04	27.72	100.00	3.4900	MH-R-488
SC-RS-96	0.04	29.60	100.00	3.4900	MH-R-489

SC-RS-97	0.07	54.86	97.00	2.9100	MH-R-490
SC-RS-98	0.03	28.46	94.00	2.8700	MH-R-443
SC-RS-99	0.03	29.63	97.00	2.8200	MH-R-444
SC-RS-100	0.06	62.02	92.00	2.7700	MH-R-445
SC-RS-101	0.03	32.66	95.00	2.7100	MH-R-446
SC-RS-102	0.03	34.29	96.00	2.6200	MH-R-447
SC-RS-103	0.05	76.43	98.00	2.5700	MH-R-448
SC-RS-104	0.02	25.13	96.00	2.4000	MH-R-449
SC-RS-105	0.02	23.36	100.00	2.3600	MH-R-450
SC-RS-106	0.04	39.11	100.00	2.2300	MH-R-360
SC-RS-107	0.03	36.30	100.00	1.6500	MH-R-361
SC-RS-108	0.03	33.55	100.00	1.7900	MH-R-362
SC-RS-109	0.09	30.87	100.00	3.2300	MH-R-363
SC-RS-110	0.12	13.50	90.00	2.5500	MH-R-364
SC-RS-111	0.06	20.61	100.00	4.0100	MH-R-365
SC-RS-112	0.06	20.77	100.00	3.9900	MH-R-366
SC-RS-113	0.11	41.97	100.00	3.3600	MH-R-367
SC-RS-114	0.06	21.17	100.00	3.3400	MH-R-368
SC-RS-115	0.05	21.47	100.00	3.3300	MH-R-369
SC-RS-116	0.05	22.06	77.00	3.9100	MH-R-370
SC-RS-117	0.05	21.89	76.00	3.8600	MH-R-371
SC-RS-118	0.10	44.31	79.00	3.2700	MH-R-372
SC-RS-119	0.05	22.41	100.00	3.7900	MH-R-373
SC-RS-120	0.05	22.81	100.00	3.7600	MH-R-374
SC-RS-121	0.09	45.37	100.00	3.1900	MH-R-375

SC-RS-122	0.04	23.06	100.00	3.1700	MH-R-376
SC-RS-123	0.04	23.46	100.00	3.1400	MH-R-377
SC-RS-124	0.08	48.05	100.00	3.1100	MH-R-378
SC-RS-125	0.04	24.24	100.00	3.0800	MH-R-379
SC-RS-126	0.04	25.00	100.00	3.0500	MH-R-380
SC-RS-127	0.07	51.23	100.00	3.0200	MH-R-381
SC-RS-128	0.04	26.29	100.00	2.9800	MH-R-382
SC-RS-129	0.05	21.38	100.00	3.2900	MH-R-383
SC-RS-130	0.10	43.05	100.00	2.7100	MH-R-384
SC-RS-131	0.05	21.73	100.00	3.2600	MH-R-385
SC-RS-132	0.05	21.57	100.00	3.2800	MH-R-386
SC-RS-133	0.11	42.06	100.00	3.3200	MH-R-387
SC-RS-134	0.21	35.37	100.00	59.1300	MH-R-388
SC-RS-135	0.04	39.71	100.00	2.0100	MH-R-389
SC-RS-136	0.06	59.79	100.00	2.9700	MH-R-390
SC-RS-137	0.04	24.29	100.00	2.6400	MH-R-391
SC-RS-138	0.05	21.06	100.00	2.7200	MH-R-392
SC-RS-139	0.04	39.77	100.00	1.8700	MH-R-393
SC-RS-140	0.02	19.22	100.00	1.7300	MH-R-394
SC-RS-141	0.03	30.87	100.00	2.7700	MH-R-395
SC-RS-143	0.05	20.89	100.00	3.3300	MH-R-397
SC-RS-144	0.02	19.46	100.00	2.0800	MH-R-398
SC-RS-145	0.03	29.07	100.00	2.9100	MH-R-399
SC-RS-146	0.07	51.90	100.00	3.3800	MH-R-400
SC-RS-147	0.04	23.52	100.00	3.6100	MH-R-401

SC-RS-148	0.05	21.92	100.00	3.7900	MH-R-402
SC-RS-149	0.11	41.67	100.00	3.9300	MH-R-403
SC-RS-150	0.12	40.15	100.00	2.7600	MH-R-404
SC-RS-151	0.04	39.17	100.00	1.9700	MH-R-405
SC-RS-152	0.03	27.06	100.00	3.2900	MH-R-406
SC-RS-153	0.04	24.41	100.00	3.4800	MH-R-407
SC-RS-154	0.04	23.04	100.00	3.6600	MH-R-408
SC-RS-155	0.05	22.15	100.00	3.7600	MH-R-409
SC-RS-156	0.10	43.52	88.00	3.2600	MH-R-410
SC-RS-157	0.05	21.80	100.00	3.2500	MH-R-411
SC-RS-158	0.05	22.10	100.00	3.2300	MH-R-412(OUTFALL))
SC-RS-159	0.04	22.66	100.00	3.7000	MH-R-412'
SC-RS-160	0.04	24.22	100.00	3.5400	MH-R-413
SC-RS-161	0.03	27.71	100.00	3.2400	MH-R-414
SC-RS-162	0.02	25.38	100.00	2.6000	MH-R-415
SC-RS-163	0.12	40.13	100.00	2.7600	MH-R-416
SC-RS-164	0.05	21.53	100.00	2.7000	MH-R-417
SC-RS-165	0.04	24.21	100.00	2.3700	MH-R-418
SC-RS-166	0.06	61.63	100.00	3.0200	MH-R-419
SC-RS-167	0.12	40.23	100.00	3.4000	MH-R-420
SC-RS-168	0.04	42.58	100.00	2.0800	MH-R-421
SC-RS-169	0.11	41.15	100.00	3.3500	MH-R-422
SC-RS-170	0.04	22.43	100.00	3.7200	MH-R-423
SC-RS-171	0.04	25.18	100.00	3.4500	MH-R-424
SC-RS-172	0.06	57.16	100.00	0.5000	MH-R-425

SC-RS-173	0.03	29.50	100.00	2.4900	MH-R-426
SC-RS-174	0.03	29.80	100.00	2.5000	MH-R-427
SC-RS-175	0.06	61.42	100.00	2.7800	MH-R-428
SC-RS-176	0.03	27.59	100.00	2.5700	MH-R-429
SC-RS-177	0.04	25.19	100.00	2.6200	MH-R-430
SC-RS-178	0.05	52.87	100.00	2.7000	MH-R-431
SC-RS-179	0.03	30.73	100.00	3.0200	MH-R-432
SC-RS-180	0.03	27.25	100.00	3.2800	MH-R-433
SC-RS-181	0.08	49.36	100.00	3.0500	MH-R-434
SC-RS-182	0.09	44.42	100.00	2.6900	MH-R-435
SC-RS-183	0.04	46.02	100.00	2.3500	MH-R-436
SC-RS-184	0.03	27.80	100.00	2.6400	MH-R-437
SC-RS-185	0.03	29.31	100.00	2.8800	MH-R-438
SC-RS-186	0.73	41.57	92.00	2.3800	MH-R-439
SC-RS-187	0.06	57.15	100.00	3.2000	MH-R-440
SC-RS-188	0.08	48.61	100.00	3.5300	MH-R-441
SC-LS-189	4.46	102.11	88.00	2.8400	MH-L-398
SC-LS-190	2.14	57.57	84.00	3.2800	MH-L-406
SC-LS-191	2.14	57.75	84.00	3.2800	MH-AL-01
SC-LS-R-1	0.05	5.50	100.00	0.5000	MH-YDK-L1
SC-RS-R-1	0.05	5.50	100.00	0.5000	MH-YDK-R1
SC-LS-R-2	0.20	5.50	100.00	1.5000	MH-YDK-L2
SC-RS-R-2	0.20	5.50	100.00	1.5000	MH-YDK-R2
SC-LS-R-3	0.14	5.50	100.00	3.3000	MH-YDK-L3
SC-RS-R-3	0.14	5.50	100.00	3.3000	MH-YDK-R3

SC-RS-R-4	0.26	5.50	100.00	3.2000	MH-YDK-R4
SC-LS-R-4	0.49	5.50	100.00	2.7000	MH-YDK-L4
SC-RS-R-5	0.30	5.50	100.00	2.2000	MH-YDK-R5
SC-LS-R-5	0.20	5.50	100.00	1.4000	MH-YDK-L5
SC-RS-R-6	0.13	5.50	100.00	0.9000	MH-YDK-R6

Appendix B: Node (Manholes) summary

Table B1:-Node (Manholes) summary

Name	Type	Invert Elev. (m)	Max. Depth (m)	Ponded Area
MH-L-486	JUNCTION	2338.00	2.00	0.0
MH-L-487	JUNCTION	2338.10	2.00	0.0
MH-L-488	JUNCTION	2338.20	2.00	0.0
MH-L-489	JUNCTION	2338.30	2.00	0.0
MH-L-490	JUNCTION	2338.40	2.00	0.0
MH-L-456	JUNCTION	2338.38	2.00	0.0
MH-L-457	JUNCTION	2338.27	2.00	0.0
MH-L-458	JUNCTION	2338.15	2.00	0.0
MH-L-459	JUNCTION	2338.03	2.00	0.0
MH-L-460	JUNCTION	2337.91	2.00	0.0
MH-L-461	JUNCTION	2337.79	2.00	0.0
MH-L-462	JUNCTION	2337.56	2.00	0.0
MH-L-463	JUNCTION	2337.28	2.00	0.0
MH-L-464	JUNCTION	2336.99	2.00	0.0
MH-L-465	JUNCTION	2336.71	2.00	0.0
MH-L-367	JUNCTION	2336.20	2.00	0.0
MH-L-368	JUNCTION	2335.77	2.00	0.0
MH-L-369	JUNCTION	2335.29	2.00	0.0
MH-L-370	JUNCTION	2334.79	2.00	0.0
MH-L-371	JUNCTION	2334.30	2.00	0.0

MH-L-372	JUNCTION	2333.80	2.00	0.0
MH-L-373	JUNCTION	2333.30	2.00	0.0
MH-L-374	JUNCTION	2332.81	2.00	0.0
MH-L-375	JUNCTION	2332.31	2.00	0.0
MH-L-376	JUNCTION	2331.78	2.00	0.0
MH-L-377	JUNCTION	2331.24	2.00	0.0
MH-L-378	JUNCTION	2330.67	2.00	0.0
MH-L-379	JUNCTION	2330.08	2.00	0.0
MH-L-380	JUNCTION	2329.47	2.00	0.0
MH-L-381	JUNCTION	2328.84	2.00	0.0
MH-L-382	JUNCTION	2328.18	2.00	0.0
MH-L-383	JUNCTION	2327.37	2.00	0.0
MH-L-384	JUNCTION	2326.59	2.00	0.0
MH-L-385	JUNCTION	2324.58	2.00	0.0
MH-L-386	JUNCTION	2323.79	2.00	0.0
MH-L-387	JUNCTION	2322.19	2.00	0.0
MH-L-388	JUNCTION	2321.39	2.00	0.0
MH-L-389	JUNCTION	2320.57	2.00	0.0
MH-L-390	JUNCTION	2319.76	2.00	0.0
MH-L-391	JUNCTION	2318.96	2.00	0.0
MH-L-392	JUNCTION	2318.16	2.00	0.0
MH-L-393	JUNCTION	2317.36	2.00	0.0
MH-L-394	JUNCTION	2316.57	2.00	0.0
MH-L-395	JUNCTION	2315.78	2.00	0.0
MH-L-396	JUNCTION	2315.07	2.00	0.0

MH-L-397	JUNCTION	2313.97	2.00	0.0
MH-L-398	JUNCTION	2313.44	2.00	0.0
MH-L-399	JUNCTION	2312.86	2.00	0.0
MH-L-402	JUNCTION	2311.44	2.00	0.0
MH-L-403	JUNCTION	2310.97	2.00	0.0
MH-L-404	JUNCTION	2310.50	2.00	0.0
MH-L-405	JUNCTION	2310.00	2.00	0.0
MH-AL-01	JUNCTION	2309.70	2.00	0.0
MH-L-406	JUNCTION	2309.48	2.00	0.0
MH-L-407	JUNCTION	2309.19	2.00	0.0
MH-L-408	JUNCTION	2308.45	2.00	0.0
MH-L-409	JUNCTION	2307.55	2.00	0.0
MH-L-410	JUNCTION	2306.96	2.00	0.0
MH-L-411	JUNCTION	2306.30	2.00	0.0
MH-L-412	JUNCTION	2305.87	2.00	0.0
MH-L-413	JUNCTION	2305.67	2.00	0.0
MH-L-414	JUNCTION	2305.47	2.00	0.0
MH-L-415	JUNCTION	2305.27	2.00	0.0
MH-L-416	JUNCTION	2305.07	2.00	0.0
MH-L-417	JUNCTION	2304.53	2.00	0.0
MH-L-418	JUNCTION	2303.92	2.00	0.0
MH-L-419	JUNCTION	2303.31	2.00	0.0
MH-L-420	JUNCTION	2302.74	2.00	0.0
MH-L-421	JUNCTION	2302.22	2.00	0.0
MH-L-422	JUNCTION	2301.63	2.00	0.0

MH-L-423	JUNCTION	2301.03	2.00	0.0
MH-L-424	JUNCTION	2300.52	2.00	0.0
MH-L-425	JUNCTION	2300.34	2.00	0.0
MH-L-426	JUNCTION	2300.00	2.00	0.0
MH-L-427	JUNCTION	2299.66	2.00	0.0
MH-L-428	JUNCTION	2299.28	2.00	0.0
MH-L-429	JUNCTION	2298.81	2.00	0.0
MH-L-430	JUNCTION	2298.25	2.00	0.0
MH-L-431	JUNCTION	2297.68	2.00	0.0
MH-L-432	JUNCTION	2297.28	2.00	0.0
MH-L-433	JUNCTION	2297.03	2.00	0.0
MH-L-434	JUNCTION	2296.78	2.00	0.0
MH-L-435	JUNCTION	2296.00	2.00	0.0
MH-L-436	JUNCTION	2295.66	2.00	0.0
MH-L-437	JUNCTION	2295.46	2.00	0.0
MH-L-438	JUNCTION	2295.29	2.00	0.0
MH-L-439	JUNCTION	2295.10	2.00	0.0
MH-L-440	JUNCTION	2294.93	2.00	0.0
MH-L-440'	JUNCTION	2294.76	2.00	0.0
MH-L-441	JUNCTION	2294.69	2.00	0.0
MH-L-442	JUNCTION	2294.34	2.00	0.0
MH-L-443	JUNCTION	2293.72	2.00	0.0
MH-L-444	JUNCTION	2292.99	2.00	0.0
MH-L-445	JUNCTION	2292.26	2.00	0.0
MH-R-486	JUNCTION	2338.00	2.00	0.0

MH-R-487	JUNCTION	2338.10	2.00	0.0
MH-R-488	JUNCTION	2338.20	2.00	0.0
MH-R-489	JUNCTION	2338.30	2.00	0.0
MH-R-490	JUNCTION	2338.40	2.00	0.0
MH-R-443	JUNCTION	2338.38	2.00	0.0
MH-R-444	JUNCTION	2338.27	2.00	0.0
MH-R-445	JUNCTION	2338.15	2.00	0.0
MH-R-446	JUNCTION	2338.03	2.00	0.0
MH-R-447	JUNCTION	2337.91	2.00	0.0
MH-R-448	JUNCTION	2337.79	2.00	0.0
MH-R-449	JUNCTION	2337.56	2.00	0.0
MH-R-450	JUNCTION	2337.27	2.00	0.0
MH-R-360	JUNCTION	2336.28	2.00	0.0
MH-R-361	JUNCTION	2335.84	2.00	0.0
MH-R-362	JUNCTION	2335.36	2.00	0.0
MH-R-363	JUNCTION	2334.86	2.00	0.0
MH-R-364	JUNCTION	2334.37	2.00	0.0
MH-R-365	JUNCTION	2333.87	2.00	0.0
MH-R-366	JUNCTION	2333.38	2.00	0.0
MH-R-367	JUNCTION	2332.88	2.00	0.0
MH-R-368	JUNCTION	2332.38	2.00	0.0
MH-R-369	JUNCTION	2331.86	2.00	0.0
MH-R-370	JUNCTION	2331.31	2.00	0.0
MH-R-371	JUNCTION	2330.74	2.00	0.0
MH-R-372	JUNCTION	2330.16	2.00	0.0

MH-R-373	JUNCTION	2329.55	2.00	0.0
MH-R-374	JUNCTION	2328.91	2.00	0.0
MH-R-375	JUNCTION	2328.26	2.00	0.0
MH-R-376	JUNCTION	2327.58	2.00	0.0
MH-R-377	JUNCTION	2326.88	2.00	0.0
MH-R-378	JUNCTION	2326.18	2.00	0.0
MH-R-379	JUNCTION	2325.44	2.00	0.0
MH-R-380	JUNCTION	2324.66	2.00	0.0
MH-R-381	JUNCTION	2323.89	2.00	0.0
MH-R-382	JUNCTION	2323.12	2.00	0.0
MH-R-383	JUNCTION	2322.12	2.00	0.0
MH-R-384	JUNCTION	2321.36	2.00	0.0
MH-R-385	JUNCTION	2320.60	2.00	0.0
MH-R-386	JUNCTION	2319.80	2.00	0.0
MH-R-387	JUNCTION	2319.00	2.00	0.0
MH-R-388	JUNCTION	2318.20	2.00	0.0
MH-R-389	JUNCTION	2317.40	2.00	0.0
MH-R-390	JUNCTION	2316.60	2.00	0.0
MH-R-391	JUNCTION	2315.80	2.00	0.0
MH-R-392	JUNCTION	2314.97	2.00	0.0
MH-R-393	JUNCTION	2314.18	2.00	0.0
MH-R-394	JUNCTION	2313.68	2.00	0.0
MH-R-395	JUNCTION	2312.98	2.00	0.0
MH-R-397	JUNCTION	2311.95	2.00	0.0
MH-R-398	JUNCTION	2311.47	2.00	0.0

MH-R-399	JUNCTION	2311.00	2.00	0.0
MH-R-400	JUNCTION	2310.53	2.00	0.0
MH-R-401	JUNCTION	2310.06	2.00	0.0
MH-R-402	JUNCTION	2309.59	2.00	0.0
MH-R-403	JUNCTION	2309.11	2.00	0.0
MH-R-404	JUNCTION	2308.64	2.00	0.0
MH-R-405	JUNCTION	2308.31	2.00	0.0
MH-R-406	JUNCTION	2307.06	2.00	0.0
MH-R-407	JUNCTION	2306.75	2.00	0.0
MH-R-408	JUNCTION	2306.27	2.00	0.0
MH-R-409	JUNCTION	2305.78	2.00	0.0
MH-R-410	JUNCTION	2305.31	2.00	0.0
MH-R-411	JUNCTION	2304.84	2.00	0.0
MH-R-412'	JUNCTION	2304.12	2.00	0.0
MH-R-413	JUNCTION	2303.41	2.00	0.0
MH-R-414	JUNCTION	2302.94	2.00	0.0
MH-R-415	JUNCTION	2302.50	2.00	0.0
MH-R-416	JUNCTION	2302.05	2.00	0.0
MH-R-417	JUNCTION	2301.62	2.00	0.0
MH-R-418	JUNCTION	2301.21	2.00	0.0
MH-R-419	JUNCTION	2300.85	2.00	0.0
MH-R-420	JUNCTION	2300.10	2.00	0.0
MH-R-421	JUNCTION	2299.56	2.00	0.0
MH-R-422	JUNCTION	2299.25	2.00	0.0
MH-R-423	JUNCTION	2298.94	2.00	0.0

MH-R-424	JUNCTION	2298.61	2.00	0.0
MH-R-425	JUNCTION	2297.69	2.00	0.0
MH-R-426	JUNCTION	2297.07	2.00	0.0
MH-R-427	JUNCTION	2296.63	2.00	0.0
MH-R-428	JUNCTION	2296.33	2.00	0.0
MH-R-429	JUNCTION	2296.07	2.00	0.0
MH-R-430	JUNCTION	2295.92	2.00	0.0
MH-R-431	JUNCTION	2295.80	2.00	0.0
MH-R-432	JUNCTION	2295.67	2.00	0.0
MH-R-433	JUNCTION	2295.55	2.00	0.0
MH-R-434	JUNCTION	2295.36	2.00	0.0
MH-R-435	JUNCTION	2295.02	2.00	0.0
MH-R-436	JUNCTION	2294.39	2.00	0.0
MH-R-437	JUNCTION	2293.90	2.00	0.0
MH-R-438	JUNCTION	2293.42	2.00	0.0
MH-R-439	JUNCTION	2292.85	2.00	0.0
MH-R-440	JUNCTION	2292.63	2.00	0.0
MH-R-441	JUNCTION	2291.91	2.00	0.0
MH-YDK-L1	JUNCTION	2340.70	0.82	0.0
MH-YDK-R1	JUNCTION	2340.70	0.82	0.0
MH-YDK-L2	JUNCTION	2334.58	0.82	0.0
MH-YDK-R2	JUNCTION	2334.58	0.82	0.0
MH-YDK-L3	JUNCTION	2326.57	0.82	0.0
MH-YDK-R3	JUNCTION	2326.57	0.82	0.0
MH-YDK-L4	JUNCTION	2299.68	0.82	0.0

MH-YDK-R4	JUNCTION	2311.42	0.82	0.0
MH-YDK-R6	JUNCTION	2297.65	0.82	0.0
MH-YDK-R5	JUNCTION	2301.28	0.82	0.0
MH-YDK-L5	JUNCTION	2297.65	0.82	0.0
MH-R-412(OUTFALL))	OUTFALL	2304.37	1.05	0.0
R_SLAB_CULVERT-2	OUTFALL	2287.43	4.00	0.0
R_SLAB_CULVERT-1	OUTFALL	2309.30	3.00	0.0
L-SLAB_CULVERT-2	STORAGE	2287.76	4.00	0.0
L-SLAB_CULVERT-1	STORAGE	2309.40	3.00	0.0

Appendix C: Conduit link summary

Table C1:-Conduit link summary

Name	From Node	To Node	Type	Length (m)	%Slope	Roughness
PIPE-L1	MH-L-490	MH-L-489	CONDUIT	20.0	0.5000	0.0130
PIPE-L2	MH-L-489	MH-L-488	CONDUIT	20.0	0.5000	0.0130
PIPE-L3	MH-L-488	MH-L-487	CONDUIT	20.0	0.5000	0.0130
PIPE-L4	MH-L-487	MH-L-486	CONDUIT	20.0	0.5000	0.0130
PIPE-L5	MH-L-456	MH-L-457	CONDUIT	20.0	0.5500	0.0130
PIPE-L6	MH-L-457	MH-L-458	CONDUIT	20.0	0.6000	0.0130
PIPE-L7	MH-L-458	MH-L-459	CONDUIT	20.0	0.6000	0.0130
PIPE-L8	MH-L-459	MH-L-460	CONDUIT	20.0	0.6000	0.0130
PIPE-L9	MH-L-460	MH-L-461	CONDUIT	20.0	0.6000	0.0130
PIPE-L10	MH-L-461	MH-L-462	CONDUIT	20.0	1.1501	0.0130
PIPE-L11	MH-L-462	MH-L-463	CONDUIT	20.0	1.4001	0.0130
PIPE-L12	MH-L-463	MH-L-464	CONDUIT	18.0	1.6113	0.0130
PIPE-L13	MH-L-464	MH-L-465	CONDUIT	16.0	1.7503	0.0130
PIPE-L14	MH-L-465	MH-L-367	CONDUIT	26.0	1.9619	0.0130
PIPE-L15	MH-L-367	MH-L-368	CONDUIT	20.0	2.1505	0.0130
PIPE-L16	MH-L-368	MH-L-369	CONDUIT	20.0	2.4007	0.0130
PIPE-L17	MH-L-369	MH-L-370	CONDUIT	20.0	2.5008	0.0130
PIPE-L18	MH-L-370	MH-L-371	CONDUIT	20.0	2.4507	0.0130
PIPE-L19	MH-L-371	MH-L-372	CONDUIT	20.0	2.5008	0.0130
PIPE-L20	MH-L-372	MH-L-373	CONDUIT	20.0	2.5008	0.0130

PIPE-L21	MH-L-373	MH-L-374	CONDUIT	20.0	2.4507	0.0130
PIPE-L22	MH-L-374	MH-L-375	CONDUIT	20.0	2.5008	0.0130
PIPE-L23	MH-L-375	MH-L-376	CONDUIT	20.0	2.6509	0.0130
PIPE-L24	MH-L-376	MH-L-377	CONDUIT	20.0	2.7010	0.0130
PIPE-L25	MH-L-377	MH-L-378	CONDUIT	20.0	2.8512	0.0130
PIPE-L26	MH-L-378	MH-L-379	CONDUIT	20.0	2.9513	0.0130
PIPE-L27	MH-L-379	MH-L-380	CONDUIT	20.0	3.0514	0.0130
PIPE-L28	MH-L-380	MH-L-381	CONDUIT	20.0	3.1516	0.0130
PIPE-L29	MH-L-381	MH-L-382	CONDUIT	20.0	3.3018	0.0130
PIPE-L30	MH-L-382	MH-L-383	CONDUIT	24.0	3.3769	0.0130
PIPE-L31	MH-L-383	MH-L-384	CONDUIT	22.0	3.5477	0.0130
PIPE-L32	MH-L-384	MH-L-385	CONDUIT	54.0	3.7248	0.0130
PIPE-L33	MH-L-385	MH-L-386	CONDUIT	20.0	3.9531	0.0130
PIPE-L34	MH-L-386	MH-L-387	CONDUIT	40.0	4.0032	0.0130
PIPE-L35	MH-L-387	MH-L-388	CONDUIT	20.0	4.0032	0.0130
PIPE-L36	MH-L-388	MH-L-389	CONDUIT	20.0	4.1035	0.0130
PIPE-L37	MH-L-389	MH-L-390	CONDUIT	20.0	4.0533	0.0130
PIPE-L38	MH-L-390	MH-L-391	CONDUIT	20.0	4.0032	0.0130
PIPE-L39	MH-L-391	MH-L-392	CONDUIT	20.0	4.0032	0.0130
PIPE-L40	MH-L-392	MH-L-393	CONDUIT	20.0	4.0032	0.0130
PIPE-L41	MH-L-393	MH-L-394	CONDUIT	20.0	3.9531	0.0130
PIPE-L42	MH-L-394	MH-L-395	CONDUIT	20.0	3.9531	0.0130
PIPE-L43	MH-L-395	MH-L-396	CONDUIT	20.0	3.5522	0.0130
PIPE-L44	MH-L-396	MH-L-397	CONDUIT	29.0	3.7958	0.0130
PIPE-L45	MH-L-397	MH-L-398	CONDUIT	16.0	3.3143	0.0130

PIPE-L46	MH-L-398	MH-L-399	CONDUIT	20.0	2.9012	0.0130
PIPE-L47	MH-L-399	L-SLAB_CULVERT-1	CONDUIT	29.0	6.0802	0.0130
PIPE-L48	MH-L-402	MH-L-403	CONDUIT	20.0	2.3506	0.0130
PIPE-L49	MH-L-403	MH-L-404	CONDUIT	20.0	2.3506	0.0130
PIPE-L50	MH-L-404	MH-L-405	CONDUIT	20.0	2.5008	0.0130
PIPE-L51	MH-L-405	MH-AL-01	CONDUIT	11.5	2.6096	0.0130
PIPE-L52	MH-AL-01	MH-L-406	CONDUIT	8.5	2.5891	0.0130
PIPE-L53	MH-L-406	MH-L-407	CONDUIT	20.0	1.4502	0.0130
PIPE-L54	MH-L-407	MH-L-408	CONDUIT	28.0	2.6438	0.0130
PIPE-L55	MH-L-408	MH-L-409	CONDUIT	40.0	2.2506	0.0130
PIPE-L56	MH-L-409	MH-L-410	CONDUIT	16.0	3.6900	0.0130
PIPE-L57	MH-L-410	MH-L-411	CONDUIT	20.0	3.3018	0.0130
PIPE-L58	MH-L-411	MH-L-412	CONDUIT	20.0	2.1505	0.0130
PIPE-L59	MH-L-412	MH-L-413	CONDUIT	20.0	1.0001	0.0130
PIPE-L60	MH-L-413	MH-L-414	CONDUIT	20.0	1.0001	0.0130
PIPE-L61	MH-L-414	MH-L-415	CONDUIT	20.0	1.0001	0.0130
PIPE-L62	MH-L-415	MH-L-416	CONDUIT	20.0	1.0001	0.0130
PIPE-L63	MH-L-416	MH-L-417	CONDUIT	20.0	2.7010	0.0130
PIPE-L64	MH-L-417	MH-L-418	CONDUIT	20.0	3.0514	0.0130
PIPE-L65	MH-L-418	MH-L-419	CONDUIT	20.0	3.0514	0.0130
PIPE-L66	MH-L-419	MH-L-420	CONDUIT	20.0	2.8512	0.0130
PIPE-L67	MH-L-420	MH-L-421	CONDUIT	20.0	2.6009	0.0130
PIPE-L68	MH-L-421	MH-L-422	CONDUIT	20.0	2.9513	0.0130
PIPE-L69	MH-L-422	MH-L-423	CONDUIT	20.0	3.0014	0.0130
PIPE-L70	MH-L-423	MH-L-424	CONDUIT	20.0	2.5508	0.0130

PIPE-L71	MH-L-424	MH-L-425	CONDUIT	20.0	0.9000	0.0130
PIPE-L72	MH-L-425	MH-L-426	CONDUIT	20.0	1.7002	0.0130
PIPE-L73	MH-L-426	MH-L-427	CONDUIT	20.0	1.7002	0.0130
PIPE-L74	MH-L-427	MH-L-428	CONDUIT	20.0	1.9003	0.0130
PIPE-L75	MH-L-428	MH-L-429	CONDUIT	20.0	2.3506	0.0130
PIPE-L76	MH-L-429	MH-L-430	CONDUIT	20.0	2.8011	0.0130
PIPE-L77	MH-L-430	MH-L-431	CONDUIT	20.0	2.8512	0.0130
PIPE-L78	MH-L-431	MH-L-432	CONDUIT	20.0	2.0004	0.0130
PIPE-L79	MH-L-432	MH-L-433	CONDUIT	20.0	1.2501	0.0130
PIPE-L80	MH-L-433	MH-L-434	CONDUIT	20.0	1.2501	0.0130
PIPE-L81	MH-L-434	MH-L-435	CONDUIT	20.0	3.9030	0.0130
PIPE-L82	MH-L-435	MH-L-436	CONDUIT	20.0	1.7002	0.0130
PIPE-L83	MH-L-436	MH-L-437	CONDUIT	20.0	1.0001	0.0130
PIPE-L84	MH-L-437	MH-L-438	CONDUIT	20.0	0.8500	0.0130
PIPE-L85	MH-L-438	MH-L-439	CONDUIT	20.0	0.9500	0.0130
PIPE-L86	MH-L-439	MH-L-440	CONDUIT	20.0	0.8500	0.0130
PIPE-L87	MH-L-440	MH-L-440'	CONDUIT	20.0	0.8500	0.0130
PIPE-L88	MH-L-440'	MH-L-441	CONDUIT	14.0	0.5000	0.0130
PIPE-L89	MH-L-441	MH-L-442	CONDUIT	50.0	0.7000	0.0130
PIPE-L90	MH-L-442	MH-L-443	CONDUIT	20.0	3.1015	0.0130
PIPE-L91	MH-L-443	MH-L-444	CONDUIT	20.0	3.6524	0.0130
PIPE-L92	MH-L-444	MH-L-445	CONDUIT	20.0	3.6524	0.0130
PIPE-L93	MH-L-445	L-SLAB_CULVERT-2	CONDUIT	20.0	9.0367	0.0130
PIPE-R94	MH-R-490	MH-R-489	CONDUIT	20.0	0.5000	0.0130
PIPE-R95	MH-R-489	MH-R-488	CONDUIT	20.0	0.5000	0.0130

PIPE-R96	MH-R-488	MH-R-487	CONDUIT	20.0	0.5000	0.0130
PIPE-R97	MH-R-487	MH-R-486	CONDUIT	20.0	0.5000	0.0130
PIPE-R99	MH-R-444	MH-R-445	CONDUIT	20.0	0.6000	0.0130
PIPE-R100	MH-R-445	MH-R-446	CONDUIT	20.0	0.6000	0.0130
PIPE-R101	MH-R-446	MH-R-447	CONDUIT	20.0	0.6000	0.0130
PIPE-R102	MH-R-447	MH-R-448	CONDUIT	20.0	0.6000	0.0130
PIPE-R103	MH-R-448	MH-R-449	CONDUIT	20.0	1.1501	0.0130
PIPE-R104	MH-R-449	MH-R-450	CONDUIT	20.0	1.4502	0.0130
PIPE-R105	MH-R-450	MH-R-360	CONDUIT	20.0	4.9561	0.0130
PIPE-R106	MH-R-360	MH-R-361	CONDUIT	20.0	2.2005	0.0130
PIPE-R107	MH-R-361	MH-R-362	CONDUIT	20.0	2.4007	0.0130
PIPE-R108	MH-R-362	MH-R-363	CONDUIT	20.0	2.5008	0.0130
PIPE-R110	MH-R-364	MH-R-365	CONDUIT	20.0	2.5008	0.0130
PIPE-R111	MH-R-365	MH-R-366	CONDUIT	20.0	2.4507	0.0130
PIPE-R113	MH-R-367	MH-R-368	CONDUIT	20.0	2.5008	0.0130
PIPE-R114	MH-R-368	MH-R-369	CONDUIT	20.0	2.6009	0.0130
PIPE-R115	MH-R-369	MH-R-370	CONDUIT	20.0	2.7510	0.0130
PIPE-R116	MH-R-370	MH-R-371	CONDUIT	20.0	2.8512	0.0130
PIPE-R117	MH-R-371	MH-R-372	CONDUIT	20.0	2.9012	0.0130
PIPE-R118	MH-R-372	MH-R-373	CONDUIT	20.0	3.0514	0.0130
PIPE-R119	MH-R-373	MH-R-374	CONDUIT	20.0	3.2016	0.0130
PIPE-R120	MH-R-374	MH-R-375	CONDUIT	20.0	3.2517	0.0130
PIPE-R121	MH-R-375	MH-R-376	CONDUIT	20.0	3.4020	0.0130
PIPE-R122	MH-R-376	MH-R-377	CONDUIT	20.0	3.5021	0.0130
PIPE-R123	MH-R-377	MH-R-378	CONDUIT	20.0	3.5021	0.0130

PIPE-R124	MH-R-378	MH-R-379	CONDUIT	20.0	3.7025	0.0130
PIPE-R125	MH-R-379	MH-R-380	CONDUIT	20.0	3.9030	0.0130
PIPE-R126	MH-R-380	MH-R-381	CONDUIT	20.0	3.8529	0.0130
PIPE-R127	MH-R-381	MH-R-382	CONDUIT	20.0	3.8529	0.0130
PIPE-R128	MH-R-382	MH-R-383	CONDUIT	20.0	5.0063	0.0130
PIPE-R129	MH-R-383	MH-R-384	CONDUIT	20.0	3.8027	0.0130
PIPE-R130	MH-R-384	MH-R-385	CONDUIT	20.0	3.8027	0.0130
PIPE-R131	MH-R-385	MH-R-386	CONDUIT	20.0	4.0032	0.0130
PIPE-R132	MH-R-386	MH-R-387	CONDUIT	20.0	4.0032	0.0130
PIPE-R133	MH-R-387	MH-R-388	CONDUIT	20.0	4.0032	0.0130
PIPE-R134	MH-R-388	MH-R-389	CONDUIT	20.0	4.0032	0.0130
PIPE-R135	MH-R-389	MH-R-390	CONDUIT	20.0	4.0032	0.0130
PIPE-R136	MH-R-390	MH-R-391	CONDUIT	20.0	4.0032	0.0130
PIPE-R137	MH-R-391	MH-R-392	CONDUIT	20.0	4.1536	0.0130
PIPE-R138	MH-R-392	MH-R-393	CONDUIT	20.0	3.9531	0.0130
PIPE-R139	MH-R-393	MH-R-394	CONDUIT	20.0	2.5008	0.0130
PIPE-R140	MH-R-394	MH-R-395	CONDUIT	20.0	3.5021	0.0130
PIPE-R142	MH-R-397	MH-R-398	CONDUIT	20.0	2.4007	0.0130
PIPE-R143	MH-R-398	MH-R-399	CONDUIT	20.0	2.3506	0.0130
PIPE-R144	MH-R-399	MH-R-400	CONDUIT	20.0	2.3506	0.0130
PIPE-R145	MH-R-400	MH-R-401	CONDUIT	20.0	2.3506	0.0130
PIPE-R146	MH-R-401	MH-R-402	CONDUIT	20.0	2.3506	0.0130
PIPE-R147	MH-R-402	MH-R-403	CONDUIT	20.0	2.4007	0.0130
PIPE-R148	MH-R-403	MH-R-404	CONDUIT	20.0	2.3506	0.0130
PIPE-R149	MH-R-404	MH-R-405	CONDUIT	14.0	2.3578	0.0130

PIPE-R150	MH-R-405	MH-R-406	CONDUIT	53.0	2.3591	0.0130
PIPE-R151	MH-R-406	MH-R-407	CONDUIT	13.0	2.3853	0.0130
PIPE-R152	MH-R-407	MH-R-408	CONDUIT	20.0	2.4007	0.0130
PIPE-R153	MH-R-408	MH-R-409	CONDUIT	20.0	2.4507	0.0130
PIPE-R154	MH-R-409	MH-R-410	CONDUIT	20.0	2.3506	0.0130
PIPE-R157	MH-R-412'	MH-R-413	CONDUIT	30.0	2.3673	0.0130
PIPE-R158	MH-R-413	MH-R-414	CONDUIT	20.0	2.3506	0.0130
PIPE-R159	MH-R-414	MH-R-415	CONDUIT	20.0	2.2005	0.0130
PIPE-R161	MH-R-416	MH-R-417	CONDUIT	20.0	2.1505	0.0130
PIPE-R162	MH-R-417	MH-R-418	CONDUIT	20.0	2.0504	0.0130
PIPE-R163	MH-R-418	MH-R-419	CONDUIT	20.0	1.8003	0.0130
PIPE-R164	MH-R-419	MH-R-420	CONDUIT	30.0	2.5008	0.0130
PIPE-R165	MH-R-420	MH-R-421	CONDUIT	20.0	2.7010	0.0130
PIPE-R166	MH-R-421	MH-R-422	CONDUIT	20.0	1.5502	0.0130
PIPE-R167	MH-R-422	MH-R-423	CONDUIT	20.0	1.5502	0.0130
PIPE-R168	MH-R-423	MH-R-424	CONDUIT	20.0	1.6502	0.0130
PIPE-R169	MH-R-424	MH-R-425	CONDUIT	20.0	4.6049	0.0130
PIPE-R170	MH-R-425	MH-R-426	CONDUIT	20.0	3.1015	0.0130
PIPE-R171	MH-R-426	MH-R-427	CONDUIT	20.0	2.2005	0.0130
PIPE-R172	MH-R-427	MH-R-428	CONDUIT	20.0	1.5002	0.0130
PIPE-R173	MH-R-428	MH-R-429	CONDUIT	20.0	1.3001	0.0130
PIPE-R174	MH-R-429	MH-R-430	CONDUIT	20.0	0.7500	0.0130
PIPE-R175	MH-R-430	MH-R-431	CONDUIT	20.0	0.6000	0.0130
PIPE-R176	MH-R-431	MH-R-432	CONDUIT	20.0	0.6500	0.0130
PIPE-R177	MH-R-432	MH-R-433	CONDUIT	20.0	0.6000	0.0130

PIPE-R178	MH-R-433	MH-R-434	CONDUIT	20.0	0.9500	0.0130
PIPE-R179	MH-R-434	MH-R-435	CONDUIT	40.0	0.8500	0.0130
PIPE-R180	MH-R-435	MH-R-436	CONDUIT	20.0	3.1516	0.0130
PIPE-R181	MH-R-436	MH-R-437	CONDUIT	20.0	2.4507	0.0130
PIPE-R182	MH-R-437	MH-R-438	CONDUIT	20.0	2.4007	0.0130
PIPE-R183	MH-R-438	MH-R-439	CONDUIT	20.0	2.8512	0.0130
PIPE-R184	MH-R-439	MH-R-440	CONDUIT	20.0	1.1001	0.0130
PIPE-R185	MH-R-440	MH-R-441	CONDUIT	20.0	3.6023	0.0130
PIPE-R186	MH-R-441	R_SLAB_CULVERT-2	CONDUIT	20.0	8.9355	0.0130
PIPE-R98	MH-R-443	MH-R-444	CONDUIT	20.0	0.5500	0.0130
PIPE-R109	MH-R-363	MH-R-364	CONDUIT	20.0	2.4507	0.0130
PIPE-R112	MH-R-366	MH-R-367	CONDUIT	20.0	2.5008	0.0130
PIPE-R160	MH-R-415	MH-R-416	CONDUIT	20.0	2.2506	0.0130
PIPE-R156	MH-R-411	MH-R-412(OUTFALL))	CONDUIT	20.0	2.3506	0.0130
PIPE-R155	MH-R-410	MH-R-411	CONDUIT	20.0	2.3506	0.0130
PIPE-Rail-L1	MH-YDK-L1	MH-L-486	CONDUIT	9.5	26.1101	0.0130
PIPE-Rail-L2	MH-YDK-L2	MH-L-375	CONDUIT	9.5	21.1976	0.0130
PIPE-Rail-L3	MH-YDK-L3	MH-L-386	CONDUIT	9.5	30.6028	0.0130
PIPE-Rail-L4	MH-YDK-L4	MH-L-431	CONDUIT	9.5	18.1463	0.0130
PIPE-Rail-L5	MH-YDK-L5	MH-L-442	CONDUIT	9.5	33.4053	0.0130
PIPE-Rail-R1	MH-YDK-R1	MH-R-486	CONDUIT	9.5	26.1101	0.0130
PIPE-Rail-R2	MH-YDK-R2	MH-R-368	CONDUIT	9.5	20.4124	0.0130
PIPE-Rail-R3	MH-YDK-R3	MH-R-381	CONDUIT	9.5	25.8779	0.0130
PIPE-Rail-R4	MH-YDK-R4	MH-R-406	CONDUIT	9.5	47.2712	0.0130

PIPE-Rail-R5	MH-YDK-R5	MH-R-432	CONDUIT	9.5	67.4078	0.0130
PIPE-Rail-R6	MH-YDK-R6	MH-R-437	CONDUIT	9.5	42.9625	0.0130

Appendix D: Rainfall Intensity Hyetograph for all Return Periods

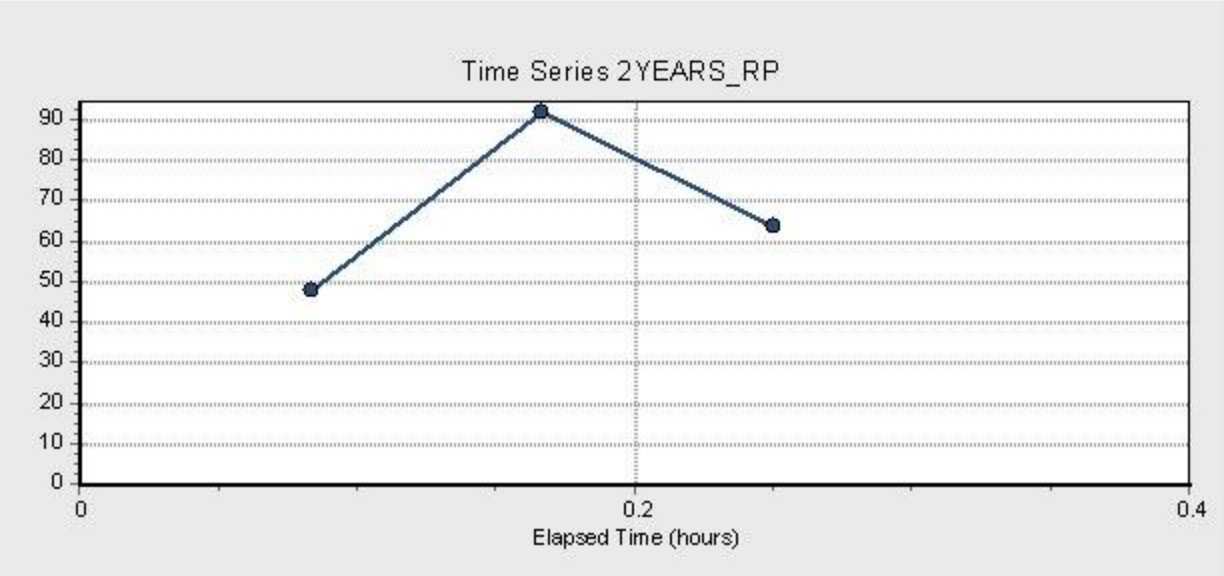


Figure D1:-Rainfall intensity for 2years of Return Period (15min)

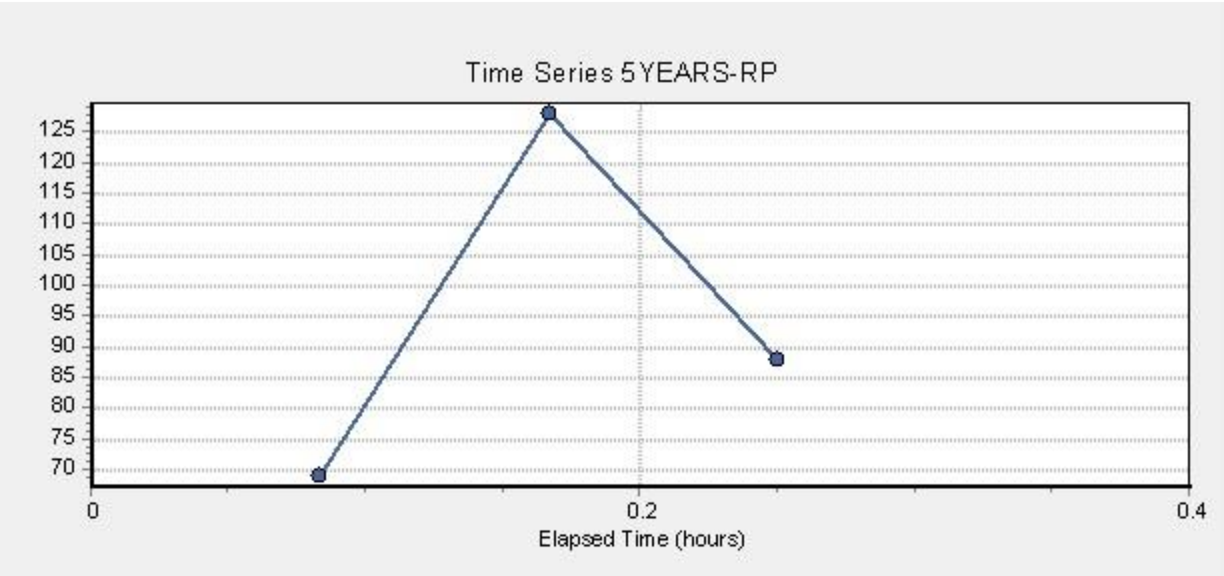


Figure D2:-Rainfall intensity for 5years of Return Period (15min)

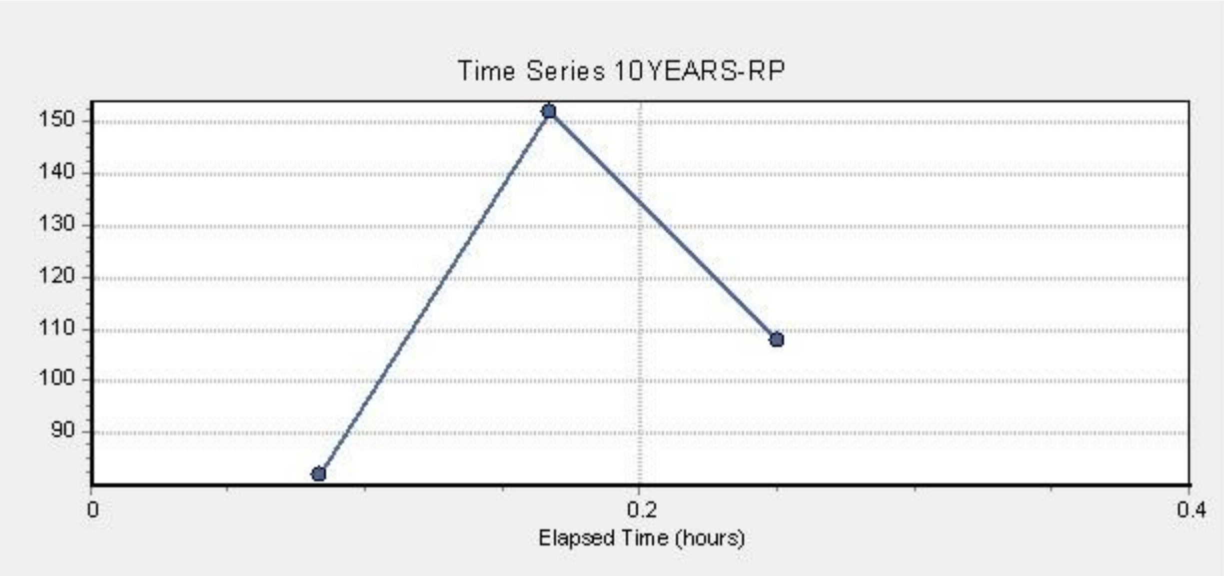


Figure D3:-Rainfall intensity for 10years of Return Period (15min)

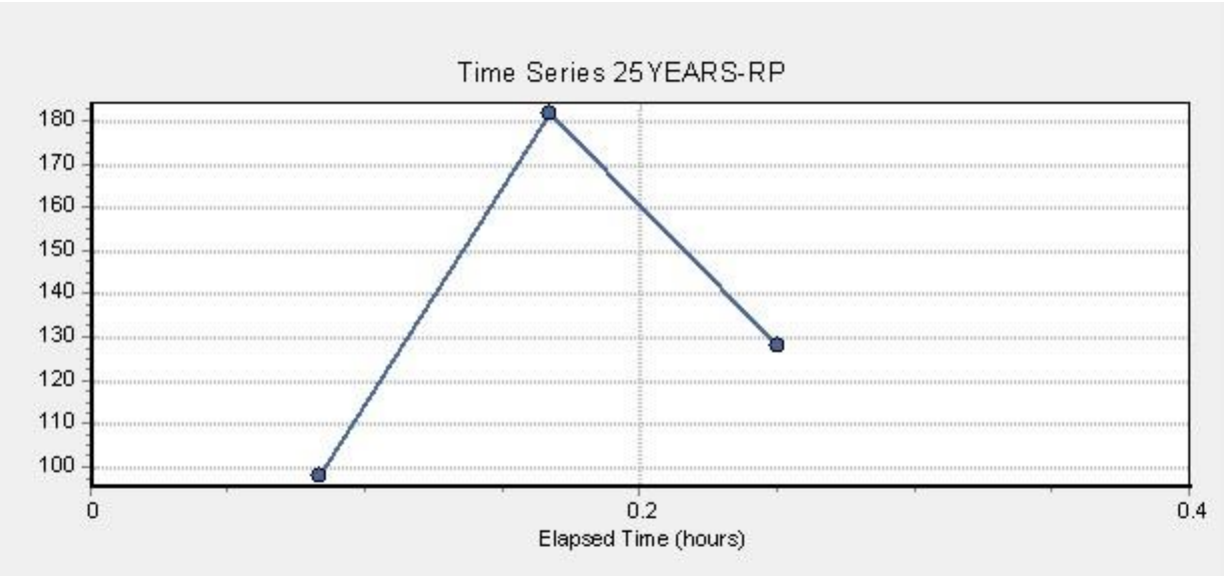


Figure D4:-Rainfall intensity for 25years of Return Period (15min)

Figure D5:-Rainfall intensity for 50years of Return Period (15min)

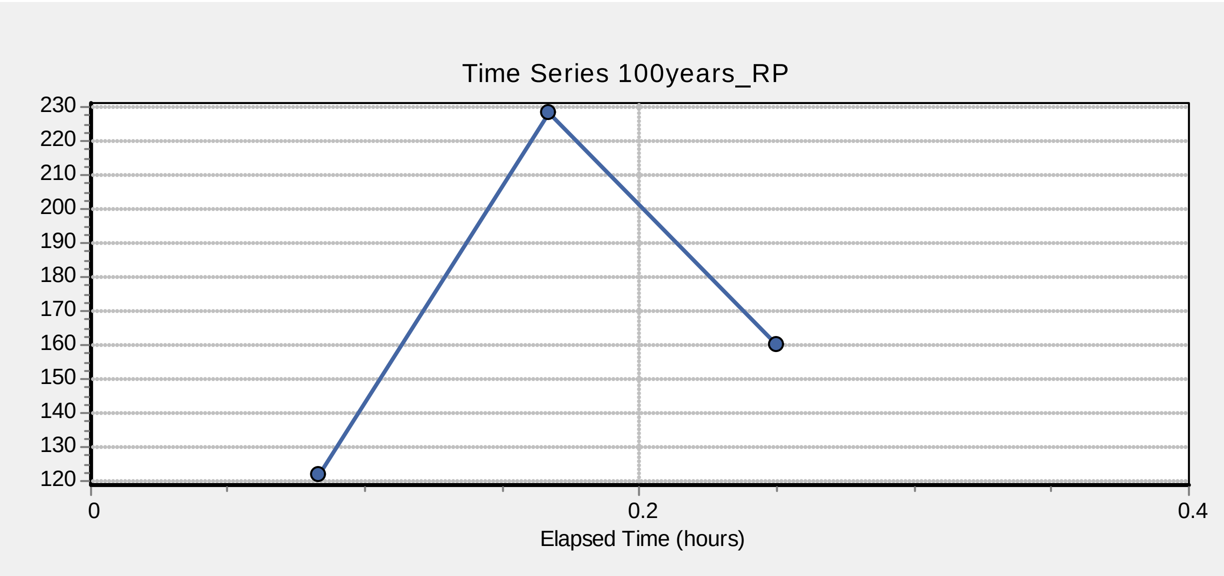


Figure D6:-Rainfall intensity for 100years of Return Period (15min)

Appendix E: Conduit surcharge summary

Table E1: conduit surcharged for 2years of return period

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstrea mFull	Hours above Normal flow	Hours capacity limited
PIPE-L46	0.01	0.08	0.01	0.08	0.08
PIPE-L59	0.08	0.08	0.08	0.08	0.08
PIPE-L60	0.01	0.08	0.01	0.08	0.08
PIPE-L61	0.01	0.08	0.01	0.08	0.08
PIPE-L62	0.01	0.08	0.01	0.08	0.08
PIPE-L71	0.17	0.17	0.17	0.17	0.17
PIPE-L79	0.01	0.08	0.01	0.08	0.08
PIPE-L80	0.01	0.08	0.01	0.08	0.08
PIPE-L88	0.08	0.17	0.08	0.08	0.17

Table E2: conduit surcharged for 5years of return period

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstrea mFull	Hours above Normal flow	Hours capacity limited
PIPE-L45	0.01	0.01	0.01	0.08	0.01
PIPE-L46	0.17	0.17	0.17	0.01	0.17
PIPE-L53	0.17	0.17	0.17	0.17	0.17
PIPE-L59	0.17	0.17	0.17	0.17	0.17
PIPE-L60	0.01	0.17	0.01	0.17	0.17
PIPE-L61	0.01	0.17	0.01	0.17	0.17
PIPE-L62	0.01	0.17	0.01	0.17	0.17
PIPE-L71	0.17	0.17	0.17	0.17	0.17
PIPE-L79	0.01	0.17	0.01	0.17	0.17
PIPE-L80	0.01	0.17	0.01	0.17	0.17
PIPE-L86	0.01	0.08	0.01	0.08	0.08
PIPE-L87	0.01	0.08	0.01	0.08	0.08
PIPE-L88	0.17	0.17	0.17	0.17	0.17

Table E3: conduit surcharged for 10years of return period

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstrea mFull	Hours above Normal flow	Hours capacity limited
PIPE-L45	0.17	0.17	0.17	0.17	0.17
PIPE-L46	0.17	0.17	0.17	0.01	0.17
PIPE-L53	0.17	0.17	0.17	0.17	0.17
PIPE-L59	0.17	0.17	0.17	0.17	0.17
PIPE-L60	0.01	0.17	0.01	0.17	0.17
PIPE-L61	0.01	0.17	0.01	0.17	0.17
PIPE-L62	0.01	0.17	0.01	0.08	0.17
PIPE-L71	0.17	0.17	0.17	0.17	0.17
PIPE-L79	0.17	0.17	0.17	0.01	0.17
PIPE-L80	0.01	0.17	0.01	0.17	0.17
PIPE-L87	0.01	0.01	0.01	0.08	0.01
PIPE-L88	0.17	0.25	0.17	0.25	0.25

Table E4: conduit surcharged for 25years of return period

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstrea mFull	Hours above Normal flow	Hours capacity limited
PIPE-L45	0.17	0.17	0.17	0.17	0.17
PIPE-L46	0.17	0.17	0.17	0.01	0.17
PIPE-L53	0.17	0.17	0.17	0.17	0.17
PIPE-L59	0.17	0.17	0.17	0.17	0.17
PIPE-L60	0.01	0.17	0.01	0.17	0.17
PIPE-L61	0.01	0.17	0.01	0.08	0.17
PIPE-L62	0.01	0.17	0.01	0.08	0.17
PIPE-L71	0.17	0.17	0.17	0.17	0.17
PIPE-L79	0.17	0.17	0.17	0.01	0.17
PIPE-L80	0.01	0.17	0.01	0.17	0.17
PIPE-L86	0.01	0.08	0.01	0.08	0.08
PIPE-L87	0.01	0.08	0.01	0.08	0.08
PIPE-L88	0.25	0.25	0.25	0.25	0.25

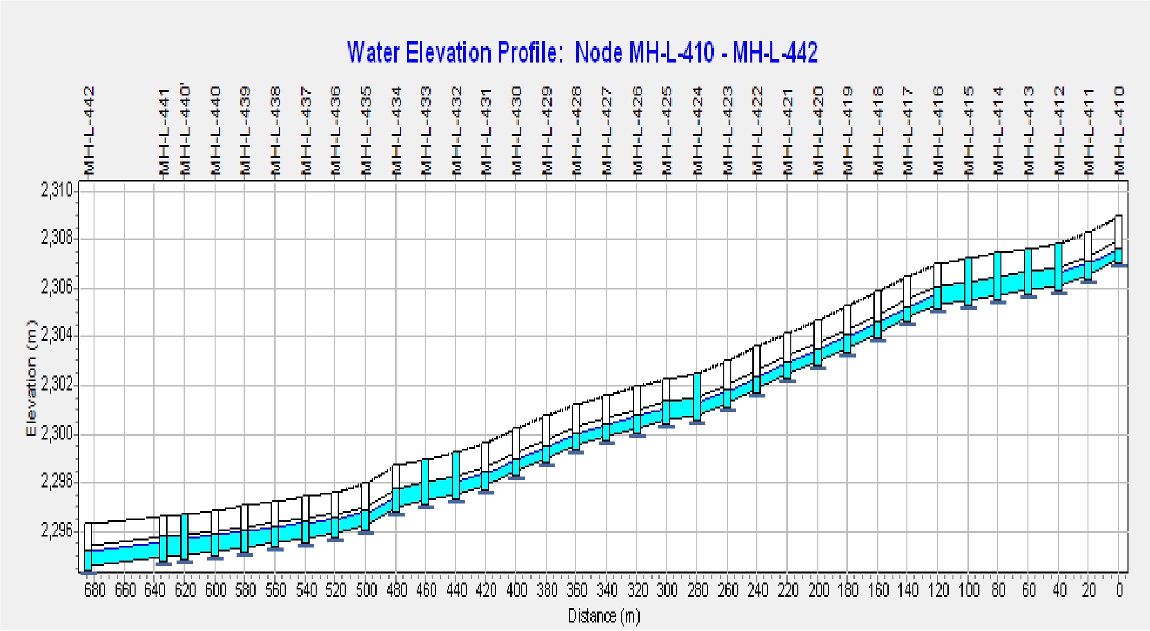
Table E5: conduit surcharged for 50years of return period

Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstreamFull	Hours above Normal flow	Hours capacity limited
PIPE-L33	0.01	0.08	0.01	0.08	0.08
PIPE-L43	0.01	0.08	0.01	0.08	0.08
PIPE-L44	0.01	0.08	0.01	0.08	0.08
PIPE-L45	0.17	0.17	0.17	0.17	0.17
PIPE-L46	0.17	0.17	0.17	0.01	0.17
PIPE-L52	0.08	0.17	0.08	0.17	0.17
PIPE-L53	0.17	0.17	0.17	0.17	0.17
PIPE-L59	0.17	0.17	0.17	0.17	0.17
PIPE-L60	0.01	0.17	0.01	0.17	0.17
PIPE-L61	0.01	0.17	0.01	0.08	0.17
PIPE-L62	0.08	0.08	0.08	0.17	0.08
PIPE-L71	0.17	0.25	0.17	0.25	0.25
PIPE-L79	0.17	0.17	0.17	0.01	0.17
PIPE-L80	0.01	0.17	0.01	0.17	0.17
PIPE-L86	0.01	0.08	0.01	0.08	0.08
PIPE-L87	0.08	0.08	0.08	0.01	0.08
PIPE-L88	0.25	0.25	0.25	0.25	0.25
PIPE-R184	0.01	0.08	0.01	0.08	0.08

Table E6: conduit surcharged for 100years of return period

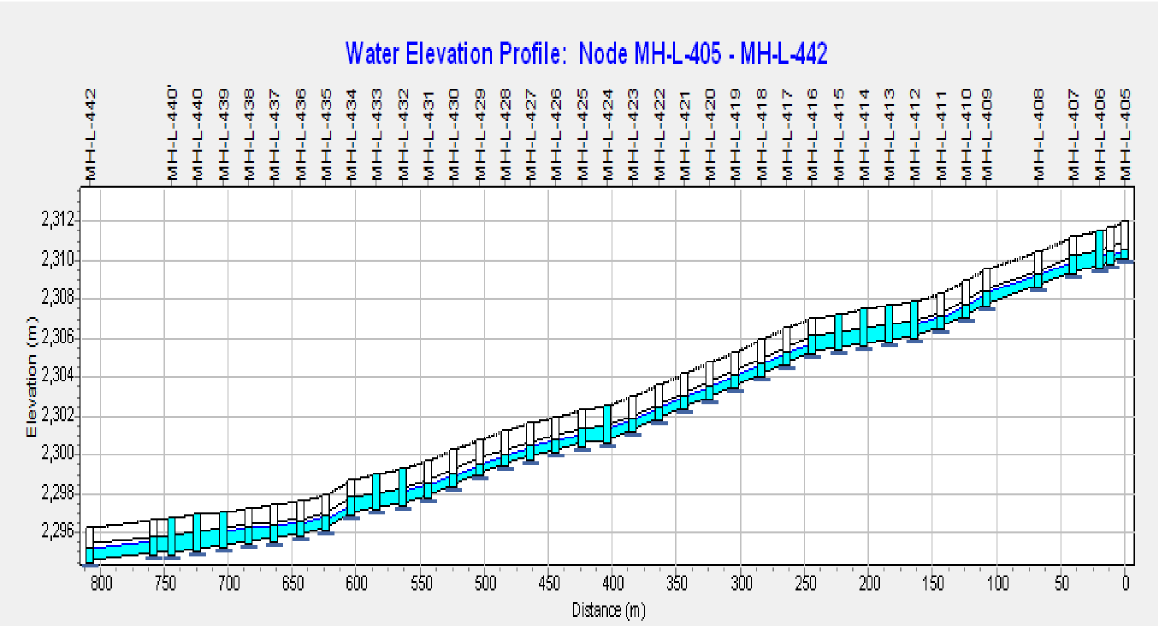
Conduit	Hours Both Ends Full	Hours Upstream Full	Hours downstreamFull	Hours above Normal flow	Hours capacity limited
PIPE-L31	0.01	0.08	0.01	0.08	0.08
PIPE-L32	0.01	0.08	0.01	0.08	0.08
PIPE-L33	0.08	0.08	0.08	0.08	0.08
PIPE-L41	0.01	0.08	0.01	0.01	0.08
PIPE-L42	0.01	0.08	0.01	0.01	0.08
PIPE-L43	0.01	0.17	0.01	0.08	0.17
PIPE-L44	0.01	0.08	0.01	0.08	0.08
PIPE-L45	0.17	0.17	0.17	0.17	0.17
PIPE-L46	0.17	0.17	0.17	0.01	0.17
PIPE-L52	0.17	0.17	0.17	0.17	0.17
PIPE-L53	0.17	0.17	0.17	0.17	0.17
PIPE-L58	0.01	0.08	0.01	0.08	0.08
PIPE-L59	0.17	0.17	0.17	0.17	0.17
PIPE-L60	0.01	0.17	0.01	0.08	0.17
PIPE-L61	0.08	0.17	0.08	0.17	0.17
PIPE-L62	0.01	0.17	0.01	0.17	0.17
PIPE-L70	0.01	0.08	0.01	0.08	0.08
PIPE-L71	0.25	0.25	0.25	0.25	0.25
PIPE-L78	0.01	0.08	0.01	0.08	0.08
PIPE-L79	0.17	0.17	0.17	0.01	0.17
PIPE-L80	0.01	0.17	0.01	0.08	0.17
PIPE-L84	0.01	0.08	0.01	0.08	0.08
PIPE-L85	0.01	0.08	0.01	0.08	0.08
PIPE-L86	0.08	0.17	0.08	0.17	0.17
PIPE-L87	0.01	0.17	0.01	0.17	0.17
PIPE-L88	0.25	0.25	0.25	0.25	0.25
PIPE-R184	0.17	0.17	0.17	0.01	0.17
PIPE-Rail-L4	0.01	0.08	0.01	0.25	0.08
PIPE-Rail-R5	0.01	0.01	0.01	0.17	0.01

Appendix F: Flooding profiles for different return periods



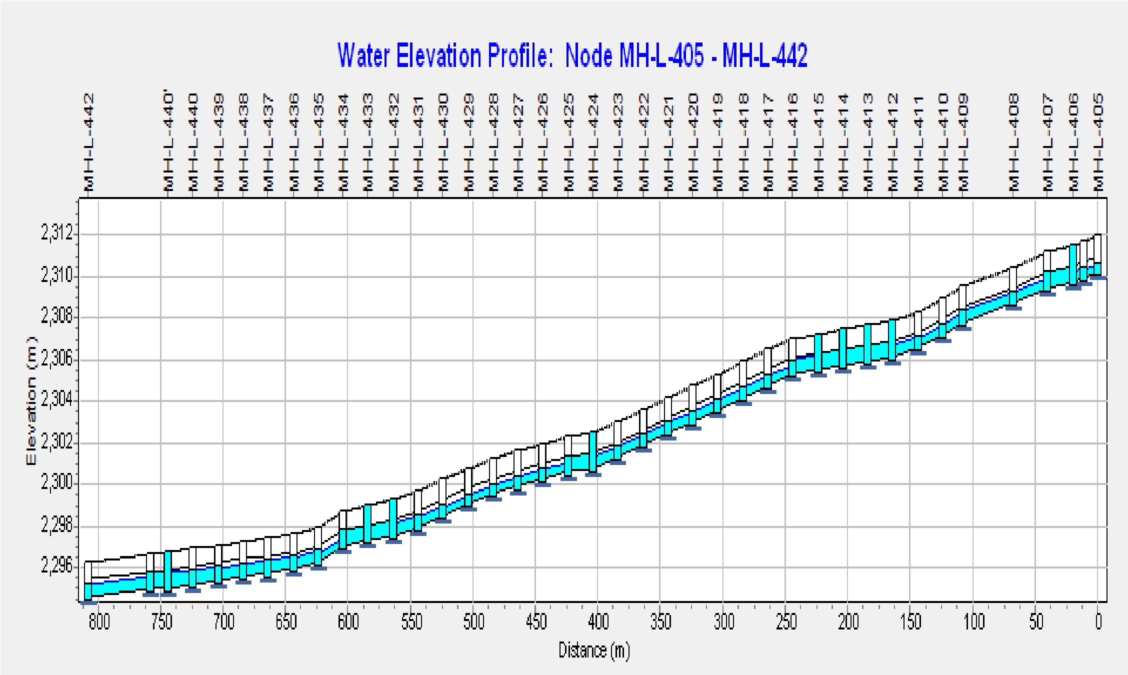
MH-L-410 is 1.24 km far from Mesualekiya

Figure F1:-2years of return period flooded manholes



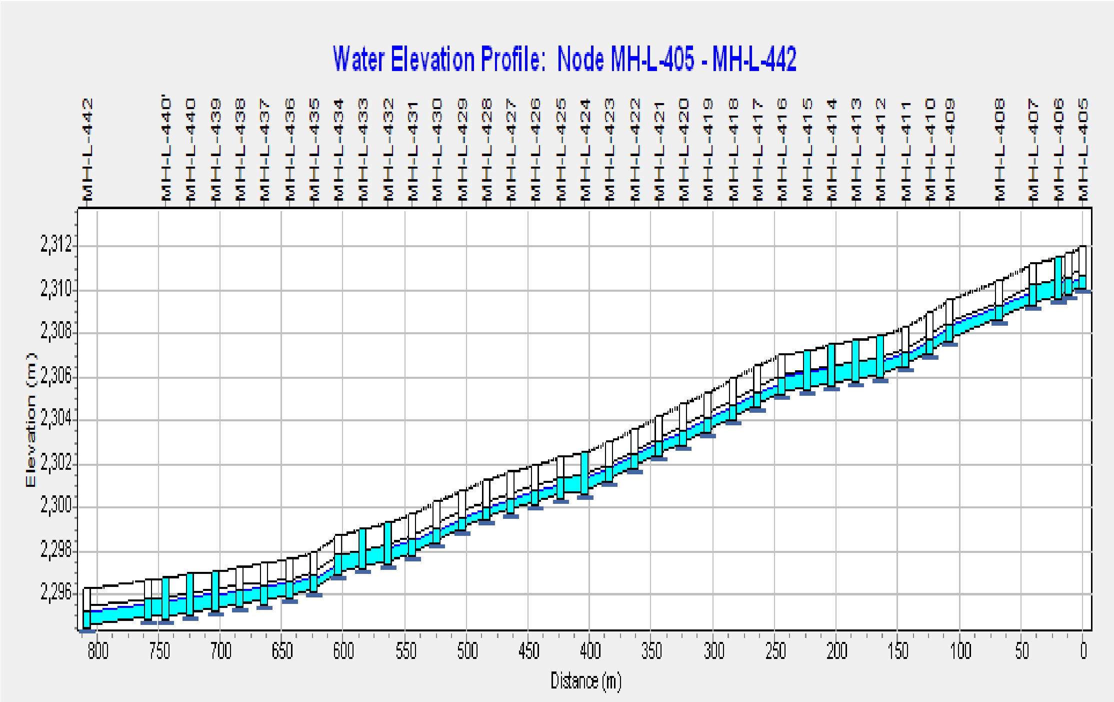
MH-L-405 is 1.13 km far from Mesualekiya

Figure F2:-5years of return period flooded manholes



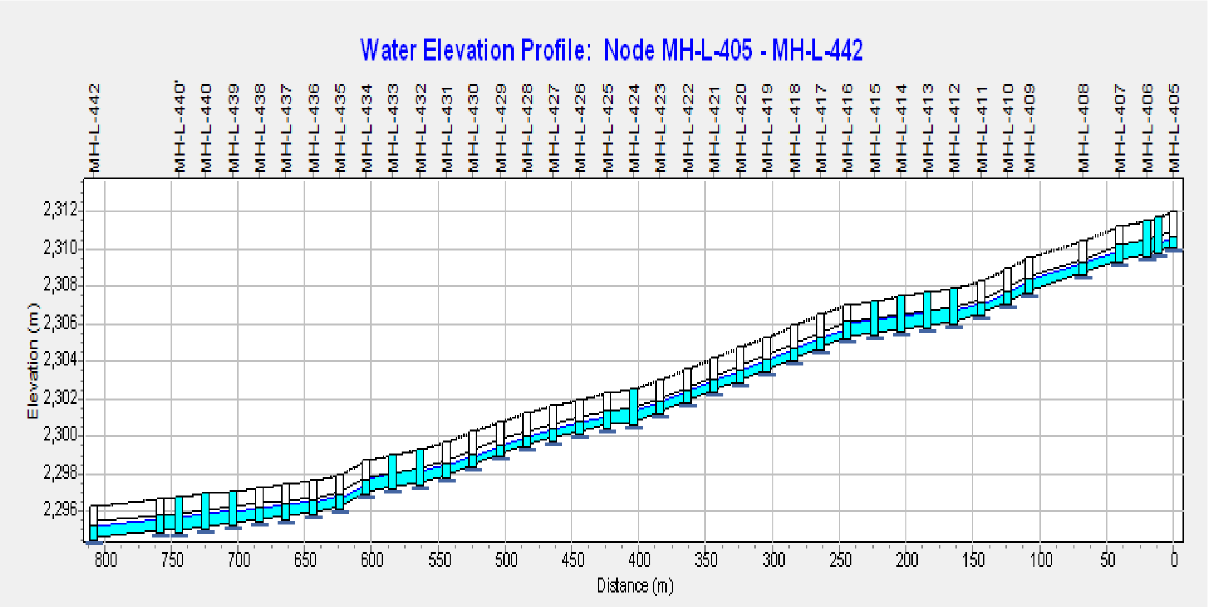
MH-L-405 is 1.13 km far from Mesualekiya

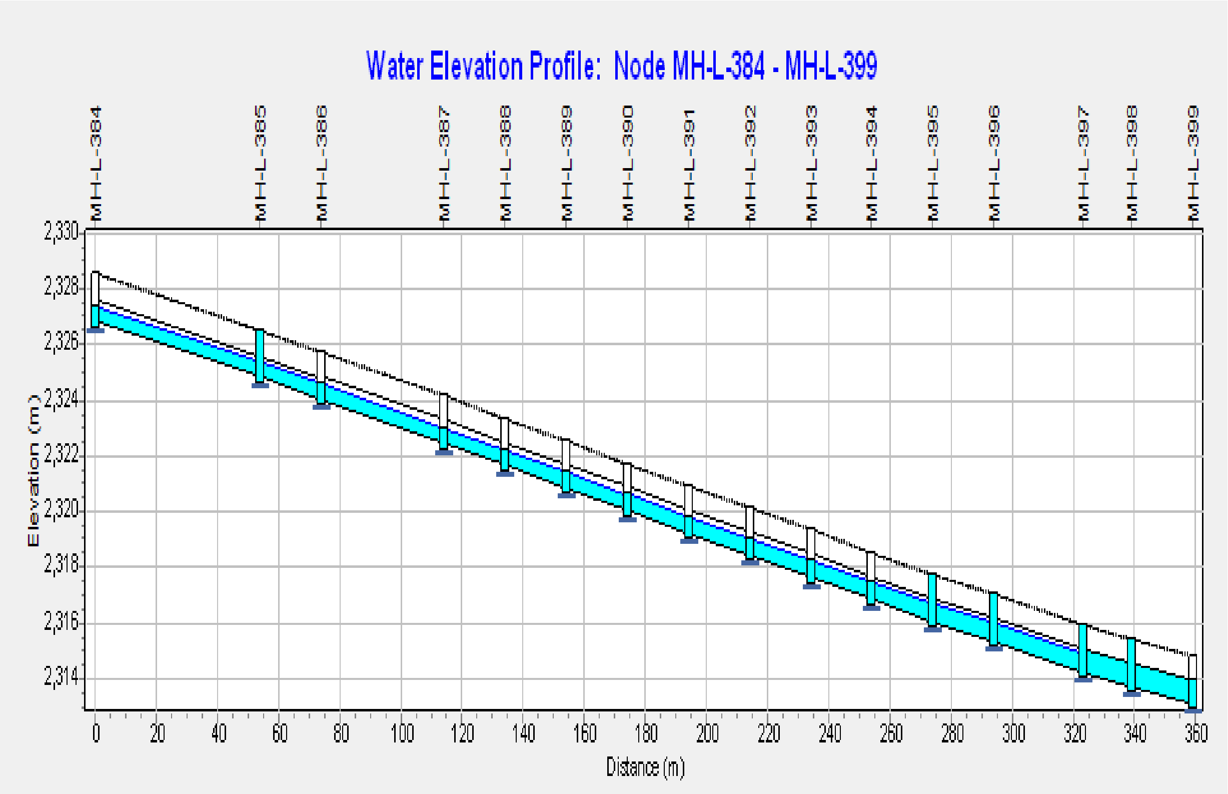
Figure F3:-10years of return period flooded manholes



MH-L-405 is 1.13 km far from Mesualekiya

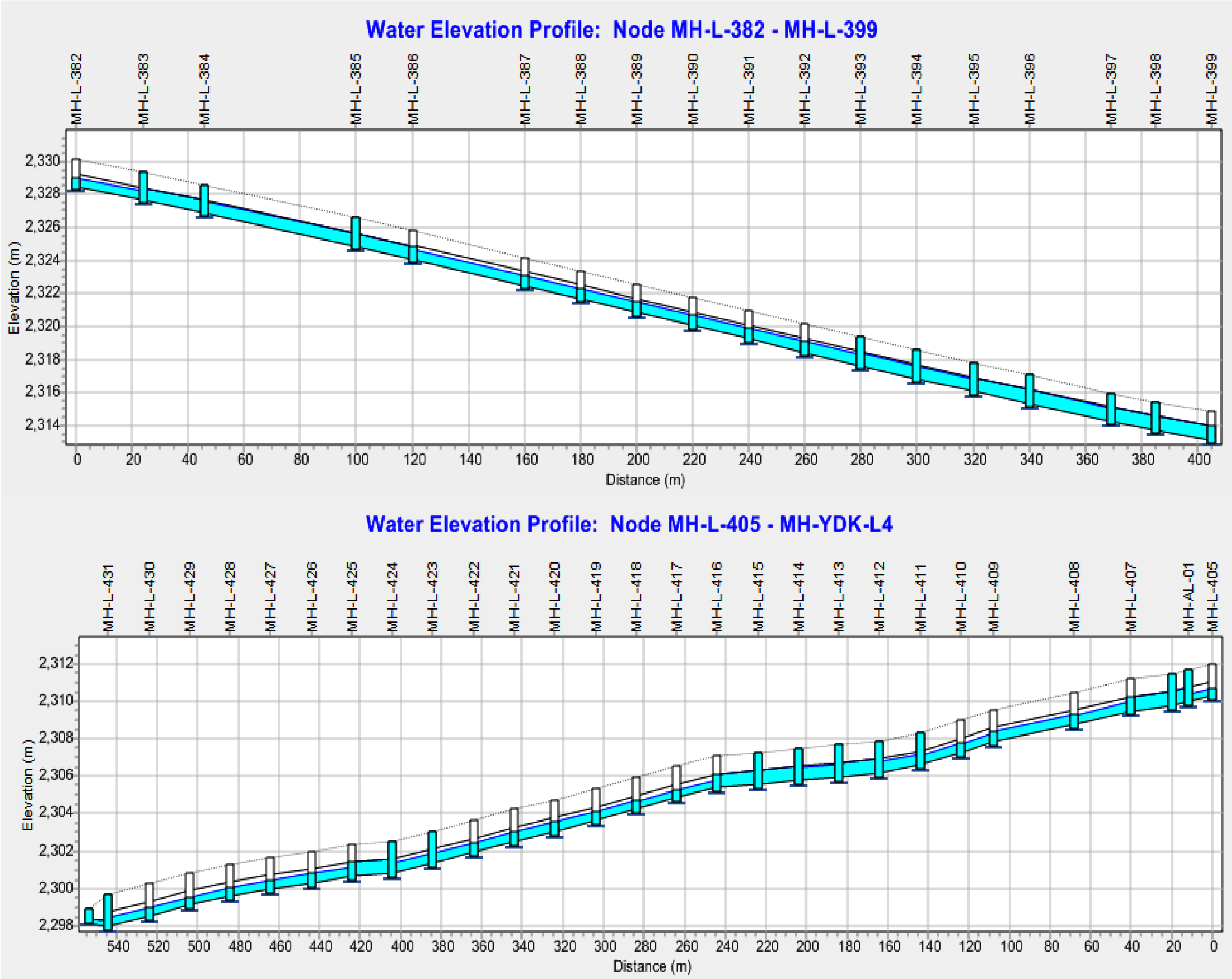
Figure F4:-25years of return period flooded manholes





MH-L-384 is 650 m far from Mesualekiya

Figure F5:-50years of return period flooded manholes



MH-L-382 is 614 m far from Mesualekiya

Figure F6:-100 years of return period flooded manholes

Appendix G: Manhole locations on Google Map

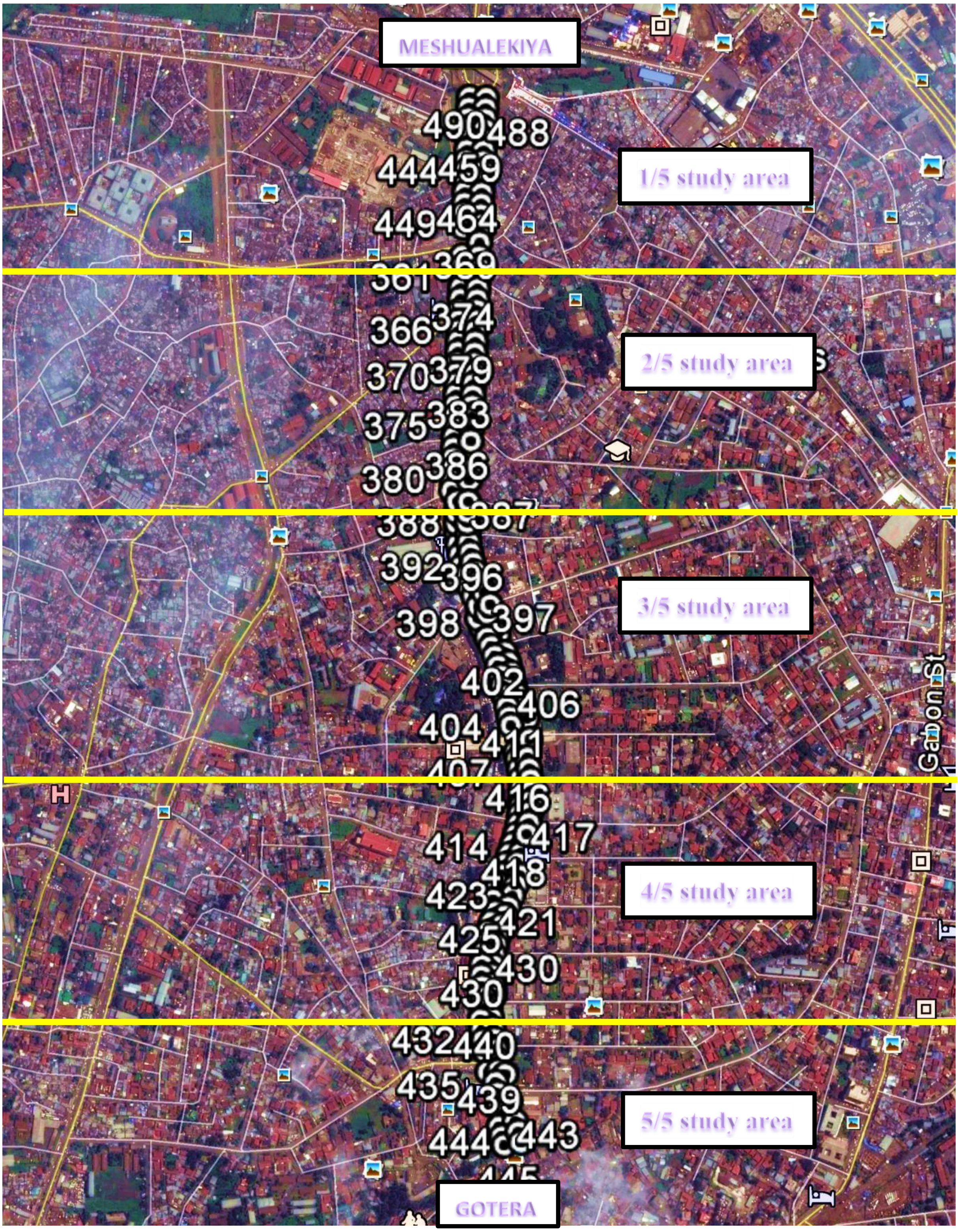


Figure G1: Manhole Locations

Figure G2:1/5 study area

Figure G3:2/5 study area

Figure G4:3/5 study area

Figure G5:4/5 study area

Figure G6:5/5 study area