Addis Ababa University

School of Graduate studies

Addis Ababa institute of Technology (AAiT)

Department of Civil and Environmental Engineering

Assessing the performance of integrated storm drainage system of Addis Ababa light rail transit and Addis Ababa city road

"Case study on East-West line of Light Railway Transit, from Summit Roundabout to Gurd-Sholla"

By: Surafel Belayneh

Advisor: Zerihun Getaneh

March 11,2016

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A project Presented to the

School of Graduate Studies

Addis Ababa University Institute of Technology

In partial fulfillment of the requirements for the Masters Degree of Engineering in civil Engineering

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Date defended____________________________

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(External examiner) (Signature)

Declaration and copy rights

I, Surafel Belayneh, declares that this project 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 ....

Acknowledgement

I have no words to say thank you to all my families and friends who helps me, support me and encourage in every step of my way and make me to be who I am now.

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Abstract

Recently, Addis Ababa is facing with problems related to improper functioning of the drainage systems. This problem become a serious issue during the rainy seasons. Some roads are flooded with usual rain. Light railway transit is introduced to the city since 2014. The railway uses the road drainage network for disposal of runoff generated from the catchment.

This project deals with the assessment of the performance of the integrated drainage systems of light railway and road way. The study mainly focus on the cause of flooding on East west line at Sahlite - Meheret round about.

The project use EPA SWMM v5.1 for the hydrology and hydraulics modeling in conjunction with ARC GIS 10.1 for the catchment delineation using the manholes as a catchment out let. Fifteen minutes intensity is taken from the IDF curve developed from Bole station for return period of 2,5,10,25,50 and 100 years.

The modeling result show that for return period of 10 and 25 years, two manholes were flooded for about 12 minutes and the volume of runoff is about 49 cubic meter for manhole designated as A16 and 7 cubic meter for junction designated as C32, so the project state the remedial measure to be taken to overcome the problems.

Pipe connecting the manhole designated as A16-A15-A14 and B13 should be changed from 750 mm to 1200 mm diameter concrete pipe. It is found that there is a differences between the design and construction for pipe connecting A30-A31 and C32 the design provide 750 mm diameter concrete pipe and due to the flooding the pipe where replaced with 3m by 2m rectangular box culvert, and to overcome the common undesirable spreading of the storm water on the surface of the road for common intensity, the manhole inlet and the pipe should be cleaned frequently.

Key words, *EPA SWMM,ARC GIS, urban flooding*

Abbreviations

AA- Addis Ababa

AAU- Addis Ababa University

AACRA- Addis Ababa City Road Authority

AAEPA- Addis Ababa Environmental Protection Authority

AREMA - American Railway Engineering Maintenance of way Association

CN- Curve Number

CMS - Cubic Meter per Second

DM- Drainage Manual

ERA- Ethiopian Road Authority

EMA- Ethiopian Meteorological Agency

EPA- Environmental Protection Agency

ERC- Ethiopian Railway Corporation

FHWA- Federal Highway Administration

FUPCoB- Federal Urban Planning Coordinating Bureau

LID - Low Impact Development

LRT- Light Rail Transit

SWMM - Storm Water Management Model

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Chapter One

Introduction

1.1. **Background information**

Recently Addis Ababa, the capital city of Ethiopia, is facing challenges resulting from years of lack of coordination between different organizations. Drainage facilities built some years back were unable to give their intended functions now and some are needed to be replaced by new ones. In spite of massive road constructions in the capital, Addis Ababa, poor storm drainage has become one defining attribute of the city, destroying its positive image. (Desta Gebre-hiwot, the Ethiopian herald, poor drainage system deteriorating and traffic jams,).

Now a days the city has many ongoing constructions like roads, light railway lines, buildings and other infrastructures to meet all necessary requirements for the inhabitant of the city and to meet the standard for capital city of both Ethiopia and Africa. These activities change the infiltration characteristics of the catchment, which influence the amount of rainfall changed directly to runoff.

In addition to the change in land use and land cover of the city, during rainy seasons inadequacy of the storm drainage system create a nightmare for the existing road network. As a result watching the storm water over flowing on street and sometimes create temporary pond on each degraded road way is not new for the road users and it highly challenge them to accomplish their day to day activities easily.

1.2. **Overview of AA LRT project**

Addis Ababa, which is the capital city of Ethiopia, has an expanded area of over 540sq. km and is situated at an altitude of about 2500meters above sea level. (Ethiopian Statistic Agency, 2008). The light rail system of Addis Ababa have two lines one running from east to west and the other one is from north to south. It has a total length of 32.25 kilometers. It is a standard gauge and conventional ballasted track bedded on asphalt bitumen. It uses electric as the source of energy to transport passengers from -station to station. There are 39 stations in both lines.

Each train has a capacity to carry 286 passengers. This will enable the light rail transit to provide a transportation service to 15,000 passengers per hour per direction (PPHPD) and 60,000 in all four directions.

Of the two rail lines, the east-west line extend 17.35 kilometers, stretching from Ayat Village to Tor Hailoch, and passing through Megenagna, Legehar and Mexico Square. The north-south line, which is 16.9 kilometers in length, passes through Menelik II Square, Merkato, Lideta, Legehar, Meskel Square, Gotera and Kaliti. Additionally, two lines have a common track of about 2.7 km.

It has underground, semi-underground, at grade and elevated sections. The ballast is bedded on asphalt bitumen to increase the track strength which in other hand facilitates to drain out the storm precipitation efficiently from the system. The rainfall precipitation on the track is collected and conveyed to the road side ditch through buried cross drainage pipes spaced 100 to 400meter apart.

1.3. **Problem statement**

In past few decades the population growth of Addis Ababa increase dramatically. According to the 2008 census report it reaches 3.384 million with 3.8% annual growth estimated in 2014. Due to this reason rapid and also unplanned urbanization create many difficulties to the city municipalities for proper management.

The city is widened continuously in all directions without controlling. Now a day's constructing roads, housing programs ,which is creating more and more impervious surfaces in the city, and also providing sustainable water supplies for the city's inhabitant gives a great attentions in current government policies. This activities in old part of city relay on the existing urban drainage network which also create additional loads on the drainage network.

Urban transport on the other hand became one of the major problems for the city. The problem arises from many factors like upgrading and rebuilding of the old road network to carry the current traffics, degraded roads which also create congestions of traffic. There are many remedial measures taken by the government to overcome such the above mentioned problems, one of them is application of mass transit system. The Addis Ababa Light Rail Transit project is one of the project that is implemented in this year (2015).

The AA LRT lines are segregated in road right of way except at elevated and tunnel sections. The roadway intersections are protected by light signals with transit priority.

The continuous change of land use create large percentage of impervious surface (asphalt roads, parking lots, buildings, etc.) so the infiltration rate is highly minimized and more and more instantaneous run-off is common in rainy seasons.

The light railways lines drainage system is connected directly to the AACR drainage systems with buried cross drainage pipe under the road ways. The drainage system of the newly built Light Railway Lines are totally relay on the old AACR drainage system, which exhibit unsatisfactory operation like over flowing, blockage of inlets, manholes by solid wastes and siltation also play a great roll in minimizing the section of the conveyance system.

The road system can tolerate an over flow up to 30 cm depth. When the road system experiences flooding the light railway lines will also experience it due the connection of their drainage systems. But when it comes to the railway the instantaneous runoff will wash away the ballast and create problems like deviation of the track on both vertical and horizontal plains. Blockage of outlet create pounding. Due to the high frequency of the light rail, degradation of the ballast material is significant, so the system needs frequent maintenance. As a result operation cost and reliability the system falls in questions.

1.4. **Importance of the project**

The severity of the storm drainage problems is became one way of describing the current conditions of Addis Ababa in every newspapers, scientific journals and many other studies related to storm water management. Generally, managing storm water drainage system in Addis Ababa has multi purposes. It will make sure that the sustainability of the infrastructures as well as it helps to create pleasant environment for its habitants. Conducting this project has the following significance

- The study will assess the performance of the integrated storm drainage systems and it will identify the short coming of the drainage network of the systems built in the city,
- The result of this study will create a chance for the client of both AA LRT and AACRA to evaluate their systems and to take appropriate measure to enhance the performance of system for both roadways and light railway systems.
- The outcomes of this project can be used for further studies related to storm drainage problem of the city

Chapter Two

Literature Review

2.1. **Introduction**

This chapter covers the important theories and concepts developed by many scientists which used as the basis of the research. At the beginning it reviews some astonished works done by ancient civilization also followed by the problem they had had on the process of using the systems.

Urban storm drainage components, facilities and their importance, track drainage system with its typology, urban storm drainage design, method of computing the runoff volume on urban section is reviewed successively. Modeling of urban drainage network is final issue to be covered by this chapter.

2.2. **History of urban drainage**

"The history of man is reflected in the history of sewers…"*. Victor Hugo, *Les Misörables

Flood protection, drainage and sanitations need high attentions on all societies. Since early civilization, various means have been used to provide these essential services. Some of the earliest urban drainage structures were built about 5000 years again the time of the Mesopotamian Empire (Wolfe, 2000). In subsequent history, many of these structures and associated systems were abandoned, but their remnants can still be found in various places around the world.

The Minoan civilization flourished on the Island of Crete from about 2800 BC to 1100 BC. The ruins from this civilization located on the Aegean Sea revealed elaborate systems of well-built stone drains, which carried sanitary sewage, roof runoff, and general surface drainage (Gray 1940). Knossos, approximately 5 kilometers from Heraklion, the modern capital of Crete, was one of the most ancient and most unique cities of the Aegean. The drainage systems at Knossos were consisting of two separate systems, one to collect the sewage and the other to collect rain water (see figure 2.1). After the collapse of the Minoan civilization and before the Greek influence, which was roughly from 1100 to 700B.C., there was disarray in the Aegean society. The uses of drains were fairly extensive in Minoan palaces and later their use was rediscovered by the Greeks, as they started living in settlements.

The Romans were the only civilization in all of western Asia and Europe from ancient times to 1800s to build a carefully planned road system with properly drained surfaces. Along some roadways they implemented curb and gutters to direct surface runoff to rock-lined open drainage channels (Hill 1984). Many of the roadbed were graded to direct the surface runoff from the streets toward the drainage channels.

In addition to the urban drainage component incorporated into roadway design and construction, the Romans used rainwater collection extensively in their drainage system. Typically rainwater falling onto an urban area would be stored for local use. Rainfall on rooftops was often collected into a cistern located in the interior of the house (Hodge 1992). Figure 2.1 shows a picture of one of the massive underground structures built to store water draining from the large area. Unfortunately the various approaches used at that time for wastewater disposal were not hygienic and numerous epidemics of typhoid and cholera in Europe and the United States, particularly between the 1830sand 1870s, prompted city governments to find other solutions for dealing with sewage disposal and eventually its treatment (Wolfe, 2000).

Figure 2.1 Minoan storm drain at Knossos dating to 1500 BC. (Daedalus 2002) at the left and picture of Roman cistern in Fermo, Italy.

At the end of the nineteenth century significant progress was achieved in urban surface water drainage, with the development of empirical design methods for sizing drainage pipes. Intuitive reasoning about conversion of rainfall into runoff led to the development of the rational method, which is generally credited to Mulvaney (Ireland, 1851). In subsequent years, many variations of this fundamental formula have been developed and applied around the world. Essentially the method holds that the rate of flow (runoff) from a surface exposed to rainfall may be calculated from the product of the rainfall intensity and the surface area, with a reduction for the loss of water due to cracks, puddles, soaking into the surface and evaporation. This reduction factor is called a runoff coefficient.

Urban drainage is defined to include two types of fluids: wastewater and storm water (Butler and Davis 2000). Wastewater is water that after use for life support, industrial processes, or life enhancement must be collected disposed of appropriately to prevent nuisance and polluted conditions from developing in urban areas. Storm water is runoff produced by excess precipitation. Historically the two waters have either been combined in to a single conduit (i.e. combined sewers), or have kept separate during collection and disposal (i.e. separate sewer). Only storm water drainage will be discussed in this research.

2.2.1 **History of Urban drainage system problems**

In ancient civilization, they were developing the drainage system by trial and error, all the problem were exhibited on combined sewer systems. Those problems in some civilization directly contribute for the downfall of their civilization. This research review some of the problem raised on some civilization.

Flooding, bad odor, facilitating a good conditions for mosquito’s reproduction (which causes malaria) and transmission of disease especially the water born ones were the result of the poor drainage system developed in each civilization. Persian civilization were one example of ancient civilization practicing urban drainage, as time passed changes in the Persian attitudes and behavior contributed to water pollution problems and the eventual downfall of the civilization (Niemczynowicz 1997). The Romans were also a victim of unplanned waste water disposal at the Tiber River. Undoubtedly, this area as well as the surrounding one became much more wholesome with the elimination of the malaria and its accompanying malaria. Ancient Romans had not associated the malaria with the mosquitoes that are prevalent in swampy areas; rather, they attributed it to odors of rotting swamp vegetation. (Greg Tardieu, 1986).

In Paris, underground sewer, known as the "beltwaysewer,'' built by Hugues Aubriot at 1370 discharged into the seine River and acted as a collector for the sewers on one side of the seine. The outfall of the sewer, near the Louvre, produced terrible odors that even offended Louis XII. There were consistent maintenance problems in European covered sewers during the Middle Ages. A survey of covered sewers in Paris conducted during 1636 found all 24 clogged and in serious disrepair (Krupa 1991).

One of the challenges of third world countries in this new century concerns the management of cities, where there is a trend to uncontrollable urban explosion and the accumulation of problems. In this challenge, the question of water management constitutes one of the burning issues on two grounds: resources and risks (Wondimu A., 2000).

In Addis Ababa, in each of 3 cyclical events in the last two decades, flooding affected 7,000 inhabitants, with loss of human life (12 fatalities in 1978, 9 in 1995). In the case of Addis Ababa, where the site presents favorable topographic conditions, two factors aggravated the risks: precarious housing and river-bank occupation.

2.3. **Components of urban storm Drainage System**

According to AACRA drainage manual (urban storm drainage system composed of two components, which are minor and major drainage systems.

2.3.1 **Major drainage component**

Floods of higher frequency beyond the capacity of the minor system. An overland relief for stormwater flows exceeding the capacity of the minor system is provided by the major system. The major system designed for more infrequent storm events, such as the 25-,50-,and 100- years storms(HEC22 1996). The major system essentially consisites of pathways provided for the runoff to flow to natural or manmade reciving channels such as streams, creeks, or rivers. A 100 year event should use as check storm for the major systems.(AACRA, DM, 2004)

2.3.2 **Minor storm drainage components**

The minor system consists of sub- components that have been historically considered to be part of the “storm drainage system”. It is also referred to as the “conveyance” system. The minor systems is normally designed to carry a runoff storm event up to 10 years return period (HEC22 1996).

It includes;

- Curbs
- Gutters
- Inlets
- Access holes
- Ditches
- Open channels
- Pipes and other conduits
- Detention and retention basins, and other facilities like pumps and water quality control facilities.

The ACCRA manual categorize the main drainage components of the minor drainage system according to their functions as:

- Collection of the runoff from the road surface and right-of-way;
- Conveyance of the storm water from the roadway surface and right-of-way.
- Discharging of the storm water to a receiving body without causing adverse on-or off-site impact on the environment.

The function of the minor drainage system is described as below.

2.3.2.1 Storm water collection

The function of storm water collection is performed through the use of roadside and median ditches, gutters, and drainage inlets.

- ***Road side and median ditches,*** these element are used to intercept the runoff and carry it to an adequate storm drain
- ***Gutters***, gutters intercept pavement runoff and carry it along the road way to the storm inlet.
- ***Drainage Inlets,*** they receive the surface water collected in dicthes and gutters and serve to convay the surface water to storm drains. They also limit the spread of surface water onto travel lanes when located along shoulder of the raodway. The term "inlets" also refers to all types of inlets such as grate inlets,curb inlets, slotted inlets, etc.

2.3.2.2 Stormwater conveyance

The main storm drainage systems conveys the storm water through the right-of-way to its discharge points. The storm drains are connected with the access holes or other access structures.

- ***Storm Drains,*** it constitute that portion of the storm drainage system that receives runoff from inlets and conveys the runoff to some point where it is discharged into a channel, water body, or other piped system. They can be closed conduit or open channel. They consists of one or more pipes or conveyance channels connecting two or more inlets.
- ***Access Holes, Junction Boxes, and Inlets.*** This elements are access structures and alignments control points in storm drainage systems. This structures are located at the intersections of two or more storm drains when there is a change in the pipe size, and at change in alignment.
- ***Storm water Discharge Control,*** discharge controls can be classified as quantity and quality controls. These controls aim to offset potential runoff impact on the environment.(AACRA,2004)

If one element doesn't operate efficiently the effect will be shown in -whole system. So one should take a great care in design as well as in construction and operation time checking every elements of the system is mandatory.

2.4. **Track drainage system**

Railway is one of the oldest means of motorized transportation systems in human history. The railway system has many sub-systems. The vehicle system, power systems, signal system, track systems are some of the sub-systems. Drainage system is also one of the most important component of the railway sub-systems.

Track drainage plays a significance roll on the overall performance of the railways systems. Having adequate track drainage system makes the railway system efficient, reliable and it will decrease the maintenance costs throughout its service life. Without providing adequate track drainage, the system reliability will fall in doubt. Track formation may become saturated leading to weakening and subsequent failure. Formation failure may be indicated by any of the following; mud pumping up through the ballast, repeated top and line problems, bog holes, or heaving of the formation.(TMC 421, track DM).

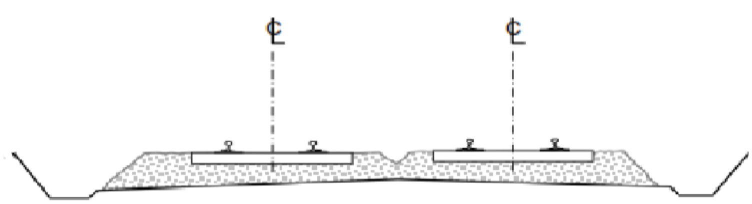


Figure 2.2 Typical Track Formation.

Track drainage consists of surface drainage and subsurface drainage.

2.4.1 **Surface Drainage**

Surface drainage removes surface runoff before it enters the track structure, as well as collecting water percolating out of the track structure. There are three main types of surface drainage. These are;

Cess drains, Cess drains are surface drains located at formation level at the side of tracks, to remove water that has percolated through the ballast and is flowing along the capping layer towards the outside of the track formation. Cess drains are primarily intended for the protection of the formation by keeping the formation dry.

Catch drains or top drains, the purpose of catch drains to intercept overland flow or runoff before it reaches the track. They reduce the possibility of causing damage to the track or related structures, such as cuttings or embankments. Catch drains are generally located on the uphill side of a cutting to catch water flowing down the hill and remove it prior to reaching the cutting. If this water was allowed to flow over the cutting face, it may cause excessive erosion and subsequent silting up of cess drains.

Mitre drains. Mitre drains are connected to cess and catch drains to provide an escape for water from these drains. Mitre drains should be provided at regular intervals to remove water before it slows down and starts to deposit any sediment that it may be carrying.

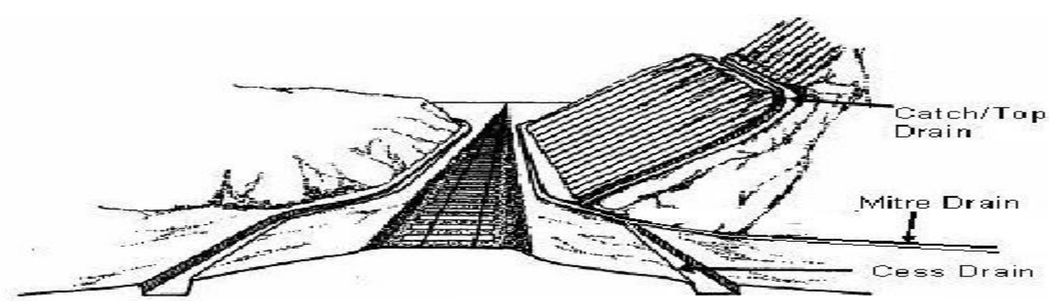


Figure 2.3 Surface Drainage Types

2.4.2 **Sub- surface drainage**

Subsurface drains are used where adequate surface drainage cannot be provided due to some restriction or lack of available fall due to outlet restrictions. Locations where these circumstances may occur are:

- Platforms
- Cuttings
- Junctions
- Multiple tracks
- Bridges

Subsurface drainage is necessary for maintaining the integrity of the track formation and ensuring the stability of earth slopes. It used for drainage of the track structure, controlling of the ground water and draining of the slopes. Subsurface drainage provided in locations where the water table is at or near earth works level. Subsurface drainage shall be provided along the cess, between, across, or under tracks as required (TMC 421, track DM).

Subsurface drains normally used for track drainage can be classified into three types according to their location and geometry:

- Longitudinal drain
- Transverse drain
- Drainage blankets.

2.5. **Urban storm drainage design**

Designing a new urban storm drainage systems is a relative simple task, when considering the implementation of a design with in a newly constructing urban area. Open channels, inlet structures, access holes and pipes are integrated in order to collect and convey the calculated discharge for the design rainfall. Rates of infiltration, runoff coefficients and other characteristics of the catchment area can easily measures or predicated. More or less drainage will not be a problem for further development of that area, provided that the operation is supervised and appropriate maintenance is undertaking periodically. In such cases, design is made by dividing the whole catchment in to sub-catchment which composes of the part of the urban land draining in to the system in defined way. So computing the flow in each point at specific time is possible which gives a chance for the designer to provide adequate drainage infrastructures that guarantee the reliability of the system and facilitate for further development instead of being a problem.

When a drainage system already exists and fails, like in most part of Addis Ababa, it become very difficult to propose adequate corrective measures for the system rehabilitation without considering its systemic behavior. The combination of superficial generated flows with drainage net flows may be diverse. Ones the waters is spilled out of the storm drain system, it may flows on roads and highways, in an unpredicted way. The roads and highways used as a means of conveyance and leads the water to down streams reaches of the catchment which create complete new flow pattern in the down steams of the system. This results flooding of the down streams at sever storm and sometimes create temporary ponds in lower open areas and on degraded road's surfaces. The combination of these effects is a difficult question to be assessed in full scale, sometimes, the proposed solutions may not be effective in this case detailed analysis and using powerful computer programs may give sufficient solutions.

2.5.1 **Storm water computations**

The amount of discharge produced by a catchment can be computed by using different methods. The selection of this computation method is highly dependent on the importance of the project in titled and the budget available at hand. These methods are available from simple hand calculation to highly sophisticated and powerful computer software's. There is always a limitation on each methods.

Rational methods

The Rational Method is used for flood estimation and also can be used to estimate storm water 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

- 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.

During the last few decades, rational method is widely used. Despite of its limitation, its simplicity even now a day's became first choice of designers to find the design discharge for small catchments.

Q = CiA/3.60---Eq. 2.1

Where:

Q is peak discharge (cubic meter per second – cms)

C is ratio or peak runoff rate to average rainfall rate over the time of concentration (runoff-coefficient) ($0 \leq C \leq 1$) 0 means completely pervious surface and 1 is impervious.

i is rainfall intensity (mm/hour)

A is area of watershed under consideration (sq.km)

In general the rational method should be applied to drainage basins less than 0.5 sq.km in area and is best suited for well-defined drainage basins, such as urban areas (AREMA Sec 3.3.2.3).

The runoff coefficient is dependent on the surface condition of the catchment. In case of urban areas each segment has probably different surface conditions. The cumulative of the runoff coefficient will be taken for the computation purpose. For n sub catchment having different surface conditions the runoff produced can be found by using this equations;

$$Q = i\sum_{j=1}^{n} C_j A_j \text{ --Eq. 2.2}$$

The recommended value of the runoff coefficient for different urban watershed is shown in Appendix A.

The idea behind the rational method is for a given constant rainfall intensity the magnitude- of the runoff will increase and the pick is happen when all the catchment start to contribute. The time gap between the starting of the rainfall to produce its pick discharge is known as ***time of concentrations.*** Different researches for different places developed an empirical equation for determination of the time of concentration. Time of concentration is affected by factors like surface roughness, channel shape and flow pattern and stream slope. The following table shows two empirical equations suggested by FUPCoB to calculate time of concentrations.

Method and Date	Equations for T_c(in min otherwise stated)	Remarks
Air port	$T_c = 3.64(1.1\text{-}C)\ L^{0.83}/H^{0.33}$ Where: T_C= Time of concentration (hr.) L= Flow length from the remotest point to the point of interest in km H= Elevation difference in m C= Runoff coefficient (unit less)	Airport formula used when the land is covered more than 75% by impervious layer.
Federal Aviation Administration (1970)	$T_c = 1.8(1.1\text{-}C)\ L^{0.50}/S^{0.333}$ C= Rational method runoff coefficient L= Length of overland flow, in fit.	Developed form air field drainage data assembled by corps of Engineers, method is intended for use of airfield drainage problems, but has been used frequently for overland flow in urban basin.

Table 2.1 Equation used to compute time of concentration. Source Applied Hydrology. VenTe Chow. P.500

One of the limitation for the rational methods is, when the catchment is wide/ greater than 0.5 sq.km the method is no longer give reliable solutions. So other method like SCS, computer programs must be used for efficient design.

SCS methods

The SCS-CN method is an event-based model developed by USDA soil conservation service (***scs***)United States natural resource conservation service (UNRCS) or SCS method is widely used for the estimation of flood on medium sized catchments.

The curve number CN is a land-cover index for a given land and soil type to determine the amount of rainfall that infiltrates in to the ground and the amount becomes runoff for a specific storm event (USDA, 1986). According to FUPCoB manual this method is recommended to use when the catchment area is between 0.5 sq.km to 13 sq.km.

The SCS method is derived by assuming that no runoff will occur until rainfall equals to an initial abstraction, I_a and also overcome cumulative infiltration F which is the actual retention before runoff begins. The potential retentions S is equal to the aggregate of the cumulative infiltration and initial abstraction. If P_e is effective storm precipitation which is equal to the difference between storm precipitation and abstraction, and if r_d is depth of runoff then

$$\frac{F}{S} = \frac{rd}{Pe} \quad \text{---Eq.2.3}$$

From the observed data, $I_a = 0.2*S$, then the equation can be rewrite as P_e=(P-0.2*S).

The peak discharge in SCS method is derived by approximation of triangular hydrograph resulting from excess rainfall of specified duration D

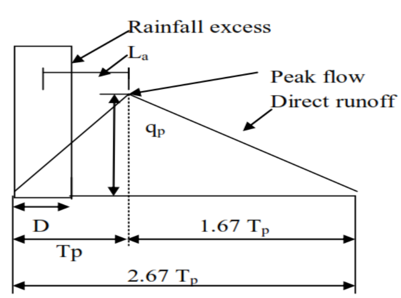


Figure 2.4 SCS Triangular Hydrograph.

The lag time is assumed to be 0.6 t_c. The time to rise is Tp. The base of the triangle is assumed to be 2.67 of Tp.

$T_p = 0.5 * D + 0.6 * t_c$---Eq. 2.4

From the triangular hydrograph assuming that the excess rainfall depth is equal to the runoff depth, the peak discharge can be computed by using the following equation.

$q_p = \frac{0.208*A*r_d}{0.5D+0.6tc}$ --Eq. 2.5

Where;

$q_{p=}$ peak discharge

A= Area of the water shade in sq.km

D = duration of excess rainfall in hr.

t_c= time of concentration in hr. Kirpich formula can be used to determine time of concentration.

r_d= excess rainfall depth in mm. can be computed with the next formula.

The depth of runoff resulting from the required return period rainfall depth of duration corresponding to the time of concentration can be calculated by using the following equation.

$r_d = \frac{(P-0.2*S)^2}{(P+0.8*S)}$--Eq. 2.6

The potential maximum retention, S, is related to hydrologic soil properties, land cover, condition of the moisture content of the catchment prior to the rainfall event and its expressed by a dimensionless index termed as catchment's curve number. The CN and S are related as;

$S = \frac{25400}{CN} - 254$---Eq 2.7

Based on infiltration rates, the Soil Conservation Service (SCS) has divided soils into four hydrologic soil groups as follows:-

Group A: Soils with a low runoff potential due to high infiltration rates.

Group B: Soils with moderately low runoff potential due to moderate infiltration rates

Group C: Soils with moderately high runoff potential due to slow infiltration rates.

Group D: Soils with a high runoff potential due to very slow infiltration rates.

2.6. **Storm Drainage Experience of Addis Ababa**

Besides the real situation that everyone can see the short coming of the drainage system of Addis Ababa especially during rainy seasons, many researchers have done and been doing a lot of researches to identify the problems and to propose a reliable solutions. Some research finding are initiating to do this research.

Although having a light railway transit is new for the city, many researchers have been done on the drainage system of Addis Ababa road network. On this project the intrusion of the AA LRT will be examined with existed drainage system of the city road network.

All researchers have agreed upon that the rapid urbanization leading the conversion of a large portion of the land to impervious surface is one cause of flooding in the city during past few decades. Others argue that the problem arise from insufficient operation. On this research some of important research output is reviewed as bellow.

According to the research done on drainage systems yeka sub-city, this sub-city also has been facing with the challenges induced from the problems related to drainage systems. The geographical location of the sub-city makes vulnerable for flooding due to the deforestation and an illegal settlement on Yeka Mountain. The study shows that the runoff coefficient of this mountain increase about three folds (from 0.25 to 0.70) which means, almost 70 percent of the precipitation is converted to direct runoff.

This change with the insufficient provision of drainage structure and lack of proper maintenance and operation of the system leads the problem to be worse. The study also revealed that the urban storm drainage line integration with roads is about 271.33 m, which means for one kilometer of road only 271.33m of drain line is constructed. The rest 728.67 meters of the road has not provided with any drainage facilities. This facilitates the overland flow. When the storm intensity is high this condition is changed to flood and incur many problems for both the inhabitant and for the government. The inhabitant lost their property and many water born disease spread on the government side the rebuilding of the infrastructures is additional cost and the social insecurity has also raised as a questions. Environmental degradation due to the flood is exhibited on the study area. Deterioration of the road system which has a direct negative impact on the transportation systems of the sub-city is one big social problem developed due to the floods.

Figure 2.5 highly eroded road (A) and flooded road surface (B). *Source (Danachew A, study of urban drainage system in Addis Ababa, Yeka sub-city.2011..)*

The researcher also provided some remedial measures to be done by the stake holders to minimize the risk caused by the system failure. Afforestation of Yeka Mountain with indigenous trees will decrease the amount of runoff in other word the infiltration capacity is increased by doing that. Provision of sufficient drainage facilities to guide and control the storm water should get give a great concern. Grassing and use of permeable structures on gardens, vacant areas, river and road sides to increase infiltration and reduce flooding hazards like the one which has been experienced by the AAEPA on Jelissa River around Gurd Shola. (Dagnachew Adugna, 2011).

The other important study which is done on the investigation of storm drainage systems of Addis Ababa a case study on “Ring roads” found that the on specific problematic section, inadequate design, construction problem and efficiency of operational management fall in questions. Among the causes of the flooding on the road pavement; large inlet spaces, minimum curb inlet opening due to construction related problems, problem on selection of appropriate type of inlets based on the geometry of the roads, illegal solid waste disposals on the road and drainage facilitates like in access holes, and capability of client to manage the road drainage systems is in doubt. Based on this identified problem proper measurement that has to be taken by the responsible parties is also described by the research.

These researches and more other facts that can be seen during any storm event, initiate to study the reliability of the integration between the drainage systems of the Addis Ababa Light Rail Transit with the existing Addis Ababa Road.

2.7. **Hydraulics of highway**

The primary target of the pavement drainage design is for efficient and rapid removal of storm water from the roadway surface. Storm water flowing on the roadway with a guidance of the curb stone is a special case of open-channel flow in a shallow depth with more likely triangular shape cross section.

When water stays on the pavement, it create traffic congestion which interns also contribute traffic accidents caused by loss of visibility from splash and spray of it. During the design of pavement drainage, the discharge and allowable spread of water across the pavement cross sections are the controlling points.

The amount of allowable storm water spread across the street is dependent on the speed limit and volume of the traffic accommodate by the traffic lane. The higher speed and high volume of traffic lane should be designed to minimize if possible to eliminate spread of storm water during the design period.

The roadway geometric design features greatly affect the drainage pattern on the pavement. This features include curbs, gutters, shoulders, inlets, longitudinal and lateral slope of the roadway by itself.

2.7.1 Flow in gutters

The triangular shaped flow defined by curbs, gutters and the spread onto the pavement create an open-channel flow for conveying the storm water runoff. The slope adjacent to the curb may have steep slope relative to the cross fall of the road. The hydraulic design of the flow can be done using modified Manning's formula and Izzard formula (AACRA drainage manual 2004).

Modification of the Manning formula is necessary for the computation of flow in triangular channels because the hydraulic radius in the equation does not adequately describe the gutter cross section, particularly where the top width of the water surface is more than forty times the depth at the curb (FHWA, August 2001).

The capacity of gutters having the same cross slope with the roads, can determined by using the following modified Manning's formula.

$$Q = (0.375\, F) d^{\frac{8}{3}} S_o^{0.5}\, Z/n \quad \text{--Eq. 2.8}$$

Where;

Q = the total flow in m^3/s

F = flow correction factor (0.9 for simple triangular sections and 0.8 for gutter sections having different slope from the cross slope of roadway.

n =Manning's roughness coefficient (for asphalt pavement of rough texture n is taken 0.016)

T = width of flow or spread in the gutter measured in meter

d = the greatest gutter depth in meter

S_o = the longitudinal slope meter/meter

Desirable gutter grades should not be less than 0.5%. Minimum pavement cross slope should not be less than 2% for new construction/re-construction (AACRA drainage manual 2004).

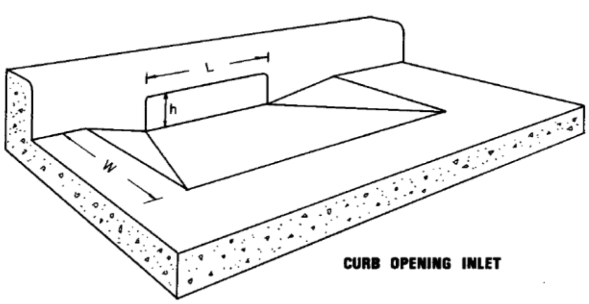
2.7.2 Pavement drainage inlets

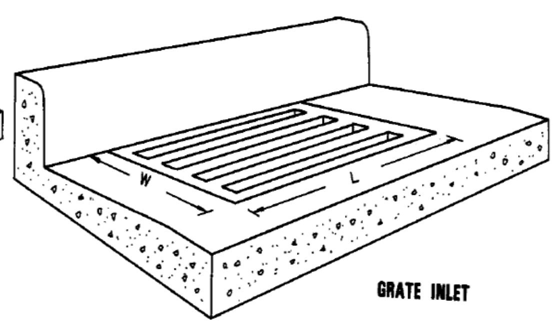
When the capacity of gutters, curbs exceeded considerable amount of storm water will be spread across the traffic lane to overcome this kind of problem the flow should be diverted fully or partially at every few meters laterally. This can be achieved by providing drainage inlets at reasonable intervals at the roadway sides, which are connected with the side drains.

Drainage inlets that are used for intercepting the runoff from the pavement surface can be categorized in to four major classes.

- ***Curb-opening inlets***
- ***Grate inlets***
- ***Slotted drains and ;***
- ***Combination of the above inlets types.***

Each class has a many variation in design and installed with or without the depression of the gutter.





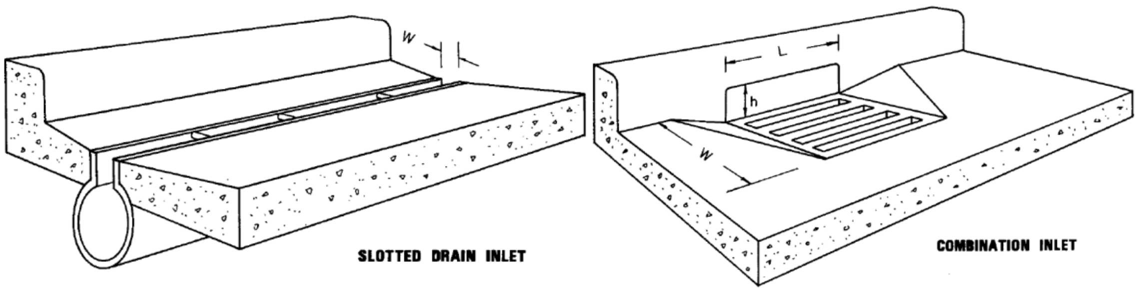


Figure 2.6 highway drainage inlets types. *(Source FHWA).*

The capacity of the inlets is a function of many factors which includes the inlet type itself, location of the inlets (flat or sag locations), design of gutters, clogging condition, etc.

Inlet in continuous grade operate as weir flow, but while they are installed on sag positions they are acting like an orifice flow as the depth increase above them. Orifice flow begins at depths dependent on inlet size, curb opening height, or the slot width of the inlet. At the depth where weir flow occurs and those where orifice flow occur, flow is in the transition stage and may be ill-defined and poorly behaved (FHWA).

The location and spacing of inlets is governed by the following factors;

- The amount of runoff
- The longitudinal grade and cross slope
- The location and geometrics of interchanges and at-grade intersections,
- Tolerable water spread
- The inlet capacity
- Accessibility for maintenance and inspection
- Volume and movements of vehicles and pedestrians, and
- Amount of debris

The efficiency of inlets intercepting flow in sag portion is critical, since it creates hazardous pounding. Selecting the appropriate type and position of the inlets is a key points in intercepting the roadway flow.

Inlet Type	**Applicable setting**	**Advantages**	**Disadvantage**
Grate	Sumps and continuous grades (should be made bicycle safe)	Perform well over wide range of grades	Can become clogged lose some capacity with increasing grades
Curb-opening	Sumps and continuous grades (but not steep grade)	Do not clog easily Bicycle safe	Lose capacity with increasing grade.
Combination	Sumps and continuous grades (should be made bicycle safe)	High capacity Do not clog easily	More expensive than grate or curb-opening acting alone
Slotted	Locations where sheet flow must be intercepted.	Intercept flow over wide section	Susceptible to clogging

Table 2.2 Applicable settings for various inlet types.

2.7.3 Manholes

Manholes are one of the essential element in pipe drainage system. They shall be required where there is a change in pipe size, pipe directions, when pipes meeting with a different elevations, or when there is a junction of two or more sewer. At curved sewer section manhole may be required at the beginning or end of the section.

Another purpose of the manhole is to extract the sediments and debris entered to the pipe system and transported by the pipe. For this reasons the maximum spacing between consecutive manholes should not exceed 100 meters (AACRA, drainage manual 2004)

2.8. Modeling of urban storm drainage network

Modeling of urban drainage is one of the most difficult task to execute. The complexity of it is resulting from, highly irregular geometry of the catchment, the morphology of the catchment is exceptionally artificial and often contrary to natural flow paths.

There are three urban drainage modeling approaches. Which are 1D, 1D-1D and 1D-2D modeling approaches. Among these approaches the 1D modeling approach is adopted for this research. Only underground sewer network is modeled in this approach.

Different software's are available for the design and analysis of urban storm drainage systems; some of them are listed below

- Storm water management model (EPA SWMM)
- ISIS either 1D or 2D (Halcrow)
- HEC-HMS (US Army Corps of Engineers)
- HY -8 (FHWA)

From the above listed software's for this specific project SWMM is used because of the following reasons. EPA SWMM V5.1 is

- ✓ public domain software and freely copied
- ✓ the software is preliminary developed for urban drainage system
- ✓ the hydrology and hydraulics component are embedded on it
- ✓ it has simple user interface so that one can catch up essential's of the software components

2.8.1 Storm Water Management Model (SWMM)

SWMM is public domain software that can be freely copied and distributed. SWMM is a dynamic rainfall-runoff-routing simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas.

The EPA SWMM is a dynamic rainfall-runoff-routing simulation model used for single event or long-term (continuous) simulation of runoff quantity and quality from primarily urban areas. The runoff component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.(www.epa.gov/swmm)

SWMM contains several blocks for analysis of different process. Two of them are used in this study, the RUNOFF and EXTRAN blocks (Huber et al., 1984; Huber and Dickinson, 1988). The

RUNOFF block performs hydrologic simulation and its outputs are taken as input to the EXTRAN block, which routes the conduit flow in a storm sewer system using an explicit numerical solution of the Saint–Venant equations.

The runoff component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads. The routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators. SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

SWMM is a very powerful software for simulating the runoff caused by the storm precipitation. Both the hydrological and hydraulics modeling can be done using SWMM.

2.8.1.1 Hydrological Modeling

Hydrological modeling of the catchment is used to predict the volume or peak discharge from the catchment on a specific outlet at a specified time. There are many methods developed for calculating the peak discharge but their applicability depends mainly on the availability of the data.

The hydrological parameters which depends on the climate and morphological condition are important input for modeling programs.

SWMM accounts for various hydrologic processes that produce runoff from urban areas. These include:

- Time-varying rainfall
- Evaporation of standing surface water
- Snow accumulation and melting
- Rainfall interception from depression storage
- Infiltration of rainfall into unsaturated soil layers

- Percolation of infiltrated water into groundwater layers
- Interflow between groundwater and the drainage system
- Nonlinear reservoir routing of overland flow
- Capture and retention of rainfall/runoff with various types of low impact development (LID) practices.

Spatial variability in all of these processes is achieved by dividing a study area into a collection of smaller, homogeneous sub catchment areas, each containing its own fraction of pervious and impervious sub-areas. Overland flow can be routed between sub-areas, between sub catchments, or between entry points of a drainage system

2.8.1.2 Hydraulics modeling

The result of hydrological modeling is used as an input data for hydraulics modeling. Hydraulics modeling enables to set optimum opening and size and shape of drainage structures.

SWMM also contains a flexible set of hydraulic modeling capabilities used to route runoff and external inflows through the drainage system network of pipes, channels, storage/treatment units and diversion structures. These include the ability to:

- handle networks of unlimited size
- Use a wide variety of standard closed and open conduit shapes as well as natural channels
- Model special elements such as storage/treatment units, flow dividers, pumps, weirs, and orifices
- Apply external flows and water quality inputs from surface runoff, groundwater interflow,
- Rainfall-dependent infiltration/inflow, dry weather sanitary flow, and user-defined inflows
- Utilize either kinematic wave or full dynamic wave flow routing methods model various flow regimes, such as backwater, surcharging, reverse flow, and surface ponding

Apply user-defined dynamic control rules to simulate the operation of pumps, orifice openings, and weir crest levels *(EPA-SWMM V.5 user's manual. P_ii)* .

Chapter Three

Objective of the study

3.1. **General objectives**

The main objective of the research is to assess the performance of integrated drainage systems of AA LRT and AACRA and pinpoint the problems faced so far along with respective recommendations to have safe and sustainable storm drainage system.

3.2. **Specific objectives**

The specific objective of the study are

- Assess the capacity of track drainage systems
- Assess the capacity of drainage systems provided for the road network along with the AA LRT network
- Predict the system's capacity for its design period
- Identify the short coming of the system component i.e. inlet, open channel and pipe flows
- Check the connection of the two separate systems

3.3. **Scope of the study**

The study is geographically limited on the East-West line of LRT between Ayat terminal and Megenagna Terminal. Generally it assess the performance of the integrated storm drainage systems of LRT and AACR. The specific focus is to examine and check the connections between the two separate drainage systems. The impact of adding the loads from LRT to AACR is simulated by using freely available software which is, storm water management model version 5.1. Only the storm drainage is concerned other illegalized connection is not part of this study.

Chapter Four

Materials and Methods

4.1. Introduction

This chapter covers the material necessary for the research, procedures followed, methods of computations that will need and helps to achieve the aforementioned objectives on the introductory chapter. The beginning of the chapter will focused on the material used, the kind of data collected and their respective uses are described accordingly. Finally the methodology employed on the research is described successively.

4.2. Materials

Hand GPS; to get the X and Y coordinates of the major and minor crossing, connection of the two systems, inlets, etc.

Tape Meter; to measure the existing structures openings, accumulation of sedimentation on side channel (intercepting ditches), etc.

Maps; different maps like topographical maps, street maps and google earth is used for careful examination of the study area.

DEM; is a grid of square cell; and each cell value represents the elevation of the land surface .DEM is used as an input data for ARC-GIS for catchment delineation and estimation of catchment characteristic. DEM data's are taken from USGS 30x30 meter.

Metrological Data ; daily rainfall data from Ethiopian Metrological Agency (EMA)

Global Mapper ; is used to pre-process the DEM data before it can be used as input for GIS.

ARC-GIS 10.1; is a power full software used to process the DEM data.

SWMM V.5.1; is a freely available software used to model urban drainage systems**.**

4.3. Methodologies

4.3.1 Data type and Method of collection

Data type

Collecting relevant data of the watershed characteristics is one of the major work to be done before any hydrological and hydraulics design of drainage facilities. For this project, primary and secondary data, which has a direct relation with the problem stated at the beginning of this project and will be able to lead the identification of the problems, were collected.

- ***Primary Data;*** field survey/observation of existing drainage systems of both AA LRT and AACR are closely examined based on the check list developed to meet the general and specific objectives of this project.

Due to the seasonal characteristics of the rainfall event the actual condition of the storm drainage system operation cannot be seen while this project is conducted, even though if it is a rainy season, while this project is conducted, important scenario of the storm drainage problems may not be captured because one cannot be anywhere at a fixed time. So, interviewing people who lives nearby the road net work is also used as other means of gathering relevant information for the evaluation of the system performance and operational management of the client in this case Addis Ababa city road Authority.(*Both the interview questions and checklists are listed in appendix C).*

- ***Secondary data;*** the topographical map of Addis Ababa is collected from Ethiopia mapping Agency. The map scale is 1:50,000 and prepared almost three decades ago. So supplementary materials will be used in conjunction to this map to see the current situation.

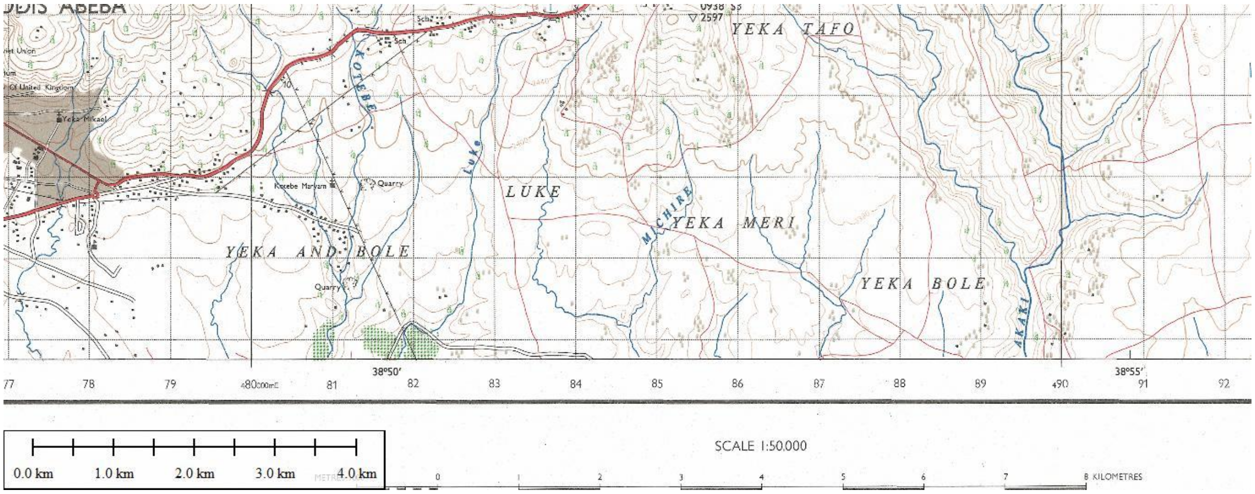


Figure 4.1 Topographical map of study area. (Source EMA).

4.3.1.1 Study area description

- **Geographical location**

This project was proposed to assess the performance of integrated drainage systems of AACR and AA LRT on the east –west line. On this line drainage problems is usually exhibited from Ayat to Megenagna ,the focus area is selected from Summit Roundabout to Gurd-Shola. The area is located between38^{0} 49’18’’ E to 38^{0} 51’1.8’’ E and 9^{0} 00’54’ N to 9^{0}’02’06’’.

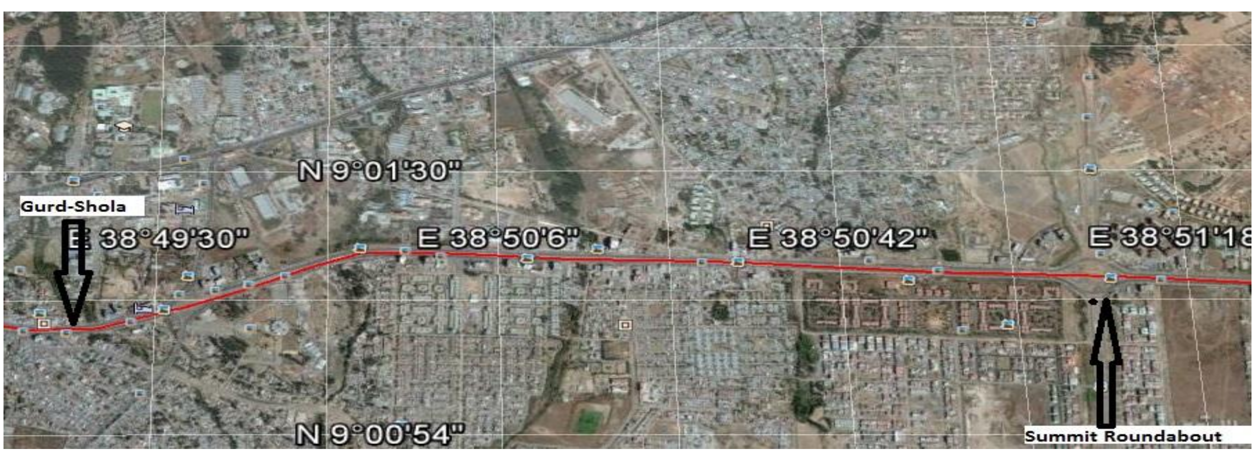


Figure 4.2 Study area. Source (Google Earth, Jan 2015)

From field survey and data collected by using interviewing people live side by the road, from CMC round about to Gurd-shola, it is found that common flooding occurs tikure abay near Ayema international hotel, in front of civil service college, around sahlite miheret and near Gurd-Sholla telecommunication center.

The rail road located at grade section is more susceptible for floods, so on this project a great infancies is given to on sections located at grade. The specific place for further study was selected to meet the specific objectives. Based on the data collected, the specific area to be modeled and studied is the integration of the two drainage system located at around Sahlite miheret round about.

- ***Rainfall characteristics;*** the seasonality of the rainfall in the focus area is generally governed by the migration of the Inter Tropical Convergence Zone (ITCZ). The forward and the backward migration of the ITCZ produce substantial rainfall bringing moisture from the south Atlantic and Indian Oceans. The focus area receives most of its rainfall from June to September. Little showering is common in April and May. Addis Ababa wins an annual average of 1089 mm precipitation.

- ***Temperature;*** the average temperature is around 15.9 degree Celsius, the mean monthly temperature have variation 3 degree Celsius. The range of average temperature is 13.7 degree Celsius. The hottest month is May with a mean temperature 18 degree Celsius and the coolest month is January with a mean temperature of 15 degree Celsius (EMA, 2015).

- ***Land use and land cover***; the land use of the study area is mostly occupied with buildings serves as both residential and commercial, large compounds of governmental institutes and large area covered by grasses also available. The land cover of the study area is mostly impervious as it is utilized for buildings and roads, the pervious surface composed of bare land, little eucalyptuses trees and largely by small grasses.

From field survey and with the aid of Google Earth the proportion of the pervious area illustrated on the table below. For land use and land cover only the chain-age start from Summit roundabout and goes to Gurd-Shola (0+000 refers Summit Roundabout).

Chain-age	0+000 to 0+940	0+940 to 1+980	1+980 to 2+840	2+840 to 4+340
% of impervious area	80	65	50	65
% of pervious area	20	35	50	35

Table 4.1 Ratio of Pervious to impervious surface of the catchment (source field survey February 2015)

Data collection methods

- ***Field survey;*** field survey is used to examine the current status of the drainage systems components especially focused on the inlets both the grate and manholes opening, manholes, curbs and gutters, to some extent the level of blockage in pipes and etc. in conjunction with the data gathered from interview the focus area is selected.
- ***Interview;*** interviewing the local people live around the line is aimed to collect data related to the flooding conditions, the major problem which is caused the flood in their attitudes and to get some information about the maintenance schedule of the drainage system. Asking more than one person at specific place has been done for better results.
- ***By requesting respective organization;*** all secondary data's are collected from the respected authority and legally accepted, known organizations. This data will be used for the evaluation and checking.

4.3.2 **Analysis Methods**

4.3.2.1 Intensity Duration Frequency Curve (IDF)

One of the first steps in many hydrologic design projects, such as in urban drainage design, is the determination of the rainfall event or events to be used. The most common approach is to use a design storm or event that involves a relationship between rainfall intensity (or depth), duration, and the frequency or return period appropriate for the facility and site location.

In this case, the IDF curve of Addis Ababa is used for the determination of the intensity of the rainfall for different return period with different duration. AACRA drainage manual 2004 provide two IDF curve for Addis Ababa developed by using two metrological station. One from Addis Ababa Observatory and the other is from Bole.

This project use the one developed from Bole due to the closeness of the focus area to this meteorological station.

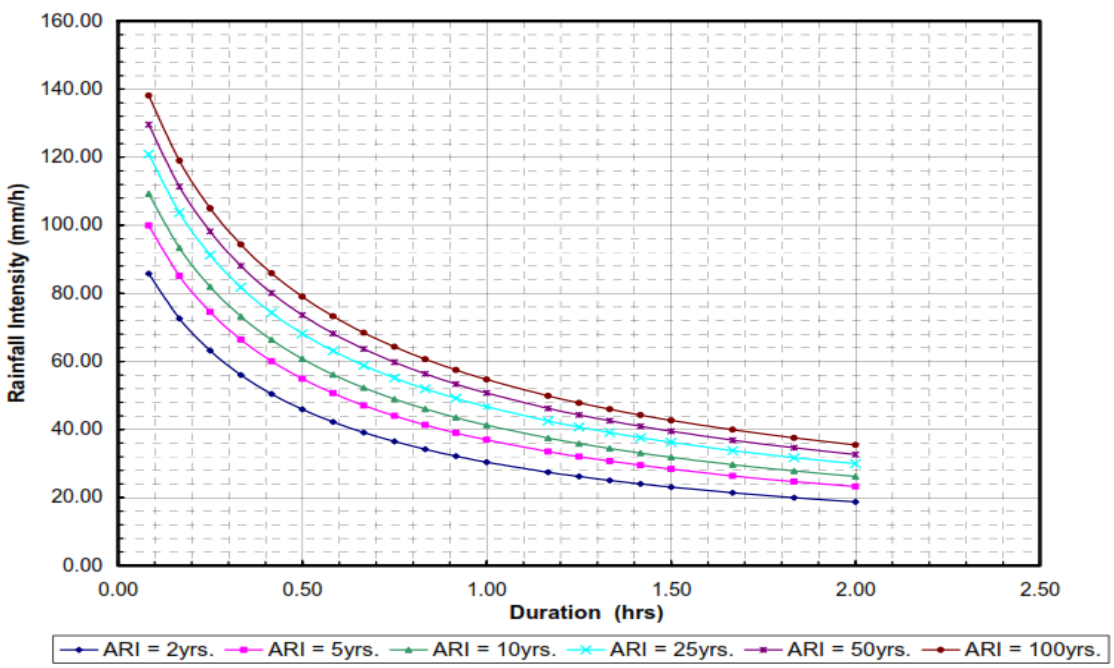


Figure 4.2 Intensity -Duration Curve (Addis Ababa, Bole), Source AACRA drainage manual 2004.

The design data and report of the CMC–Megenagna Road is collected from Core Consulting Engineers, which was finished on Jan, 2013 documented with the title "*Hydrological/Hydraulics and Structures Report detailed engineering design and tender document preparation for east-west road project*".

The design drawing of CMC- Megenagna Road is collected from AACRA, which helps to see the cross section and longitudinal profile of the road, the height and condition of the curb stone, spacing between adjoining inlets and its openings, manhole sizes and their invert elevations, pipe size, invert elevation and crown of the pipe and others are relevant data sets used for both comparison of existing situations.

4.3.2.2 Alternating Block Method

This is one of the method to prepare a design storm hyetograph. Rainfall hyetographs refer to the time distribution of rainfall intensities or depth over a watershed. Storm hyetograph is used as an input for storm water management model for analysis. Vent Chow shows how to develop the storm hyetograph from rainfall intensity duration curve. The following steps used rainfall hyetograph.

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

   P=iTd………………………………………………………………….. (Eq. 4.1)

Where: P=rainfall depth (mm)

i=intensity from IDF curve (mm/hr)

Td=duration time (hr)

The differences between consecutive 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 process is illustrated below the table.

Return Period	Duration (min)	Intensity (mm/hr)	Rainfall (mm)	Increment of rainfall(mm)	Ordinated Block
2	5	86.00	7.17	7.17	3.58
	10	73.00	12.17	5.00	7.17
	15	63.00	15.75	3.58	5.00
5	5	100.00	8.33	8.33	4.56
	10	85.00	14.19	5.86	8.33
	15	75.00	18.75	4.56	5.86
10	5	109.00	9.08	9.08	4.97
	10	93.00	15.53	6.45	9.08
	15	82.00	20.5	4.97	6.45
25	5	121.00	10.08	10.08	5.3
	10	103.00	17.20	7.12	10.08
	15	90.00	22.50	5.3	7.12
50	5	129.00	10.75	10.75	6.07
	10	111.00	18.43	7.68	10.75
	15	98.00	24.50	6.07	7.68
100	5	138.00	11.49	11.49	6.38
	10	119.00	19.87	8.38	11.49
	15	105.00	26.25	6.38	8.38

Table 4.2 Design storm rainfall hyetograph computation sheet

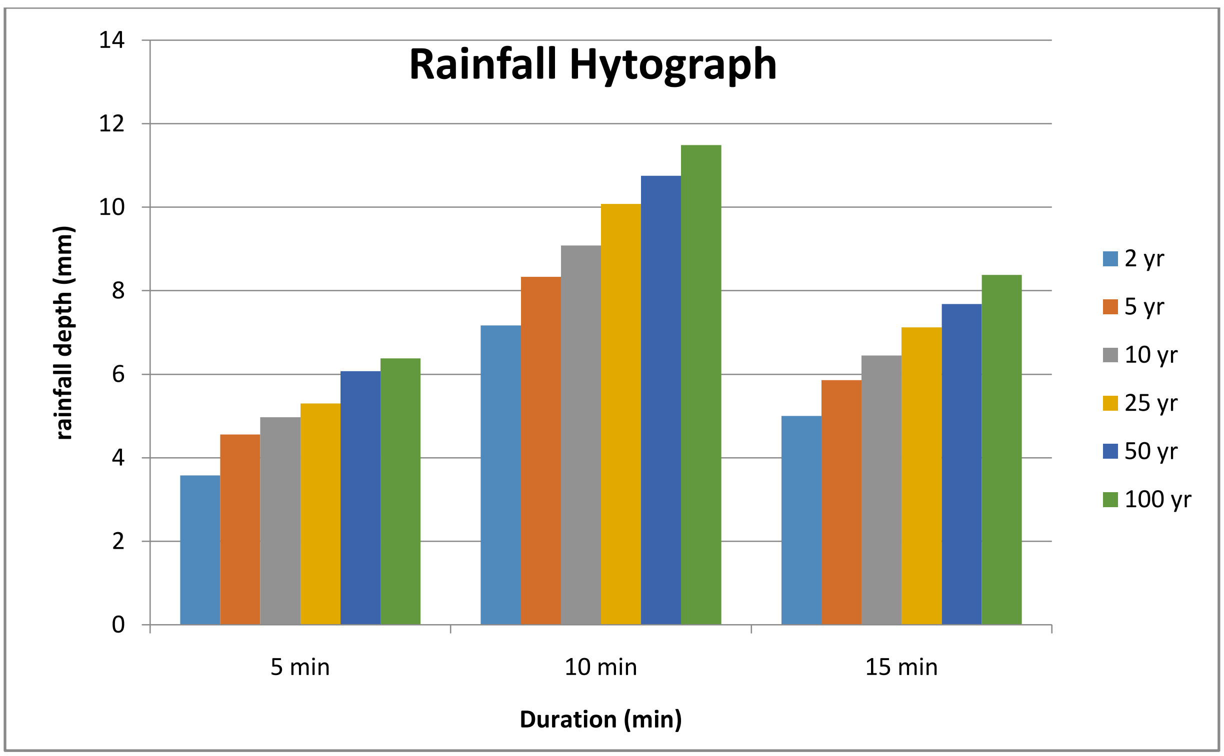


Figure 4.3 Rainfall Hyetograph

4.3.2.3 Rational Methods

This relationship is believed to provide adequate results for catchments less than 80ha as per AACRA Drainage Design Manual, 2003. The main assumption in this formula is that the maximum rate of flow results from a uniform rainfall intensity over the entire drainage area where the rainfall has duration equal to the time of concentration.

The principal requirement for determining the discharge is to select the average rainfall intensity for a selected frequency of recurrence.

$Q_T = 0.00278CIA$ --Eq. 4.2

Where: Q_T = Peak discharge (m^3/sec) for return period T years

C = Runoff coefficient

A = catchment's area (ha)

I = Average rainfall intensity for a duration equal to the time of concentration, for a selected return period, mm/hr

The rational equation given above is applicable for return periods 5 to 10 years. For less frequent flood computation the rational equation should be multiplied by 1.1, 1.2, and 1.25 for return periods 25, 50 and 100 years recurrence interval respectively.(AACRA manual 2004.)

Run of Coefficient

One of the parameters in rational method for computing flood is the runoff coefficient, C, watershed runoff coefficients depend upon the land use ,soil type and also it depends on the slope of the watershed. The recommended value of the runoff coefficient for different urban watershed is shown in Appendix A.

Time of Concentration:

a) Sheet-flow Travel Time Method

This method is used basically for overland flow with uniform slope and short distance not exceeding 100m. The time of concentration can be computed using the following equation.

$$t_c = \frac{5.476}{P_2^{0.5}}\left[\frac{nL}{\sqrt{S}}\right]^{0.8}$$ ---Eq.4.3

Where t_c = time of concentration (minutes)

N = Manning's roughness coefficient

S = slope of the surface (m/m)

L = flow length (upper limit of 91m)

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

b) Kirpich formula Method

The concentration time T_C in hours is calculated with the help of Kirpich formula.

$$T_C = 0.0195\left(\frac{L}{(\Delta H / L)^{0.5}}\right)^{0.77}\left(\frac{1}{60}\right)$$ ---Eq. 4.4

Where T_C = concentration time (hrs)

L = main stream length (m) in the basin from its source to the crossing point

ΔH = maximum difference in level (m) of the main stream from its source to the crossing point

c) Velocity Method

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

$$T_C = \frac{L}{3600 * V}$$ ---Eq. 4.5

Where T_C = Time of concentration [hrs]

L = Distance from remote point to the point of crossing [m]

V = Average velocity [m/sec]

Taking in to account the terrain type, land use and soil condition of the project area, suitable runoff coefficients will be determined. The dominate factor in the selection of rational formula is land use/ percentage of area paved.

4.3.3 **Modeling**

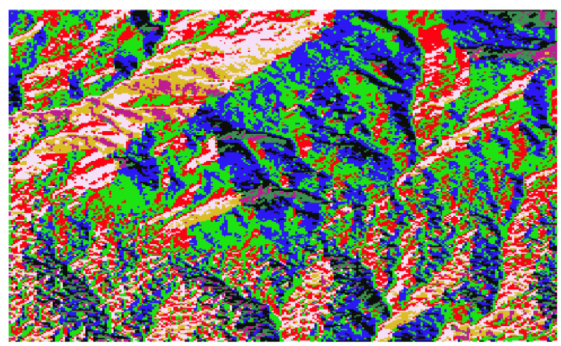
4.3.3.1 Catchment area delineation using ARC-GIS 10.1

For this project DEM data 30 meter grid is used. The DEM data is pre processed on Global Mapper v 15.00. The original DEM data which is from USGS 9 degree N and 38 degree E is selected and then the DEM is projected on desired projection after that the DEM is cropped for the specific area under study. Using Arc Catalog 10.1 for the exported Geo tiff data pyramid and statistical analysis was done.

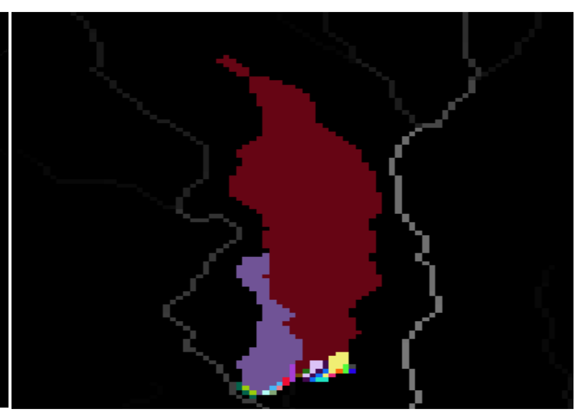
The Hydrologic modeling tools of Arc GIS enables to process the DEM data. On Arc toolbox using spatial analyst the hydrology part have multiple option for the DEM processing. The steps that was followed to delineate the catchment by using the manholes as the catchment outlet is described as follows.

- Open Arc Catalog 10.1, Add the DEM data build pyramid and also statistic calculation is done before using the DEM data on Arc Map.
- Open Arc Map 10.1, add the DEM and using the extension Arc toolbox ,the Spatial Analyst tools have the hydrology part consists of basin, fill, flow accumulation, flow direction, flow length, sink, snap pour point, stream link, stream order, stream to feature and watershed.
- ***Fill*** ; this step fill the sinks of raw DEM the output DEM is a depression less.
- ***Flow direction***; this step defines the direction of the steepest descent for each terrain cell.
- ***Flow accumulation***; this step determines the number of upstream cells draining to a given cell.

- ***Sink*** ; A sink is a cell or set of spatially connected cells whose flow direction cannot be assigned in a flow direction raster. This can occur when all neighboring cells are higher than the processing cell or when two cells flow into each other, creating a two-cell loop.
- After doing this, on Arc Catalog the shape file is created and this shape file is named as snap pour point and by using editor tool snap every man hole which will be used as the sub-catchment out let.
- ***Snap pour point***; the Snap Pour Point tool is used to ensure the selection of points of high accumulated flow when delineating drainage basins using the Watershed tool. Snap Pour Point will search within a snap distance around the specified pour points for the cell of highest accumulated flow and move the pour point to that location.
- Then after the above step is done, by using the Arc Hydro tools in terrain preprocessing the final output which will be used for an input to SWMM for hydrological and hydraulics modeling.

i) clipped DEM for the project area *ii) Flow direction*

iii) Flow accumulation *iv) catchment delineation for each node*

Figure 4.4 Catchment delineation for each node using Arc Map 10.1

From the above analysis Arc Map produce 30 catchment. For further analysis the catchment slope, centroid are also computed by using ARC GIS 10.1, which will be used as input data for the SWMM sub catchment.

Modeling steps for SWMM

The following steps were used for the hydrologic and hydraulics.

a) Each project has a set of default values that are used unless overridden by the SWMM user. These values fall into three categories:

- Default ID labels (labels used to identify nodes and links when they are first created.
- Default sub catchment properties (e.g., area, width, slope, etc.)
- Default node/link properties (eg., node invert, conduit length, routing method). (EPA SWMM user manual.

b) SWMM can use either US units or SI metric units. The choice of flow units determines what unit system is used for all other quantities: So metric system will be used for this specific project.

c) Draw the network which represent the physical condition.

d) Select the analysis methods

e) run the simulation

The model have 29 sub-catchment, 32 nodes out of which 2 of them are an outfall and 30 of them are junctions.

4.3.3.2 Hydrological modeling

- **Sub-catchment : -**for all sub-catchments the following data's are needed Area in hectare, catchment width (the ratio of area to the longest flow path in watershed),slope in percentage of raise, infiltration method and percentage of impervious area.

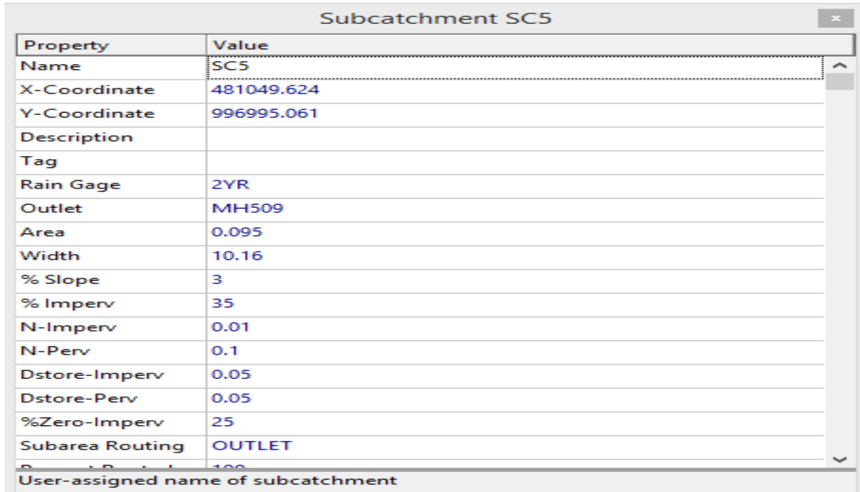


Figure 4.5 Sub catchment characteristic editor dialog box

Horton's infiltration method is used. This method is based on empirical observations showing that infiltration decreases exponentially from an initial maximum rate to some minimum rate over the course of a long rainfall event. Input parameters required by this method include the maximum and minimum infiltration rates, a decay coefficient that describes how fast the rate decreases over time, and the time it takes a fully saturated soil to completely dry (used to compute the recovery of infiltration rate during dry periods).(SWMM user manual).

Infiltration parameters are highly dependent on the soil type and the rainfall characteristics'. Most of the study area covered by clay soil and also some of the area is covered by vegetation and most of it not covered so from the table (see Appendix 1) maximum infiltration rate is taken as 8.1 mm/hr, the final infiltration rate taken as 0.13 mm/hr and the drying time ranges from 1 to 14 days depending on the climate condition, in this case the simulation is just for steady state and it use fifteen minutes rainfall which doesn't have any significance so it left as default value which is 4 days.

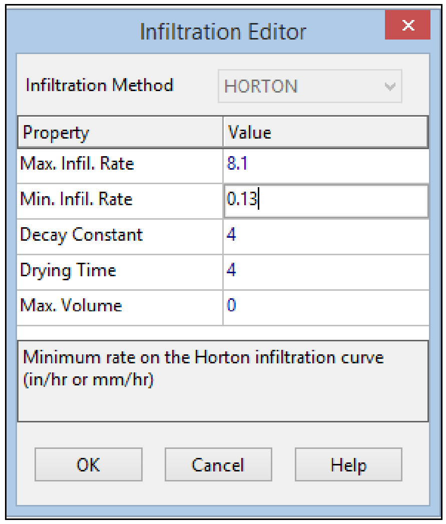


Figure 4.6 Infiltration Editor dialog box

4.3.3.3 Hydraulics modeling

Physical characteristics of the drainage system network is represented here by nodes and links.

- **Nodes (Manholes);** invert elevation , surface area 1.21 square meters, for dynamic wave simulation, maximum depth is needed. All the necessary data was collected from the design data. maximum depth is taken as 2 meters for all manholes and 3 meters for culverts.

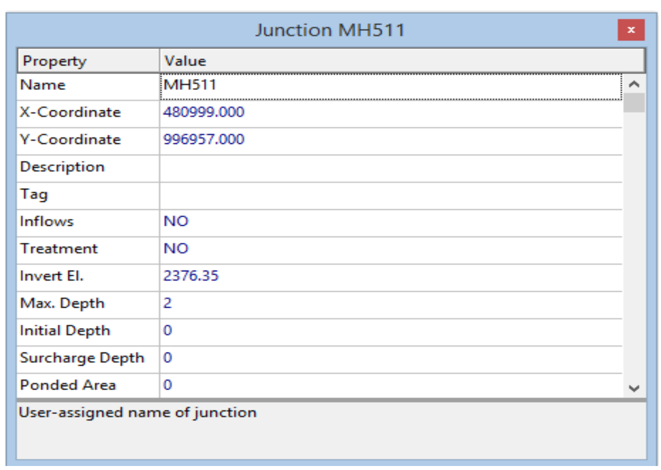


Figure 4.7 Junction or node editor dialog box

- **Links (conduits and culvert)** ; conduit used here is reinforced concrete pipe so manning roughness is taken as 0.013 from AACRA drainage manual, the length is taken as the distance between the manholes which the pipe is going to connect and the inlet outlet offset is taken as 0.30 meters , and entry and exist loss 0.2 which is also taken from AACRA manual. The shape are circular for pipe and rectangular for culvert, the size of the conduit is ranging from 75 cm dia to 1 meter dia.

Type of Pipe	Manning's *n*
Reinforced Concrete	0.013
Fibre Reinforced Concrete	0.013
UPVC	0.011

Table 4.3 Manning roughness of pipe source AACRA Manual

After all the data have been feed to the SWMM, finally before it runs the routing method is set to be kinematic wave and the force method is Hazen William's. Then finally the model runs for each return period and the result can be seen using graphs, table and even in animations.

Figure 4.8 detail drainage plan for sahlite-mariam roundabout

A3 paper

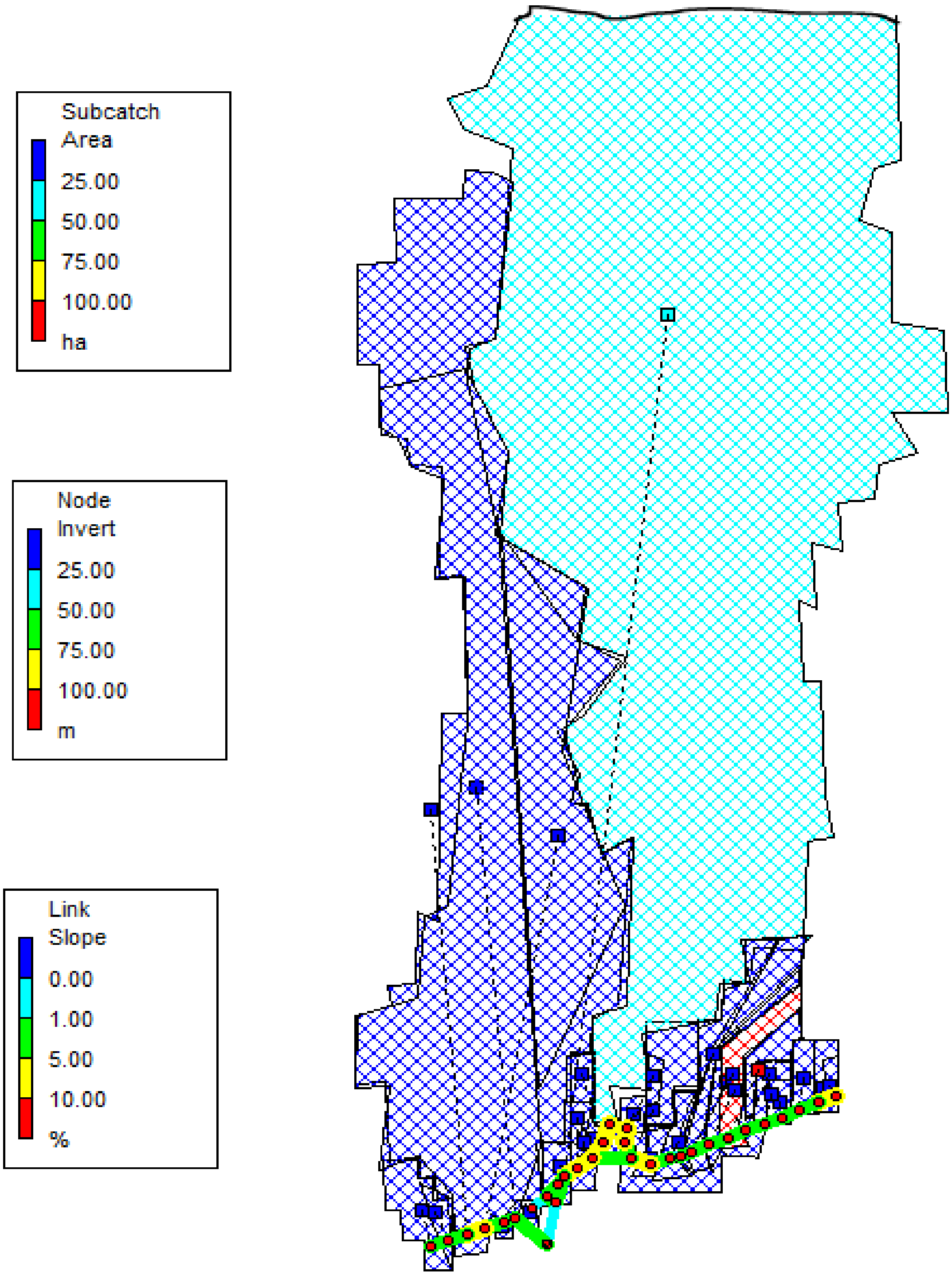


Figure 4.9 Drainage system network and resulting catchment around Sahlite Mariam roundabout

Flow generated from the railway track only

Rational method is used to determine the runoff produced from the track.

- length of the catchment is 309 meters
- width of the catchment is 11 meters , so Area in hectare will be 0.3399 ha.
- average slope for the catchment is 3.5 percent
- runoff coefficient is taken as .95 because the ballast is bedded on the asphalt.

	Q= 0.00278*CiA		
	i is taken for 15 min duration		
Q10	0.098	cms	
Q25	0.109	cms	

The above discharge was used as inflow for culvert which is found cabable of the flow from all links that are connected to it.

Chapter Five

Result and Discussion

5.1. Peak discharge results

The ultimate goal of the hydrologic modeling is to obtain the design peak discharge and that of hydraulics modeling is to provide drainage structures or components for efficient and safe. According to AACRA drainage manual minor drainage components should designed for 10 years return period which is the same as that of the AREMA manual, AREMA manual is frequently used in relation with railway drainage system.

The following tables shows the design discharge for each node for 10 and 25 years of return period.

Node	Type	Max lateral inflow (CMS)	Max total inflow (CMS)	Lateral inflow volume10^6 ltr	Total inflow volume 10^6 ltr	Node	Type	Max lateral inflow (CMS)	Max total inflow (CMS)	Lateral inflow volume10 ^6 ltr	Total inflow volume 10^6 ltr
MH508	JUNCTION	0.015	0.014	0.015	0.015	A35	JUNCTION	0.010	0.014	0.000	0.013
MH509	JUNCTION	0.032	0.010	0.016	0.031	MH517	JUNCTION	0.757	0.014	0.013	1.210
MH510	JUNCTION	0.061	0.010	0.031	0.062	MH518	JUNCTION	0.751	0.014	0.522	1.190
MH511	JUNCTION	0.084	0.010	0.018	0.080	MH519	JUNCTION	0.400	0.014	0.589	0.673
MH512	JUNCTION	0.138	0.011	0.048	0.127	MH520	JUNCTION	0.068	0.014	0.028	0.083
MR513	JUNCTION	0.207	0.010	0.058	0.186	MH521	JUNCTION	0.040	0.014	0.056	0.056
MH514	JUNCTION	0.828	0.014	9.160	9.340	A12	JUNCTION	0.078	0.010	0.043	0.061
MH515	JUNCTION	0.863	0.014	0.039	9.380	A11	JUNCTION	0.024	0.010	0.018	0.018
MH516	JUNCTION	1.049	0.014	0.290	9.670	B33	JUNCTION	1.278	0.013	0.071	9.960
A16	JUNCTION	1.116	0.014	0.065	9.730	PIPJ1	JUNCTION	2.781	0.014	5.110	15.100
A15	JUNCTION	1.008	0.012	0.036	9.720	PIPJ2	JUNCTION	2.787	0.014	0.000	15.100
A14	JUNCTION	1.027	0.013	0.018	9.740	A34	JUNCTION	0.000	0.000	0.000	0.000
B13	JUNCTION	1.162	0.013	0.060	9.860	A36	JUNCTION	0.010	0.014	0.013	0.013
A30	JUNCTION	0.022	0.010	0.018	0.018	A38	JUNCTION	2.779	0.014	0.000	15.100
C32	JUNCTION	1.210	0.013	0.000	9.900	A37	JUNCTION	1.189	0.014	0.735	1.940
A31	JUNCTION	0.051	0.010	0.023	0.041	OF1	OUTFALL	0.000	0.000	0.000	0.000

Table 5.1 Manhole inflow in CMS for 10 year return period

Node	Type	Max lateral inflow (CMS)	Max total inflow (CMS)	Lateral inflow volume1 0^6 ltr	Total inflow volume 10^6 ltr	Node	Type	Max lateral inflow (CMS)	Max total inflow (CMS)	Lateral inflow volume1 0^6 ltr	Total inflow volume 10^6 ltr
MH508	JUNCTION	0.017	0.017	0.017	0.017	A35	JUNCTION	0.000	0.011	0.000	0.015
MH509	JUNCTION	0.020	0.036	0.018	0.035	MH517	JUNCTION	0.011	0.859	0.015	1.380
MH510	JUNCTION	0.033	0.069	0.035	0.069	MH518	JUNCTION	0.397	0.850	0.594	1.370
MH511	JUNCTION	0.027	0.095	0.020	0.089	MH519	JUNCTION	0.375	0.453	0.681	0.775
MH512	JUNCTION	0.062	0.156	0.054	0.142	MH520	JUNCTION	0.033	0.078	0.031	0.094
MR513	JUNCTION	0.078	0.234	0.065	0.207	MH521	JUNCTION	0.046	0.046	0.063	0.063
MH514	JUNCTION	0.744	0.960	10.600	10.800	A12	JUNCTION	0.061	0.087	0.048	0.067
MH515	JUNCTION	0.045	1.000	0.044	10.800	A11	JUNCTION	0.027	0.027	0.019	0.019
MH516	JUNCTION	0.214	1.206	0.333	11.100	B33	JUNCTION	0.084	1.311	0.080	11.400
A16	JUNCTION	0.088	1.280	0.072	11.200	PIPJ1	JUNCTION	1.829	3.067	5.790	17.200
A15	JUNCTION	0.051	1.009	0.039	11.100	PIPJ2	JUNCTION	0.000	3.071	0.000	17.200
A14	JUNCTION	0.029	1.032	0.020	11.100	A34	JUNCTION	0.000	0.000	0.000	0.000
B13	JUNCTION	0.074	1.187	0.067	11.300	A36	JUNCTION	0.011	0.011	0.015	0.015
A30	JUNCTION	0.025	0.025	0.020	0.020	A38	JUNCTION	0.000	3.059	0.000	17.200
C32	JUNCTION	0.000	1.233	0.000	11.300	A37	JUNCTION	0.492	1.349	0.846	2.230
A31	JUNCTION	0.033	0.058	0.025	0.045	OF	OUTFALL	0.000	0.000	0.000	0.000

Table 5.2 Manhole inflow in CMS for 25 years return period

5.2. **Flooding Results**

The result shows that the following nodes (manholes) flooded for 10 and 25 years of return period.

Node	Hours Flooded	Max Rate CMS	Hours of max Flooding	Total flood vol 10^6 ltr	max ponded vol 1000 m3
A16	0.13	0.208	0:20	0.049	0
C32	0.01	0.225	0:00	0.007	0

Table 5.3 Node flooded for 10year return period

Node	Hours Flooded	Max Rate CMS	Hours of max Flooding	Total flood vol 10^6 ltr	max ponded vol 1000 m3
A16	0.2	0.374	0:20	0.132	0
C32	0.01	0.225	0:00	0.007	0

Table 5.4 Flooded manhole for 25 years return period

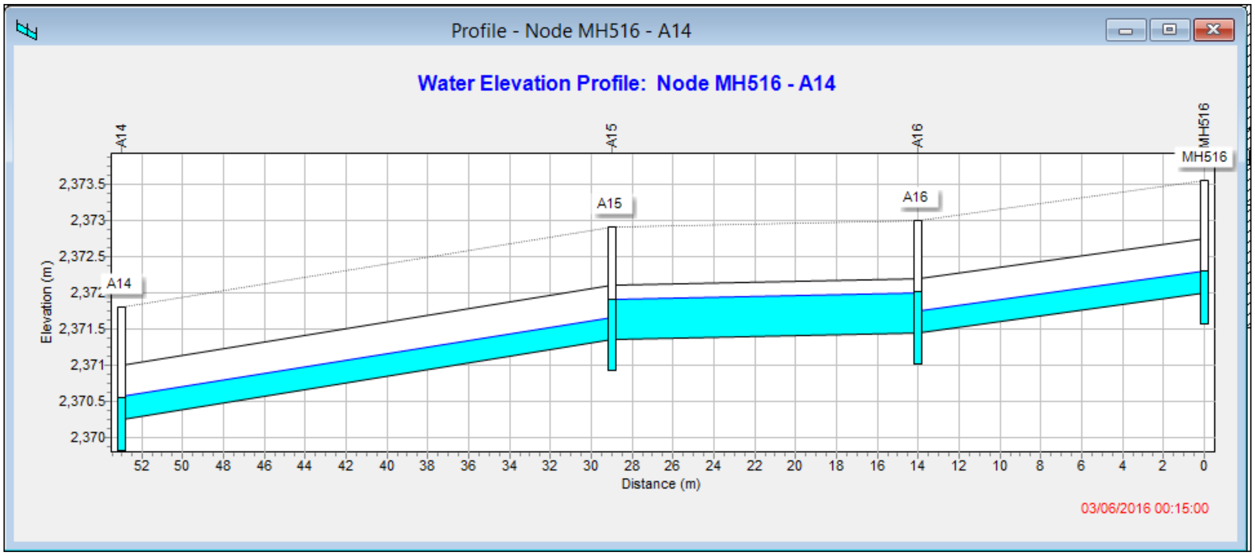


Figure 5.1 Water elevation profile for 25 year return at Manhole A14,A15,A16 and MHR516

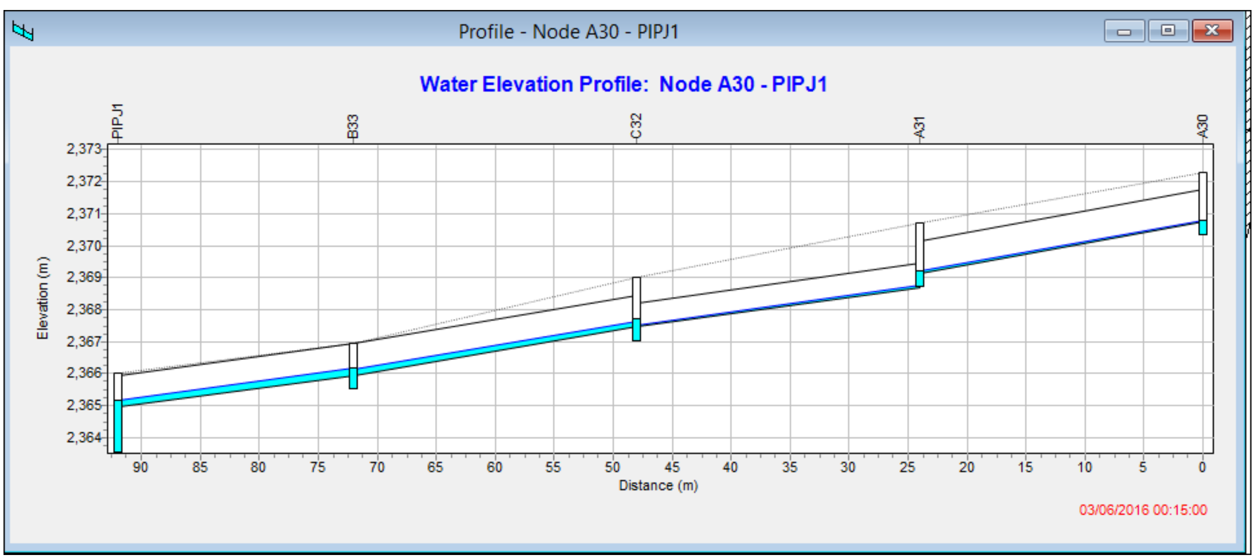


Figure 5.2 Water elevation profile for 25 year return at Manhole A30,A31,C32 and B33

As we can see from table 5.3 and table 5.4 , Man hole designated as A16 is flooded for both 10 and 25 years return period. From site visit, the surface elevation of node A16 is a little bit higher than the surface of the railway crossing so there will be a flood for 12 minutes until the runoff disposed.

5.3. **Discussion**

5.3.1. Design review

The inlet discharge to the man hole is predicted by the core consulting PLC is different from the EPA SWMM output because the contributing area they considered is smaller than that of the areas delineated by the ARC GIS v 10.1, which has direct influence on the discharge. The design uses contributing area for each node is from 1250 meter squares to 1500 meter squares, the model result shows the catchment area is greater than the value mentioned above. The catchment area with its properties is showed on the table at appendix B.

5.3.2. Construction review

On site visit it can be clearly seen that the pipe connecting the manholes designated as A31,A30 and B 33 were changed from diameter 750 mm to a rectangular open channel coved by concrete grill. This shows that the roundabout was at risk when the above noted node was connected by 750 mm diameter.

5.3.3. Operation review

The reason why there is always water spread out on the road surface after the common rain, the drainage component like manhole, the opening is closed by solid wastes and siltation caused by illegal deposition of construction materials on walk ways.

From the interview it was found that the drainage asset management didn't clean and maintain the components located around the sahlite- mariam for the last two years. The following pictures shows the condition of the manhole inlets.

Figure 5.3 Condition of Manholes inlets

5.4. Remedial measures

To overcome the flooding problem related to low frequency storms, return period 10 years and above the following pipe is recommended to change. From the hydrological modeling the catchment discharge used in hydraulic modeling. The hydraulic modeling can be easily done by giving a trial dimensions and run the simulation finally check the requirements that are to be fulfilled, which are maximum and minimum velocity in the pipe, the following recommendations were given.

- Pipe 10 , connect manhole A16 & A15 is constructed by using 750 mm diameter pipe, so the pipe size should increased to 1200mm diameter pipe.
- Pipe 11, connect manholes A15 & A14 is constructed by using 750 mm diameter pipe, so the pipe size should increased to 1200mm diameter pipe.
- Pipe 12, connect manholes A14 & B13 is constructed by using 750 mm diameter pipe, so the pipe size should increased to 1200mm diameter pipe.
- Pipe 15,17 and 19 where constructed by using 750 mm diameter pipe and 2*1000mm diameter so 1200 mm diameter will not accommodate the discharge safely, so a rectangular channel with 2.3 meter height and 1.5 meter bottom width covered with concrete grill would give pleasant situation for the focused area.
- The drainage asset management team should create awareness for the public to protect the drainage system elements from the damage and should make a routine and periodic maintenance.

Chapter Six

Conclusion

Now a day's using computer programs for urban drainage design is become not an option but it is a must. Hand calculation for design of urban drainage network is time taking and cumbersome approach. This project tries to assess the performance of the existing drainage network using freely available software which is basically designed for urban drainage design.

So using EPA SWMM which is accepted for design of urban drainage complexes in much easier way. As provided by the codes both AREMA and AACRA drainage manual for drainage structures fall in minor categories should be designed for 10 years return period and it should be checked for 25 years return period for worst scenario.

The capacity of existing storm drainage network on East West line at Sahlite- Mariam round about is assessed for 10 and 25 years of return period and it is found that there are manholes flooded for 12 minutes with 49 cubic meter of runoff volume.

The connection of the railway ditch to AACRA drainage structure were done on the culvert which pass under the roundabout, the result of the analysis showed no difference before connecting and after connecting the two system for 25 year return period at all, so it can be said that it is a safe connection for this specific locations.

It is found that the of manhole inlets were blocked with solid waste and ramps constructed to pass curb stone located in front of Management institute and Beshale hotel contribute for undesirable spread of storm water during the rainy season.

Chapter Seven

Recommendations

This project recommended that urban drainage design should be done by using software like EPA SWMM.

It is a better choice for any kinds of problem related to complex nature of urban drainage system because, EPA SWMM have several components

- the runoff component of SWMM operates on a collection of sub catchment areas that receive precipitation and generate runoff and pollutant loads,
- the routing portion of SWMM transports this runoff through a system of pipes, channels, storage/treatment devices, pumps, and regulators.
- SWMM tracks the quantity and quality of runoff generated within each sub catchment, and the flow rate, flow depth, and quality of water in each pipe and channel during a simulation period comprised of multiple time steps.

In addition the SWMM is a public free domain software.

For the AACRA drainage asset management they should work on creating awareness to the society to how to keep the structures safe and create ownership feeling.

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Appendices

Appendix A

Appendix A1. Recommended runoff coefficient for urban watersheds.

Run Off Coefficients for Urban Watersheds	
Type of Drainage Area	**Runoff Coefficient**
Business:	
• Down town/ city center areas	0.70-0.95
• Neighborhood area	0.30-0.70
Residential:	
• Single-family areas	0.30-0.30
• Multi-units, detached	0.40-0.60
• Multi-units, attached	0.60-0.75
• Suburban	0.35-0.40
• Apartment dwelling areas	0.30-0.70
Industrial:	
• Light areas	0.30-0.80
• Heavy areas	0.60-0.90
Parks, cemeteries	0.10-0.25
Playgrounds	0.30-0.40
Railroad yards	0.30-0.40
Unimproved areas:	
• Sand or sandy loam soil, 0-3%	0.15-0.20
• Sand or sandy loam soil, 3-5%	0.20-0.25
• Black or fine-grained soil, 0-3%	0.18-0.25
• Black or fine-grained soil, 3-5%	0.25-0.30
• Black or fine-grained soil, >5%	0.70-0.80
• Deep sand area	0.05-0.15
• Steep grassed slopes	0.70
Lawns:	
• Sandy soil, flat 2%	0.05-0.10
• Sandy soil, average 2-7%	0.10-0.15
• Sandy soil, steep 7%	0.15-0.20
• Heavy soil, flat 2-7%	0.13-0.17
• Heavy soil, average2-7%	0.18-0.22
• Heavy soil, steep 7%	0.25-0.35
Streets:	
• Asphalt	0.85-0.95
• Concrete	0.90-0.95
• Brick	0.70-0.85
Drives and walks	0.75-0.95
Roofs	0.75-0.95

Source. Horner (2001), Hydraulic Design Manual TxDOT.

Appendix 2A, Horton's initial infiltration by soil type source (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

Appendix 2A, 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

Appendix 3A, Permissible velocities for pipes and box sections (AACRA manual.)

Flow Condition	Absolute Minimum (m/s)	Desirable Minimum (m/s)	Desirable Maximum (m/s)	Absolute Maximum (m/s)
Partially full	0.7	1.2	4.7	7.0
Full	0.6	1.0	4.0	6.0

Appendix B

Software outputs

- ***Sub catchment data***

Name	Area	Width	%Imperv	%Slope	Rain Gage	Outlet
SC5	0.10	10.16	35.00	3.0000	25YR	MH509
SC5'	0.10	10.16	25.00	2.5000	25YR	MH508
SC4	0.19	10.16	35.00	3.2500	25YR	MH510
SC3	0.09	7.81	75.00	3.5000	25YR	MH511
SC7	0.34	13.06	56.00	4.2000	25YR	B13
SC2	0.09	7.61	69.00	6.5000	25YR	A11
SC8	2.14	25.04	25.00	0.5000	25YR	MH516
SC6	0.10	12.70	42.00	4.2000	25YR	A30
SC1	46.00	61.00	45.00	3.6900	25YR	PIPJ1
SC9	0.19	10.16	25.00	0.5000	25YR	B33
SC12	0.39	13.06	20.00	4.0000	25YR	MH521
SC13	0.09	7.61	25.00	0.5000	25YR	MH517
SC11	0.09	7.61	25.00	0.5000	25YR	A36
SC10	6.14	50.32	25.00	3.5000	25YR	A37
SC8'1	0.28	25.00	40.00	4.2000	25YR	MH512
SC8'2	0.32	20.00	55.00	4.5000	25YR	MR513
SC8'3	336.00	16.00	35.00	6.0000	25YR	MH514
SC8'4	0.24	12.00	38.00	5.5000	25YR	MH515
SC8'5	0.36	15.00	55.00	6.0000	25YR	MH516
SC8'6	0.34	18.00	69.00	3.0000	25YR	A16
SC8'7	0.17	9.00	95.00	4.0000	25YR	A15
SC8'8	0.09	18.00	62.00	6.0000	25YR	A14

SC7'	0.22	10.80	69.00	5.9000	25YR	A12
SC6'1	0.11	7.00	96.00	3.0000	25YR	A31
SC6'2	0.12	8.00	56.00	3.9000	25YR	B33
SC6'3	0.12	12.00	69.00	3.6000	25YR	B33
SC12'	0.17	13.20	34.00	3.9000	25YR	MH520
SC10'	3.84	30.00	36.00	4.2000	25YR	MH518
SC10"	5.37	25.00	25.00	4.6000	25YR	MH519

- ***Node Summary***

Name	Type	Invert Elev.	Max. Depth	Ponded Area
MH508	JUNCTION	2379.23	2.00	0.0
MH509	JUNCTION	2378.27	2.00	0.0
MH510	JUNCTION	2377.31	2.00	0.0
MH511	JUNCTION	2376.35	2.00	0.0
MH512	JUNCTION	2375.39	2.00	0.0
MR513	JUNCTION	2374.43	2.00	0.0
MH514	JUNCTION	2373.47	2.00	0.0
MH515	JUNCTION	2372.51	1.20	0.0
MH516	JUNCTION	2371.55	2.00	0.0
A16	JUNCTION	2371.00	2.00	0.0
A15	JUNCTION	2370.90	2.00	0.0
A14	JUNCTION	2369.80	2.00	0.0
B13	JUNCTION	2368.50	2.00	0.0
C32	JUNCTION	2367.00	2.00	0.0
A30	JUNCTION	2370.30	2.00	0.0
A31	JUNCTION	2368.70	2.00	0.0
A35	JUNCTION	2363.00	2.00	0.0
MH517	JUNCTION	2363.34	2.00	0.0
MH518	JUNCTION	2364.30	2.00	0.0

Name	Type	Invert Elev.	Max. Depth	Ponded Area
MH519	JUNCTION	2365.54	2.00	0.0
MH520	JUNCTION	2366.22	2.00	0.0
MH521	JUNCTION	2367.18	2.00	0.0
A12	JUNCTION	2369.35	2.00	0.0
A11	JUNCTION	2370.60	2.00	0.0
B33	JUNCTION	2365.50	2.00	0.0
PIPJ1	JUNCTION	2363.50	2.50	0.0
PIPJ2	JUNCTION	2362.00	3.00	0.0
A34	JUNCTION	2363.80	1.20	0.0
A36	JUNCTION	2363.10	2.00	0.0
OF	JUNCTION	2361.50	3.00	0.0
A37	JUNCTION	2362.73	2.00	0.0

- Link Summary

Name	From Node	To Node	Type	Length	%Slope	Roughness
PIPE1	MH508	MH509	CONDUIT	24.0	5.6758	0.0130
PIPE2	MH509	MH510	CONDUIT	24.0	4.0032	0.0130
PIPE3	MH510	MH511	CONDUIT	24.0	4.0032	0.0130
PIPE4	MH511	MH512	CONDUIT	24.0	4.0032	0.0130
PIPE5	MH512	MR513	CONDUIT	24.0	4.0032	0.0130
PIPE6	MR513	MH514	CONDUIT	24.0	4.0032	0.0130
PIPE7	MH514	MH515	CONDUIT	24.0	4.0032	0.0130

Name	From Node	To Node	Type	Length	%Slope	Roughness
PIPE8	MH515	MH516	CONDUIT	24.0	4.0032	0.0130
PIPE9	MH516	A16	CONDUIT	14.0	3.9316	0.0130
PIPE10	A16	A15	CONDUIT	15.0	0.6667	0.0130
PIPE11	A15	A14	CONDUIT	24.0	4.5882	0.0130
PIPE12	A14	B13	CONDUIT	24.0	5.4246	0.0130
PIPE13	A12	B13	CONDUIT	20.0	4.2538	0.0130
PIPE15	A30	A31	CONDUIT	24.0	6.6815	0.0130
PIPE16	A11	A12	CONDUIT	20.0	6.2622	0.0130
PIPE17	A31	C32	CONDUIT	24.0	7.1012	0.0130
PIPE18	B13	C32	CONDUIT	51.0	2.9424	0.0130
PIPE19	C32	B33	CONDUIT	24.0	6.2622	0.0130
PIPE20	B33	PIPJ1	CONDUIT	20.0	10.0504	0.0130
PIPE22	A34	A35	CONDUIT	21.0	3.8123	0.0130
PIPE23	A36	A35	CONDUIT	24.0	0.4167	0.0130
PIPE24	A35	PIPJ2	CONDUIT	14.0	3.2159	0.0130
CULPIPE1	PIPJ1	PIPJ2	CONDUIT	34.5	4.3519	0.0100

Name	From Node	To Node	Type	Length	%Slope	Roughness
CULPIPE2	PIPJ2	OF	CONDUIT	55.0	0.9091	0.0130
PIPE25	A37	OF1	CONDUIT	53.3	3.2505	0.0130
PIPE26	MH517	A37	CONDUIT	14.0	4.3613	0.0130
PIPE27	MH518	MH517	CONDUIT	24.0	4.0032	0.0130
PIPE28	MH519	MH518	CONDUIT	24.0	5.1736	0.0130
PIPE29	MH520	MH519	CONDUIT	24.0	2.8345	0.0130
PIPE30	MH521	MH520	CONDUIT	24.0	4.0032	0.0130

- ***Cross Section Summary***

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Conduit	Shape	Full Depth	Full Area	Hyd. Rad.	Max. Width	No. of Barrels	Full Flow
PIPE1	CIRCULAR	1.00	0.79	0.25	1.00	1	5.71
PIPE2	CIRCULAR	1.00	0.79	0.25	1.00	1	4.80
PIPE3	CIRCULAR	1.00	0.79	0.25	1.00	1	4.80
PIPE4	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23
PIPE5	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23

PIPE6	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23
PIPE7	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23
PIPE8	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23
PIPE9	CIRCULAR	0.75	0.44	0.19	0.75	1	2.21
PIPE10	CIRCULAR	1.00	0.79	0.25	1.00	1	1.96
PIPE11	CIRCULAR	1.00	0.79	0.25	1.00	1	5.14
PIPE12	CIRCULAR	1.00	0.79	0.25	1.00	1	5.59
PIPE13	CIRCULAR	0.75	0.44	0.19	0.75	1	2.30
PIPE15	RECT_CLOSED	2.00	3.00	0.43	1.50	1	33.91
PIPE16	CIRCULAR	0.75	0.44	0.19	0.75	1	2.79
PIPE17	RECT_CLOSED	2.00	3.00	0.43	1.50	1	34.96
PIPE18	CIRCULAR	0.85	0.57	0.21	0.85	2	2.67
PIPE19	CIRCULAR	1.20	1.13	0.30	1.20	2	9.76
PIPE20	CIRCULAR	1.20	1.13	0.30	1.20	2	12.36
PIPE22	CIRCULAR	0.75	0.44	0.19	0.75	1	2.17
PIPE23	CIRCULAR	0.85	0.57	0.21	0.85	1	1.00
PIPE24	CIRCULAR	1.00	0.79	0.25	1.00	1	4.30

CULPIPE1	RECT_CLOSED	2.50	7.50	0.68	3.00	1	121.22
CULPIPE2	RECT_CLOSED	3.00	9.00	0.75	3.00	1	54.50
PIPE25	CIRCULAR	1.00	0.79	0.25	1.00	1	4.32
PIPE26	CIRCULAR	1.00	0.79	0.25	1.00	1	6.51
PIPE27	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23
PIPE28	CIRCULAR	0.75	0.44	0.19	0.75	1	2.53
PIPE29	CIRCULAR	0.75	0.44	0.19	0.75	1	1.87
PIPE30	CIRCULAR	0.75	0.44	0.19	0.75	1	2.23

- Link Flow Summary

Link	Type	Maximum |Flow| CMS	Time of Occurrence days hr:min	Max |Veloc| m/sec	Max Full Flow	Max/ Full Depth
PIPE1	CONDUIT	0.017	0 00:20	1.62	0.00	0.04
PIPE2	CONDUIT	0.036	0 00:15	1.80	0.01	0.06
PIPE3	CONDUIT	0.069	0 00:15	2.19	0.01	0.08
PIPE4	CONDUIT	0.096	0 00:16	2.53	0.04	0.14
PIPE5	CONDUIT	0.156	0 00:15	2.91	0.07	0.18
PIPE6	CONDUIT	0.235	0 00:15	3.28	0.11	0.22

PIPE7	CONDUIT	0.960	0	00:20	4.86	0.43	0.46
PIPE8	CONDUIT	1.001	0	00:20	4.91	0.45	0.47
PIPE9	CONDUIT	1.213	0	00:20	5.11	0.55	0.53
PIPE10	CONDUIT	1.286	0	00:20	2.66	0.66	0.59
PIPE11	CONDUIT	1.323	0	00:20	5.49	0.26	0.35
PIPE12	CONDUIT	1.341	0	00:20	5.84	0.24	0.33
PIPE13	CONDUIT	0.087	0	00:15	2.50	0.04	0.13
PIPE15	CONDUIT	0.025	0	00:15	1.16	0.00	0.01
PIPE16	CONDUIT	0.027	0	00:15	2.00	0.01	0.07
PIPE17	CONDUIT	0.058	0	00:15	1.65	0.00	0.01
PIPE18	CONDUIT	1.478	0	00:20	4.02	0.28	0.36
PIPE19	CONDUIT	1.528	0	00:20	5.15	0.08	0.19
PIPE20	CONDUIT	1.594	0	00:20	6.15	0.06	0.17
PIPE22	CONDUIT	0.000	0	00:00	0.00	0.00	0.00
PIPE23	CONDUIT	0.011	0	00:20	0.59	0.01	0.07
PIPE24	CONDUIT	0.011	0	00:20	1.17	0.00	0.04
CULPIPE1	CONDUIT	3.420	0	00:20	6.23	0.03	0.07

CULPIPE2	CONDUIT	3.434	0	00:20	3.21	0.06	0.12
PIPE25	CONDUIT	1.352	0	00:20	4.86	0.31	0.38
PIPE26	CONDUIT	0.862	0	00:20	5.75	0.13	0.25
PIPE27	CONDUIT	0.853	0	00:20	4.70	0.38	0.43
PIPE28	CONDUIT	0.454	0	00:20	4.33	0.18	0.29
PIPE29	CONDUIT	0.078	0	00:20	2.10	0.04	0.14
PIPE30	CONDUIT	0.046	0	00:20	2.04	0.02	0.10

14.1. **Appendix C.**

Interview questions

1. What happen when it rains here?
2. Is flooding a problem in this area?
   - If the answer is yes,
3. How do you rate it?
   a) Very serious b) serious c) not serious
4. How long it takes to clear the storm water from the surface after the rain stopped?
5. What do you think the cause of flooding?
   a) Absence of drainage facilities
   b) In adequate operation of the drainage facilities
6. What remedial measures taken by the authorities?

Check lists

1. Condition of side ditches (intercepting open channel), extent of blockage,
2. Conditions of the inlets,
3. Condition of curb stones,
4. Condition of manholes covers
5. Condition of manholes, checking the standing water on the manhole if the cover is already damaged or removed.