Addis Ababa University

Addis Ababa Institute of Technology

School of Graduate Studies

Sustainable Storm Water Management by Implementing low impact development in JEMO, Addis Ababa

(A Case Study in Urban stormwater management)

A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil and Environmental Engineering (Major Hydraulic Engineering)

BY

Kidist Ketema

Advisor: Dr.-Ing. Geremew Sahilu

Addis Ababa University Ethiopia

December, 2018

CERTIFICATION

The undersigned certify that she has read the Thesis entitled Sustainable Storm Water Management by Implementing Low Impact Development in Jemo, Addis Ababa (A CASE STUDY in urban stormwater management) and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

……………………………………….

Dr. -Ing.Geremew Sahilu

(Advisor)

………………………………………………………….

Date

DECLARATION AND COPY RIGHT

I, Kidist Ketema, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

Signature______________________________

Date_______________________________

Kidist Ketema
kidy1234589@gmail.com
Pho.No.+251912862377
December, 2018

ACKNOWLEDGEMENT

Above all I thank the almighty GOD for His guidance and grace upon me during all my works and in all my life.

I would like to express my sincere gratitude and appreciation to Dr.-Ing.Geremew Sahilu for encouragement, guidance, keen interest and support from the initial to the final level of this thesis. I feel so blessed to have him as my advisor because he was very helpful to an extent that I find the research part of my Master's degree more stable.

I would like to deliver a special thank for National Meteorological Service Agency, who supplied me rainfall data free of charge and Addis Ababa road authority.

Iam very grateful to Addis Ababa Institute of Technology, Department of Civil & Environmental Engineering for allowing me to take part in the Master Program.

I would like to express my warm feeling of appreciation and tank to my friends who helped me in all stages and all my class met of Hydraulic Engineering who were spiritually with me, and gave me the strength to finalize my duties successfully. Thanks for your encouragement and true friendship! Your friendship meant a great deal to me.

Last but not least, I am very grateful to my lecturers and families who in one way or another supported me during the whole length of this research.

Kidist Ketema

kidy1234589@gmail.com

Pho.No.+251912862377

December,2018

DEDICATION

Dedicated to my Father.

ABSTRACT

Urbanization leads to the replacement of natural areas by impervious surfaces and affects the catchment hydrological cycle with adverse environmental impacts. Low impact development tools (LID) that mimic hydrological processes of natural areas have been developed and applied to mitigate these impacts. Due to a lack of management in urban storm there is a problem of drainage flooding of the Study area during intensive rainfall. This study deals with identify the critical parts of the drainage system with risk of flooding for JEMO catchment and to investigate sustainable urban drainage solutions for better control of stormwater runoff. In the present study Storm Water Management Model (SWMM) has been explored for the catchment JEMO, Addis Ababa. The catchments have been divided into various sub catchments and are modeled for ten year rainfall event. The model deals with a flexible set of hydraulic modeling capabilities, in particular it is used to assess infiltration using Horton method and flow routing analysis using dynamic wave method. The external inflows through the drainage system network of pipes, channels and outlet structures were also considered. Rainfall events in which runoff, water depth profile, and outflow hydrograph are obtained. The catchments have been divided into various sub catchments and modeled for 2006-2016 rainfall events. The data collected was then be analyzed quantitatively and qualitatively, and the result of the study thus presented in tables and in figures. From the study made, generally it was observed that the drainage system have nodes flooded and overflow thereby resulting damages to road surface material and flooding in the area. To assist local governments in their efforts to develop more effective stormwater management programs, an innovative comprehensive approach to stormwater management referred to as Low-Impact Development (LID) has been developed. Low-Impact Development technology employs microscale and distributed management techniques. Finally, after the critical locations of overflow are identified, feasibility of suggested LID and their effectiveness in urban flood management are considered. The results of the study show the significance of using LID in improving the urban drainage system.

Key Words: Urban Flood, Stormwater, Stormwater Management, Low Impact Development.

Table of Content

CERTIFICATION i
DECLARATION AND COPY RIGHT iii
ACKNOWLEDGEMENT iv
DEDICATION v
ABSTRACT vi
LIST OF FIGURE xi
LIST OF TABLES xii
LIST OF TABLES IN APPENDIX PART xii
ABBREVATION AND ACRONYM xiii
CHAPTER ONE 1
1. INTRODUCTION 1
1.1 Background 1
1.2 Problem of Statement 3
1.3 Objectives 4
1.3.1General Objective 4
1.3.2Specific Objective 4
1.3.3 Research Question 4
1.4 Scope and Limitation of the Study 4
1.5 Significance of the Study 5
CHAPTER TWO 6
2. LITRETURE REVIEW 6
2.1 Storm Drainage Conditions of Addis Ababa 6
2.2 Effect of Urbanization 6
2.3 Storm Water and Drainage System 9
2.4 Functions of Road Drainage Structures 10
2.5 Causes of Flooding 10

2.6 Impacts of Traditional Development 12
2.7 Impact of Low Impact Development 12
2.7.1 Source Control and Prevention Techniques in LID 13
2.7.1.1 Prevention 14
2.7.1.2 Source Control 14
2.7.1.3 Onsite Control 14
2.7.1.4 Slow Transport 14
2.7.1.5 Downstream Control 14
2.7.2 Prevention Technique 15
2.7.2.1Green Roof 15
2.7.2.2 Permeable Pavements 16
2.7.2.3 Rainwater Harvesting 17
2.7.2.4 Infiltration Trench 18
2.7.2.5 Infiltration Basin 19
2.7.2.6 Bioretention 20
2.8 An Overview on Models 21
2.9 Gutter and Curb 23
CHAPTER THREE 24
MATERIALS AND METHODS 24
3.1 General Description of Study Area 24
3.1.1 Climate 26
3.1.2 Temperature 26
3.1.3 Vegetation 26
3.1.4 Population 26
3.1.5 Geological setting of the study area 27
3.2 Data Collection 29
3.2.1 Primary Data 29

3.2.2 Secondary Data 29
3.3 Materials 29
3.4 Analysis Method of the Study 29
3.5 Hydrological Process 30
3.6 Modeling Rainfall using EP SWMM5 38
3.7 Governing Equation 40
3.8 Storm Drainage Hydraulic Elements Modeling 42
3.8.1 Curb and Gutter 42
3.8.2 Inlet Function and Selection 42
3.8.3 Design Consideration 43
3.9 Design and Construction of Rain Gardens 46
CHAPTER FOUR 50
4. RESULT AND DISCUSSION 50
4.1 Results from IDF Curve 50
4.1.1 Comparison of observed (hourly) versus compute (daily) IDF values at Ayertena station 50
4.1.2 Comparison of IDF Results 55
4.2 Result from EP SWMM5 Model 55
4.2 Storm Water Management System 59
4.3 Result from RainGarden 61
4.4 Result from Storm Drain Outfalls 63
4.5 Result from Flow Routing 64
4.6 Model sensitivity Analysis Result 65
4.7 Result from Gutter 69
CHAPTER 5 71
CONCLUSION AND RECOMMENDATION 71
5.1 CONCLUSION 71
5.2 RECOMMENDATION 74

REFERENCE 75

APPENDICES 77

LIST OF FIGURE

Figure 1: Demonstration of water transport as a result of precipitation before urbanization and after urbanization (based on Butler and Davies, 2004). 7
Figure 2: Example of green roof in Portugal 15
Figure 3: Green roof section 16
Figure 4: permeable pavement 17
Figure 5: Rainwater Harvesting 17
Figure 6: infiltration trench 18
Figure 7: Infiltration basin 19
Figure 8: rain garden 21
Figure 9: Location of the study area Jemo Area (ARC GIS) 25
Figure 10: Modeled study area top view and present flooding condition 28
Figure 11:L-moment diagram 35
Figure 12: Idealized representation of subcatchment 40
Figure 13: nonlinear reservoir model of subcatchment (SWMM manual) 40
Figure 14: Curb opening inlet 43
Figure 15: Simplified illustration of bio retention area 48
Figure 16: IDF curve using daily rainfall data 51
Figure 17: IDF Curve using hourly rainfall data 52
Figure 18: graphical comparison between observed and computed intensity for 5year frequency 52
Figure 19: observed and computed intensity vs duration for 50 year frequency 53
Figure 20:% difference between computed and observed intensity for 50 year return period 54
Figure 21: Observed vs Computed intensity for 50yr return period 54
Figure 22: Project Layout 56
Figure 23 junction profile 58
Figure 24: Unit Hydrograph 65
Figure 25: model performance 68
Figure 26: flow from EPA vs. Observed runoff 69

LIST OF TABLES

Table 1: Outlier test for ayertena station 33
Table 2: Design Storm for different return period 50
Table 3: peak discharge result for each subcatchment from EPA 57
Table 4: Node flooding 58
Table 5: Analytical hierarchy process value for ranking 59
Table 6: AHP Matrix Form 60
Table 7: Result from rain garden 62
Table 8: Cost Estimate for Rain Garden 63
Table 9: Outfall loading 64
Table 10 : Sensitive value for peak flow 65
Table 11: peak flow of EPA and Rational method 68

LIST OF TABLES IN APPENDIX PART

Appendix table 1: Daily Rain fall data of ayertena station 77
Appendix table 2: maximum daily rainfall 89
Appendix table 3:skew coefficient for different return 90
Appendix table 4: design storm for different return 91
Appendix table 5:Intensty for a given return period for JEMO 91
Appendix table 6: model functionality comparison 92
Appendix table 7: Deign Discharge for 50yr return period by rational 93
Appendix table 8: recommended runoff coefficient (C) for various selected land uses 94
Appendix table 9: Value of manning roughness coefficient (n) for uniform 95
Appendix table 10: typical hydrological soil group of Ethiopia 97
Appendix table 11: LID Usage From Each Subcatchment 99

ABBREVATION AND ACRONYM

AACRA--------------------Addis Ababa City Road Authority

AASHTO------------------American Association of State Highway and Transportation Official

AAU------------------------Addis Ababa University

AHP-------------------------Analytical Hierarchy Process

A2---------------------------Rainfall Region Classification of Ethiopian Road Authority

BMP-------------------------Best Management Practice

CSO-------------------------Combined Sewer Overflow

DEM------------------------Digital Elevation Model

EEA-------------------------European Environmental Agency

EGL-------------------------Energy Grade Line

EP---------------------------Environmental Protection

EPA-------------------------Environmental Protection Agency

ERA-------------------------Ethiopian Road Authority

FHWA----------------------Federal Highway Administration

GIS--------------------------Geographical Information System

Ha--------------------------Hectare

HGL-------------------------Hydraulic Grade Line

LID--------------------------Low Impact Development

M----------------------------Meter

m^3/sec----------------------Meter Cubic per Second

SWMM---------------------Storm Water Management Model

SUDS-----------------------Sustainable Urban Drainage System

UH--------------------------Unit Hydrograph

CHAPTER ONE

1. INTRODUCTION

1.1 Background

Though Water is very essential for all life on earth, it can also cause devastation through erosion and flooding. Due to the development of infrastructures as a result of urbanization, the surface runoff water greatly increased in the town damaging the roads. The contributed runoff water thus need to be safely disposed to the rivers/outlet channels so that the functional utility of the road infrastructure maintained and thereby avoid the damages which otherwise occurred to the road and property.

In the last decades the high rate of urbanization has resulted in a large increase in impervious coverage in the landscape. Impervious surfaces decrease rainfall infiltration in the soil increasing runoff both in terms of peak flow and volume. Rain water in the urban landscape is therefore mainly directed into the municipal storm sewer system, creating serious problems in case of heavy rains, and reducing water availability and quality. The low impact development (LID) approach has been recommended as an alternative to traditional stormwater design. Such techniques are also called water sensitive urban design (WSUD) in Australia (Lloyd, 2001) and sustainable urban drainage systems (SUDS) in the United Kingdom (CIRIA, 2000). Research on individual LID practices has greatly increased in recent years (Dietz, 2007). Along with the development of towns and cities, naturally vegetated areas have successively been replaced with hard-surfaced areas as the urbanization proceeded (Environment Agency, 2003).Typically, stormwater drainage is designed to collect, convey, and discharge runoff from urban areas as quickly as possible in order to prevent flooding (Delleur 2003). Sustainability calls for development to be carried out in a manner that limits impacts to the natural functions of landscapes, hydrologic systems, and habitats (Porter 2007).

Sustainable storm water management treats storm water as a reusable resource rather than a waste product, and seeks to incorporate flood prevention, good drainage, and efficient conveyance into a site. It also takes a watershed approach to managing storm water, meaning that it looks at storm water as part of the larger hydrologic system.

The idea with SUDS is that in the best possible way regenerate the natural system of stormwater handling, in order to reduce peak flows and provide treatment for the storm water on its way to the recipients. With the urbanization follows an increase in hard surfaces, where the water is unable to penetrate. This means that stormwater runs on the hardened surfaces without any retardation. The consequences are high peak flows, which arrive quickly after the storm commences.

Urban drainage is a vital city infrastructure to conveying water away from urban areas. To minimize the flood impacts, the principle is to carry water away from the urbanized areas as quickly and completely as possible (Chocat et al.2004; Stahre,2006). Traditionally, drainage systems mainly consist of pipe networks with underground structures. Such systems are very costly to build; therefore a service level is often proposed to indicate an acceptable frequency of system over loading, thus achieving a balance between the capital investment and the risk level of flooding. This means even with a functioning drainage system, the design capacity is still limited to cope with the extreme rainfalls and floods are expected to occur when the system gets overloaded. The design of any storm drainage system involves the accumulation of basic data, familiarity with the project site, and a basic understanding of the hydrologic and hydraulic principle and drainage policy associated with that design .The design of a storm drain system is generally a process that involve s a project develops(ADOT Hydraulics manual). Surface runoff is the main contributor to the failure and damage of roads. Water can be in the form of ground water, surface water streams and rivers or rain, as runoff from the surrounding areas. In addition, water may flow laterally from the pavement edges or it may seep upward from a high ground water table. Excessive water content in the pavement base, sub-base, and subgrade soils can cause early distress and lead to a structural or functional failure of pavement, if counter measures are not undertaken (Rokade et al 2007).Movement of the wheel on a pavement with a saturated subgrade can produce a moving pressure wave, which in turn can create large hydrostatic forces within the structural section. These pulsating pore pressures significantly influence the load-carrying capacity of all parts of the pavement structure (Cedergren, 1974).

Due to inadequate integration between road and urban stormwater drainage infrastructure provision and poor management significant proportion of the area is exposed to flooding hazard. To overcome these problems the management has to reduce the amount of runoff entering into the drainage system. Recently, JEMO road is facing broad water logging during the rainy season (July to August) as result of a serious problem of poor drainage. Poor existing drains and their improper operation and management mainly cause severe flooding which creates damages and problems to the road pavement and road users.

1.2 Problem of Statement

The development of urban areas has had a significant impact on urban stormwater runoff and generation. The result will be that urban areas experience a faster moving runoff flow with a higher peak flow that will enter the urban drainage system at a faster rate. Due to the replacement of natural soil cover with impervious surfaces such as concrete roads, rooftops and buildings within cities.

Traditional development results in the increase of impervious surfaces in the forms of rooftops, roads, driveways and parking lots. Impervious surfaces effectively halt infiltration, limit evaporation and transpiration losses, and reduce interception and depression storage. An increase in impervious surfaces within a watershed has been documented to result in increased peak flows and increased total runoff volume

The visual assessment, along the drainage system, in many points, Suggest there is a common flooding problem which creates a sever traffic crowding especially in rainy season. The flooding do also affect the asphalt pavement by eroding and creating a number of depressions and result in longer period impact even after a rain. The impact is too much on the socio – economic activity of the area in which it affects day to day activities of the community. Jemo, the study area, is one of the sites having this problem in the city of Addis Ababa. Addis Ababa City Road Authority (AACRA) is the responsible body for managing, repairing and maintaining the roads in the city. The authority is investing a lot of money for maintaining hole damages caused by flooding and cleaning blocked drainages. However, the problem remains the same every year.

Due to a lack of management in urban stormwter there is a problem of drainage flooding of the Study area during intensive rainfall and Experts alike tend to use Alternative Low Impact Development to make a drainage system sustainable. This study is commenced with the aim of investigating the cause behind such drainage flooding and applying the low impact development to make the drainage system sustainable.

1.3 Objectives

1.3.1General Objective

The objective of this study is to identify the critical parts of the drainage system with risk of flooding for JEMO catchment and to investigate sustainable urban drainage solutions for better control of stormwater runoff.

1.3.2Specific Objective

- To develop hourly and daily Intensity- Duration- Frequency curves for different durations and return periods.
- To simulate the performance of the system by taking into account the upcoming changes in runoff.
- Introduce the concept of LID, and describe possible solution.
- Finally, analyze which sustainable urban drainage methods are most suitable in JEMO.

1.3.3 Research Question

- How can we develop best sustainable urban drainage solution for the problem?
- What are basic problems of drainage systems of the study area?
- How does the sustainable urban drainage system approach SWWM model analysis the value adequately?
- What conditions can be required to implement LID technologies to the study area?

1.4 Scope and Limitation of the Study

This thesis includes the model of the drainage utility using SWMM. These software has a limitation on the large catchment delineation, and for the large catchment it is very tedious and the aim of this thesis was to model the drainage for Jemo Area, but due to the limitation of software the model only covers around 7.7km pipe length and 9 sub catchments. In this nine sub catchments the runoff from each sub-catchments were modeled and flood routing was done.

Also the drainage networks were simulated by considering each sub catchments. The software needs primary data with high quality to minimize the errors within the data, but to collect the primary data there was a financial limitation. The other limitation was problem of secondary data from AACRA there was no recorded data in AACRA. So that, this thesis models overall drainage utility.

1.5 Significance of the Study

The topic of sustainable stormwater management (also known as integrative stormwater management) is significant because it incorporates many aspects of geography, namely resource management, hydrology and urban/environmental planning/policy. The implementation of stormwater BMP's not only reduces runoff volume of stormwater also improves the quality of the water and improves upon the aesthetics of the cityscape.

CHAPTER TWO

2. LITRETURE REVIEW

2.1 Storm Drainage Conditions of Addis Ababa

Proper storm water drainage system problem occurs in the city, Addis Ababa, especially at Gotera- Welo Sefer road, Saris- Gotera road and on the ring road (Dessalegn, 2011) and in Addis Ketema Sub-city (Dagnachew, 2011).This literatures reveal that no doubt on the existence of drainage problem in the city, especially on areas where the studies referring to. Congested traffic due to flooding of roads after small depth of rainfall, erosion of pavements resulting in reduction of service life of road infrastructure and impact of road flooding on nearby community are consequences of poor drainage system in the area. These problems would be solved if good design, construction and maintenance of drainage infrastructures were practiced. In addition, smaller inlet spacing, higher inlet efficiency and frequent maintenance would alleviate the flood problem totally (Dessalegn, 2011) The pattern of urbanization and modernization in Ethiopia has meant increase densification along with urban infrastructure development. The combined effect of this results in higher rain drop intensity and consequently accelerated and concentrated runoff. Inadequate integration between road and urban storm water drainage infrastructure provision and poor management, significant proportion of the study area is exposed to flooding hazards/risks. This has resulted in negative impacts on urban storm water drainage provision and management. The major causes of flooding was found to be the blockage of urban storm water drainage lines along with inadequate/poor integration between road and urban storm water drainage infrastructures. The paper recommended improvement in the integration of road and urban storm water drainage infrastructure and integrated solid waste management to prevent over flowing of flood as a result of blockage of drains (Dagnachew, 2011)

2.2 Effect of Urbanization

The development of urban areas has had a significant impact on urban stormwater runoff and generation (Butler and Davis, 2004) .Due to this, stormwater is transported downstream at a much faster rate (since water moves faster over hard surfaces in comparison to natural surfaces).

The result will be that urban areas experience a faster moving runoff flow (with a higher peak flow) that will enter the urban drainage system at a faster rate. But the urban runoff flow will also die away much faster (compared to natural green areas) which will result in a higher peak flow (Butler and Davies, 2004).due to the replacement of natural green infiltration surfaces (i.e. natural soil cover) with impervious surfaces (such as concrete roads, rooftops and buildings) within cities (EPA, 2009).

A) Before Urbanization B) After Urbanization

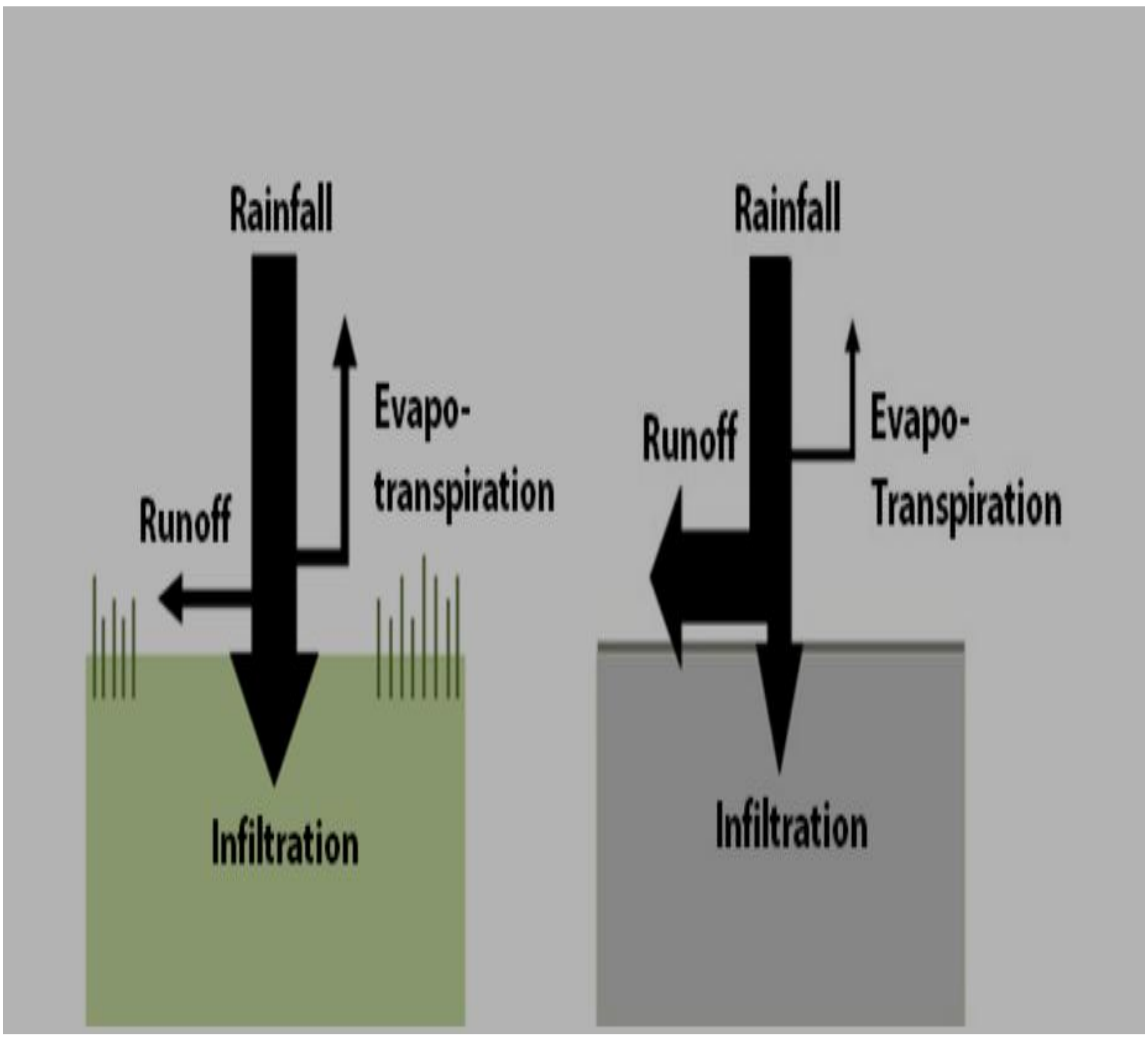


Figure 1: Demonstration of water transport as a result of precipitation before urbanization and after urbanization (based on Butler and Davies, 2004).

According to US-EPA (1999), the main impacts of the urbanization on the hydrologic cycle are due to modifications on the impervious area, which changes processes as evapotranspiration, runoff and the shallow and deep infiltration. The difference in peak-flows for pre and post-urban conditions can be seen in Figure below.

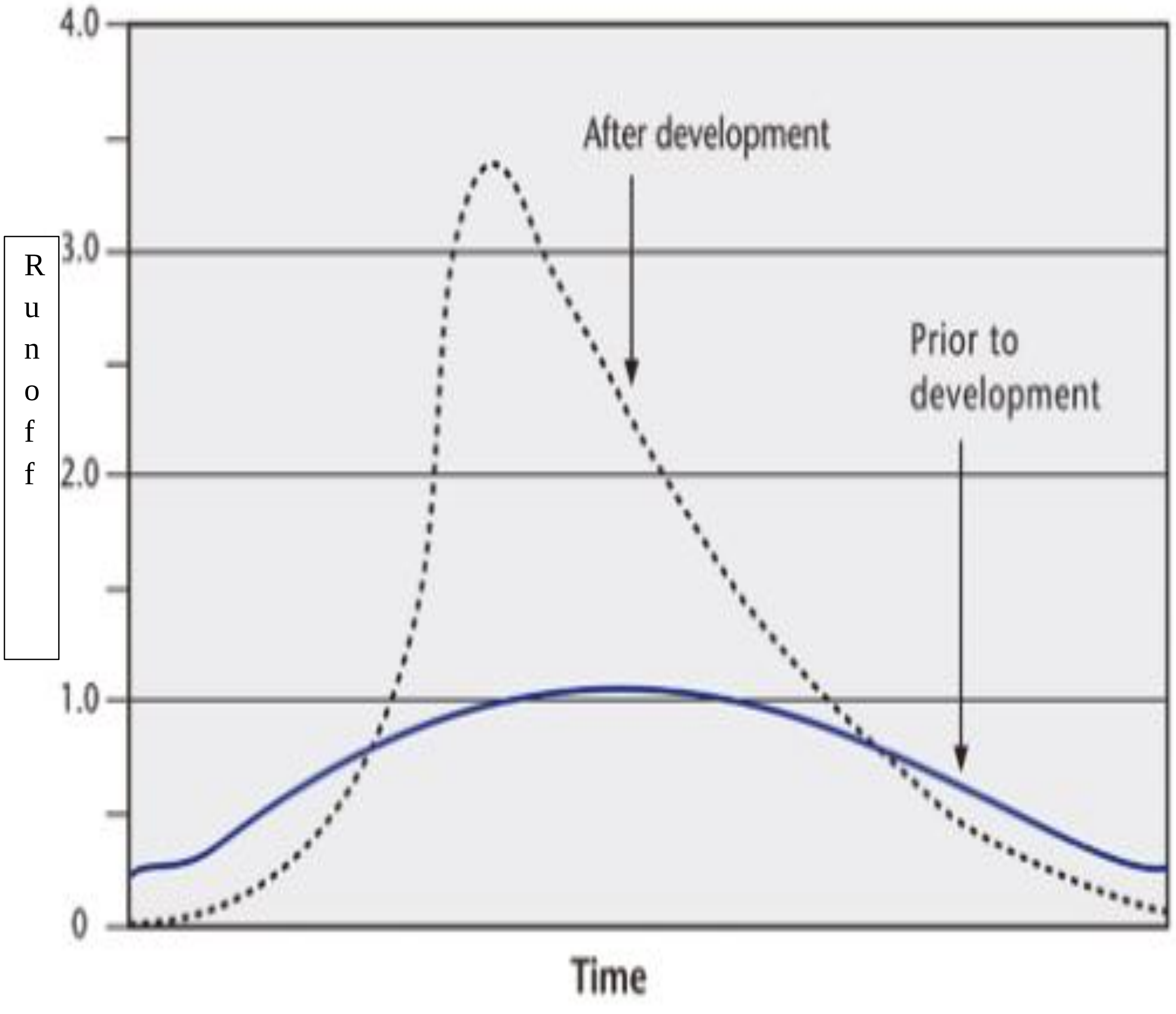


Figure 2: impact of urbanization on runoff quantity (environmental agency, 2003)

2.3 Storm Water and Drainage System

Storm drainage system is a collection of structures to collect and convey storm water runoff from land areas to a discharge location in a manner that adequately rains the road way and minimizes the potential for flooding and erosion to adjacent properties (ADOT Hydraulic manual) described. Storm drainage facilities collect storm water runoff and convey it through the carriageway right-of-way in a manner that adequately drains the carriageway and minimizes the potential for flooding and erosion to properties adjacent to the right-of way. Storm drainage facilities consist of curbs, gutters, storm drains, channels and culverts. The placement and hydraulic capacities of storm drainage structures and conveyances shall be designed to take into consideration damage to adjacent property and to secure as low a degree of risk of traffic interruption by flooding as is consistent with the importance of the road, the design traffic service requirements, and available funds (ERA Drainage Design Manual – 2002). The storm water results from all kind of precipitation (snow melt, rainfall, etc...) and comprises the water flowing in the surface (Butler & Davies, 2000). Therefore, the characteristics of both the rainfall and the catchment area represent important factors in the storm water properties. Indeed, part of the water of the rainfall goes to initial losses as interception, depression storage, infiltration and evapotranspiration. The remaining water is the runoff (Durrans & Haestad, 2003).

An important social aspect is to maintain public health and safety; hence an efficient drainage of storm water and wastewater is essential to avoid impact of flooding on life and property. In addition, the current environmental awareness involves the protection of the receiving waters from the pollutants that may be dragged by water flowing in the surface during heavy rain events (Viessman et al., 2009). The separated system comprises two separate pipelines for waste and storm water protecting from flooding in the basement and floors of houses in low-lying during extreme rainfalls, as well as avoiding the release of pollutants into the environment (EPA, 1999). Storm water is normally less polluted than sewage water, so that it can be led to detention basins or watercourses saving energy and cost, whereas wastewater requires a deeper treatment. In our country the sewerage and the storm water or drainage system is isolated. These brings the flooding of the drainage system due to the over loading of the drainage canal. The storm water is conveyed with open channel and it joins the river near to the area without any treatment.

2.4 Functions of Road Drainage Structures

Drainage structures collect, transport, and dispose of surface/sub-surface water originating on or near the roadway right of way or flowing in streams crossing bordering the right of way. It prevents erosion of the back slope by runoff from the hill above. It intercepts water, not allowing it to enter side drain that may cause greater discharge in side drains. In steep terrain, culvert capacity is usually governed by inlet control. The water depth at the entrance conditions governs the capacity of culverts subject to inlet control. The entrance conditions include the geometry of the opening, the wing walls, head walls, the angle of wing walls & head walls and the protection of the culvert in to the headwater pond. Pipe roughness, outlet conditions including tail water level do not influence flow capacity of culverts operating under inlet control. When the culvert barrel is not capable of conveying as much flow as the inlet opening will accept the outlet control occurs (FHWA, 2001).

2.5 Causes of Flooding

A flood is an excess of water (or mud) on land that's normally dry and is a situation wherein the inundation is caused by high flow, or overflow of water in an established watercourse, such as a river, stream, or drainage ditch; or ponding of water at or near the point where the rain falls. Flooding is a duration type event. A flood can strike anywhere without warning, occurs when a large volume of rain falls within a short time. In general flooding are categorized in to two: according to duration (as Slow-onset, Rapid-onset and flash flooding) and according to location (Coastal Flooding, Arroyos Flooding, River Flooding and Urban Flooding).

Urban area is paved with roads, houses etc and the discharge of heavy rain can't absorbed into the ground due to drainage constraints leads to flooding of streets, underpasses, low lying areas and storm drains .Causes of urban flooding are either natural or human. The natural causes are heavy rainfall or flash floods, lack of lakes and silting. On the other hand, human causes are: Population pressure: Because of large amount of people, more materials are needed, like wood, land, food, etc. This aggravates overgrazing, over cultivation and soil erosion which increases the risk of flooding. Deforestation: Large areas of forests near the rivers/catchment of cities are used to make rooms for settlements, roads and farmlands and is being cleared due to which soil is quickly lost to drains. This raises the drain bed causing overflow and in turn urban flooding.

Urbanization: leads to paving of surfaces which decreases ground absorption and increases the speed and amount of surface flow. The water rushes down suddenly intothe streams from their catchment areas leading to a sudden rise in water level and flash floods. Unplanned urbanization is the key cause of urban flooding. Various kinds of depression and low lying areas near or around the cities which were act as cushions and flood absorbers are gradually filled up and built upon due to urbanization pressure. This results in inadequate channel capacity causing urban flooding. Poor Water and Sewerage Management: Old drainage and sewerage system has not been repaired nor it is adequate now (Er. Pareva, 2005) Urban flooding is specific in the fact that the cause is a lack of drainage in an urban area.

A lot of the sewerage and drainage network would be old and its condition may be unknown. They cannot cope with the volume of water or are blocked by rubbish and by non-biodegradable plastic bags. Sewers overflow because of illegal connections and the sewer system cannot cope with the increased volumes. As new developments cover previously permeable ground, the amount of rainwater running off the surface into drains and sewers increases dramatically. Developments encroach floodplains, obstructing floodways and causing loss of natural flood storage. Continued development and redevelopment to higher density land uses by high land costs. The proportion of impermeable ground in existing developments is increasing as people build patios and pave over front gardens. Increased impervious areas such as roads, roofs and paving, due to increasing development densities means more run-offs. Some of the major hydrological effects of urbanization are: (1) Increased water demand, often exceeding the available natural resources; (2) Increased wastewater, burdening rivers and lakes and endangering the ecology; (3) Increased peak flow; (4) Reduced infiltration and (5) Reduced groundwater recharge, increased use of groundwater, and diminishing base flow of streams.

According to natural hydrological phenomena, due to increased impervious area precipitation responds quickly reducing the time to peak and producing higher peak flows in the drainage channels (Debu Mukherja. July 2016).

2.6 Impacts of Traditional Development

Traditional development results in the increase of impervious surfaces in the forms of rooftops, roads, driveways and parking lots (Schueler, 1994a).

Impervious surfaces effectively halt infiltration, limit evaporation and transpiration losses, and reduce interception and depression storage (Hollis, 1975, 1977). An increase in impervious surfaces within a watershed has been documented to result in increased peak flows and increased total runoff volume (Leopold, 1968; Jennings and Jarnagin, 2002). These changes in flow regime can result in channel erosion (Booth, 1990), increased flood frequency (Leopold, 1968), and stream biological degradation (Booth, *et al*,. 2004). These hydrological changes are often addressed as a public safety issue, resulting in the construction of systems that convey stormwater quickly and efficiently away from developed areas. Such systems, however, have the concomitant effect of further increasing peak flows farther downstream unless stormwater detention methods are used (Hollis, 1975; Arnold and Gibbons, 2007).

2.7 Impact of Low Impact Development

The LID design approach is to preserve the hydrological function of a landscape by maintaining as many areas of high infiltration and low runoff potential on a site as is practical. Furthermore, any post development excess runoff is managed through a distributed approach that integrates stormwater controls throughout the site (Prince George's County, 1999b).

Common 4 LID techniques used to preserve hydrological function and control stormwater include cluster development, permeable pavement, bioretention areas, and grassed swales (Prince George's County, 1999a; USEPA, 2000). Cluster development has the potential to reduce impervious surfaces using a compact pattern of development (Schueler, 1994b). Brander et al. (2004) used a modified version of the Natural Resources Conservation Service (NRCS) Curve Number (CN) method to model a conventional development characterized by large lots and little open space and a cluster development using smaller lots and maximized open space.

For a 100-year 24-h storm with 15.24 cm of total rainfall, the conventional development resulted in 2.29 cm more runoff than from the cluster development (Brander et al., 2004).

Compared to traditional, impervious urban surfaces, permeable pavements reduce runoff volume (Brattebo and Booth, 2003; Gilbert and Clausen, 2006) and peak flow rates (Pratt *et al*., 1989; Booth and Leavitt, 1999; Collins *et al.*, 2006). In a study comparing asphalt, permeable paver, and crushed stone driveways, paver driveways had 72% less runoff and crushed stone driveways had 98% less runoff than traditional asphalt (Gilbert and Clausen, 2006).

Bioretention areas, including rain gardens, reduce runoff through interception, retention, evapotranspiration and infiltration (Prince George's County, 1999a). Rain gardens designed to store 2.54 cm (1 in) of roof runoff were shown to infiltrate 95.4% of inflow water (Dietz and Clausen, 2006). A study conducted in Norway found that despite concerns of reduced performance in winter months, bioretention had no significant difference in retention time or lag time between seasons (Muthanna *et al*,. 2008). Grassed swales can be used to control runoff by reducing runoff velocity and infiltrating stormwater (Schueler, 1987). A study in Brevard County, Florida found that residential subdivisions using grassed swale BMPs had less stormwater runoff than subdivisions using traditional curb and gutter systems (Kercher, *et al*., 1983). Another study in Florida found that parking lot sections that used grassed swales had about 30% less runoff when compared to sections without swales (Rushton, 2001). Schueler (1994c) found that factors such as slope, soil type, and grass density affect infiltration rates and play an important role in the performance of a swale. When implemented at a watershed scale, LID design in a residential development has been shown to decrease storm runoff volume and flow rate compared to predevelopment conditions (Bedan and Clausen, 2009).

2.7.1 Source Control and Prevention Techniques in LID

Source control and prevention techniques are designed to counter increased discharge from developed sites, as close to the source as possible and to minimize the volume of water discharged from the site. This offers the benefits of reduced flood risk and improved water quality. It helps to restore underground water resources and maintain flows in surface watercourses during dry weather.

The general idea is to handle the water as early as possible (SEPA, 2011). The different steps of implementation in a sustainable storm water drainage showed are explained below.

2.7.1.1 Prevention

To handle the pollution or take care of the rainwater before it enters the system, this is the first action. If the contaminants don't enter the system, then there is no need to remove them. Measures of prevention include the sweeping of roads and car-parks from dust and detritus (SEPA, 2011).

Another way of achieving the goals of less pollutants in the storm water is to raise people's awareness concerning polluting. By doing this, governments hope there will be a reduced burden on the storm water drainage systems, and a reduced stress for the recipients (LaBranche et al., 2007).

2.7.1.2 Source Control

As the name explains, storm water is taken care of near its source. The closer to the source the water is taken care of; the less is needed to be taken care of further down the flow path. These measures are often realized on private ground, with examples such as green areas, permeable pavements, green roofs or rainwater harvesting (Falkirk Council, 2009).

2.7.1.3 Onsite Control

Water from adjacent areas like roofs, car parks or local squares are conducted to infiltration or detention basins where the outlets often are regulated. This makes it possible to retain the water temporarily, reducing the worst peak-flows (SEPA, 2011).

2.7.1.4 Slow Transport

Storm water running along the flow path towards the next sustainable urban drainage solution should be slowed down, in order to mitigate the stress on downstream solutions and recipients. This can be realized by letting the surface water run through a vegetated strip or a dike (Persson et al., 2009).

2.7.1.5 Downstream Control

The last step in this scheme is the downstream control, with common solutions such as ponds or wetlands. Water from a vast area is retained in these solutions for a period of time, further contributing to creating a more controlled flow, and removing contaminants from the stormwater (SEPA, 2011).

2.7.2 Prevention Technique

A range of factors to be considered when selecting Suds such that the most appropriate technique is adopted and Suds are successfully implemented. Such factors include site suitability, available land space, cost, maintenance issues and community acceptance.

2.7.2.1Green Roof

Effective control of rainfall runoff at-source minimizes the necessity of large flow structures. In most developed cities, approximately 40-50% of the impervious urban surface area are roofs (Stovin, 2009), existing a great potential to develop green roofs as an at source solution. According to Stovin (2009) “any technique that reduces the rate and volume of roof runoff has the potential to contribute to improved storm water management”. A green roof is an engineered multi-layered structure which covers a building’s roof with vegetation (Razzaghmanesh, 2014 and Woods Ballard, 2007).

Green roofs can be used to reduce the volume and rate of runoff so that downstream SUDS and other drainage infrastructure can be reduced in size. Green roofs replace traditional black roofs and are minimally invasive. They can enhance evapotranspiration (Marasco et al., 2014), thereby decreasing local air temperatures and pose as a solution to the Urban Heat Island (UHI) effect, as well as reduce rainfall runoff and peak flow, being an at-source detention and retention technology. At the same time increase vegetated areas in cities as many other benefits, regarding water quantity and quality. Many conventional flat roof systems used in industrial buildings could be converted to green roofs without exceeding design loadings. There are additional benefits; green roofs improve lagging and extend roof life.

Figure 2: Example of green roof in Portugal

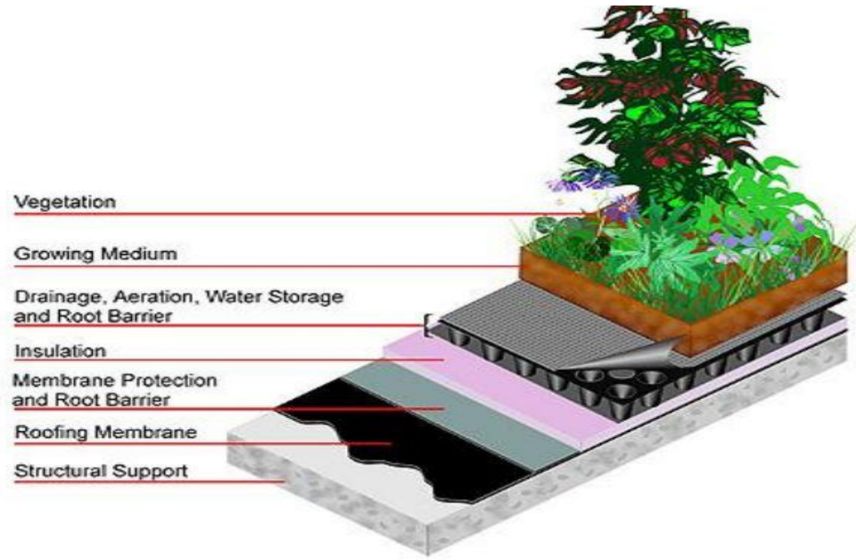


Figure 3: Green roof section

2.7.2.2 Permeable Pavements

Permeable pavement is an alternative to conventional paving in which water filters through the paved structure rather than running off it. Both the surface and the sub-grade need to be designed with this function in mind. Water may be allowed to infiltrate directly into the subsoil where conditions are suitable. Alternatively, it can be held in a reservoir structure under the paving for use again, infiltration or delayed discharge. The permeable paving can be made from materials such as gravel, grass Crete, concrete blocks designed for the purpose or porous asphalt.

Figure 4: permeable pavement

2.7.2.3 Rainwater Harvesting

Rainwater from roofs and hard surfaces such as car parks can be stored and used in and around properties. The simple rainwater barrel, used for watering plants, is a familiar method of storage. There has been a recent growth in the use of the collected water for a range of non-potable uses, particularly for flushing toilets. Stored water is generally held in a suitably sized underground tank and pumped to the point of use. A mains water supply is usually provided as a back-up if rainwater is not available.

Figure 5: Rainwater Harvesting

2.7.2.4 Infiltration Trench

An infiltration trench is a shallow, excavated trench that has been lined with a geotextile and backfilled with stone to create an underground reservoir. Storm water runoff flowing into the trench gradually infiltrates into the subsoil. An overflow may be required for extreme rainfalls that exceed the capacity of the reservoir. The performance of the trench depends largely on the permeability of the soil and the depth to the water table. Infiltration trenches usually serve small catchment areas up to 2-3 hectares in common with other source control techniques. The closer they are to the source of the runoff the more effective they will be. The operational life of the trench may be enhanced by providing pre-treatment for the inflow, such as a filter strip, gully or sump pit, to remove excessive solids. Regular maintenance will be required for most pretreatment designs. Infiltration trenches that are properly constructed and maintained can significantly reduce levels of solids, coli forms, trace metals and organic matter. Levels of nutrients can also be reduced.

Figure 6: infiltration trench

2.7.2.5 Infiltration Basin

Infiltration Basins are shallow, impounded areas designed to temporarily store and infiltrate stormwater runoff. The size and shape can vary from one large basin to multiple, smaller basins throughout a site. Ideally, the basin should avoid disturbance of existing vegetation. If disturbance is unavoidable, replanting and landscaping may be necessary and should integrate the existing landscape as finely as possible and compaction of the soil must be prevented Infiltration Basins use the existing soil mantle to reduce the volume of stormwater runoff by infiltration and evapotranspiration. The quality of the runoff is also improved by the natural cleansing processes of the existing soil mantle and also by the vegetation planted in the basins. The key to promoting infiltration is to provide enough surface area for the volume of runoff to be absorbed to meet the criteria .An engineered overflow structure should be provided for the larger storms.

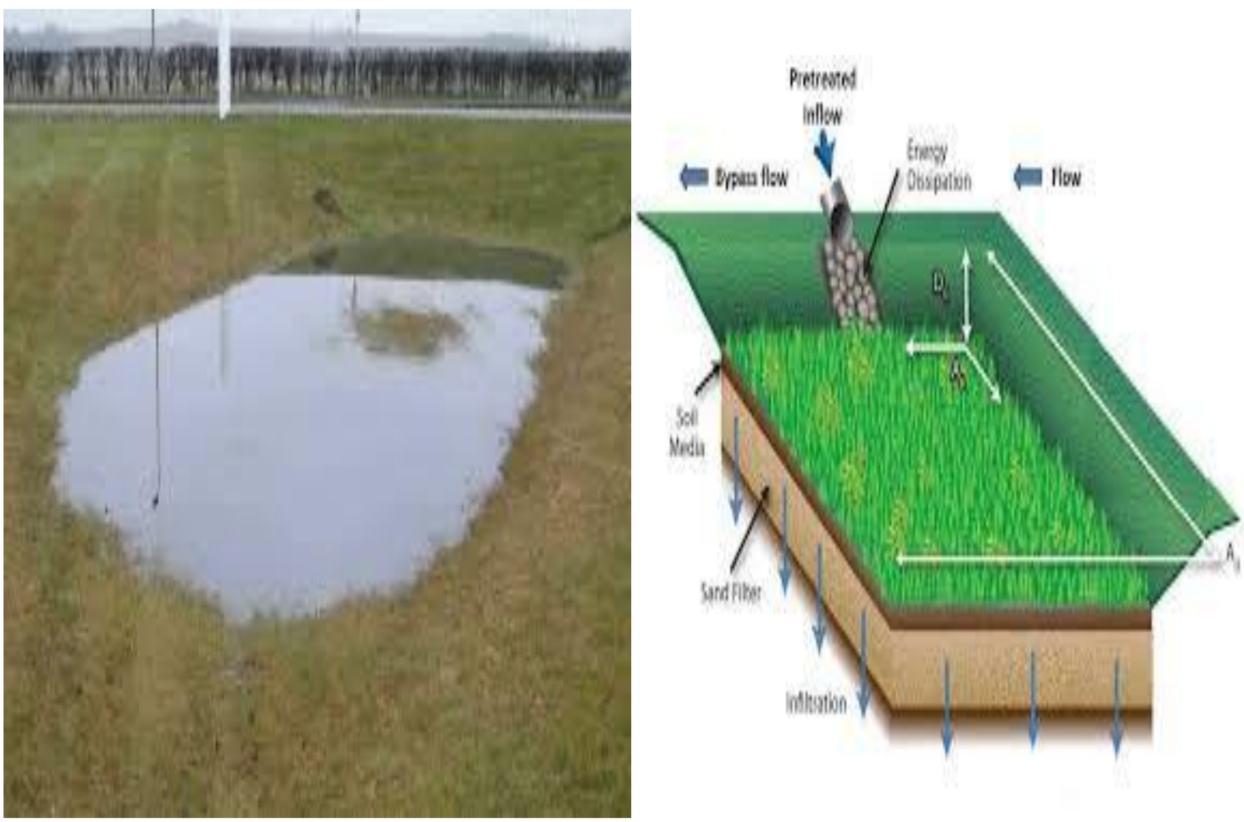


Figure 7: Infiltration basin

2.7.2.6 Bioretention

Bioretention areas are solutions which have few limits, and are well suited for retrofitting purposes in ultra-urban areas (Stormwater Center, 2011). According to (Brown, Stein,Warner 2001) the maximum ponding depth for water is 0.2 meters above the level of the soil. An additional freeboard of at least 5 centimeters over the maximum depth of the water should be added to the construction, according to the same source. Since space is very limited in the central areas of Xiamen, vertical sides are supposed to keep the ponding water in the bioretention area. Brown, Stein, Warner (2001) continues by stating that the bioretention area normally occupies approximately 10% of the drainage area and that stormwater from a catchment larger than 2 hectares shouldn´t be conducted to the device. TRCA et al., (2010) has an even more restricting approach, states that the runoff areas normally are small, with a maximum no larger than0.8 hectares. If local soil-conditions are limiting, under drains can be used to lead the water away from the bioretention area.. A perforated pipe with a protective geotextile filter fabric is normally used as an under drain (TRCA et al., 2010). TRCA et al.,(2010) states that the maximum ponding time of the water in the bio retention area should be 24 hours, since this is less than the breeding-cycle of mosquitoes. The minimum depth of the engineered soil in the bioretention area is 0.75 meters (Brown, Stein, Warner, 2007).

Rain garden benefits include:

- Less storm water runoff
- Slower runoff
- Less pollution in the runoff
- More water to replenish groundwater supplies
- Improved landscape.

Figure 8: rain garden

2.8 An Overview on Models

A GIS is a system of hardware, software and procedures to facilitate the management, manipulation, analysis, modeling, representation and display of geo-referenced data to solve complex problems regarding planning and management of resources (NCGIA, US 1990).There are two types of data models in GIS. There are two conceptual representations used in GIS: grid (sometimes called 'raster') and vector. These are very different ways of thinking about geography, which lead to very different methods of analysis.

The grid or 'raster' representation of a map assumes that the map area is divided into cells (sometimes erroneously called pixels), normally square or at least rectangular, on a regular grid. Each cell is supposedly homogeneous, in that the map is incapable of providing information at any resolution finer than the individual cell. The map shows exactly one value (land use, elevation etc.) for each cell. This is a very simple representation in the computer: conceptually, a 2-D matrix of values which correspond to a grid placed over the paper map.

The vector representation of a map is points on a map are stored in the computer with their 'exact' (to the precision of the original map and the storage capacity of the computer) coordinates. Points can be connected to form lines (straight or described by some other parametric function) or chains; can be connected back to the starting point to enclose polygons or areas.

Global mapper is a software use to generate contours using DEM digital elevation model (30mx30m) and also to generate the watershed of the modeling area. Arch SWAT Software is also used to model and analyze flood especially for rural areas with a large catchments.

EP SWMM5 is used in urban areas flood modeling and analyses to fix the drainage size by considering the pervious and impervious areas. So this thesis is flood modeling in urban areas and the SWMM software is more comfortable. SWMM was used, adapted and calibrated for the Ballona Creek Watershed, a catchment in Southern California. A geographic information system (GIS) was used to process the input data and generate the spatial distribution of precipitation. Catchment was delineated by 1579 catchments, 2648 channels and over 263 km long pipes. ARCINFO GIS was used to compute the sub catchment and channels/pipes slopes. The slopes were then used to compute the impervious depression storage coefficients.

SWMM was used on watershed of Cascina Scala, Pavia in Italy, to produce the time varying hydrograph. Study also compared SWMM and fuzzy logic. The study revealed for the events with total rainfall less than 25 mm, the correlation trend produced from either the SWMM or the fuzzy logic model fits well with measured data. However, for rainfall greater than 25 mm, from fuzzy logic's predictions fit better than the SWMM results. SWMM accounts for the spatial variability of rainfall by allowing the user to define any number of Rain Gage objects along with their individual data sources, and assign any rain gage to a particular SWMM Sub catchment object (i.e., land parcel) from which runoff is computed. If multiple gages are available, this is a much better procedure than is the use of spatially averaged (e.g. Thiesson weighted) data, because averaged data tend to have short-term time variations removed (i.e., rainfall pulses are "lowered" and "spread out"). In general, if the rainfall is uniform spatially, as might be expected from cyclonic (e.g., frontal) systems, these spatial considerations are not as important. In making this judgment, the storm size and speed in relation to the total study area size must be considered.

Storm movement can significantly affect hydrographs computed at the catchment outlet (Yen and Chow, 1968; Surkan, 1974; James and Drake, 1980; James and Shtifter, 1981).When more than one gage is available to apply to the simulation, it is possible to simulate moving storms, as rainfall in one part of the basin may be different from rainfall in another part of the basin. Movement of a storm in the downstream direction increases the hydrograph peak, while ovement upstream tends to level out the hydrograph (Surkan, 1974; James and Drake, 1980; James and Shtifter, 1981).

2.9 Gutter and Curb

Urban stormwater collection and conveyance systems are critical components of the urban infrastructure. Proper design is essential to minimize flood damage and limit disruptions. The primary function of the system is to collect excess stormwater in street gutters, convey it through storm drains and along the street right-of-way, and discharge it into a detention basin, water quality best management practice (BMP), or the nearest receiving water body (FHWA 2009).

Proper and functional urban stormwater collection and conveyance systems:

- Promote safe passage of vehicular traffic during minor storm events.
- Maintain public safety and manage flooding during major storm events.
- Minimize capital and maintenance costs of the system.
- The ability of an inlet to intercept flow (i.e., hydraulic capacity) on a continuous grade increases to a degree with increasing gutter flow, but the capture efficiency decreases.

The capacity of an inlet varies with the type of inlet. For grate inlets, the capacity is largely dependent on the amount of water flowing over the grate, the grate configuration and spacing. For curb-opening inlets, the capacity is largely dependent on the length of the opening, street and gutter cross slope, and the flow depth at the curb. Local gutter depression at the curb opening will increase the capacity. Combination inlets on a continuous grade (i.e., not in a sump location) intercept up to 18% more than grate inlets alone and are much less likely to clog completely (CSU 2009). Slotted inlets function in a manner similar to curb-opening inlets (FHWA 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 General Description of Study Area

Addis Ababa is located in the central highlands of Ethiopia. Geographically, it is located at 9º 38" 0""N between 38º 42" 0""E, with the elevation of 2326m above sea level at Bole International Airport, in the southern periphery, and the highest over 3700 m at Yeka Mountains, north of the city. This means, an average elevation of 2408 meters above sea level having an average minimum temperature of 5C^{o}, maximum temperature 27C^{o}, and average annual rainfall of 1188.27 millimeter. (CSA, 2004 and Addis Ababa City Administration, 2004) Addis Ababa is constituted as a City Government. The city covers a total area of 530 square kilometers (53000 ha) (CSA, 2007). Out of Ethiopia"s estimated urban population of nearly 12 million, about 2.738248 or 23 per cent of the total lives in Addis Ababa, of which 1304518 (47.6%) are male and 1433730 (52.4%) female. The average number of persons per household is 4.1, and the total number of households in the city is 651970. The rate of growth of the population of the city is estimated to be 2.1% (CSA, 2007). The City has gained international status by being the seat of the African Union, several international organizations and numerous embassies. Addis Ababa is located in the central part Ethiopia and belongs to the western highlands. The metropolis located in the highlands is also close to the Rift Valley.

Addis Ababa is bordered by all sides by the Regional State of Oromiya Regional State. Addis Ababa is divided into ten Sub-Cities stemming from the 2003 reforms onwards and every sub-city has its own administrative autonomy. The spatial organization shows that Lideta, Kirkos, Arada and Addis-Ketema represent the core or central area where as Akaki, Nefas-SilkLafto, Kolfe Keraniyo, Gulele, Yeka and Bole correspond partly to the expansion areas at their peripheries.

Nifas Silk-Lafto, also spelled Niffassilk Lafto, is one of the 10 sub cities of Addis Ababa, the capital of Ethiopia. As of 2011 its population was of 335,740. The district is located in the southwestern area of the city. It borders with the districts of Kolfe Keranio, Lideta, Kirkos and Bole and Akaki Kaliti.

The land area covered by Nifas Silk sub city is 5876.02 hectares and this constitutes 11.31% of the total land area of the city which makes the sub city in 5th place in land area covered from the 10 sub cities. Among the 12 Woredas in the sub city the largest area is covered by Woreda 01. In the sub city 28.84% of land is residential area and 14.86% of the area is road network in which much of the land is covered with different constructions. The sub city has more than 17 condominium sites including the biggest sites like Jemo and Gofa condominium sites. Jemo sites cover about 2756,700 m^2.

The study area, Jemo area, is suited in Addis Ababa Nefassilk Lafto sub city, its geographic coordinate 38°40'0''E longitude and 8°9'0''N latitude with altitude 2386 m a.s.l. Jemo is found in Nifas silk Lafto sub city woreda 1 administration area.it is found in the largest woreda of the sub city The population of the site is determined based on the data obtained from Addis Ababa Housing Development office area development plans of residential buildings. Jemo sites cover more than about 2,756,700 m^2.The modeled area contains all types of urban area means, there is commercial, administration, and business area and area that is not developed.

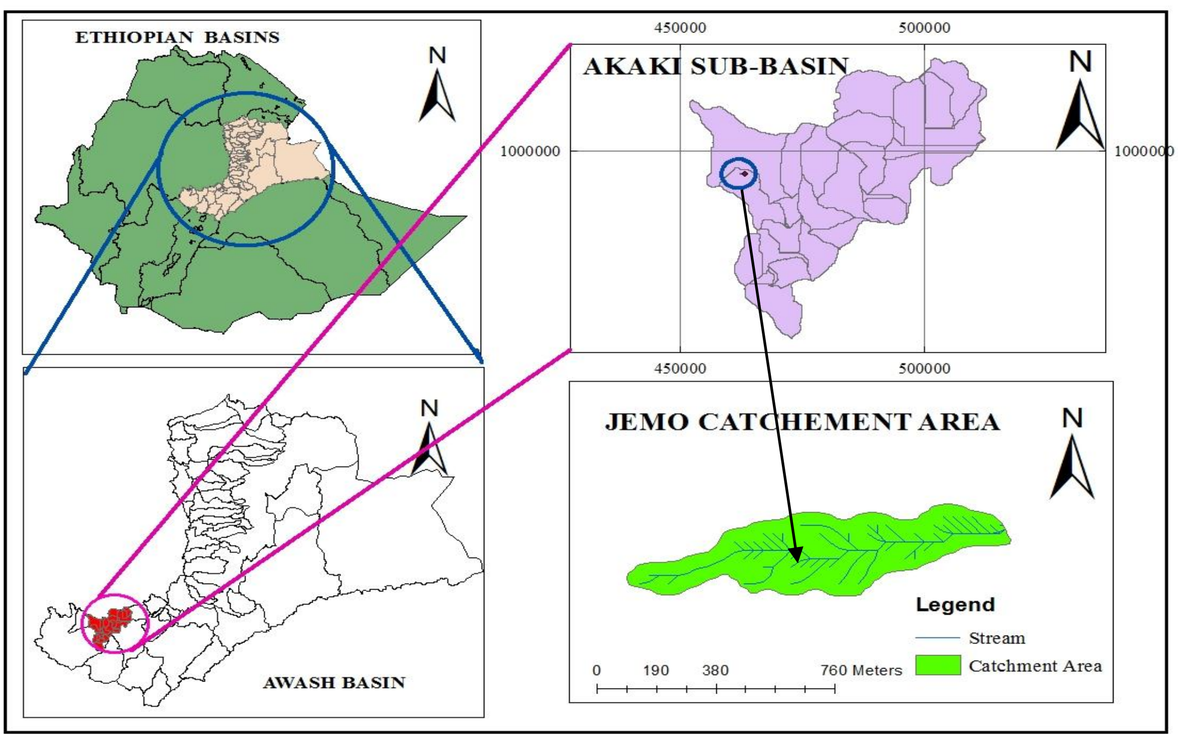


Figure 9: Location of the study area Jemo Area (ARC GIS)

3.1.1 Climate

Addis Ababa city is positioned near equator having very constant temperature from month to month. as part of the Ethiopia climate and based on the national atlas of Ethiopia(1981);the city of Addis Ababa in general and that of Jomo falls within dega and weina dega climatic zone, with altitudinal variation of 2240 to2284 meters a.s.l.

3.1.2 Temperature

On the basis of the climatic zones that prevail to the city and data samples retrieved from the national metrological agencies of the federal democratic republic of Ethiopia, the effective mean annual temperature of Addis Ababa city is in the order of 10 ^{0}c-30 ^{0}c.it is characterized by cold to moderately hot weather condition.

3.1.3 Vegetation

Since Ethiopia has a wide altitudinal range from 120m b.s.l at Dalol to 4,533m b.s.l at Ras Dashen, the country is endowed with diversity of vegetation.

After the foundation of the City (1886), a number of eucalyptus plantations become dominant around Gullelle and Yeka sub-cities. Eucalyptus tree aggravate surface flow of water for flooding since it doesn`t allow undergrowth and insects to exist (Kissa, 2001, cited in Endale 2013). According to Hayal et al. 2011 and annual reports, currently the city is endowed with15 parks with a total area of 817,164 meter square, and 8148 hectare of urban forests in the same source the study area, nifas silk lafto subcity with a total area of 63.59 kilometer square .

3.1.4 Population

The population of Addis Ababa is currently about 3,434,000according to the 2014 population projection with annual growth rate of 3.8% (CSA: 2013). The same report shows that 47.4% of the City's populations are males and the rest 52.6% are females. Nefas silk-Lafto-Sub city has an area of 63.59 km2with 396,486 Population size and density of 6235 persons per km2. From396, 486 of population in nifas silk lafto sub city 59463 population is found in Jemo.

3.1.5 Geological setting of the study area

JEMO area is located in Addis Ababa city, with in the central highland of which is situated within the central highland of Ethiopia close to the rift margin where thick successions of volcanic rocks predominate. The modeled area contains all types of urban area means, there is commercial, administration, and business area and also these modeled areas contain areas that are not developed. The modeled area has only one types of soil Chromic Luvisols.

As per geological map of Ethiopia the geological formations of the project corridors are classified into the following volcanic formations:-

- NQtb=Bishoftu formation: alkaline basalt and trachyte.
- Nn=Nazert series: ignimbrites, unwelded tuffs,ash flows,rhyolitic flows,domes and trachyte.
- PNa=Alajae formation: transitional and sub alkaline basalts with minor rhyolite and trachyte eruptive.
- Ncb=chilalo formation (upper part):Alkaline basalt
- Nc=chilalo formation (lower part):Alkaline basalt trachyte,trachy-basalt,paralkaline,rhyolite with sub –ordinate alkaline basalt.

Figure 10: Modeled study area top view and present flooding condition

3.2 Data Collection

3.2.1 Primary Data

- Site observation and water level marks during summer is conducted.

3.2.2 Secondary Data

- Rainfall records of different stations were collected from the National Meteorological Services Agency, (A.A Bole, Akaki, Ayertena, and A.A Observatory gauged rainfall data)
- Land use , soil characteristics of the catchment area and Nodes and outlets /outfalls invert elevation were collected from Addis Ababa city road authority (AACRA)
- DEM from ministry of water resource.

3.3 Materials

Rainfall, Temperature and Wind Speed data recorded daily intervals were, collected from National meteorological Agency. The period of data was 25 year (1992 – 2008 G.C). The original data were tabulated in the Appendix A.

The materials used for this research are:-

- ARC-GIS to obtain hydrological and physical parameters and spatial information of the catchments of the study area.
- DEM data is used as an input data for ARC-GIS software for catchment delineation and estimation of catchment characteristic.
- Google Earth Software to verify water shed and divides of catchments of the study area.
- Storm water management model to determine the peak runoff
- Hydrological, meteorological data and design document

3.4 Analysis Method of the Study

The thesis will focus on implementing best management practice in Jemo Area. Therefore the data’s gathered in the above method will be analyzed critically on the responses found from the record data, observation and officially recognized reviews.

The final data analyzed will be presented with suitable forms such as tabular, diagrammatic, graphical etc. each with the summary and recommendation to each problems rise in the research.

The main steps that are used to address the specific objectives of this study are;

- Selection of meteorological station using theisson polygon method
- Estimation of missing rain fall data using normal ratio method
- Check the quality of data using double mass curve techniques
- Design rainfall analysis (frequency analysis by using different statically probability distribution method formulas and select better fit using L-moment)
- Develop hourly and daily IDF curve for 2, 5,10,25,50 and 100 year return period using Log-Pearson Type
- Google Earth Software to verify water shed and divides of catchments of the study area.
- Applying Storm Water management model(SWMM) to determine peak runoff
- Then the finally step is to solve the problem of town based on the analysis by recommended possible mitigation measure.

3.5 Hydrological Process

Rain fall data

Rainfall is the most common factor used to predict design discharge. Precipitation gauge were collected from the National Meteorological Services Agency (NMSA).these rainfall data are belong to Bole station, Observatory, Ayertena and Akaki stations. Daily rainfall data is available at these stations. The data from these gauging stations have been used to develop IDF. IDF Curve calculates intensity from precipitation data inputs for subcatchments.

Estimating missing rainfall data

Due to the absence of observer or instrumental failure rainfall data record occasionally are incomplete. In the estimation of missing data from a raingauge station, performance of a group of neighboring stations including the one with missing data are considered. A comparison of the recordings of these stations are made by using their normal rainfall as standard of comparisons.In such a case one can estimate the missing data by using the nearest station rainfall data.

Procedure of Missing Data Estimation

Given the annual precipitation values P1, P2, P3,….Pm at neighbouring M stations 1,2,3,……M respectively, it is required to find the missing annual precipitation Px at a station X not included in the above M stations. Further the normal annual precipitation N1, N2, N3 ,…….Ni,…..at each of the above (M+1) stations, including station ,are known. If the normal annual precipitation at various stations are within about 10% of the normal annual precipitation at station X then a simple arithmetic average procedure is followed to estimate Px but if the normal annual precipitation is vary considerably the normal ratio method is preferable for this research the normal ratio method is used.

Px= $P1\frac{Nx}{N1}+P2\frac{Nx}{N2}+\cdots Pn\frac{Nx}{Nn}$

Provided N1, N2, or N3 differ by more than 10% of Nx

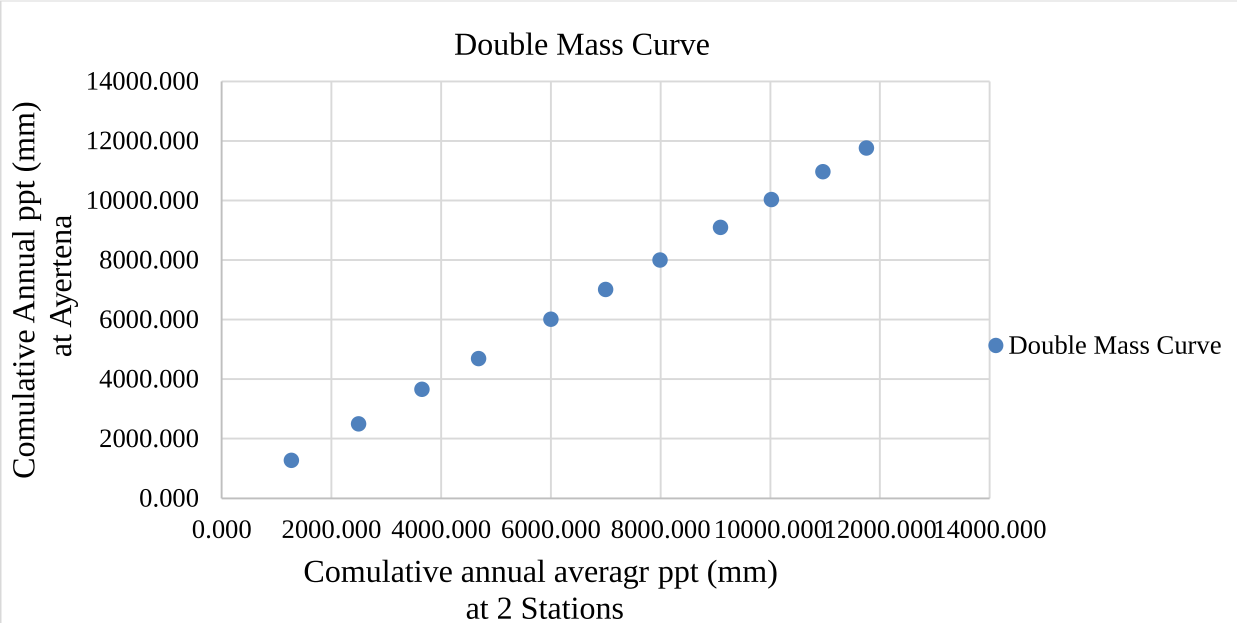
Where:

N1,N2……… Nx- is annual rainfall of known stations

Nx-annual rain fall of unknown station

Checking the accuracy of the data

If the conditions relevant to the recording of a raingauge stations have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. Double mass curve technique is often used to test the consistency of rainfall record. The procedure is that accumulated rainfall at the gauge station whose record is in doubt is plotted as ordinate versus the average concurrent accumulated average rainfall of nearby stations whose rainfall data are reliable. A double mass curve graph was drawn to check the consistency of the collected data. And it is observed that the data of most of the stations are consistent.



Testing for Outliers

An outlier is an observation that deviates significantly from the bulk of the data, which may be due to errors in data collection, or recording, or due to natural causes. The presence of outliers in the data causes difficulties when fitting a distribution to the data. Low and high outliers are both possible and have different effects on the analysis (Rao and Hamed, 2000) The retention or deletion of these outliers can significantly affect the magnitude of statistical parameters computed from the data, especially for small samples. As it is cited in Rao and Hamed (2000) Grubbs and Beck (G-B) (1972) test is used to detect outliers. In this test the quantities XH and XL are calculated using the following equations.

$$X_H = \exp(\overline{X} + K_n * S)$$

$$X_L = \exp(\overline{X} - K_n * S)$$

Where : X and S are the mean and standard deviations of the natural logarithm of the annual rainfall peaks respectively and Kn , is the G-B statistic tabulated for various sample sizes and significant levels by Grubbs and Beck(1972). At 10% significant level, the following approximation proposed by Pilon et al. (1985) is used, where N is the sample size.

$$Kn = -3.62201 + 6.28446N^{\frac{1}{4}} - 2.49835N^{\frac{1}{2}} + 0.49146N^{\frac{3}{4}} - 0.037911N$$

Sample values greater than XH are considered to be high outliers, while those less than XL are considered to be low outliers. The result of the outliers test for rainfall depths Ayertena station is indicated in table 1.

Table 1: Outlier test for ayertena station

Annual maximum ppt of ayertena station		Log y	y-Y	(y-Y)^2	(y-Y)^3	Outerlier	
						Higher	Lower
2006	46.5	1.667	0.094	0.009	0.001	Ok	Ok
2007	30.8	1.489	-0.085	0.007	-0.001	Ok	Ok
2008	34.7	1.540	-0.034	0.001	0.000	Ok	Ok
2009	22.9	1.360	-0.214	0.046	-0.010	Ok	Lower
2010	36.4	1.561	-0.013	0.000	0.000	Ok	Ok
2011	34.9	1.543	-0.031	0.001	0.000	Ok	Ok
2012	43.4	1.637	0.064	0.004	0.000	Ok	Ok
2013	42.6	1.629	0.056	0.003	0.000	Ok	Ok
2014	39.6	1.598	0.024	0.001	0.000	Ok	Ok
2015	44.6	1.649	0.075	0.006	0.000	Ok	Ok
2016	43.5	1.638	0.065	0.004	0.000	Ok	Ok

	Outerlier	RF Depth
Higher	1.76	57.88
Lower	1.39	24.28

Regional Frequency Analysis

Regional frequency analysis is applied when no local data are available at a site of interest or the data are insufficient for a reliable estimation of the required return period. Hosking (1990) has defined L-moments to summaries theoretical distribution and observed samples. Analogous to the conventional MRDs, the L-moment ratio diagrams are based on the relations between the L-moment ratios. A diagram based on L-Cs (τ_3) versus L-Ck (τ_4) is used to identify appropriate distributions that best fits the rainfall data.

To select the type of distribution fit to the given data are computed as follow.

Uniform distribution, $\tau 3$ and $\tau 4 = 0$

Exponential distribution, $\tau 3 = 1/3$ and $\tau 4 = 1/6$

Normal distribution, $\tau 3 = 0$ and $\tau 4 = 0.1226$

Gumbel distribution (GEV 1) , $\tau 3 = 0.1699$ and $\tau 4 = 0.1504$

Log normal distribution , $\tau 4 = 0.12282 + 0.77518(\tau 3)^2 + 0.12279(\tau 3)^4 - 0.13638(\tau 3)^6 +0.113638(\tau 3)^8$

General extreme value, $\tau 4 = 0.10701 + 0.1109(\tau 3) + 0.84838(\tau 3)^2 - 0.06669 (\tau 3)^3 + 0.00567(\tau 3)^4 -0.04208(\tau 3)^5+0.03763(\tau 3)^6$

Pearson type III, $\tau 4 = 0.1224 + 0.30115(\tau 3)^2 + 0.95812(\tau 3)^4 - 0.57488(\tau 3)^6 + 0.19383(\tau 3)^8$

Gamma, $\tau 4 = 0.1224 + 0.30115(\tau 3)^2 + 0.95812(\tau 3)^4 - 0.57488(\tau 3)^6 + 0.19383(\tau 3)^8$

Generalized Pareto, $\tau 4 = 0.20196(\tau 3) + 0.95924(\tau 3)^2 - 0.20096(\tau 3)^3 + 0.04061(\tau 3)^4$

Where:

$\lambda 1 = \beta o =$

$\lambda 2 = 2 \beta 1 - \beta o =$

$\lambda 3 = 6 \beta 2 - 6 \beta 1 + \beta o$

$\lambda 4 = 20\beta 3 - 30 \beta 2+12 \beta 1 - \beta o$

$\tau = \lambda 2/ \lambda 1$

$\tau 3 = \lambda 3 / \lambda 2$

$\tau 4 = \lambda 4/\lambda 2$

The unbiased parameters are computed as follows

$\beta_r = \sum(PPT)/n$

$\beta_1 = \sum(((n-i)*Ppt\ i)/(n*(n-1)))$

$\beta_2 = \sum(((i-1)(i-2)*Ppti)/(n*(n-1)(n-2)))$

$\beta_3 = \sum(((i-1)(i-2)(i-3)*Ppti)/(n*(n-1)(n-2)(n-3))$

Finally, the L-moment ratios are calculated as:

L-moment mean (L-mean): L-mean = $\tau 1 = \lambda 1$

L-moment Coefficient of variation (L-CV): L-CV = $\tau 2 = \lambda 2/\lambda 1$

L-moment coef. of skew (L-Skewness) = $\tau 3 = \lambda 3/\lambda 2$

L-moment coef. of kurtosis (L-Kurtosis) = $\tau 3 = \lambda 4/\lambda 2$

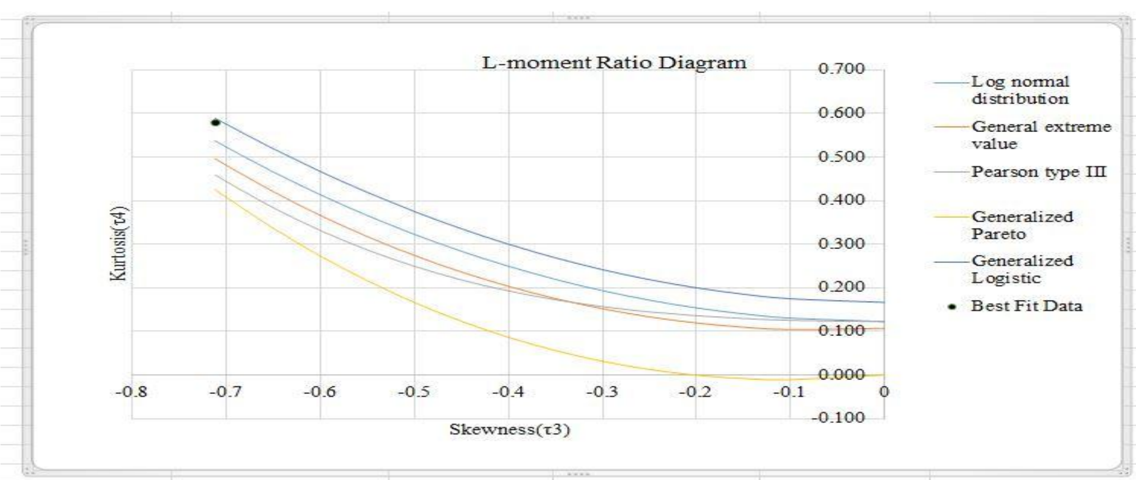


Figure 11:L-moment diagram

Modeling rainfall computation

In order to apply flood estimation models for peak discharge computation using available rainfall data, the rainfall depth-duration-frequency relationship is required. Rainfall records were obtained from the National Meteorological Services Agency located in Bole sub city. Available rainfall data on these stations has been collected and analyzed in order to prepare the necessary depth or intensity input data for peak discharges computation.

The analysis and processing is aimed at determination of appropriate intensity-duration relationship applicable for the thesis. Estimates of maximum rainfall depths for different return periods (T) are obtained by statistical technique of frequency analysis. Extreme value type I, Gumbel, Log-Normal and Log Pearson Type III distributions are used for modeling storm determination of desired return periods in areas where appropriate IDF curves are not available. Thus, the analysis consists of determining maximum rainfall depths associated with T value of interest.In the absence extreme rainfall values for periods less than 24 hours (12, 6, 3 or less than these hours) ,it is difficult to apply regression analysis to drive appropriate IDF curve for a given area, hence rainfall ratio method is used to estimate the rainfall depth to be distributed on a given duration based on a 24 hour rainfall. With this condition, the following the relationship adopted for IDF development at a given station.

Rt /R24 = (t / 24) [(b + 24)n / (b + t)n]

where: Rt: R24 -Rainfall ratio, Rt: Rainfall in a given durations (hr.) R24: Rainfall in 24 hours, n: constant, b: constant, t: time (hr) Based on studies of a large number of rainfall gauges in East Africa, the average values of b and n are found to be 0.3 and 0.9 respectively. These values have been adopted for this thesis project IDF development. Extreme rainfall depth station for different return periods was determined using Log Pearson Type III distributions analysis.

1. Assemble the rainfall series Xi.

2. Calculate the logarithms Yi of X

$$Yi = logXi$$

3. Calculate the mean Y, standard deviation Sy and skew coefficient Csy

$$Y = \frac{1}{N}\sum_{i=1}^{n} Yi$$

$$Sy = \sqrt{\frac{1}{N-1}\sum_{i=1}^{n}(Yi - Y)^2}$$

$$Csy = \frac{ay}{(sy)^3}$$

$$where$$

$$ay = \frac{n}{(n-1)(n-2)}\sum_{i=1}^{n}(Yi - Y)^3$$ Or skewness

n-is the number of members of the series

4. Calculate the logarithms of the rainfalls for each of several chosen probability levels Pj using the frequency formula:

Log RFj = Y + Kj*Sy

Where Kj is the frequency factor (a function of the probability level desired and the skew coefficient. Calculation of frequency factors is shown below.

$$KT = Z + (Z^2 - 1)K + \frac{1}{3}(Z^3 - 6Z)K^2 - (Z^2 - 1)K^3 + ZK^4 + \frac{1}{3}K^3$$

Where $K = \frac{Cs}{6}$

The value of Z corresponding to an exceedence probability of P (P=1/T) can be calculated by finding the value of an intermediate variable w:

$$W = (ln\left[(\tfrac{1}{P^2})\right])^{0.5}$$ (0<P<=0.5)

P > 0.5, (1 – P) is substituted for P

Then calculate Z using the approximation:

$$Z = W - \frac{2.515517 + 0.802853W + 0.010328W^2}{1 + 1.432788W + 0.189269W^2 + 0.001308W^3}$$

5. Calculate the rainfalls for each probability level (or return period) by taking the

   Anti-logarithms of the logRFj values.

3.6 Modeling Rainfall using EP SWMM5

SWMM is a dynamic rainfall-runoff 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.

Model set up procedure

- Set the coordinates of area map/image
- Draw network representative and describe sub catchments
- Edit the properties of the object that make up the system
- Describe how the system is operated
- Select a set of analysis options
- Run Simulation for Rainfall/Runoff and Flow routing

Computational Method

SWMM is a physically based, discrete-time simulation model. It employs principles of conservation of mass, energy, and momentum wherever appropriate.

This section briefly describes the methods SWMM uses to model storm water runoff quantity and quality through the following physical processes:

- Surface runoff
- Ground water
- Infiltration
- Flow routing
- Water quality routing
- Snow melt

Surface runoff

The conceptual view of surface runoff used by SWMM is each subcatchment surface is treated as a nonlinear reservoir. Inflow comes from precipitation and any designated upstream subcatchments.

There are several outflows, including infiltration, evaporation, and surface runoff. The capacity of this "reservoir" is the maximum depression storage, which is the maximum surface storage provided by ponding, surface wetting, and interception. Surface runoff per unit area, Q, occurs only when the depth of water in the "reservoir" exceeds the maximum depression storage, dp, in which case the outflow is given by Manning's equation. Depth of water over the subcatchment (d in feet) is continuously updated with time (t in seconds) by solving numerically a water balance equation over the subcatchment.

Infiltration

Infiltration is the process of rainfall penetrating the ground surface into the unsaturated soil zone of pervious subcatchments areas.

Green-Ampt Method is used for this study because the Horton equation captures the basic behavior of infiltration but the physical interpretation of the exponential constant is uncertain. Green and Ampt (1911) presented an approach that is based on fundamental physics and also gives results that match empirical observations.

This method for modeling infiltration assumes that a sharp wetting front exists in the soil column, separating soil with some initial moisture content below from saturated soil above.

In reality, there is often not a sharp wetting front and/or the soil above the wetting front may not saturate. The equation to use if you need to consider the most realistic situation is the Richard’s equation; but Richard’s equation is not available in SWMM. The input parameters required are the initial moisture deficit of the soil, the soil's hydraulic conductivity, and the suction head at the wetting front.

Ground water

After computing the water fluxes that exist during a given time step, a mass balance is written for the change in water volume stored in each zone so that a new water table depth and unsaturated zone moisture content can be computed for the next time step.

Snow melt

The snowmelt routine in SWMM is a part of the runoff modeling process. It updates the state of the snow packs associated with each subcatchment by accounting for snow accumulation, snow redistribution by areal depletion and removal operations. Any snowmelt coming off the pack is treated as an additional rainfall input onto the subcatchment.

3.7 Governing Equation

SWMM conceptualizes a subcatchment as a rectangular surface that has a uniform slope S and a width W that drains to a single outlet channel. Overland flow is generated by modeling the subcatchment as a nonlinear reservoir.

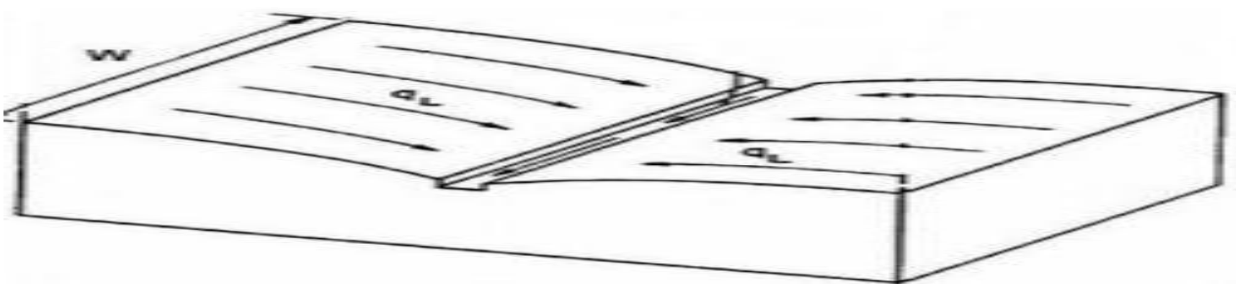


Figure 12: Idealized representation of subcatchment

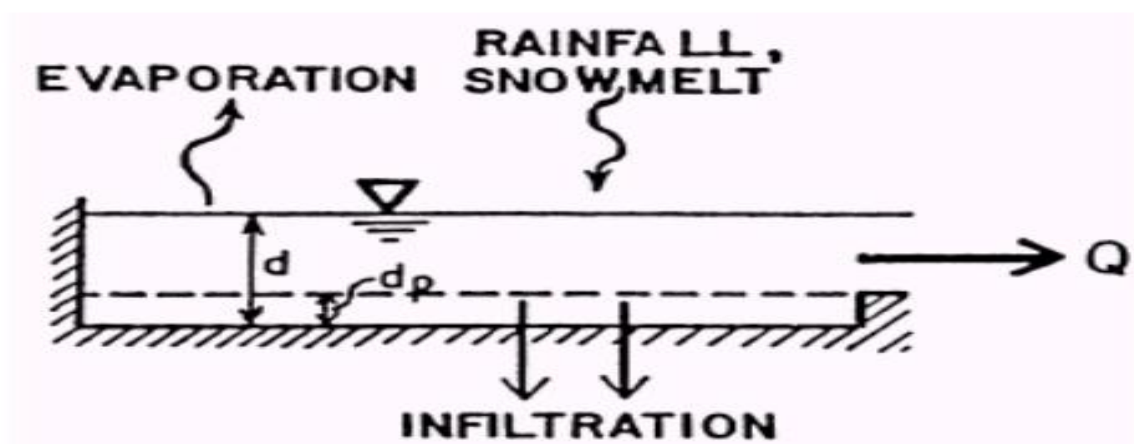


Figure 13: nonlinear reservoir model of subcatchment (SWMM manual)

Fig 13. Represents the subcatchment experiences inflow from precipitation (rainfall and snowmelt) and losses from evaporation and infiltration.

The net excess ponds a top the subcatchment surface to a depth d. Ponded water above the depression storage depth ds can become runoff outflow q. Depression storage accounts for initial rainfall abstractions such as surface ponding, interception by flat roofs and vegetation, and surface wetting.

SWMM uses the Manning equation to express the relationship between flow rate (*Q*), cross sectional area (*A*), hydraulic radius (*R*), and slope (*S*) in all conduits. For standard U.S. units,

$$\mathrm{Q} = \frac{1.49}{n} A R^{0.66} S^{0.5}$$

Where *n* is the Manning roughness coefficient. The slope *S* is interpreted as either the conduit slope or the friction slope (i.e., head loss per unit length), depending on the flow routing method used.

For pipes with Circular Force Main cross-sections either the Hazen-Williams or Darcy-Weisbach formula is used in place of the Manning equation for fully pressurized flow. For U.S. units the Hazen-Williams formula is:

$$Q = 1.318 C A R^{0.63} S^{0.54}$$

Where:

C is the Hazen-Williams C-factor which varies inversely with surface roughness and is supplied as one of the cross-section's parameters.

The Darcy-Weisbach formula is:

$$Q = \sqrt{\frac{8g}{f}} \mathrm{A} R^{0.5} \mathrm{S}^{0.5}$$

Where: *g* is the acceleration of gravity and *f* is the Darcy-Weisbach friction factor.

For turbulent flow, the latter is determined from the height of the roughness elements on the walls of the pipe (supplied as an input parameter) and the flow's Reynolds Number using the Colebrook-White equation. The choice of which equation to use is a user-supplied option.

A conduit does not have to be assigned a Force Main shape for it to pressurize. Any of the closed cross-section shapes can potentially pressurize and thus function as force mains that use the Manning equation to compute friction losses.

3.8 Storm Drainage Hydraulic Elements Modeling

Urban stormwater collection and conveyance systems are critical components of the urban infrastructure. Proper design is essential to minimize flood damage and limit disruptions. The primary function of the system is to collect excess stormwater in street gutters, convey it through storm drains and along the street right-of-way, and discharge it into a detention basin, water quality best management practice (BMP), or the nearest receiving water body.

The modeling of these elements is dependent on storm frequency and the allowable spread of storm water on the pavement surface.

3.8.1 Curb and Gutter

Roadway and structure pavement drainage should be considered early in a project design, while the roadway geometry is still being developed since the hydraulic capacity of gutters and inlets is determined by the longitudinal slope and super elevation of the pavement. The imperviousness of the roadway pavement will result in significant runoff from any rainfall event.

To ensure safety to the traveling public, careful consideration must be given to removing the runoff from the roadway through structure pavement drainage facilities.

3.8.2 Inlet Function and Selection

Inlets collect excess stormwater from the street, transition the flow into storm drains, and can provide maintenance access to the storm drain system. The hydraulic capacity of a storm drain inlet depends upon its geometry as well as the characteristics of the gutter flow.

Inlet capacity governs both the rate of water removal from the gutter and the amount of water that can enter the storm drainage system. Inadequate inlet capacity or poor inlet location may cause flooding on the roadway resulting in a hazard to the traveling public.

There are four major types of inlets: grate, curb opening, combination, and slotted. The most commonly used is Curb –opening drop inlet structure. The curb-opening inlet is one of the major types of inlets used in highway and city drainage systems. It has the advantage of being clogged with debris, and has particularly good performance at locations where the longitudinal grade is relatively flat.

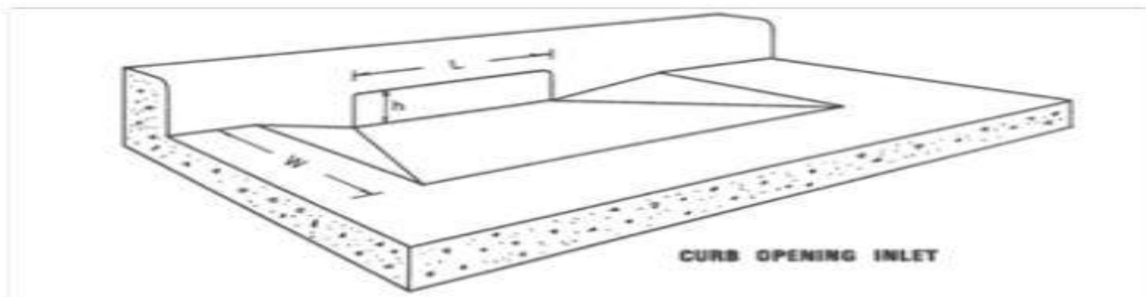


Figure 14: Curb opening inlet

3.8.3 Design Consideration

Frequently roadway geometry dictates the location of inlets. Inlets are placed at low points (sumps), median breaks, and at intersections. Additional inlets should be placed where the design peak flow on the street half is approaching the allowable capacity of the street half. Allowable street capacity will be exceeded and storm drains will be underutilized when inlets are not located properly or not designed for adequate capacity (Akan and Houghtalen 2002).

To a great degree, allowable street capacity dictates the placement of inlets. Inlets placed on continuous grades are generally designed to intercept only a portion of the gutter flow during the minor (design) storm (i.e. some flow bypasses to down gradient inlets). The hydraulics of curb-opening inlets are less complicated than grate inlets.

The efficiency, E, of a curb opening inlet is calculated as:

$E = 1 - \left[1 - \left(\frac{L}{LT}\right)\right]$……………………For L<LT, otherwise E=1.0

Where:

L = curb-opening length (ft)

LT = curb-opening length required to capture 100% of gutter flow (ft).

But most curb-opening inlets are in a composite street section and many also have a localized depression, so LT should then be calculated as

$$LT = 0.38Q^{0.51}S_L^{0.058}\left(\frac{1}{nSe}\right)^{0.46}$$

Where:

Q = total flow (cfs)

SL= longitudinal street slope (ft/ft)

Se= equivalent cross slope (ft/ft)

n = Manning's roughness coefficient.

To compute gutter flow, the Manning's equation is integrated for an increment of width across the section. The resulting equation is:

$$Q = \frac{Ku}{n}Sx^{1.67}SL^{0.5}T^{2.67}$$

Where:

Ku = 0.376

n = Manning's coefficient:

Q = flow rate, m3/s

T = width of flow (spread), m:

S_x = cross slope, m/m

SL = longitudinal slope, m/m

$$Se = Sx + \frac{Sw}{Eo}$$

Where;

Sw = cross slope of the gutter measured from the cross slope of the pavement,

Sx=Cross slope m/m

Eo = ratio of flow in the depressed section to total gutter flow determined by the Gutter configuration upstream of the inlet.

$$Sw = Sx + \frac{a}{w}$$

Where:
EO = *QW/Q*, the ratio of gutter flow, *QW*, to total flow *Q*
W = width of the gutter (typical value = 2 ft)
SW = the gutter cross slope (typical value = 1/12 or 0.0833 [ft/ft])
a = gutter depression = WSW - WSX (typical value for *WSW* for a 2-ft gutter section is 0.1667 ft).

The effectiveness of the inlet is expressed as efficiency defined as:

$$E = \frac{Qi}{Q}$$

Where:
E = inlet efficiency (fraction of gutter flow captured by inlet)
Qi = intercepted flow rate (cfs)
Q = total half-street flow rate (cfs).

Bypass (or carryover) flow is not intercepted by the inlet.

By definition,

$$\mathrm{Qb} = \mathrm{Q} - \mathrm{Qi}$$

Where:

Qb = bypass (or carryover) flow rate (cfs).

From the geometry, it can be shown that:

$$Y = a + TSx$$

And

$$A = \frac{SxT^2 + aW}{2}$$

Where:

y = flow depth above depressed gutter section (ft). Note that the depth of flow at the gutter line is defined as *d*, where $d = y + a$ (see Figure 7-2).

A = flow area (ft^2)

The depth of water at the vertical edge of the gutter section, computed as follow:

$$d = TSx$$

3.9 Design and Construction of Rain Gardens

Two common rain garden designs are used for stormwater retention the first one is Planted depression is placed downstream from a drainage area. This design is commonly used in home and retail landscapes to collect rain from roofs or in sandy soil areas with high infiltration rates. For information on designing and building a residential rain garden and second Existing soil is replaced with layers of high-infiltration soils, gravel, and mulch, and a variety of vegetation is planted. This design also commonly includes a perforated drainage pipe placed at the bottom of the growing media but above the gravel layer. It is best suited for clay soil, parking lots, and highway medians.

Selecting Site

To select the location for a rain garden, consider the existing land use, vegetation, slope, proximity to building foundations, and the aesthetic value of the site. A rain garden should be designed to collect runoff from an area of no more than 1 to 2 acres. Larger areas can produce flows that cause erosion.

If the rain garden will collect runoff from a parking lot, replace some of the paved area instead of putting the rain garden in an existing grassed area that already filters stormwater. Avoid placing the rain garden close to soil disturbed by construction so that the rain garden won't be clogged by sediments from the construction site runoff.

If it must be close to a disturbance, use best management practices such as installing silt fences to protect the garden. In clay areas, it should be at least 10 feet (but preferably 30 feet) away from buildings to prevent any damage to foundations.

Rain Garden Design

Follow these steps to build a rain garden:

- Fill the bottom foot (the retention zone) with gravel (0.5 to 1.5 inches in diameter
- At the top of this layer, place a perforated under drain pipe for drainage purposes
- Lay a filter fabric over the grave land the drain to reduce the silting of the gravel zone (infiltration such as clayey soils, bring in soil from another area.
- The soil should consist mainly of sand or another coarse material such as crushed expanded shale, yet still contain some fine material and organics to support plant growth. For clay soil, use a mix of 50 percent compost, 25 percent native soil and 25 percent expanded shale (or similar material). For sandy soils, use a 50 to 75 percent native soil and 25 to 50 percent compost mix. Use well-aged yard waste compost.
- Add 2 inches of mulch, preferably well-aged shredded hardwood, which will not float, on top of the soil around the plants.Build the rain garden to hold 6 to 9 inches of water over the top of the soil. Assuming that the gravel and soil are 30 percent pore space, calculate the depth of water the rain garden will hold at full capacity.
- One foot of gravel with 30 percent pore space will hold 3.6 inches of water. One and a half feet of expanded shale/clay/compost mix with a 30 percent pore space will hold 5.4 inches of water.
- Add the 6 inches of standing water on top of the rain garden soil for a total water depth of 15 inches.

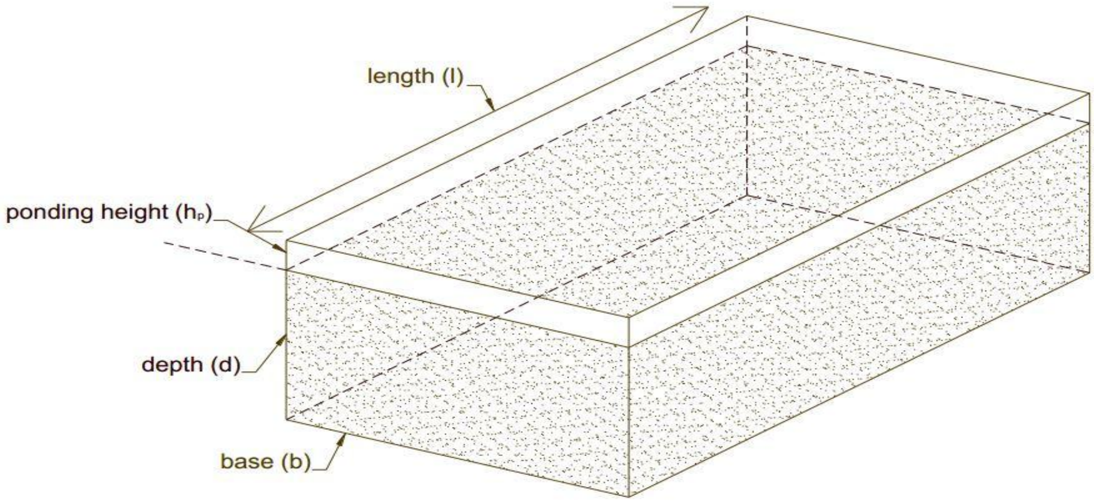


Figure 15: Simplified illustration of bio retention area

The total volume of water possible for initial storage (Vtotal) can be decided by the equation:

$$Vtotal = Abioretention * Hp + Vbioretention * Wsc$$

Where Abioretentio is the area of the solution (m2), Hp is the ponding height of the water (m), Vbioretention is the volume of the bioretention area and Wsc is the water holding capacity of the soil (%). The dimensioning volume of stormwater conducted to the bioretention area (ha) can be decided by:

$$\mathrm{Qdim.} = \emptyset * \mathrm{Acatch} * \mathrm{I}$$

Where (∅)is the runoff coefficient , A catch is the catchment area (m2) and I is the dimensioning precipitation (m). For asphalt and concrete, the runoff coefficient is 0.8. Since these solutions only handle stormwater from a very limited area, it is assumed that the entire catchment consists of hardened surfaces with the runoff coefficient 0.8.

The size of the catchment area can be decided by the equation:

$$\mathrm{Acatch.} = \frac{\mathrm{Vtotal}}{\mathrm{Qdim\ per\ unit\ area}}$$

When the maximum storage volume is decided, the catchment area is the only unknown element in equations. By rearranging these calculations, this area may be decided.

The ponding time of the water (Tp) can easily be decided by the equation:

$$Tp = \frac{\mathrm{Hp}}{\mathrm{Gi}}$$

Where :(Gi) is the infiltration rate of the soil media (m/h).

CHAPTER FOUR

4. RESULT AND DISCUSSION

4.1 Results from IDF Curve

Using the daily and hourly maximum rainfall from metrological agency, design rainfall was calculated using Log Pearson type III distribution methods. The values are compared with different return period. The intensity of the rainfall for design purposes is obtained from the intensity-duration frequency (IDF) relationship for the sub catchment.

Table 2: Design Storm for different return period

Applying log pearson type III distribution							Design storm
Return period		exceedance probablity	skewness coefficient	K(T,n)	Sy	Yt	XT
100		0.01		2.70935		1.83571	68.5041
50		0.02		2.32491		1.79856	62.8872
25		0.04	0.1	1.91609	5.59	1.75905	57.4183
10		0.1		1.32059		1.70149	50.2917
5		0.2		0.80193		1.65137	44.8094
2		0.5		-0.0877		1.56538	36.7611

4.1.1 Comparison of observed (hourly) versus compute (daily) IDF values at Ayertena station

Observed and computed intensities are plotted on the same graph and goodness of fit is evaluated. The percentage difference between computed and observed intensities is plotted versus duration of rainfall for different return periods.

Figure 19. shows the graphical comparisons of the computed and observed intensities with the percentage difference of estimate from the observed value are compared graphically.

For lower durations a relatively higher difference between computed and observed intensity was seen from the graph of percentage difference.

Results of comparison between the hourly IDF curves for modified data set indicate high difference between the hourly and daily intensity. Therefore it is recommended to proceed with potential revisions of the standards using the hourly rainfall data. Based on this comparison it is recommended that the study area proceeds with a change upwards of IDF curves. Our recommendation is that the current IDF curves should be revised using hourly rainfall data.

.

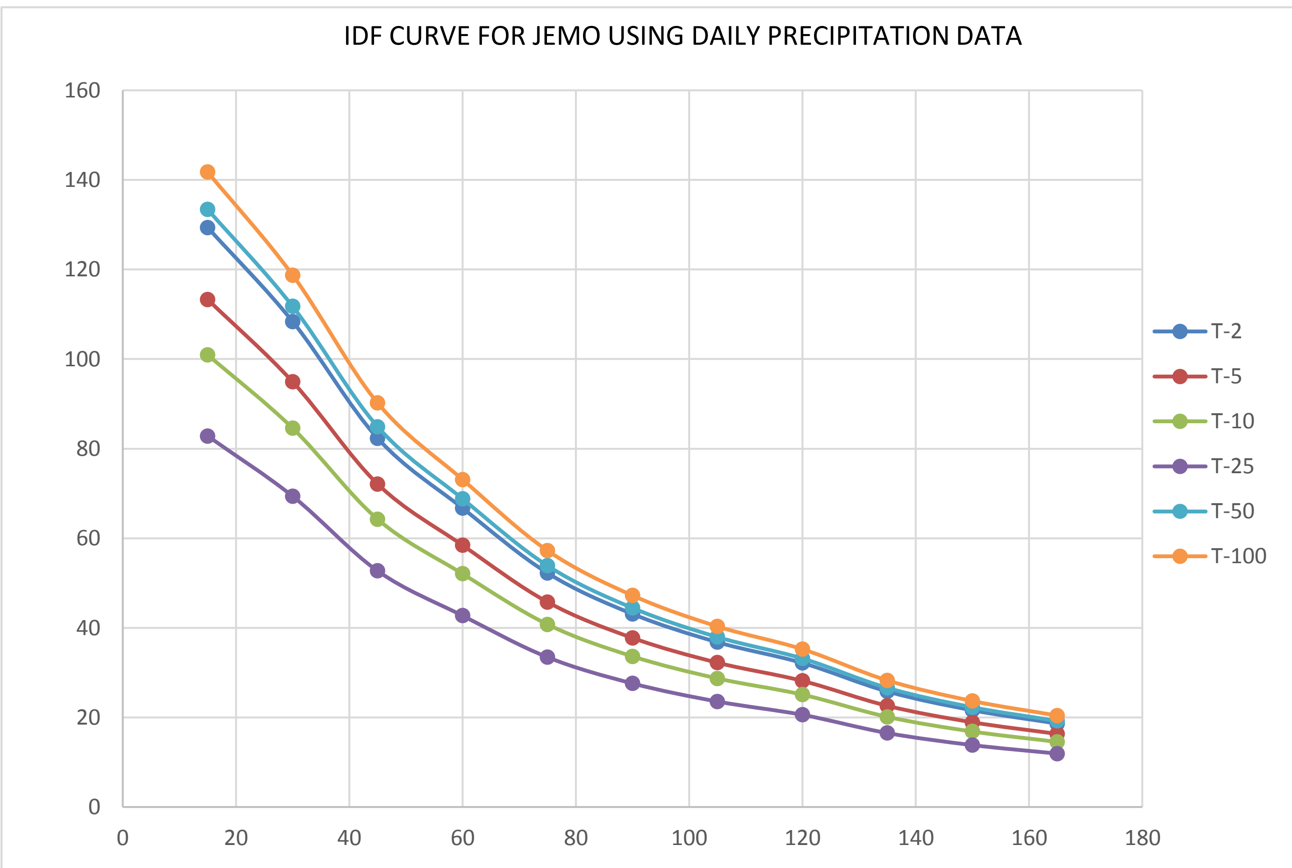


Figure 16: IDF curve using daily rainfall data

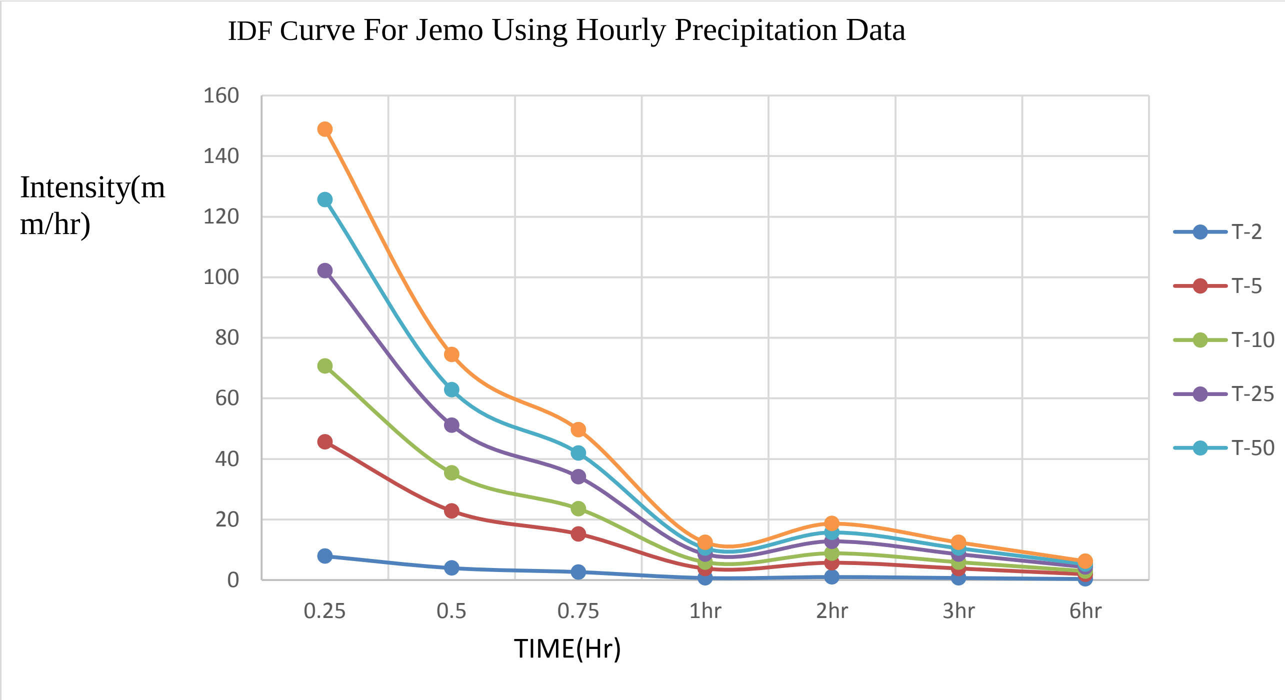


Figure 17: IDF Curve using hourly rainfall data

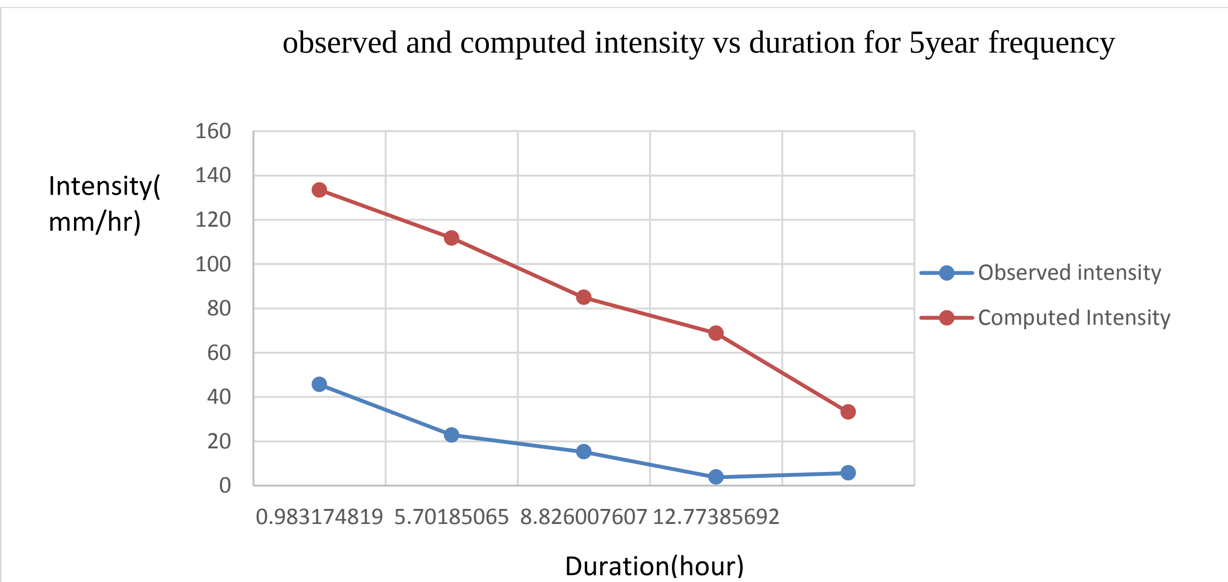
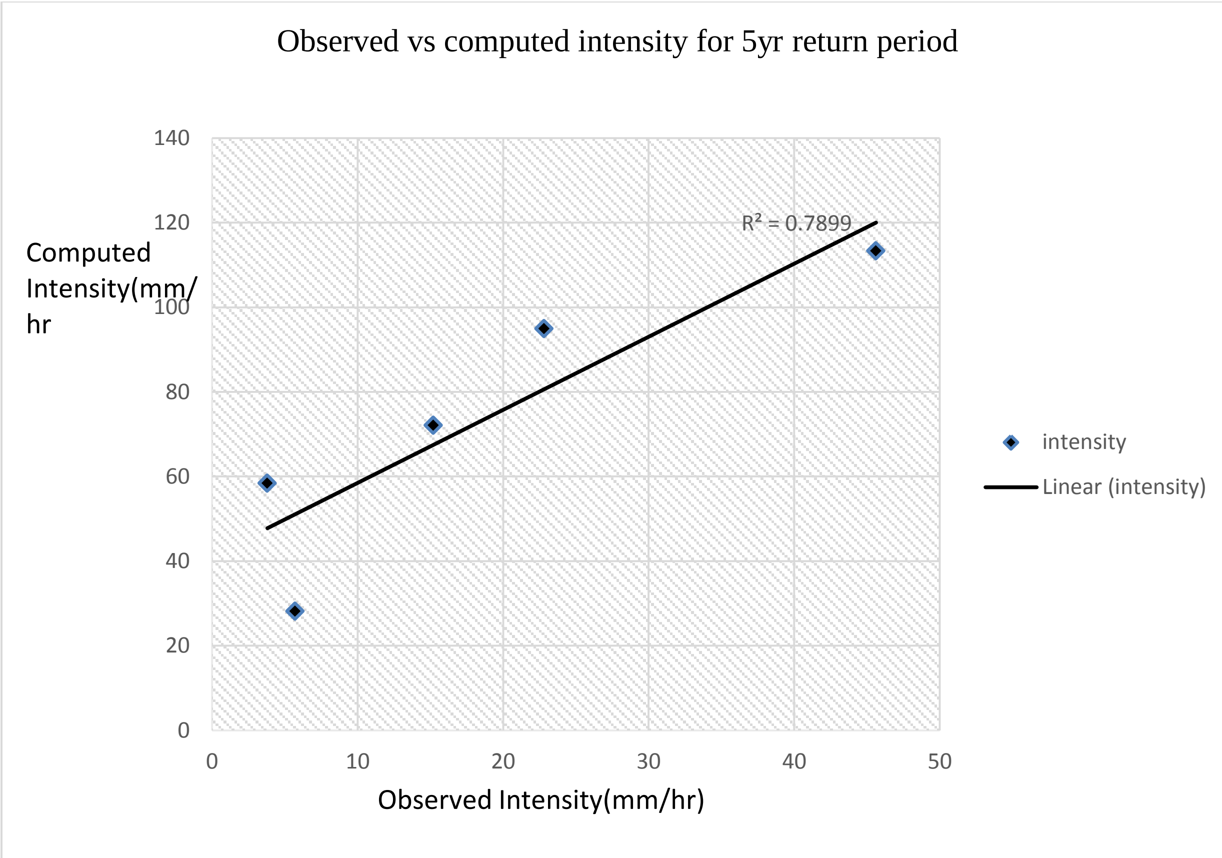


Figure 18: graphical comparison between observed and computed intensity for 5year frequency



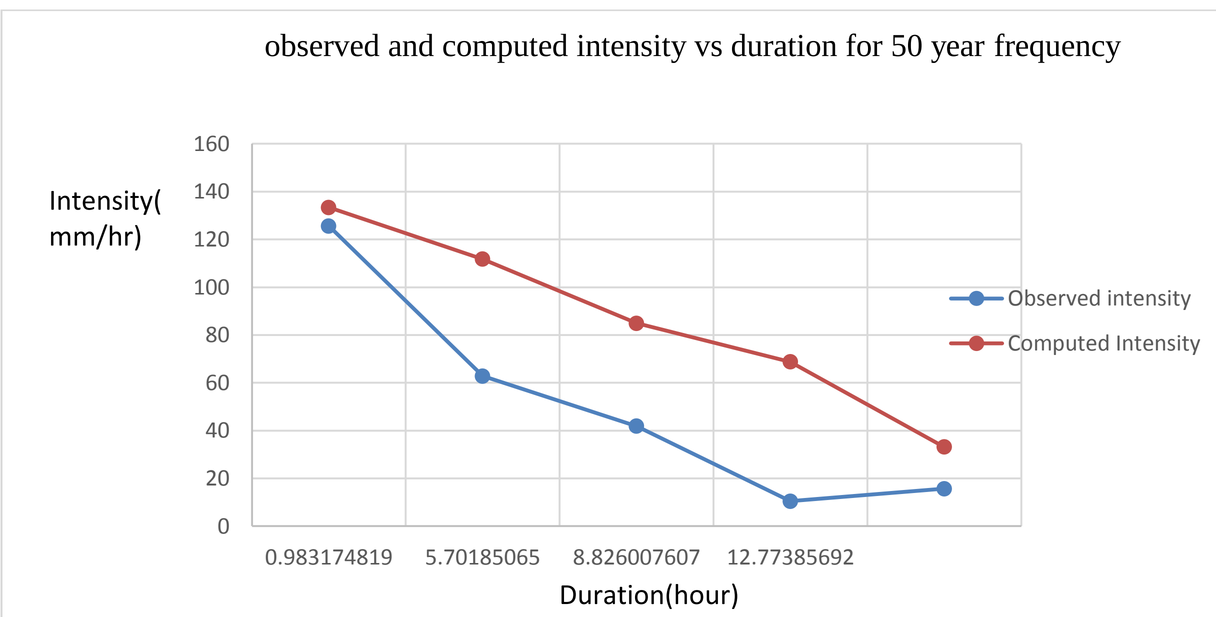


Figure 19: observed and computed intensity vs duration for 50 year frequency

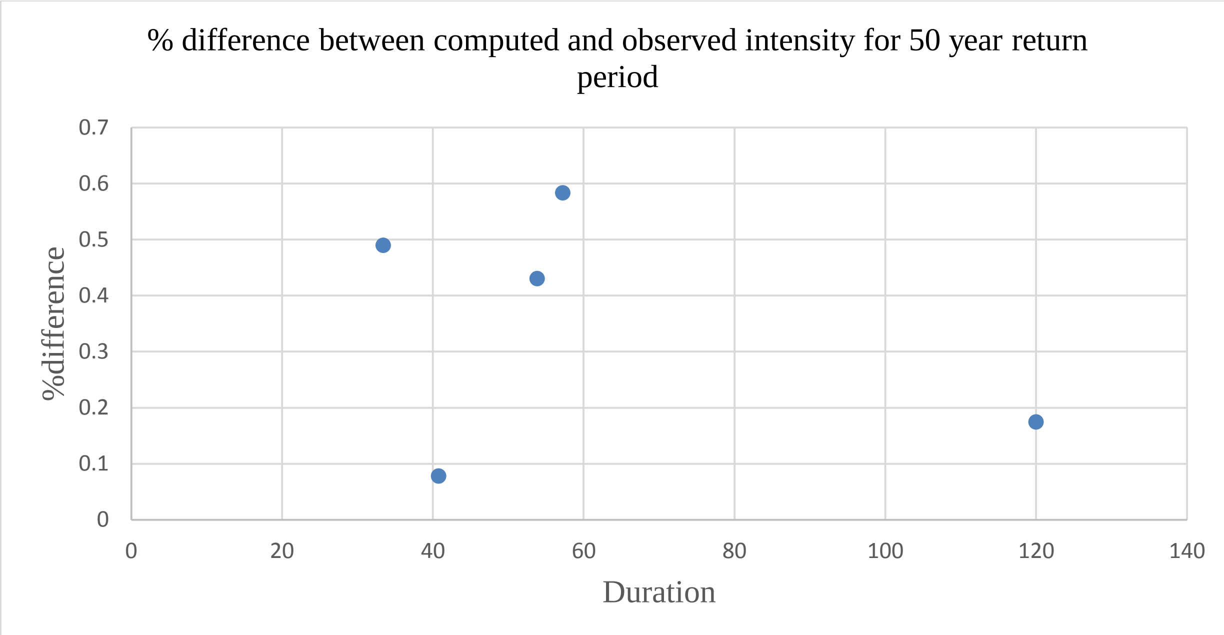


Figure 20:% difference between computed and observed intensity for 50 year return period

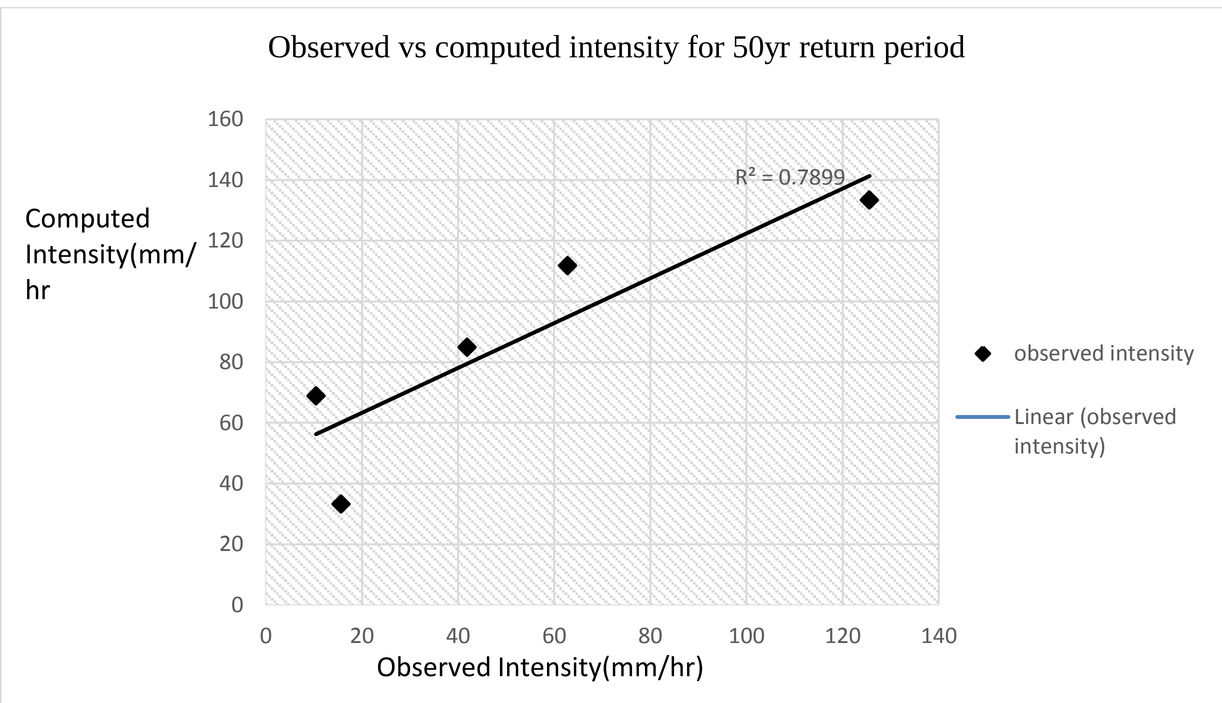


Figure 21: Observed vs Computed intensity for 50yr return period

4.1.2 Comparison of IDF Results

Updated IDF curves for hourly and daily rainfall intensity are compared for the JEMO. Results of the comparison for original data set are shown on figure above .The comparison results indicate that hourly rainfall intensity for short durations and return periods have great difference with daily rainfall intensity. The outputs of the study indicate that: the daily rainfall intensity have significant increase in rainfall intensity for a range of durations and return periods, and the increase in rainfall intensity and magnitude may have major implications on ways in which current (and future) municipal water management infrastructure is designed, operated, and maintained. The comparisons of hourly and daily IDF curves for Jemo reveal that the computed values higher than observed values. The rainfall intensity patterns in Jemo most certainly change with the hourly and daily rainfall data. This report quantifies these changes and their impact on design, operation and maintenance of municipal water management infrastructure (such as roads, bridges, culverts, drains, sewer and conveyance systems, etc). The results presented in the previous Section of the report in terms of rainfall intensity duration frequency data for the study area suggest the need for change the IDF curves used as standards for water management infrastructure design, operation and maintenance in order to take into account potential impact of hourly rainfall intensity.

Current Water Management Design Standards

Currently, Jemo area regional IDF curves as standards for water management infrastructure design, operation and maintenance. Conveyance systems are designed based on a curve provided by ERA, while most other storm water management facilities are designed using criteria provided by Ethiopia road authority design manual (2013). The IDF curve in use today for design of drainage systems has been adopted from Ethiopia road authority.

4.2 Result from EP SWMM5 Model

Different case scenarios have been considered in this study to obtain a fully understanding of the system performance under multiple working conditions. Firstly, the model has been run with the continuous rainfall events with different return periods to analyze the current performance. By running the hydrological model with the intensity data, the runoff generation within the area was obtained.

Numerical simulation is carried out for10 year events, taken as extreme events from each year from 2006-2016 rainfall data. These extreme events are in hourly duration. The catchments have been divided into various sub catchments and are modeled for ten year rainfall event. The view of catchment used for simulation in SWMM is shown in Fig.22. The water profile plot is obtained for conduits from node J1 to J10 is as shown in Fig. 23.

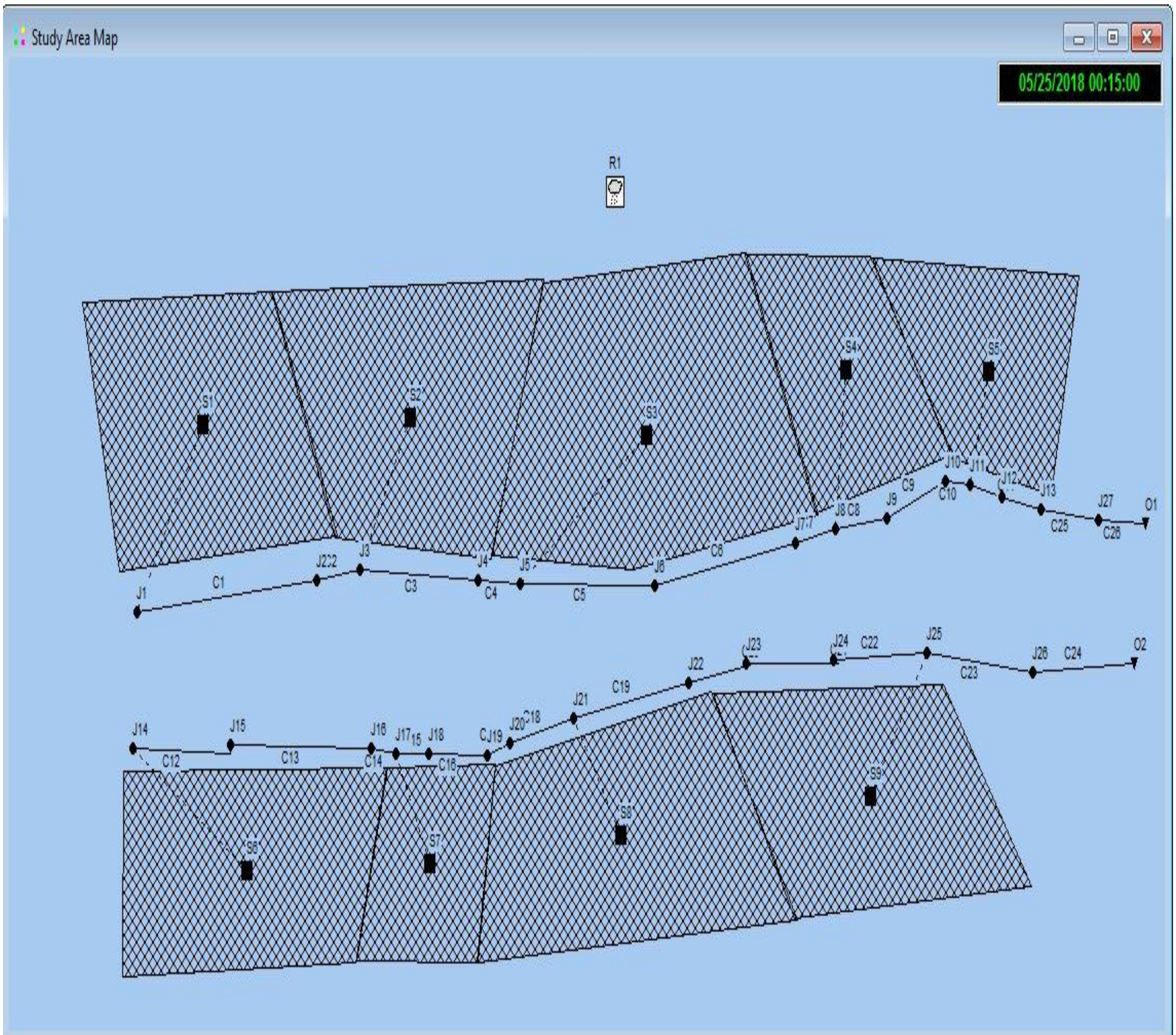


Figure 22: Project Layout

Table 3: peak discharge result for each subcatchment from EPA

Study Area Map

Summary Results

Topic: Subcatchment Runoff Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
S1	80.26	0.00	0.02	0.75	80.17	0.80	0.25	0.999
S2	80.26	0.00	0.02	0.09	80.74	1.21	0.37	1.006
S3	80.26	0.00	0.02	0.13	80.52	1.61	0.45	1.003
S4	80.26	0.00	0.02	0.22	79.65	1.99	0.53	0.992
S5	80.26	0.00	0.02	0.56	65.38	1.96	0.54	0.815
S6	80.26	0.00	0.02	0.36	78.80	2.36	0.58	0.982
S7	80.26	0.00	0.02	0.35	78.70	2.75	0.67	0.981
S8	80.26	0.00	0.02	0.41	78.05	3.51	0.80	0.972
S9	80.26	0.00	0.02	0.44	77.68	3.88	0.87	0.968

The manholes/Junctions are all modeled as circular manholes with different diameter. It has been assumed that there are no energy losses in the manholes. Moreover, the model includes boundary conditions to represent various types of water loads, as infiltration or fixed water levels. The precipitation is introduced into the model by associating each sub-catchment to the rainfall time-series.

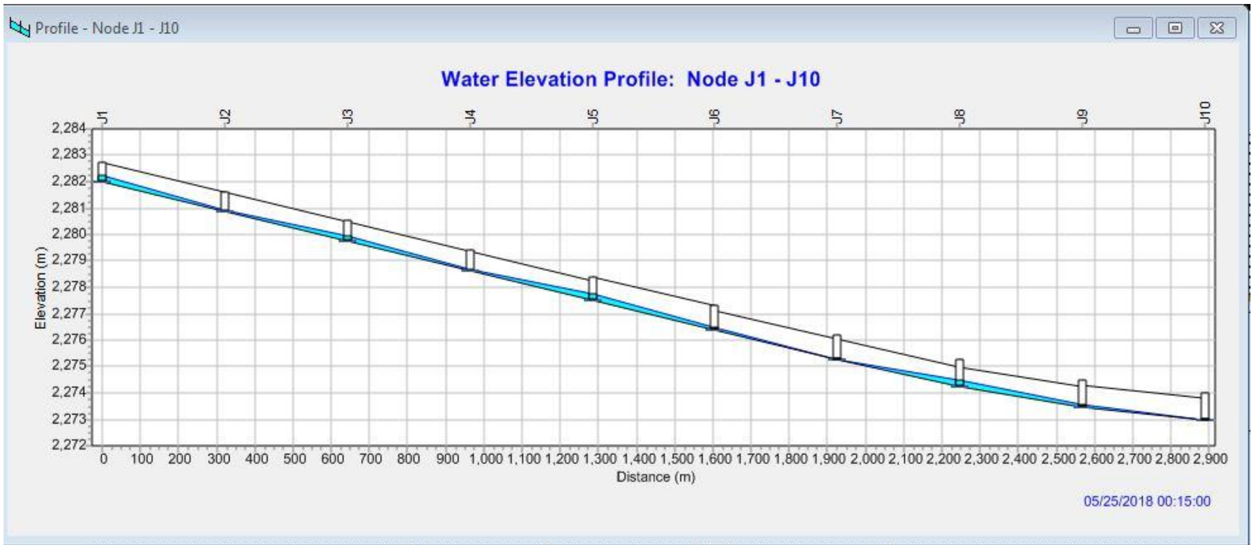


Figure 23 junction profile

Table 4: Node flooding

Summary Results

Topic: Node Flooding — Click a column header to sort the column.

Node	Hours Flooded	Maximum Rate CMS	Day of Maximum Flooding	Hour of Maximum Flooding	Total Flood Volume 10^6 ltr	Maximum Ponded Depth Meters
J6	0.46	0.492	0	00:30	0.468	0.000
J7	0.67	0.212	0	00:26	0.172	0.000
J8	1.08	0.743	0	00:30	1.673	0.000
J9	0.01	0.096	0	00:25	0.003	0.000
J21	1.65	1.612	0	00:40	4.980	0.000

Calculations are presented, the total runoff from whole sub-catchments by SWMM is 5.07 m3/sec. The runoff obtained in the simulation is then used as input data at each node connected to a catchment. From the result, it was observed that the drainage system have nodes flooded and overflow thereby resulting damages to road surface material and flooding in the area. The simulation status report shows that sections between junctions 6, 7, 8, J9 and J21 are surcharged.

The same study was done in India and the total runoff from seven sub catchments by SWMM is 2.177m3/sec, whereas by Rational Method is1.109m3/sec. (M. L. Waikar* and Undegaonkar Namita U, January, 2015) Urban Flood Modeling by using EPA SWMM 5 SRTM University‟s Research Journal of Science April 2015 /Spl. Vol., no 1; (ISSN : 2277 - 8594 Print)

4.2 Storm Water Management System

With the urbanization follows an increase in hard surfaces, where the water is unable to penetrate. This means that stormwater runs on the hardened surfaces without any retardation. The consequences are high peak flows, which arrive quickly after the storm commences, in order to reduce peak flows the idea with SUDS is applied for this study to regenerate the natural system of stormwater handling which is Low impact development (LID) technique used to depress the negative influence of water quantity of the runoff process caused by urbanization to allow regional runoff processes to return to a natural undeveloped state to the largest degree possible by controlling the quantity of storm runoff. Regarding the former, LID measures primarily reduce the flood peak and volume by increasing the infiltration and onsite storage. Only the reduction of surface runoff quantity was involved in this study, and the relevant practice measure includes bio-retention, Green roof, infiltration trench and permeable pavement is applied and Analytical hierarchy process (AHP) is selected because the AHP generates a weight for each evaluation criterion according to the decision maker’s pairwise comparisons of the criteria than other methods. Finally AHP defined the problem, compute the criteria weight and matrix of option scores and rank the option depending on four criteria which are reduction of discharge, cost, Available space and interest of users depend up on discussion. Then after developing a matrix the method with maximum Eigen value which is rain garden (bioretention) method is selected for this study because the maximum Eigen value is gain from raingarden.

Table 5: Analytical hierarchy process value for ranking

Measurement of strength	given intensity	Ratio
Extreme Importance	1	0.111
Very importance	2	0.125

Very strong Importance	3	0.142
Strongly to very strong	4	0.166
Strong Importance	5	0.2
Moderately to Strong	6	0.25
Moderate Importance	7	0.33
Equally to Moderately	8	0.5
Equal Importance	9	1

Table 6: AHP Matrix Form

Attribute	Permeable pavement	Infiltration trench	Green roof	Rain garden
Cost	2	9	3	1
Available Space	2	7	9	5
Volume reduction	8	8	5	7
Community acceptance	1	1	5	8

4.3 Result from RainGarden

The rain garden will received the drainage from 400 m2 of paved surfaces and from about 250000m^2 lawn surrounding the garden site. The calculated garden surface resulted in approximately 3200m^2.According to the method the maximum depth of the garden was set to 20 cm, since a deeper basin would pond water too long.

In our case study the formal shape of the garden was devised to adapt to the overall design style of the area. The selection of the plant species for the garden was firstly based on their water requirements and tolerances to wet and dry conditions, that make possible for the plants to thrive in the different areas of the garden. Because of the location within an urban park and the prevalent aesthetic function of the rain garden borders, the species where however selected among ornamental plants considering the color scheme and the flowering sequence throughout spring and summer. Rain gardens combine their function as bioretention structures with an aesthetic role in the urbanized landscape. In urban and perurban parks where more natural features are present and larger surfaces are available other kind of bioretention measures can be incorporated in the landscape design, sometimes with the purpose of reducing runoff peaks from adjacent residential areas. Such parks can include wetlands with native vegetation and are often designed, following ecological and environmental principles.

In study area, the green areas cover almost 15% of the surface area. Since the green areas mentioned above is not enough to protect the area from flooding so construction of additional bioretention area is applied for better handling stormwater, and become a part of the stormwater management .To increase the potential bioretention area, the small tree, flowers and grasses must be spread along and at the center of the pavement.

To calculate the total potential effects of implementing bioretention areas in the investigated district, the same equations and assumptions as in chapter 3, where bioretention areas are evaluated were used. The dimensioning storm is, like for the example regarding bioretention, set to a 24-hour storm with a recurrence time of 10 years. The potential catchment area acceptable by the bioretention solutions as displayed in appendix part.

A percentage of 4.549% of the drainage area is a less than 10%, the suggested proportion by Brown, Stein, Warner (2001).

Calculations show that the proportions between the potential catchment and the bioretention area do not change with the altering of the size of the latter. This fact makes it easy to decide the appropriate drainage area when designing bioretention areas as a stormwater solution.

A ponding time of 4.16 hours is well below the set limit of 24 hours, which ensures the prevention of breeding possibilities for mosquitoes. The result shows that there is no flooding after implying rain garden. From this simulation the peak discharge is reduced from 5.07m3/sec to 2.56 m^3/sec by using total area of 0.32 ha for design of rain garden from 25ha of the total catchment area. The results of the study show the significance of using LID in improving the urban drainage system. Rain garden was effective in reducing peak runoff and volume and the cost analysis for the work is done on table 8.

Table 7: Result from rain garden

Summary Results

Topic: Subcatchment Runoff   Click a column header to sort the column.

Subcatchment	Total Precip mm	Total Runon mm	Total Evap mm	Total Infil mm	Total Runoff mm	Total Runoff 10^6 ltr	Peak Runoff CMS	Runoff Coeff
S1	80.26	0.00	0.10	1.06	72.19	0.72	0.23	0.899
S2	80.26	0.00	0.10	0.89	72.31	1.08	0.34	0.901
S3	80.26	0.00	0.10	0.97	63.16	1.26	0.38	0.787
S4	80.26	0.00	0.10	1.36	63.28	1.58	0.43	0.788
S5	80.26	0.00	0.10	1.11	40.96	1.23	0.32	0.510
S6	80.26	0.00	0.10	0.87	5.60	0.20	0.05	0.070
S7	80.26	0.00	0.10	0.95	11.66	0.47	0.09	0.145
S8	80.26	0.00	0.10	1.94	20.52	0.92	0.15	0.256
S9	80.26	0.00	0.10	2.38	68.47	3.42	0.76	0.853

Table 8: Cost Estimate for Rain Garden

activity	**unit**	**Unit cost**	**Cost for 0.32ha**
Excavation	Cubic meter	40 Birr	128000
New soil import and installation	Cubic Meter	13.50 Birr	41600
Gravel import and installation	Cubic Meter	13.50 Birr	41600
Filter fabric	Meter Square	13.50 Birr	41600
Mulch	Meter Square	13.50 Birr	41600
Perforated pipe	Meter	54 Birr	172800
Overflow Drop Box	1Box	1350 Birr	1350
Plants	Meter Square	30 Birr	96000
Total			391750 Birr
Cost/area			122Birr/M^2

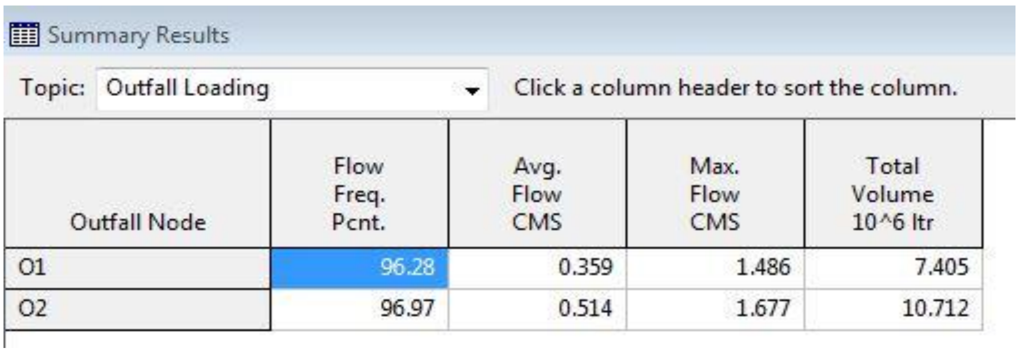
4.4 Result from Storm Drain Outfalls

All storm drains have an outlet where flow from the storm drainage system is discharged. The discharge point can be a natural river or stream, an existing storm drainage system, or a channel which is either existing or proposed for the purpose of conveying the storm water away from the highway. The procedure for calculating the energy grade line through a storm drainage system begins at the outfall. Therefore, consideration of outfall conditions is an important part of storm drain modeling.

Discharge should always be in the direction of flow of the river or stream. Protection of the bed and edges of the watercourse at the point of entry (by means of rock amour, gabions, headwalls etc.) will help to prevent erosion by water discharging from the pipe during heavy storms.

This should be confirmed at the site level through keen observation at the outfall points during flood time and also by investigating the stability of the bank during construction phase. There is an out let structure in study area which is manmade channel the flow from the drainage system is flow to this out let structures and the amount of discharge to the outlet structure is computed using SWMM.

Table 9: Outfall loading


Summary Results

Topic: Outfall Loading   Click a column header to sort the column.

Outfall Node	Flow Freq. Pcnt.	Avg. Flow CMS	Max. Flow CMS	Total Volume 10^6 ltr
O1	96.28	0.359	1.486	7.405
O2	96.97	0.514	1.677	10.712

4.5 Result from Flow Routing

Flow routing within a conduit link in SWMM is governed by the conservation of mass and Momentum equations for gradually varied, unsteady flow (i.e., the Saint Venant flow equations).The SWMM user has a choice on the level of sophistication used to solve these equations but for this research Dynamic Wave Routing is preferable. 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. Even for small catchments, runoff and consequent model predictions (and prototype measurements) may be very sensitive to spatial variations of the rainfall. For instance, thunderstorms (convective rainfall) may be highly localized, and nearby gages may have very dissimilar readings. Study for modeling accuracy (or even more specifically, for a successful calibration of SWMM), it is essential that rain gages be located within and adjacent to the catchment.

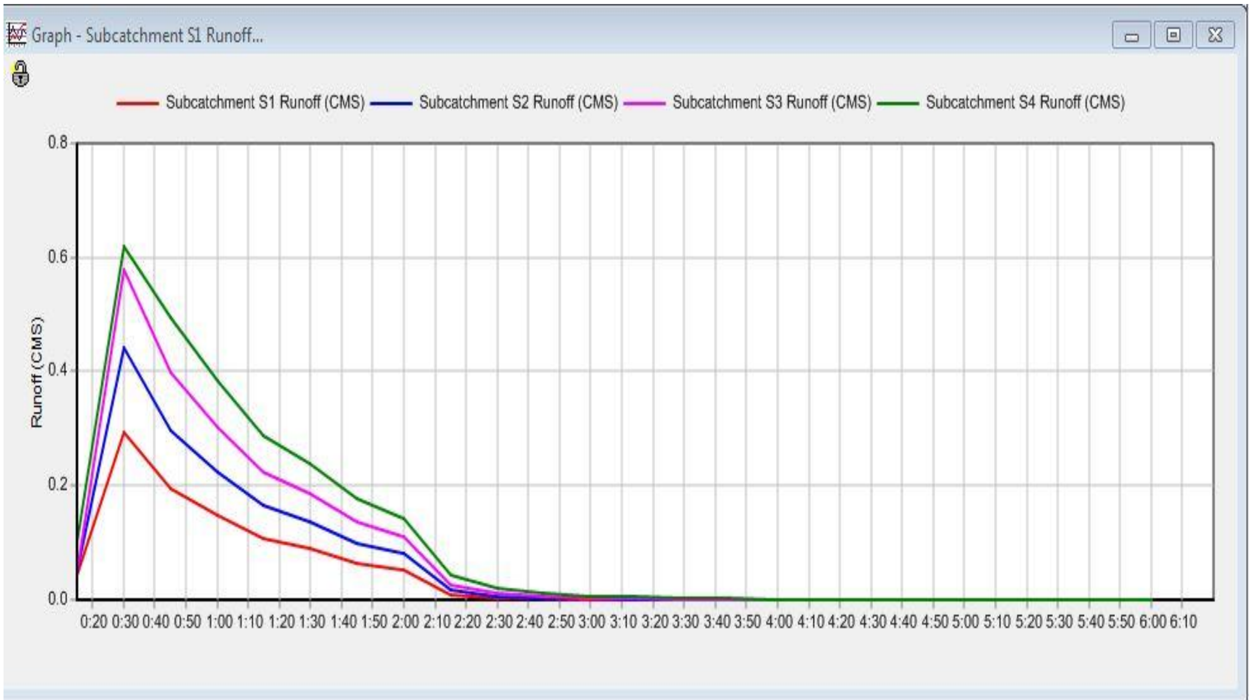


Figure 24: Unit Hydrograph

4.6 Model sensitivity Analysis Result

It is necessary to conduct a detailed sensitivity analysis to evaluate the main parameters of the SWMM which are the most sensitive parameters affecting the rainfall-runoff-routing simulation in the model. Sensitivity analysis can be applied to identify the relative influence of each model input parameter on the model outputs

Table 10 : Sensitive value for peak flow

Name of Parameter	Meaning	Value Range	Initial values	Used values/ Sensitivity for peak flow
N-Impervious	Manning's roughness coefficient for impervious	0.005-0.5	0.020	0.021
N-Pervious	Manning's	0.05-0.50	0.1	0.29

	roughness coefficient for pervious			
Dstore-imp.	Depth of depression storage on impervious area	0-3	0.05	0.01
Dstore-per.	Depth of depression storage on pervious area	2.5-7.6	4	6
Conduit roughness	Manning roughness coefficient for roughness	0.011-0.024	0.02	0.024
Infiltration method	Green Ampt Suction Head	3.5	3.5	3.5
	Green Ampt Conductivity	0.5	0.5	0.5
	Green Ampt Initial Deficit	0.25-0.26	0.25	0.26

Model performance evaluation

Coefficient of Determination (R2)

$$R^2 = (\frac{\sum_{t=1}^{n}(\text{ qtobs} - \text{qtobs. ave})(\text{qtsim} - \text{qtsim. ave})^2}{\sqrt{\sum_{t=1}^{n}(\,(qtobs - qtobs.ave)}\sqrt{\sum_{t=1}^{n}(\,qtsim - qsim.ave)^2}})^2$$

The Nash-Sutcliffe coefficient (RNS)

$$RNS = 1 - \frac{\sum_{t=1}^{n}(\text{ qtobs} - \text{qtsim})^2}{\sum_{t=1}^{n}(\,(\text{qtobs} - \text{qtobs. ave})^2}$$

Relative Error (RE)

$$RE = 1 - \frac{\sum_{t=1}^{n} \left| \text{qtobs} - \text{qtsim} \right|}{\sum_{t=1}^{n} qtobs.}$$

Where qtobs and qtavrobs are the calculated and average flow respectively and qtsim and qtavrsim are the simulated and average flow respectively at time t, t is time, and n is the total number of time steps.

Acceptable level of Model performance

RNS Between 0 and 1 indicates acceptable models

< 0 indicates poor models

= 1 perfect models

= 0 Model is no better than using as an estimator

RE < 30%

R^2 Approach to one and its shown on the graph.

RNS values of 0.9954 were deemed acceptable, and the RE values of the calculated outflow were less than 6% of the simulated outflow, which shows that the simulated curves were a good fit for the simulated curves. The simulated and calculated values for runoff were correlated, and the R2 values of 0.99 were deemed acceptable. The calibration and verification results indicated that the model structure and parameters matched the runoff-producing pattern and that the calibrated model was suitable for simulating storm runoff in the study area.

Table 11: peak flow of EPA and Rational method

Sub catchment	Rational method 10yr runoff(cms)	EPA 10yr runoff (cms)	Difference
S1	0.32	0.33	-0.01
S2	0.463	0.49	-0.027
S3	0.584	0.59	-0.006
S4	0.695	0.69	-0.025
S5	0.796	0.71	-0.054
S6	0.89	0.76	-0.07
S7	0.977	0.88	-0.093
S8	1.059	1.17	-0.111
S9	1.136	1.15	-0.124
Total Q	6.92	6.77	

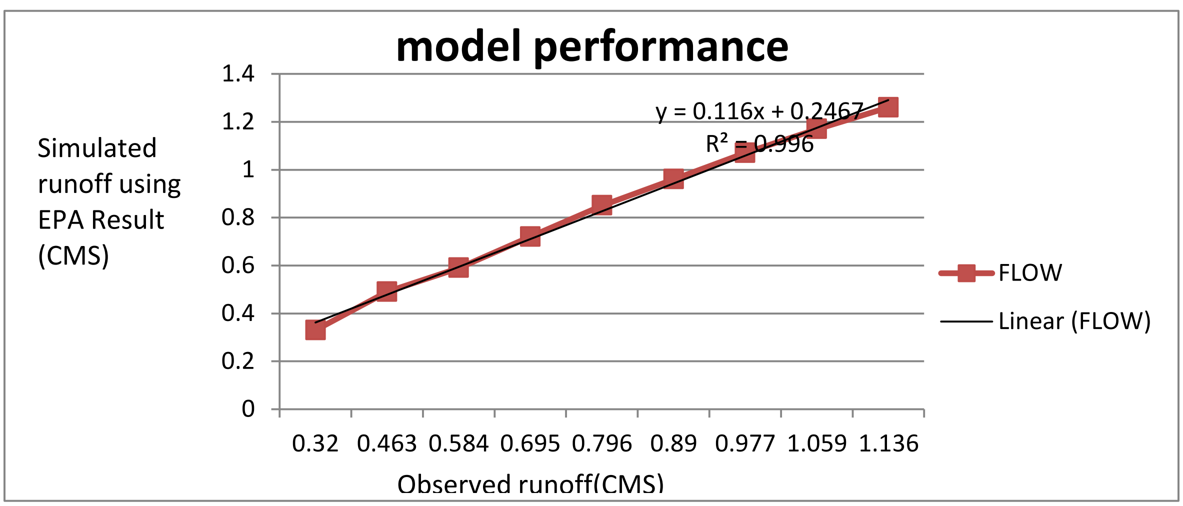


Figure 25: model performance

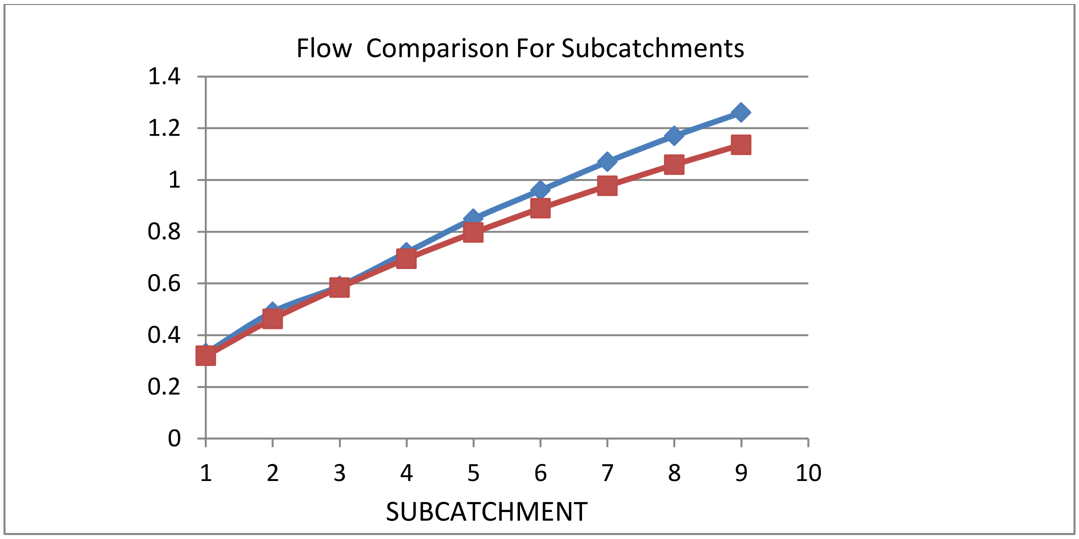


Figure 26: flow from EPA vs. Observed runoff

4.7 Result from Gutter

A roadway with a gutter section should normally be placed at a minimum longitudinal slope of 0.3 percent to 0.5 percent to allow for reasonable drainage. The flatter slopes may be used with wider shoulders and the 0.5 percent should be used as a minimum for narrow shoulders. Superelevation and/or widening transitions can create a gutter profile far different from the centerline profile. The designer must carefully examine the geometric profile of the gutter to eliminate the formation of sumps or birdbaths created by these transitions. These areas should be identified and eliminated. Both the longitudinal and cross (transverse) slope of a street are important in calculating hydraulic capacity. The capacity of the street increases as the longitudinal slope increases. UDFCD prescribes a minimum longitudinal slope of 0.4% for positive drainage (Wright-McLaughlin 1969). Public safety considerations limit the maximum allowable flow capacity of the gutter on steep slopes. The cross slope represents the slope from the street crown to the interface of the street and gutter, measured perpendicular to the direction of traffic.

UDFCD recommends a minimum cross slope of 1% for positive drainage; however, a cross slope of 2% is more typical. Driver comfort and safety considerations limit the maximum cross slope.

Use of standard curb and gutter sections typically produces a composite section with milder cross slopes for drive lanes and steeper cross slopes within the gutter width for increased flow capacity, Contributing drainage area determination to the pavement drainage facility (Curb–gutter section). The pavement width of the approach road contributing to the gutter from observation 15m, and the width side walk 2.5m. The length of the pavement gutter run considered (distance between two consecutive inlets 17m.

Hence, pavement surface area =width * run length =15 X 17m = 0.025ha Likely, side walk (pedestrian road) area =2.5m X 17 = 0.004ha

Time of concentration determination for the water to reach the gutter section from remote point of the contributing area Flow for contributing area usually less than 100m run is sheet flow where TC determined first by determining the flow velocity (based on the land use) & dividing it to the flow distance the flow velocity for paved area and shallow gutter flow with cross slope of 2.5 % (pavement cross slope) is nearly 1m/s, again for Pedestrian road surface with slope of 3%, the flow velocity become 1.1m/s Then, applying equation for Time of Concentration,

Tc=D/ (60*V) =15/ (60*1) =0.25 minutes for pavement surface & 0.04 minute for Side walk reach. But the minimum Tc value used shouldn‟t be less than 7 minutes (FHWA, Urban drainage manual recommendation) Rainfall intensity determination for duration equal to Tc of given return period (10 years in this case) from IDF curve of the region in Figure 12 For Tc equal to 7 minutes from IDF curve, I = 108mm/hr. Appropriate Runoff coefficient determination for the surface. For asphalted surface, from Appendix D C= 0.83 ,for brick c=0.78 . Discharge estimation using rational method =0.83*108*0.025*1/360 =0.0062m3/s (from pavement surface) & 0.0009m3/s (from pedestrian road).

Total discharge to gutter section, (0.0062+0.0009) m3/s =0.0071 m3/s & considering discharge flexibility factor of 1.5 to accommodate discharge which may enter to the gutter section from different direction, the discharge for each gutter become 0.01065 m3/s. The total gutter flow is o.88m^3/sec, efficiency 10% and effectiveness 11.36%.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

LID is a viable cost effective alternative approach to stormwater management and the protection of natural resources. LID is designed to provide tangible economic incentives to a developer to save more natural areas and reduce stormwater and roadway infrastructure costs. LID can achieve greater natural conservation by using conservation as a stormwater BMP. As more natural areas are saved less runoff is generated and stormwater management costs are reduced. This allows multiple uses of landscape features to achieve environmental, economic, and aesthetic benefits. Additionally, developers have economic incentives to provide better environmental protection by reducing short and long term infrastructure costs by reducing impervious areas, eliminate curbs/gutters and stormwater ponds to achieve LID stormwater controls. Reduction of the infrastructure also reduces infrastructure maintenance burdens making LID development more economically sustainable. Since stormwater management is controlled on each lot using multifunctional landscapes, that portion of the building area that would have been used for stormwater ponds can, in some cases, be used for additional flood control and used for building, parking lots, open space or habitat enhancements. LID promotes public awareness, education and participation in environmental protection. As every property owner's landscape functions as part of the watershed, they must be educated on the benefits and the need for maintenance of the landscape and pollution prevention measures. LID developments can be designed in a very environmentally sensitive manner to protect streams, wetlands, forests, and habitat and save energy. The unique environmental protection objectives of a LID development can create a greater sense of community pride based on environmental stewardship. During the development of LID it was learned that current analytical models such as TR-55 or HEC-1 are not well suited for use with very small watersheds. There is a significant amount of work needed to upgrade current models to better quantify the affects of microscale site design control techniques.

The US EPA SWMM 5 model and GIS were applied to an urban catchment in JEMO site Sample calculations are presented, the total runoff from whole catchment by SWMM is 5.77 m3 /sec. whereas by Rational Method is 6.92 m3 /sec. Also peak runoff for sub catchments from both methods is shown in Table14. Results of simulation show that rational method gives relatively excess runoff values as compared to SWMM. However, the SWMM Parameters need Sensitivity analysis for more reliable results. It is felt that the coupling of the GIS and SWMM create a useful and time saver modeling tool that can be used for large watersheds. The application of SWMM achieves catchment responses to peak flow and runoff volume, which are the two most essential catchment responses in urban drainage planning.. Dynamic wave routing and Green AMPT approaches were applied to analyze flow routing and infiltration processes. The results show that there are nodes flooded at J5, J6, J7, J8 and J21 in the entire Drainage system and there are overflow sections. Thus the site storm network system has been not well planned and has no sufficient carrying capacity to cater the simulated rainfall event. Four SWMM parameters were used for Sensitivity analysis: imperviousness, depression storage, pervious and channel Manning coefficient. The parameter sensitivity analysis shows the parameter strength. The urban flood processes were simulated with different return period design precipitation, and the results show that, for the 5, 10, 50 and 100 year return period precipitation; the studied area will be flooded. Analysis of the precipitation characteristics of the study area gives a good idea about the intensity of rainfall, runoff which can be useful in determining the design parameters of the drains. SWMM provides us with the peak runoff and the average runoff and also the return period for all the precipitation events that have taken place during the time period that was entered for analysis. Hence it becomes easier to decide the design runoff and design return period for the precipitation event. A sensitivity analysis was performed that showed that imperviousness and depression storage are the most sensitive parameters affecting total runoff and peak flow.

The timing of the peak flow was affected only by the Manning coefficient and the effect was small. The Sensitivity analysis and verification results indicate that the model structure and parameters fitted the runoff producing pattern. The total simulation accuracy of the runoff and network systems as assessed by statistical methods, were RNS, =0.995, RE=6%, and R2=0.99.

Through numerical simulations, the effectiveness in different LID scenarios was evaluated in three aspects, which was the runoff volume reduction, the peak discharge reduction and the aesthetic, respectively. The bio-retention was selected and assigned as different scenarios. It was concluded among the entire single LID measures, rain garden exhibited a significant reduction and controlling effectiveness in Quantity aspects. The effectiveness of all the LID measures decreased as the rainfall intensity increased. Generally it can be concluded that drainage system of the study area found to be inadequate due to insufficient node profile, insufficient drainage structures provision, improper maintenance and lack of proper interconnection this leads resulting damages to road surfacing material and flooding problems in the area.

5.2 RECOMMENDATION

- Following recommendations are provided on the basis of study results on IF curve:
  - In order to be economical in management of water infrastructure it is recommended to use the modified IDF curve that developed using hourly rainfall intensity.
  - Results of comparison between the updated IDF curves for the modified data set indicate higher difference between the hourly and daily rainfall intensity.
  - Therefore the recommendation is to proceed with possible revisions of the standards using hourly rainfall intensity. Based on this comparison our recommendation to the study area is to evaluate potential change of IDF curves is greater than 10%.
  - We suggest that the design manual that Ethiopia road authority used must be update using hourly rainfall intensity.

- Developing the skill of SWMM software for planning, analysis and modeling of storm water runoff and drainage systems in urban areas and monitoring the infrastructures.
- Pipe diameters should be completely updated according to new ERA hydrology manual.
- The system includes some pipes whose dimensions do not correspond to the drainage system model, so that a review of the system model is recommended to increase the model reliability.
- Since the main line has shown to be severely overloaded, it is recommended to study the feasibility of increasing its capacity either by duplicating the network or replacing the current pipes.
- Use of the research study results for further study of other sub catchment of Addis Ababa city in order to have a standardized and harmonized urban drainage systems.
- Application of a LID System in the whole area connected to main line in order to reduce the runoff to be conveyed by the drainage system, as well as to lower the cost of pipe by means of decreasing diameter. The performance of the grass ditch network should be optimized to collect as much water as possible from more impervious areas.

REFERENCE

Aad, M. P. A., Suidan, M. T., and Shuster, W. D. (2009). “Modeling techniques of best management practices: Rain barrels and rain gardens using EPA SWMM-5.”

J. Hydrol. Eng., 15(6), 434-443.

Addis Ababa City Road Authority, 2003. Drainage Design Manual. 1st ed. Addis Ababa.

ANI SHABRI (2007): A Comparison Of Plotting Formulas For The Pearson Type

III Distribution

Barco, J., Wong, K. M., and Stenstrom, M. K. (2008). “Automatic calibration of the US EPA SWMM model for a large urban catchment.”

Brown, S.A., Stein, S.M. & Warner, J.C. (2009): Urban drainage design manual.Publication

No. FHWA-NHI-10-009. United States Department of Transportation Federal

Highway Administration, 2009.

Butler, D. & Davies, J.W. (2000): Urban drainage. E & FN Spon, London.

CLUVA , Climate change and vulnerability of African cities Research briefs.

Construction Industry Research and Information Association (2012): Sustainable drainage systems: promoting good practice. CIRIA,

United Kingdom, http://www.ciria.com/suds/index.html.

Darshan Mal (2017): Estimation of Storm Runoff Quantity Using Rational Method and SWMM

Durrans S. & Haestad Methods (2003): Storm water conveyance. Designing and modeling.

European Environmental Agency (2001): Sustainable water use in Europe.

Part 3: Extreme hydrological events: floods and droughts. Environmental Issues

Report No 21, Copenhagen.

Environmental Protection Agency (1999): Combined Sewer Overflow Management Fact Sheet: Sewer separation, United States, Washington, D.C.

Environmental Protection Agency, Washington, 2003 Protecting water quality from urban runoff. United States Environmental Agency (EPA).

Ethiopian Roads Authority, Drainage Design Manual,2013.

Giuseppe DEL GIUDICE (2016): Sensitivity Analysis and Calibration of a Rainfall-Runoff Model with the Combined Use of EPA-SWMM and Genetic Algorithm

Google Earth, (https://earth.google.com/)- accessed on 3.5.2014.

Janet Barco, April 2008 Automatic Calibration of the U.S. EPA SWMM Model for a Large Urban Catchment

M. L. Waikar* and Undegaonkar Namita U, January, 2015, Urban Flood Modeling by using EPA SWMM 5 SRTM University’s Research Journal of Science April 2015 /Spl. Vol., no 1; (ISSN : 2277 - 8594 Print

Pettersson, T. (2011): Sustainable Urban Drainage Systems, Department of Civil and Environmental Engineering, Chalmers University of Technology.

SWMM Reference Manual, (http://www.epa.gov/water-research/storm-water-management-modelswmm)- accessed on 2.4.2014.

United Nation Environmental Protection, (2004); environmentally sound technologies in wastewater treatment for the implementation of the UNEP Global Programmed of Action (GPA) "Guidance on municipal wastewater. The Hague: United Nations Environment Programmed Global Programmed of Action (UNEP/GPA), Coordination Office.

World Meteorological Organization, 2008: Urban flood risk management. Document N.11, Flood Management Tool Series.

APPENDICES

Appendix table 1: Daily Rain fall data of ayertena station

Station Ayertena										
Elevation 2325					Latitude 38.696			Longitude 8.983056		
Prec.	Prec.	Prec.	Prec.	Prec.	Prec.	Prec.	Prec.	Prec.	Prec.	Prec.
2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
0	0	0	0	4.2	0	0	0	0	0	0
0	0	0	0	1.1	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	2.1	0	0	0
0	0	0	0	0	0	0	2.4	0	0	0
0	0	0	0	0	0	0	0	0	0	4.8
0	0	0	0	0	0	0	0	0	0	7.3
0	0	0	0	0	0	0	0	0	0	15.8
0	0	0	0	0	0	0	0	0	0	3.1
0	0	0	0	0	0	0	0	0	0	2.6
0	0	0	0	0	0	0	0	0	0	12.9
0	0	0	0	0	0	0	0	0	0	0.4
0	0	0	0	0	0	0	0	0	0	0.8
0	0	0	4.8	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	1.6	0	0	0	0	0	0	0

1.7	0	0	6.1	0	0	0	0	0	0	0
0.1	0	0	1.4	0	0	0	0	0	0	0
0	1.2	0	1.8	0	0	0	0	0	0	0
0	5.3	0	0	0.1	0	0	0	0	0	0
0	0	0	12.4	0	0	0	0	0	0	0
0	0	0	1.8	0	0	0	0	0	0	0
0	9.4	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	15.9
0	6	0	0	0	0	0	0	0	0	6.4
0	0	0	0	0	0	0	0	0	0	0
0	29.4	0	0	0	0	0	0	0	0	0
0	7.2	0	0	0	0	0	0	0	0	0
1.8	0	0	0	0	0	0	0	0	0	0
0.002	14.5	0	0	0	0	0	0	0	0	0
1.8	12.2	0	0	0	0	0	0	0	0	0
0	0	0	0	10.4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0.4	0	0
0	0	0	0	11.3	0	0	0	8.6	0	0
0	0	4.2	0	32.6	0	0	0	5.8	0	0
0	0	1.6	0	18.4	0	0	0	0.6	0	0
0	0	0	0	10.9	0	0	0	0	0	0
0	0	0	0	8.5	0	0	0	0	0	0
0	0	0	0	6.4	0	0	0	0	0	0
0	0	0	0	2.6	0	0	0	0	0	0
0	0	0	0	10.4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1.2	0	0	0	0	0	0
0	0	0	0	0	0	0	0	3.1	0	0
0	0	0	0.1	0.6	2.5	0	0	8.8	0	0
0	0	0	0	1.7	6.5	0	0	0	0	0

0	0	0	0	12.4	1.2	0	0	0	0	0
0	0.1	0	0	1.4	0	0	0	0	0	0
3.1	0	0	0	0	0	0	0	0	0	0
8.9	0	0	0	0	0	0	0	0	0	0
0.2	0	0	0	0	0	0	0	6.2	0	0
3.9	0	0	0	1.5	0	0	0	3.4	0	0
0	0.6	0	0	2.4	0	0	0	0.6	0	0
23.1	0.8	0	0	1.2	14.2	0	0	0	0	0
0	0	0	0	1.4	19.4	0	0	0	0	0
0	0	0	0	5.9	0.9	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	59.4	0	0	0	0	0	0
0	0	0	0	5.6	0	0	0	0	0	0.4
0	0	0	0	2.4	0	0	0	0	0	4.3
0	0	0	0	0	0	0	0	0	0	6.4
0	0	0	0	0	0	0	0	0	0	0.6
0	0	0	0	1.1	0	0	0	0	0	6.1
0	0	0	0	0	0	0	0	0	0	5.4
0	0	0	0	0	0	0	0	0	0	2.8
0.1	0	0	0	0	0	0	0	0	0	13.6
0	0	0	0	0	0	0	0	0	0	3.2
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	4.8	0	0
0	0	0	0	0	0	0	0	7.4	0	0
0	0	0	0	0	0	0	1.1	0.2	0	0
0	0	0	0	0	0	0	0	0	0	0
0	2.4	0	0	0	0	0	19.6	0	0	0
0	3.6	0	0	0	0	0	0.8	0	0	0
0	12.4	0	0	0	0	0	1.8	0	0	0
0	32.4	0	0	0	0	0	2.8	0	0	0
11.3	29.9	0	0	1.2	0	0	10.6	0	2.2	0

0	0	0	0	3.6	0	0	18.6	0	4.4	0
0	0	0	0	6.8	0	0	0	6.5	8.2	1.2
0.2	0	0	0	0	0	0	5.2	14.6	0.5	0.8
0	8.6	0	0	0	0	0	0	1.4	4.2	0
0	0.6	0	0	0	0	0	2.4	0.6	2.4	0.1
0	0	0	3.6	10.4	0	0	0	3.6	6.2	3.2
0	2.9	0	12.4	7.9	0	0	0	11.4	1.2	2.4
0	1.8	0	0.6	9.6	0	0	0	1.1	0	0
0	0.4	0	10.3	22.6	0	0.4	0	0.8	0	0
0	0	0	0	18.4	0	9.5	0	9.5	0	0
1.4	0	1.5	0	1.6	0	10.4	0	7.3	0	0
9.3	0	3.1	6.4	0	0	12.4	0	1.8	0	4.2
38.6	0	0	1.9	1.2	38.1	0	0	3.4	0	2.7
0	0	0	3.6	0	0	2.4	2.4	0.1	0	16.5
0	0	0	1.2	0	0	4.7	5.2	5.6	0	0
0	0	0	2.9	0	0	5.2	1.6	16.8	0	0
3.2	0.5	0	0	0.8	4.1	1.5	11.8	0	0	0
5.6	23.4	6.4	0	0	1.4	0	0.1	0	0	6.4
11.1	7.2	8.2	0	0	5.2	0.9	2.4	0	0.8	0
2.6	0.7	10.2	26.7	0	6.7	0	1.1	0	6	0
0	16.7	1.2	5.1	3.2	0	6.2	0.4	0	0	4.2
1.1	1.1	2.4	0	13.4	0	3.1	3.2	0	0	16.5
2.6	7.1	0	0	16.9	3.7	3.2	0	0	0.6	11.6
0	25.6	0	0	20.1	0	1.4	6.2	0	2.1	36.7
0	0	0	2.9	1.4	0	0	0	0	0	13.4
0	20.4	0	0	0.5	21.4	4.2	5.4	0	0	8.3
0	1.4	0	0	0	16.5	4.6	21.4	0	0	2.2
0	0	0	0	3.8	12.3	1.7	5.4	0	0	0
0	1.8	0	0	0.7	6.8	5.6	0	0	0	4.2
0	2.6	0	0	6.5	1.1	2.2	0	0	0	1.2
2.4	0	0	0	7.8	0	0	16.4	0	0	5.6

11.3	0	0	0	0.9	0	0	9.6	0	0	0
0	0	0	0	1.4	0	0	0	0	0	0
0	0	0	0	4.3	0	0	2.8	0	0	7.6
0	0	0	0	2.4	0	1.8	0	0	0	4.4
2.6	0	0	0	0.4	0	3.2	1.8	0	0	1.4
5.4	0	1.2	0	6.5	0	2.4	0.6	0	0	13.2
8.8	0.1	0.6	0	4.1	0	9.5	0	0	0	14.6
6.1	0	0	0	10.1	0	8.4	0	1	0	0
4.7	0	1.7	0	0	0	7.5	0	0	0	6.8
8.6	0	2.4	0	7.6	0	0	19.9	0.8	0	10.4
1.9	0	6	0	4.2	0	0	4.4	13.2	0	15.3
3.2	0	0	14.5	5.4	0	0	0	2.4	0	27.9
1.2	0	0	1.9	3.6	1.6	0	2.5	6.4	1.6	1.2
2.6	0	0	0	3.2	4.9	0	8.5	0	12.8	0
4.4	6.2	4.2	1.1	2.6	9.4	0	11.6	0	5.6	21.1
0.6	3.2	19.4	0	0.4	3.6	0	13.2	22.4	0	43.5
60.1	0.4	8.2	8.7	0	5.1	0.4	4.2	0	0	17.3
0	0	11.6	0	0.1	11.4	0	0	25.1	15.1	0
0	0	18.2	0	4.4	1.2	0	0	6.9	8.9	0
0	0	2.4	0	3.6	0	1.2	0	4.1	6.5	4.4
0	0	8.2	0	4.1	11.8	0	0	0.8	1	1.2
0	0	2.8	0	2.6	9.4	4.2	1.8	2.5	0	8.6
0	4.6	0.6	0	6.6	6.9	0	0	0	0	5.4
0	0	0	0	12.4	2.4	0	0	0	0	0
0	14.2	0	2.2	4.4	0.9	0.5	0	0	0	0
0	11.1	0	5.4	3.5	6.8	3.6	0	0	0	0
0	0	0	0.6	2.9	4.2	0.8	0	6.2	0	1
0	0	0	2.1	0	0.1	0	0	0	0	10.3
0	0	5.9	0	0	0	0	0	0	0	12.2
0	0	0	0	9.4	0	0	2.1	8.4	0	0
0	0	0	0	0.1	1.4	0	0	4.8	6.7	0

0	0	0	0	0	5.4	0	0	11.4	0	0
0	0	0	0	24.5	0	0	5.1	7.4	4.4	0
4.3	0	0	0	1.1	3.7	0	14.6	2.2	7.2	0
1.2	0	0	0	0	2.4	0	1.4	0	11.4	1.8
0	20.1	0	0.1	4.1	6.6	0	1.8	0.6	16.1	1.2
0.6	30.8	0	0	0	34.9	0	0	15.6	0.9	0.4
3.2	3.2	0	0	0	1.2	0	0	1.8	26.8	0
2.4	6.7	0	0	0	2.1	0	0	0	1.6	0
6	2.6	2.6	0	0.1	4.2	0	0	0	0	0
0.6	0	6.4	0	0	0	0	4.5	0	0	0
5.4	0	6.7	0	2.5	0	0	0	0	0	0
8.6	10.1	5.9	0	0	1.1	0	9.8	0	0	0
4.5	0	11.4	1.7	0.4	0.1	1.8	0	0	0	0.6
15.9	0	4.2	0	6.2	0.6	0	0	0	0	1.8
4.2	3	8.4	0	0	0	7.2	2.4	0	1.4	10.1
1.5	12	7.2	0	0	0.2	1.6	0	0	16.8	0
0.6	0	9.6	0	0	9.6	0.4	0	0.6	0	0.1
3.1	0	6.4	0	15.1	2.6	0	1.4	3.2	0	1.9
0	0	0.6	0	2.2	5.1	0	0	1.4	1.4	0
9.1	2.3	4.2	0	9.1	8.9	0.8	5.2	0	3.6	0
19	0	0	0	5.8	4.6	9.6	0.9	0	6.1	0.6
0.4	9.5	5.1	0	20.4	3.6	1.4	8.6	0	0.4	2.4
4.2	10.4	4.3	6.4	0.1	7.2	0	0.4	0	1.2	10.5
0	0	1.2	4.9	3.6	6.2	0	1.8	0	5.2	2.1
0	0	0	11.5	11.8	1.6	0	1.1	0	0	0.6
3.6	5.3	2.6	0	4.3	0	0	19.8	0	0	5.2
0.1	8.2	4.5	5.2	2.7	0	1.2	22.5	0	2.2	16.5
8.1	6.5	10.4	0	15.6	1.4	1.4	0.2	3.6	11.6	7.3
8.4	5.5	8.3	0	6.3	1.2	10.8	4.7	1.6	1.8	23.4
9.4	6.1	2.4	0	10.1	3.3	11.4	1.2	5.4	3.2	26.8
9.8	9.8	0	0	6.5	0.2	3.6	5.4	1.6	1.1	4.5

2.4	8.9	0	3.7	2.4	4.5	0	11.2	26.5	0.6	11.8
3.3	6.3	4.6	1.4	0	0	8.9	0.8	11.9	0.8	7.9
0	10.5	5.2	8.1	16.4	10.2	0	0	3.4	2.6	0.6
4.2	16.6	0	8.4	6.9	11.8	4.1	1.6	6.6	10.4	5.8
5.6	11.2	0	10.5	11.6	9.6	4.5	10.4	2.2	6.5	1.2
6.3	12.1	2.2	13.2	6.7	2.4	6	0	7.6	7.2	0.8
15.2	5.9	0	11.2	21.4	12.1	0	5.4	0	6.5	1.9
2.4	0	0	8.2	9.2	0	14.2	1	0	21.4	9.6
6.6	10.6	0	3.866	2.6	18.4	6.6	21.2	9.8	12.3	10.5
19.8	13.4	0	0.2	5.9	0	12.7	15.8	4.2	4.6	8.2
6.1	14.6	0	1.666	21.4	2.5	10.3	14.2	0	16.8	11.8
16.2	21.4	1.3	0.4666	12.5	8.7	5.9	6.6	3.8	1.2	3.4
8.4	5.4	7.6	10.86	0	0	29.4	2.6	10.4	2.6	6.6
1.7	26.9	5.3	12.8	18.4	9.7	22.4	12.7	18.4	4.5	3.4
3.2	28.4	6.2	8.5	5.8	1.4	7.6	5.2	10.5	6.4	11.6
5.3	14.1	4.3	6.666	0.6	12.6	11.7	29.4	4.4	2.2	5.4
3.6	2.6	10.2	5.4	7.1	14.6	5.5	4.5	35.2	16.6	4.2
6.4	0	0	5.066	16.3	23.4	3.8	8.2	30.6	1.8	16.8
27.3	0	0	3.5	20.4	0	5.9	0	0	9.2	10.4
21.7	0	13.3	3.4	10.6	16.4	18.9	1.2	3.3	3.2	16.2
20.1	4.5	10	8.733	26.4	3.2	21.2	0	19.4	14.4	27.4
0	6.4	0	14.93	9.2	9.4	14.5	0	6.5	2.6	5.2
0	1.4	0	13.93	15.1	1.6	7.2	4	7.6	1.4	8.6
4.2	6.8	12.5	4.466	16.6	6.2	16.4	12.8	11.4	2.1	7.8
8.4	20.2	0	11.1	0	7.8	11.5	8.2	12.2	15.4	11.2
10.4	16.5	0	8.633	5.9	5.9	5.4	9.6	1	6.6	6.8
4.6	9.5	1.4	2.4	14.9	11.7	8.9	14.8	21.2	0.8	9.7
9.6	0	4.1	18.6	11.6	9.2	15.2	24.6	0.8	21.2	21.2
20.2	0	5.8	7.8	36.4	0	31.6	12.9	5.6	5.7	14.6
9.2	0	4.6	21.433	14.7	0.4	6.1	28.2	0	2.5	2.4
1.7	11.9	3.4	12.766	2.6	2.9	15.6	4.2	4.2	22.2	0.8

1.6	5.6	1.2	18.4	11.1	5.5	5.4	12.1	0	6.9	11.4
31.7	4.5	8.2	8.1333	12.5	19.1	8.8	0	6.5	1.3	5.8
31.4	15.4	9.4	17.966	15.9	15.8	29.6	8.4	7.6	0	10.4
30.4	11.2	12.5	3.8333	9.6	7.3	1.2	12.1	5.9	2.1	6.6
20.2	21.6	11.4	15.166	16.9	17.6	11.4	0	12.6	1.6	8.9
18.6	15.3	7.1	5.5333	6.2	16.4	6.4	18.4	2.5	21.4	20.8
12.4	26.4	8.5	6.7333	1	2.1	7.2	3.2	0	11.8	22.3
19.5	11.2	14.2	11.5	0	11.1	9.6	9.6	1.4	9.6	0.4
1.4	5.1	1.4	12.5	0	0.8	14.6	16.8	9.6	1.2	1.8
14.4	16.8	3.6	22.9	5.4	16.8	2.2	1.6	7.8	1.6	4.4
11.6	9.6	6.4	7.2333	0.1	4.3	29.8	8.4	0	1.9	3.8
13.8	14.4	8.4	10.2	0.8	1.2	0.6	11.4	2.5	2.8	1.1
6.4	25.6	9.6	10.3	10.6	15.4	1.2	21.8	1.2	0	6.4
12.9	11.4	4.2	20.566	6.9	8.9	0.9	19.6	19.8	5.8	15.6
8.9	1.9	7.6	8.1	2.2	13.6	4.4	3.6	14.4	3.2	10.8
3.2	3.6	13.2	0.4	8.9	11.2	3.6	15.8	8.9	21.6	39.6
2.4	6.2	11.6	12.6	3.4	5.1	16.4	14.9	32.9	16.8	24.2
10.8	4.5	19.4	3.3666	0	0.6	33.8	6.6	2.8	13.4	2.4
6.4	15.4	10.8	3.1	28.6	11.3	4.9	11.7	12.6	0	14.2
12.9	14.6	2.2	7.2	3.5	9.2	0.8	5.4	10.4	14.2	13.2
8.9	10.9	0	7.6	5.4	18.1	2.7	12.3	16.1	10.5	7.8
10.3	22.4	3.6	15.333	6.1	12.6	1.5	18.9	0	18.1	0
3.4	4.2	21.4	7	2.9	10.6	4.1	9.7	18.8	0.6	22.8
4.6	1.1	4.5	5.4666	8.5	1.1	13.4	4.6	5.4	35.6	16.9
4.3	5.4	4.9	20.7	0	5.4	26.8	13.1	0.8	23.2	0.1
5.8	9.2	9.2	17.9	10.1	9.2	7.9	21.5	33.2	20.2	4.5
2.3	6.3	21.4	12.133	9.4	6.3	1.4	4.6	2.4	25.2	20.6
2.9	4.2	10.8	9.3333	1.6	4.2	10.2	1.1	6.2	41.9	11.4
8.1	2.6	18.6	5.2	12.2	2.6	2.2	11.5	1.4	5.5	2.2
10.4	29.8	4.4	4.6666	1.6	29.8	11.6	42.6	18.5	16.2	5.7
1.6	6.4	2.6	21.1	3.2	6.4	14.4	8.8	1.6	14.4	10.8

6.3	0.5	5.8	12.366	0	0.5	29.6	19.4	11.1	5.6	29.1
31.4	16.8	1.5	16.2	4.4	16.8	1.4	5.4	26.3	0	3.5
2.5	6.6	9.4	8.9333	2.4	6.6	19.2	4.3	4.4	0	11.2
3.2	12.6	6.8	7.0333	5.9	12.6	0.6	7.7	2.2	12.2	38.6
6.4	5.4	4.1	10.033	30.6	9.7	3.8	6.8	0	4.5	2.5
0.6	29.4	6.3	8.6666	0	11.9	1.3	28.9	4.6	2.1	10.9
5.2	28.6	3.7	13.633	10.9	2.8	21.6	22.6	11.2	32.2	0
0.4	4.2	8.8	4.9666	11.1	29.3	0.4	39.2	12.6	14.6	1.4
8	8.6	21.5	1.6666	15.4	34.2	11.6	0.4	1.6	33.6	16.8
17.1	6.5	14.4	13.7	0	26.6	14.4	22.6	0.8	3.8	0
37.5	1.2	16.8	13.533	4.4	4.4	43.4	18.4	0	12.2	0
6.3	0	5.9	3	0	0.9	0.9	16.5	16.4	6.5	0
	18.6	7.4	10.066	5.2	21.2	20	26.6	28.5	10.7	0
14.9	0.4	4.1	11	0.8	15.9	5.6	8.4	1.4	1.2	0
28.6	7.4	5.6	1.5666	6.4	6.5	10	2.1	0.6	44.6	0
3.2	0	19.3	12.033	7.2	11.2	0	5.5	11.4	14.7	0
21.5	11.7	15.4	11.266	3.9	0.6	1.5	14.4	5.2	51.2	0
4.4	3.4	6.2	0	0	2.7	0.6	2.6	4.5	2.6	0
0.1	8.2	4.5	0	0	9.9	3.6	0	39.6	1.2	0
0	5.9	10.6	0	5.8	10.2	26.8	14.6	21.4	3.4	0
5.6	6.9	25.9	0	1.4	0.8	32.2	5.1	9.4	10.8	0
19.9	9.6	12.5	0	10.9	4.6	0.9	0	15.1	13.4	0
9.6	14.8	10.4	0.8666	15.6	8.7	21.8	3.3	10.6	0	0
4.1	19.2	4.3	6.2666	9.7	0	6.6	21.4	1.5	0	0
18.9	1.4	16.3	0	0	0	11.2	2.4	0	4.8	0
2.4	0	0	0	0	6.4	0	0	6.8	11.4	0
11.6	0	2.8	0	0	1.1	26.4	3.6	12.6	0	0
13.4	0.6	6.6	0	1.3	7.4	6.7	0	21.4	0	0
18.6	1.2	18.2	0	0	0	8.4	0	5.6	21.4	0
3.2	2.9	34.7	0	0	2.8	10.2	5.6	1.4	6.5	0
8	11.4	4.4	0	0	11.5	0	1.1	11.6	1.2	0

0.1	1.6	0	0.2666	0	1.3	6.6	18.6	1.4	0.4	0
0	0.8	9.6	4.8	5.6	0	3.8	10.4	21.4	0	1.1
17.1	2.1	14.4	0	0	0	0	0	4.5	0	2.4
11.6	3.2	16.4	0	3.4	27.2	0	0	3.8	0	1
46.5	1.4	4.1	0	0	26.5	0	0	0	2.2	2.1
2.4	2.6	7.5	0	0	26.3	0	0	0	0.8	0
0	0	0	0	0	26.7	0	14.4	0	0	0
0	0.1	0	0	0.1	26.1	16.9	14.8	16.9	0	0
0	11.4	0	0	0	25.6	0	0.4	2.4	0	0
0	6.7	0	0	0	25.2	0	0	0	0	1.9
0	3.3	0	0	0	25.7	0	21.4	4.9	0	0
0	0	0	0	0	24.6	0	9.2	7.6	0	0
0	0	0	0	0	24.6	0	1.6	1.8	0	0
0	0	0	0.3	0	24.4	0	2.8	0	0	0
0	0	0	3.5666	0	23.8	0	1.2	0.1	0	0
0	0	0	13.633	0	23.6	0	3.1	3.6	0	0
0.4	0	0	14.5	0	24.5	0	0.6	0.8	0	0
0	0	0	8.3333	0	24.5	0	0	0	0	0
0	0	0	0	0	25	0	0	0	0	0
0	0	0	0	0	25.4	0	4.2	0	0	0
0	1.4	0	0	0	26.2	0	0	0	0	0
0	0	0	0	0	26.6	0	0	0	0	0
0.1	0	0	0	0	26.2	0	0	0	0	0
0	1.3	0	0	0	26	0	0	0	0	0
0	0	0	0	0	25.5	0	0	0	0	0
6.4	0	0	0	0	25.2	0	0	0	0	0
2.4	2.5	0	0	0	24.5	0	0	0	0	0
0	0	0	0	0	25.5	0	0	0	0	0
0.6	0	0	0	0	25.4	0	0	0	0	0
0	0	0	0	0	26	0	0	0	0	0
0.1	0	0	0	0	25.8	0	0	0	0	0

0	0	0	0	0	25.6	0	0	0	0	0
0	0	21.2	0	0	0	0	0	0	0	0
0	0	24.4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0.2	0	0	0	0
4.2	0	4.2	0	0	0	2.7	0	0	0	0
6.6	0	18.1	0	0	0	0	0	0	0	0
15.2	0	0.4	0	0	0	0	0	0	0	0
0	0	0.3	0	0	0	0	0	0	0	0
0	0	5.2	0	0	0	0	0	0	0	0
34.6	0	17.1	0	0	0	0	0	0	0	0
0	0.1	18.2	0	0	0	0	1.8	0	0.6	0.6
0	1.2	6.3	0	0	0	0	0.1	0	3.6	3.6
0	0	4.5	0	0	0	0	0	0	1.8	1.8
0	0	9.4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0.8	0.8
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0.8	0	0	0
0	0	0	0	0	0	0	22.4	0	0	0
0	0	0	0	4.6	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.1	0	0	0	0	0	0	4.6	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0.6	0	0	0	0	0	0
0	0	0	0	4.5	0	0	0	0	0	0

0	0	0	0	2.4	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	2.4333	9.6	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	1.03333	0	0	0	0	0	0	0
0	0	0	0.3333	0	0	0.1	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
1.1	0	0	0	0	0	0	0	0	0	0
0.6	0	0	0	0	0	0	0	0	0	0
2.8	0	0	0	0	0	0	0	0	0	0
1.2	0	0	0	0	0	0	0	0	0	0
0.9	0	0	0	0	0	6.8	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0.6	0	0	4.2666	0	0	0	0	0	0	0
0	0	0	30.666	0	0	0	0	0	0	0
0	0	0	6.4333	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	4.8	0	0	4.8	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0
0	0	1.6	0	0	1.6	0	0	0	0	0
0	0	6.1	0	0	6.1	0	0	0	0	0
0	0	1.4	0.9	0	1.4	0	0	0	0	0
0	0	1.8	5.4666	0	1.8	0	0	0	0	0
0	0	0	1.6666	0	0	0	0	0	0	0
0	0	12.4	0	0	12.4	0	0	0	0	0

0	0	1.8	2.0333	0	1.8	0	0	0	0	0
0	0	0	0.4	0	0	0	0	0	0	0
0	0	0	0.1	2.2	0	0	0	0	0	0
0	0	0	0.1	9.6	0	0	0	0	0	0
0	0	0	0.2	0.5	0	0	0	0	0	0
0	0	0	1.3333	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0

Appendix table 2: maximum daily rainfall

24hr Maximum Daily rainfall Data										
2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
46.5	30.8	34.7	22.9	36.4	34.9	43.4	42.6	39.6	44.6	43.5

Appendix table 3:skew coefficient for different return

K_T values for Pearson Type III distribution (positive skew)

Skew coefficient C_s or C_w	Return period in years						
	2	5	10	25	50	100	200
	Exceedence probability						
	0.50	0.20	0.10	0.04	0.02	0.01	0.005
3.0	−0.396	0.420	1.180	2.278	3.152	4.051	4.970
2.9	−0.390	0.440	1.195	2.277	3.134	4.013	4.909
2.8	−0.384	0.460	1.210	2.275	3.114	3.973	4.847
2.7	−0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	−0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	−0.360	0.518	1.250	2.262	3.048	3.845	4.652
2.4	−0.351	0.537	1.262	2.256	3.023	3.800	4.584
2.3	−0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	−0.330	0.574	1.284	2.240	2.970	3.705	4.444
2.1	−0.319	0.592	1.294	2.230	2.942	3.656	4.372
2.0	−0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	−0.294	0.627	1.310	2.207	2.881	3.553	4.223
1.8	−0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	−0.268	0.660	1.324	2.179	2.815	3.444	4.069
1.6	−0.254	0.675	1.329	2.163	2.780	3.388	3.990
1.5	−0.240	0.690	1.333	2.146	2.743	3.330	3.910
1.4	−0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	−0.210	0.719	1.339	2.108	2.666	3.211	3.745
1.2	−0.195	0.732	1.340	2.087	2.626	3.149	3.661
1.1	−0.180	0.745	1.341	2.066	2.585	3.087	3.575
1.0	−0.164	0.758	1.340	2.043	2.542	3.022	3.489
0.9	−0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	−0.132	0.780	1.336	1.993	2.453	2.891	3.312
0.7	−0.116	0.790	1.333	1.967	2.407	2.824	3.223
0.6	−0.099	0.800	1.328	1.939	2.359	2.755	3.132
0.5	−0.083	0.808	1.323	1.910	2.311	2.686	3.041
0.4	−0.066	0.816	1.317	1.880	2.261	2.615	2.949
0.3	−0.050	0.824	1.309	1.849	2.211	2.544	2.856
0.2	−0.033	0.830	1.301	1.818	2.159	2.472	2.763
0.1	−0.017	0.836	1.292	1.785	2.107	2.400	2.670
0.0	0	0.842	1.282	1.751	2.054	2.326	2.576

(Source: Vent Chow)

Appendix table 4: design storm for different return

24 hr Rainfall Depth (mm) vs Frequency (yr)								
Return Period Years	**2**	**5**	**10**	**25**	**50**	**100**	**200**	**500**
RR-A1	50.30	66.02	76.28	89.13	98.63	108.06	117.48	130.00
RR-A2	51.92	65.52	74.45	85.70	94.07	102.45	110.91	122.27
RR-A3	47.54	59.61	67.66	77.92	85.62	93.34	101.13	111.58
RR-A4	50.39	63.83	72.28	82.55	89.97	97.20	104.32	113.63
RR-B1	58.87	71.26	79.29	89.35	96.84	104.37	112.02	122.41
RR-B2	55.26	69.95	79.68	92.03	101.29	110.61	120.07	132.87
RR-C	56.52	71.04	80.54	92.52	101.48	110.50	119.66	132.06
RR-D	56.23	76.84	90.37	107.46	120.23	133.05	146.00	163.44

Source: Ethiopian Roads Authority, 2013.Drainage Design Manual.

Appendix table 5:Intensty for a given return period for JEMO

Duration (min)	Duration (hr)	Rainfall Ratio	Depth for a given return period				Intensity for a given return period			
			2yr	5yr	10yr	25yr	2yr	5yr	10yr	25yr
5	0.083	0.145	10.77	9.441	8.412	6.901	82.8193	100.951	113.302	129.357
10	0.1666	0.243	18.06	15.81	14.09	11.56	69.3816	84.5717	94.9188	108.369
20	0.3333	0.370	27.44	24.03	21.41	17.56	52.7086	64.2483	72.1090	82.3271
30	0.5	0.449	33.35	29.21	26.03	21.35	42.7139	52.0655	58.4356	66.7161
45	0.75	0.528	39.17	34.31	30.57	25.08	33.4410	40.7625	45.7497	52.2326
60	1	0.581	43.09	37.74	33.63	27.59	27.5931	33.6342	37.7493	43.0985
75	1.25	0.620	45.98	40.27	35.88	29.44	23.5533	28.7099	32.2225	36.7886
90	1.5	0.650	48.23	42.24	37.64	30.88	20.5875	25.0949	28.1652	32.1563
120	2	0.695	51.58	45.17	40.25	33.02	16.5118	20.1268	22.5893	25.7903

150	2.5	0.728	54.01	47.31	42.15	34.58	13.8327	16.8612	18.9241	21.6057
180	3	0.753	55.907	48.968	43.630	35.793	11.93131	14.54349	16.32286	18.63586

Appendix table 6: model functionality comparison

Topic	Item	Model		
		SWMM 5.0	MOUSE / MIKE URBAN	INFOWORKS CS
Hydraulics	Flow Routing	Dynamic Wave	Dynamic Wave	Dynamic Wave
	Routing Engine	Explicit numerical engine can have stability issues if the model not constructed and reviewed carefully.	Implicit numerical engine, a stable and fast hydraulic engine. Though it is considered to be a slightly slower engine than InfoWorks.	Implicit numerical engine. Generally considered the fastest and most stable fully dynamic engine.
	Inlet Control	No	No	Yes
	Detention Storage	Yes	Yes	Yes
	RTC	Yes	Yes	Yes
	Pumps	Yes	Yes	Yes
	Irregular XS	Yes	Yes	Yes
Hydrology	Surface Runoff	Utilizes a non-linear reservoir model to simulate runoff.	Provides a number of surface runoff models, such as a time area method and a Kinematic wave model(Non Linear Reservoir Model). This model behaves exactly the same as the SWMM non-linear reservoir model.	Provides a number of surface runoff models, including the SWMM non-linear reservoir model.
	Infiltration	Provides three infiltration options, Curve Number, Horton's Equation and Green Ampt.	In addition to the RDII model (see below) MOUSE utilizes the Horton's Equation or SCS Curve Number to simulate infiltration.	Fixed PR Model (simple percentage) Green Ampt Model Horton Infiltration Model New UK PR Model Wallingford Procedure Model Constant Infiltration Model US SCS Model
	RDII	Provides either unit hydrographs to simulate RDII or a groundwater infiltration module to simulate the influence of groundwater table on infiltration flow.	MOUSE employs a complex RDII model.	Provides either unit hydrographs to simulate RDII or a groundwater infiltration module to simulate the influence of groundwater table on infiltration flow. As per SWMM.
	Continuous Simulation	Yes	Yes	Yes
Water Quality	Pollutant Build Up / Washoff	Yes	Yes	Yes
	Pollutants Modeled	Yes	Yes	Yes
	Treatment	Yes	Yes	Yes
Miscellaneous	LTS - Job List	No	Yes - MOUSE provides a job list file which allows a selected number of events to be run by the HD model.	No
	Statistics	Yes	Yes	Yes
Use Ability	User Interface	Basic user interface.	Good user interface.	Sophisticated user interface.
	Data Management	None	Reasonable data management with the scenario manager.	Excellent data management.
	Result Display	Reasonable	Good	Excellent
	Support	No formal support. A SWMM Users List server, allows subscribers to ask questions and exchange information.	Comprehensive	Comprehensive
Price	Purchase Cost	Free	~$15k to $40k dependant on pipe limitation and modules selected.	~$30k to $60k dependant on node limitation selected.
	Maintenance Cost	Free	~10% of the purchase price	~15% of the purchase price

(Source: Ashley et al., 2007)

Appendix table 7: Deign Discharge for 50yr return period by rational

Contributory Width(m)	Length (m)	Drainage area(m^2)	Average slope	Time of conc.(min)	10yr Intensity	Runoff coefficient	Q10yr (CMS)
50	200	10000	0.030	4.45	129.86	0.8	0.327
50	500	15000		6.08	108.79		0.463
50	400	20000		7.58	82.65		0.584
50	500	25000		9.01	66.98		0.695
50	600	30000		10.36	52.44		0.796
50	700	35000		11.67	43.27		0.898
50	800	40000		12.93	36.93		0.977
50	900	45000		14.16	32.28		1.059
50	1000	50000		15.36	25.89		1.136

Appendix table 8: recommended runoff coefficient (C) for various selected land uses

	Runoff Coefficient, C					
	Soil Group A			Soil Group B		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.08	0.11	0.14	0.10	0.14	0.18
Meadow	0.14	0.22	0.30	0.20	0.28	0.37
Pasture	0.15	0.25	0.37	0.23	0.34	0.45
Farmland	0.14	0.18	0.22	0.16	0.21	0.28
Res. 1 acre	0.22	0.26	0.29	0.24	0.28	0.34
Res. 1/2 acre	0.25	0.29	0.32	0.28	0.32	0.36
Res. 1/3 acre	0.28	0.32	0.35	0.30	0.35	0.39
Res. 1/4 acre	0.30	0.34	0.37	0.33	0.37	0.42
Res. 1/8 acre	0.33	0.37	0.40	0.35	0.39	0.44
Industrial	0.85	0.85	0.86	0.85	0.86	0.86
Commercial	0.88	0.88	0.89	0.89	0.89	0.89
Streets: ROW	0.76	0.77	0.79	0.80	0.82	0.84
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.65	0.67	0.69	0.66	0.68	0.70

	Runoff Coefficient, C					
	Soil Group C			Soil Group D		
Slope :	< 2%	2-6%	> 6%	< 2%	2-6%	> 6%
Forest	0.12	0.16	0.20	0.15	0.20	0.25
Meadow	0.26	0.35	0.44	0.30	0.40	0.50
Pasture	0.30	0.42	0.52	0.37	0.50	0.62
Farmland	0.20	0.25	0.34	0.24	0.29	0.41
Res. 1 acre	0.28	0.32	0.40	0.31	0.35	0.46
Res. 1/2 acre	0.31	0.35	0.42	0.34	0.38	0.46
Res. 1/3 acre	0.33	0.38	0.45	0.36	0.40	0.50
Res. 1/4 acre	0.36	0.40	0.47	0.38	0.42	0.52
Res. 1/8 acre	0.38	0.42	0.49	0.41	0.45	0.54
Industrial	0.86	0.86	0.87	0.86	0.86	0.88
Commercial	0.89	0.89	0.90	0.89	0.89	0.90
Streets: ROW	0.84	0.85	0.89	0.89	0.91	0.95
Parking	0.95	0.96	0.97	0.95	0.96	0.97
Disturbed Area	0.68	0.70	0.72	0.69	0.72	0.75

Appendix table 9: Value of manning roughness coefficient (n) for uniform

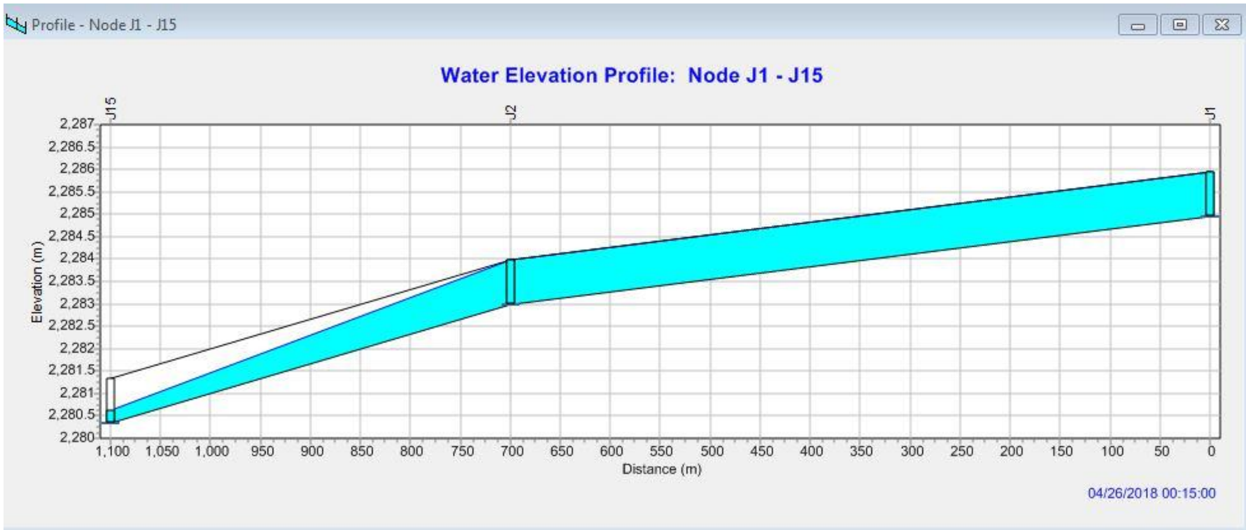
Type of Channel and Description	Minimum	Normal	Maximum
EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense Weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Backhoe-excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2 Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
NATURAL STREAMS			
1 Minor streams (top width at flood stage < 30 m)			
a. Streams on Plain			
1. Clean, straight, full stage, no rims or deep pools	0.025	0.030	0.033
2. Same as above, but more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools and shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8 Very weedy reaches, deep pools, or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages			
1. Bottom: gravel, cobbles, and few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2 Flood Plains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050

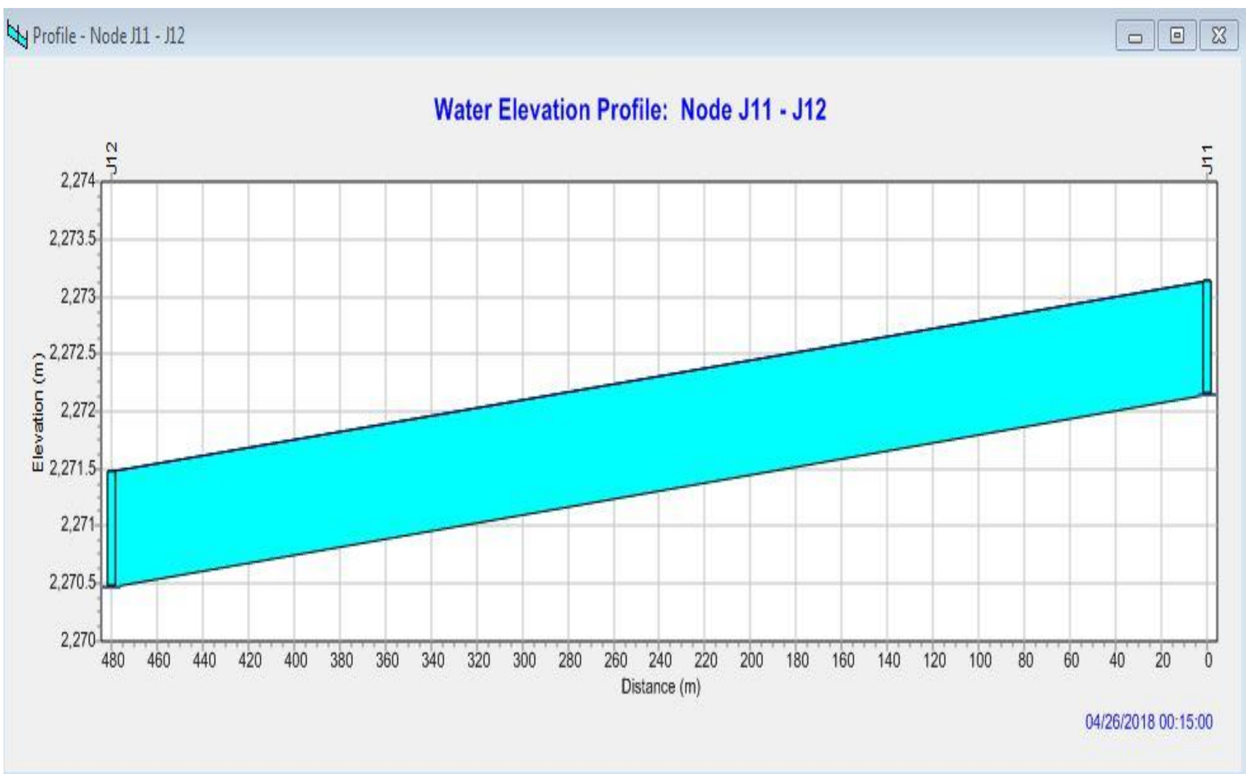
Type of Channel and Description	Minimum	Normal	Maximum
b. Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy growth of spouts	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
3 Major Streams (top width at flood stage > 30 m). The n value is less than that for minor streams of similar description, because banks offer less effective resistance.			
a. Regular section with no boulders or brush	0.025	--	0.060
b. Irregular and rough section	0.035	--	0.100
4 Various Open Channel Surfaces			
a. Concrete	0.012-	0.020	
b. Gravel bottom with:			
Concrete	0.020		
Mortared stone	0.023		
Riprap	0.033		
c. Natural Stream Channels			
Clean, straight stream	0.030		
Clean, winding stream	0.040		
Winding with weeds and pools	0.050		
With heavy brush and timber	0.100		
d. Flood Plains			
Pasture	0.035		
Field Crops	0.040		
Light Brush and Weeds	0.050		
Dense Brush	0.070		
Dense Trees	0.100		

Appendix table 10: typical hydrological soil group of Ethiopia

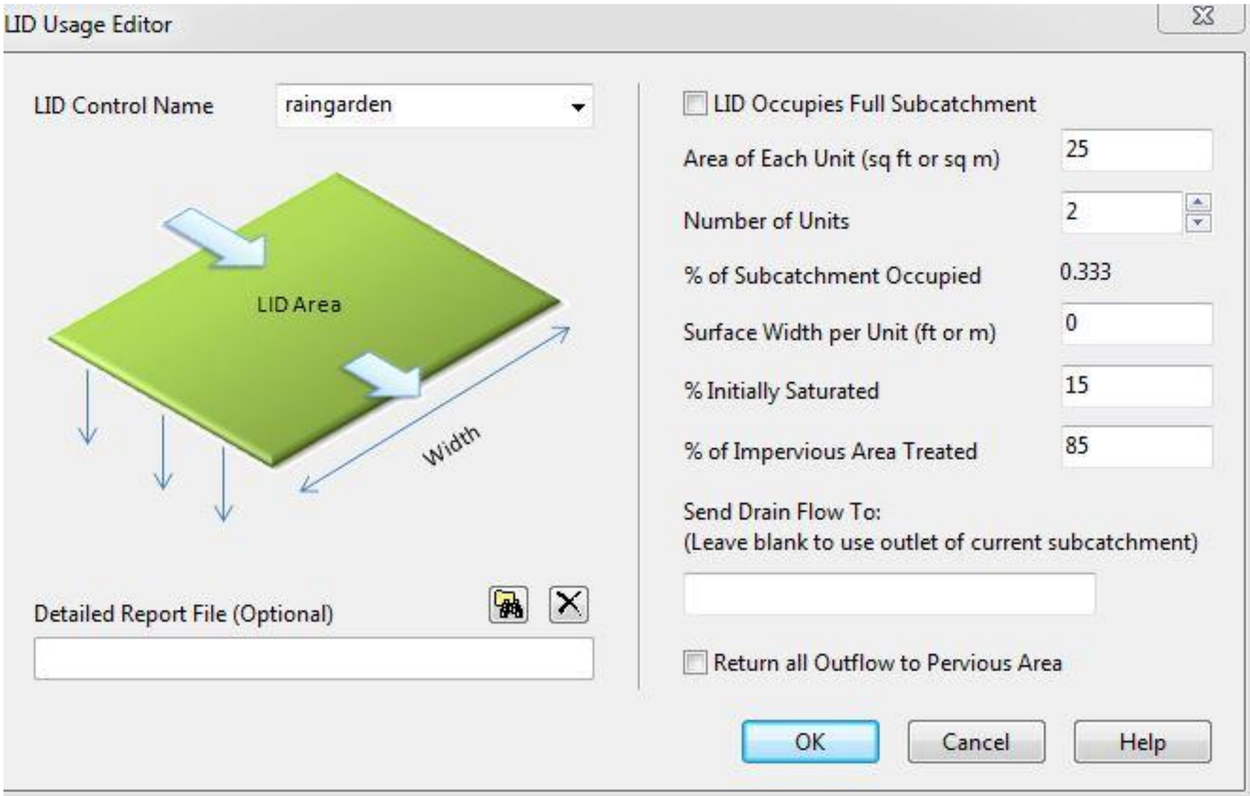
	Soil Types	Hydrologic Soil C
Ao	Orthic Acrisols	B
Bc	Chromic Cambisols	B
Bd	Dystric Cambisols	B
Be	Eutric Cambisols	B
Bh	Humic Cambisols	C
Bk	Calcic Cambisols	B
Bv	Vertic Cambisols	B
Ck	Calcic Chernozems	B
E	Rendzinas	D
Hh	Haplic Phaeozems	C
Hl	Luvic Phaeozems	C
I	Lithosols	D
Jc	Calcaric Fluvisols	B
Je	Eutric Fluvisols	B
Lc	Chromic Luvisols	B
Lo	Orthic Luvisols	B
Lv	Vertic Luvisols	C
Nd	Dystric Nitosols	B
Ne	Eutric Nitosols	B
Od	Dystric Histosols	D
Oe	Eutric Histosols	D
Qc	Cambric Arenosols	A
Rc	Calcaric Regosols	A
Re	Eutric Regosols	A
Th	Humic Andosols	B
Tm	Mollic Andosols	B
Tv	Vitric Andosols	B
Vc	Chromic Vertisols	D
Vp	Pellic Vertisols	D
Xh	Haplic Xerosols	B
Xk	Caloic Xerosols	B
Xl	Luvic Xerosols	C
Yy	Gypsic Yermosols	B
Zg	Gleyic Solonchaks	D
Zo	Orthic Solonchaks	B

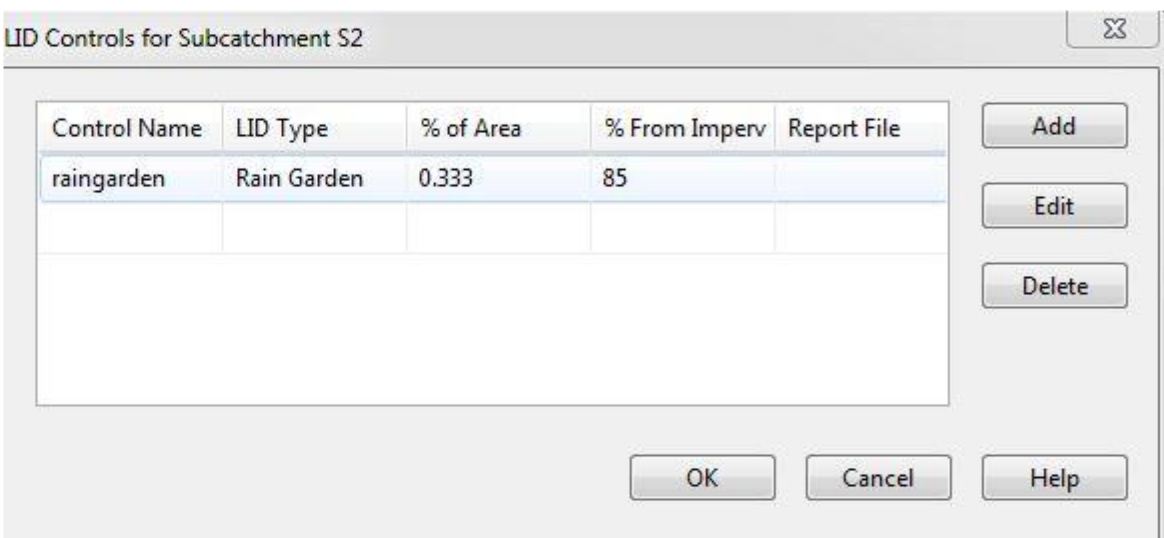
Appendix L:Water elevation profile

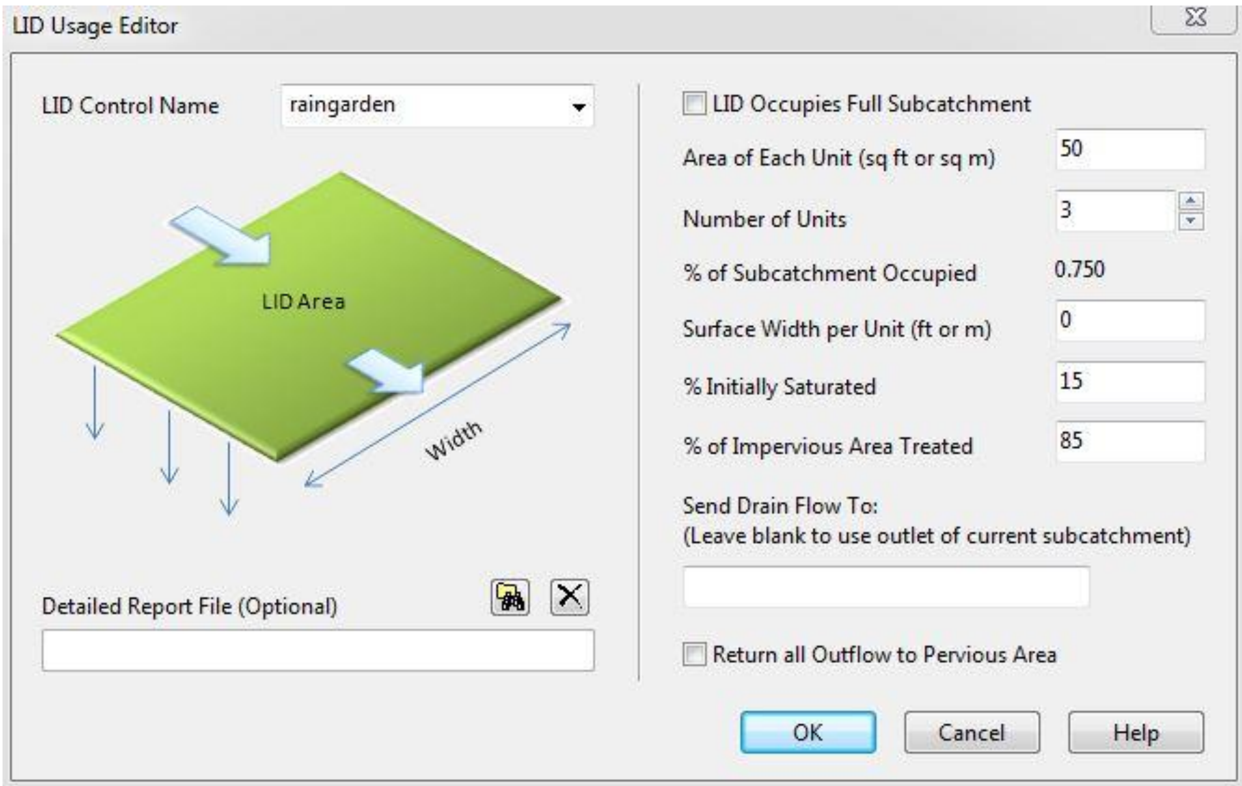


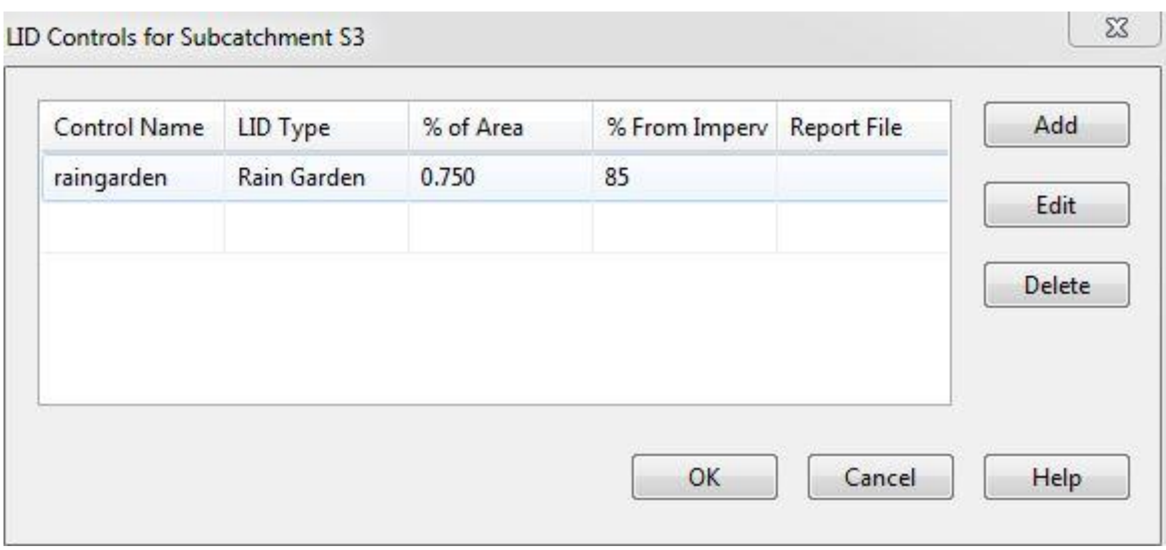


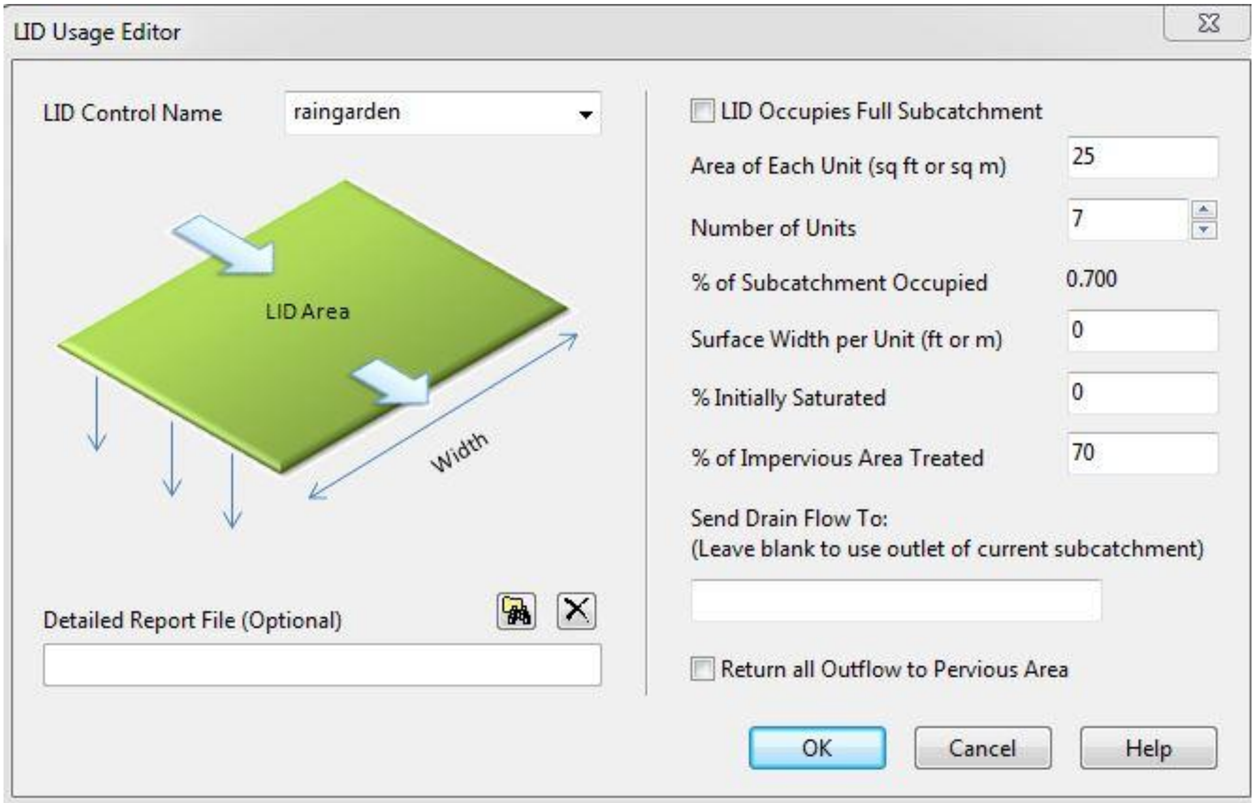
Appendix table 11: LID Usage From Each Subcatchment

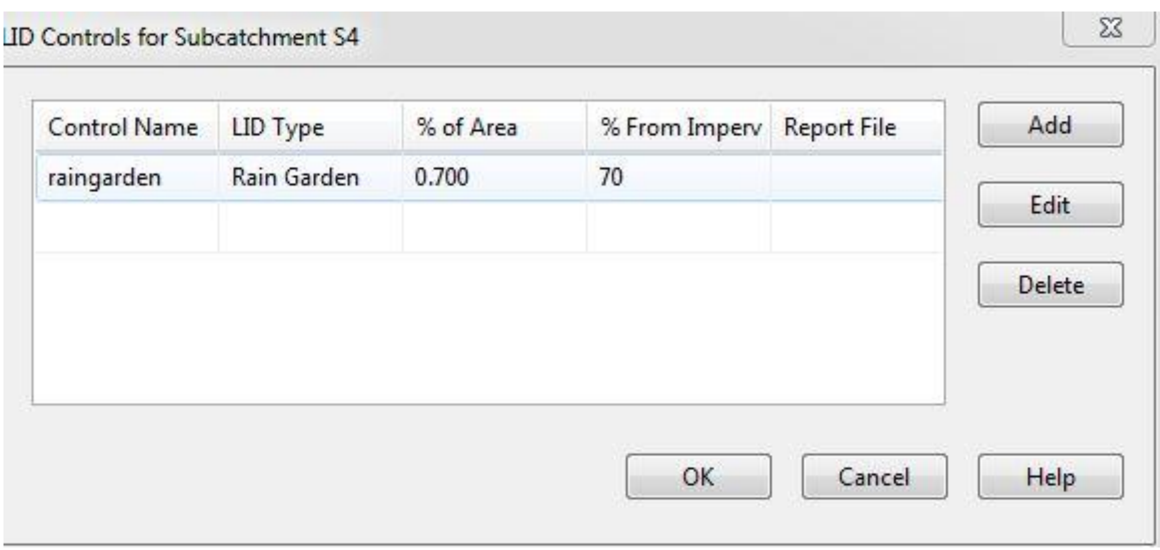





LID Usage Editor
LID Control Name
raingarden
LID Area
Width
Detailed Report File (Optional)
LID Occupies Full Subcatchment
Area of Each Unit (sq ft or sq m)
50
Number of Units
3
% of Subcatchment Occupied
0.750
Surface Width per Unit (ft or m)
0
% Initially Saturated
15
% of Impervious Area Treated
85
Send Drain Flow To:
(Leave blank to use outlet of current subcatchment)
Return all Outflow to Pervious Area
OK
Cancel
Help


LID Controls for Subcatchment S3
Control Name
LID Type
% of Area
% From Imperv
Report File
raingarden
Rain Garden
0.750
85
Add
Edit
Delete
OK
Cancel
Help


LID Usage Editor
LID Control Name
raingarden
LID Area
Width
Detailed Report File (Optional)
LID Occupies Full Subcatchment
Area of Each Unit (sq ft or sq m)
25
Number of Units
7
% of Subcatchment Occupied
0.700
Surface Width per Unit (ft or m)
0
% Initially Saturated
0
% of Impervious Area Treated
70
Send Drain Flow To:
(Leave blank to use outlet of current subcatchment)
Return all Outflow to Pervious Area
OK
Cancel
Help


LID Controls for Subcatchment S4
Control Name
LID Type
% of Area
% From Imperv
Report File
raingarden
Rain Garden
0.700
70
Add
Edit
Delete
OK
Cancel
Help