JIMMA UNIVERSITY

SCHOOL OF GRADUTE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

# INVESTIGATION ON THE CAUSES OF HIGHWAY DRAINAGE SYSTEM PROBLEM IN ADDIS KETEMA SUB CITY OF ADDIS ABABA.

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial fulfilment of the Requirements for the Degree of Masters Science in Civil Engineering (Highway Engineering).

BY:

BINIYAM HAGEZOM

March, 2018

Jimma, Ethiopia

JIMMA UNIVERSITY

SCHOOL OF GRADUTE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIROMENTAL ENGINEERING

HIGHWAY ENGINEERING STREAM

# INVESTIGATION ON THE CAUSES OF HIGHWAY DRAINAGE SYSTEM PROBLEM IN ADDIS KETEMA SUB CITY OF ADDIS ABABA.

A Thesis Submitted to the School of Graduate Studies of Jimma University in Partial fulfilment of the Requirements for the Degree of Masters Science in Civil Engineering (Highway Engineering).

BY:

BINIYAM HAGEZOM

Advisor: Dr.Ing Tamene Adugna, Ph.D.

Co-Advoser: Tarekegn Kumela , M.S.C

March, 2018

Jimma, Ethiopia

# DECLARATION

I, the undersigned, declare that this thesis entitled **"** Investigation on the cause of Highway Drainage system problem in Addis ketema sub city of Addis Ababa**."** is my original work and has not been presented by any other person for an award of a degree in this or any other university, and all sources of materials used for thesis have been dually acknowledged.

Candidate;

Mr. BINIYAM HAGEZOM

Signature Date________________

As master research advisors, we here by certify that we have read and we evaluate this MSc research paper under our guidance by Mr. BINIYAM HAGEZOM entitled Investigation on the cause of Highway Drainage system problem in Addis ketema sub city of Addis Ababa. We recommended that it can be submitted as fulfilling the MSc thesis requirements. I will submit this thesis for examination with my approval as University Supervisor

Advisors

**Dr.Ing Tamene Adugna, Ph.D.** _________________ ______________________

Advisor: Signature Date

**Tarekegn Kumela , M.S.C** _________________ ______________________

Co-Advisor: Signature Date

# ACKNOWLEDGEMENT

First Praise and Glory to Almighty **GOD** for bestowing me strength with health and power to complete this work

Next, I would like to express my sincere thanks and appreciation to my main advisor **Dr. Ing Tamene Adugna** and co-advisor **Tarekegn Kumela.Msc.,** for their effort and commitment in sharing their knowledge towards me. I want to show unreserved appreciation for their advice and support through

Secondly, I would like to say all my deepest thanks from my bottom of heart thankful to the Jimma University, and to all my lecturers who have taught me in who create this beautiful environment for me and have got the chance of this lovely education. And also Jimma Institute of Technology, thank you for all the knowledge and guidance.

My special gratefulness goes to my Wife marta chala for her love, support, encouragement, patience and understanding. I would like to express my love and appreciation to my lovely Mother Asefu Gebreegiziabeher, my Father Hagezom Arefom and to my Brother Fitsum Hagezom for their limitless thoughts, care and love.

# ABSTRACT

*Proper drainage system is required in developing urban areas. In Addis Ababa, drainage problem become an issue during rainy season. This study deals with investigation of urban drainage problem of Addis Ababa and a possible mitigation measure to overcome the problem. Despite there are many places in the addis ketema sub city facing urban drainage problem by considering major road and economical value selecting criteria; are selected for this study.*

*Data collection methods were carried out using both primary and secondary data sources, which was accomplished with the help of topographic map and design data. The method used to investigate management problem direct field data collection and site visit the construction problem is analyzed using field survey as well as comparison of design with what is implemented in the ground. And evaluated by redesigning of the system using the computation sheet used in (FHWA) urban drainage design manual and (AACRA) urban drainage design manual. Design of urban drainage system evaluated in this research includes inlet spacing, pipe sizing and The Values of inlet spacing and pipe sizing obtained by redesigning was compared with what was implemented in the ground. Finally the collected data were after analyzed presented using Microsoft-excel, AutoCAD, tables, graphs and percentages.*

*The result of this study shown that the problem was caused by sedimentation and insufficient drainage operation, over spaced inlet spacing and minimum pipe size was used. The investigation also shown; the curb inlets were over spaced and constructed with very small opening, the operation system of the drainage was in sufficient, negligence of siltation and debris control analysis in pipe size design, lack of Morphometry of hydrology consideration on design and Insufficient drainage operation maintenance and management*

*Large inlet spacing was a cause over spread of storm water in the pavement of the road. This can be minimized by providing extra inlets especially on the sag point. The hydraulic capacity of existing pipe size was not sufficient to accommodate the flow with debris and silt sediment. Because of negligence of siltation and debris control analysis in pipe size design. Lack of consideration Morphometry of hydrology on design this leads to failure of drainage structures due to inadequate pipe size of drainage structures. Inadequate drainage operational management was also a cause of inlet not to work properly which aggravate the problem in the study area, so scheduled follow up and maintenance activity should be done Another measure to be taken was the upgrading of wetland; this will help stop the frequent back-flows which cause flooding and increase infiltration*

***Kay word**:-Drainage structure, curb inlet, hydraulic capacity, Morphometry of hydrology*

TABLE OF CONTENTS

# List of Tables

Page



# List of Figures

**Page**

# List of Acronyms

| | |
|---|---|
| AACRA | Addis Ababa City Road Authority |
| AEE | African Evangelical Enterprise |
| AKCC | Addis ketam sub city administration Council |
| AMREF | African Medical and Research Foundation |
| CBO | Community Based Organizations |
| ERA | Ethiopia Road Authority |
| FHWA | American Federal Highway Administration |
| HGL | The hydraulic grade line |
| IDF | Intensity duration frequency curves |
| LC | Local Councilor |
| LGDP | Local Government Development Program |
| NGO | Non-Government Organization |
| SUDS | Sustainable Urban Drainage Systems |
| TCDSc | Transport construction Design Share Company |
| V.I.P | Ventilated Improved Pit Latrines |
| WSL | Water Surf |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Drainage is one of the most important factors to be considered in the road design, construction and maintenance projects. It is generally accepted that road structures work well and last longer to give the desired service. When a road fails, whether it is asphalt or gravel, in adequate drainage is often a major factor to be considered. The main cause of failure of the structure of drainage is runoff water, quality of construction material and lack of safety. Water is also the main contributor to the failure of drainage 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 pavement the edges or it may seep upward from a high ground water table (Butlers and Davies, 2004).

Drainage systems are required in developing urban areas for road safety and proper environmental condition. The two types of water that requires drainage are waste water and storm water. Urban drainage systems handle these two types of water with separate or combined drainage system. In Addis Ababa, capital city of Ethiopia, most of the drainage systems are separate and this study deals with the investigation on highway drainage system problem of addis ketema sub city in addis ababa on the Pauster To Sebategna - Abinet And, SefereSelam -Autobus Ter - Goijjam Berenda Road. Storm water is generated by rain fall and consists of that portion of rainfall that runs off from urban surface. Hence, the properties of storm water, in terms of quality and quantity, are intrinsically linked to the natural and characteristic of both the rainfall and the catchment (Butlers and Davies, 2004).

Drainage design is an integral component in the design of highway. Drainage design for highway facilities must strive to maintain compatibility and minimize interference with existing drainage patterns, control flooding of the roadway surface for design flood events, and minimize potential l impacts from highway related storm water runoff. (FHWA, 2001).

Storm water collection systems must be designed to provide adequate surface drainage. Traffic safety is intimately related to surface drainage. Surface drainage is a function of transverse and longitudinal pavement slope, pavement roughness, inlet spacing, and inlet capacity (FHWA, 2001)

The sites which are selected for investigation are among the major roads which are constructed in Addis Ketema sub city in Addis Ababa and along these roads areas which are highly affected by the drainage problem are identified for detail study. Using the available data the drainage system of the roads is evaluated and compared with the original design as well as what is implemented in the ground. Depending on the problem investigated what are the effects of poor drainage system and a possible mitigation is also recommended.

## 1.2 Statement of the Problem

In the world construction of Highway is one of a key factor for economic growth. Due to this currently, highway construction activities are developed globally and consuming a lot amount of resources. Besides that it generates much amount of additional costs like that of highway maintenance cost for repair or replacement before the design period, because of the failures of the road at its early Age, among different highway failure factors drainage system problem is the main and critical factor. This may have a great impact on the coming new highway construction.

Ethiopian government has made significantly strive in improving the road network coverage in the country, Provision of a modern, integrated and safe Highway Construction activity it also play a great role for economic benefits, a good roads are a boon to the tourism and other industry it reduce accident traffic delay and congestion. But failure of highway Construction before the design period is become a serious problem. The highway drainage system includes the pavement and the water handling system which includes pavement surface, shoulders, drains and culverts. These elements of the drainage system must be properly designed, built, and maintained. When a road fails, inadequate drainage often is a major factor. Poor design can direct water back onto the road or keep it from draining away. Too much water remaining on the surface combine with traffic action may cause potholes, cracks and pavement failure. This leads to reduce the quality of road network and increasing traveling time those are a great impact on economic activity.

Even if Addis Ababa is the place of head quarter of Africa union In Addis Ababa, recently constructed roads were reported to deteriorate rapidly after opened to traffic. These deteriorations were contributed to many reasons such as, climatic changes, poor drainage and low quality pavement materials. The most common road distresses are cracks, potholes, , raveling, depressions and damaged edges. These poor drainage affect the safety and riding quality on the pavement as they may lead to premature failure and traffic hazards. Before going into maintenance strategies, engineers must look into the causes of highway drainage system problem.

Much of addis ketema area is built up due to urbanization this increases the catchments of storm water during rainy seasons because of the iron sheets on the buildings, and flood water generated in the area as a result of the household and commercial activities, without adequate provision for drainage systems /channels. The surface runoff and waste water therefore often result into stagnant water and flooding. This lead to increase in moisture content decreases the strength of the pavement. Poor drainage causes the premature failure of the pavement loading during and after the rainfall which is the main cause of congested traffic flow, Erosion of pavement and negative impact on environmental health and difficulty on day today activity of people. Addis ketema is one of the most economical valuable sub city in Addis Ababa. So this Poor highway drainage system affects economic and social activity. Because of these the effect of the highway drainage system problem in Addis Ketema Sub city is very ad verse’s this paper aims to identify the causes of highway drainage system problem and to give possible solution.

## 1.3 Research Questions

1) What are the effects of poor design and construction of curb inlet?
2) How inadequate Hydraulic capacity of the existing drainage structure affect the drainage system?
3) What are the main cause and contributing factors for the failure of drainage structure?
4) What are the possible major action taken to overcome the drainage system problem?

## 1.4 Objective of the study

### 1.4.1 General objective

To investigate the cause of highway drainage system problem in Addis ketema Sub city of Addis Ababa and to give a possible solution for the problem

### 1.4.2 Specific objective

- To evaluate the existing design and construction of curb inlet spacing
- To analyze Hydraulic capacity of existing drainage structure
- To evaluate the main cause and contributing factors for the failure of drainage structure
- To suggest possible mitigation measures On highway drainage structure maintenance and management

## 1.5 Significance of the Research

To minimize the possible damage of drainage structures and increase serviceability Addis ketema Sub city, concerned body organizations can use it as reference for drainage infrastructure proper design. To reduce the pavement distress problems. To increase the integration of the infrastructures for increasing the service time of the drainage. The problem of drainage in Addis ketema Sub city is increased from time to time and difficult to move the societies from place to place during the summer season. This research is basically to solving the problem related to the drainage in the selected areas of the town and used for Addis Ababa admiration communities, ERA and Addis ketema Sub city towns as a reference in terms of maintenances and design.

## 1.6 Scopes of the study

This study is geographically limited to Addis Ketema Sub city of Addis Ababa. Specifically from Seffere selam to Gojjam berenda and Pauster to Abinet Road The research does not include structural design of all types of drainage structures. The study of this research investigates which occurs in the above mentioned roads.is covered only the type and severity of the problem of drainage system failure Based on the available data the design and construction curb inlet, hydraulic capacity of the existing drainage system and the operational management of the drainage system is evaluated and a possible mitigation measures are included.

# CHAPTE TWO

# REVIEW OF RELATED LITERATURE

## 2.1Description of Highway Drainage Structure

Drainage is a system includes the pavement and the water handling system. Logically they must be properly designed, built, and maintained. Poor design can direct water back onto the road or keep it from draining away. Too much water remaining on the surface combine with traffic action to cause potholes, cracks and pavement failure. The failure of drainage can adversely the water handling system includes: road surface, shoulders, drains and culverts; curb, gutter and storm sewer. When a road fails, whether it's concrete, asphalt or gravel, inadequate drainage often is a major factor affect pavement performance. Inadequate drainage leads to major cause of pavement distresses due to large amount of costly repairs before reaching their design life. Pavement service life can be increased by 50% if water can be drained without delay. Similarly, pavement systems incorporating good drainage can be expected to have a design life of two to three times that of un - drained pavement sections. To achieve proper drainage, drains (or ditches) a long side of road are essential to collect water from road surface and surrounding areas and lead it to an exit point where it can be safely discharged (Mays, 2004).

The use of edge drains was also for conventional asphalt pavements with unbound dense-graded aggregate bases, the addition of appeared to reduce fatigue cracking, but not rutting. The Subsurface drainage is also a key element in design of pavement. The Performance of Pavement Subsurface drainage, summarized findings on the effectiveness of subsurface drainage on flexible pavements. They found that structural capacity and drain ability which are key factors in the performance of flexible pavements. If either factor was poor, there was an increased incidence of rutting and fatigue cracking. It was noted that these factors should be carefully considered during the design phase of flexible pavements.

Another key factor in the performance of subsurface drainage will whether edge drain outlet pipes will clogged. Clogged outlet pipes will found to have a detrimental effect on the performance of flexible pavements. Clogged outlets led to increase fatigue cracking and rutting and could lead to stripping. In addition, permeable base sections will found to have better fatigue performance than all other types of evaluated pavement sections. However, there was not a significant difference in the rutting performance of permeable base sections and other a predictive model of pavement performance that includes the effect of moisture on pavement materials properties and the quality of the subsurface drainage. In this model, the duration of pavement wetness is first estimated taking climatic conditions as wells drainage into account. Then, assuming the pavement system has a 50% reduction in strength when wet. (Highway and Traffic Engineering in Developing countries by Bent Thagesen).

The use of drainage systems by humans has a long history dating back to the early third millennium B. C. during the Indus civilization. Not far behind were the Mesopotamians (Adams, 1981). The Minoan civilization on Crete, in the second millennium B.C. also had extensive drainage systems. Knossos, approximately 5 kilometers from Herakleion, the modern capital of Crete, was one of the most ancient and most unique cities of the Aegean and of Europe.

The drainage systems at Knossos were most interesting, consisting of two separate systems, one to collect the sewage and the other to collect rain water. After the collapse of the Minoan civilization and before the Greek influence, which was roughly from 1100 to 700 B.C., there was disarray in the Aegean society. The uses of drains were fairly extensive in Minoan palaces and later their use was rediscovered by the Greeks, as they started living in settlements.

Community drainage systems were a relatively late development of the Greeks (Crouch, 1993). Drainage in Greek cities included sewers under the streets in residential areas and drainage channels in public areas. Components of the drainage systems included eave troughs for individual buildings, drain pipes through walls or foundation of individual houses, collector channels in neighborhoods, and drains in public areas.

After the Greeks, many of the cities and towns were eventually taken over by the Romans. Many Roman cities did not have any type of drainage system, especially those in the outer parts of the Roman Empire. In the more developed communities, stone drains were provided. In the old established cities that were originally built without storm drains, it was difficult to install them during later times.

This is why cities such as Pompeii did not have a full network of storm drains. The older parts of the cities had a somewhat random layout because of no urban planning, whereas the newer parts of the cities were built on a square grid street pattern. The downtown core of Pompeii, around the forum, does have the random layout; whereas rectangular city blocks were used in the later expansion of the city. Ironically, the older part of Pompeii was the only part that did have storm drain (Mays, 2004).

## 2.2 Components of Urban Drainage system

### 2.2.1 Surface Drainage

The surface drainage elements include road surface, side drains, gutters and storm sewer systems. These elements work together as a system to prevent water from penetrating the pavement, remove it from the travel lanes to the side drains or gutter, and carry it away from the road.

A complete highway drainage system design includes consideration of both major and minor drainage systems. The minor system, sometimes referred to as the "Convenience" system, consists of the components that have been historically considered as part of the "highway drainage system".

These components includes.

- Curbs
- Gutters
- Ditches
- Inlets
- Access holes
- Side Drains
- Shoulders
- Road Surface
- Cross-section Slope
- Pipes and other conduits
- open channels, pumps, detention basins
- Water quality control facilities, etc.

#### 2.2.1.1 Road Surface

The road surface geometric features, carriageway cross-section slope and longitudinal gradient and shoulders which enable the water to flow off the road surface to side drains that collect and lead water away from the road.

#### 2.2.1.2 Side Drains

The side's drains need to have sufficient capacity to collect all rainwater from the road surface and dispose it quickly and in a controlled manner to minimize damage. In most of the center of the town it can be safely discharge, but if the external road side of drainage is do not covered properly by asphalts it's difficult to dispose to the drainage and facilitates to damage of the road side

Figure 2.1 side drain (January 2017)

#### 2.2.1.3 Gutters, and Curbs

The roadway surface water can be removed by a series of drains that carry the water into a collection and disposal system. The curb, gutter, and inlet design must keep flooding within the parameters established in roadway drainage guidelines. The hydraulic efficiency of inlets is related to the roadway grade, the cross grade, the inlet geometry, and the design of the curb and gutters Curbs are divided into two classes: barrier and mountable. Barrier curbs are steep faced and generally 6 to 8 in (150 to 200 mm) high. Mountable curbs are generally 6 in these are parts of a drainage system that receive runoff at grade and permit the water to flow downward into underground storm drains. Inlet should be capable of passing design floods without Clogging with debris. The entrance to inlets should be protected with a grating set flush with the surface of gutters or medians, so as not to be a hazard to vehicles. At the study area of addis ketema sub city the entrance to the inlet is closed by wastes and silts, the runoff water is flow back to the main road and difficult There are also areas where inlets are nearly always required. These include sag points, points of super elevation reversal, street intersections, and at bridges.

Where an inlet is required in the vicinity of a driveway, it should always be located up stream of the driveway. If it is located downstream, the driveway may affect the flow and cause a significant portion to bypass the inlet. Finally, the type and size of the inlet have a direct affected on location and spacing. Similarly, designing for greater spread and allowing some bypass of the upstream inlets to occur with the residual being intercepted by those farther downstream (carryover flow) will result in fewer inlets. The basic types of inlets are the curb opening inlet .Two other types frequently used are the slotted drain inlet and the combination inlet (AACRA, 2003).

### 2.2.1.4 Cross-section Slope

ERA manual recommend for roads with asphalt surfaces that, the camber is normally 2 to 3%, because water will easily flow off a hard, waterproof surface. In Addis ketema sub city, the slopping doesn't consider during the construction period. This slope facilitates discharge of water from sections of the road surface with limited cross-slop (AACRA, 2003).

### 2.2.1.5 Shoulders

Shoulder is the structural function of a road pavement, providing lateral support for the pavement layers. They should help in removing surface water from the road surface and facilitate the internal drainage of the pavement. They are especially important when unbound materials are used in the pavement .From a functional point of view a minimum width of 1m is recommended and it is also recommended that shoulders on paved road having a width less than 1m should be paved and used for emergency and temporary parking. Due to the drainage filled by debris and silts, the water come back to shoulder and protect from flow of the internal drainage of the pavement.

The minor system is normally designed to carry runoff from 10 year frequency storm events. The major system provides overland relief for storm water flows exceeding the capacity of the minor system. This usually occurs during more infrequent storm events, such as the 25-, 50-, and 100-year storms. The major system is composed of pathways that are provided – knowingly or unknowingly -for the runoff to flow to natural or manmade receiving channels such as streams, creeks, or rivers (AACRA, 2003).

### 2.2.2 Storm water Collection

Storm water collection is a function of the minor storm drainage system which is accommodated through the use of roadside and median ditches, gutters, and drainage inlets. Roadside and median ditches are used to intercept runoff and carry it to an adequate storm drain. These ditches should have adequate capacity for the design runoff and should be located and shaped in a manner that does not present a traffic hazard. If necessary, channel linings should be provided to control erosion in ditches. Where design velocities will permit, vegetative linings should be used.

Gutters are used to intercept pavement runoff and carry it along the roadway shoulder to an adequate storm drain inlet. Curbs are typically installed in combination with gutters where runoff from the pavement surface would erode fill slopes and/or where right-of-way requirements or topographic conditions will not permit the development of roadside ditches. Pavement sections are typically curbed in urban settings. Parabolic gutters without curbs are used in some areas.

Inlets are the receptors for surface water collected in ditches and gutters, and serve as the mechanism whereby surface water enters storm drains. When located along the shoulder of the roadway, storm drain inlets are sized and located to limit the spread of surface water on to travel lanes. The term "inlets," as used here, refers to all types of inlets such as grate inlets, curb inlets, slotted inlets, etc. Drainage inlet locations are often established by the roadway geometries as well as by the intent to reduce the spread of water onto the roadway surface. Generally, inlets are placed at low points in the gutter grade, intersections, crosswalks, cross-slope reversals, and on side streets to prevent the water from flowing onto the main road. Additionally, inlets are placed upgrade of bridges to prevent drainage onto bridge decks and downgrade of bridges to prevent the Flow of water from the bridge onto the roadway surface (Mays, 2004).

### 2.2.3 Storm water Conveyance

Upon reaching the main drainage system, storm water is conveyed along and through the right-of-way to its discharge point via storm drains connected by access holes or other drainage access structures. In some cases, storm water pump stations may also be required as a part of the conveyance system. Storm drains are defined as that portion of the storm drainage system that receive runoff from inlets and conveys the runoff to some point where it is discharged into a channel, water body, or other piped system. Storm drains can be closed conduit or open channel; they consist of one or more pipes or conveyance channels connecting two or more inlets.

Access holes, junction boxes and inlets serve as access structures and alignment control points in storm drainage systems. Critical design parameters related to these structures include access structure spacing and storm drain deflection. Spacing limits are often dictated by maintenance activities. In addition, these structures should be located at the intersections of two or more storm drains, when there is a change in the pipe size, and at changes in alignment (horizontal or vertical) (AACRA, 2003)

In areas where gravity drainage is impossible or not economically justifiable, storm water pump stations are often required to drain depressed sections of road ways. Detention/ retention facilities are used to control the quantity of runoff discharged to receiving waters. A reduction in runoff quantity can be achieved by the storage of runoff in detention/retention basins, storm drainage pipes, swales and channels, or other storage facilities Outlet controls on these facilities are used to reduce the rate of storm water discharge. This concept should be considered for use in highway drainage design where existing downstream receiving channels are inadequate to handle peak flow rates from the highway project, where highway development would contribute to increased peak flow rates and aggravate downstream flooding problems, or as a technique to reduce the size and associated cost of outfalls from highway storm drainage facilities (FHWA, 2001)

Storm water is generated by rainfall, and consists of that proportion of rainfall that runs off from urban surfaces. The transformation of a rainfall hyetograph into a surface runoff hydrograph involves two principal parts. Firstly, losses due to interception, depression storage, infiltration and evapotranspiration are deducted from the rainfall. Secondly, the resulting effective rainfall is transformed by surface routing into an overland flow hydrograph (Butlers and Davies, 2004)

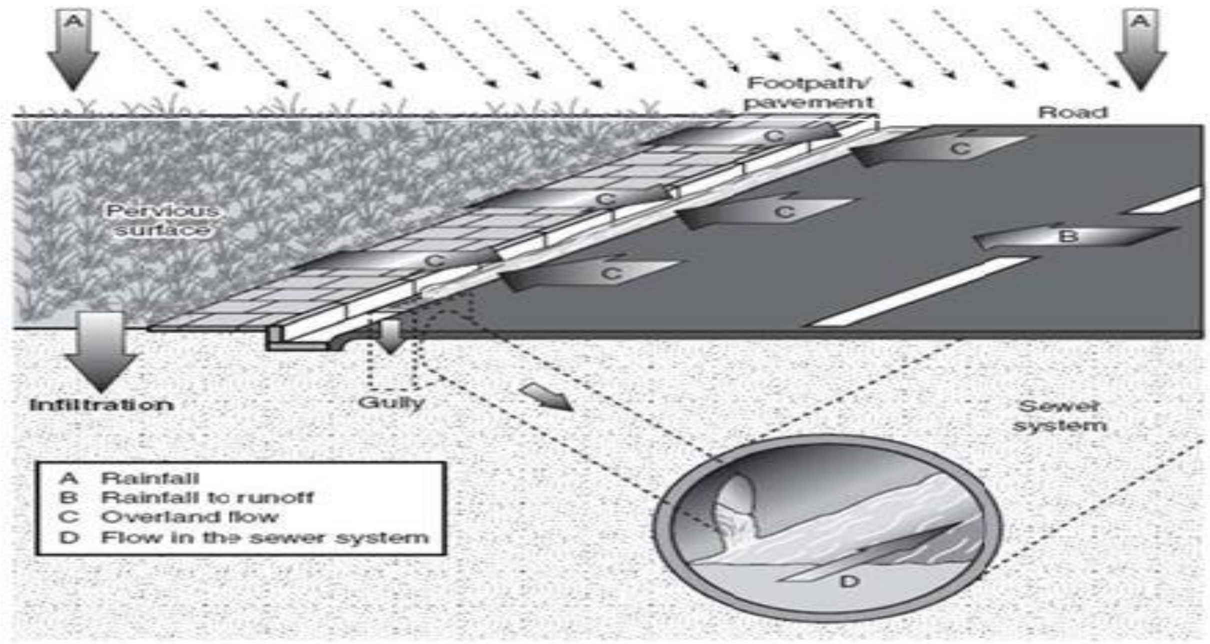



Figure 2.2 urban water runoff generation processes (Butlers and Davies, 2004)

## 2.3. Storm Water Computation

One of the most commonly used equations for the calculation of peak flow from small areas is the rational formula, given as:

$$Q = \frac{CIA}{K_u} \qquad (2.1)$$

Where:

Q = Flow, $m^3/s$

C = dimensionless runoff coefficient

I = rainfall intensity, mm/hr

A = drainage area, hectares, ha

$K_u$ = units conversion factor equal to 360

Assumptions inherent in the rational formula are as follows

- Peak flow occurs when the entire watershed is contributing to the flow
- Rainfall intensity is the same over the entire drainage area.
- Rainfall intensity is uniform over a time duration equal to the time of concentration, tc. The time of concentration is the time required for water to travel from the hydraulically most remote point of the basin to the point of interest.

- Frequency of the computed peak flow is the same as that of the rainfall intensity, i.e., the 10-year rainfall intensity is assumed to produce the 10-year peak flow.
- Coefficient of runoff is the same for all storms of all recurrence probabilities.

Because of these inherent assumptions, the Rational formula should only be applied to drainage areas smaller than 80 ha (200 ac) (Mays, 2004)

## 2.3.1. Runoff Coefficient

The runoff coefficient, C, in equation above is a function of the ground cover. It relates the estimated peak discharge to a theoretical maximum of 100 percent runoff. Typical values for C are given in the table (see table A-21 in the appendix III). If the basin contains varying amounts of different land cover or other abstractions, a composite coefficient can be calculated through areal weighing as follows

$$C= \frac{\sum CxAx}{A\,Total} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2.2)$$

Where

x = subscript designating values for incremental areas with consistent land cover

$C_x$ = runoff coefficient for area $A_x$

$A_x$ = area having runoff coefficient $C_x$

### 2.3.2 Rainfall Intensity

Intensity duration frequency curves (IDF curve) are necessary to calculate the intensity of rainfall used for the design. Regional IDF curve are available which are shown in fig 2.3 are used for computation. Depending on the location of the study area with respect to the station where the IDF is produced, we choose the IDF curve for a given computation

The relation between storm duration, storm intensity, and storm return interval, is represented by a family of curves called the intensity-duration-frequency curves, or IDF Curves. Quantification of rainfall is generally carried out using is opluvial (Return Period) maps and intensity-duration-frequency (IDF) curves (Chow et al., 1988).

Various rainfall contour maps developed to provide the design rain depths for various return periods and durations (Hershfield, 1961).

The IDF relationship is a mathematical relationship between the rainfall intensity, the duration, and the return period (the annual frequency of exceedance). For this research, IDF curves are used to quantify rainfall. The study area is found in the rainfall region of addis ketema

The IDF curve at Observatory is used for Pauster To Sebategna - Abinet Roads ,Sefere Selam - Autobus Tera - Goijjam Berenda Road study areas,. The criterion for choosing a given station is the nearness of the station to the site

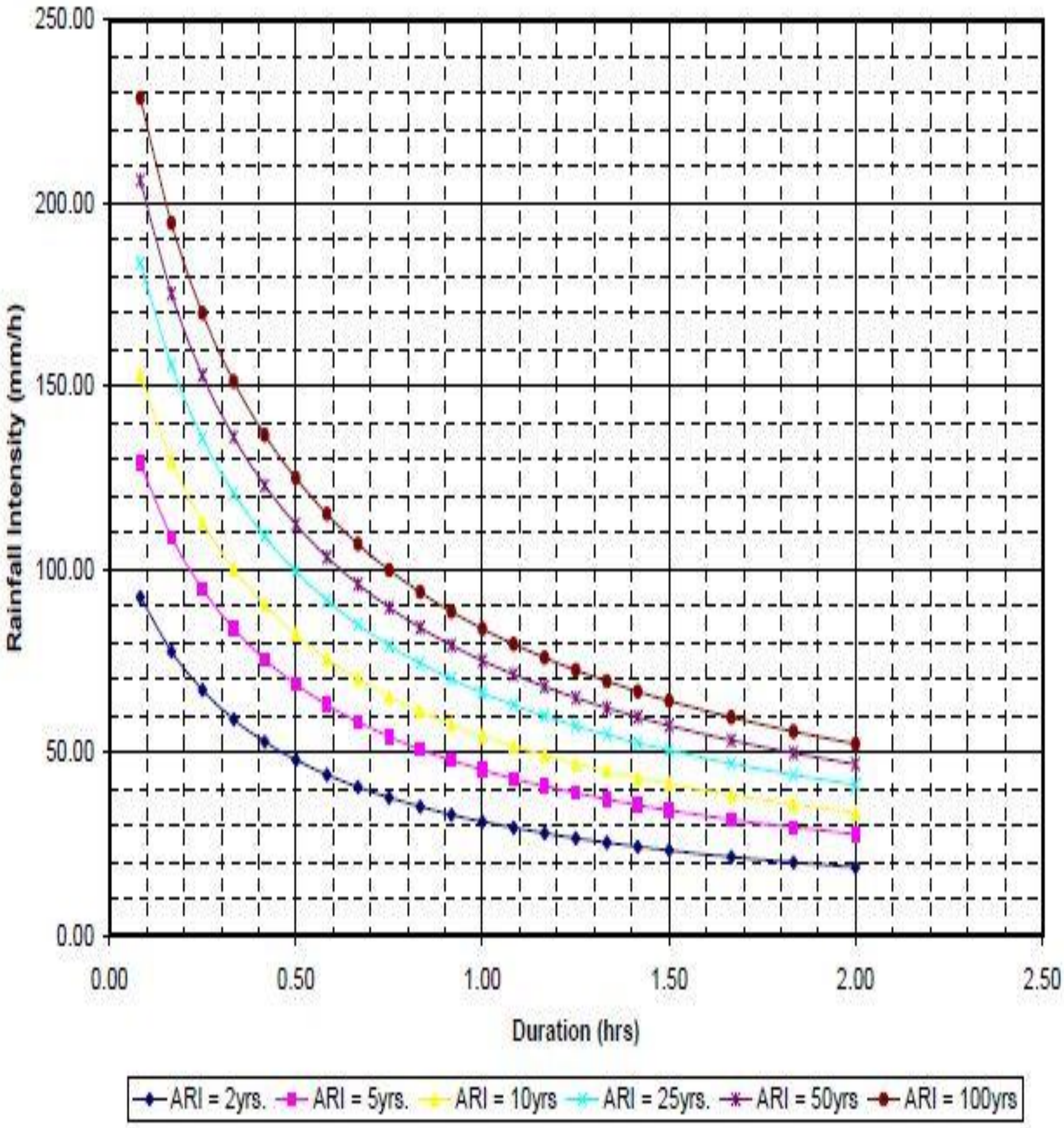



Figure 2.3 Intensity Duration Frequency Curve (Addis Ababa Observatory

### 2.3.3 Time of Concentration

The time of concentration of a watershed is often defined to be the time required for a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet. It is not possible to point to a particular point on a watershed and say, "the time of concentration is measured from this point". Neither it is possible to measure the time of concentration. Instead, the concept of time concentration is useful for describing the time response of a watershed to a driving impulse, namely that of watershed runoff. There are a number of methods that can be used to estimate time of concentration (tc), some of which are intended to calculate the flow velocity within individual segments of the flow path (e.g., shallow concentrated flow, open channel flow, etc.). The time of concentration can be calculated as the sum of the travel times within the various consecutive flow segments. The time of concentration can be calculated as the sum of the travel times within the various consecutive flow segments (FHWA, 2001)

**Sheet Flow Travel Time**

Sheet flow is the shallow mass of runoff on a planar surface with a uniform depth across the sloping surface. This usually occurs at the headwater of streams over relatively short distances, rarely more than about 130 m, and possibly less than 25 m. Sheet flow is commonly estimated with a version of the kinematic wave equation, a derivative of Manning's equation, as follows (FHWA, 2001)

$$Tti = \frac{Ku}{I^{0.4}} \left(\frac{nL}{\sqrt[2]{S}}\right) \ldots\ldots\ldots\ldots (2.3)$$

Where:

$T_{ti}$ = sheet flow travel time, min
n = roughness coefficient. (See table A-22 in the appendix III)
L = flow length, m
I = rainfall intensity, mm/hr
S = surface slope, m/m
$K_u$ = empirical coefficient equal to 6.92

Since I depend on tc and tc is not initially known, the computation of tc is an iterative process. An initial estimate of tc is assumed and used to obtain I from the IDF curve for the locality. The tc is then computed from equation 2.3 and used to check the initial value of tc. If they are not the same, the process is repeated until two successive tc estimates are the same.

**Shallow Concentrated Flow Velocity**

After short distances of at most 130 m, sheet flow tends to concentrate in rills and then gullies of increasing proportions. Such flow is usually referred to as shallow concentrated flow. The velocity of such flow can be estimated using a relationship between velocity and slope as follows (FHWA, 2001)

V= $K_u\ K\ S_p\ ^{0.5}$……………. (2.4)

Where:

$K_u$ = 1.0

V = velocity, m/s

k = intercept coefficient (table 2.1)

Sp = slope, percent

Table 2.1 Intercept coefficient for Velocity Vs slope relationship (FHWA, 2001)

| **Land Cover/ Flow Regime** | **K** |
|---|---|
| Forest with heavy ground litter, hay meadow (Overland flow) | 0.076 |
| Trash fallow or minimum tillage cultivation; contour or strip cropped; woodland (overland flow) | 0.152 |
| Short grass pasture (overland flow) | 0.213 |
| Cultivated straight row (overland flow) | 0.274 |
| Nearly bare and untilled (overland flow); alluvial fans in western mountain region | 0.305 |
| Grassed waterway (shallow concentrated flow) | 0.457 |
| Unpaved area (shallow concentrated flow); small upland gullies | 0.491 |
| Paved area (shallow concentrated flow); small upland gullies | 0.619 |

**Open Channel and Pipe Flow Velocity**

Flow in gullies empties into channels or pipes. Cross-section geometry and roughness should be obtained for all channel reaches in the watershed. Manning's equation can be used to estimate average flow velocities in pipes and open channels as follows: (FHWA, 2001).

$$v=\frac{K_u}{n}R^{2/3}S^{1/2} \ldots \ldots \ldots\ldots (2.5)$$

Where:

n = roughness coefficient (see table A-22 in appendix)

V = velocity, m/s

R = hydraulic radius (defined as the flow area divided by the wetted perimeter) m

S = slope, m/m

$K_u$ = units conversion factor equal to 1

For a circular pipe flowing full, the hydraulic radius is one-fourth of the diameter. For a wide rectangular channel (W > 10 d), the hydraulic radius is approximately equal to the depth. The travel time is then calculated as follows:

$$Tti= \frac{L}{60V} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

$T_{ti}$ = travel time for segment i, min

L = flow length for segment i, m

V = velocity for segment i, m/s

## 2.4. Pavement drainage

### 2.4.1. Design Frequency and Spread

The objective of highway urban drainage design is to provide for safe passage of vehicles during the design storm event. The design of a drainage system for a curbed highway pavement section is to collect runoff in the gutter and convey it to pavement inlets in a manner that provides reasonable safety for traffic and pedestrians at a reasonable cost. As spread from the curb increases, the risks of traffic accidents and delays, and the nuisance and possible hazard to pedestrian traffic increase.

The process of selecting the recurrence interval and spread for design involves; decisions regarding acceptable risks of accidents, traffic delays and acceptable costs for the drainage system. Risks associated with water on traffic lanes are greater with high traffic volumes, high speeds, and higher highway classifications than with lower volumes, speeds, and highway classifications (Debo and Reese, 2003)

Table 2.2 provides suggested minimum design frequencies and spread based on the type of highway and traffic speed.

Table 2.2 Suggested Minimum Design Frequencies and Spread (FHWA, 2001)

| **Road Classification** | **Design Frequency** | **Design Spread** |
|---|---|---|
| High volume or divided or bi - dire ctional | | |
| < 70 km/hr (45 mph) | 10 Years | shoulder + 1m (3 ft) |
| > 70 km/hr (45 mph) | 10 Years | Shoulder |
| Sag Point | 50 Years | Shoulder + 1m (3 ft) |
| | | |
| Collector | | |
| < 70 km/hr (45 mph) | 10 | 1/2 Driving Lane |
| >70 km/hr (45 mph) | 10 | Shoulder |
| Sag point | 10 | 1/2 Driving Lane |
| Low Street | | |
| Low ADT | 5 | 1/2 Driving Lane |
| High ADT | 10 | 1/2 Driving Lane |
| Sag point | 10 | 1/2 Driving Lane |

### 2.4.2 Flow in Gutters

Gutter Flow calculations are necessary to establish the spread of water on the shoulder, parking lane, or pavement section. A modification of the Manning's equation can be used for computing flow in triangular channels. The modification is necessary because the hydraulic radius in the equation does not adequately describe the gutter cross section, particularly where the top width of the water surface may be more than 40 times the depth at the curb. To compute gutter flow, the Manning's equation is integrated for an increment of width across the section. The resulting equation is: (FHWA, 2001)

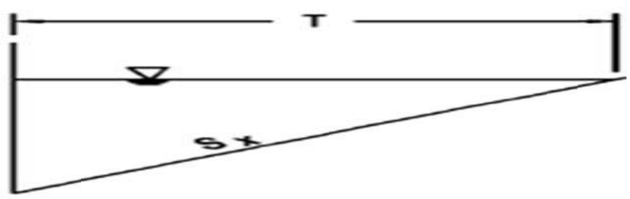



Figure 2.4 Triangular gutter cross section

$$Q = \frac{KuSx^{1.67}SL^{0.5}T^{2.67}}{n} \quad \ldots\ldots (2.7)$$

Or in terms of T

$$T = \left(\frac{Qn}{KuSx^{1.67}SL^{0.5}}\right)^{0.375} \ldots\ldots\ldots\ldots (2.8)$$

Where:

Ku=0.376

n=Manning's coefficient (refer table C&D)

Q = flow rate, $m^3/s$

T = width of flow (spread), m

$S_x$ = cross slope, m/m

$S_L$ = longitudinal slope, m/m

Spreads on the pavement and flow depth at the curb are often used as criteria for spacing pavement drainage inlets.

d= TSx………………………………. (2.9)

Where:

d = depth of flow, m

T= Width of flow (spread), m

Sx= Cross Sectional Slope

Table 2.3 Manning's n for Street and Pavement Gutters (FHWA, 2001)

| **Types of Gutter or Pavement** | **manning's** |
|---|---|
| concrete gutter | 0.012 |
| Asphalt Pavement | |
| Smooth texture | 0.013 |
| Rough texture | 0.016 |
| Concrete gutter asphalt pavement | |
| Smooth texture | 0.013 |
| Rough | 0.015 |
| Concrete Pavement | |
| Float Finish | 0.014 |
| Broom Finish | 0.016 |
| For gutter with small slope, where sedime0.02nt may accumulate , increase above values of "n" by | 0/02 |

### 2.4.3 Gutter Flow Time

The Flow time in gutters is an important component of the time of concentration for the contributing drainage area to an inlet. To find the gutter flow component of the time of concentration, a method for estimating the average velocity in a reach of gutter is needed. The velocity in a gutter varies with the flow rate and the flow rate varies with the distance along the gutter, i.e., both the velocity and flow rate in a gutter are spatially varied. The time of flow can be estimated by dividing the length of the gutter with an average velocity obtained in equation 2.10 (Debo and Reese, 2003).

$$v= \frac{Ku({s_L}^{0.5}{s_x}^{0.67}T^{0.67})}{n} \quad \text{(2.10)}$$

Where:

$K_u$ = 0.752

T = width of flow (spread), m

$S_x$ = cross slope, m/m

$S_L$=Longitudinal Slope

m/ n = manning

coefficient (table 2.3)

V = velocity in the triangular channel, m/s

#### 2.4.4. Drainage Inlet Design

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 drainage system. Inadequate inlet capacity or poor inlet location may cause flooding on the roadway resulting in a hazard to the traveling public (Butlers and Davies, 2004).

#### 2.4.4.1 Inlet Types

Highway drain inlets are used to collect runoff and discharge it to an underground drainage system Inlets used for the drainage of highway surfaces can be divided into the following four classes:

1, Grate inlets
3, Slotted inlets
2, Combination inlets
4, Curb-opening inlets

Grate inlets consist of an opening in the gutter or ditch covered by a grate. Curb opening inlets are vertical openings in the curb covered by a top slab. The principal advantage of grate inlets is that they are installed along the roadway where the water is flowing. Their principal disadvantage is that they may be clogged by floating trash or debris. Curb inlets are most effective on flatter slopes, in sags, and with flows which typically carry significant amounts of floating debris. The interception capacity of curb-opening inlets decreases as the gutter grade steepens. Consequently, the use of curb-opening inlets is recommended in sags and on grades less than 3%. Slotted inlets consist of a pipe cut along the longitudinal axis with bars perpendicular to the opening to maintain the slotted opening. Combination inlets consist of both a curb-opening inlet and a grate inlet placed in a side-by-side configuration, but the curb opening may be located in part upstream of the grate (Debo and Reese, 2003).

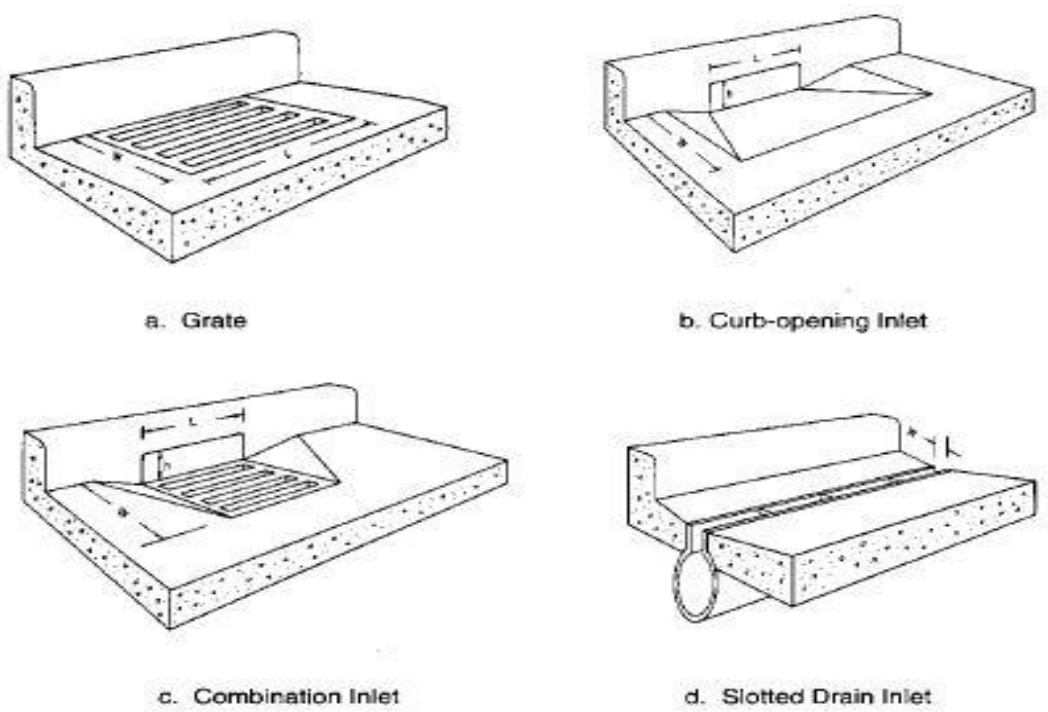



Figure 2.5 Classes of urban drain inlets

### 2.4.4.2. Factors Affecting Inlet Interception Capacity and Efficiency

Inlet interception capacity, $Q_i$, is the flow intercepted by an inlet under a given set of conditions. The efficiency of an inlet, E, is the percent of total flow that the inlet will intercept for those conditions. The efficiency of an inlet changes with changes in cross slope, longitudinal slope, total gutter flow, and, to a lesser extent, pavement roughness. In mathematical form, efficiency, E, is defined by the following equation.

$$E=\frac{Qi}{Q} \quad (2.11)$$

Where:

E = inlet efficiency

Q = total gutter flow, $m^3/s$

$Q_i$ = intercepted flow, $m^3/s$

Flow that is not intercepted by an inlet is termed carryover or bypass and is defined as follows:

$$Qb=Q-Qi \quad (2.12)$$

Where

$Q_b$= bypass flow, $m^3/s$

Q=Discarge $m^3/s$

The interception capacity of all inlet configurations increases with increasing flow rates, and inlet efficiency generally decreases with increasing flow rates. Factors affecting gutter flow also affect inlet interception capacity. The depth of water next to the curb is the major factor in the interception capacity of both grate inlets and curb-opening inlets. The interception capacity of a grate inlet depends on the amount of water flowing over the grate, the size and configuration of the grate and the velocity of flow in the gutter. The efficiency of a grate is dependent on the same factors and total flow in the gutter. Interception capacity of a curb-opening inlet is largely dependent on flow depth at the curb and curbs opening length. Flow depth at the curb and consequently, curb-opening inlet interception capacity and efficiency, is increased by the use of a local gutter depression at the curb-opening or a continuously depressed gutter to increase the proportion of the total flow adjacent to the curb. Top slab supports placed flush with the curb line can substantially reduce the interception capacity of curb openings (FHWA, 2001).

## 2.4.4.3. Interception Capacity of Curb-Opening Inlets

Curb-opening inlets are effective in the drainage of highway pavements where flow depth at the curb is sufficient for the inlet to perform efficiently, as discussed in above. Curb openings are less susceptible to clogging and offer little interference to traffic operation. They are a viable alternative to grates on flatter grades where grates would be in traffic lanes or would be hazardous for pedestrians or bicyclists. Curb opening heights vary in dimension; however, a typical maximum height is approximately 100 to 150 mm (4 to 6 in). The length of the curb opening inlet required for total interception of gutter flow on a pavement section with a uniform cross slope is expressed by equation.

$$L_{T=} k_u(Q^{0.42} {s_L}^{0.3} (\frac{1}{nsx})^{0.6} \text{..................} (2.17)$$

Where:

L = curb-opening length, m

$K_u$ = 0.817 n = manning coefficient (table 2.3)

$L_T$ = curb opening length required to intercept 100 percent of the gutter flow, m

$S_L$ = longitudinal slope

Q = gutter flow, $m^3/s$

The efficiency of curb-opening inlets shorter than the length required for total interception is expressed by equation

$$E=1-(1-\frac{L}{L_T})^{1.8} \text{...............................} (2.18)$$

Where:

L = curb-opening length, m

The length of inlet required for total interception by depressed curb-opening inlets or curb openings in depressed gutter sections can be found by the use of an equivalent cross slope, Se, in equation above in place of Sx. Se can be computed using equation below.

Se= Sx+ Sw Eo………………………….….. (2.19)

Where:

S'w = cross slope of the gutter measured from the cross slope of the pavement, Sx, m/m

S'w = a / [1000 W], for W in m; or = $S_W - S_X$

a = gutter depression, mm

Eo = ratio of flow in the depressed section to total gutter flow determined by the gutter configuration upstream of the inlet. Eo is the same ratio as used to compute the frontal flow interception of a grate inlet (Mays, 2004)

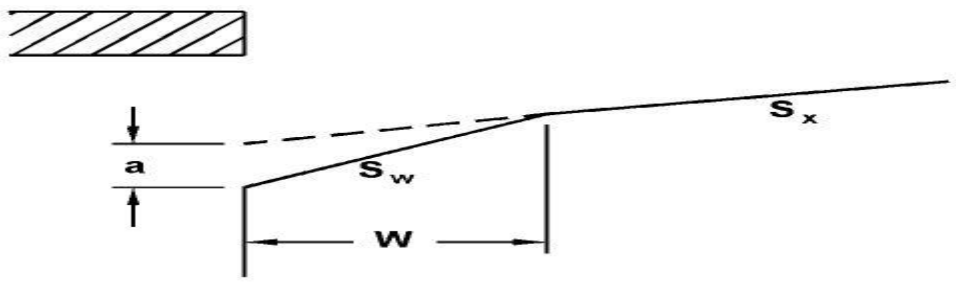



Figure 2.6 Depressed curb opening inlet..

The location of inlets is determined by geometric controls which require inlets at specific locations, the use and location of flanking inlets in sag vertical curves, and the criterion of spread on the pavement. In order to adequately design the location of the inlets for a given project, the following information is needed:

Layout or plan sheet suitable for outlining drainage areas

- Road profiles
- Typical cross sections
- Grading cross sections
- Super elevation diagrams
- Contour maps

There are a number of locations where inlets may be necessary with little regard to contributing drainage area. These locations should be marked on the plans prior to any computations regarding discharge, water spread, inlet capacity, or flow bypass. Examples of such locations follow.

- At all low points in the gutter grade
- Immediately upstream of median breaks, entrance/exit ramp gores, cross walks, and street intersections., i.e., at any location where water could flow onto the travel way
- Immediately upgrade of bridges (to prevent pavement drainage from flowing onto bridge decks)
- Immediately downstream of bridges (to intercept bridge deck drainage)
- Immediately upgrade of cross slope reversals
- Immediately upgrade from pedestrian cross walks
- At the end of channels in cut sections
- On side streets immediately upgrade from intersection
- Behind curbs, shoulders or sidewalks to drain low area

In addition to the areas identified above, runoff from areas draining towards the highway pavement should be intercepted by roadside channels or inlets before it reaches the roadway. This applies to drainage from cut slopes, side streets, and other areas alongside the pavement. Curbed pavement sections and pavement drainage inlets are inefficient means for handling extraneous drainage (FHWA, 2001)

## 2.5. Storm drains

A storm drain is that portion of the highway drainage system which receives surface water through inlets and conveys the water through conduits to an outfall. It is composed of different lengths and sizes of pipe or conduit connected by appurtenant structures (Butlers and Davies, 2004)

## 2.5.1. Hydraulics of urban Drainage Systems

### 2.5.1.1 Flow Type Assumptions

The design procedures presented here assume that flow within each urban drain segment is steady and uniform. This means that the discharge and flow depth in each segment are assumed to be constant with respect to time and distance. Also, since storm drain conduits are typically prismatic, the average velocity throughout a segment is considered to be constant. In actual storm drainage systems, the flow at each inlet is variable, and flow conditions are not truly steady or uniform. However, since the usual hydrologic methods employed in storm drain design are based on computed peak discharges at the beginning of each run, it is a conservative practice to design using the steady uniform flow assumption (Debo and Reese, 2003)

### 2.5.1.2. Hydraulic Capacity

The hydraulic capacity of urban drain is controlled by its size, shape, slope, and friction resistance. Several flow friction formulas have been advanced which define the relationship between flow capacity and these parameters. The most widely used formula for gravity and pressure flow in urban drains is Manning's Equation (AACRA, 2003)

$$V=\frac{K\text{v}}{n}D^{0.6}{s_o}^{0.5} \quad \ldots\ldots\ldots\ldots\ldots (2.20)$$

$$Q=\frac{KQ}{n}D^{6.67}{s_o}^{0.5} \ldots\ldots\ldots\ldots\ldots\ldots \text{(2.21)}$$

Where

V = mean velocity, m/s

Q = rate of flow, m3/s

$K_V$09

$K_Q$=

n = Manning's coefficient (refer table 7-1)

D = storm drain diameter, m

$S_o$ = slope of the hydraulic grade line, m/m

The value of manning coefficient is indicated in table D&E in the Appendix iv.

Table 2.4 Manning's Coefficients for Storm Drain Conduits (Larry W. Mays, 2004)

| **Type of culvert** | **Roughness corrugation** | **Manning's n** |
|---|---|---|
| Concrete Pipe | Smooth | 0.010-0.011 |
| Concrete Boxes | Smooth | 0.012-0.015 |
| Spiral Rib Metal Pipe | Smooth | 0.010-0.011 |
| Corrugated Polyethylene | Smooth | 0.009-0.015 |
| Corrugated Polyethylene | Corrugated | 0.018-0.025 |
| Polyvinyl chloride (PVC) | Smooth | 0.009-0.011 |

# CHAPTER THREE

# RESEARCH METHODOLOGY

## 3.1 Study Area

### 3.1.1 Location of study area

Addis Ketema Sub-city is located in the capital city of Ethiopia, Addis Ababa. It is located between 38° 44' 24 " E latitude and 8° 1' 48" N longitude. It is situated at the center and is accessible to all parts of the city, Addis Ababa It is one the largest town and geographically it is flattened and sloppy surface and weina–dega climatic conditions. The annually rain season is from February-October. It has many major road across the town and more of the towns of major and internal roads are covered by asphalt concrete pavement road and cobblestone. (Addis Ababa City Administration Integrated Land information center, April 2013).

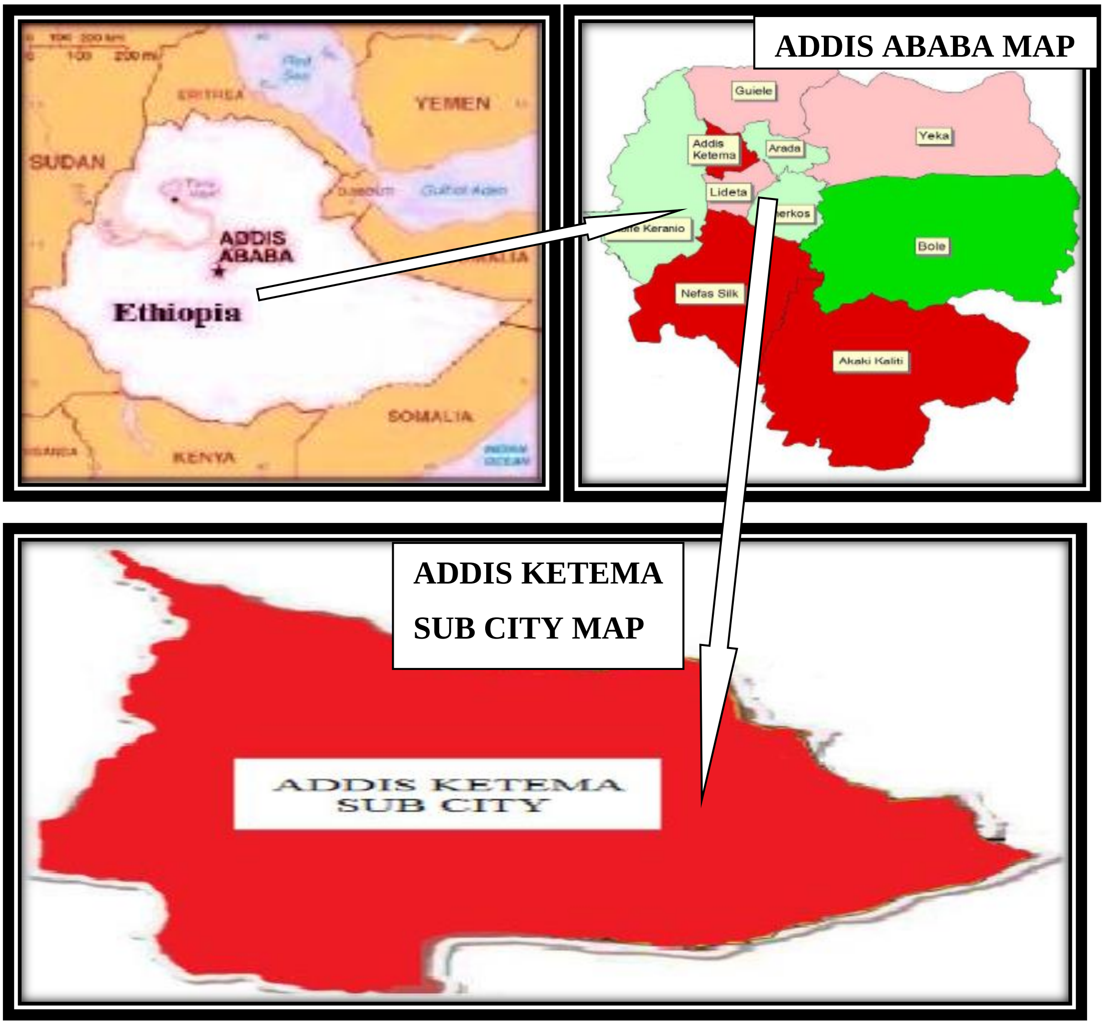



Figure 3.1 Ethiopia, Addis Ababa, Addis Ketema sub city map (ICL, 2016)

### 3.1.2 Topography (Relif)

Elevation is an indicator that enables a simple understanding of Topography (relief) for a given area. From the Elevation map we can see that Addis Ketema is characterized by a homogeneous type of topography with insignificant elevation difference. Generally in the sub city, the altitude ranged from 2343 to 2546 meters above sea level which have a range of 203 meters. (Addis Ababa City Administration Integrated Land information center, April 2013).

The following routes are the research study are

- ✓ Pauster To Sebategna - Abinet Roads
- ✓ Mesalemiya - Autobus Tera - Goijjam Berenda Road

### 3.1.3 Slope (Steepness)

Slope is another means describing topography for a given area.it is a measure of terrain steepness that is the degree to which land is not horizontal .The range of slope values in degrees is 0 to 90.For percent rise, There is 0 for near infinity. A Flat suface is 0 percent, a 45 degree surface is 100 percent, and as the suface becomes more vertical, the percent rise becomes increasingly larger." In this slope analysis map, slope is measured as perecentage rise classified in to 6 different ranges. Addis Ketema is undulating to rolling surfaced sub city in which 77.92 % of its land area comprising less than 10% slope (Addis Ababa City Administration Integrated Land information center, April 2013).

### 3.1.4 Climate

Addis ketema sub city has warm temperature rainy climate .its distinct dry month is winter .the mean temperature of coldest month is 18 $^{o}$c and for more than four month above 10 $^{o}$c. rain fall of the driest winter month is less than one tenth of wettest summer month. The rain fall amount and its distribution vary considerably from one area to other such that the lowest is about 60 cm and highest is about 200cm. (Addis Ababa City Administration Integrated Land information center, April 2013).

### 3.1.5 Soil character

The geological formation of the project area are mainly composed of basaltic and trachtte ,which is derived from volcanic rock that have been decompose to various degree In particular major geology soil formation is a residue derived from basaltic and trachytic rock. The formation of the residue soil is classified mainly as clay and black cotton soil. (Addis Ababa City Administration Integrated Land information center, April 2013).

## 3.2 investigation Methodology

Based on the data collected on the site and design report, the following methodology is adopted to investigate the cause of the problem. The construction and urban drainage operation of the system is evaluated by preparing questioner, observing the existing construction and operation system of the urban drainage. To evaluate the curb in let Efficiency, first researcher have to check the existing interception and hydraulic capacity of curb inlet and by assessing other contributing factor .finally we try to identify the success and the short coming of the drainage system.

## 3.3 Research Design

The study was both quantitative and qualitative because, among other things, it involved the observation of the nature of the drainage as well as the collection of the views from the community, especially those aimed at establishing whether there was any notable human interference with streams causing any observable drainage related problem. In this design a number of variables were investigated, and measures so far taken to reduce poor drainage systems in Addis Ketema sub city. Analytical level of data collection was used for some variables depending on the facts to arrive at the conclusion. The survey design was made in sketched samples of the findings, thus from carefully selected samples more information was gathered.

**Study Population:** Drainage structures along the study Area.

**Sampling Technique:** For the better accomplishment of this research systematic random sampling technique were used.

## 3.4 Sample size selection

For this research study the field observation study was required representative sample size of highway drainage system operation calculated by using the formula below.

$$n = \frac{Z^2PqN}{e^2(N-1)+Z^2pq}$$ ……….…………3.1 (Chava and Nachmias, 1996)

Representative Sample Size (n) of Pauster-Sebategna-Abinet Road curb inlet Drainage structures.

Where: N=Number of total population is 318, n=sample size; p=sample population assuming a 95% confidence level of the target population; q=1-p, e=Acceptable error i.e. 5% while Z=the standard normal deviate at the required confidence level i.e. 1.96.

$$n = \frac{1.96^2 * 0.95 * (1-0.95) * 318}{0.05^2(248-1) + 1.96^2 * 0.95(1-0.95)}$$

n = 72.6 or say 73 curb inlet (Sample Frame used is 72 curb inlet)

Representative Sample Size (n) of curb inlets are tabulated below

Table 3.1 Representative Sample Size (n) of curb inlet Drainage structures

| NO | ROUTE | Number of curb in let structure (N) | Required sample size of (n) |
|---|---|---|---|
| 1 | Pauster-Sebategna-Abinet Road | 318 | 73 |
| 2 | Mesalemiya-autobustera-Gojjam berenda Road | 324 | 74 |

## 3.5 Study Variables

### 3.5.1 Dependent variable:

Highway drainage system problem and its effect

### 3.5.2 Independent variable:

- ✓ Inlet spacing
- ✓ Hydraulic capacity of Pipe culvert
- ✓ Longitudinal slope
- ✓ Flow Velocity
- ✓ Hydrological Morphometry parameters
  - Melton ration
  - Drainage density

## 3.6 Data Collection and Data Analysis

### 3.6.1 Data Collection

**Instruments in data collection**

A number of instruments were used for data collection including Tape, photo camera, leveling machine

#### 3.6.1.1 Primary data

**1 Direct observations and photograph**

The data collection techniques stated above were supplemented with field observation and survey photography, to enable the identification of the problem.

**2. Field survey & design drawings**.

To attain the stated objectives, various data were collected by direct field survey and from design drawings. Primary data which are collected during field survey includes:

- Existing inlet type and spacing
- Operating management of Inlets
- Size and existing condition of curb inlet

These data were collected in the research period. January 2017 and February 2017 are the two months when the data was collected. In addition to the primary data, there are also secondary data which are collected during the research period in the month of July 2017 and August 2017. These data includes

#### 3.6.1.2 Secondary data

Publications, journals, newsletters, and newspapers among other sources were used so as to gather literature review on the status of education and awareness

- Topographic maps
- Digital Elevation Models (DEMs),
- Land use map of the study area
- Contour map of the study area
- Cross slope and longitudinal slope of the road in the study areas
- IDF curve of the study area

### 3.6.2 Data analysis

#### 3.6.2.1 Hydrology and Hydraulics Evaluation

From the design report of the study area, we observe that rational method was used to estimate the peak flow of the study areas. The rational method is a reasonable formula for computing the peak discharge for small catchment. We need to evaluate the hydrology and hydraulics of the study areas because of the following reasons:

While using the rational formula in pauster To Sebategna - Abinet Roads , Sefere selam - Autobus Tera- Goijjam Berenda Road and the Kirpich formula was used in the original design but Kirpich formula was developed for rural areas and used for a well-defined channel and steep slopes having a slope of (3% to 10 %). For evaluation we choose Federal aviation administration formula which is frequently used and recommended for urban basin (Chow, etal)

In the design report of (Autobus Tera) - Goijjam Berenda road, the area is calculated only by considering the road pavement and walk way but sheet flow up to 150 m can contribute to the peak flow. So we have to consider areas contributing to the inlet beyond the road surface. In the design report, the intensity of rain fall is calculated by taking nearest station which is the observatory metrology station.

Addis Ketema Subcity Boundary and Road Net Work

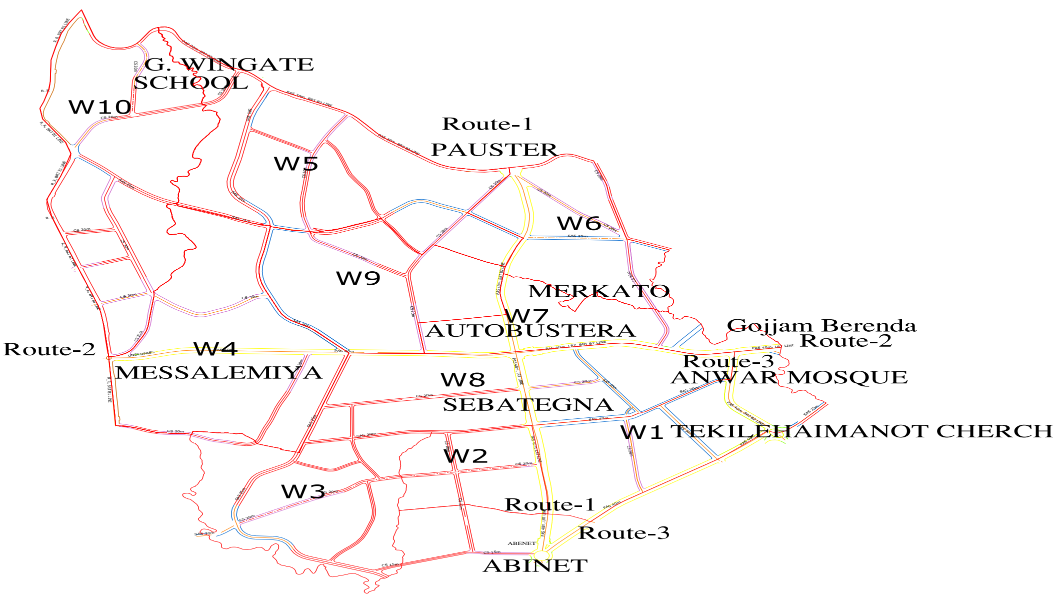



Figure 2 Road Net Work of the study area (Addis ababa city Road Autority ,2013)

ROUTE -1 pauster -Sebategna - Abinet Roads it covers 3.180 km

ROUTE-2 Sefere Selam - Autobus Tera- Goijjam Berenda Road it covers 3.239 km.

- ✓ To check the efficiency of inlet used in the study area we have to re-design the system to get the parameters used in inlet efficiency calculation.

### 3.6.2.2 Inlet spacing

Based on the concept, primary inlet are allocated along the alignment of the road and then using inlet spacing sheet in the appendix II inlets are spaced along the road Spreads on the pavement and flow depth at the curb are often used as criteria for using the spread sheet. The basic parameters in the spread sheet are obtained as follows:

Drainage area*:* - Using contour map, road alignment and cross section; the areas which contribute to a particular inlet is approximately calculated.

Time of concentration: - time of concentration can easily be computed using federal aviation administration formula (1970) which is frequently used and recommended for over land flow in urban basin. (Chow, etal, 2004).

$$T_c = 1.8*(1.1-C)* \frac{L^{0.5}}{S^{0.33}} \qquad (3.2)$$

Where:

C= Rational method runoff coefficient
L= Length of overland flow, ft
S= Surface slope, %
Rainfall Intensity and flow (Q): IDF curve is used for determining rainfall intensity. The Curve was prepared using the data obtained from the metrological stations (Addis Ababa Observatory).

IDF Curve

The flow (Q),

Runoff coefficient(C),
Velocity (V),
Ratio of flow in depressed section to total gutter flow ($E_o$),
Intercepted flow ($Q_i$),

By pass flow ($Q_b$) and

Efficiency (E) are calculate

**Design frequency and spread**:

The spread and design frequency of the roads selected based on table 2.2. Pauster-Sebategna - Abinet and Sefere Selam-Autobis tera Roads are high volume roads having speed < 70 km/hr. So the design frequency selected for the design is 10 years and design spread becomes shoulder + 1m. For all roads at the sag point design frequency is taken as 50 years and the design spread is become shoulder + 1m.The calculated spread according to equation 2.8 should be less than design spread written above. If the calculated spread exceeds the design spread, we have to decrease inlet spacing until we get safe design spread as well as the depth at the curb become less than the curb h

### 3.6.2.3 Hydraulic capacity of Pipe sizing

the hydraulic capacity of the existing pipe sizing is done based on the computation sheet in the appendix II and like inlet spacing basic parameters are calculated as follows

**Peak discharge**

Rational Formula

The Rational Method is based on the Rational Formula:

Q = CIA/360 ……………………………..….(3.3)

Where:

Q = the peak rate of runoff (cfs)

C = Runoff coefficient–a non-dimensional coefficient equal to the ratio of runoff volume to Rainfall volume

I = average intensity of rainfall for a duration equal to the time of concentration, tc (inches/hour)

A = tributary area (acres).

Actually, Q has a unit of inches per hour per acre (in/hour/ac); however, since this rate of acreinches/hour differs from cubic feet per second (cfs) by less than one percent, the more common units of cfs are used. The time of concentration is defined as the time required for water to flow from the most remote point of the tributary area to the design point, and is determined for the selected flow length that represents the longest waterway through a rural watershed or the most representative flow path through the impervious portion in an urban catchment. The general procedure for Rational Method calculations for a single catchment is as follows:

1. Delineate the catchment boundary and determine its area.

2. Determine the overland flow length and slope of each reach.

3. Determine the time of concentration, tc, for the selected waterway.

4. Find the rainfall intensity, I, for the design storm using the calculated tc and the rainfall intensity duration-frequency curve.

5. Determine the runoff coefficient, C.

6. Calculate the peak flow rate, Q, from the catchment.

2.2 Assumptions

The basic assumptions for the application of the Rational Method include:

1. The computed maximum rate of runoff to the design point is a function of the average rainfall rate.

During the time of concentration to that point.

2. The hydrologic losses in the catchment are homogeneous and uniform. The runoff coefficients vary.

With respect to type of soils, imperviousness percentage, and rainfall frequencies. These coefficients.

Represent the average antecedent soil moisture condition.

3. The depth of rainfall used is one that occurs from the start of the storm to the time of concentration.

The design rainfall depth during that period is converted to the average rainfall intensity for that Period.

4. The maximum runoff rate occurs when the entire area is contributing flow. This assumption is not.

Valid where a more intensely developed portion of the catchment with a shorter time of concentration.

**Runoff Coefficient**

The runoff coefficient, C is a function of the ground cover and a host of other hydrologic abstractions. It relates the estimated peak discharge to a theoretical maximum of 100% runoff. Typical values for C are given in Table 3-1. If the basin contains varying amounts of different land cover or other abstractions, a composite coefficient can be calculated through areal weighing as follows.

Weighted C = Σ (Cx Ax)/Atotal …………………………….. (3.4)

Where: x=Subscript designating values for incremental areas with consistent land cover

**Drainage area**: The length of the contributing area can be taken the distance between the two consecutive inlets and the width can be taken from the top map of the area, so we can easily estimate the contributing area by multiplying the length with the width.

**Time of concentration**: Inlet time is obtained the same way as we used in inlet spacing spread sheet but to get the system time we have to consider the time at which the storm pass through the catchment area.

**3.6.2.4 Longitudinal slope of the road**: Longitudinal slope is a roadway feature considered during gutter, inlet, and pavement drainage design analysis. The following general guidelines are presented: A minimum longitudinal gradient is more important for a curbed pavement than for an uncurbed pavement since the water is constrained by the curb. However, flat gradients on uncurbed pavements can lead to a spread problem if vegetation or other debris is allowed to build up along the pavement edge.

Desirable gutter grades should not be less than 0.5 percent for curbed pavements with an absolute minimum of 0.3 percent. Minimum grades can be maintained in very flat terrain by use of a rolling profile, or by warping the cross slope to achieve rolling gutter profiles. To provide adequate drainage in sag vertical curves, a minimum slope of 0.3 percent should be maintained within 50 feet of the low point of the curve.

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.

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.

### 3.6.2.5 Drainage and Morphometry of hydrology Evaluation

#### 3.6.2.5.1 Digital elevation model (DEM)

Topography is defined by a digital elevation model (DEM) that describe that elevation of any point in a given area at a specific spatial resolution .in other word, the dem is any digital representation of a topographic surface and specifically to raster or regular grid of spot height .it is a basic input of ARC GIS to get watershed and river or stream. The 90by 90 meter resolution DEM was used to get the Watershed and to analyze the drainage problem and Morphometry of hydrology .the 90*90 D.E.M for Addis ketema sub city basin was obtained from ministry of water resources (MOWR), GIS and remote sensing branch and before the DEM data was load in to arc GIS interface it was converted in the grid format using conversion tool of ARC GIS 10.3 software. It was also projected in to coordinate system wgs 1984_utm_zone 38N.

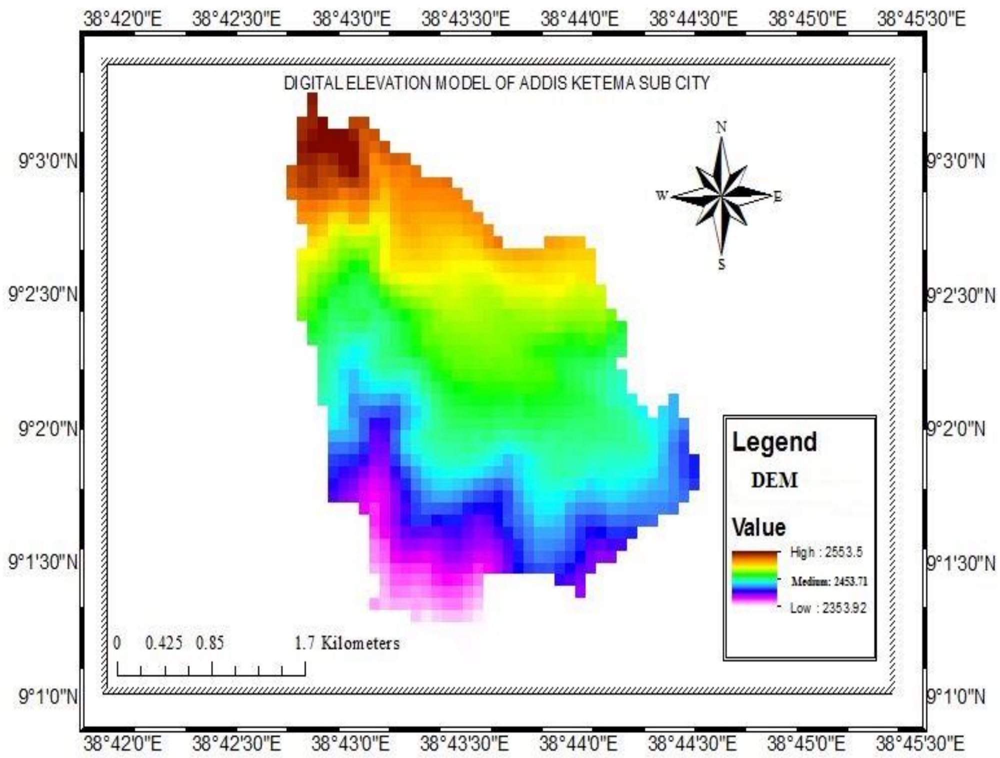



Figure 3.3 Digital elevation model of study Area (DEM)

### **3.6.2.5.2**. Topographical map of the study area

Topographical map is a detailed two–dimensional representation of natural and human made feature on the earth's surface? To get the boundary of the study area on the DEM Addis ababa topographic map with Coordinate system wgs 1984_utm_zone 38N Extract by mask by Using ARC GIS software was used. Addis Ababa topographic map was obtained from Ethiopia mapping agency.

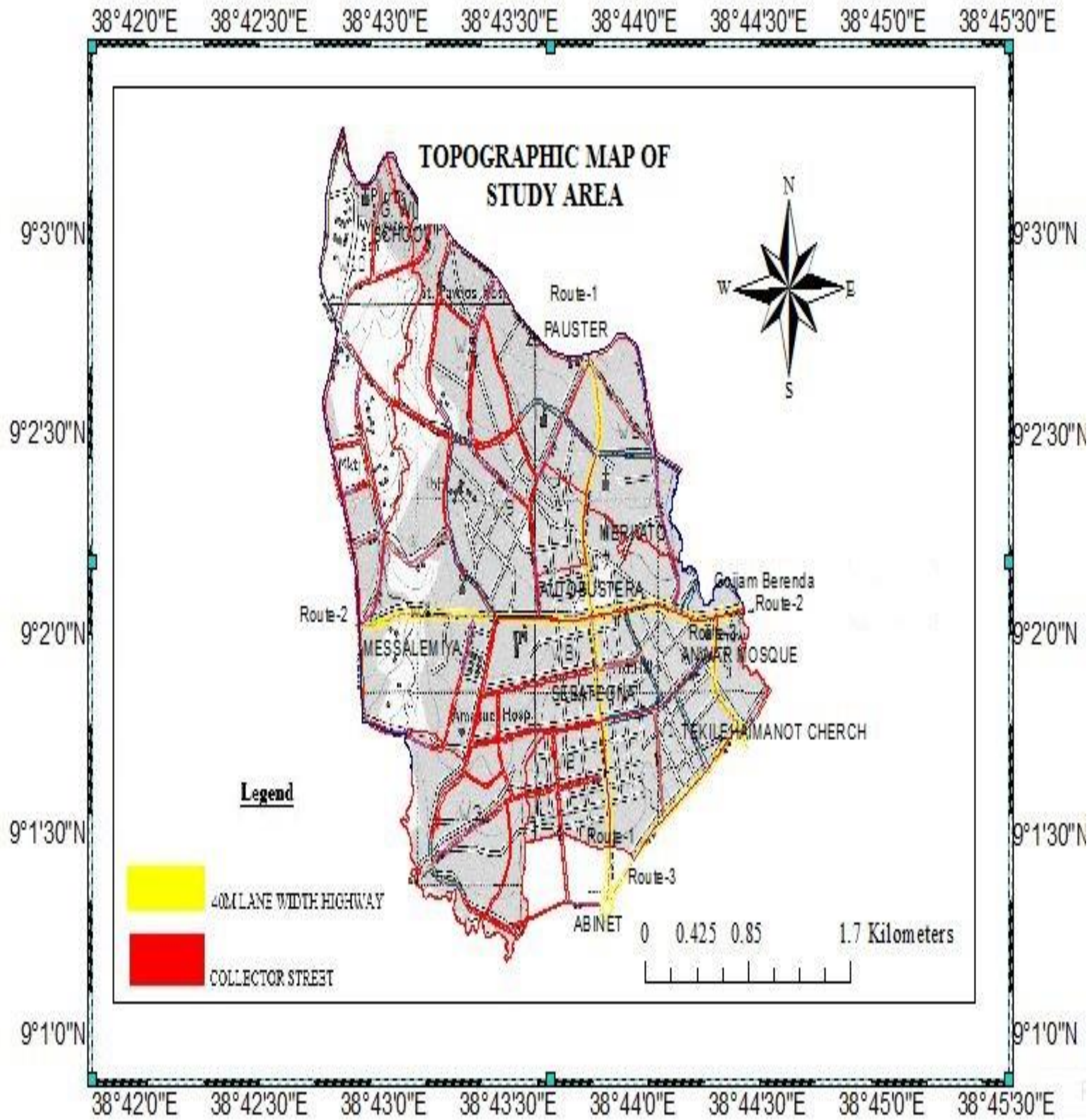



Figure 4 Topographical map of the study area

### 3.6.2.5.3 **Melton Ratio**

$$(R) = \frac{\text{Max. Basin relief - Min. basin relief}}{\sqrt{A_b}} \quad \ldots\ldots\ldots\ldots 3.5$$

Where,

(R) = Melton Ratio

Ab = Area of basin,

R= Melton ratio

Table 3.22 watershed feature type attribute and geometric output of the study area

| Future type | Attribute | | | | Geometry | | |
|---|---|---|---|---|---|---|---|
| | ID | inflow | outflow | Drainage Area (m2) | Length (Km) | Elevation(M) | |
| | | | | | | Min | Max |
| Watershed | 1 | 45 | 168 | 1.428 | 1.097 | 2446 | 2499 |
| | 2 | 41 | 266 | 2.261 | 2.67 | 2420 | 2497 |
| | 3 | 41 | 46 | 0.3909 | 0.389 | 2446 | 2461 |
| | 4 | 219 | 258 | 2.193 | 0.719 | 2412 | 2446 |
| | 5 | 40 | 86 | 0.731 | 0.341 | 2412 | 2435 |
| | 6 | 347 | 430 | 3.654 | 1.014 | 2376 | 2412 |
| | 7 | 45 | 202 | 1.717 | 1.556 | 2353 | 2439 |
| | 8 | 41 | 100 | 0.85 | 0.433 | 2400 | 2431 |
| | 9 | 40 | 50 | 0.4249 | 0.259 | 2366 | 2376 |
| SUM | - | 859 | 1606 | 13.6498 | 8.478 | - | - |

### 3.6.2.5.4 Drainage Density

**(Dd)** $=L_u/A$ ……………………………………3.5

Where
Dd, = density (Km/Km2)
$L_u$=total stream length, and
A=Drainage Area ($Km^2$

Table 3.3 stream feature type attribute and geometry output of the study area

| Future type | Attribute | Geometry | |
|---|---|---|---|
| | ID | Perimeter( 9km) | Drainage Area (km2) |
| Stream | 1 | 6.435 | 1.436 |
| | 2 | 10.659 | 2.269 |
| | 3 | 4.232 | 0.3994 |
| | 4 | 3.493 | 0.3654 |
| | 5 | 4.779 | 0.739 |
| | 6 | 4.78 | 0.722 |
| | 7 | 8.641 | 1.725 |
| | 8 | 5.514 | 0.858 |
| | 9 | 3.495 | 0.4334 |
| sum | 9 | 52,028 | 8.942 |

### 3.6.2.6 Urban Drainage Operation Management Evaluation

Pauster - Sebategna - Abinet Roads and SefereSelam - Autobus Tera - Goijjam Berenda Road is evaluated by direct observation of curb inlet condition, Disposal of solid and liquid waste which affected the drainage system, and the condition of curbs after construction. The Curb inlet conditions in the area are categorized in to three. The first categories are inlets working without problem. The second categories are inlets whose covers are partially removed due to poor awareness and illegal people. Even if the second category of inlets operates properly, they are highly exposed to be filled with debris and silt. So, the researcher categories these inlets as inlets operate with problem.

The last categories of inlets are inlets inlets whose covers are totally removed and which are totally out of function due to totally filled with silt and garbage , pavement and cover overlap and Inlet opening blocked by cement morta. The researcher tries to identify the three categories of inlet quantitatively. The above data collected are helpful to identify the cause of the problem which is going to be investigated on this research. Data analysis began by arranging data collected from the field is summarized as shown in tabular form.

Table 3.4 Summary of curb Inlets Data at Pauster-Sebategna-Abinet Road

| S.no | Description | Number | Remark |
|---|---|---|---|
| 1 | Inlets in good condition | 27 | Curb Inlets function (operate) properly |
| 2 | Inlets in fair condition | 11 | Curb Inlets function(operate) with problem some part of opening filled with silt and garbage |
| 3 | Inlets in poor condition | 34 | Cub Inlets out function with cover or without cover<br>➢ totally filled with silt and garbage<br>➢ pavement and cover overlap<br>➢ Inlet opening blocked by cement mortar |
| | **Total** | 73 | |

Fig 3.5 a) Inlets in good condition

Fig 3.5 b) Inlets without cover (removed), filled with silt and out of function

Fig3.5 c) Inlets with cover but totally filled with silt and out of function

Fig 3.5 d) Inlet operate with problem

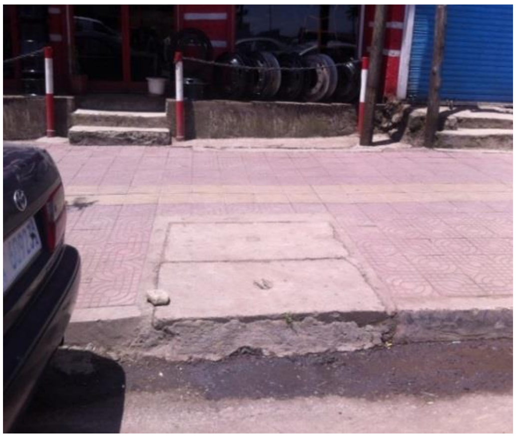


Fig3.5e) Curb inlets opening blocked by c cement mortar I

Fig 3.5 f) Curb inlet opening Curb inlets opening blocked by solid waste

Figure 3.5 a,-f ) Condition of inlet and curs in Pauster To Sebategna Abinet Roads(January 2018)

Table 3.5 Summary of curb Inlets Data at Sefere Selam-Autobustera-Gojjam berenda Road

| S.no | Description | Number | Remark |
|---|---|---|---|
| 1 | Inlets in good condition | 20 | Curb Inlets function (operate) properly |
| 2 | Inlets in fair condition | 16 | Curb Inlets function(operate) with problem some part of opening filled with silt and garbage |
| 3 | Inlets in poor condition | 38 | Cub Inlets out function with cover or without cover<br>➢ totally filled with silt and garbage<br>➢ pavement and cover overlap<br>➢ Inlet opening blocked by cement mortar |
| | **Total** | 74 | |

Fig 3.6 a) Inlets in good condition

Fig 3.6 b) Inlets without cover (removed), Filled with silt and out of function

*Fig 3.6 c)* Inlets with cover but totally filled With silt and out of function

*Fig 3.6 d)* Inlet operate with problem

Fig 3.6 e) Curb inlets opening Filled with silt and out of function

Fig 3.6 f) Curb inlet opening Blocked by cement Mortar

Figure 3.6 Condition of curbs inlet in sefere selam- Autobus Tera - Goijjam Berenda Road (January 2018 )

# CHAPTER FOUR

# RESULT AND DISCUSSION

This chapter includes all the discussions from survey findings after the questionnaire survey was carried out,

## 4.1 Respondents' profile

On This study the questionnaire has two parts there were selected totally one hundred (100) respondent from those the first part 36 respondents from highway consultant and contractor that were 12 from AACRA design office, 12 from Highway Engineers and consultant and 12 from co contractor. Accordingly In the second part, 64 respondents from the society, Sub city & Wereda administrators, 40 from Residential community, and 9 Sub city & Wereda administrators and 15 from Community based officer in the sub city was participated to respond the questioner.

Those all respondents were asked to identify the main causes of highway drainage system problem and to identify the major contributing factor. As show in appendix -c the distribution of number of questioner to the consultants, contractors and society. Under this section the results that have been obtained from processing of 100 questionnaires using Excel and the results are prepared to putting in percent the information.

### 4.1.1 Respondents Educational Background

The level of education of respondents during the questionnaires survey. From the total 100 questionnaires analyzed, 13 (13%) of the respondents had MSc, 48 (48%) hold a BSc. degree while 19 (19%) of them had a diploma, 16% high school completed and 4(4%) under high school grade. This result in the level of education indicate that site personnel were qualified enough to give reliable information by understanding each of the question of the questionnaire about highway drainage system problem and to identify the major contributing factor. And how it could be minimized.

## 4.2 Result obtained from questionnaires

Research questionnaires were given to both resident engineer and site Engineer who are responsible for design and construction of highway in Ethiopia to to identify the major contributing factor,

Table 4 .1 The major causes of highway drainage problem

| The major causes | Highway Engineering | Geotechnical Engineering | Hydraulic Engineer | Total | Percent |
|---|---|---|---|---|---|
| Lack of giving attention for drainage design in the road design | 2 | 2 | 3 | 7 | 19.4% |
| Lack of good operating management and maintenance | 6 | 5 | 4 | 15 | 41.6% |
| Unwise usage of the drainage system by the community | 3 | 4 | 5 | 12 | 33.3% |
| Poor construction of drainage structure | 1 | 1 | - | 2 | 5.5% |

As obtained from research result 19.4 % are Lack of giving detail attention for drainage design in the road design. 33.3% are unwise usage of the drainage system by the community. 41.6% Lack of good operating management and maintenance. Research questionnaires were given to both Residential community, Sub city & Wereda administrators who are responsible to protect one of their Infrastructure highway drainage problem to identify for the Cause of Blocked curb inlet opening by cement mortar or other material and Reason of bad smile of curb inlet opening

Table 4.2 Cause of Blocked curb inlet opening by cement mortar or other material

| The major causes of Blocked curb inlet opening by cement mortar | Residential community | Sub city & Wereda administrators | Community based officer in the sub city | Total | Percent |
|---|---|---|---|---|---|
| Lack of awareness in the community | 12 | 2 | 5 | 19 | 29.6% |
| Due to Bad smile that comes from curb inlet opening | 23 | 6 | 8 | 38 | 59.3% |
| To block the Dispose off solid wastes by the community | 5 | 1 | 3 | 9 | 14.0% |

As showen in the result The major causes of Blocked curb inlet opening by cement mortar 29.6 % are Lack of awareness in the community 14% are To block the Dispose off solid wastes by the community.59.35% are Due to Bad smile that comes from curb inlet opening

Table 4.3 Reason of bad smile of curb inlet opening

| The major causes | Residential community | Sub city & Wereda administrators | Community based officer in the sub city | Total | Percent |
|---|---|---|---|---|---|
| Connecting toilet sludge and sware pipe to the drainage pipe | 22 | 5 | 9 | 36 | 56.2 % |
| Due to the lack of operating and maintenance management | 13 | 3 | 4 | 20 | 31.2% |
| Due to dispose off solid wastes at the inlet opening | 5 | 1 | 2 | 8 | 12.5% |

As it can be seen in the result Reason of bad smile of curb inlet opening. 12.5% are Due to dispose off solid wastes at the inlet opening, 31.25% Due to the lack of operating and maintenance management,56.2% Connecting toilet sludge and sware pipe to the drainage pipe.

## 4.3 Curb Inlet Efficiency Evaluation

4.3.1 Pauster - Sebategna - Abinet Road (North to South)

And Mesalemiya - Autobus Tera – Gojjam Berenda Road (East –west)

**Inlet Spacing**

From the data collection chapter, we can observe that curb inlets are used for collecting storm water from the gutter. For evaluating the inlet spacing and the efficiency of the inlet, we use inlet spacing computation sheet in FHWA drainage design manual. According to the methodology used the full and detail new inlet spacing design computation sheet is done in the appendix. Here is the sample computation result of curb inlet spacing efficiency.

Initial inlet station = 0+000.000

Upper contributing station = 0+015.000

$S_x$ (cross slope of the road) = 2.5 %

$S_L$ (Longitudinal slope) = 4.07%

Qb (Previous by pass flow) = 0m$^3$/Sec, for initially

Length of sheet flow (L) = 81 (from contour map)

Run of coefficient (C) = 0.70 (from land use map, equation 2.2 and table E )

Slope of sheet flow (S) = 3.21% (from contour map)

Allowable spread = shoulder +1= 2.5 m

Area (A) = 81*(0+015.000-0+000.000) *10$^{-4}$ = 0.1215 ha

Time of concentration (equation 3.1)

$T_c$= 1.8*(1.1-0.7)* $\frac{(3.28*81)^{0.5}}{3.2^{0.33}}$ = 8.0226 min

From the IDF curve of observatory station I = 133.45 mm/hr.

Q (Total gutter flow, equation 2.2)

Q = $\frac{0.7*133.45*0.1215}{360}$ = 0.0315 m$^3$/Sec (equation 2.1)

T (Spread) = T=$(\frac{0.0315*0.016}{0.0376*0.025^{1.67}0.0407^{0.5}})^{0.375}$ = 1.5379 m < 2.5 m ok! (Using equation 2.8)

d (depth at the gutter) =1.5379 m*0.02=0.05142 m < 0.17 m ok! (Using equation 2.9)

Curb opening length required to intercept 100% of gutter flow

($L_T$) = $0.817 * (0.0315^{0.42} * 0407^{0.3} * (\frac{1}{0.016*0.025})^{0.6}$ =14.6936 m (using equation 2.17) Efficiency of curb inlet (E) = E=1-$(1-\frac{1}{6.194})^{1.8}$ =27.16 % (2.18) (using equation 2.18)

$Q_i$ (Intercepted flow) = 27.16 %*0.0315 = 0.0086 m$^3$ /sec (using equation 2.13)

Qb (by pass flow) = 0.0315 – 0.0086 = 0.023 m$^3$/sec (using equation 2.12)

This procedure will be repeated by assuming the next station of inlet and computing spread and depth of gutter. Starting from 0+000 up to 0+173 station tabulated in Tables Below.

This Evaluation of Efficiency for Existing Curb Inlet design computation has taken from Pauster - Sebategna - Abinet Road the detail computation sheet. The detail computation is shown in the appendix.

1, Existing curb inlet Efficiency

Table 4.4 **curb inlet efficiency**

| INLET N0 | Station | ELEVAT | Qb (m^3⁄s) | Q (m3/s) | T (m) | d (m) | Lt (m) | E(%) Efficie | Qi (m3/s) | Qb (m3/s) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0+000 | 2482.3436 | 0m^3⁄s | - | - | - | - | - | - | **0m^3⁄s** |
| 2 | 0+015 | 2481.6426 | 0m^3⁄s | 0.032 | 1.538 | 0.038 | 6.194 | 0.272 | 0.009 | 0.023 |
| 3 | 0+030 | 2481.0326 | 0.023 | 0.032 | 1.535 | 0.038 | 6.356 | 0.265 | 0.009 | 0.024 |
| 4 | 0+050 | 2480.3926 | 0.024 | 0.041 | 1.795 | 0.045 | 6.154 | 0.273 | 0.011 | 0.030 |
| 5 | 0+070 | 2479.7926 | 0.030 | 0.041 | 1.858 | 0.046 | 5.746 | 0.291 | 0.012 | 0.029 |
| 6 | 0+093 | 2479.2926 | 0.029 | 0.047 | 2.096 | 0.052 | 5.308 | 0.313 | 0.015 | 0.032 |
| 7 | 0+111 | 2478.8926 | 0.032 | 0.037 | 1.797 | 0.045 | 5.418 | 0.307 | 0.011 | 0.025 |
| 8 | 0+131 | 2478.4586 | 0.025 | 0.041 | 1.864 | 0.047 | 5.698 | 0.293 | 0.012 | 0.029 |
| 9 | 0+155 | 2477.9686 | 0.029 | 0.049 | 2.147 | 0.054 | 5.317 | 0.313 | 0.015 | 0.034 |
| 10 | 0+173 | 2477.5686 | 0.034 | 9.223 | 0.037 | 1.853 | 0.046 | 5.103 | 0.325 | 0.012 |

As identifed in the study from 84.5 % of curb inlets are less than 50 % ,only 15.5 curb inlet are above 50% effececy wihich in dicates efficency of curb in let to intercepted is less than by the by pass flow which means that 84.5 % of flow is bypass flow. According to the surface discharge ,alocation of the curb in let spacing station is too distant .due to this the efficency is decreased.

since surface driange dealth effectivly leading away the water that collectes on the pavement surface .becacuse of inadeqate intercepted Efficiency of curb in let the surface run off in the pavment and sholder have not been removed effectievly this condtion leades to the pavement and shouder to accumulate the run off on the pavemnt this also the main impact on pavement detoreration.and traffic flow.

Table 4.5 **Sefere selam - Autobus Tera – Gojjam Berenda Road**

| INLET N0 | Station | ELEVAT | Qb (m^3⁄s) | Q (m3/s) | T (m) | d (m) | Lt (m) | E(%) Efficie | Qi (m3/s) | Qb (m3/s) |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 0+000.000 | 2414.824 | 0m^3⁄s | - | - | - | **-** | **-** | **-** | 0.000 |
| 2 | 0+020.000 | 2414.766 | 0.000 | 0.043 | 2.171 | 0.043 | **6.704** | **0.252** | **0.011** | **0.032** |
| 3 | 0+040.000 | 2414.264 | 0.032 | 0.042 | 2.424 | 0.048 | **5.248** | **0.317** | **0.013** | **0.029** |
| 4 | 0+060.000 | 2413.995 | 0.029 | 0.041 | 2.899 | 0.058 | **3.540** | **0.450** | **0.018** | **0.023** |
| 5 | 0+085.000 | 2413.896 | 0.023 | 0.051 | 5.207 | 0.104 | **1.406** | **0.893** | **0.046** | **0.005** |
| 6 | 0+108.000 | 2413.89 | 0.005 | 0.070 | 4.933 | 0.099 | **2.264** | **0.650** | **0.045** | **0.024** |
| 7 | 0+128.000 | 2413.873 | 0.024 | 0.061 | 2.657 | 0.053 | **6.728** | **0.252** | **0.015** | **0.045** |
| 8 | 0+148.000 | 2413.528 | 0.045 | 0.061 | 4.933 | 0.099 | **1.920** | **0.734** | **0.045** | **0.016** |
| 9 | 0+168.000 | 2413.516 | 0.016 | 0.061 | 3.261 | 0.065 | **4.444** | **0.368** | **0.022** | **0.038** |
| 10 | 0+188.000 | 2413.4 | 0.038 | 0.061 | 7.804 | 0.156 | **1.558** | **0.843** | **0.051** | **0.010** |

As identified in this study 63%of computed spread are larger than the allowable spread 36% of the computed spread are exceed , as the spread width exceed the limit ,occurrence of accumulation of water on the pavement surface increase

81% curb in lets were below 50%effecency only 18.63% of curb inlets are working with above 50% efficiency, by pass flow is much greater than the intercepted by the curb inlet. Especially in the case of sefereselam- autobistera -gojam berenda road 52.5% of the road are below 0.5 longitudinal slope this also aggravated the factor beside the exceedance of spread width. This indicate pavement surface water is not remove effectively like that of the above pauster atobistera abinet road this road cecebitable to pavement deterioration due to pavement surface water were not remove that may lead to over flow and other related problem.

## 4.4 Hydraulic capacity of existing drainage structure Evaluation

FHWA design manual is used as a guide to evaluate the Hydraulic capacity of existing pipe sizing of the urban drainage system. The following procedure shows the sample computation and the result of the detail computation.

### 4.4.1 Peak discharge by rational method

**Runoff Coefficient**

Since the basin contains varying amounts of different land cover or other abstractions, a composite coefficient can be calculated through areal weighing as follows

Weighted C = Σ (Cx Ax)/A total

On this research the catchment area has five sub basin and the runoff coefficient and drainage area are listed below

Sub Basin 1

Residential multi-unit detached Surface characteristics C1=0.6

Drainage area A1= 0.1428ha

Sub Basin 2 and 3

Asphaltic street Surface characteristics C2 and C3=0.95

Drainage area A2= 0.3909 ha

Drainage area A3=0.2193 ha

Sub Basin 4

Residential multi-unit detached Surface characteristics C1=0.6

Drainage area A4= 0.0731ha

Sub Basin 5

Unimproved Surface characteristics C5=0.3

Drainage area A5= 0.3654 ha

$$\textbf{Weighted C} = \frac{(C1*A1+C2*A2+C3*A3+C4*A4+C5*A5)}{At}$$

Weighted C=0.688

**Rainfall intensity (I)**

To determine rainfall intensity the (ID curve) was obtained by using time of concentration Rainfall intensity, duration, and frequency curves are necessary to use the Rational method.

**The time of concentration (Tc)**

The time of concentration were computed by iterative process using the equation of sheet flow

Were ku =6.92, roughness coefficient (n) =0.011 Slope of basin (S)= and flow length=942

Determine the sheet flow travel time using Equation 3-2

$$Tc= \frac{KU}{I^{0.4}} \left(\frac{nL}{S^{0.5}}\right)^{0.6}$$

Since I is being sought and is also in the equation, an iterative approach must be used by estimating a time of concentration (which includes the channel and shallow concentrated flow times computed above) and then reading a rainfall intensity from the appropriate IDF curve, try a sheet-flow time of concentration of 25 minutes. The time of concentration for the entire watershed is then 15+ 5 = 20 min (say 30 min). From the IDF curve in Figure 3-1 the intensity is 80 mm/hr. Now use Equation 3-3 to see how good the 15 minute estimate for sheet flow was. 3-12 first, solve the equation in terms of I.

Tt1 = [6.92/(I)0.4] [(0.01)(942)/(0.043)0.5] 0.6 = (79.03)/ I0.4.

Insert 80 mm for I, one gets 13.6 min. Since 13.6 < the assumed 15 min, try the intensity for 8 +5 = 13 minutes from Figure 3-1 which is 120 mm/hr.

Insert 120 mm for I, one gets 11.6 min. Since 11.6 < the assumed 13 min, try the intensity for 6.6+5 = 11.6 minutes from Figure 3-1 which is 130 mm/hr

Insert 130 mm for I, and a time of 11.2 min was found. This value is close to the 11.6 min.

Use 11.6 minutes for Segment.

Using rational equation method the peak discharge for basin 1 is computed as follows

**Peak Discharge**

Q= $\left(\frac{CIA}{360}\right)$

$Q = \left(\frac{0.67 * 130 * 13.8}{360}\right)$

Q= 3.368 $m^3$/s

**Hydraulic capacity of existing drainage structure**

From actual measurement of the existing circular pipe drainage structure

Where

A=cross sectional area of the drainage 0.6358

n= manning Roughness coefficient 0.012

S=slope of the drainage 0.043

R=Hydraulic radius 0.225

Q= $\frac{1}{n} * (S)^{1/2}(R)^{2/3} * A$

Q= 2.47$m^3$/s

Open channel pipe flow velocity

V= $\frac{ku}{n} * (S)^{1/2}(R)^{2/3}$

n = roughness coefficient 0.015 (see table C&D)

R= hydraulic radius 0.25 (defined as the flow area divided by the wetted perimeter)

S= slope, 0.028 m/m

Ku= units conversion factor equal to 1

V= 4.34m /s

The detail computation Hydraulic capacity of existing drainage structure are tabulated in the table below.

Table 4.6 Hydraulic capacity of existing drainage structure

| Name of street | Station | Pipe Diam... (m) | n Overland/ concret | S | R RR | A ($m^2$) | Q ($m^3/s$) | V ($m^2/s$) |
|---|---|---|---|---|---|---|---|---|
| Pauster to Sebategna | 0+000 - 0+660 | 1 | 0.012 0.015 | 0.028 | 0.25 | 0.785 | 4.344 | 4.427 |
| | 0+680 - 1+640 | 1 | 0.012 0.015 | 0.015 | 0.25 | 0.785 | 3.179 | 3.240 |
| Sebategna to Abinet | 0+000 - 1+100 | 0.9 | 0.012 0.015 | 0.043 | 0.225 | 0.635 | 4.064 | 5.114 |
| | 1+120 - 1+300 | 1 | 0.012 0.015 | 0.051 | 0.25 | 0.785 | 5.804 | 5.915 |
| | 1+320 - 1+540 | 1.2 | 0.012 0.015 | 0.048 | 0.3 | 1.130 | 9.248 | 6.545 |
| Sefereselamm to Autobistera | 0+000 - 0+580 | 0.9 | 0.012 0.015 | 0.017 | 0.225 | 0.635 | 2.555 | 3.215 |
| | 0+000 - 1+850 | 1 | 0.012 0.015 | 0.0044 | 0.25 | 0.785 | 0.519 | 0.529 |
| Autobistera to Gojjam Berenda | 0+000 - 0+680 | 0.9 | 0.012 0.015 | 0.025 | 0.225 | 0.635 | 3.099 | 3.899 |
| | 0+700 - 1+434 | 1 | 0.012 0.015 | 0.032 | 0.25 | 0.785 | 4.643 | 4.732 |

There is also siltation problem in the road drainage system. to prevent siltation the desirable minimum velocity have been checked it should be above 0.7 $m^2/s$ for the sedimentation control condition using mining's formula

As shown in the table 4.6 V=0.529 $m^2/s$ which is <0.7 .the road side channel receiving the catchment run off from Sefereselam to Autobistera has the velocity less than that of the minimum velocity.

Accordingly, the peak rate of runoff and hydraulic capacities of the channel constructed were computed Since the calculated peak discharge were 3.36 m3/s the hydraulic capacity of The pipe culvert drainage structure is above the peak discharge so the drainage system of town is properly draining but from sefere selam to autobis tera at the station of 0+000 up 1+850 and pauster to sebategna at the station of 0+680 - 1+640 the hydraulic capacity of The pipe culvert drainage structure is below the peak discharge due this The pipe culvert drainage structure has not the capacity to properly drain .this improper pipe size is also the cause of over flow specially at rainy season.

## 4.5 Longitudinal slope of the road

Table 4.7 Pauster - Sebategna – Abinet Road Longitudinal slope

| **Distribution or coverage ,%** | **Slope in percentage** | | | |
|---|---|---|---|---|
| | <0.5 | 0.5-2 | 2 - 4 | 4 - 6.8 |
| **Longitudinal slope** | 2.53% | 20.82% | 34.825% | 41.74% |

Table 4.8 Sefereselam - Autobus Tera – Gojjam Berenda Road Longitudinal slope

| **Distribution or coverage ,%** | **Slope in percentage** | | | |
|---|---|---|---|---|
| | <0.5 | 0.5 - 2 | 2 - 4 | 4 - 6.8 |
| **Longitudinal slope** | 52.4% | 19.38% | 17.81% | 10.63% |

To provide adequate drainage system minimum grade of 0.5 % shall be maintained but as shown in the above table 4.7 and table 4.8 from Pauster - Sebategna – Abinet Road 2.35% and Sefereselam - Autobus Tera – Gojjam Berenda road 52.4% have less the 0.5 percent which is below the required minimum longitudinal slop value for adequate drainage.

Since slope are necessary to allow free movement of flow the minimum required slope need to be satisfied .small slope can result pond inside the ditch which is stagnant water which gives favorable condition to accumulation of water in the road.

## 4.6 Drainage and Morphometry of hydrology Analysis

### 4.6.1 Watershed and stream feature types of the study Area

Watersheds are hydrological drainage basins, land areas, which catch rain or snow and drains to a specific marshes, streams, lakes or ground water aquifers (Musa, 2001). The analyst then uses topographic features on the map to determine where a divide is located. Today, computer programs are widely used to derive watershed from DEM. Using ArcGIS we can generate preliminary watershed boundaries in just a fraction of time. Watershed analysis provides the process of formulation and carrying out of a course of action involving modification of the natural system of watershed to achieve specified objectives. This can be integrated into a GIS environment for better and faster result.

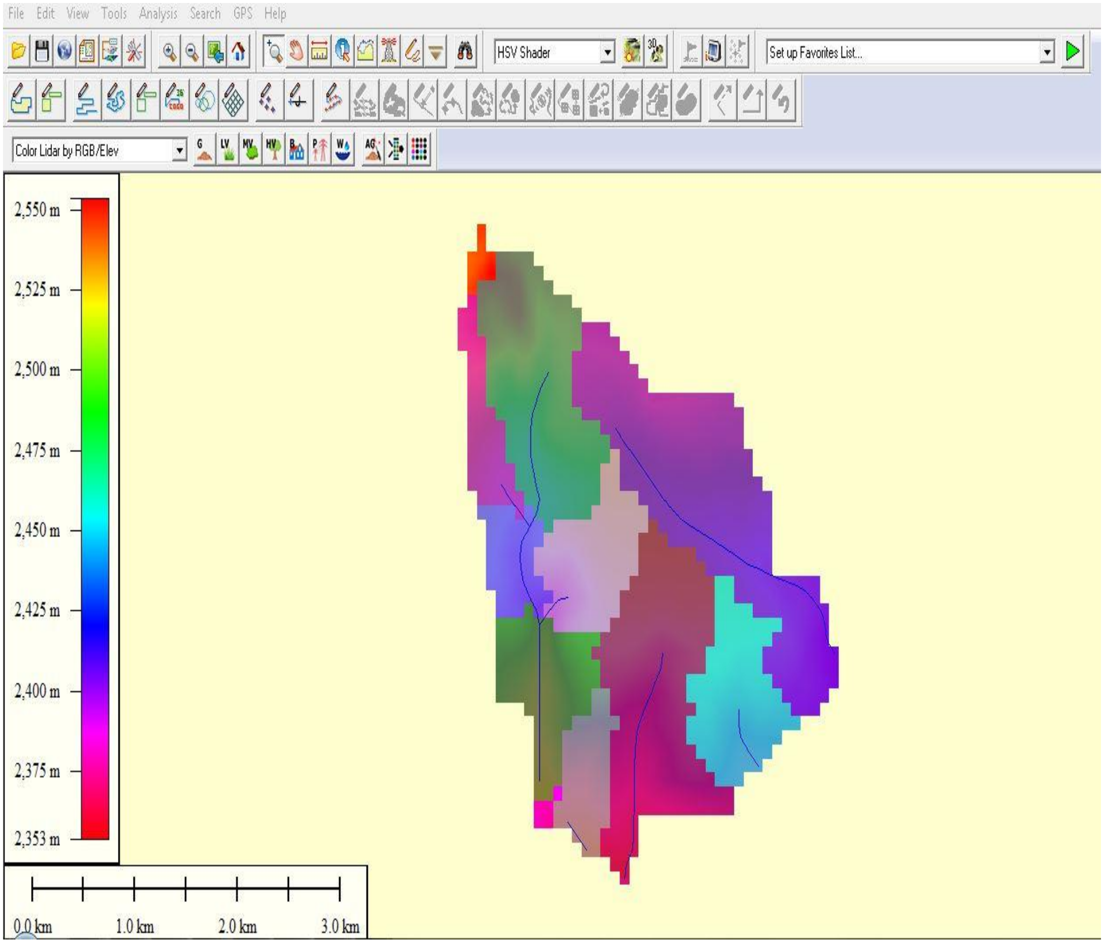



Figure 4.1 Watershed and stream feature types of the study area tio(R)

### 4.6.2 Melton Ratio(R) $= \frac{\text{Max. Basin relief - Min. basin relief}}{\sqrt{A_b}}$

Where, Ab = Area of basin, R= Melton ratio

Table 4.9 Melton ratio value of watershed feature type attribute and geometric output of the study area

| Future type | Attribute | | | | Geometry | | | **Melton ratio** |
|---|---|---|---|---|---|---|---|---|
| | ID | inflow | outflow | Drainage Area (km2) | Elevation (M) | | Elevation difference | |
| | | | | | Min | Max | | |
| watershed | 1 | 45 | 168 | 1.428 | 2446 | 2499 | 53 | 0.4435 |
| | 2 | 41 | 266 | 2.261 | 2420 | 2497 | 77 | 0.5120 |
| | 3 | 41 | 46 | 0.3909 | 2446 | 2461 | 15 | 0.2399 |
| | 4 | 219 | 258 | 2.193 | 2412 | 2446 | 34 | 0.2295 |
| | 5 | 40 | 86 | 0.731 | 2412 | 2435 | 23 | 0.2690 |
| | 6 | 347 | 430 | 3.654 | 2376 | 2412 | 36 | 0.1883 |
| | 7 | 45 | 202 | 1.717 | 2353 | 2439 | 86 | 0.6563 |
| | 8 | 41 | 100 | 0.85 | 2400 | 2431 | 31 | 0.3362 |
| | 9 | 40 | 50 | 0.4249 | 2366 | 2376 | 10 | 0.1534 |

As Five watershed areas are prone to conventional flooding(R< 0.30) while four watershed area is prone to sediment flow (R> 0.3) ID of 1,2,7,and 8 from these watershed ID2,7&8 included selected route due to this reason drainage structures that are found in this sub city are blocked by sediment.

### 4.6.3 Drainage Density (Dd)

$Dd = L_u / A$

Where, $_{Dd}$= density (Km/Km2)

$L_u$=total stream length, and

A=Drainage Area (Km$^2$)

Therefore, $D_d$=8.km/8.9472km$^2$ = 0.9475 km/km$^2$

Table 4.10 drainage density stream feature type attribute and geometry output of the study area

| Future type | Attribute | | | Geometry | | | **Drainage Density (Dd** |
|---|---|---|---|---|---|---|---|
| | ID | inflow | outflow | Stream Length (Km) | Perimeter ( 9km) | Drainage Area (km2) | |
| Stream | 1 | 45 | 168 | 1.097 | 6.435 | 1.436 | 0.4435 |
| | 2 | 41 | 266 | 2.67 | 10.659 | 2.269 | 0.5120 |
| | 3 | 41 | 46 | 0.389 | 4.232 | 0.3994 | 0.2399 |
| | 4 | 219 | 258 | 0.719 | 3.493 | 0.3654 | 0.2295 |
| | 5 | 40 | 86 | 0.341 | 4.779 | 0.739 | 0.2690 |
| | 6 | 347 | 430 | 1.014 | 4.78 | 0.722 | 0.1883 |
| | 7 | 45 | 202 | 1.556 | 8.641 | 1.725 | 0.6563 |
| | 8 | 41 | 100 | 0.433 | 5.514 | 0.858 | 0.3362 |
| | 9 | 40 | 50 | 0.259 | 3.495 | 0.4334 | 0.1534 |
| SUM | 9 | 859 | 1606 | **8.478** | 52.028 | **8.9472** | - |

| **Total Drainage Density** | Total Stream Length (Km) / Total Drainage Area (km2) | **8.478/8.9472** | **= 0.947559** |
|---|---|---|---|

Depending on the calculated value of drainage density of the study area i.e. 0.9475km/km2. As a result of this, the study area vegetation cover is poor Table 3.10 drainage density stream feature type attribute and geometry output of the study area.

## 4.7 Urban Drainage Operation management Evaluation

**FHWA Culvert assessment and decision making**

Procedures manual is used as a guide to evaluate the operation of the urban drainage system. Which data was tabulated and presented in chapter four in data analysis .in the study area .the final result of Evaluation of curb inlets operation as follows.

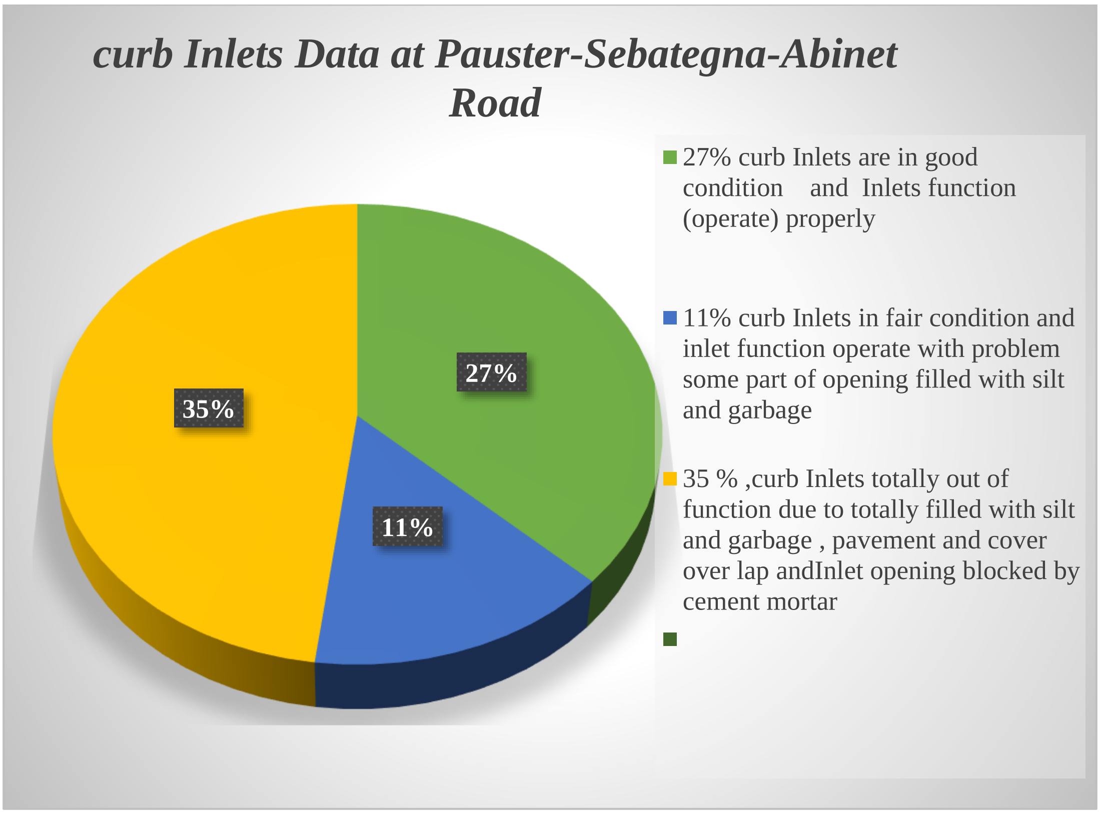



Figure 4.2 Condition of curbs inlet Pauster - Sebategna - Abinet Roads

The data collected shows that, the inlet in Pauster - Sebategna - Abinet Roads. only 27% of curb Inlets function (operate) properly 35% of Curb in let is not properly working it is out of function due to totally filled with silt and garbage ,Inlet opening blocked by cement mortar and pavement and cover overlap Due to inadequate drainage operational management. The silt and garbage at the entrance of the inlet blocked the entrance of runoff to the pipe drain system. From data analysis we can see 11 % Curb Inlets function (operate) with problem some part of opening filled with silt and due to inadequate drainage operational management.

### 4.7.2 Urban Drainage Operation Evaluation

sefere selam - Autobus Tera - Gojjam Berenda Road

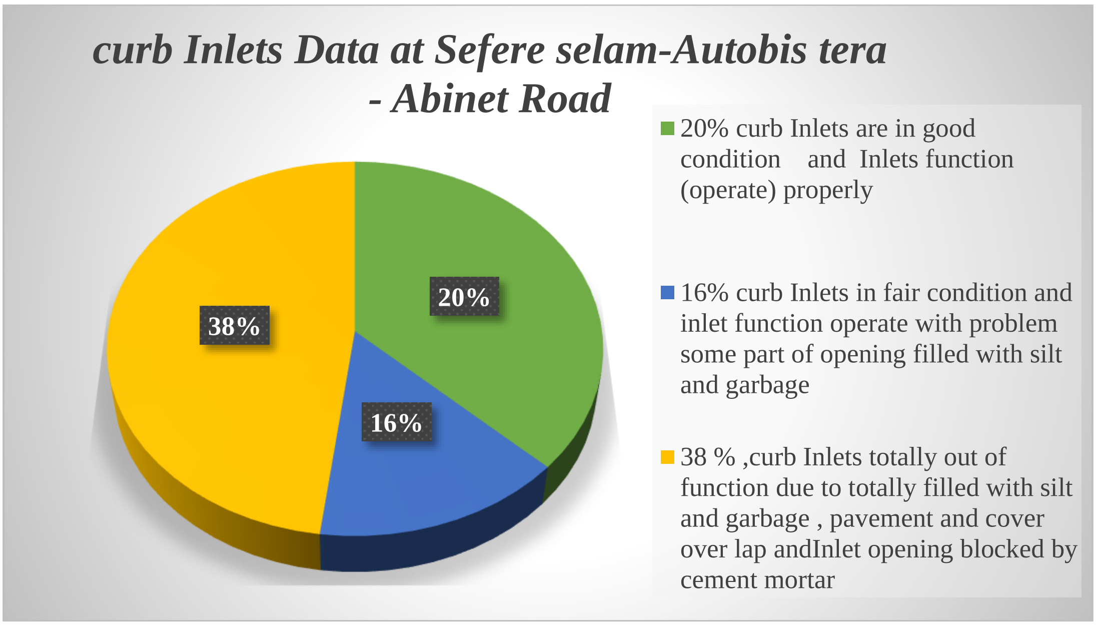



Figure 3 Condition of curbs inlet Pauster - Sebategna - Abinet Roads

The data collected shows that, the inlet in Pauster - Sebategna - Abinet Roads. only 20% of curb Curb Inlets function (operate) properly 38% of Curb in let is not properly working it is out of function due to totally filled with silt and garbage ,Inlet opening blocked by cement mortar and pavement and cover overlap Due to inadequate drainage operational management.. From data analysis we can see 16 % Curb Inlets function (operate) with problem some part of opening filled with silt and The silt and garbage at the entrance of the inlet blocked the entrance of runoff to the pipe drain system due to. Especially from Mikal church to autobis tera market entry road the curb inlets in the area are out of function due to the exceeding of design life, as well as inadequate operational management problem

The data analysis of the study area shows, Even in some chainage the pavement and the inlet cover (Manhole cover) removed, not closed properly opened fully or partially and overlap each other, so the urban water unable to enter to the inlet properly.

From the above three evaluation From the design analysis and field observation it was observed that, the existing pipe size is not relatively enough to carry the storm discharge the problem in Pauster - Sebategna - Abinet Roads is caused by the combination of design problem (Pipe sizing and inlet spacing), and inadequate drainage management.

Inadequate drainage operation management is because of unawareness of community who dispose solid and liquid wastes in to the inlets and on the pavement of the road, removal of inlet cover and accumulation of silt for long period of time without inspection.

4.8 Propose drainage management system

*Table 4.11 Propose drainage management system during dry season*

| S.no | Description | Team | Number | Period | Remark |
|---|---|---|---|---|---|
| **Primary stage (Maintenance)** | | | | | |
| 1 | **Curb Inlets** | Inspector | 1 | | |
| | For maintaining one km drainage system ( In average 30 - 40 inlets exist) | Mason | 2 | | |
| | | Helper | 4 | | |
| | | Daily laborers | 4 | Two days | |
| **Secondary stage (Evaluation)** | | | | | |
| | | Welder | 2 | | |
| | | Helper | 4 | | |
| | | Daily laborers | 6 | | |
| 2 | **Curb Inlets** | Inspector | 1 | | |
| | For managing one k.m drainage system ( In average 30 - 40 inlets exist) | Mason | 2 | | |
| | | Helper | 4 | | |
| | | Daily laborers | 4 | One day | Once in a month |
| | **Third stage (follow up)** | | | | |
| | | Daily laborers | 6 | | |
| 3 | **Curb Inlets** | Inspector | 1 | | |
| | For managing one k.m drainage system ( In average 30 - 40 inlets exist) | Daily laborers | 4 | One day | Once in a month |

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

Based on the Result obtained, the following conclusion and recommendation are listed:

In the study area it is observed that drainage problem is a cause of flooding on pavement, Congested traffic flow and difficulty on day to day activity of people. To investigate the cause of The problem, we try to evaluate the current inlet spacing and The hydraulic capacity of existing side pipe sizing by redesigning the system in the problem areas and Site investigation is done by collecting direct field data to assess the storm drainage construction And operation management problem.

Large inlet spacing is a cause over spread of storm water in the pavement of the road. The efficiency of existing curb inlets is not sufficient because of this current in let spacing can't work properly .so from the analysis we can see the in efficiency of curb inlets in the study area having Large inlet spacing design is a cause of over flow on spread of storm water in the pavement of the road that also the major cause in pavement distress due to too much delay of storm water in the pavement.

The hydraulic capacity of existing pipe size is not sufficient to accommodate the flow with debris and silt sediment. Because of negligence of siltation and debris control analysis in pipe size design this leads to failure of drainage structures due to inadequate pipe size of drainage structures. From the research result Mesalemiya-autobis tera Road,and mikale church -autobistera Section of the road are more prone to drainage problem in the study area.

The allowable minmum value for road longitudinal slope is 0.5% as per era recommendation .in the study area. Totally 54.93 % of longitudinal slope are below the minimum required because of this accumulation of flow on the pavement surface were build up. From the result section we can easily observe that the problem in the study area caused by lack of consideration Drainage and Morphometry of hydrology on design, Depending on the analysis value of Drainage and Morphometry of hydrology From total 9 watershed areas Four are watershed areas are prone to sediment flow (R>

0.3) Addis ketema sub city due to this reason drainage structures that are found in this town are blocked by sediment .while five watershed area is prone to conventional flooding($R< 0.30$) Depending on the analysis of 9 watershed areas value of drainage density of the study area i.e. 0.9475 km/km2. As a result of this, the study area vegetation cover is poor. Due to this reason drainage structures that are found in this town are blocked by sediment

Due to The toilet sludge and liquid waste which is escape from residential area, café and restaurants and joins illegally in to the storm drainage system of Addis ketema road is a basic problem in bad smile of in let spacing opining especially during rainy Season. So this is the main Cause, peoples who lives near to inside of the road purposely to block the inlet spacing by cement mortar.

Inadequate drainage operational management is also a cause of inlet not to work properly. Since in the study area prone to sediment flow and vegetation cover is poor. Absence of adequate drainage operational management also aggravate the effect of the sediment flow on drainage structures that are found in this sub city are blocked by sediment problem.

## 5.2 Recommendations

Large inlet spacing is a cause over spread of storm water in the pavement of the road. This can be minimized by providing extra inlets especially on the sag point.

Changing of this improper pipe size to 1.2 m diameter from sefere selam to autobis tera at the station of 0+000 up 1+850 and pauster to sebategna at the station of 0+680 - 1+640. The hydraulic capacity of the proposed pipe culvert drainage structure was $3.7m^3/s$ which is above the peak discharge due to this the pipe culvert drainage structure has the capacity to drain properly. It will have also great roll to overcome.in the cause of over flow especially at rainy season.

Another measure to be taken is the upgrading of wetland; this will help stop the frequent back-flows which cause flooding by increase infiltration. The use of green space in the design of Sustainable Urban Drainage Systems allows water to be controlled using trees, vegetation, and green area.

Inadequate drainage operational management is also a cause of inlet not to work properly Which aggravate also the other problem in the study area so take The measures in proper and periodic time schedule to inspection and de silting and cleaning of inlet from garbage and putting traps in drainage systems to trap garbage from blocking and also scheduled follow up and maintenance activity should be done by the concerned organization main drainage system of Addis ketema sub city.

Addis ketema sub City Council and formulate a wide campaign on public awareness and sensitization through different way concerning. This will enhance better solid waste disposal, waste water disposal and avoiding attachment of with the toilet sludge and liquid waste storm drainage system. When policies and penalties are developed, the community should also ensure and control that action .and also there is a follow up or else it would be reduced a complete effect. This will help in achieving proper drainage system

# REFERENCES


**[1].AACRA, 2003**: Drainage design manual

**[2].Abwot, P (1999).** The impacts of road construction on the drainage: a case study of Entebbe road

**[3].Ajayi, J.O.K. (1993).** Managing the lagos metropolitan storm water runoff problems under structural adjustment. Publishhed by African world press. Nigeria.

**[4].**A**merican Concrete Pipe association**, 2000: Concrete pipe design manual

**[5].**Longman Harlow, 310 pp. paper back (co-published in the USA by Wiley, New York)

**[6].**. **Clarence, J. V (1984).** Applied stream sanitation. John Wiley and Sons New York.

**[7].Clifton, Van. (2000).** Draft study on implementation of community managed and labour-based works using community and private contracts, ILO, August 2000.

**[8].David Butler and John Davies**, 2004: Urban drainage

**[9].Dedericksen, A. (1978).** Soil and water conservation engineering, Schwab Department of Agriculture,

**[10].ERA**, 2002 Drainage design manual

**[11].FHWA** (U.S Department of Transportation Federal highway admission),2001: Urban drainage design manual Larry W. Mays, 2004: Storm water collection system design hand book

**[12].Gordon, M. John, C. G and Daniel, A. O. (1971).** Elements of water.

**[13].Malcom, H. (1998).** Surveying for dilapidations: a practical guide to the law and it‟s application/London: Estate Gazette.

**[14].HRAC, (1997).** „The community rating system: An evaluation session summaries from the 1999 is application/London: the Estate Gazette J.IWEM, 4 August. John Wiley and sons Chichesterm-Newyork, USA.

**[15].Kemigisha, B. A. (1996).** The enforcement of the Law relating to degradation of wetlands: acase study of Nakivubo wetlands/ Kampala: Makerere University.

**[16].Knapp, B. (1986).** Systematic geography. Collins Educational, London.

**[17].Linsley, M and Franzini, P (1972).** Water resource engineering Marle Press Company. Washington, USA London and NewYork. Longman scientific and technical, Essex, England: second Edition...

[18].**Platt, R.H. and Dawson, A.P (1997).** The taking issues and regulations of hazards research and applications info‟ workshop.at the Institute of behavioral science university of Colorado, Washington USA.

[19].**Radwarisk, S.A. (1960).** The soil and landuse of the Buganda: A recognize survey‟ in memoirs of the research division series-soils, number 4.

[20].**Raj Vir Singh, (1991).** Drainage and salinity control‟ First Edition, Human Shu Publications Lagos Nigeria.

[21].**Raven Johnson Berg (1993).** Municipal waste water pollution.

[22].**Smission, R.P.M. (1980).** „The single pipe system for storm water management‟ prog. Wat. Tech. 13, 203-214.

[23].**Sonuga , F. (1993).** „Challenges of the drainage in the developing countries‟ in proc. 6th int. Sounders college publishers San Diego New York.

[24].**TCDSc, 2000**: design report

[25].**The New Vision (1999)**.Article was published by New Vision printing press on Wednesday the 13th October pg 3.

[26].**Thomas N. Debo. Andrew J. Reese**, 2003: Municipal storm water management Ven Te Chow, etal, Applied Hydrology

[27].**World Bank Publications (1996).** Sanitation in developing countries, urbanmanagement, World Bank-Washington DC.

[28].**World Health Organization Report (1992).** Our planet, our health. World Health Organization.

# APPENDIX I; -

**JIMMA UNIVERSITY**

**SCHOOL OF GRADUATE STUDIES**

**JIMMA INSTITUTE OF TECHNOLOGY**

**FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING**

**"INVESTIGATION ON THE CAUSE OF HIGHWAY DRAINAGE SYSTEM PROBLEM IN ADDIS KETEMA SUB CITY OF ADDIS ABABA**

## Section -1 Questionnaire For Consultant Firms

Basic information about the consultant of design office

1. Company name: …………………………………………………

2. Profession

Project manager ☐ Resident engineer ☐ Office engineer ☐

Site engineer ☐ Quantity Surveyor ☐ Site supervisor ☐

If other, please specify here _________________________

3. Level of education

Certificate and Diploma ☐ Bachelor's Degree ☐

Master's Degree ☐ PhD ☐

If other, please specify…………………………………

4. Level of experience in years

0-5 ☐ 5-10 ☐ 10-15 ☐ 15-20 ☐ > 20 ☐

11 Question are listed below to gain information from you regarding the cause of highway drainage system problem in addis ketema sub city of addis ababa

1. Do you think there is surface drainage problem in addis ketema sub city?

Yes ☐ No ☐

6. if your answer is yes Based on your experience what is the cause of highway drainage problem in the addis ketema sub city?

☐ Lack of giving attention for drainage design in the road design

☐ Poor drainage design

☐ Lack of good operating management and maintenance

☐ Poor usage of community

## Section -1 Questionnaire For community Firms

Basic information about the community

1. Marital status………………………………………………………………

2. Occupation? ………………………………………………...……………...

3 Village of Residence? ……………………………………………………………

4. Responsibility in the village? ……………………………………………….. ,

5. Profession…………………………………

6. Level of education

Certificate and Diploma ☐ Bachelor’s Degree ☐

Master’s Degree ☐ PhD ☐

If other, please specify…………………………………

11 Question are listed below to gain information from you regarding the cause of highway drainage system problem in addis ketema sub city of addis ababa .

1**.** What do you understand by the term highway drainage system?

______________________________________________________________________

2. Do you know the purpose of road side surface drainage system?

☐ Yes ☐ No

3 If yes could you list what you know?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

__________

4. Do you think there is a surface drainage problem in addis ketema sub city?

☐Yes ☐ No

6. if your answer is yes .Why people block curb inlet opening by cement mortar or other material

☐ Lack of awareness in the community

☐ Due to Bad smile that comes from curb inlet opening

If there is other reason specify here ________________________________________

6. If your answer is 2 what do you think the reason of bad smile of curb inlet opening

☐ Connecting toilet sludge and sware pipe to the drainage pipe

☐ Due to the lack of operating and management

If there is other reason specify here ______________________________________

7. Regarding the usage of road side drainage what is expected from the community

_____________________________________________________________________

_____________________________________________________________________

_____________________________________________________________________

__________10,Where do you dispose off solid wastes and waste water?

_____________________________________________________________________

______11, how do you dispose toilet sullage

Open spaces ☐ Drain channels ☐ Soak pit ☐

8. Level of education

Certificate and Diploma ☐ Bachelor’s Degree ☐

Master’s Degree ☐ PhD ☐

If other, please specify………………………………

# APPENDIX II ; -

## **Efficiency and interception capacity of curb** inlet spacing (Detail Design Computation Sheet)

### Pauster –sebategna-Abinet Road

| INLET N0 | I.Stat | ELEV | Sx(%) | SL(%) | Qb(m^3⁄s) | Ls(m) | C | S(%) | A(ha) | Tc(min) | I(mm/hr) | Q(m3/s) | T(m) | d(m) | LT(m) | E | Qi (m3/s) | Qb(m3/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 0.00 | 2482.34 | - | - | 0m^3⁄s | - | - | - | - | - | - | - | - | - | **-** | **-** | **-** | **0m^3⁄s** |
| 2.00 | 15.00 | 2481.64 | 0.03 | 0.04 | 0m^3⁄s | 81.00 | 0.70 | 0.03 | 0.12 | 8.02 | 133.45 | 0.03 | 1.54 | 0.04 | **6.19** | **0.27** | **0.01** | **0.02** |
| 3.00 | 30.00 | 2481.03 | 0.03 | 0.04 | 0.02 | 81.00 | 0.70 | 0.04 | 0.12 | 7.64 | 135.9 | 0.03 | 1.53 | 0.04 | **6.36** | **0.27** | **0.01** | **0.02** |
| 4.00 | 50.00 | 2480.39 | 0.03 | 0.03 | 0.02 | 81.00 | 0.70 | 0.02 | 0.16 | 8.79 | 129.8 | 0.04 | 1.79 | 0.04 | **6.15** | **0.27** | **0.01** | **0.03** |
| 5.00 | 70.00 | 2479.79 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.50 | 130 | 0.04 | 1.86 | 0.05 | **5.75** | **0.29** | **0.01** | **0.03** |
| 6.00 | 93.00 | 2479.29 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.19 | 9.74 | 130 | 0.05 | 2.10 | 0.05 | **5.31** | **0.31** | **0.01** | **0.03** |
| 7.00 | 111.00 | 2478.89 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.15 | 8.75 | 129.8 | 0.04 | 1.80 | 0.04 | **5.42** | **0.31** | **0.01** | **0.03** |
| 8.00 | 131.00 | 2478.46 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.71 | 129.8 | 0.04 | 1.86 | 0.05 | **5.70** | **0.29** | **0.01** | **0.03** |
| 9.00 | 155.00 | 2477.97 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.19 | 9.88 | 130 | 0.05 | 2.15 | 0.05 | **5.32** | **0.31** | **0.02** | **0.03** |
| 10.00 | 173.00 | 2477.57 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.15 | 9.22 | 130 | 0.04 | 1.85 | 0.05 | **5.10** | **0.32** | **0.01** | **0.02** |
| 11.00 | 195.00 | 2477.20 | 0.03 | 0.02 | 0.02 | 81.00 | 0.70 | 0.02 | 0.18 | 9.65 | 130 | 0.05 | 2.05 | 0.05 | **5.27** | **0.32** | **0.01** | **0.03** |
| 12.00 | 215.00 | 2476.80 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.38 | 130 | 0.04 | 1.95 | 0.05 | **5.23** | **0.32** | **0.01** | **0.03** |
| 13.00 | 241.00 | 2476.41 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.21 | 9.49 | 130 | 0.05 | 2.16 | 0.05 | **5.76** | **0.29** | **0.02** | **0.04** |
| 14.00 | 261.00 | 2475.93 | 0.03 | 0.02 | 0.04 | 81.00 | 0.70 | 0.02 | 0.16 | 9.31 | 130 | 0.04 | 1.94 | 0.05 | **5.28** | **0.31** | **0.01** | **0.03** |
| 15.00 | 281.00 | 2475.53 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.33 | 130 | 0.04 | 2.06 | 0.05 | **4.67** | **0.35** | **0.01** | **0.03** |
| 16.00 | 302.00 | 2475.24 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.17 | 9.89 | 130 | 0.04 | 2.04 | 0.05 | **5.02** | **0.33** | **0.01** | **0.03** |
| 17.00 | 317.00 | 2474.89 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.12 | 12.78 | 130 | 0.03 | 2.09 | 0.05 | **3.23** | **0.49** | **0.01** | **0.02** |
| 18.00 | 337.00 | 2474.77 | 0.03 | 0.00 | 0.02 | 81.00 | 0.70 | 0.00 | 0.16 | 21.27 | 130 | 0.04 | 3.17 | 0.08 | **1.95** | **0.73** | **0.03** | **0.01** |
| 19.00 | 357.00 | 2474.74 | 0.03 | 0.01 | 0.01 | 81.00 | 0.70 | 0.01 | 0.16 | 11.07 | 130 | 0.04 | 2.14 | 0.05 | **4.31** | **0.38** | **0.02** | **0.03** |
| 20.00 | 377.00 | 2474.51 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.05 | 130 | 0.04 | 1.91 | 0.05 | **5.45** | **0.31** | **0.01** | **0.03** |
| 21.00 | 402.00 | 2474.07 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.20 | 9.68 | 130 | 0.05 | 2.15 | 0.05 | **5.54** | **0.30** | **0.02** | **0.04** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.00 | 422.00 | 2473.63 | 0.03 | 0.01 | 0.04 | 81.00 | 0.70 | 0.01 | 0.16 | 11.22 | 130 | 0.04 | 2.16 | 0.05 | **4.24** | **0.38** | **0.02** | **0.03** |
| 23.00 | 442.00 | 2473.41 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.73 | 130 | 0.04 | 1.99 | 0.05 | **5.01** | **0.33** | **0.01** | **0.03** |
| 24.00 | 457.00 | 2473.06 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.12 | 9.02 | 130 | 0.03 | 1.71 | 0.04 | **4.85** | **0.34** | **0.01** | **0.02** |
| 25.00 | 477.00 | 2472.73 | 0.03 | 0.02 | 0.02 | 81.00 | 0.70 | 0.02 | 0.16 | 8.85 | 129.8 | 0.04 | 1.88 | 0.05 | **5.60** | **0.30** | **0.01** | **0.03** |
| 26.00 | 497.00 | 2472.26 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.14 | 133.45 | 0.04 | 1.81 | 0.05 | **6.24** | **0.27** | **0.01** | **0.03** |
| 27.00 | 517.00 | 2471.66 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.67 | 129.8 | 0.04 | 1.75 | 0.04 | **6.45** | **0.26** | **0.01** | **0.03** |
| 28.00 | 542.00 | 2470.98 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.20 | 10.16 | 130 | 0.05 | 2.03 | 0.05 | **6.26** | **0.27** | **0.01** | **0.04** |
| 29.00 | 562.00 | 2470.37 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.02 | 0.16 | 8.97 | 129.8 | 0.04 | 1.78 | 0.04 | **6.28** | **0.27** | **0.01** | **0.03** |
| 30.00 | 582.00 | 2469.73 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.67 | 129.8 | 0.04 | 1.75 | 0.04 | **6.45** | **0.26** | **0.01** | **0.03** |
| 31.00 | 600.00 | 2469.05 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.04 | 0.15 | 7.37 | 135.9 | 0.04 | 1.59 | 0.04 | **7.29** | **0.23** | **0.01** | **0.03** |
| 32.00 | 620.00 | 2468.15 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.69 | 135.9 | 0.04 | 1.69 | 0.04 | **7.32** | **0.23** | **0.01** | **0.03** |
| 33.00 | 640.00 | 2467.25 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.69 | 135.9 | 0.04 | 1.69 | 0.04 | **7.32** | **0.23** | **0.01** | **0.03** |
| 34.00 | 660.00 | 2466.35 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.74 | 135.9 | 0.04 | 1.70 | 0.04 | **7.27** | **0.23** | **0.01** | **0.03** |
| 35.00 | 680.00 | 2465.47 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.13 | 138.35 | 0.04 | 1.70 | 0.04 | **7.37** | **0.23** | **0.01** | **0.03** |
| 36.00 | 700.00 | 2464.57 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.00 | 138.35 | 0.04 | 1.69 | 0.04 | **7.53** | **0.23** | **0.01** | **0.03** |
| 37.00 | 720.00 | 2463.62 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.13 | 138.35 | 0.04 | 1.70 | 0.04 | **7.37** | **0.23** | **0.01** | **0.03** |
| 38.00 | 740.00 | 2462.72 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.95 | 129.8 | 0.04 | 1.89 | 0.05 | **5.52** | **0.30** | **0.01** | **0.03** |
| 39.00 | 755.00 | 2462.27 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.12 | 8.47 | 129.8 | 0.03 | 1.65 | 0.04 | **5.21** | **0.32** | **0.01** | **0.02** |
| 40.00 | 770.00 | 2461.87 | 0.03 | 0.02 | 0.02 | 81.00 | 0.70 | 0.02 | 0.12 | 9.75 | 130 | 0.03 | 1.79 | 0.04 | **4.43** | **0.37** | **0.01** | **0.02** |
| 41.00 | 780.00 | 2461.61 | 0.03 | 0.01 | 0.02 | 81.00 | 0.70 | 0.01 | 0.08 | 11.66 | 130 | 0.02 | 1.70 | 0.04 | **3.03** | **0.51** | **0.01** | **0.01** |
| 42.00 | 800.00 | 2461.51 | 0.03 | 0.01 | 0.01 | 81.00 | 0.70 | 0.01 | 0.16 | 13.74 | 130 | 0.04 | 2.43 | 0.06 | **3.34** | **0.47** | **0.02** | **0.02** |
| 43.00 | 820.00 | 2461.39 | 0.03 | 0.01 | 0.02 | 81.00 | 0.70 | 0.01 | 0.16 | 12.17 | 130 | 0.04 | 2.26 | 0.06 | **3.86** | **0.42** | **0.02** | **0.02** |
| 44.00 | 830.00 | 2461.21 | 0.03 | 0.01 | 0.02 | 81.00 | 0.70 | 0.01 | 0.08 | 11.66 | 130 | 0.02 | 1.70 | 0.04 | **3.03** | **0.51** | **0.01** | **0.01** |
| 45.00 | 845.00 | 2461.11 | 0.03 | 0.04 | 0.01 | 81.00 | 0.70 | 0.04 | 0.12 | 7.42 | 135.9 | 0.03 | 1.55 | 0.04 | **6.20** | **0.27** | **0.01** | **0.02** |
| 46.00 | 865.00 | 2460.51 | 0.03 | 0.03 | 0.02 | 81.00 | 0.70 | 0.03 | 0.16 | 8.14 | 133.45 | 0.04 | 1.81 | 0.05 | **6.23** | **0.27** | **0.01** | **0.03** |
| 47.00 | 885.00 | 2459.91 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.65 | 129.8 | 0.04 | 1.86 | 0.05 | **5.74** | **0.29** | **0.01** | **0.03** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 48.00 | 895.00 | 2459.41 | 0.03 | -0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.08 | 12.63 | 130 | 0.02 | 1.70 | 0.04 | **3.03** | **0.51** | **0.01** | **0.01** |
| 49.00 | 905.00 | 2459.51 | 0.03 | -0.01 | -0.01 | 81.00 | 0.70 | 0.01 | 0.08 | 12.15 | 130 | 0.02 | 1.70 | 0.04 | **3.03** | **0.51** | **0.01** | **0.01** |
| 50.00 | 920.00 | 2459.61 | 0.03 | 0.01 | 0.01 | 81.00 | 0.70 | 0.01 | 0.12 | 11.05 | 130 | 0.03 | 2.12 | 0.05 | **3.14** | **0.50** | **0.02** | **0.02** |
| 51.00 | 940.00 | 2459.51 | 0.03 | 0.00 | 0.02 | 81.00 | 0.70 | 0.00 | 0.16 | 18.08 | 130 | 0.04 | 2.86 | 0.07 | **2.40** | **0.62** | **0.03** | **0.02** |
| 52.00 | 960.00 | 2459.46 | 0.03 | 0.03 | 0.02 | 81.00 | 0.70 | 0.03 | 0.16 | 8.65 | 129.8 | 0.04 | 1.86 | 0.05 | **5.74** | **0.29** | **0.01** | **0.03** |
| 53.00 | 980.00 | 2458.96 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.65 | 129.8 | 0.04 | 1.86 | 0.05 | **5.74** | **0.29** | **0.01** | **0.03** |
| 54.00 | 1005.00 | 2458.46 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.20 | 8.76 | 129.8 | 0.05 | 2.03 | 0.05 | **6.21** | **0.27** | **0.01** | **0.04** |
| 55.00 | 1025.00 | 2457.85 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.03 | 0.16 | 7.94 | 133.45 | 0.04 | 1.79 | 0.04 | **6.42** | **0.26** | **0.01** | **0.03** |
| 56.00 | 1045.00 | 2457.20 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 6.87 | 138.35 | 0.04 | 1.67 | 0.04 | **7.70** | **0.22** | **0.01** | **0.03** |
| 57.00 | 1070.00 | 2456.20 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.06 | 0.20 | 6.68 | 138.35 | 0.05 | 1.78 | 0.04 | **8.74** | **0.20** | **0.01** | **0.04** |
| 58.00 | 1095.00 | 2454.82 | 0.03 | 0.05 | 0.04 | 81.00 | 0.70 | 0.05 | 0.20 | 7.05 | 138.35 | 0.05 | 1.84 | 0.05 | **8.21** | **0.21** | **0.01** | **0.04** |
| 59.00 | 1120.00 | 2453.65 | 0.03 | 0.04 | 0.04 | 81.00 | 0.70 | 0.04 | 0.20 | 7.64 | 135.9 | 0.05 | 1.91 | 0.05 | **7.42** | **0.23** | **0.01** | **0.04** |
| 60.00 | 1140.00 | 2452.74 | 0.03 | 0.04 | 0.04 | 81.00 | 0.70 | 0.04 | 0.16 | 7.52 | 135.9 | 0.04 | 1.74 | 0.04 | **6.89** | **0.25** | **0.01** | **0.03** |
| 61.00 | 1160.00 | 2451.98 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.52 | 135.9 | 0.04 | 1.74 | 0.04 | **6.88** | **0.25** | **0.01** | **0.03** |
| 62.00 | 1180.00 | 2451.21 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.57 | 135.9 | 0.04 | 1.75 | 0.04 | **6.84** | **0.25** | **0.01** | **0.03** |
| 63.00 | 1200.00 | 2450.46 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.20 | 133.45 | 0.04 | 1.82 | 0.05 | **6.18** | **0.27** | **0.01** | **0.03** |
| 64.00 | 1220.00 | 2449.87 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.47 | 130 | 0.04 | 1.96 | 0.05 | **5.17** | **0.32** | **0.01** | **0.03** |
| 65.00 | 1240.00 | 2449.49 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.89 | 130 | 0.04 | 2.12 | 0.05 | **4.40** | **0.37** | **0.02** | **0.03** |
| 66.00 | 1267.00 | 2449.24 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.22 | 12.03 | 130 | 0.06 | 2.51 | 0.06 | **4.43** | **0.37** | **0.02** | **0.03** |
| 67.00 | 1287.00 | 2449.00 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.92 | 130 | 0.04 | 2.12 | 0.05 | **4.38** | **0.37** | **0.02** | **0.03** |
| 68.00 | 1307.00 | 2448.75 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.93 | 130 | 0.04 | 2.13 | 0.05 | **4.37** | **0.37** | **0.02** | **0.03** |
| 69.00 | 1334.00 | 2448.51 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.22 | 12.03 | 130 | 0.06 | 2.51 | 0.06 | **4.43** | **0.37** | **0.02** | **0.03** |
| 70.00 | 1354.00 | 2448.26 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.92 | 130 | 0.04 | 2.12 | 0.05 | **4.38** | **0.37** | **0.02** | **0.03** |
| 71.00 | 1381.00 | 2448.02 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.22 | 12.03 | 130 | 0.06 | 2.51 | 0.06 | **4.43** | **0.37** | **0.02** | **0.03** |
| 72.00 | 1408.00 | 2447.77 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.22 | 12.03 | 130 | 0.06 | 2.51 | 0.06 | **4.43** | **0.37** | **0.02** | **0.03** |
| 73.00 | 1428.00 | 2447.53 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.92 | 130 | 0.04 | 2.12 | 0.05 | **4.38** | **0.37** | **0.02** | **0.03** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 74.00 | 1448.00 | 2447.28 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.92 | 130 | 0.04 | 2.12 | 0.05 | **4.38** | **0.37** | **0.02** | **0.03** |
| 75.00 | 1468.00 | 2447.04 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.44 | 130 | 0.04 | 2.07 | 0.05 | **4.62** | **0.36** | **0.01** | **0.03** |
| 76.00 | 1488.00 | 2446.76 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.86 | 129.8 | 0.04 | 1.88 | 0.05 | **5.59** | **0.30** | **0.01** | **0.03** |
| 77.00 | 1508.00 | 2446.29 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 7.89 | 133.45 | 0.04 | 1.78 | 0.04 | **6.46** | **0.26** | **0.01** | **0.03** |
| 78.00 | 1528.00 | 2445.63 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.61 | 135.9 | 0.04 | 1.76 | 0.04 | **6.79** | **0.25** | **0.01** | **0.03** |
| 79.00 | 1548.00 | 2444.89 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.70 | 135.9 | 0.04 | 1.77 | 0.04 | **6.70** | **0.25** | **0.01** | **0.03** |
| 80.00 | 1570.00 | 2444.18 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.18 | 8.95 | 129.8 | 0.04 | 1.96 | 0.05 | **5.75** | **0.29** | **0.01** | **0.03** |
| 81.00 | 1592.00 | 2443.68 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.18 | 9.80 | 130 | 0.05 | 2.07 | 0.05 | **5.18** | **0.32** | **0.01** | **0.03** |
| 82.00 | 1618.00 | 2443.31 | 0.03 | 0.01 | 0.03 | 81.00 | 0.70 | 0.01 | 0.21 | 10.35 | 130 | 0.05 | 2.27 | 0.06 | **5.21** | **0.32** | **0.02** | **0.04** |
| 83.00 | 1640.00 | 2442.93 | 0.03 | 0.02 | 0.04 | 81.00 | 0.70 | 0.02 | 0.18 | 9.76 | 130 | 0.05 | 2.06 | 0.05 | **5.20** | **0.32** | **0.01** | **0.03** |
| 84.00 | 1660.00 | 2442.55 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.90 | 129.8 | 0.04 | 1.89 | 0.05 | **5.56** | **0.30** | **0.01** | **0.03** |
| 85.00 | 1680.00 | 2442.09 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.32 | 133.45 | 0.04 | 1.84 | 0.05 | **6.08** | **0.28** | **0.01** | **0.03** |
| 86.00 | 1700.00 | 2441.53 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 7.87 | 133.45 | 0.04 | 1.78 | 0.04 | **6.49** | **0.26** | **0.01** | **0.03** |
| 87.00 | 1720.00 | 2440.86 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.50 | 135.9 | 0.04 | 1.74 | 0.04 | **6.91** | **0.25** | **0.01** | **0.03** |
| 88.00 | 1740.00 | 2440.09 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.21 | 135.9 | 0.04 | 1.70 | 0.04 | **7.23** | **0.23** | **0.01** | **0.03** |
| 89.00 | 1762.00 | 2439.22 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.04 | 0.18 | 7.36 | 135.9 | 0.05 | 1.79 | 0.04 | **7.35** | **0.23** | **0.01** | **0.04** |
| 90.00 | 1784.00 | 2438.32 | 0.03 | 0.04 | 0.04 | 81.00 | 0.70 | 0.04 | 0.18 | 7.36 | 135.9 | 0.05 | 1.79 | 0.04 | **7.35** | **0.23** | **0.01** | **0.04** |
| 91.00 | 1804.00 | 2437.42 | 0.03 | 0.05 | 0.04 | 81.00 | 0.70 | 0.05 | 0.16 | 7.13 | 138.35 | 0.04 | 1.70 | 0.04 | **7.37** | **0.23** | **0.01** | **0.03** |
| 92.00 | 1824.00 | 2436.52 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.67 | 129.8 | 0.04 | 1.66 | 0.04 | **7.18** | **0.24** | **0.01** | **0.03** |
| 93.00 | 1846.00 | 2435.62 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.18 | 9.20 | 130 | 0.05 | 1.76 | 0.04 | **7.21** | **0.24** | **0.01** | **0.03** |
| 94.00 | 1866.00 | 2434.72 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.67 | 129.8 | 0.04 | 1.66 | 0.04 | **7.18** | **0.24** | **0.01** | **0.03** |
| 95.00 | 1888.00 | 2433.82 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.18 | 9.20 | 130 | 0.05 | 1.76 | 0.04 | **7.21** | **0.24** | **0.01** | **0.03** |
| 96.00 | 1908.00 | 2432.92 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.60 | 129.8 | 0.04 | 1.66 | 0.04 | **7.22** | **0.24** | **0.01** | **0.03** |
| 97.00 | 1928.00 | 2432.00 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.75 | 129.8 | 0.04 | 1.67 | 0.04 | **7.14** | **0.24** | **0.01** | **0.03** |
| 98.00 | 1948.00 | 2431.12 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.67 | 129.8 | 0.04 | 1.66 | 0.04 | **7.18** | **0.24** | **0.01** | **0.03** |
| 99.00 | 1968.00 | 2430.22 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.77 | 129.8 | 0.04 | 1.67 | 0.04 | **7.13** | **0.24** | **0.01** | **0.03** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 100.00 | 1988.00 | 2429.33 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.58 | 129.8 | 0.04 | 1.66 | 0.04 | **7.23** | **0.24** | **0.01** | **0.03** |
| 101.00 | 2008.00 | 2428.42 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.67 | 129.8 | 0.04 | 1.66 | 0.04 | **7.18** | **0.24** | **0.01** | **0.03** |
| 102.00 | 2028.00 | 2427.51 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.44 | 129.8 | 0.04 | 1.65 | 0.04 | **7.31** | **0.23** | **0.01** | **0.03** |
| 103.00 | 2048.00 | 2426.57 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.14 | 133.45 | 0.04 | 1.65 | 0.04 | **7.58** | **0.22** | **0.01** | **0.03** |
| 104.00 | 2068.00 | 2425.56 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 7.88 | 133.45 | 0.04 | 1.63 | 0.04 | **7.75** | **0.22** | **0.01** | **0.03** |
| 105.00 | 2088.00 | 2424.50 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.65 | 135.9 | 0.04 | 1.62 | 0.04 | **7.98** | **0.21** | **0.01** | **0.03** |
| 106.00 | 2108.00 | 2423.37 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.45 | 135.9 | 0.04 | 1.60 | 0.04 | **8.15** | **0.21** | **0.01** | **0.03** |
| 107.00 | 2128.00 | 2422.17 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.28 | 135.9 | 0.04 | 1.59 | 0.04 | **8.29** | **0.21** | **0.01** | **0.03** |
| 108.00 | 2148.00 | 2420.92 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.16 | 138.35 | 0.04 | 1.59 | 0.04 | **8.47** | **0.20** | **0.01** | **0.03** |
| 109.00 | 2168.00 | 2419.63 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.36 | 135.9 | 0.04 | 1.60 | 0.04 | **8.22** | **0.21** | **0.01** | **0.03** |
| 110.00 | 2188.00 | 2418.40 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 111.00 | 2208.00 | 2417.14 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.32** | **0.21** | **0.01** | **0.03** |
| 112.00 | 2228.00 | 2415.88 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 113.00 | 2248.00 | 2414.63 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 114.00 | 2268.00 | 2413.37 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 115.00 | 2293.00 | 2412.11 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.20 | 8.13 | 133.45 | 0.05 | 1.79 | 0.04 | **8.33** | **0.21** | **0.01** | **0.04** |
| 116.00 | 2313.00 | 2410.85 | 0.03 | 0.06 | 0.04 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 117.00 | 2333.00 | 2409.59 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.25 | 135.9 | 0.04 | 1.59 | 0.04 | **8.31** | **0.21** | **0.01** | **0.03** |
| 118.00 | 2353.00 | 2408.33 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.21 | 135.9 | 0.04 | 1.59 | 0.04 | **8.35** | **0.21** | **0.01** | **0.03** |
| 119.00 | 2373.00 | 2407.06 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.15 | 138.35 | 0.04 | 1.59 | 0.04 | **8.47** | **0.20** | **0.01** | **0.03** |
| 120.00 | 2398.00 | 2405.76 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.20 | 7.93 | 133.45 | 0.05 | 1.77 | 0.04 | **8.47** | **0.20** | **0.01** | **0.04** |
| 121.00 | 2418.00 | 2404.44 | 0.03 | 0.07 | 0.04 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 122.00 | 2438.00 | 2403.10 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 6.98 | 138.35 | 0.04 | 1.58 | 0.04 | **8.64** | **0.20** | **0.01** | **0.03** |
| 123.00 | 2458.00 | 2401.73 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 6.96 | 138.35 | 0.04 | 1.57 | 0.04 | **8.66** | **0.20** | **0.01** | **0.03** |
| 124.00 | 2478.00 | 2400.36 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 6.96 | 138.35 | 0.04 | 1.57 | 0.04 | **8.66** | **0.20** | **0.01** | **0.03** |
| 125.00 | 2498.00 | 2398.99 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 6.96 | 138.35 | 0.04 | 1.57 | 0.04 | **8.66** | **0.20** | **0.01** | **0.03** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 126.00 | 2518.00 | 2397.61 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.03 | 138.35 | 0.04 | 1.58 | 0.04 | **8.60** | **0.20** | **0.01** | **0.03** |
| 127.00 | 2538.00 | 2396.27 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.16 | 7.64 | 135.9 | 0.04 | 1.62 | 0.04 | **7.99** | **0.21** | **0.01** | **0.03** |
| 128.00 | 2558.00 | 2395.13 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 8.77 | 129.8 | 0.04 | 1.67 | 0.04 | **7.13** | **0.24** | **0.01** | **0.03** |
| 129.00 | 2583.00 | 2394.25 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.03 | 0.20 | 8.39 | 133.45 | 0.05 | 2.00 | 0.05 | **6.61** | **0.26** | **0.01** | **0.04** |
| 130.00 | 2608.00 | 2393.56 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.03 | 0.20 | 8.45 | 129.8 | 0.05 | 1.99 | 0.05 | **6.48** | **0.26** | **0.01** | **0.04** |
| 131.00 | 2635.00 | 2392.89 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.03 | 0.22 | 8.52 | 129.8 | 0.06 | 2.06 | 0.05 | **6.63** | **0.25** | **0.01** | **0.04** |
| 132.00 | 2662.00 | 2392.18 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.03 | 0.22 | 8.06 | 133.45 | 0.06 | 2.02 | 0.05 | **7.15** | **0.24** | **0.01** | **0.04** |
| 133.00 | 2682.00 | 2391.35 | 0.03 | 0.05 | 0.04 | 81.00 | 0.70 | 0.05 | 0.16 | 6.96 | 138.35 | 0.04 | 1.68 | 0.04 | **7.59** | **0.22** | **0.01** | **0.03** |
| 134.00 | 2702.00 | 2390.38 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.06 | 0.16 | 6.67 | 138.35 | 0.04 | 1.64 | 0.04 | **7.97** | **0.21** | **0.01** | **0.03** |
| 135.00 | 2728.00 | 2389.27 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.05 | 0.21 | 7.01 | 138.35 | 0.06 | 1.86 | 0.05 | **8.41** | **0.20** | **0.01** | **0.05** |
| 136.00 | 2748.00 | 2388.04 | 0.03 | 0.07 | 0.05 | 81.00 | 0.70 | 0.05 | 0.16 | 7.06 | 138.35 | 0.04 | 1.58 | 0.04 | **8.56** | **0.20** | **0.01** | **0.03** |
| 137.00 | 2768.00 | 2386.70 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 138.00 | 2788.00 | 2385.36 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 139.00 | 2808.00 | 2384.02 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 140.00 | 2828.00 | 2382.69 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 141.00 | 2848.00 | 2381.35 | 0.03 | 0.07 | 0.03 | 81.00 | 0.70 | 0.05 | 0.16 | 7.04 | 138.35 | 0.04 | 1.58 | 0.04 | **8.58** | **0.20** | **0.01** | **0.03** |
| 142.00 | 2871.00 | 2380.01 | 0.03 | 0.06 | 0.03 | 81.00 | 0.70 | 0.04 | 0.19 | 7.54 | 135.9 | 0.05 | 1.70 | 0.04 | **8.56** | **0.20** | **0.01** | **0.04** |
| 143.00 | 2891.00 | 2378.67 | 0.03 | 0.06 | 0.04 | 81.00 | 0.70 | 0.04 | 0.16 | 7.16 | 138.35 | 0.04 | 1.59 | 0.04 | **8.46** | **0.20** | **0.01** | **0.03** |
| 144.00 | 2911.00 | 2377.38 | 0.03 | 0.05 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 7.90 | 133.45 | 0.04 | 1.63 | 0.04 | **7.74** | **0.22** | **0.01** | **0.03** |
| 145.00 | 2931.00 | 2376.31 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.24 | 130 | 0.04 | 1.70 | 0.04 | **6.91** | **0.25** | **0.01** | **0.03** |
| 146.00 | 2956.00 | 2375.50 | 0.03 | 0.02 | 0.03 | 81.00 | 0.70 | 0.00 | 0.20 | 15.63 | 130 | 0.05 | 2.03 | 0.05 | **6.23** | **0.27** | **0.01** | **0.04** |
| 147.00 | 2976.00 | 2374.89 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.01 | 0.16 | 12.11 | 130 | 0.04 | 1.81 | 0.05 | **6.09** | **0.28** | **0.01** | **0.03** |
| 148.00 | 2996.00 | 2374.31 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 12.08 | 130 | 0.04 | 1.81 | 0.05 | **6.09** | **0.28** | **0.01** | **0.03** |
| 149.00 | 3014.00 | 2373.73 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.15 | 10.93 | 130 | 0.04 | 1.70 | 0.04 | **6.07** | **0.28** | **0.01** | **0.03** |
| 150.00 | 3034.00 | 2373.15 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 12.08 | 130 | 0.04 | 1.81 | 0.05 | **6.09** | **0.28** | **0.01** | **0.03** |
| 151.00 | 3054.00 | 2372.56 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 11.64 | 130 | 0.04 | 1.79 | 0.04 | **6.18** | **0.27** | **0.01** | **0.03** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 152.00 | 3074.00 | 2371.96 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 11.14 | 130 | 0.04 | 1.78 | 0.04 | **6.29** | **0.27** | **0.01** | **0.03** |
| 153.00 | 3096.00 | 2371.32 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.18 | 11.68 | 130 | 0.05 | 1.86 | 0.05 | **6.42** | **0.26** | **0.01** | **0.03** |
| 154.00 | 3116.00 | 2370.66 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.16 | 10.36 | 130 | 0.04 | 1.75 | 0.04 | **6.50** | **0.26** | **0.01** | **0.03** |
| 155.00 | 3136.00 | 2369.97 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 10.06 | 130 | 0.04 | 1.74 | 0.04 | **6.60** | **0.26** | **0.01** | **0.03** |
| 156.00 | 3162.00 | 2369.25 | 0.03 | 0.03 | 0.03 | 81.00 | 0.70 | 0.01 | 0.21 | 12.63 | 130 | 0.05 | 2.01 | 0.05 | **6.70** | **0.25** | **0.01** | **0.04** |
| 157.00 | 3184.00 | 2368.52 | 0.03 | 0.03 | 0.04 | 81.00 | 0.70 | 0.01 | 0.18 | 10.75 | 130 | 0.05 | 1.83 | 0.05 | **6.65** | **0.25** | **0.01** | **0.03** |
| 158.00 | 3204.00 | 2367.79 | 0.03 | 0.04 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.97 | 130 | 0.04 | 1.73 | 0.04 | **6.63** | **0.26** | **0.01** | **0.03** |

Sefere Selam Autobis Tera Gojjam berenda

| INLET NO | I.Stat | ELEVATION | Sx(%) | SL(%) | Qb(m^3⁄s) | Ls(m) | C | S(%) | A(ha) | Tc(min) | I(mm/hr) | Q(m3/s) | T(m) | d(m) | LT(m) | E(%) | Qi (m3/s) | Qb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.00 | 0.00 | 2414.82 | - | - | 0m^3⁄s | - | - | - | - | - | - | - | - | - | **-** | **-** | **-** | 0.00 |
| 2.00 | 20.00 | 2414.77 | 0.02 | 0.03 | 0.00 | 81.00 | 0.70 | 0.04 | 0.16 | 7.36 | 135.9 | 0.04 | 2.17 | 0.04 | **6.70** | **0.25** | **0.01** | **0.03** |
| 3.00 | 40.00 | 2414.26 | 0.02 | 0.01 | 0.03 | 81.00 | 0.70 | 0.03 | 0.16 | 8.22 | 133.45 | 0.04 | 2.42 | 0.05 | **5.25** | **0.32** | **0.01** | **0.03** |
| 4.00 | 60.00 | 2413.99 | 0.02 | 0.00 | 0.03 | 81.00 | 0.70 | 0.02 | 0.16 | 9.20 | 130 | 0.04 | 2.90 | 0.06 | **3.54** | **0.45** | **0.02** | **0.02** |
| 5.00 | 85.00 | 2413.90 | 0.02 | 0.00 | 0.02 | 81.00 | 0.70 | 0.02 | 0.20 | 9.98 | 130 | 0.05 | 5.21 | 0.10 | **1.41** | **0.89** | **0.05** | **0.01** |
| 6.00 | 108.00 | 2413.89 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.19 | 4.94 | 150 | 0.07 | 4.93 | 0.10 | **2.26** | **0.65** | **0.05** | **0.02** |
| 7.00 | 128.00 | 2413.87 | 0.02 | 0.02 | 0.02 | 81.00 | 0.90 | 0.05 | 0.16 | 3.38 | 150 | 0.06 | 2.66 | 0.05 | **6.73** | **0.25** | **0.02** | **0.05** |
| 8.00 | 148.00 | 2413.53 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.96 | 150 | 0.06 | 4.93 | 0.10 | **1.92** | **0.73** | **0.04** | **0.02** |
| 9.00 | 168.00 | 2413.52 | 0.02 | 0.01 | 0.02 | 81.00 | 0.90 | 0.05 | 0.16 | 3.41 | 150 | 0.06 | 3.26 | 0.07 | **4.44** | **0.37** | **0.02** | **0.04** |
| 10.00 | 188.00 | 2413.40 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 5.02 | 150 | 0.06 | 7.80 | 0.16 | **1.56** | **0.84** | **0.05** | **0.01** |
| 11.00 | 208.00 | 2413.40 | 0.02 | 0.02 | 0.01 | 81.00 | 0.90 | 0.04 | 0.16 | 3.66 | 150 | 0.06 | 2.70 | 0.05 | **6.50** | **0.26** | **0.02** | **0.04** |
| 12.00 | 233.00 | 2413.08 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.03 | 0.20 | 4.23 | 150 | 0.08 | 3.15 | 0.06 | **6.22** | **0.27** | **0.02** | **0.06** |
| 13.00 | 258.00 | 2412.87 | 0.02 | 0.00 | 0.06 | 81.00 | 0.90 | 0.02 | 0.20 | 4.96 | 150 | 0.08 | 5.36 | 0.11 | **2.11** | **0.69** | **0.05** | **0.02** |
| 14.00 | 278.00 | 2412.85 | 0.02 | 0.00 | 0.02 | 81.00 | 0.90 | 0.03 | 0.16 | 4.23 | 150 | 0.06 | 4.60 | 0.09 | **2.21** | **0.66** | **0.04** | **0.02** |
| 15.00 | 298.00 | 2412.83 | 0.02 | 0.04 | 0.02 | 81.00 | 0.90 | 0.05 | 0.16 | 3.36 | 150 | 0.06 | 2.29 | 0.05 | **9.12** | **0.19** | **0.01** | **0.05** |
| 16.00 | 318.00 | 2412.07 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 5.01 | 150 | 0.06 | 6.82 | 0.14 | **1.80** | **0.77** | **0.05** | **0.01** |
| 17.00 | 338.00 | 2412.06 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.16 | 4.85 | 150 | 0.06 | 4.07 | 0.08 | **2.83** | **0.54** | **0.03** | **0.03** |
| 18.00 | 363.00 | 2412.03 | 0.02 | 0.00 | 0.03 | 81.00 | 0.90 | 0.00 | 0.20 | 9.97 | 130 | 0.07 | 5.31 | 0.11 | **1.82** | **0.76** | **0.05** | **0.02** |
| 19.00 | 383.00 | 2412.02 | 0.02 | 0.00 | 0.02 | 81.00 | 0.90 | 0.00 | 0.16 | 7.59 | 135.9 | 0.06 | 3.28 | 0.07 | **3.91** | **0.41** | **0.02** | **0.03** |
| 20.00 | 403.00 | 2411.93 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 7.37 | 135.9 | 0.06 | 3.23 | 0.06 | **4.04** | **0.40** | **0.02** | **0.03** |
| 21.00 | 423.00 | 2411.83 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 7.37 | 135.9 | 0.06 | 3.23 | 0.06 | **4.04** | **0.40** | **0.02** | **0.03** |
| 22.00 | 443.00 | 2411.73 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 7.37 | 135.9 | 0.06 | 3.23 | 0.06 | **4.04** | **0.40** | **0.02** | **0.03** |
| 23.00 | 463.00 | 2411.63 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 7.34 | 135.9 | 0.06 | 3.22 | 0.06 | **4.05** | **0.40** | **0.02** | **0.03** |
| 24.00 | 483.00 | 2411.52 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 6.56 | 143.8 | 0.06 | 3.09 | 0.06 | **4.73** | **0.35** | **0.02** | **0.04** |
| 25.00 | 503.00 | 2411.38 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 5.81 | 150 | 0.06 | 2.93 | 0.06 | **5.53** | **0.30** | **0.02** | **0.04** |
| 26.00 | 523.00 | 2411.18 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 5.32 | 150 | 0.06 | 2.78 | 0.06 | **6.12** | **0.27** | **0.02** | **0.04** |
| 27.00 | 543.00 | 2410.91 | 0.02 | 0.02 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.97 | 150 | 0.06 | 2.68 | 0.05 | **6.63** | **0.25** | **0.02** | **0.05** |
| 28.00 | 563.00 | 2410.58 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.69 | 150 | 0.06 | 2.59 | 0.05 | **7.08** | **0.24** | **0.01** | **0.05** |
| 29.00 | 583.00 | 2410.18 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 30.00 | 603.00 | 2409.77 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 31.00 | 623.00 | 2409.35 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 32.00 | 643.00 | 2408.94 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 33.00 | 663.00 | 2408.52 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.78 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |

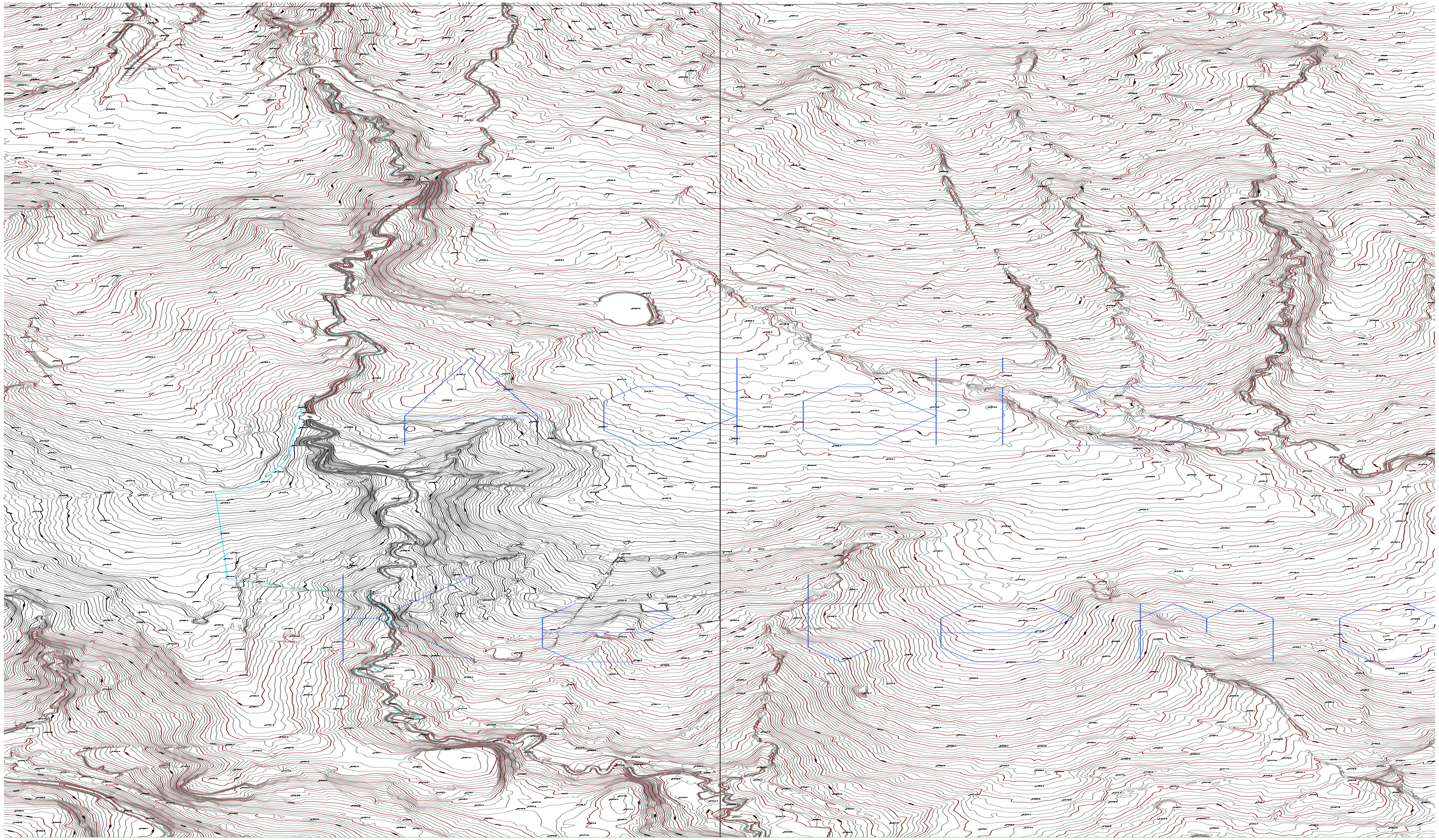
| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 34.00 | 683.00 | 2408.11 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 3.93 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 35.00 | 703.00 | 2407.69 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.63 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 36.00 | 723.00 | 2407.28 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 37.00 | 743.00 | 2406.86 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 38.00 | 763.00 | 2406.45 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 39.00 | 783.00 | 2406.03 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 40.00 | 803.00 | 2405.62 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.22** | **0.24** | **0.01** | **0.05** |
| 41.00 | 823.00 | 2405.20 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.57 | 0.05 | **7.21** | **0.24** | **0.01** | **0.05** |
| 42.00 | 843.00 | 2404.79 | 0.02 | 0.01 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.08 | 150 | 0.06 | 2.76 | 0.06 | **6.22** | **0.27** | **0.02** | **0.04** |
| 43.00 | 863.00 | 2404.51 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.72 | 150 | 0.06 | 3.60 | 0.07 | **3.63** | **0.44** | **0.03** | **0.03** |
| 44.00 | 883.00 | 2404.44 | 0.02 | 0.00 | 0.03 | 81.00 | 0.90 | 0.02 | 0.16 | 4.77 | 150 | 0.06 | 3.74 | 0.07 | **3.37** | **0.47** | **0.03** | **0.03** |
| 45.00 | 903.00 | 2404.38 | 0.02 | 0.00 | 0.03 | 81.00 | 0.90 | 0.06 | 0.16 | 3.32 | 150 | 0.06 | 6.04 | 0.12 | **1.27** | **0.94** | **0.06** | **0.00** |
| 46.00 | 928.00 | 2404.38 | 0.02 | 0.00 | 0.00 | 81.00 | 0.90 | 0.06 | 0.20 | 3.34 | 150 | 0.08 | 4.98 | 0.10 | **2.45** | **0.61** | **0.05** | **0.03** |
| 47.00 | 948.00 | 2404.40 | 0.02 | 0.00 | 0.03 | 81.00 | 0.90 | 0.05 | 0.16 | 3.41 | 150 | 0.06 | 3.43 | 0.07 | **4.01** | **0.40** | **0.02** | **0.04** |
| 48.00 | 968.00 | 2404.49 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.07 | 0.16 | 3.11 | 150 | 0.06 | 2.84 | 0.06 | **5.89** | **0.28** | **0.02** | **0.04** |
| 49.00 | 988.00 | 2404.24 | 0.02 | -0.04 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.82 | 150 | 0.06 | 2.29 | 0.05 | **9.08** | **0.19** | **0.01** | **0.05** |
| 50.00 | 1008.00 | 2405.00 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 5.36 | 150 | 0.06 | 2.24 | 0.04 | **9.51** | **0.18** | **0.01** | **0.05** |
| 51.00 | 1028.00 | 2405.86 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 5.36 | 150 | 0.06 | 2.24 | 0.04 | **9.51** | **0.18** | **0.01** | **0.05** |
| 52.00 | 1048.00 | 2406.72 | 0.02 | 0.01 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 3.95 | 150 | 0.06 | 3.13 | 0.06 | **4.82** | **0.34** | **0.02** | **0.04** |
| 53.00 | 1068.00 | 2406.57 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.45 | 150 | 0.06 | 3.72 | 0.07 | **3.40** | **0.47** | **0.03** | **0.03** |
| 54.00 | 1088.00 | 2406.63 | 0.02 | -0.02 | 0.03 | 81.00 | 0.90 | 0.04 | 0.16 | 3.77 | 150 | 0.06 | 2.64 | 0.05 | **6.82** | **0.25** | **0.02** | **0.05** |
| 55.00 | 1111.00 | 2406.99 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.06 | 0.19 | 3.33 | 150 | 0.07 | 5.67 | 0.11 | **1.70** | **0.80** | **0.06** | **0.01** |
| 56.00 | 1136.00 | 2406.99 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.06 | 0.20 | 3.32 | 150 | 0.08 | 7.41 | 0.15 | **1.89** | **0.74** | **0.06** | **0.02** |
| 57.00 | 1156.00 | 2406.99 | 0.02 | 0.01 | 0.02 | 81.00 | 0.90 | 0.07 | 0.16 | 3.08 | 150 | 0.06 | 2.75 | 0.06 | **6.27** | **0.27** | **0.02** | **0.04** |
| 58.00 | 1181.00 | 2406.71 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.06 | 0.20 | 3.32 | 150 | 0.08 | 7.82 | 0.16 | **1.78** | **0.77** | **0.06** | **0.02** |
| 59.00 | 1206.00 | 2406.70 | 0.02 | 0.00 | 0.02 | 81.00 | 0.90 | 0.06 | 0.20 | 3.32 | 150 | 0.08 | 6.67 | 0.13 | **1.36** | **0.91** | **0.07** | **0.01** |
| 60.00 | 1231.00 | 2406.70 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.20 | 4.99 | 150 | 0.08 | 6.01 | 0.12 | **1.67** | **0.81** | **0.06** | **0.01** |
| 61.00 | 1251.00 | 2406.69 | 0.02 | 0.01 | 0.01 | 81.00 | 0.90 | 0.03 | 0.16 | 4.31 | 150 | 0.06 | 2.97 | 0.06 | **5.36** | **0.31** | **0.02** | **0.04** |
| 62.00 | 1271.00 | 2406.50 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.59 | 150 | 0.06 | 3.35 | 0.07 | **4.21** | **0.39** | **0.02** | **0.04** |
| 63.00 | 1291.00 | 2406.40 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.69 | 150 | 0.06 | 3.54 | 0.07 | **3.75** | **0.43** | **0.03** | **0.03** |
| 64.00 | 1311.00 | 2406.33 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.03 | 0.16 | 4.15 | 150 | 0.06 | 2.82 | 0.06 | **5.97** | **0.28** | **0.02** | **0.04** |
| 65.00 | 1331.00 | 2406.08 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.71 | 150 | 0.06 | 3.59 | 0.07 | **3.66** | **0.44** | **0.03** | **0.03** |
| 66.00 | 1351.00 | 2406.01 | 0.02 | 0.02 | 0.03 | 81.00 | 0.90 | 0.04 | 0.16 | 3.70 | 150 | 0.06 | 2.49 | 0.05 | **7.69** | **0.22** | **0.01** | **0.05** |
| 67.00 | 1371.00 | 2405.52 | 0.02 | 0.03 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.66 | 150 | 0.06 | 2.46 | 0.05 | **7.84** | **0.22** | **0.01** | **0.05** |
| 68.00 | 1396.00 | 2405.00 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.02 | 0.20 | 4.96 | 150 | 0.08 | 5.32 | 0.11 | **2.15** | **0.68** | **0.05** | **0.02** |
| 69.00 | 1416.00 | 2404.99 | 0.02 | 0.00 | 0.02 | 81.00 | 0.90 | 0.02 | 0.16 | 4.86 | 150 | 0.06 | 4.10 | 0.08 | **2.79** | **0.55** | **0.03** | **0.03** |
| 70.00 | 1436.00 | 2404.96 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.02 | 0.16 | 4.55 | 150 | 0.06 | 3.28 | 0.07 | **4.38** | **0.37** | **0.02** | **0.04** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 71.00 | 1456.00 | 2404.85 | 0.02 | 0.02 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.68 | 150 | 0.06 | 2.58 | 0.05 | **7.13** | **0.24** | **0.01** | **0.05** |
| 72.00 | 1476.00 | 2404.44 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 7.12 | 138.35 | 0.06 | 2.49 | 0.05 | **6.96** | **0.24** | **0.01** | **0.04** |
| 73.00 | 1496.00 | 2404.03 | 0.02 | 0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 9.18 | 130 | 0.05 | 2.51 | 0.05 | **6.39** | **0.26** | **0.01** | **0.04** |
| 74.00 | 1516.00 | 2403.68 | 0.02 | 0.03 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.11 | 143.8 | 0.06 | 2.30 | 0.05 | **8.55** | **0.20** | **0.01** | **0.05** |
| 75.00 | 1536.00 | 2403.01 | 0.02 | 0.04 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.72 | 150 | 0.06 | 2.23 | 0.04 | **9.63** | **0.18** | **0.01** | **0.05** |
| 76.00 | 1556.00 | 2402.12 | 0.02 | 0.04 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.82 | 150 | 0.06 | 2.28 | 0.05 | **9.19** | **0.19** | **0.01** | **0.05** |
| 77.00 | 1576.00 | 2401.34 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.11 | 0.16 | 2.67 | 150 | 0.06 | 2.68 | 0.05 | **6.63** | **0.25** | **0.02** | **0.05** |
| 78.00 | 1596.00 | 2401.01 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 3.93 | 150 | 0.06 | 2.18 | 0.04 | **10.07** | **0.17** | **0.01** | **0.05** |
| 79.00 | 1616.00 | 2400.01 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.00 | 0.16 | 12.14 | 130 | 0.05 | 2.52 | 0.05 | **6.32** | **0.27** | **0.01** | **0.04** |
| 80.00 | 1636.00 | 2399.67 | 0.02 | 0.06 | 0.04 | 81.00 | 0.90 | 0.04 | 0.16 | 3.71 | 150 | 0.06 | 2.13 | 0.04 | **10.54** | **0.16** | **0.01** | **0.05** |
| 81.00 | 1656.00 | 2398.54 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.13 | 150 | 0.06 | 2.22 | 0.04 | **9.70** | **0.18** | **0.01** | **0.05** |
| 82.00 | 1676.00 | 2397.64 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.78 | 150 | 0.06 | 2.14 | 0.04 | **10.38** | **0.17** | **0.01** | **0.05** |
| 83.00 | 1696.00 | 2396.56 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.07 | 0.16 | 3.14 | 150 | 0.06 | 2.17 | 0.04 | **10.11** | **0.17** | **0.01** | **0.05** |
| 84.00 | 1716.00 | 2395.56 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 5.01 | 150 | 0.06 | 6.43 | 0.13 | **1.12** | **0.98** | **0.06** | **0.00** |
| 85.00 | 1736.00 | 2395.55 | 0.02 | 0.00 | 0.00 | 81.00 | 0.90 | 0.02 | 0.16 | 5.02 | 150 | 0.06 | 7.80 | 0.16 | **1.56** | **0.84** | **0.05** | **0.01** |
| 86.00 | 1756.00 | 2395.55 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.16 | 5.01 | 150 | 0.06 | 6.40 | 0.13 | **1.13** | **0.98** | **0.06** | **0.00** |
| 87.00 | 1776.00 | 2395.55 | 0.02 | 0.00 | 0.00 | 81.00 | 0.90 | 0.02 | 0.16 | 4.98 | 150 | 0.06 | 5.30 | 0.11 | **1.66** | **0.81** | **0.05** | **0.01** |
| 88.00 | 1796.00 | 2395.54 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.16 | 4.99 | 150 | 0.06 | 5.67 | 0.11 | **1.45** | **0.88** | **0.05** | **0.01** |
| 89.00 | 1816.00 | 2395.54 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.16 | 4.89 | 150 | 0.06 | 4.28 | 0.09 | **2.56** | **0.59** | **0.04** | **0.02** |
| 90.00 | 1836.00 | 2395.51 | 0.02 | 0.00 | 0.02 | 81.00 | 0.90 | 0.02 | 0.16 | 4.98 | 150 | 0.06 | 5.23 | 0.10 | **1.71** | **0.80** | **0.05** | **0.01** |
| 91.00 | 1856.00 | 2395.50 | 0.02 | 0.00 | 0.01 | 81.00 | 0.90 | 0.02 | 0.16 | 4.97 | 150 | 0.06 | 5.17 | 0.10 | **1.75** | **0.78** | **0.05** | **0.01** |
| 92.00 | 1876.00 | 2395.49 | 0.02 | 0.02 | 0.01 | 81.00 | 0.90 | 0.04 | 0.16 | 3.84 | 150 | 0.06 | 2.58 | 0.05 | **7.12** | **0.24** | **0.01** | **0.05** |
| 93.00 | 1896.00 | 2395.09 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 5.51 | 150 | 0.06 | 3.51 | 0.07 | **3.82** | **0.42** | **0.03** | **0.04** |
| 94.00 | 1916.00 | 2395.17 | 0.02 | -0.03 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 5.37 | 150 | 0.06 | 2.41 | 0.05 | **8.21** | **0.21** | **0.01** | **0.05** |
| 95.00 | 1936.00 | 2395.75 | 0.02 | -0.02 | 0.05 | 81.00 | 0.90 | 0.00 | 0.16 | 8.79 | 129.8 | 0.05 | 2.47 | 0.05 | **6.57** | **0.26** | **0.01** | **0.04** |
| 96.00 | 1956.00 | 2396.13 | 0.02 | -0.01 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.55 | 143.8 | 0.06 | 2.96 | 0.06 | **5.13** | **0.32** | **0.02** | **0.04** |
| 97.00 | 1976.00 | 2396.30 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.90 | 150 | 0.06 | 4.33 | 0.09 | **2.51** | **0.60** | **0.04** | **0.02** |
| 98.00 | 1996.00 | 2396.28 | 0.02 | 0.01 | 0.02 | 81.00 | 0.90 | 0.02 | 0.16 | 4.53 | 150 | 0.06 | 3.25 | 0.06 | **4.48** | **0.37** | **0.02** | **0.04** |
| 99.00 | 2016.00 | 2396.16 | 0.02 | 0.01 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.53 | 150 | 0.06 | 3.25 | 0.06 | **4.48** | **0.37** | **0.02** | **0.04** |
| 100.00 | 2036.00 | 2396.04 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.83 | 150 | 0.06 | 3.95 | 0.08 | **3.01** | **0.52** | **0.03** | **0.03** |
| 101.00 | 2056.00 | 2396.00 | 0.02 | -0.01 | 0.03 | 81.00 | 0.90 | 0.01 | 0.16 | 6.32 | 143.8 | 0.06 | 3.02 | 0.06 | **4.94** | **0.33** | **0.02** | **0.04** |
| 102.00 | 2076.00 | 2396.16 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 9.66 | 130 | 0.05 | 2.49 | 0.05 | **6.47** | **0.26** | **0.01** | **0.04** |
| 103.00 | 2096.00 | 2396.52 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.26 | 143.8 | 0.06 | 2.47 | 0.05 | **7.41** | **0.23** | **0.01** | **0.04** |
| 104.00 | 2116.00 | 2396.99 | 0.02 | -0.01 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 10.06 | 130 | 0.05 | 2.62 | 0.05 | **5.86** | **0.29** | **0.02** | **0.04** |
| 105.00 | 2136.00 | 2397.27 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 5.45 | 150 | 0.06 | 3.59 | 0.07 | **3.66** | **0.44** | **0.03** | **0.03** |
| 106.00 | 2156.00 | 2397.34 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.02 | 0.16 | 4.45 | 150 | 0.06 | 3.14 | 0.06 | **4.81** | **0.34** | **0.02** | **0.04** |
| 107.00 | 2176.00 | 2397.20 | 0.02 | 0.02 | 0.04 | 81.00 | 0.90 | 0.03 | 0.16 | 3.93 | 150 | 0.06 | 2.64 | 0.05 | **6.80** | **0.25** | **0.02** | **0.05** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 108.00 | 2196.00 | 2396.84 | 0.02 | 0.03 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.59 | 150 | 0.06 | 2.42 | 0.05 | **8.12** | **0.21** | **0.01** | **0.05** |
| 109.00 | 2216.00 | 2396.28 | 0.02 | 0.04 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.35 | 150 | 0.06 | 2.28 | 0.05 | **9.17** | **0.19** | **0.01** | **0.05** |
| 110.00 | 2236.00 | 2395.50 | 0.02 | 0.06 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.11 | 150 | 0.06 | 2.11 | 0.04 | **10.77** | **0.16** | **0.01** | **0.05** |
| 111.00 | 2256.00 | 2394.31 | 0.02 | 0.07 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.88 | 150 | 0.06 | 2.07 | 0.04 | **11.15** | **0.16** | **0.01** | **0.05** |
| 112.00 | 2276.00 | 2393.01 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.38 | 150 | 0.06 | 2.14 | 0.04 | **10.41** | **0.17** | **0.01** | **0.05** |
| 113.00 | 2296.00 | 2391.92 | 0.02 | 0.07 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.86 | 150 | 0.06 | 2.07 | 0.04 | **11.19** | **0.16** | **0.01** | **0.05** |
| 114.00 | 2316.00 | 2390.61 | 0.02 | 0.08 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.56 | 150 | 0.06 | 2.01 | 0.04 | **11.81** | **0.15** | **0.01** | **0.05** |
| 115.00 | 2336.00 | 2389.10 | 0.02 | 0.08 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.44 | 150 | 0.06 | 1.99 | 0.04 | **12.10** | **0.14** | **0.01** | **0.05** |
| 116.00 | 2356.00 | 2387.49 | 0.02 | 0.06 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.06 | 150 | 0.06 | 2.10 | 0.04 | **10.85** | **0.16** | **0.01** | **0.05** |
| 117.00 | 2376.00 | 2386.27 | 0.02 | 0.07 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.86 | 150 | 0.06 | 2.07 | 0.04 | **11.17** | **0.16** | **0.01** | **0.05** |
| 118.00 | 2396.00 | 2384.97 | 0.02 | 0.05 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.37 | 150 | 0.06 | 2.14 | 0.04 | **10.41** | **0.17** | **0.01** | **0.05** |
| 119.00 | 2416.00 | 2383.88 | 0.02 | 0.04 | 0.05 | 81.00 | 0.90 | 0.06 | 0.16 | 3.26 | 150 | 0.06 | 2.24 | 0.04 | **9.55** | **0.18** | **0.01** | **0.05** |
| 120.00 | 2436.00 | 2383.01 | 0.02 | 0.03 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.49 | 150 | 0.06 | 2.36 | 0.05 | **8.54** | **0.20** | **0.01** | **0.05** |
| 121.00 | 2456.00 | 2382.37 | 0.02 | 0.02 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.81 | 150 | 0.06 | 2.56 | 0.05 | **7.27** | **0.23** | **0.01** | **0.05** |
| 122.00 | 2476.00 | 2381.95 | 0.02 | 0.01 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.28 | 150 | 0.06 | 2.94 | 0.06 | **5.48** | **0.30** | **0.02** | **0.04** |
| 123.00 | 2496.00 | 2381.74 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 5.14 | 150 | 0.06 | 4.51 | 0.09 | **2.31** | **0.64** | **0.04** | **0.02** |
| 124.00 | 2516.00 | 2381.77 | 0.02 | -0.01 | 0.02 | 81.00 | 0.90 | 0.00 | 0.16 | 8.02 | 133.45 | 0.05 | 2.72 | 0.05 | **5.60** | **0.30** | **0.02** | **0.04** |
| 125.00 | 2536.00 | 2382.01 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.54 | 143.8 | 0.06 | 2.47 | 0.05 | **7.40** | **0.23** | **0.01** | **0.04** |
| 126.00 | 2556.00 | 2382.47 | 0.02 | -0.03 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.81 | 150 | 0.06 | 2.34 | 0.05 | **8.74** | **0.20** | **0.01** | **0.05** |
| 127.00 | 2576.00 | 2383.16 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.17 | 150 | 0.06 | 2.23 | 0.04 | **9.62** | **0.18** | **0.01** | **0.05** |
| 128.00 | 2596.00 | 2384.04 | 0.02 | -0.05 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.10 | 150 | 0.06 | 2.21 | 0.04 | **9.75** | **0.18** | **0.01** | **0.05** |
| 129.00 | 2616.00 | 2384.95 | 0.02 | -0.05 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.11 | 150 | 0.06 | 2.22 | 0.04 | **9.73** | **0.18** | **0.01** | **0.05** |
| 130.00 | 2636.00 | 2385.86 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.40 | 150 | 0.06 | 2.27 | 0.05 | **9.26** | **0.19** | **0.01** | **0.05** |
| 131.00 | 2656.00 | 2386.66 | 0.02 | -0.03 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.97 | 150 | 0.06 | 2.36 | 0.05 | **8.57** | **0.20** | **0.01** | **0.05** |
| 132.00 | 2676.00 | 2387.31 | 0.02 | -0.03 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 6.06 | 143.8 | 0.06 | 2.44 | 0.05 | **7.62** | **0.22** | **0.01** | **0.05** |
| 133.00 | 2696.00 | 2387.81 | 0.02 | -0.02 | 0.05 | 81.00 | 0.90 | 0.00 | 0.16 | 10.16 | 130 | 0.05 | 2.50 | 0.05 | **6.43** | **0.26** | **0.01** | **0.04** |
| 134.00 | 2716.00 | 2388.17 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.92 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 135.00 | 2736.00 | 2388.49 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.17 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 136.00 | 2756.00 | 2388.81 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.92 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 137.00 | 2776.00 | 2389.13 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.92 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 138.00 | 2796.00 | 2389.45 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.92 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 139.00 | 2816.00 | 2389.77 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 30.17 | 130 | 0.05 | 2.56 | 0.05 | **6.15** | **0.27** | **0.01** | **0.04** |
| 140.00 | 2836.00 | 2390.08 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.00 | 0.16 | 9.85 | 130 | 0.05 | 2.50 | 0.05 | **6.45** | **0.26** | **0.01** | **0.04** |
| 141.00 | 2856.00 | 2390.45 | 0.02 | -0.02 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.25 | 143.8 | 0.06 | 2.45 | 0.05 | **7.53** | **0.23** | **0.01** | **0.05** |
| 142.00 | 2876.00 | 2390.93 | 0.02 | -0.03 | 0.05 | 81.00 | 0.90 | 0.01 | 0.16 | 5.19 | 150 | 0.06 | 2.39 | 0.05 | **8.36** | **0.20** | **0.01** | **0.05** |
| 143.00 | 2896.00 | 2391.54 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.61 | 150 | 0.06 | 2.30 | 0.05 | **8.98** | **0.19** | **0.01** | **0.05** |
| 144.00 | 2916.00 | 2392.28 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.22 | 150 | 0.06 | 2.24 | 0.04 | **9.53** | **0.18** | **0.01** | **0.05** |

| | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 145.00 | 2936.00 | 2393.14 | 0.02 | -0.05 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 3.94 | 150 | 0.06 | 2.18 | 0.04 | **10.04** | **0.17** | **0.01** | **0.05** |
| 146.00 | 2956.00 | 2394.13 | 0.02 | -0.06 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.73 | 150 | 0.06 | 2.13 | 0.04 | **10.51** | **0.16** | **0.01** | **0.05** |
| 147.00 | 2976.00 | 2395.24 | 0.02 | -0.06 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.55 | 150 | 0.06 | 2.09 | 0.04 | **10.94** | **0.16** | **0.01** | **0.05** |
| 148.00 | 2996.00 | 2396.48 | 0.02 | -0.07 | 0.05 | 81.00 | 0.90 | 0.06 | 0.16 | 3.25 | 150 | 0.06 | 2.07 | 0.04 | **11.21** | **0.15** | **0.01** | **0.05** |
| 149.00 | 3016.00 | 2397.80 | 0.02 | -0.07 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.45 | 150 | 0.06 | 2.06 | 0.04 | **11.22** | **0.15** | **0.01** | **0.05** |
| 150.00 | 3036.00 | 2399.12 | 0.02 | -0.07 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.45 | 150 | 0.06 | 2.06 | 0.04 | **11.22** | **0.15** | **0.01** | **0.05** |
| 151.00 | 3056.00 | 2400.44 | 0.02 | -0.06 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.52 | 150 | 0.06 | 2.08 | 0.04 | **11.01** | **0.16** | **0.01** | **0.05** |
| 152.00 | 3076.00 | 2401.70 | 0.02 | -0.05 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.83 | 150 | 0.06 | 2.16 | 0.04 | **10.27** | **0.17** | **0.01** | **0.05** |
| 153.00 | 3096.00 | 2402.75 | 0.02 | -0.04 | 0.05 | 81.00 | 0.90 | 0.03 | 0.16 | 4.30 | 150 | 0.06 | 2.25 | 0.05 | **9.41** | **0.18** | **0.01** | **0.05** |
| 154.00 | 3116.00 | 2403.58 | 0.02 | -0.06 | 0.05 | 81.00 | 0.90 | 0.04 | 0.16 | 3.72 | 150 | 0.06 | 2.13 | 0.04 | **10.52** | **0.16** | **0.01** | **0.05** |
| 155.00 | 3136.00 | 2404.70 | 0.02 | 0.00 | 0.05 | 81.00 | 0.90 | 0.02 | 0.16 | 4.60 | 150 | 0.06 | 3.36 | 0.07 | **4.19** | **0.39** | **0.02** | **0.04** |
| 156.00 | 3156.00 | 2404.60 | 0.02 | -0.01 | 0.04 | 81.00 | 0.90 | 0.01 | 0.16 | 6.68 | 138.35 | 0.06 | 2.90 | 0.06 | **5.13** | **0.32** | **0.02** | **0.04** |
| 157.00 | 3176.00 | 2404.79 | 0.02 | 0.00 | 0.04 | 81.00 | 0.90 | 0.02 | 0.16 | 4.87 | 150 | 0.06 | 4.17 | 0.08 | **2.70** | **0.56** | **0.03** | **0.03** |
| 158.00 | 3196.00 | 2404.76 | 0.02 | 0.01 | 0.03 | 81.00 | 0.90 | 0.03 | 0.16 | 4.16 | 150 | 0.06 | 2.83 | 0.06 | **5.93** | **0.28** | **0.02** | **0.04** |
| 159.00 | 3216.00 | 2404.51 | 0.02 | 0.02 | 0.04 | 81.00 | 0.90 | 0.04 | 0.16 | 3.74 | 150 | 0.06 | 2.51 | 0.05 | **7.53** | **0.23** | **0.01** | **0.05** |
| 160.00 | 3236.00 | 2404.04 | 0.02 | 0.03 | 0.05 | 81.00 | 0.90 | 0.05 | 0.16 | 3.45 | 150 | 0.06 | 2.34 | 0.05 | **8.71** | **0.20** | **0.01** | **0.05** |
| 161.00 | 3256.00 | 2403.36 | 0.02 | 0.04 | 0.05 | 81.00 | 0.90 | 0.06 | 0.16 | 3.23 | 150 | 0.06 | 2.22 | 0.04 | **9.68** | **0.18** | **0.01** | **0.05** |
| 162.00 | 3276.00 | 2402.47 | 0.02 | - | - | - | - | - | - | - | - | - | - | - | **-** | **-** | **-** | **-** |

# APPENDIX III



# APPENDIX IV

Table A, Time of concentration formula

| Method and Date | Formula for $t_c$ (min) | Remarks |
|---|---|---|
| Kirpich (1940) | $t_c = 0.0078L^{0.77}S^{-0.385}$<br>$L$ = length of channel/ditch from headwater to outlet, ft<br>$S$ = average watershed slope, ft/ft | Developed from SCS data for seven rural basins in Tennessee with well-defined channel and steep slopes (3% to 10%); for overland flow on concrete or asphalt surfaces multiply $t_c$ by 0.4; for concrete channels multiply by 0.2; no adjustments for overland flow on bare soil or flow in roadside ditches. |
| California Culverts Practice (1942) | $t_c = 60(11.9L^3/H)^{0.385}$<br>$L$ = length of longest watercourse, mi<br>$H$ = elevation difference between divide and outlet, ft | Essentially the Kirpich formula; developed from small mountainous basins in California (U. S. Bureau of Reclamation, 1973, pp. 67–71). |
| Izzard (1946) | $t_c = \frac{41.025(0.0007i + c)L^{0.33}}{S^{0.333}i^{0.667}}$<br>$i$ = rainfall intensity, in/h<br>$c$ = retardance coefficient<br>$L$ = length of flow path, ft<br>$S$ = slope of flow path, ft/ft | Developed in laboratory experiments by Bureau of Public Roads for overland flow on roadway and turf surfaces; values of the retardance coefficient range from 0.0070 for very smooth pavement to 0.012 for concrete pavement to 0.06 for dense turf; solution requires iteration; product $i$ times $L$ should be $\leq 500$. |
| Federal Aviation Administration (1970) | $t_c = 1.8(1.1 - C)L^{0.50}/S^{0.333}$<br>$C$ = rational method runoff coefficient<br>$L$ = length of overland flow, ft<br>$S$ = surface slope, % | Developed from air field drainage data assembled by the Corps of Engineers; method is intended for use on airfield drainage problems, but has been used frequently for overland flow in urban basins. |

Table A-23continued

| **Method and Date** | **Formula for $t_c$ (min)** | **Remarks** |
|---|---|---|
| Kinematic wave formulas Morgali and Linsley (1965) Aron and Erborge (1973) | $t_c = \frac{0.94 L^{0.6} n^{0.6}}{(i^{0.4} S^{0.3})}$ <br> $L$ = length of overland flow, ft <br> $n$ = Manning roughness coefficient <br> $i$ = rainfall intensity in/h <br> $S$ = average overland slope ft/ft | Overland flow equation developed from kinematic wave analysis of surface runoff from developed surfaces; method requires iteration since both $i$ (rainfall intensity) and $t_c$ are unknown; superposition of intensity–duration–frequency curve gives direct graphical solution for $t_c$ |
| SCS lag equation (1973) | $t_c = \frac{100 L^{0.8}[(1000/CN) - 9]^{0.7}}{1900 S^{0.5}}$ <br> $L$ = hydraulic length of watershed (longest flow path), ft <br> CN = SCS runoff curve number <br> $S$ = average watershed slope, % | Equation developed by SCS from agricultural watershed data; it has been adapted to small urban basins under 2000 acres; found generally good where area is completely paved; for mixed areas it tends to overestimate; adjustment factors are applied to correct for channel improvement and impervious area; the equation assumes that $t_c = 1.67 \times$ basin lag. |
| SCS average velocity charts (1975, 1986) | $t_c = \frac{1}{60} \Sigma \frac{L}{V}$ <br> $L$ = length of flow path, ft <br> $V$ = average velocity in feet per second from Fig. 3-1 of TR 55 for various surfaces | Overland flow charts in Fig. 3-1 of TR 55 show average velocity as function of watercourse slope and surface cover. (See also Table 5.7.1) |

Table B Runoff Coefficients for Rational Formula

| Type of Drainage Area | Runoff Coefficient, C* |
|---|---|
| Business: | |
| Downtown areas | 0.70 - 0.95 |
| Neighborhood areas | 0.50 - 0.70 |
| | |
| Residential: | |
| Single-family areas | 0.30 - 0.50 |
| Multi-units, detached | 0.40 - 0.60 |
| Multi-units, attached | 0.60 - 0.75 |
| Suburban | 0.25 - 0.40 |
| Apartment dwelling areas | 0.50 - 0.70 |
| | |
| Industrial: | |
| Light areas | 0.50 - 0.80 |
| Heavy areas | 0.60 - 0.90 |
| | |
| Parks, cemeteries | 0.10 - 0.25 |
| Playgrounds | 0.20 - 0.40 |
| Railroad yard areas | 0.20 - 0.40 |
| Unimproved areas | 0.10 - 0.30 |
| | |
| Lawns: | |
| Sandy soil, flat, 2% | 0.05 - 0.10 |
| Sandy soil, average, 2 - 7% | 0.10 - 0.15 |
| Sandy soil, steep, 7% | 0.15 - 0.20 |
| Heavy soil, flat, 2% | 0.13 - 0.17 |
| Heavy soil, average, 2 - 7% | 0.18 - 0.22 |
| Heavy soil, steep, 7% | 0.25 - 0.35 |
| | |
| Streets: | |
| Asphaltic | 0.70 - 0.95 |
| Concrete | 0.80 - 0.95 |
| Brick | 0.70 - 0.85 |
| | |
| Drives and walks | 0.75 - 0.85 |
| | |
| Roofs | 0.75 - 0.95 |
| *Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases. | |

Table C Manning's Roughness Coefficient (n) for Overland Sheet Flow

| Type of Drainage Area | Runoff Coefficient, C* |
|---|---|
| Business: | |
| Downtown areas | 0.70 - 0.95 |
| Neighborhood areas | 0.50 - 0.70 |
| | |
| Residential: | |
| Single-family areas | 0.30 - 0.50 |
| Multi-units, detached | 0.40 - 0.60 |
| Multi-units, attached | 0.60 - 0.75 |
| Suburban | 0.25 - 0.40 |
| Apartment dwelling areas | 0.50 - 0.70 |
| | |
| Industrial: | |
| Light areas | 0.50 - 0.80 |
| Heavy areas | 0.60 - 0.90 |
| | |
| Parks, cemeteries | 0.10 - 0.25 |
| Playgrounds | 0.20 - 0.40 |
| Railroad yard areas | 0.20 - 0.40 |
| Unimproved areas | 0.10 - 0.30 |
| | |
| Lawns: | |
| Sandy soil, flat, 2% | 0.05 - 0.10 |
| Sandy soil, average, 2 - 7% | 0.10 - 0.15 |
| Sandy soil, steep, 7% | 0.15 - 0.20 |
| Heavy soil, flat, 2% | 0.13 - 0.17 |
| Heavy soil, average, 2 - 7% | 0.18 - 0.22 |
| Heavy soil, steep, 7% | 0.25 - 0.35 |
| | |
| Streets: | |
| Asphaltic | 0.70 - 0.95 |
| Concrete | 0.80 - 0.95 |
| Brick | 0.70 - 0.85 |
| | |
| Drives and walks | 0.75 - 0.85 |
| | |
| Roofs | 0.75 - 0.95 |

*Higher values are usually appropriate for steeply sloped areas and longer return periods because infiltration and other losses have a proportionally smaller effect on runoff in these cases.

Table D Manning's Roughness Coefficient (n) for Overland Sheet Flow with surface description

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

Table E Values of Manning's Coefficient (n) for Channels and Pi

| Conduit Material | Manning's n* |
|---|---|
| Closed Conduits | |
| Asbestos-cement pipe | 0.011 0.015 |
| Brick | 0.013 - 0.017 |
| Cast iron pipe | |
| Cement-lined and seal coated | 0.011 - 0.015 |
| Concrete (monolithic) | 0.012 - 0.014 |
| Concrete pipe | 0.011 - 0.015 |
| Corrugated-metal pipe - 13 mm by 64 mm (½ inch by 2 ½ inch) corrugations | |
| Plain | 0.022 - 0.026 |
| Paved invert | 0.018 - 0.022 |
| Spun asphalt lines | 0.011 - 0.015 |
| Plastic pipe (smooth) | 0.011 - 0.015 |
| Vitrified clay | |
| Pipes | 0.011 - 0.015 |
| Liner plates | 0.013 - 0.017 |
| Open Channels | |
| Lined channels | |
| Asphalt | 0.013 - 0.017 |
| Brick | 0.012 - 0.018 |
| Concrete | 0.011 - 0.020 |
| Rubble or riprap | 0.020 - 0.035 |
| Vegetal | 0.030 - 0.400 |
| Excavated or dredged | |
| Earth, straight and uniform | 0.020 - 0.030 |
| Earth, winding, fairly uniform | 0.025 - 0.040 |
| Rock | 0.030 - 0.045 |
| Unmaintained | 0.050 - 0.140 |
| Natural channels (minor streams, top width at flood stage <30 m (100 ft)) | |
| Fairly regular section | 0.030 - 0.070 |
| Irregular section with pools | 0.040 - 0.100 |
| *Lower values are usually for well-constructed and maintained (smoother) pipes and channels. | |

# APPENDIX V

Photo