JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDRAULIC AND HYDROLOGY CHAIR

Flood Inundation Mapping and Hazard Assessment: A Case of Holeta River, Ethiopia.

By: Solomon Adugna Buli

A Thesis submitted to the School of Graduate Studies of Jimma University, Jimma Institute of Technology in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering

November, 2020

Jimma, Ethiopia

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Major Advisor: -Dr.-Ing. Tamene Adugna (Ass.Prof)

Co-Advisor: - Mr. Megersa Kebede (PhD.Cand)

November, 2020

Jimma, Ethiopia

DECLARATION

I Solomon Adugna, declare that this thesis is my own work with the exception of such quotation or reference which has been attributed to their authors or sources, and this thesis has not been previously submitted to this or any other university for a degree award.

Solomon Adugna Buli

____________________ ____________________

Signature Date

We, the undersigned, certify that we have read and here by recommend for the acceptance by the Jimma University a dissertation entitled: **Flood Inundation Mapping and Hazard Assessment: A case study on Upstream-Downstream Holeta River** in partial fulfillment for the requirements for the degree of Master of Science in Hydraulic Engineering.

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APPROVAL PAGE

The thesis entitled "(**Flood Inundation Mapping and Hazard Assessment: A Case of Upstream-Downstream Holeta River, Ethiopia)**" submitted by **SOLOMON ADUGNA** is approved and accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering at Jimma Institute of Technology.

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As members of the examining board of MSc. thesis, we certify that we have read and evaluated the thesis prepared by **Solomon Adugna Buli**. We recommend that the thesis could be accepted as a Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

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ABSTRACT

Flood is a natural hazard that causes damage of property and life. Flood hazard assessment is particularly important for policy makers, in order to design mitigation strategies and implement flood risk management planning. During high rainfall depth at summer season of the year the overflow of Holeta River course is occurred and cause flood risk consequence. This study aims to map flood inundation area and hazard assessment, for upstream-Downstream Holeta River by using Geographic Information System, Analytical Hierarch Process, Hydraulic Engineering Center- River Analysis System and Hydraulic Engineering Center – Geometry River Analysis System software. The importance's of this study is to have detail information about future floods and to serve for flood preparedness. For this study, Log-Pearson Type-III was used to compute peak discharge. However, there was limited recorded data at the downstream interested point, so transposing peak discharge from upstream catchment was employed by using Drainage Area Weighting (DAW) methods. The transposing Coefficient was estimated about 2.1506. Thus, the final peak Discharges for 10, 25, 50 and 100 years was estimated 350.75, 417.445, 465.551 and 511.68 m^3/s respectively. HEC-Geo RAS Software was used to develop river geometry such as: the river centerline, river bank, flow path and cut cross-section for upstream-Downstream Holeta River. HEC-RAS, hydraulic analysis includes the computation of the water surface profiles. The flood extent area of inundation mapping for 10, 25, 50 and 100 years was estimated about 22, 24, 26, 26.7 km^2 and 49, 51, 53 and 53.5 km^2 for steady and unsteady flood flow simulation respectively. Thus, the inundation mapping was developed for different return period with their extent areas from river course. Based on degree to flooding, the importance of selected parameters were ranked to four flood hazard category, namely very low flooding, low flooding, moderate flooding and high flooding. The weight coefficients were determined for each parameter by Analytical Hierarch Process (AHP) and overlay of ranked spatial information result the final flood hazard map of study areas. The flood hazard maps indicate that 77.9, 627.01, 567.05 and 47.07km^2 corresponds with high, moderate, low and very low flood hazard areas respectively for Holeta River. Also, the flood hazard map gives the flood prone areas for upstream-Downstream Holeta River catchment. Hence, most of the catchment areas are under low flooding and moderate flooding. Some parts are very low flooding and high flooding is less in area.

Key Words: AHP, Flood Hazard, GIS, HEC-Geo RAS, HEC-RAS, Inundation Mapping

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ACRONYMS

AHP	Analytical Hierarch process
ASTER	Advanced Space borne Thermal Emission and Reflection
DEM	Digital Elevation Model
DAW	Drainage Area Weighting Methods
DPPA	Disaster prevention and preparedness
ERA	Ethiopia Road Authority
FAO	Food and Agricultural Organization
FDPPA	Ethiopian Government Disaster Prevention and Preparedness Agency
FDRE	Federal Democratic Republic of Ethiopia
FFA	Flood Frequency Analysis
FHI	Flood hazard Index
FHA	Flood hazard Assessment
FIM	Flood inundation mapping
GEV	General Extreme Value
GIS	Geographic Information System
Geo-RAS	Geographic River Analysis System
GOF	Goodness of Fit Test
GUI	Graphical User Interference
HEC	Hydraulic Engineering Center

IDW	Inverse Distance Weighting
KST	Kolmogorov –Semirnov Test
LP-III	Log-Pearson Type III
LSE	Least Square Estimate
DRMFSS	Disaster Risk Management and Food Security Sector
NDMRC	National Disaster Risk Management Commissions
MLE	Maximum Likelihood Estimates
MoE	Ministry of Education
MOM	Method of Moment
MoWE	Ministry of water and Energy Authorities, Ethiopia
RAS	River Analysis System
SAT	Spatial Analyst Tool
TIN	Triangular Irregular Network
WSE	Water Surface Elevation

1 INTRODUCTION

1.1 Background

Flood is a natural hazard that causes damage of property and life. Now days world community have been impacted by consequences of flood risk such as property damage, life, infrastructure damage, migration of ecology, economic, poverty and drought (NDRMC, 2017).

Over past decades, high deaths recorded in Africa due to flooding as a result of population settlement patterns than a consequence of climate change. The report showed that, floods displaced 2.5 million people in Africa in 2009 and more than a million in 2007. Besides, Overall African flood fatalities increased by a factor of ten from 1950 to 2009 and over 15,000 people died during the decade 2000-2009. On the other hand, the settlement in flood prone areas also increased by a factor of ten over the same period and the frequency and severity of floods in most parts of African country has increased considerably (Sinafikish, 2013).

Topographically, Ethiopia is both a highland/mountainous and lowland country. The country experiences two types of floods: flash floods and river floods. Flash floods are the ones formed from excess rains falling on upstream watersheds and gush downstream with massive concentration, speed and force. Often, they are sudden and appear unnoticed. River flood is defined as high flow that exceeds or over-tops the capacity either the natural or the artificial banks of stream (Solomon, 2012)

In most cases floods occur in the country as a result of prolonged heavy rainfall causing rivers to overflow and inundate areas along the river banks in lowland plains. Among the major river flood-prone areas are parts of Oromia and Afar regions lying along the upper, middle and downstream plains of the Awash River; parts of Somali Region along the Wabe shebelle, Genale and Dawa Rivers; low-lying areas of Gambella along the Baro, Gilo, Alwero and Akobo Rivers; downstream areas along the Omo and Bilate Rivers in SNNPR and the extensive floodplains surrounding Lake Tana and the banks of Gumera, Rib and Megech Rivers in Amhara (NDRMC, 2017)

Mankind does not have much choice rather than to accept the floods, because of unexpected natural occurrence of flooding. Therefore, to live with floods both have to have certain level of understanding, floods can be alleviated but not totally eliminated (Edna, 2007). Floods is a temporary condition of partial or complete inundation of normally dry land area which may last from hours, days and months. However, in order to find and fulfill basic human life requirement, human being practice on the River and live along the River such as unplanned rapid settlement development, uncontrolled construction of buildings and major land use changes can influence the spatial and temporal pattern of hazards (Edna, 2007).

Holeta River is found in the Oromia special Zone Surrounding Finfinnee of the Oromia National Regional state. The river originates at the mountain around 3500masl about 13km North of Holeta town and it is a tributary of the Awash River and joins it at 30km downstream of the bridge. The rains have caused Holeta river to swell and overflow or breach its courses, submerging the surrounding floodplains. Therefore, flooding is frequently observed in the Upstream-downstream of the River plain, the flood management strategy has not gone beyond strengthening rescue and relief arrangements and other post flood measures which are totally devoid of any pre-flood management and planning strategy to minimize loss of life, property and environment. The catchment area was estimated about 768.757km^2 with respect to pour point selected.

1.2 Statement of the Problem and Justification

Now days world community have been impacted by consequences of flood risk such as property damage, life, infrastructure damage of ecology, economic, poverty and drought (NDRMC, 2017; FEMA, 1997). Ethiopia is also one of the countries which suffer by such a flood problem during high rainfall season of the year (Solomon, 2012). It has been occurring at different places and times with varying magnitude. Much of these flood disasters are attributed to rivers that overflow or burst their banks and inundate downstream plain lands (Brhane, 2011).High flood, which is normally due to the intensive rainfall in the lands of the Watershed, sparse vegetation cover, topography, steep slopes, low infiltration capacity of the ground surface (Tesfay,2018).

The National Disaster Risk Management Commissions (2017) reported flooding in communities within the Awash River basin and the potential for additional flooding in areas that lie downstream. The Ethiopian flooding report (2014) indicate that, over 20,000 peoples in Oromia region were affected by floods. Some areas in Gambela region have also reported to be affected by flooding and about 13,000 peoples. Also, the lower part of Gumera catchment in Amhara region is known as one of the flood prone areas by annual flooding in the Fogera flood plain.

Owing to this, the study was carried out on flood problem in Oromia region along Holeta River in Ethiopia. The Holeta River is a tributary of the Awash River. It is a perennial river having three major users and these are Holeta Agricultural Research Center (HARC), Tsedey Farm and Village Farmers. During high rainfall depth at summer season of the year the overflow of Holeta River course is occurred and cause flood risk consequence. The river builds up from continuous rainfall on the catchments and local rainfall on the flood plain to result in flooding problems. Some of the community lives along the River boundary in order to use water for Agro economic development through crop production by Irrigation. However, their cultivated land was washed away due to floods and they have lost some of their agricultural assets. Also, some of the agricultural land of the research center and Tseday state was inundated by the flooding that were caused due to overflow of the river. Due to this reason the yield of these three users have been reduced in all affected areas.

1.3 Objective of Study

1.3.1 General Objective

The general objective of this research is to assess the flood hazard and mapping of flood inundation area along Holeta River in Ethiopia.

1.3.2 Specific Objectives

1. To estimate discharges for different return periods.
2. To simulate flood water surface profile for Holeta River.
3. To develop flood inundation map and flood hazard map for upper-downstream Holeta river.

1.4 Research Question

The following questions were proposed based on the study of research objective: -

1. What are the peak discharges for different return periods?
2. What will be the flood water surface profile for Holeta river?
3. What will be the flood inundation and flood hazard map of the areas?

1.5 Significance of the Study

A better understanding of the flooding impacts can be used to develop new strategies for protecting flood-prone areas. This study promotes the sustainability of flood plain management decisions and guides future policy and planning decisions.

One of the importance's of this study is to have detail information about future floods. Through determination of peak flood magnitude and time occurrence using flood frequency analysis and any others supporting techniques and flood plain areas along the river course is identified. Also, the flood characteristics like flood level, depth, flow velocity, hazard and others were evaluated.

Another importance of this study is to serve for flood preparedness and response having information about future flood. The occurrence of flood consequence is a probability occurrence at a certain future time period which was known by flood forecasting techniques. Therefore, the government, the people and any concerned body living along particular flood hazard and inundation areas should have enough flood information to be ready, flood hazard awareness and take alternative measurement to prevent flood risk and damage consequences.

1.6 Scope of the Study

The depth of study was bounded by the objective of the study that aimed to assess flood hazard and mapping flood inundation areas. The flood hazard assessment was accomplished using GIS software package and by fulfilling parameter required such as Digital Elevation Model (DEM), slope, rainfall, drainage, soil type and land use/ land cover. These parameters were used to develop flood hazard index for flood hazard rank or weight and mapping of flood hazard. In addition to this the river cross-section and geometry using HEC-Geo RAS and hydraulic parameters such as flood depth; flow velocity and others have simulated using HEC-RAS and finally, map flood inundation areas. Therefore, the vertical depth and horizontal length of this study have to be scoped to welcome with adequate, reliable, acceptable research result or outcomes and call objective.

1.7 Limitation of the study

Flood hazard assessment of the flood prone areas and mapping, in Ethiopia is not an easy task. At Holeta River there is a limitation of adequate and reliable rainfall and stream flow data. There is no enough rainfall metrological station and stream flow gage station to analyze the tributaries of the river. Due to this reason, the study focused only along the upper-downstream of the river catchment.

1.8 Organization of the thesis

This thesis was organized into five chapters. In the first chapter the background information, problem statement, general and specific objectives, Significance of the study and Scope of the study were discussed. In the second chapter, literature review about the subject matter was presented and it gives a scientific review of this study. In the third chapter methodologies followed for determination of flood hazard assessment and inundation mapping were presented step-by-step. As well as description of the study area, data used in the study, their sources and the methods used for data quality control were mentioned. The fourth chapter presents the results and discussion. It gives a detailed about flood prone areas in catchment scale and flood extent areas along the river. The fifth chapter summarizes the conclusion and recommendation for future study

2 LITERATURE REVIEW

2.1 Flood

By definition, any land which is usually above water level is said to be flooded if it goes under water for a period arbitrarily defined as one or two hours. Flooding can be owing to many reasons. Usually this happens when the river or the stream draining the area is over balanced by a very large volume of water beyond its capacity. A river channel is formed by the forces of nature to be able to convey the flow that is found most of the time. When the volume exceeds this, the water level rises above the banks and spreads in to the adjacent lands. This area is usually called the flood plain of the river (Senarathne, 2008).

2.2 Flood Hazard

Historically, flood damage is greater than that of any other natural hazard. However, the impacts of flooding cannot be eliminated. A sound understanding of flood behavior enables informed decision making on the management of risk (to existing and future) where practical, feasible and cost- effective to do so (BMT, 2017) (Members of the BMT group companies in Queensland government).

There are many different definitions of hazard. According to UN/ISDR (2009)" Hazard is a potentially damaging physical event, phenomenon that may cause the loss of life or injury, property damage, environmental degradation, social and economic disruption. Hazards can include latent conditions that may represent future threats and can have different origins: natural (geological, hydro meteorological and biological) or induced by human processes (environmental degradation and technological hazards). Hazards can be single, sequential or combined in their origin and effects. Each hazard is characterized by its location, intensity, and probability.

As Caddis et al. (2012) highlighted, the definition of flood hazard involves consideration of a various factor such as magnitude of floods, duration of flooding, effective warning time, depth and velocity of floodwaters, flood readiness, evacuation and access and type of development. Most of this factor are quantifiable either from flood modeling (e.g. magnitude, velocity, depth, duration of flood) or through assessment (e.g. land use, roads, human behavior).

Merz et al. (2007) defined flood hazard as the exceedance probability of a potentially damaging flood event in a particular area within a specific period of time. However, this statement does not represent the consequences of such floods to community, environment or development.

According to Zein (2009) defines hazard as “the extreme natural events which may affect different places single or combination at different times over a varying return period”. On the other hand, according to Asian Disaster Preparedness Centre (ADRC) “hazard is an event or that has a potential for causing injuries to life and damaging property and the environment”. In order to know the important definition thing of hazard, UN- ISDR (2004) proposes four elements which are probabilities, a specific period of time, a specific area and the intensity. Hazards related to geological and geo-morphological processes such as earth quake, volcanic, eruptions, landslide and floods are called geo-hazard. According to Zein, (2009) floods are defined as extremely high flows of river whereby water inundates flood plains or low laying area. Flood hazard is measured by probability occurrence of their damaging values generally as flood risk or by their impact on society and loss of lives.

Based on floods occurrence (Federal Emergency Management Agency) (FEMA, 1997) divides floods in six major classes. They are river flooding, alluvial fan floods, ice jam floods, dam break floods, local drainage and high ground water level and fluctuating lake level. In some areas, floods in Ethiopia belong to the river floods which occur in low - land flood plains. The floods are caused by high intensity and duration of rainfall making a body of water rise in the river so that overtop natural or artificial banks of a river.

The hazard assessment identifies the probability of occurrence of a specific hazard, in a specific future time, as well as its intensity and area of impact. Hazards can be single, sequential or combined in their origin and effects ((Getahun and Gebre, 2015). Each hazard level is characterized by its location intensity and probability. The flood hazard assessment needs to be presented using a simple as possible, such as indicating very high, high, medium, low and very low hazard rank.

2.3 Flood characteristics and frequency analysis

There are various characteristics of flooding that influence flood hazard and inundation area, of which some may be more significant than others. These parameters of flood characteristics are more importance to some categories of hazard and flood hazard map. These flood characteristics are: extent area, depth, duration, velocity, rate of rise of flood water, contamination and debris loads of the flood water, whether the water is fresh or salt water, warning time and previous experience of flooding are the flood character parameter. In practice, much of the focus on estimating the potential hazard that causes flooding is flood depth and velocity, which presumes an important parameter in flood hazard assessment (Getahun and Gebre, 2015). An important problem in hydrology is estimation of flood magnitudes. Planning and design of water resource projects and flood plain management depend on the frequency and magnitudes of peak discharges (Bedassa, 2016). Flood Frequency Analyses will be used to predict or design flood for sites along the river. In flood frequency analysis, a relationship between a flood magnitude Q and its return period T is developed by statistical modeling of a times series of peak flows (Samiran, 2012). The technique involves using observed annual peak flow discharge data to compute statistical information such as mean values, standard deviation, skewness and recurrence intervals. This statistical information will be used to construct frequency distributions.

2.4 Description of The Models

In this paper, ARC-GIS, HEC- GeoRAS and HEC-RAS computer modeling software along hydrological, metrological and others data will be used to assess flood hazard and mapping inundation area for Holeta River in Ethiopia.

2.4.1 Arc-GIS

A GIS is one of the key information technologies widely used to collect, store, analyze and display a large amount of spatially-distributed information in layers. In the present study, the whole basin was analyzed in the generation and propagation of flood waves and the entire river flood plain was considered for hazard assessment. Many GIS integrated modeling applications capitalized on using the GIS as a data base manager and visualization tools. Data requirements, flood inundation extent and depth are the main area where these procedures might need to be modified and differ from the manual flood hazard map declination processes (Vu thanh, 2009). GIS is effective tool to determine the high risk of flood prone areas down to small hydrological basins. In addition, GIS has its capability to manipulate multi-dimensional phenomena of natural hazards using spatial component (Kamonchat, et all, 2017). The physical factors used in GIS needs to be associated with a procedure referred to as multi-criteria analysis (MCA) that weights the parameters logically. One of the methods to determine the relative importance of the factors is Analytical Hierarchy Process (AHP) that has been used in many applications (Kamonchat, et all, 2017). This study assesses flood hazard area using spatial multi-criteria index to understand the relative importance of the parameters used. Then, the produced flood hazard map is compared and discussed with an observed flood extent from secondary data source. For this study ARC-GIS10.4.1 was used.

2.4.2 HEC-GeoRAS

HEC–GeoRAS is a computer modeling used for delineation of flood hazard affected areas. It is GIS extension with a set of procedures, tools and utilities for the preparation of river geometry. The input data required for the River geometry preparation using HEC – GeoRAS model are Triangular irregular Network (TIN), DEM and land use. The river geometry and stream flow are the input data for HEC –RAS to generate the water surface level along the River. The river stream centre line, bank lines, flow path centre lines, and cross section lines should be digitized from a previous river file and topographical datasets using HEC-GeoRAS interface. The river reach (river segment between junctions), cross-section and other related data are stored in the geo database file of HEC- GeoRAS. The interface extracts the geometric data in an .xml format is imported in to HEC-RAS (Getahun and Gebre, 2015). In this study HEC-GeoRAS10.4 version was used for works.

2.4.3 HEC-RAS

HEC- RAS is a computer program that simulates the hydraulics of water flow through natural rivers and other channels. It is developed by US Department of Defense, Army Corps of Engineers in order to manage the rivers and other public works (Getahun and Gebre, 2015). It has found wide acceptance by many others since its public release in 1995. This paper will be used the current version HEC-RAS5.0.5 which was better among previous version. HEC-RAS software is served as converter tool between ARC-GIS and HEC-GeoRAS software. The interface extracts the geometric data in an xml format is imported in to HEC-RAS. The imported file in to the geometric editor, which is a Graphical User Interface (GUI) that used to manage geographic data. In this editor, the manning friction values are entered for the cross section of the reach. Stream flow data is entered in to the stream flow editor. The output data of HEC –RAS model are water surface profile variation for different flow rates with varied recurrence intervals in desired lengths of the river, flow velocity, normal depth, critical depth and hydraulic properties and parameters of the river (Getahun and Gebre, 2015).

Study by Tate et al. (1999) to improve the HEC-RAS model's accuracy led to the development of Avenue scripts for ArcView GIS that incorporates data such field survey, stream geometry and control structures into a GIS-based terrain model. In this study HEC-RAS 5.0.5 version was used for works.

2.5 Types of Flood Maps

Merz et al. (2007), proposed four type of flood map namely as flood danger map,

Flood hazard map,

Flood vulnerability map and

Flood damage risk map

While, Di Baldassarre et al. (2010) and Merz et al. (2007), classified flood maps into three type of map known as flood hazard map, flood vulnerability maps and flood risk maps. The most common categories of map used to illustrate flood hazard is a map, that show inundation area for events with different return periods.

2.6 Use of flood maps

Van Alphen et al. (2009) noted that the types of flood maps may depend on the user/target group and their interest of using flood maps. Van Alphen and Passchier (2007) highlighted that the use of flood maps serves at least one of the three purposes of flood risk management as follow:

Preventing the build-up of new risks (planning and construction),

Reducing existing risks, and

Adapting to changes in risks factors.

While, (Report, Ethiopian Flooding, 2014) divided the use of flood map to three main institutions, flood map use by governmental agency especially for land use planning and emergency purposes (evacuation), private sector mainly in insurance industry and transnational river basin authorities.

2.7 Flood Hazard Assessment and Mapping

According to (Vu Thanh, 2009) flood hazard assessment depends on many parameters such as flooding depth, flooding duration, velocity of flood flow, timing and frequency of occurrence. Hazard index (HI) represents the level of flooding impacts. The hazard zone areas are determined from hazard factors which represents the combination of all hazard parameters. According to (Vu Thanh, 2009) the flood depth categories was taken under equal of 0.5m, thus $d < 0.5$m (Low), 0.5m< $d<1$m (moderate), 1.5m< $d< 3$m (high) and $d>3$m (very high). Also hazard index for flooding duration was given as short $t < 3$hr), medium (3hr < t < 7hr, long (7hr < t <25) and very long ($t>25$hr).

The flood hazard assessment needs to be presented using a simple classification as simple as possible, such as indicating very high, high, medium, low, or very low hazard. According to (Zein, 2009) explain a flood hazard map as a map that shows the inundation area for a scenario with a certain return period in single or several flood scenarios. The maps illustrate the intensity of flood situations and their associated exceedence probability. Whereas, the maps without exceedence probability called flood danger maps which is illustrated historic or synthetic flood events. Flood hazards are estimated based on flood depth and duration.

According to (Karim, 2010) four hazard categories were used and each category was represented by a hazard Index. A hazard index (Hi), was introduced to represent degree of hazard corresponding to different flood depths. To devise a scale for hazard index flooding areas were divided in to four depth categories based on three critical depths 0.8m, 1.0m and 3.5m. Different breaking values were checked based on the expert knowledge, local information and different possible realization and from previous knowledge. Based on the three critical values of flood depth (d), hazards were classified as low ($d < 0.8$m), Medium (0.8m $\leq d <$ 1.0m), High (1.0m $\leq d <$3.5m) and very high ($d \geq 3.5$m). As recommended by (Karim, 2010) a linear scale of hazard index (Hi = 1, 2, 3 and 4) were used to represents low, medium, high, and very high hazards respectively.

A study from past (Wildschut, 2013), Flood Hazard Mapping is flood map illustrating the flood hazard prone area i.e. the intensity of flood situations and their associated probability. Usually, flood hazard maps show synthetic events for the inundation area for a scenario with a certain return period, the spatial distribution of the water depth and flow velocity. The hazard aspect of the flood is related to the hydraulic and the hydrological parameters.

According to (Mohammed, 2017) flood hazard levels are grouped in to three: depth less than 0.76m categorized as low hazard level, depth with the range between 0.76m – 1.5m categorized as moderate hazard level and depth more than 1.5m categorized as high hazard level. Previous study (Mohammed 2017) suggests that flood hazard for each region should have different categories depending on its topographic and flood characteristics exist in the area.

2.8 Mapping of Flood Inundation

Merz et al. (2007) noted that flood maps are effective tools for assisting flood hazard management. The requirement and classification of flood maps depends on the purpose of their use. Flood hazard maps, in particular, can be defined as maps showing inundated area or different parameters such as flood depth and flood velocity.

Previous studies by Merwade and Olivera, *et all (*2008) recommends that flood inundation extent is represented as a deterministic map without consideration to the inherent uncertainties associated with various uncertain variables (precipitation, stream flow, topographic representation modeling parameters and techniques and geospatial operations) that are used to produce it.

Gilles, (2010) suggest that inundation maps are the most useful results produced from flood simulations, but uncertainties must be considered because error is introduced throughout the development process. The cumulative effect of uncertainties introduced during data collection, model development, numerical simulation, post-processing and theoretical assumption can cause result inaccurate. The most important parameters (roughness coefficients, geometry, topography (high resolution DEM), and boundary condition) need pay care in predicting inundation map.

According to Dewberry (2011) Flood Inundation mapping process includes implementing the hydrologic, hydraulic and geospatial analyses required to develop inundation mapping products. The hydrologic analyses include the determination of the peak discharges that result in a certain return period. The hydraulic analysis includes the computation of the water surface profiles. The geospatial analysis determines the flood inundation area or flood extent area from river bank.

An inundation mapping showing areas that would be affected by flooding from overflowing river courses due to high rainfall depth. An inundation map displays the spatial extent of probable for different scenarios and can present flood extent areas (Getahun and Gebre, 2015).

Merwade, (2015) suggest a need for more accurate flood inundation maps has recently arisen because of the increasing frequency and extremity of flood events. Flood inundation modeling involves hydrologic modeling to estimate peak flows, hydraulic modeling to estimate water surface elevation and terrain modeling to estimate the inundation areas.

According to Ebrahim *et al*, (2017) studied on sustainability-based flood hazard mapping. The frame work uses a hydrologic model for rainfall – runoff transformation, a 2D unsteady hydraulic model flood simulation and a GIS-based multi-criteria decision –making techniques for flood hazard mapping. The result was better by showing the overall hazard with respect to hazard weights of hazard components was investigated. There by it provides a more sustainable perspective of flood management and can greatly help the decision makers to make better-informed decisions by clearly understanding the impacts of flooding on economy, social and environment.

2.9 Flood risk in Ethiopia and their mitigation measure

In Ethiopia, in the past, there have been floods which have taken both human lives and destroyed properties. As a result of prolonged and intensive rainfall, the soil in most areas, particularly in the western, central highlands and northwestern parts of the country became saturated causing an overflow of rivers and flash floods in many areas (Dawit, 2015).

According to Joint Government and Humanitarian Partners (2006) Dire Dawa, SNNPR, Amhara, Oromiya, Gambella, Tigray, Somali and Affar Regions, the flood situation resulted in considerable human death, displacement and suffering as well as loss of property and crop damage. The current problem is the worst that has been observed in recent years. The most affected areas are Dire Dawa, South Omo Zone of SNNPR, and parts of Amhara, Oromiya, Gambella, Somali and Tigray regions. So far, the impact of the flood on human beings is not yet serious. However, it has affected a large area of crop fields.

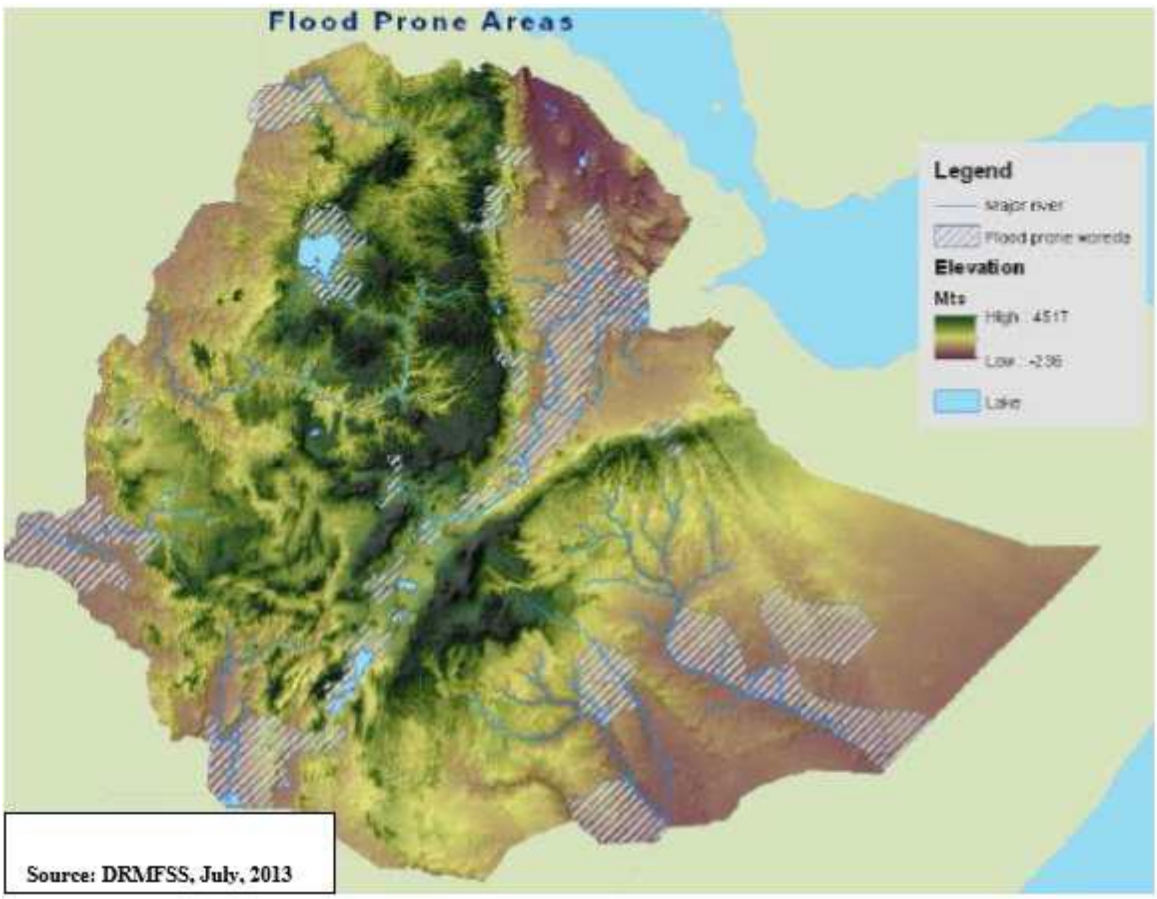


Figure 2-1 Flood prone area in Ethiopia

According to the latest information issued by the Ethiopian Government Disaster Prevention and Preparedness Agency (FDPPA) (2006), the water storage effect of vegetation, soil, shallow groundwater, wetlands and drainage has a direct impact on the flood level in downstream areas. Each of these storage media retain certain quantities of water for various periods of time and can influence the timing of tributary flows and hence their contribution to a flood event. The storage effect can be likened to a sponge and is dependent on the antecedent conditions and the magnitude of the flood (FDPPA, 2006).

According to FDRE (2013) the practice of reducing flood risk through systematic efforts to analyze and manage the causal factors of flooding, including reduced exposure to hazards, lessened vulnerability of people and poverty, wise management of land and the environment and improved the preparedness for adverse events. Flood risk assessment of the flood prone areas, in Ethiopia is not an easy task. There is a limitation of adequate and reliable rainfall, water and soil data. Flood risk is the combination of flood hazard and flood vulnerability. Flood hazard is dangerous phenomena, substance, human activity or condition that may cause loss of life, injury or other healthy impacts, property damage, loss of livelihoods and services, social and economic disruption, or environment damage (Tarekegne, 2014). Flood vulnerability is the characteristics and circumstances of a community, system or asset that make it susceptibility to the damaging effects of flood hazard. It deals with Exposure means people, property, systems or other elements of exposure under hazard zones that are there by subjected to flooding (potential loss) (Tarekegne, 2014).

Tefera (2015) suggest that flood hazard mitigation plans could be implemented as either structural or non-structural measures, depending on the particular case. These measures involve managing the effects of flooding and preventing the negative consequences. Structural measures, including levees, high flow diversion, channel modification and dams, could be implemented to mitigate flood risk by reducing the volume of run-off, water level or extent of the area of flooding. However, non-structural methods, such as flood insurance, land use regulation and flood forecasting, serve as preventive measures for reducing flood hazards.

According to Tesfay (2018) mitigation measures provides a critical foundation on which to reduce loss of life and property by avoiding or lessening the impact of hazard events. This creates safer the communities and the facilities resiliency by enabling communities to return to normal function as quickly as possible after a hazard event. Flood mitigation actions generally fall in to the following categories: Preventative Measures, Property Protection Measures, Natural Resources Protection Activities, Emergency Services (ES) Measures, Structural Mitigation Projects (so-called Engineering Structures Measures), Public Education and Awareness Activities (Tesfay, 2018).

3 MATERIALS AND METHODS

3.1 Description of Study Area

The study area, Holeta River catchment, is located in the central part of the country, 45 km west of Addis Ababa in the Oromia special Zone Surrounding Finfinnee of the Oromia National Regional state. The area is bounded between latitude 8^0 53’ 75” to 9^0 14’ North and longitude 38^0 21’ 40” to 38^0 36’ 14” East. The hydrological characteristic of the area is described by the Holeta River which is the nearby river draining in the area. The Holeta River is a tributary of the larger Awash River which joins it after travelling about 30km downstream of the bridge. The river originates at the mountain around 3500masl about 13km North of Holeta town (Kramer Kristian, 1999). This large elevation drops with a relatively short distance (about 13km) resulting in a higher slope is contributing to the flood. The catchment area was estimated about 768.757km^2 with respect to pour point selected.

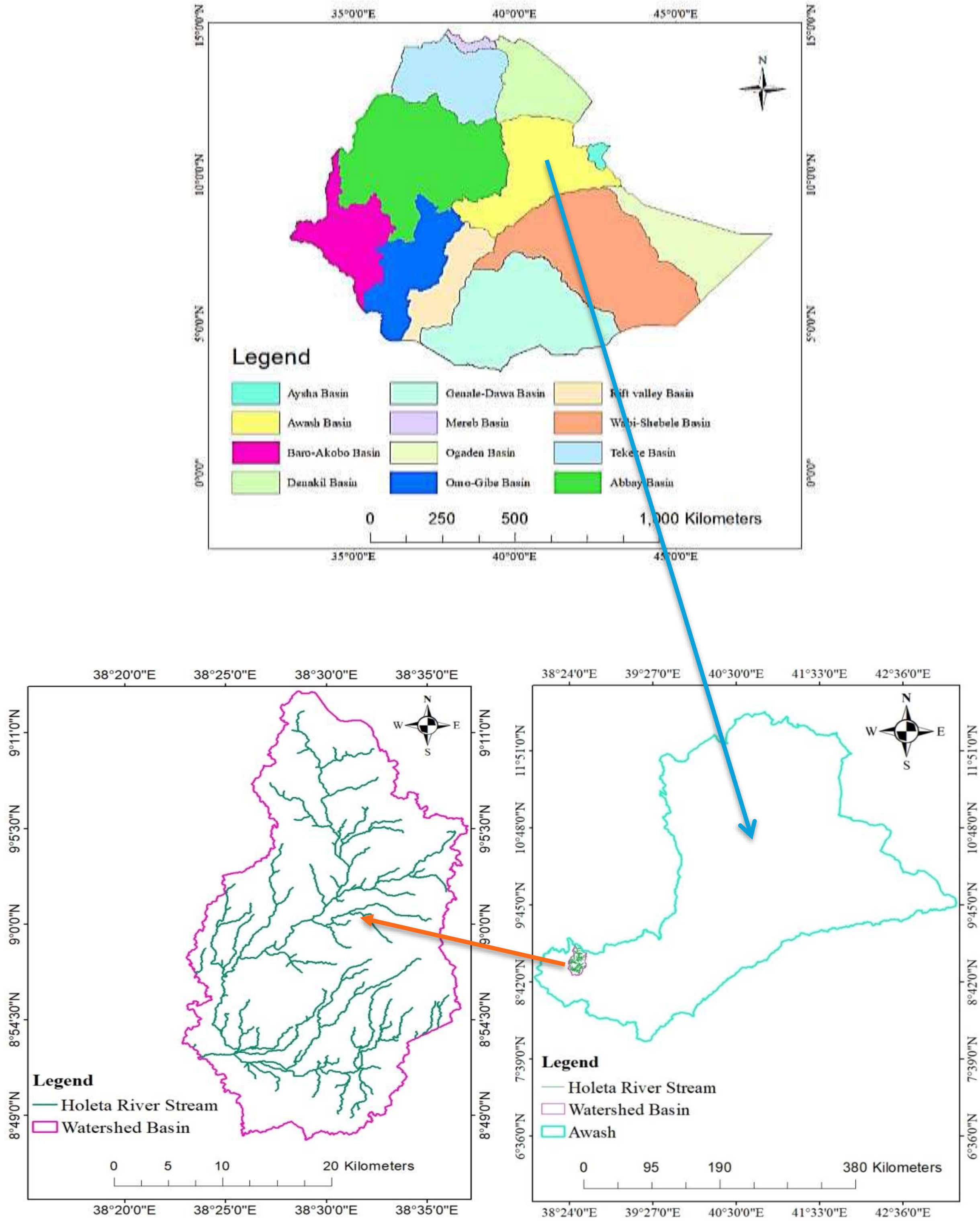


Figure 3-1 Location of study area

3.1.1 Topography

The topography of study area is characterized by a variety of elevation. It lies at an altitude of 2069–3378 meters above sea level. Holeta River originates at the mountain around 3500masl (Tibebe et al, 2013).

3.1.2 Climate

The climate of the country is mainly controlled by the seasonal migration of the Inter-Tropical Convergence Zone, which is conditioned by the convergence of trade winds of the northern and southern hemisphere and the associated atmospheric circulation. The climate of the study area is described with the air temperature ranging from 6ºC to 23ºC with the mean of 14ºC. The amount of rainfall in the mountains (3500m) is expected to be higher than that in town (2400m) and the annual rainfall is ranges between 818–1226 mm. Heavy rain is received in summer (June to August) and light rain is in spring season (December to February) (Kramer Kristian, 1999)

3.1.3 Land use /land cover

The actual meaning of land use is the way in which land is used by people in an area to produce what is needed by the people for use through the involvement of labor, capital, and available technology. Land use refers to the actual economic activity for which the land is used whereas land cover refers to the cover of the earth's surface. Different land cover types characterize the land cover of the catchment. The land use of study area can be categorized mainly Forest, agricultural, closed and open grass, shrub, water bodies, wet and bare land.

3.2 Materials used

For the proper execution of this study, materials and Software used was based on the capability to work on achieving the predetermined objectives.

Table 3-1 Materials Used

Models	Application
Arc-GIS10.4.1 Software	Used to map flood hazard area and flood inundation area
HEC-geoRAS 10.4 Software	Used to develop river cross section and alignment which serve for input data for HEC-RAS

HEC-RAS 5.0.5 Software	Used to simulates the hydraulics of water flow through Holeta river
Easy Fit 5.6 Statistical Software	Used to select the best fit probability distribution with its method of parameter estimations, a goodness of fit tests and to check the estimation accuracy of each of data of stations
XLSTAT2018 and Microsoft Excel	Used for data arrangement, filling missed data and calculate the statistical parameters of hydrological data used in the flood frequency analysis

3.3 Data preparation and processing

Defining a clear and efficient methodology is vital for the quality of the findings of the study. The various input data were required to achieve the objective of this study and to have accurate results. For this study the required secondary data was collected from GIS (Geographic Information System) department, Ministry of water, Irrigation and Energy, Ethiopia (MoWE), Ethiopian National Metrological Agency (NMA).

Table 3-2 Source of required data

Data	Source
Digital Elevation Model (30m by 30m)	Geographic Information System Department
Stream Flow and Soil	Ministry of water, Irrigation and Electricity, Ethiopia (MoWE)
land use / cover	Ethiopian Geospatial Information Agency
Rainfall	National Metrological Agency (NMA)

Holeta river was gauged near the town at the bridge crossing of the Addis – Nekemte road. The daily recorded data for different length of years for rainfall and for stream flow was collected at different gage station from National Metrological Agency (NMA) and Ministry of water, Irrigation and Energy, Ethiopia (MoWE) respectively. The following table shows the different gage station with their coordinate location.

Table 3-3 Rainfall station and Coordinate location

Station name	Latitude (in Decimal)	Longitude (in Decimal)
Holeta	9.05	38.5
Asgori	8.911	38.369
Hobole	9.091	38.593
Kimoye	9.008	38.33783
Welmera	9.221	38.476
Addisalem	9.042	38.38333
Guranda Metta	8.9072	38.5892
welenkomi	9.001833	38.3047
Menagesha	9.098	38.617

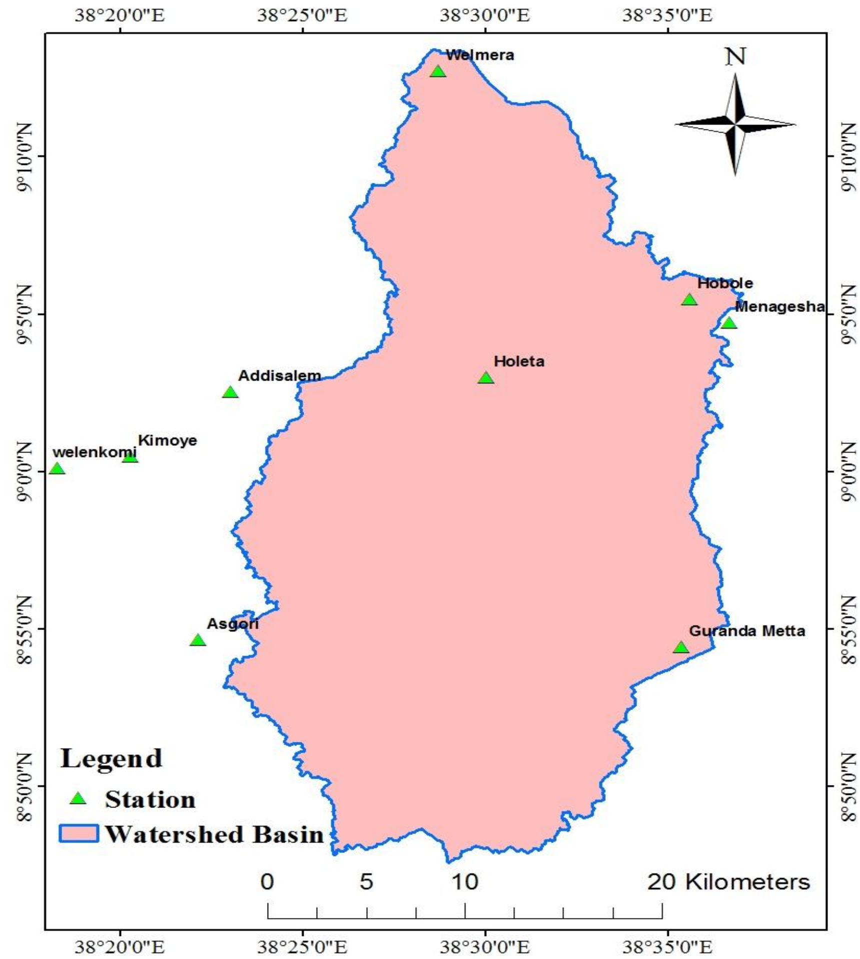


Figure 3-2 Watershade basin and Rainfall station at study area

Table 3-4 Stream flow at Holeta station (Source: MoWE)

Year	Q(m^3/s)	Year	Q(m^3/s)	Year	Q(m^3/s)	Year	Q(m^3/s)
1979	43.20129	1989	123.7572	1999	150.5319	2009	205.5933
1980	56.36805	1990	116.4535	2000	126.9854		
1981	77.50029	1991	129.1083	2001	140.3803		
1982	71.73318	1992	136.8953	2002	180.4061		
1983	68.26156	1993	140.2177	2003	165.8198		

1984	76.6378	1994	146.8367	2004	173.9397
1985	67.97133	1995	131.4453	2005	179.0995
1986	79.80047	1996	163.8584	2006	195.9228
1987	96.3347	1997	154.6717	2007	200.9362
1988	114.9801	1998	157.8321	2008	197.935

3.3.1 Filling missing data

The accuracy of the result is based on the quality of available data. Thus, before using the collected data for analysis it has to be mandatory to check missing data, inconsistency and accuracy. The period of missing data has to be filled by different methods. For this, study missing value was filled using linear Regression methods by XLSTAT software. In many cases XLSTAT is using for filling of missing temperature, rainfall and stream data, checking of trend and homogeneity. XL STAT is the richest tool for data analysis and statistical treatment with MS Excel. It can execute preparing, describing, visualizing, analyzing and modeling data, correlation tests, parametric and non-parametric tests, testing for outliers, homogeneity and trends. For quantitative data, XLSTAT allow to: Remove observations with missing values, use a mean imputation method, Use a nearest neighbor approach and algorithm. This study uses a nearest neighbor approach to fill missing data. Besides filling missing data, inconsistency problem should be checked. Inconsistency is due to instrument malfunction; the records may be failed for continuity. In this study, Double mass curve was used for checking for data consistency. The plot line should be straight and the R^2 value is found between, 0.6 - 1. As seen from the figure below the R^2 was found about 0.9 which is close to 1. Therefore, the data was a consistent and it was used for analysis.

3.3.2 Test for outliers

The Water Resources Council method recommends that adjustments be made for outliers. Outliers are data points that depart significantly from the trend of the remaining data. The retention and deletion of these outliers significantly affect the magnitude of the statistical computed from the data, especially small size (Ven Te Chow, 1988, 2010).

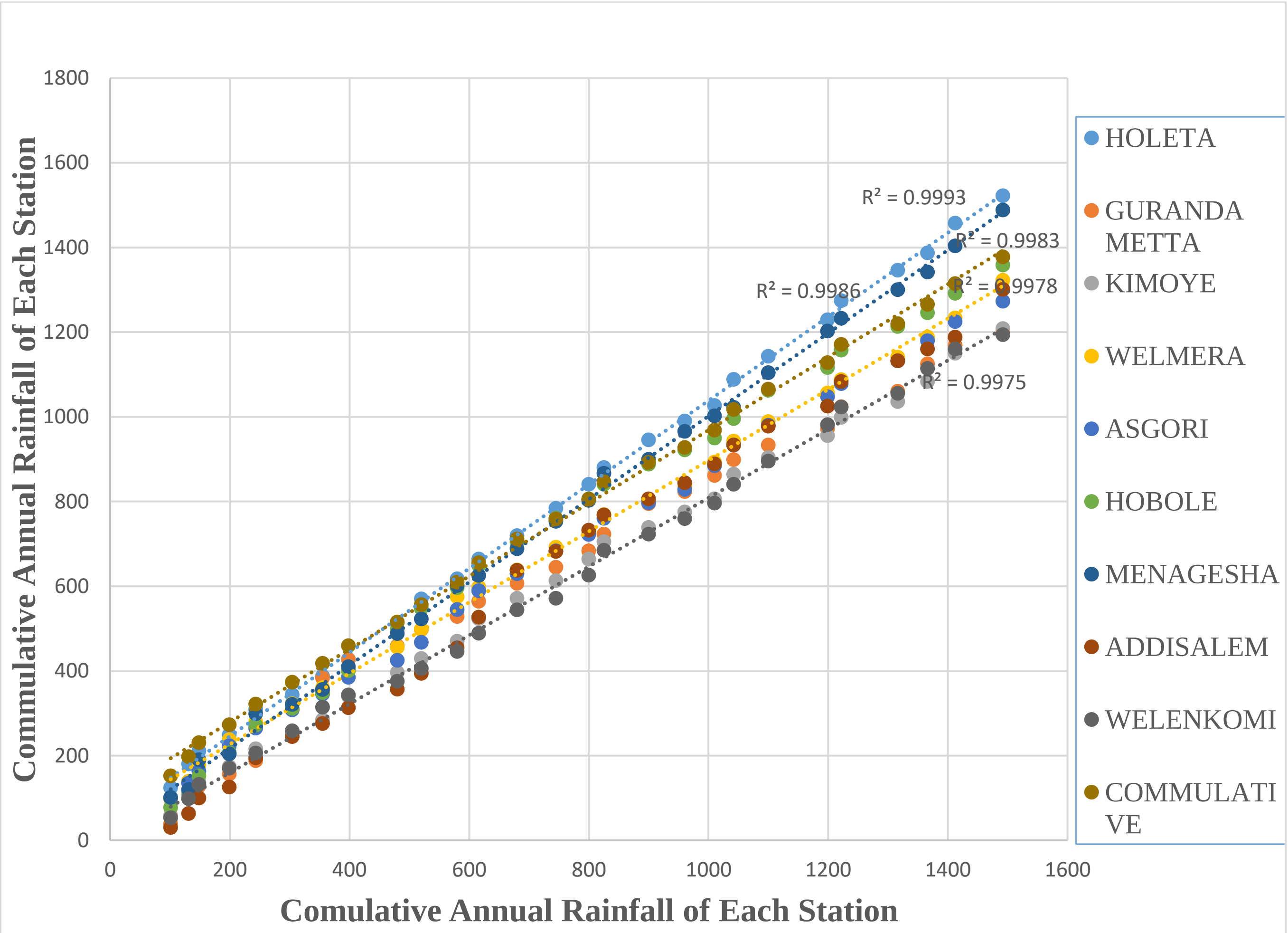


Figure 3-3 Double mass curve

According to Water Resources Council (1981) recommends that if the station skewness's is greater than+0.4, test for higher outlier are considered. If the station skewness is less than -0.4 test for lower outlier and if the station skewness is between ±0.4 tests for both outliers. The skewness coefficient for this study was CS = -0.21026, (Appendix D) which is between ±0.4, require check for higher and lower outlier's test. The following frequency, equation can be used for outliers' test:

YH=Ymean± KnSy Eq3.1

YL=Ymean- KnSy Eq3.2

Where: YH= high (+) / low (-) outlier threshold, Sy = standard Deviation. Kn = Factor based number of sample size (e.g. 31 number of data) for 10% level of significance in normally distributed data Kn= 2.577 (Ven Te Chow, 1988, 2010).

YH=224.4532 + 2.577 *79.573= 429.5728 m^3/s, and YL=224.4532- 2.577*79.573=19.3935m3/s

Thus, as seen from above table, all data are below higher outlier test above lower outlier. Therefore, all are used for analysis. Also, hydrological record data should be checked for variability. This used to check consistency of data and by using variability formula.

α=Sy√N∗Ymean..Eq3.3

α =Sy√N∗Ymean=79.573√31∗224.4532= 0.06267<1 or 6.267 %< 10%. Acceptable. Thus, 6.267% < 10%, therefore all data are reliable and adequate.

3.4 Fitting probability distribution

The probability distributions most closely fitted to the observed data depends on the nature of the occurrence and the distribution (Athulya and James, 2017). Performing flood frequency analysis requires a good understanding of probability theory and statistics and in most instances sound engineering judgment. The probability distributions are the basic concepts of statics and judging a suitable probability distribution to a given dataset. Probability function is a function representing the probability of occurrences of a random variable (Ven Te chow, 2010), (FEMA, 2007). The probability models selected for this study includes: Gumbel Max, Log-Pearson 3, Logistic, Lognormal, Lognormal (3P), Pearson 5, and Pearson 5 (3P).

The choice of distribution to be used in flood frequency analysis has been a topic of interest for a long time (Samiran, 2012). The choice of distribution is influenced by many factors, such as methods of discrimination between distributions, methods of parameters estimation, the availability of data, etc. Normally, there is no global agreement as to a preferable technique of model choice and no single on distribution accepted universally (Bedassa, 2016).

Thus, Easy Fit is a data analysis and simulation application allowing fitting probability distributions to sample data, select the best model, and apply the analysis results to make better decisions. There are a number of well-known methods which can be used to estimate distribution parameters based on available sample data. For selected distribution, Easy Fit implements one of the following parameter estimation methods: method of moments (MOM)**,** maximum likelihood estimates (MLE)**,** least squares estimate (LSE) and Method of L-moments**.** For many distributions, Easy Fit uses the maximum likelihood estimates (MLE) method involving the maximization of the log-likelihood function. Estimation by the MLE method involves the choice of parameter estimates that produce a maximum probability of occurrence of the observations (Dawit, 2015). The maximum likelihood method (MLM) is considered the most efficient method since it provides the smallest sampling variance of the estimated parameters, and hence of the estimated quintile's, compared to other methods (Dawit, 2015).

3.4.1 Goodness of fit test (GOF)

The Goodness Fit Test (GOF) is used to select the best probability distribution. It used for checking the validity of specified or assumed probability distribution model (Samiran, 2012), (Alam, 2017). There are different evaluation criteria while this study considers the distribution test below.

i. Kolmogorov –Smirnov Test (K-S test)

The test statistic in the KS test is extremely simple. A statistic based on the deviations of the sample distribution function FN (X) is used in this test.

The test statistic DN is defined as:

$$DN=\max_{1<i<n}[F_n(X_i)-F_o(X_i)] \quad \text{Eq 3.4}$$

The values of FN (x) are predictable as Nj/N, where Nj is the cumulative number of sample events in class i. The value of DN must be less than a tabulated value of DN at the specified confidence level for the distribution to be received (Desalegn *et al*, 2016). In this method, the hypotheses take dependability of a specified distributions data of stations.

The hypothesis regarding the distributional form is rejected at the chosen significance level (α) if the test statistic, D, is greater than the critical value obtained from a table. The fixed values of α (0.01, 0.05) are generally used to evaluate at various significance levels. A value of 0.05 is typically used for most applications.

This test is based on the deviation of the sample distribution function from the specified continuous hypothetical distribution function, providing a comparison of a fitted distribution with the empirical cumulative distribution function (ECDF) (Kalkidan, 2015).

ii. Anderson –Darling Tests (A-D Test)

The AD test is used to test if a sample of data came from a population with a definite distribution. It is a revision of the KS test and gives further influence to the tails than does the KS test. The KS test is distribution free in the logic that the critical values do not depend on the definite distribution being tested. This test makes utilize of the definite distribution in manipulative critical values. This has the benefit of allowing an additional perceptive test and the drawback that critical values should be intended for each distribution. The critical values for the AD test are dependent on the specific distribution that is being tested (Ghosh et al,2016). This test gives more weight to the tails than the kolmogorov – Smirnov test.

iii. Chi-square Method

The x^2 goodness of fit test is a non-parametric test that is used to get exposed how the observed value of a particular phenomenon is considerably unlike from the estimated value. In this test, the method is used to contrast the observed sample distribution with the estimated probability distribution. This test determines how fine theoretical distribution fits the experimental distribution.

In x^2 goodness of fit test, sample data is separated into intervals. Then the numbers of points that drop into the interval are compared, with the predictable numbers of points in every interval. The null hypothesis assumes that there is no notable variation between the observed and the expected value. The degree of freedom depends on the distribution of the data sample (Ghosh *et al*, 2016). In this goodness of fit test, the alternative hypothesis assumes that there is an essential variation between the observed and the expected value.

$$X^2 = \frac{(O-E)^2}{E} \qquad \text{...Eq 3.5}$$

Where X^2= Chi-Square goodness of fit test

O = observed value

E = expected value

If the considered value of x^2 goodness of fit test is less than the table value, will admit the null hypothesis and conclude that there is no important differentiation between the observed and expected value (Ghosh et al, 2016).

3.4.2 Summary of statics information

Table 3-5 Descriptive statistics

Statistic	value	percentile	value
Sample size	31	Min	73.831
Range	277.53	5%	87.332
Mean	224.45	10%	116.26
Variance	6331.9	25% (Q1)	136.38
Std. Deviation	79.573	50% (Median)	233.95
Coef. of Variation	0.35452	75% (Q3)	283.39
Std. Error	14.292	90%	337.58
Skewness	-0.21026	95%	346.58
Excess Kurtosis	-0.97454	Max	351.36

Table 3-6 Fitting result

Distribution	Parameters
Gumbel Max	σ=62.043 μ=188.64
Log-Pearson 3	α=5.8715 β=-0.17099 γ=6.3436
Logistic	σ=43.871 μ=224.45
Lognormal	σ=0.4076 μ=5.3396
Lognormal (3P)	σ=0.04172 μ=7.5394 γ=-1656.5
Pearson 5	α=5.6434 β=1073.7
Pearson 5 (3P)	α=177.55 β=1.8797E+5 γ=-841.89

Table 3-7 Goodness of Fit-summary

Distribution	Kolmogorov Smirnov		Anderson Darling		Chi-Squared	
	Statistic	Rank	Statistic	Rank	Statistic	Rank
Gumbel Max	0.15997	6	1.5495	7	4.6671	6
Log-Pearson 3	0.10911	1	0.44884	1	1.6218	1
Logistic	0.13965	4	0.5943	4	2.914	4
Lognormal	0.15952	5	0.99973	5	5.557	7
Lognormal (3P)	0.13209	3	0.48327	2	1.7207	2
Pearson 5	0.18702	7	1.3062	6	3.7301	5
Pearson 5 (3P)	0.12059	2	0.56714	3	2.6514	3

As shown from the above table of the GOF indicate that Kolmogorov- Smirnov test, Anderson Darling test and chi- squared tests are gives Log Type-III is preferable. Therefore, Log Pearson_III gives maximum value of peak discharge for different return period, K-S test for Goodness fit test (GOF) used for this study.

3.4.3 Log- Pearson type-III (LP3)

Many distributions are in common use in engineering applications. Among the well-known extreme value distributions are Gamble distribution, General extreme value (GEV) and Log-Person type-III are widely used in hydrology to describe statics of information and stream flow (FEMA, 2007). The Log-Pearson-III uses for computing peak flood magnitude in hydrologic Engineering (Haan, 1977). The location of the bound ϵ in the log-Pearson Type III distribution depends on the skewness of the data. If the data are positively skewed, and then $\log X \geq \epsilon$ and ϵ is a lower bound, while if the data are negatively skewed, $\log X \leq \epsilon$ and ϵ is an upper bound. The log transformation reduces the skewness of the transformed data and may produce transformed data which are negatively skewed from original data which are positively skewed. In that case, the application of the log-Pearson Type III distribution would impose an artificial upper bound on the data. Therefore, in this study log person-III was used to compute peak discharge for different return periods (Appendix D).

3.4.4 Transposing peak discharge

Methods for making flood peak estimates can be separated on the basis of the gauged versus ungagged site. For un- gauged site where data are not available at the point of interest, peak discharges can be made by either supplementing or transposing peak flow (linear regression or Drainage Area weighting). Drainage Area Weighted (DAW) is a widely used technique in many cases where limited stream flow data are available (Harlan, 2002).

Drainage Area weight methods are applicable for the size between the gauged to un- gauged approximate to small (about 25%) (Harlan,2002). This method is most valid in condition where watershed is similar catchment parameter like land use, soil types, slope and similar stream patterns (Harlan, 2002). Peak flow is estimated using Drainage- Area weighted using the following method.

$$Q = Q_g\left(\frac{Au}{Ag}\right)^b \quad \text{......Eq3.3}$$

Where: Au = Drainage Area of un-gauged station, Ag = Drainage Area at Gauged station, Q_u = Peak Discharge at Un-gauged Station, Q_g = peak Discharge at gauged station and b = Coefficient of Drainage Area. (Appendix C)

3.5 Analytic hierarch process (AHP)

In this study weighted approach was uses based on Analytic Hierarch Process (AHP). AHP is a multi– criteria decision making technique, which provides a systematic approach for assessing and integrating the impacts of various factors, involving several levels of dependent or independent, qualitative as well as quantitative information (Getahun and Gebre, 2015). It is a methodology to systematically determine the relative importance of a set of criteria by pair wise comparison. The weighted method uses to prioritize the relative importance of each factor relative to another factor. The hierarchical weights calculate for all layers based on the given pair– wise comparison (Kamonchat, 2017). Thus, the iteration repeats until the consistency ratio becomes less than 0.1 or 10% is acceptable (Getahun and Gebre, 2015).

Finally, the computed Eigen values uses as coefficient for the respective flood factors that is elevation, slope, drainage density, Flow accumulation, rainfall, land use and soil layers to be combined in 41 weighted overlays in Arc GIS to generate the final flood hazard map of the upstream–Downstream Holeta River Ethiopia using the following relationships. Flood Hazard = Elevation coefficient *Elevation + drainage coefficient *Drainage density + Flow coefficient* Flow accumulation + Slope coefficient* slope + rainfall coefficient *rainfall + land use coefficient *land use + Soil coefficient *soil. The frame work of generating flood hazard using Arc GIS is shown below

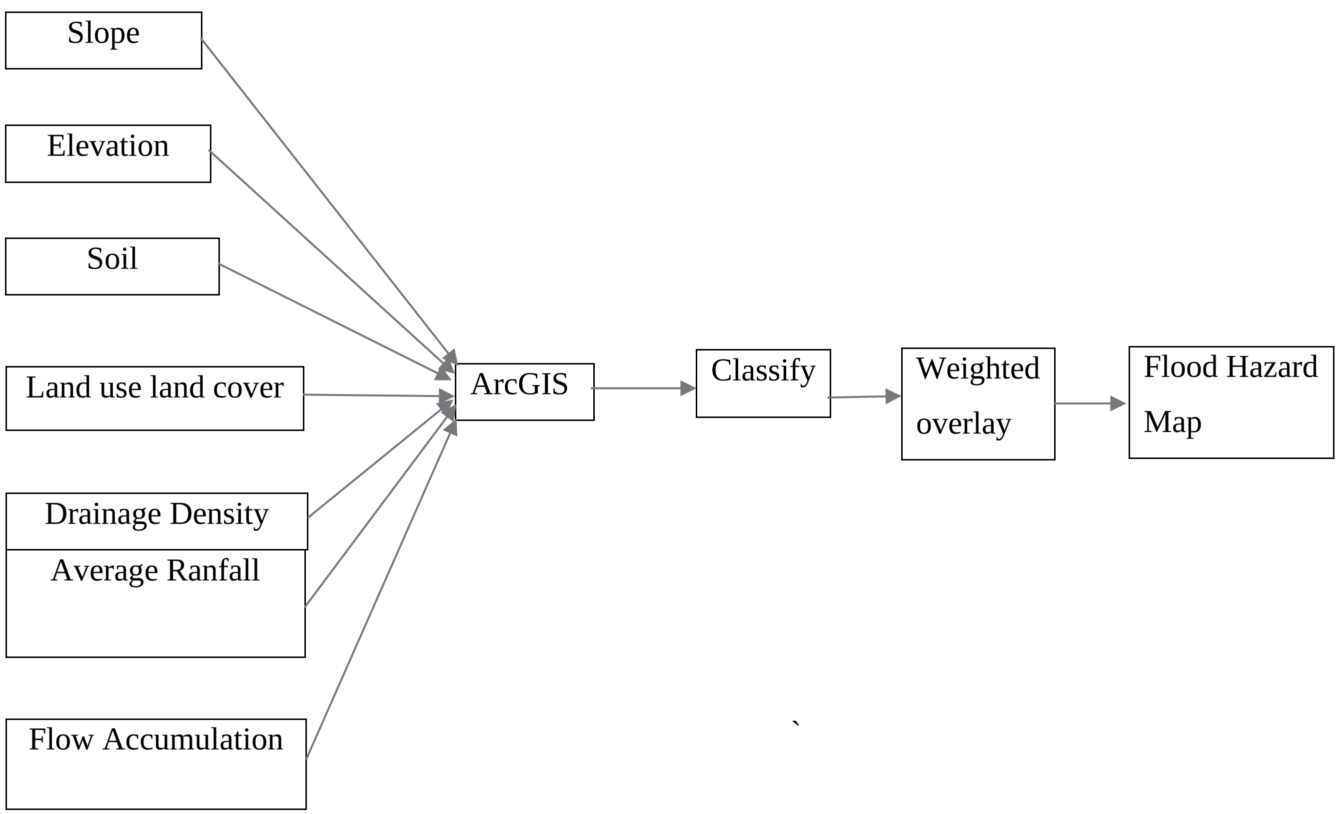


Figure 3-4 Frame work of Flood hazard map

3.6 Flood inundation mapping

The general procedure adopted for inundation modeling consists basically of five steps: i) Preparation of terrain (DEM or TIN) in Arc GIS, ii) HEC-geoRAS for Pre-Processing to generate HEC –RAS import file, iii) Running of HEC-RAS to calculate water surface profiles, IV) post-processing of HEC-RAS result V) Flood plain mapping.

3.6.1 RAS pre- processing

The RAS pre-processing is the task one's done in River Analysis system (RAS). For this, study River geometry was done by HEC-Geo RAS software. The HEC-Geo RAS is a GIS extension with a set of procedures, tools and utilities for the preparation of river geometry (Sean, 2011). HEC–Geo RAS software uses Digital Terrain Model (DTM) to create river geometry. The DEM (30 by30) was taken from department Geographic Information System, Ethiopia. In via GIS Environment, Triangular irregular Network (TIN) for Holeta river catchment was developed from DEM of the study data using the 3D spatial analysis extension. A TIN is a set of adjacent, non-overlapping triangles, computed from irregularly spaced points with x/ y coordinates and z- values (Dewberry, 2011). The TIN data structure is based on irregularly spaced point, line and polygon data interpreted as mass points and break lines. Thus, TIN allows efficient generation of surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as stream banks that are critical for hydrologic and hydraulic analyses (Dewberry, 2011). Further, the river center line, River bank, flow path; XS cross-section, 3d river centerline, 3d river cross -section developed by HEC-Geo RAS. The river stream center line, bank lines, flow path center lines, and cross section lines has to be digitized from a previous river file and topographical datasets using HEC-Geo RAS interface. The river reach (river segment between junctions), cross- section and other related data is store in the geo-database file of HEC-Geo RAS. The following section describes how each individual layer created (digitized).

1. Creating River Centre line

The River centerline layer is very important, because it represents the river network for HEC-RAS. The digitizing of stream centerline starts with selecting the sketch tool from the Editor Toolbar and digitization proceed in the direction of a river flow (Slobodan, 2009). The process begins from upstream end to the downstream end of Holeta River. After digitizing all of reaches, the name of the river was assigned. This was accomplished by the selection of Assign River code menu item and assigning appropriate names.

2. Creating River bank

The interface extracts the geometric data in export RAS data in GIS2RAS.RASImport.sdf format. The bank lines layer is used to define river channel from overbank areas. The bank lines were created in similar way as the river centerline. The digitizing of bank lines starts from the upstream end, with the left bank (looking in downstream direction) being digitizing first.

3. Creating Flow paths

The flow path layer is a set of lines that follows the center of mass of the water flowing down the river, during the flood event (Meyer and Olivera, 2007; Slobodan, 2009). For Flood plains, the flow path centerlines were digitized to represent created water flow within the flood plain. Flow path centerlines were created in the upstream to downstream flow direction.

4. Creating cross-sections

Cross-sections are one of the most important inputs to HEC-RAS. Cross-section cut lines are used to extract the elevation data from the terrain and to create a ground profile across the flow (Slobodan, 2009). The intersection of cut line's with other RAS layers such as centerline and flow path lines are used to compute HEC RAS attributes such as bank stations (locations that separate main channel from floods plain) and downstream reach length (distance between cross-section) (Slobodan,2009). The following important basic rules were followed during the process of drawing cross section cut lines (Meyer and Olivera, 2007; Slobodan, 2009): Cut lines were drawn perpendicular to a direction of flow, cut lines are drawn directionally from left to right bank, looking downstream direction and Cut line's do not intersect each other.

For this study, there are about 80 cut lines was created for Upstream-Downstream Holeta river. Thus, for each cut line's, the 2D feature class XS Cut lines are intersected with the TIN to create a feature class with 3D cross-section. Finally, Creating GIS import file for HEC-RAS so that it could import the GIS data to create the geometry file. First, choosing layer set up window and under required surface choose TIN, under required layers select river layer, XS-Cut line's layer and XS-Cut line's 3D layer, under optional layers choose banks, flow path, River 3D and optional tables are not used in this study, show all null value.

3.6.2 RAS post-processing

Hydraulic models are utilized in order to simulate the behavior of the flow in the main channel and the flood plain of a river. The peak flood discharge which was generated from probability distribution methods was used as the main input for hydraulic modeling. The other important input for RAS Post processing is geometry data of the river which was prepared using HEC –Geo RAS extension. HEC_RAS 5.0.5 is hydraulic model created by the hydrologic Engineering center which was utilized as hydraulic model in this study. HEC_RAS is well -known and popular hydraulic model which widely has been utilized in different water resources studies in different parts of the world (Sina, 2010). HEC_RAS has the capability of performing the analysis in steady state (simplicity approach; flow does not change through time) and unsteady state (more complex and realistic approach) (Sina, 2010).

The HEC-RAS software is accomplished by the following Stepwise procedures.

1. Create new project
2. View and Edit Geometric Data
3. View and Edit steady or unsteady Flow Data
4. Perform a steady or an unsteady flow simulation

3.6.2.1 Import RAS geometry

The RAS geometry was imported to HEC-RAS in GIS format. The imported Geometry file containing head, stream network and cross section information and used for hydraulic modeling in HEC-RAS (Raluca-Iustina , 2015). These importing file in to geometric editors (Graphical User Interface (GUI)), which is managing geographic data. In this study, the manning's roughness coefficient values were entered for the cross section of the reach.

Manning's n values were used in the model to define roughness for each cross section. Manning's 'n' is affected by many factors and its selection in natural channels depends heavily on engineering experience. It is influenced by various factors such as topographic heterogeneity, the bed material, the surface irregularity on the floodplain, obstructions, the variation in shapes and size and the vegetation for flood plain (Cowan's, 1956). Pictures of channels and flood plains for which the discharge has been measured and Manning's 'n' has been calculated are very useful. Once the Manning's 'n' values have been selected, it is highly recommended that they be verified with historical high-water marks and/or gauged stream flow data. Ethiopian road authority presents descriptive data and photographs for different natural and artificial channels for which roughness coefficients have been determined. Therefore, the roughness value for Holeta river was determined by comparing the ERA drainage design manual standard photos with that of Holeta river main channel and found to be between 0.045.

3.6.2.2 Steady and unsteady flow data

Similarly, for flow data, unsteady flow was assumed as dealing with flood flow depth, discharge varied throughout the river. A peak flood computed for different return period 10, 25, 50 and 100 years was used for input data. For example, the result of unsteady and steady flow distribution for different return periods is shown in the Appendix E. In HEC-RAS, hydraulic analysis is crucial to properly describe the boundary condition. Boundary condition plays a role as a connecting node that defines flux relationship between the simulation area and surrounding area (Edna, 2007). Boundary condition needs to be defined at the upper and lower boundary of the simulation domain area can be represented by either series of constant discharge, Q or series of water level, H (as function of time) (Edna, 2007). A wrong choice of boundary conditions may generate a misleading water balance of the system and consequently resulted in serious propagation of errors throughout the simulation, thus giving ambiguous results (Edna, 2007). For this study, based on the availability of data the critical depth for steady flow analysis and flow hydrograph for unsteady flow analysis was selected for boundary conditions.

3.6.2.3 Steady and unsteady flow analysis

Usually, a steady flow approach is used for floodplain management and flood insurance studies whereas unsteady flow approach is used for subcritical flow regimes (Brunner 2002, Niraj, 2017). The steady and unsteady flow analysis is the computation of hydraulic results by taking the input data of geometry data for geometry preprocessor, steady and unsteady flow data, for steady and unsteady flow simulation and the post-processor computed various RAS results (Dewberry, 2011). While, run steady and unsteady flow analysis, via performing flow analysis in HEC-RAS5.0.5 software and river cross section output was displayed in different format such as figure and table. Finally, export the computation results (water surface elevation) in GIS format. In the GIS Export, all four profile results (for the 10, 25, 50- and 100-years flow scenarios) are selected and exported using format RAS export.sdf.

3.7 RAS mapping

HEC-Geo RAS is used to generate flood inundation maps. The initial step for the HEC – Geo RAS mapping process is to transform the HEC- RAS results in to GIS format (Sean, 2011). The HEC RAS results is in RAS Export.sdf File type and have to be convert to RAS.xml File format to read in GIS data base.

3.7.1 Create layer set-up

Establishing the layer setup is a necessary step for processing the HEC-RAS results. In the layer setup window, the type of analysis and the input and output data are identified. In the layer set up for post processing, first select new analysis and named it (e.g. Flood 25year). Browse. RASexport.xml for RAS GIS Export File from user working folder. Select single terrain type and lookup from working folder. Set the output directory for HEC processing results. The default 20 map units for Rasterization cell size in layer setup window. Basically, the smaller number of map unit (1 or 2) results in a better representation of the resulting flood plain boundary during the floodplain delineation (Slobodan, 2009). Due to the large covered by the upstream-downstream Holeta river, its post-processing is quite complicated and requires the creation of a very large TIN. So, user computer hardware limitation causes the program not able to handle 1 to 5 cell resolution and 10 map units are used for best possible rasterization for this study.

3.7.2 Import RAS data

The input data entered in the layer set up, the HEC-RAS results have to be imported into the GIS in order to continue with post-processing. The RAS results introduces in a new data frame with following feature classes: River2D, XS cut lines, bounding polygon water surface elevation and bank points. This is creating a bounding polygon, which basically defines the analysis extent for inundating mapping, by connecting the endpoints XS Cut lines.

3.7.3 Inundation mapping

Floodplain mapping is performed using the water surface elevations on the XS cut line, within the limits of the bounding polygon (Slobodan, 2009). Flood plain mapping or inundation mapping includes two steps such as water surface generation and Floodplain delineation.

3.7.3.1 Water surface generation

In this step, create water surface TIN from the cross-section water surface elevation for the selected profile. For each selected water surface profile, a water surface TIN is created without consideration of the terrain model (Slobodan, 2009). The TIN is created using the ArcGIS triangulation method. This allowed for the creation of a surface using cut lines as hard break lines with constant elevation (Slobodan, 2009).

3.7.3.2 Floodplain delineation

The floodplain delineation proceeds by HEC-Geo RAS software through convert raster to grid to feature. There was a series message seen during execution. The first step, water surface TIN is converted to a GRID (water surface GRID) and subtracts the terrain GRID from water surface GRID (Slobodan, 2009); Maurer, 2015). Also, add water depth GRID to map for a different water surface profile. Additionally, convert flood plain GRID to polygon for different water surface profile. The areas which of little interest are still included in the water surface TIN. These areas are removed in the process of delineation (Maurer, 2015). Finally, a floodplain feature flood inundation depth, extent area of flood inundation map was developed along upstream-Downstream Holeta River, Ethiopia.

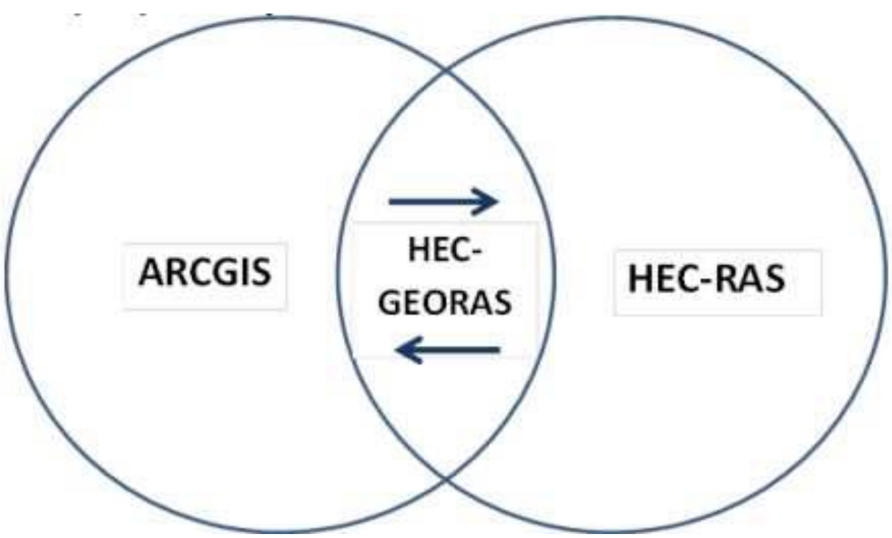


Figure 3-5 Schematics representation of the used computer software for F

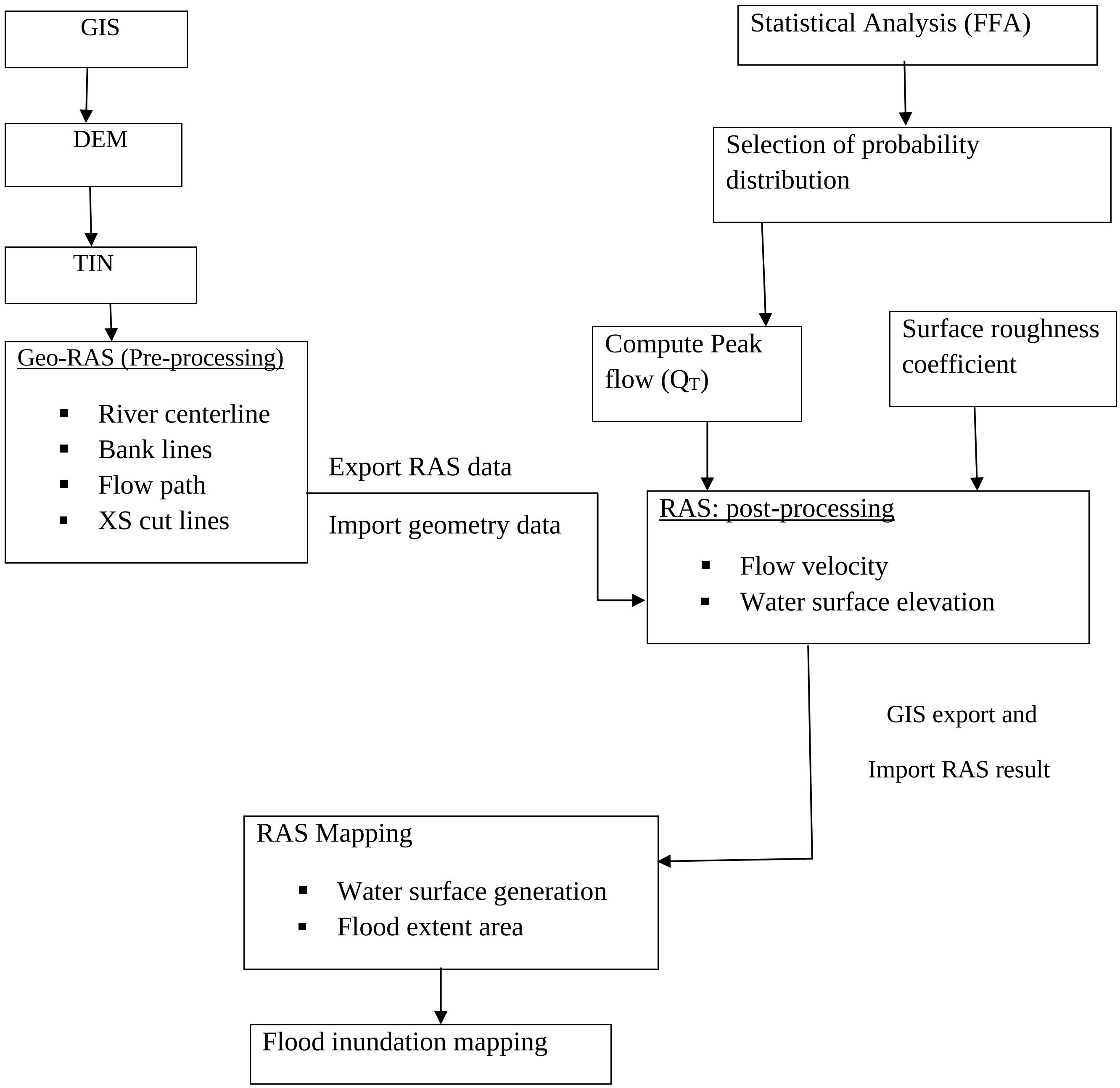


Figure 3-6 Step wise procedure for flood inundation mapping

4 RESULTS AND DISCUSSION

4.1 Flood frequency analysis

Flood frequency analysis is done based on maximum daily annual flow recorded at Holeta station from year 1979 to 2009. The probability distribution model selected are: Gumbel Max, Log-Pearson 3, Logistic, Lognormal, Lognormal (3P), Pearson 5, and Pearson 5 (3P). For selecting best fitted distribution, goodness-of-fit test has been conducted. Using Easy-Fit, Kolmogorov-Smirnov (K-S) test Anderson Darling test and chi- squared tests are found that, The Log- Pearson -III (LP3) is the best distribution among the selected probability distribution. Transposing of peak discharges was employed at downstream point using Drainage Area Weighted (DAW) methods. The transposing coefficient is 2.1506 (shown in Appendix C) and the peak discharges for Upper-downstream Holeta River for different return periods: 10, 25, 50 and 100 years become are 350.75, 417.445, 465.551 and 511.68 m^3/s respectively. This value from log-Pearson III (LP3) distribution methods have been used for flood inundation mapping.

4.2 Flood inundation mapping

An inundation map displays the spatial extent of probable flooding for different scenarios and can be present either in quantitative or qualitative ways. The general procedure adopted for inundation mapping consists basically of five steps: i) Preparation of terrain (DEM or TIN) in Arc GIS, ii) HEC-geoRAS for Pre-Processing to generate HEC–RAS import file, iii) Running of HEC-RAS to calculate water surface profiles, IV) post-processing of HEC-RAS result, V) Flood plain mapping. Flood inundation mapping was done by considering the result obtained from four simulation scenarios. For illustration purpose the inundation maps of only the DEFAULT scenarios of 10, 25, 50- and 100-year flood were analyzed for this section. The preparation Triangular irregular Network (TIN) from Digital Elevation Model is very important. A Triangulated Irregular Network (TIN) is a vector-based structure that is used to model irregularly spaced sampled points across a surface. Thus, TIN allows efficient generation of terrain surface models for the analysis and display of terrain and other types of surfaces while preserving the continuous structure of features such as stream banks that are critical for hydrologic and hydraulic analyses.

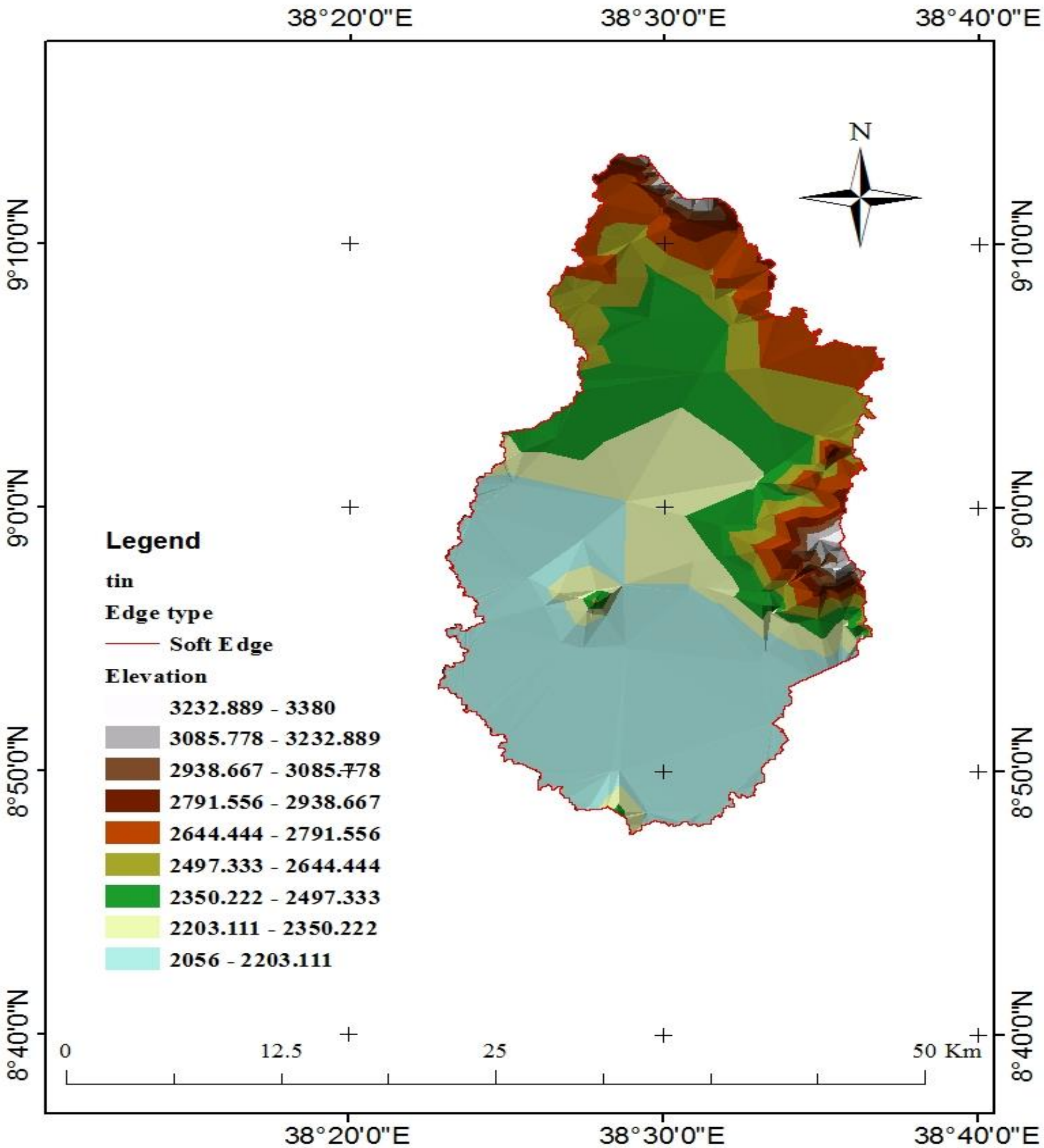


Figure 4-1 TIN from DEM

4.2.1 River geometry

The river geometry is a very important to develop flood inundation mapping. It is the pre-processing done by using HEC-geoRAS and used for HEC-RAS hydraulic analysis. The required element includes river center line, river banks, flow path and XS Cut lines. The attribute table of XS Cutlines3D, river3D and XS cut lines were shown in Appendix E gives brief information such as elevation; reach name, channel length, station number, Hydro ID and other.

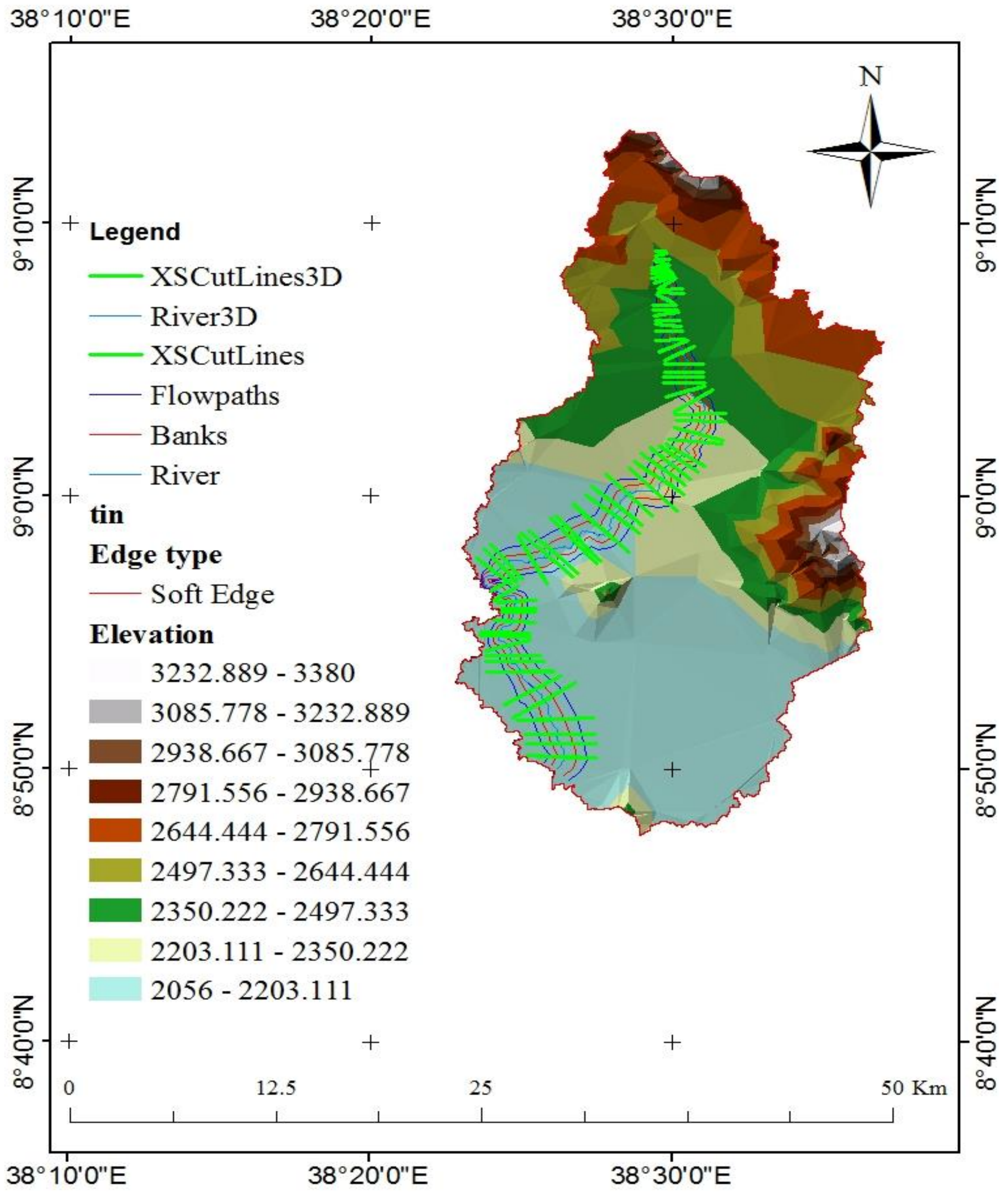


Figure 4-2 TIN and RAS geometry

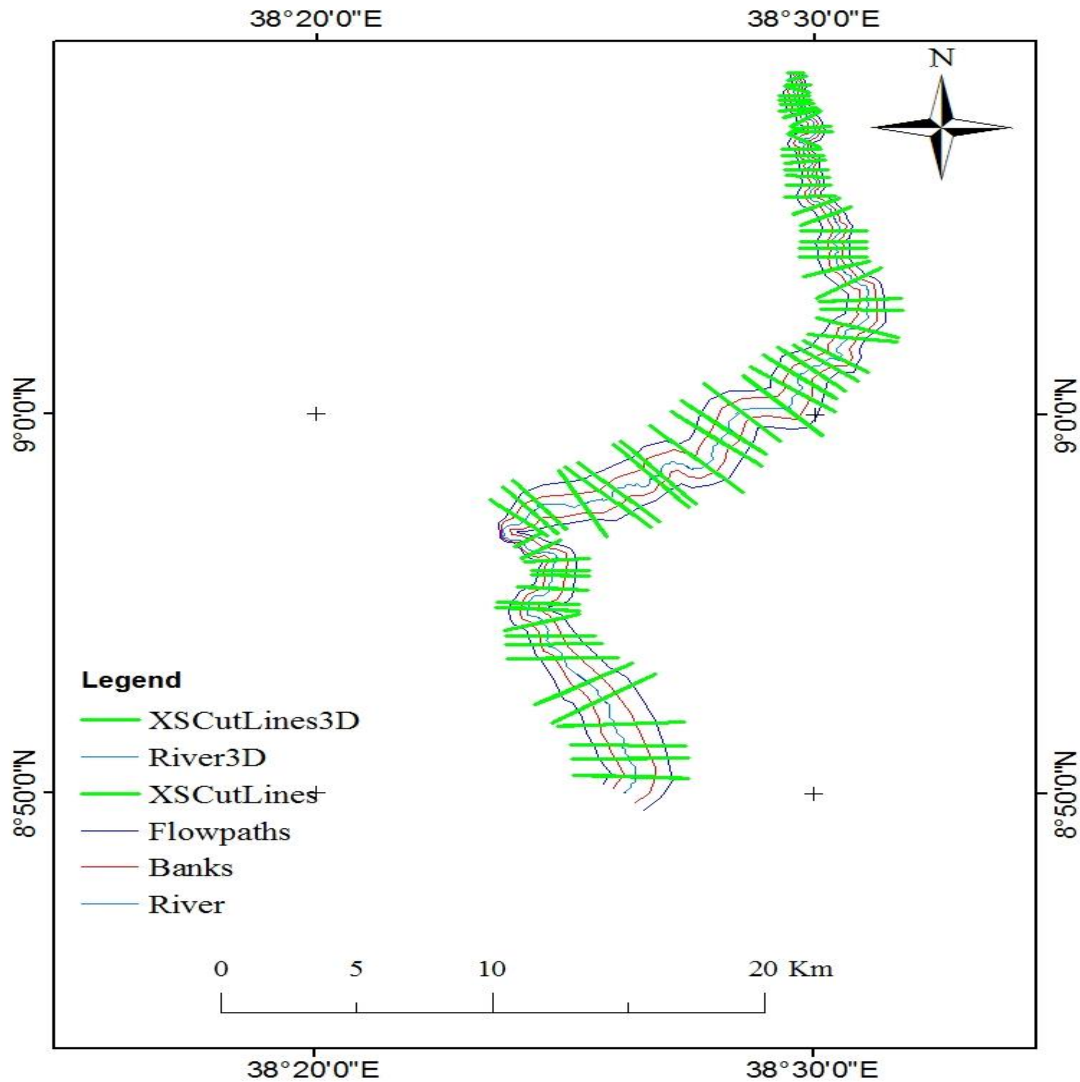


Figure 4-3 RAS geometry of Holeta river

4.2.2 Hydraulic computation

HEC-RAS is the ability to model flood events and produce water surface profiles over the length of the stream. The water surface elevations were estimated using hydraulic model. Hydraulic simulations were executed for the design discharge at different return period (10, 25, 50 and 100 years). In addition, the detail information of hydraulic computation shown in table format found in Appendix E. The water surface elevation from HEC-RAS hydraulic model are geo-referenced (mapped) on the digital terrain model. Thus, water surface converted to Triangular Irregular Network (TIN format) for post processing.

4.2.3 Inundation mapping

The RAS Mapping tool in HEC Geo RAS was used to develop generation of water surface and flood plain delineation for different flow type and return period. The hydraulic simulation from HEC-RAS data was imported to HEC-geoRAS mapping in this stage as shown in figure 4.4 below. The Inundation mapping was completed using two steps: Generation of water surface TIN and Flood plain Delineation. Generation of water surface TIN: The water surface TIN is intersected with the digital terrain model to create flood plain polygon for different flow scenario. The TIN is converted to Raster using Raster converter in GIS and RAS results was imported HEC – Geo RAS, flood bounding polygon, XS Cut line's, River 2D, water Surface Extents and Bank Points have to be created as shown figure below.

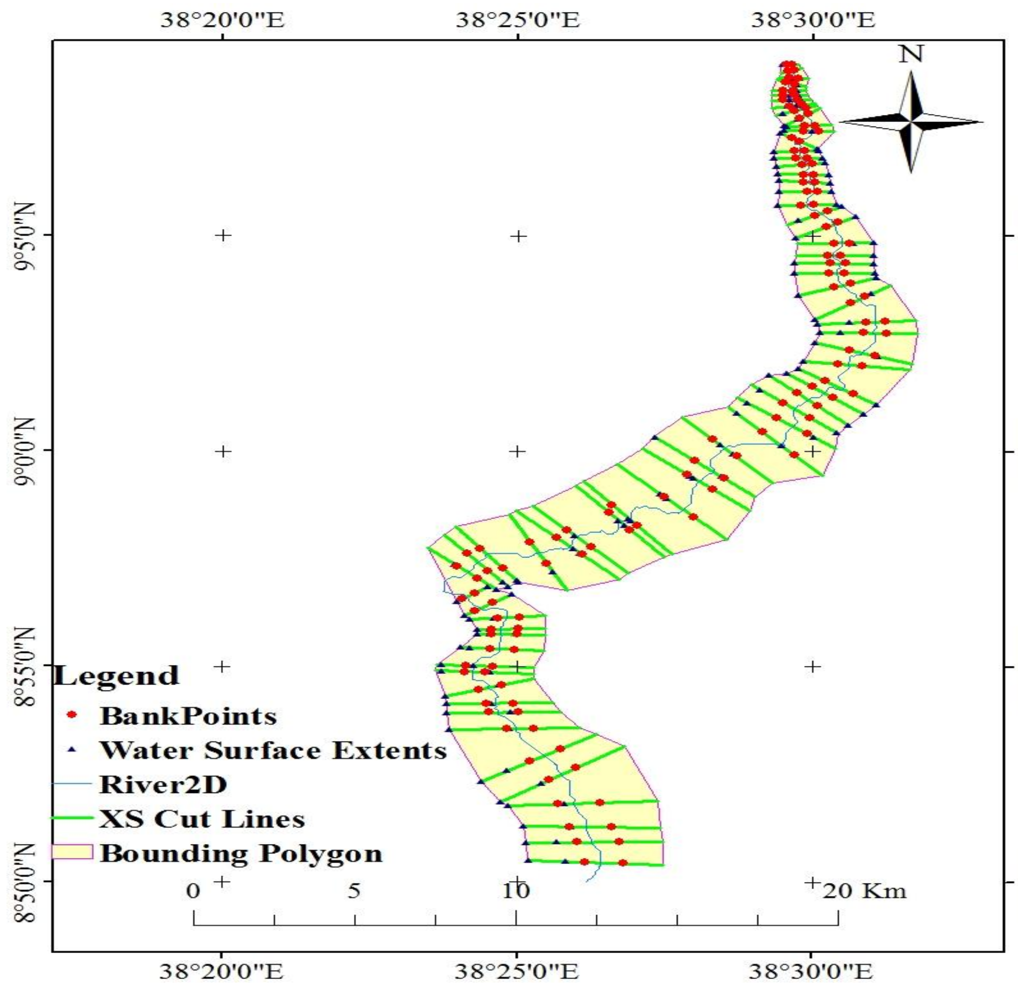


Figure 4-4 100-years Flooding RAS result

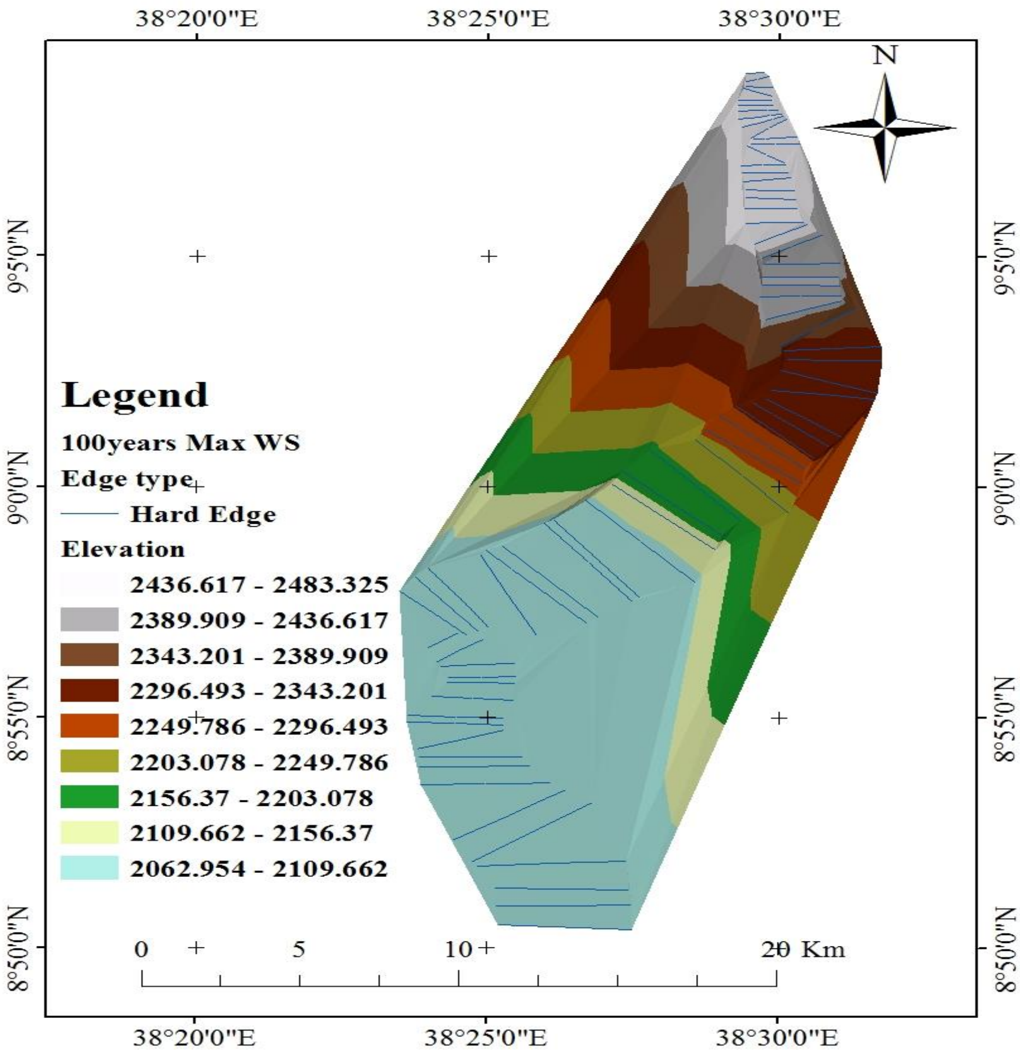
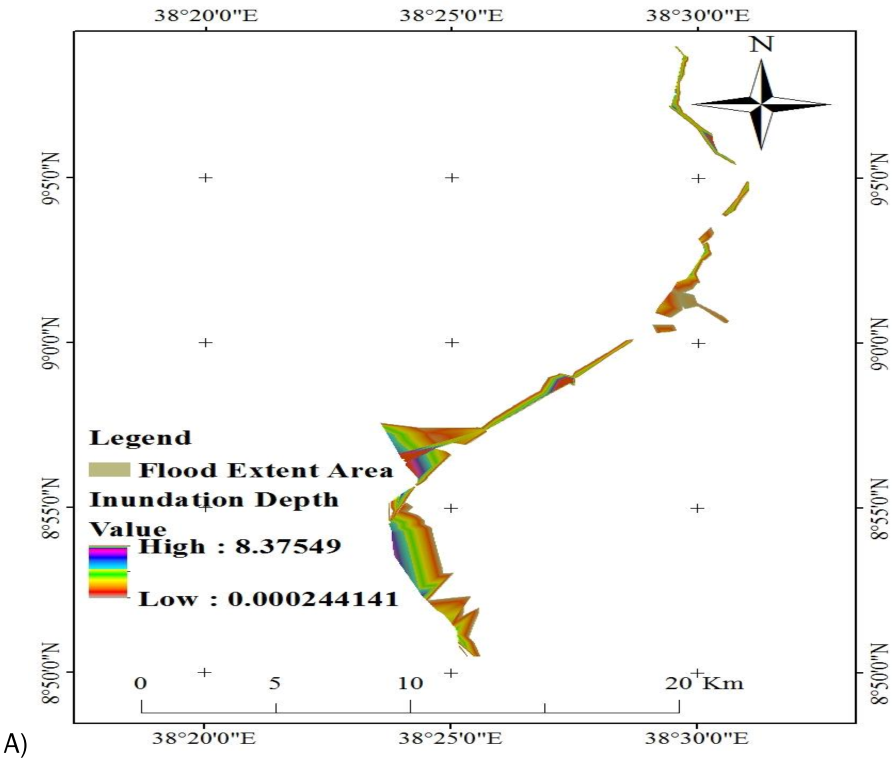
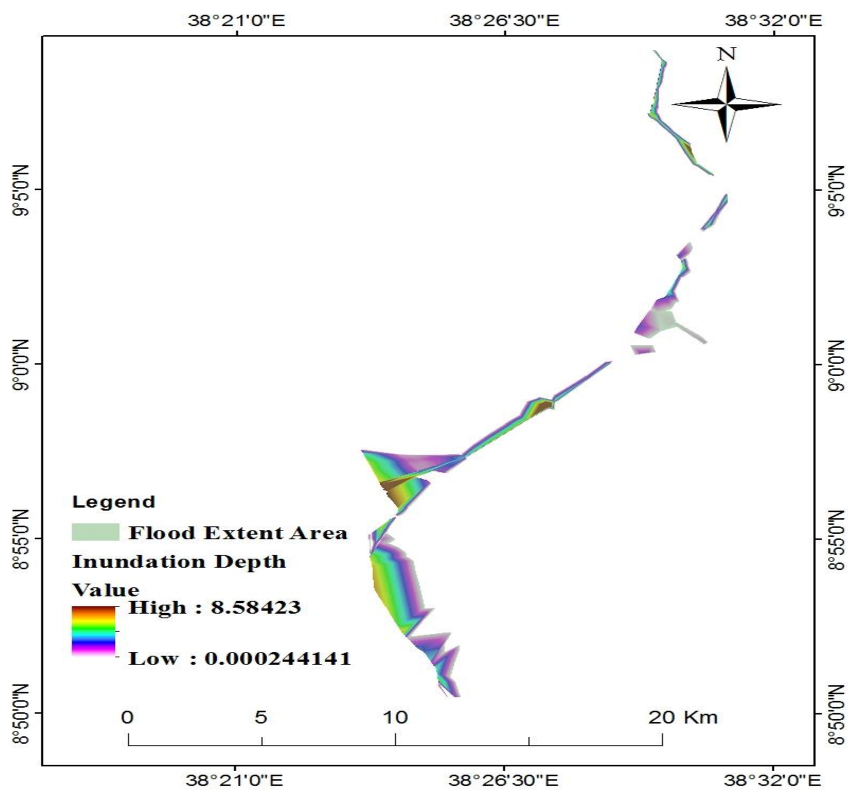


Figure 4-5 100-year Flood Water Surface TIN

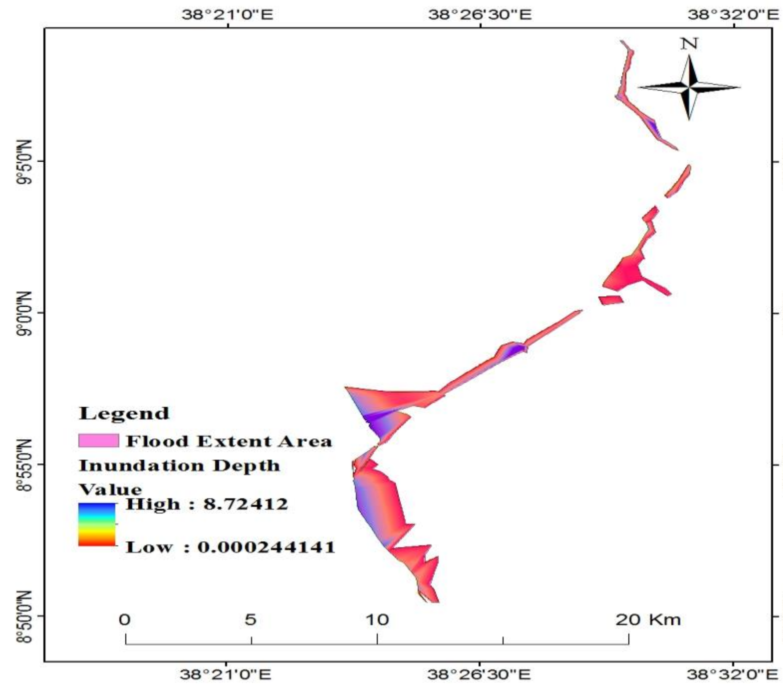
Flood plain Delineation: HEC-geoRAS can post-process the HEC-RAS data in to bounding polygon shape files that define the extents of flooding for a given flood event. The water surface TIN was converted to GRID and subtract the terrain GRID from water surface GRID. Thus, water depth GRID is created and used to map for a different water surface profile. Finally, a floodplain feature, inundation depth, extent area of flood inundation map was developed along Upstream-Downstream Holeta River. The inundation maps of the DEFAULT scenarios of 10, 25, 50 and 100 year are shown below with their flood extents area and inundation depths for both steady and unsteady flow flood simulation.


38°20'0"E
38°25'0"E
38°30'0"E
N
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 8.37549
Low : 0.000244141
0
5
10
20 Km

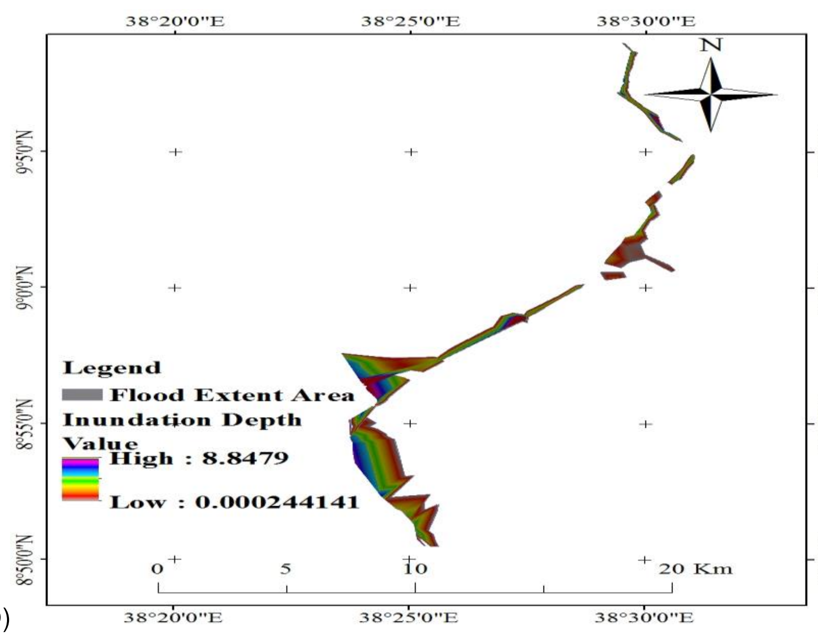
A)


38°21'0"E
38°26'30"E
38°32'0"E
N
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 8.58423
Low : 0.000244141
0
5
10
20 Km

B)



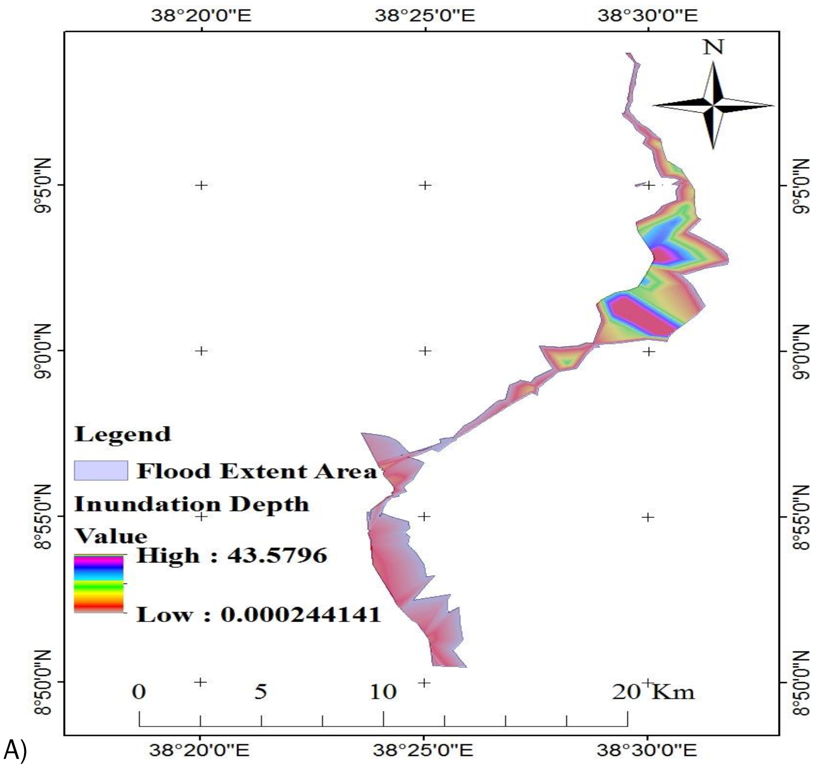
C.



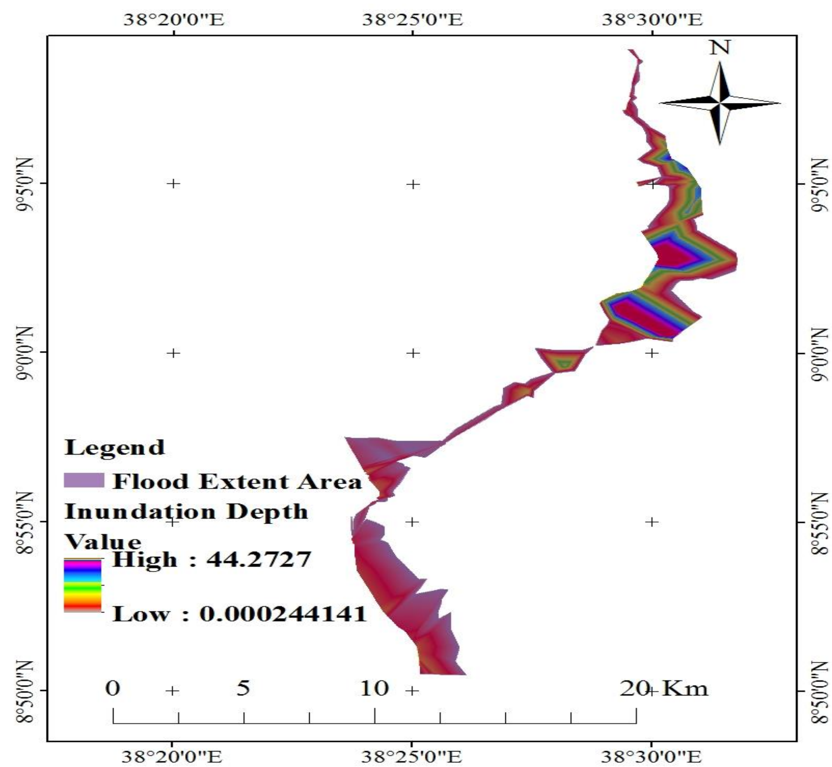
D)

Figure 4-6 Steady Flood Inundation Mapping for Holeta River

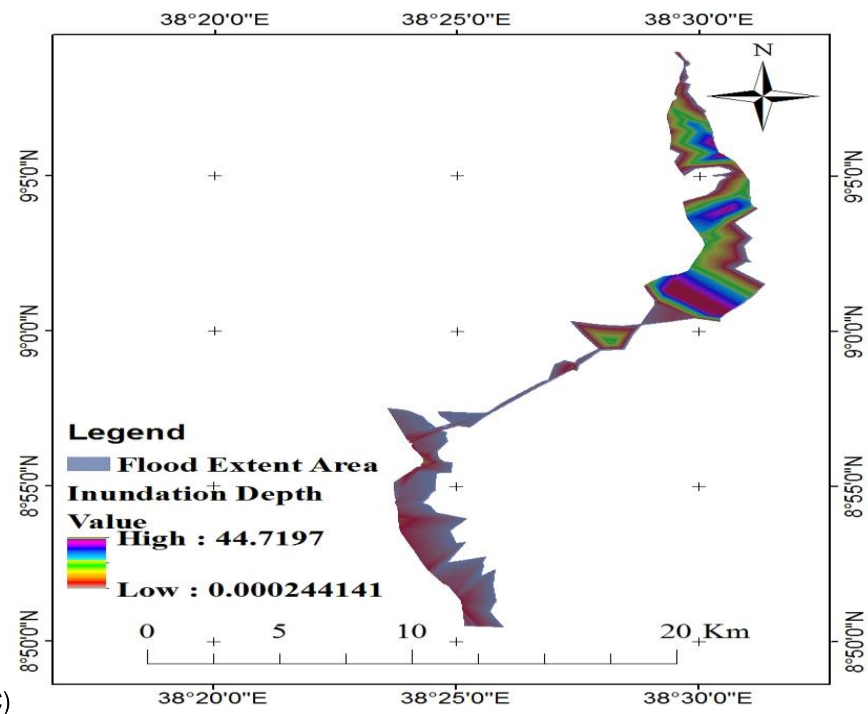
(A, B, C and D are steady 10, 25, 50- and 100-year flooding respectively)


38°20'0"E
38°25'0"E
38°30'0"E
N
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 43.5796
Low : 0.000244141
0
5
10
20 Km

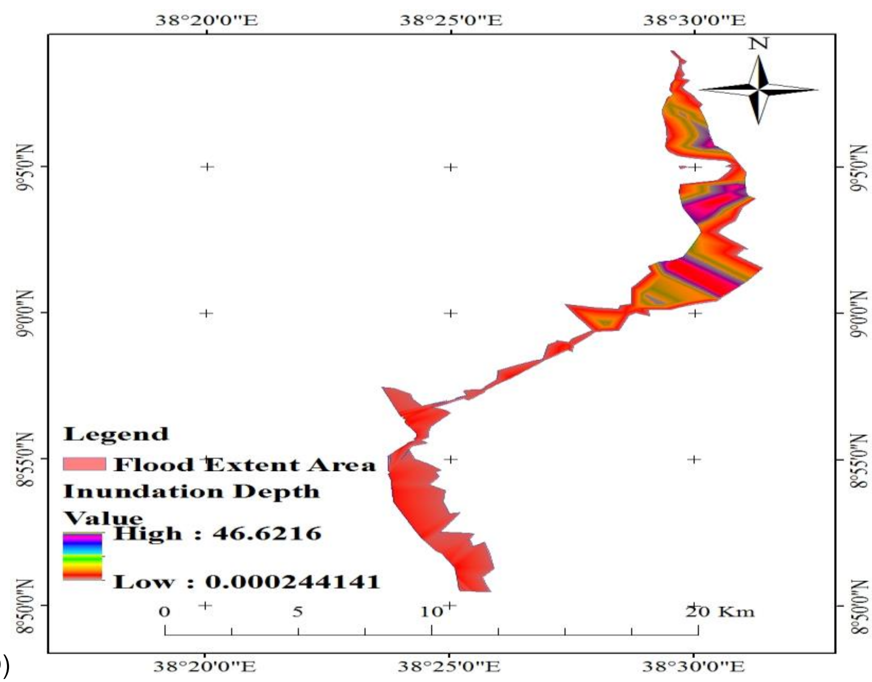
A)


38°20'0"E
38°25'0"E
38°30'0"E
N
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
Legend
Flood Extent Area
Inundation Depth
Value
High : 44.2727
Low : 0.000244141
0
5
10
20 Km

B)



C)



D)

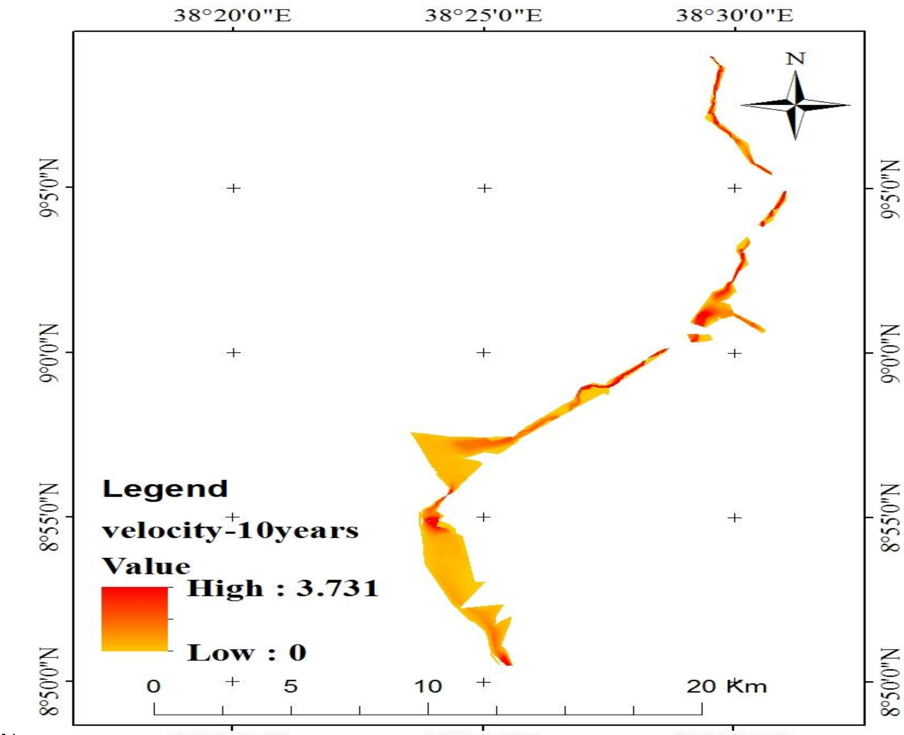
Figure 4-7 Unsteady Flood Inundation mapping for Holeta river

(A, B, C and D are unsteady 10, 25, 50- and 100-year flooding respectively)

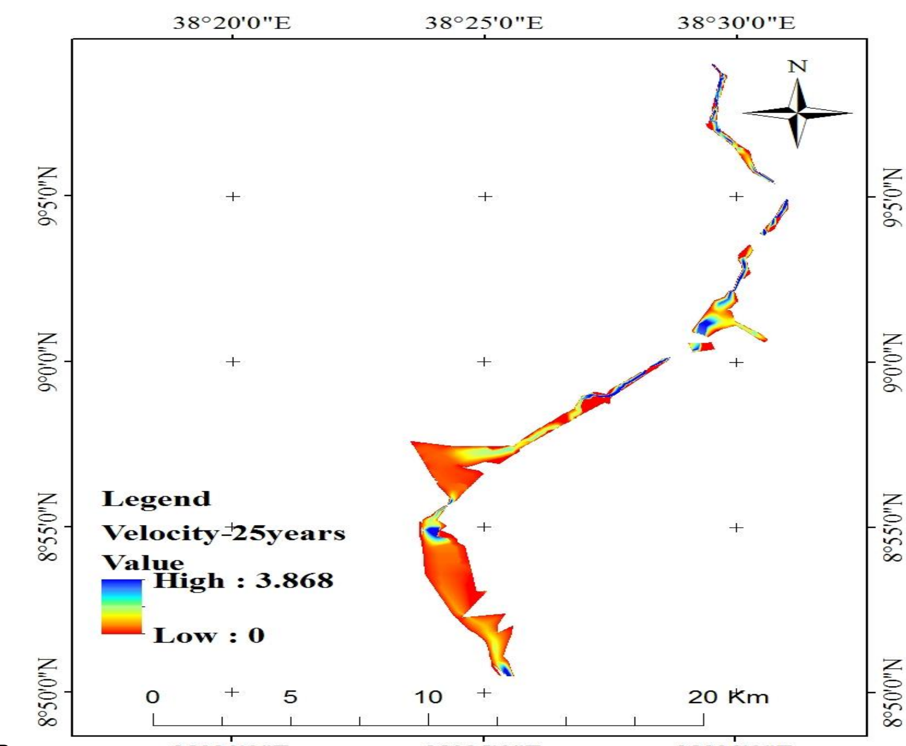
The flood inundation areas and Percentage Inundation (%) of steady and unsteady flood simulation for Upstream –Downstream Holeta River were shown in table below. The total area of flood bounding polygon was estimated about 129.539115 Km^2 using GIS software.

Table 4-1 Flood Inundation Extent Area

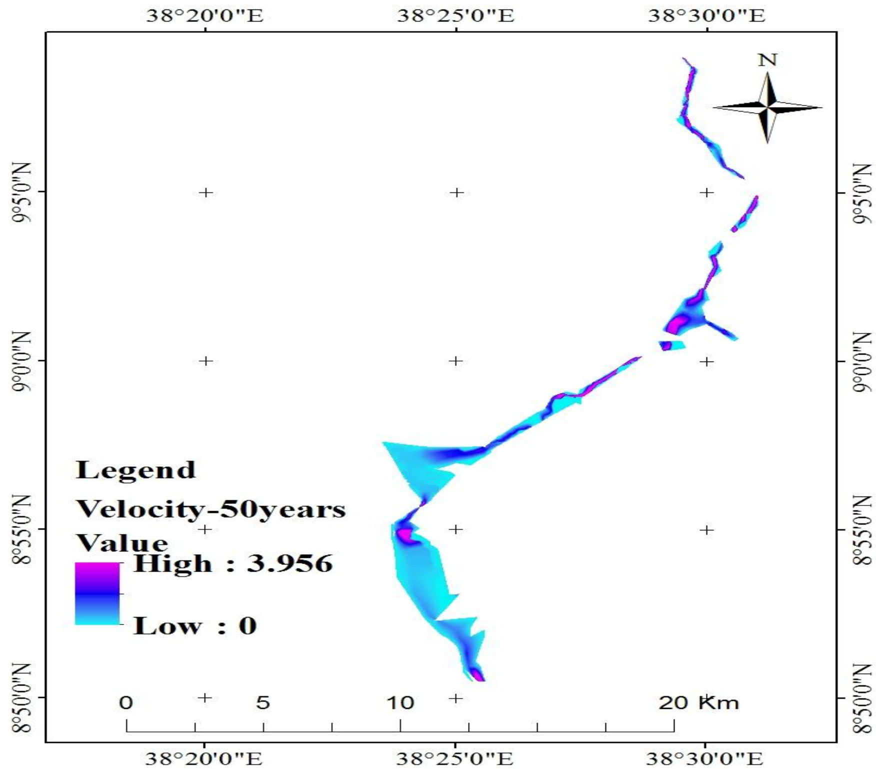
Return periods (Years)		10	25	50	100
Peak discharge (Qm^3/s)		350.75	417.445	465.551	511.68
WSE(m)	Steady	2060.8-2481.5	2060.9-2481.74	2060.96 2481.9	2061-2482
	unsteady	2064.2-2485.6	2065.96-2485.7	2066-2485.8	2066.7-2486.
Inundation areas (Km^2)	Steady	22	24	26	26.7
	unsteady	49	51	53	53.5
Percentage of Inundation (%)	steady	16.98	18.53	20.07	20.6
	unsteady	37.83	39.37	40.9	41.3
	%Diff	20.85	20.84	20.83	20.7
Inundation Depth(cm)	steady	8.38	8.58	8.72	8.84
	unsteady	43.58	44.27	44.72	46.62
Velocity (m/s)	steady	3.731	3.87	3.96	4.033


38°20'0"E
38°25'0"E
38°30'0"E
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
N
Legend
velocity-10years
Value
High : 3.731
Low : 0
0 5 10 20 Km

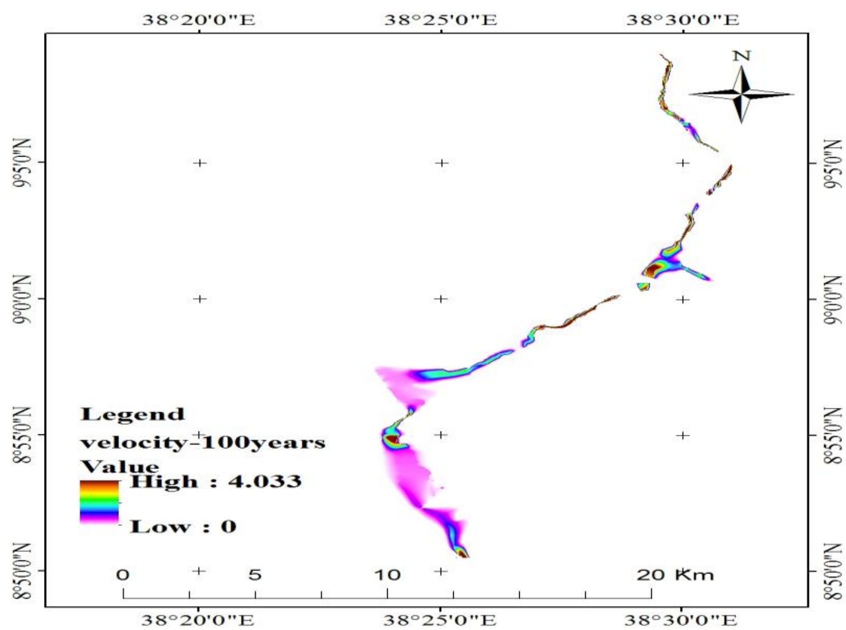
A)


38°20'0"E
38°25'0"E
38°30'0"E
9°5'0"N
9°0'0"N
8°55'0"N
8°50'0"N
N
Legend
Velocity-25years
Value
High : 3.868
Low : 0
0 5 10 20 Km

B.



C)



D)

Figure 4-8 Steady Velocity Maps for Holeta river

(A, B, C and D are Steady velocity maps for 10, 25, 50- and 100-year respectively)

4.3 Flood hazard mapping

Flood Hazard Mapping was developed using Arc GIS software. Based on the catchment-Response Approach to flood susceptibility, the flood prone area was identified. The flood generating factors varies from study to study. For this study, the selected flood generating factors are Elevation, Slope, Rainfall, Drainage Density, Flow accumulation, land use land cover and soil.

The spatial Analyst Tool (SAT) processed the raster format and re-classify them based on degree to flooding. The re-classification of these factors to four hazard level (very low hazard level, low flood hazard, moderate flood hazard and high flood hazard), based on susceptibility to flood each parameter rate to different flood hazard category. Hereby, the personal judgment, local information, professional knowledge and information from previous study help to identify the degree of flood generating factors causing flooding.

4.3.1 Elevation (E)

As water flows from higher to lower elevation, lowland areas are more prone to flooding occurrences (Olga, 2017). The elevation map is obtained from the reclassification of the DEM. The topographic elevation of Holeta River catchment is varied from 2054m to 3380m. The upstream elevation is very high and the lowest at the downstream. Thus, at upstream due to high elevation and steep slope there is high runoff during high rainfall and cause high flooding at the downstream as result the slope of the land is flat, river course allowed overflow. Topography is defined by a Digital Elevation Model (DEM), which describes the elevation of any point in a given area at a specific spatial resolution as a digital file. A DEM in needed for raster-based hydrological analysis in a GIS. The ASTER DEM has a spatial resolution of 30 by 30m, which was used for flood inundation mapping.

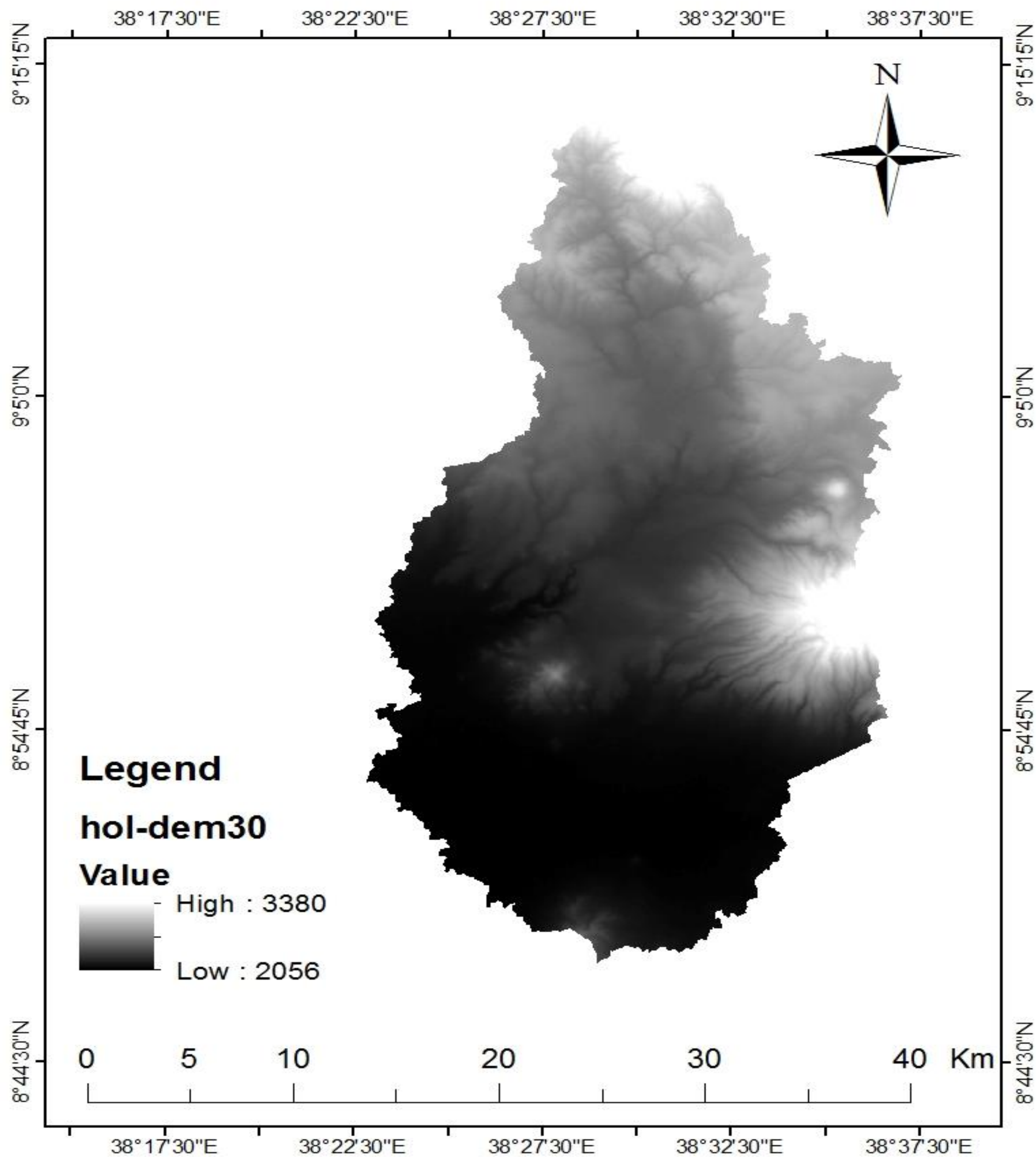


Figure 4-9 DEM of study area

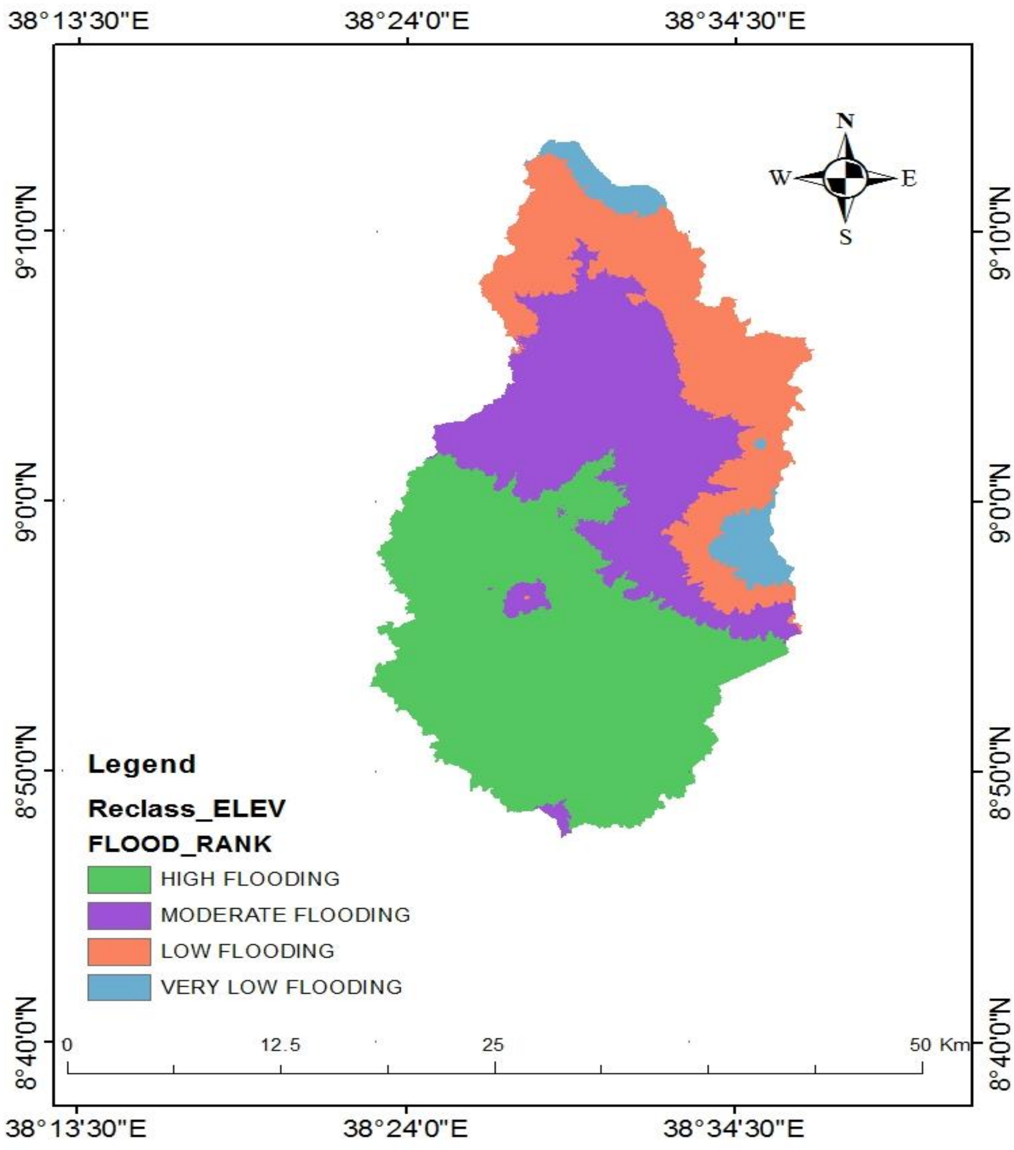


Figure 4-10 Re-classification of Elevation

4.3.2 Slope (S)

Elevation and slope are an integral part of land surface. It can be described in two different ways. One is degree of slope, which indicates the angle between ground surface and horizontal plane (Dai, 2016). The other one is percentage slope which used for this study, indicates the percentage ratio of elevation change on horizontal distance change (Dai, 2016). Also, it influences drainage, runoff exposure accessibility (Olga, 2017). Slope is highly correlated to both the volume and the velocity of the surface runoff, as well as the infiltration to the groundwater (FAO, 1990, 2006).

Flat areas flood quicker than inclined areas where runoff flows further down. For this study, based on the susceptibility to flooding the slope was ranked in to class-1 (very flat in 0-2%), class-2 (gently undulating in 2%-8%), class-3 (moderate steep in 8-30%) and class-4 (steep above 30%) (FAO, 2006).A parameter that can be derived from further analysis of Digital Elevation Model (DEM) for further analysis is the slope of terrain, which is most widely and distributed known topographic size element. The slope of the map of study area resulted from the processing of digital elevation models (DEM) using the software Arc Map (Spatial Analyst Extension).

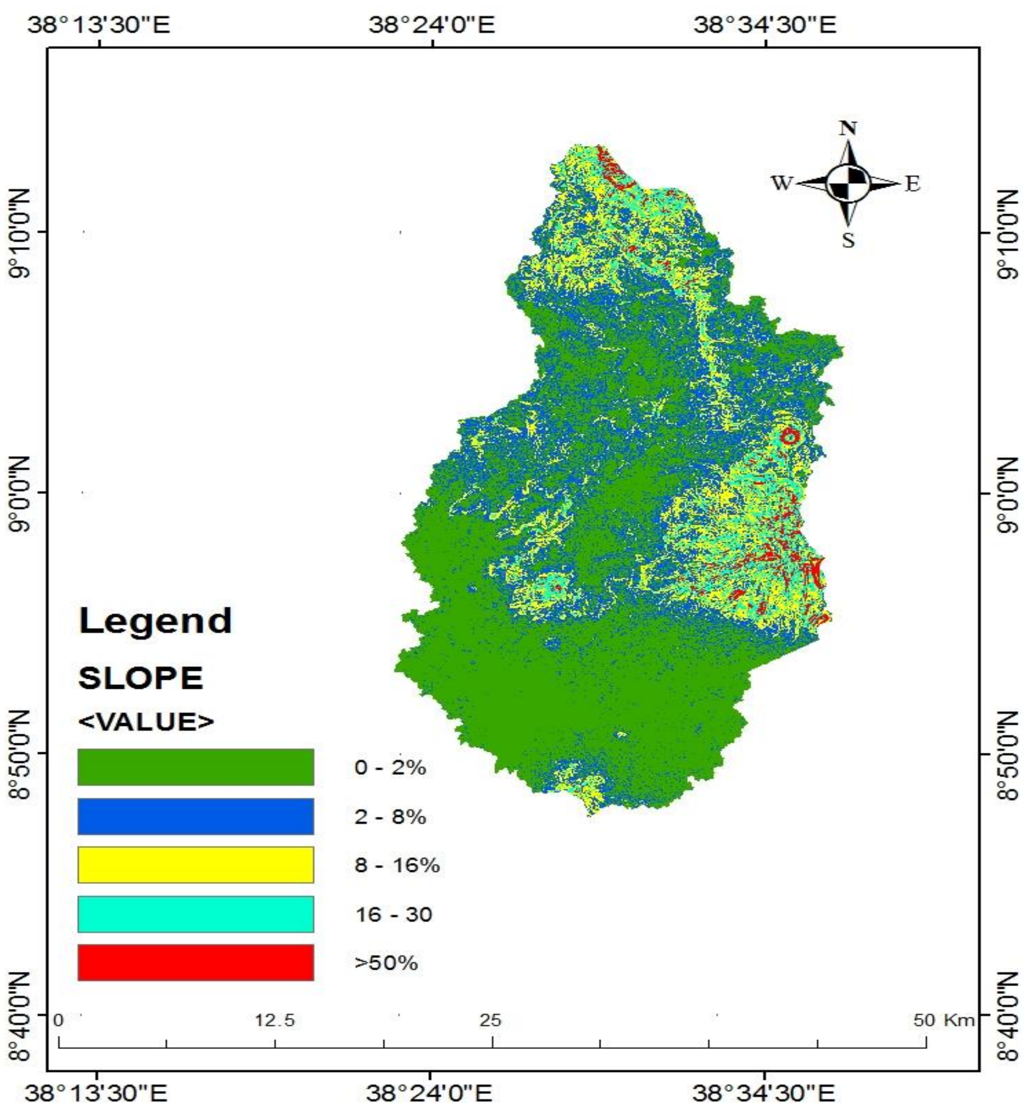


Figure 4-11 Slope of study area

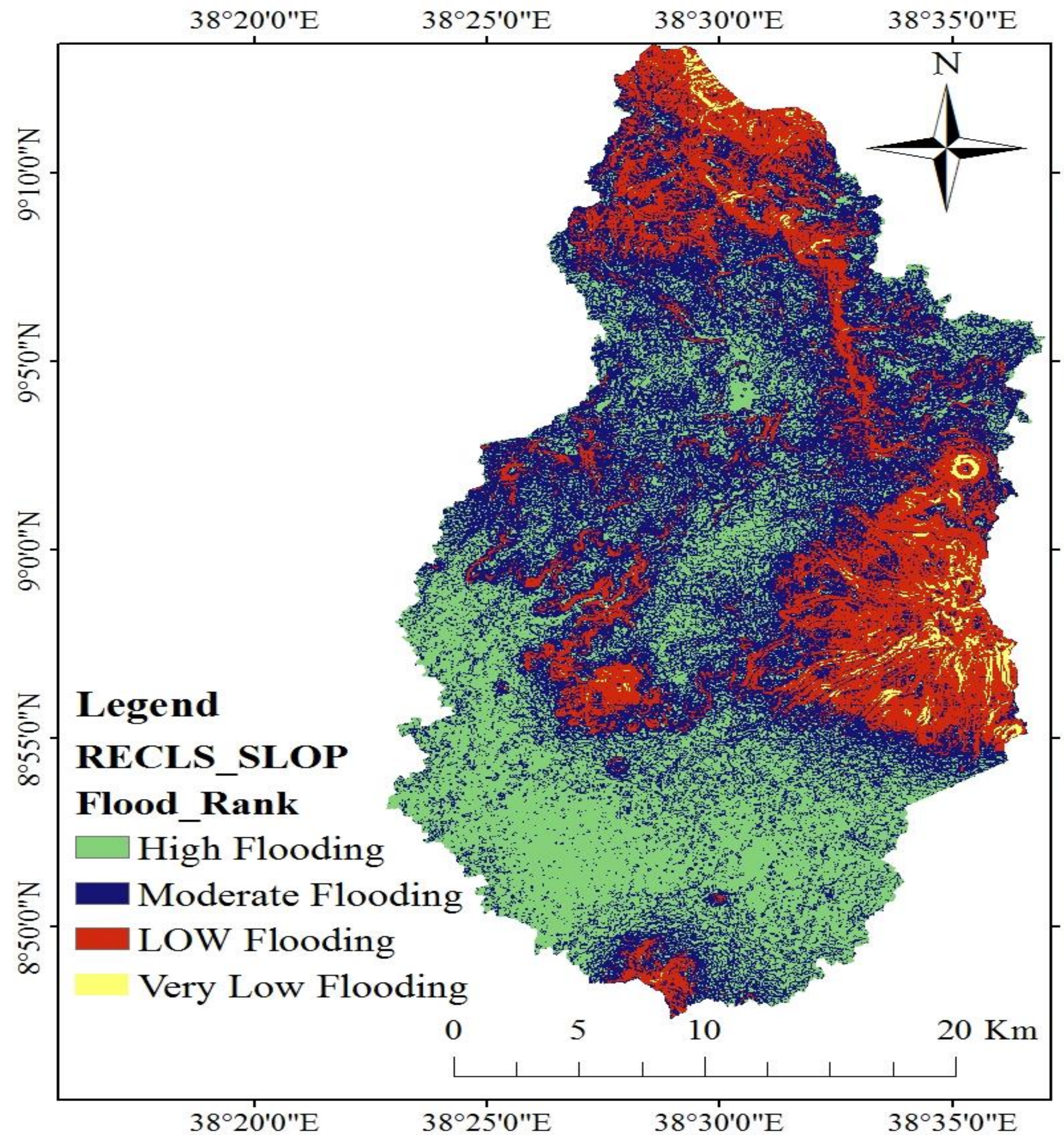


Figure 4-12 Re-classification of slope

4.3.3 Soil

Knowing the different morphological and other physical characteristics of the soil gives better understanding found on guideline for soil description (FAO, 1990, 2006). There were various soil of upstream-Downstream Holeta River as shown figure below. The soil feature type was converted in to Raster layer using conversion tool in Arc-GIS “To Raster”. Thus, the reclassification in to four flood hazard level considering the degree causing flooding.

Table 4-2 Soil degree to flooding

Class Name	Degree to Flood Susceptibility
Orthic solonchaks, Calcic Xerosols, Chromic Cambisols	Very Low Flooding
Dystric Nitisols, Eutric Nitisols	Low Flooding
Luptisols, Chromic Luvisols	Moderate Flooding
Pellic Vertisols, Chromic Vertisols	High Flooding

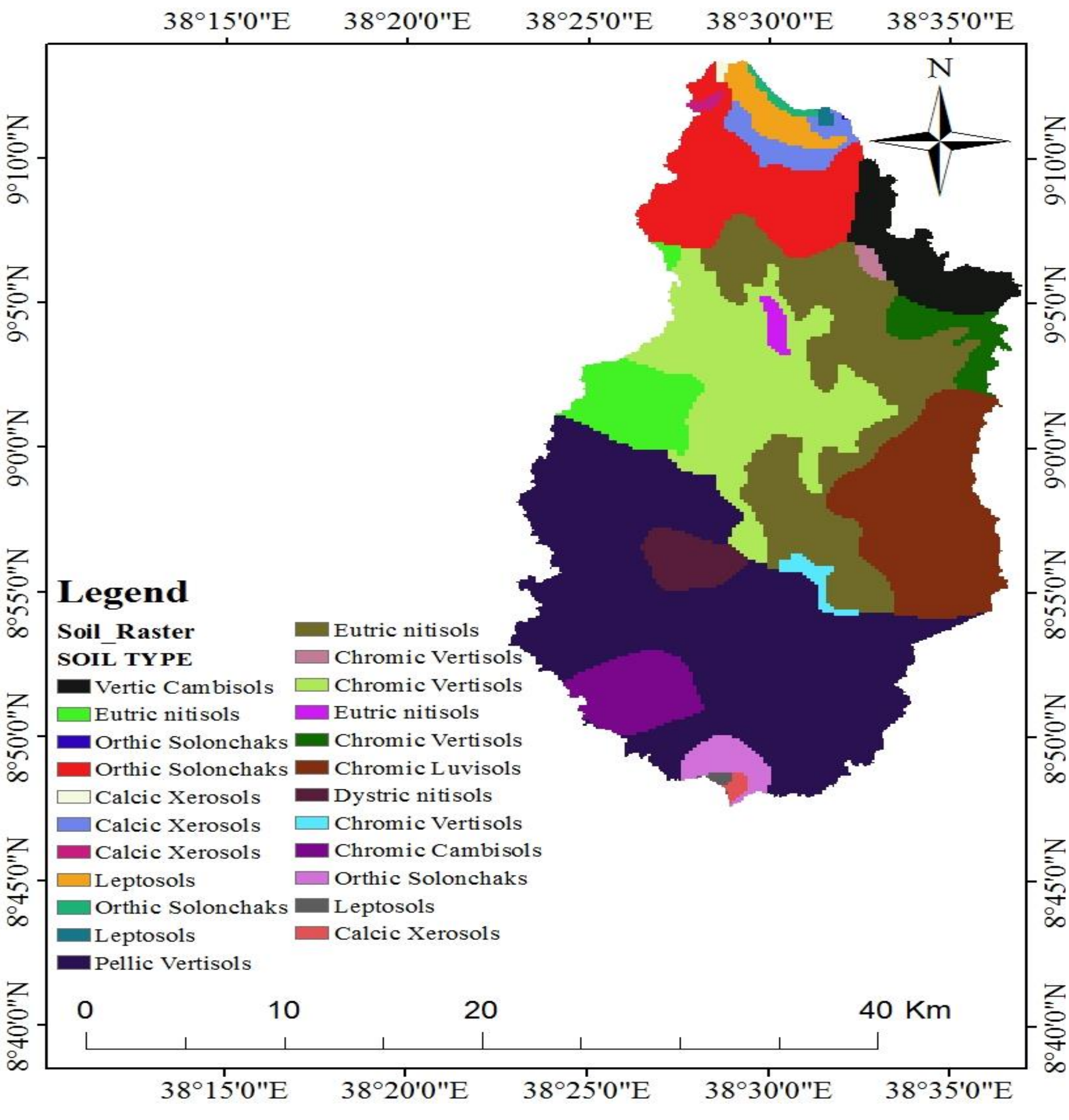


Figure 4-13 Types of soil found in the catchment

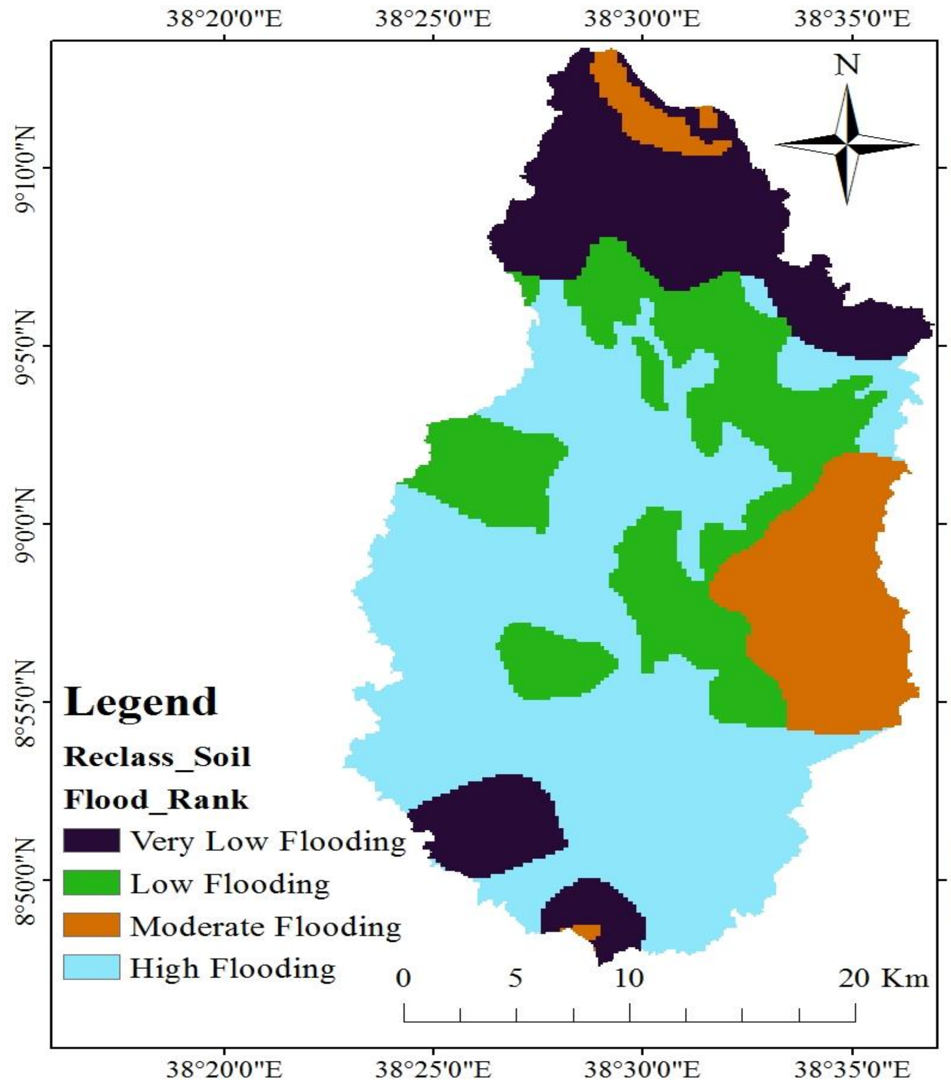


Figure 4-14 Re-classification of soil

4.3.4 Land use /cover (LULC)

The land use parameter is mainly related to the infiltration rate as a result of the existing correlation between the surface characteristics that affect (sub) surface runoff; groundwater infiltration and debris flow (Mati, 2006; Olga, 2017). The modification of natural land use land cover lead to changes rainfall – runoff characteristics of the river basin which consequently change the river flow regimes (Mati, 2006, Olga, 2017). Land use information was taken from Ethiopian Geo-Spatial Information Mapping Agency, showing that a large part of the studied area was covered by forests, Grass, shrub, bare land, wet land, water body and Crop. Based on susceptibility to flood, they were classified and ranked from very low to high flooding by using Spatial Analyst Tool

(SAT) with GIS. Forest generally favors infiltration, rating low flooding while agricultural areas allow more water to flow in the form of surface or subsurface runoff tends high flooding.

Table 4-3 LULC Degree to flooding

Class name	Degree to Flood Susceptibility
Sparse Forest, Dense forest	Very Low Flooding
Settlement, Perennial crop, Wood Land,	Low Flooding
Closed Grass, Closed Shrub, open Shrub	Moderate Flooding
Open grass, bare soil, wetland, lave field, water body, Annual crop	High Flooding

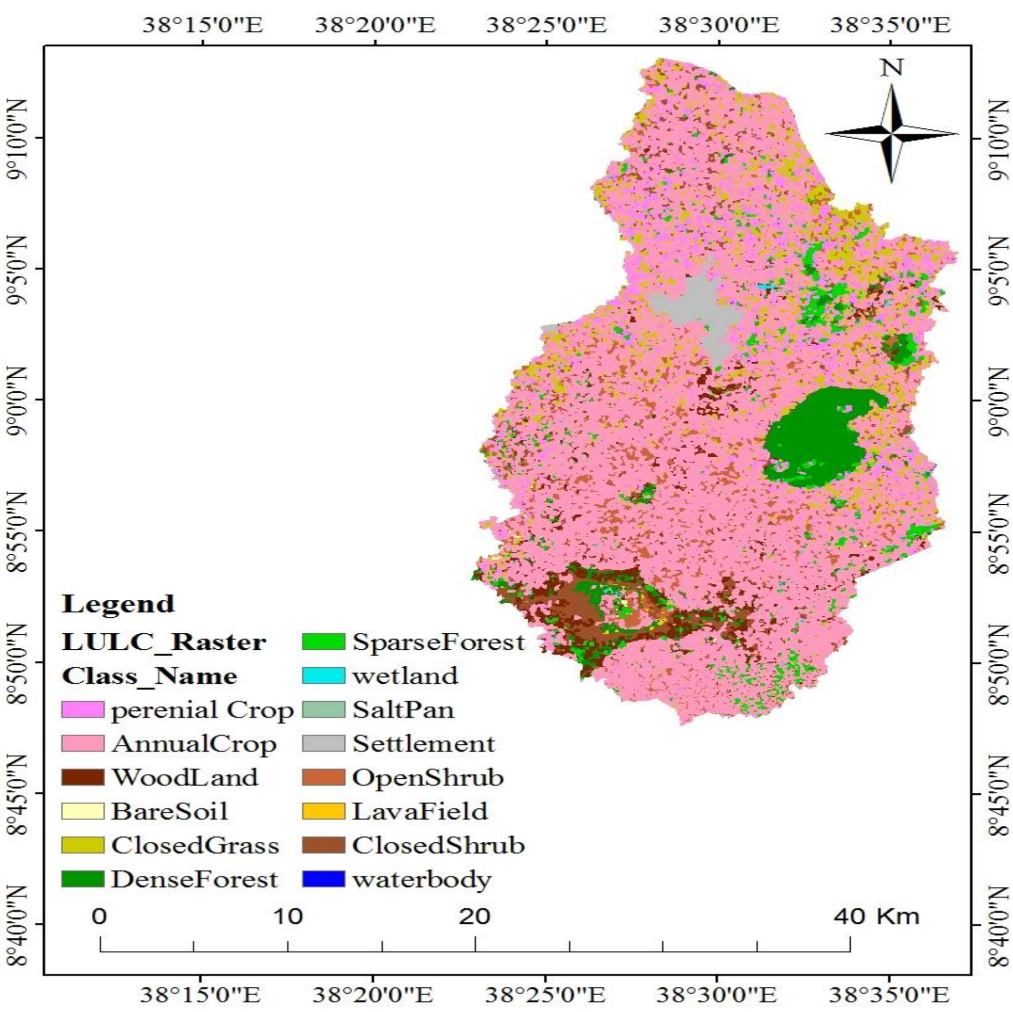


Figure 4-15 Types of LULC found in the catchment

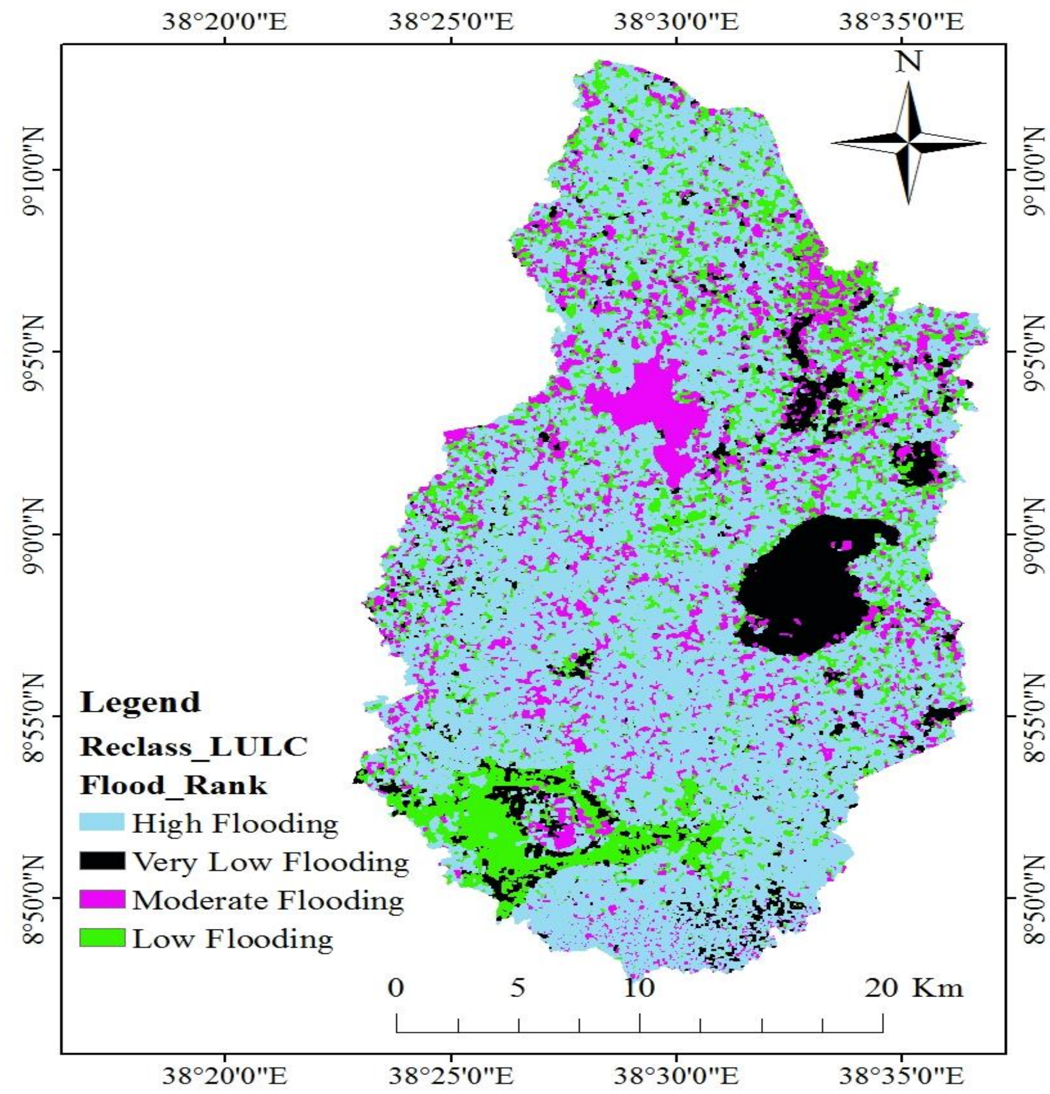


Figure 4-16 Re-classification of LULC

4.3.5 Rainfall

The parameter of rainfall intensity is expressed using the modified Fournier index (MFI), which is the sum of the average monthly rainfall intensity recorded by the rain-gauge stations (Olga, 2017). The spatial distribution of this criterion is found using the Inverse Distance Weighted (IDW) method. The spatial distribution of the values of rain intensity is illustrated in figure below. For this study, rainfall parameter is very important, because it cause overflow of river that cause flooding. Thus, high rainfall depth has degree to high flooding and low rainfall depth causes low flooding.

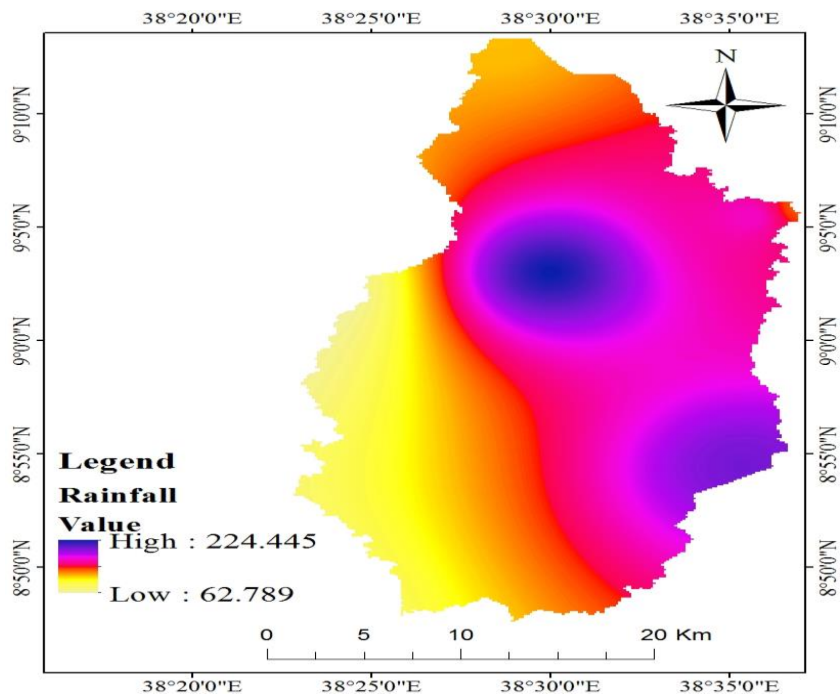


Figure 4-17 Rainfall

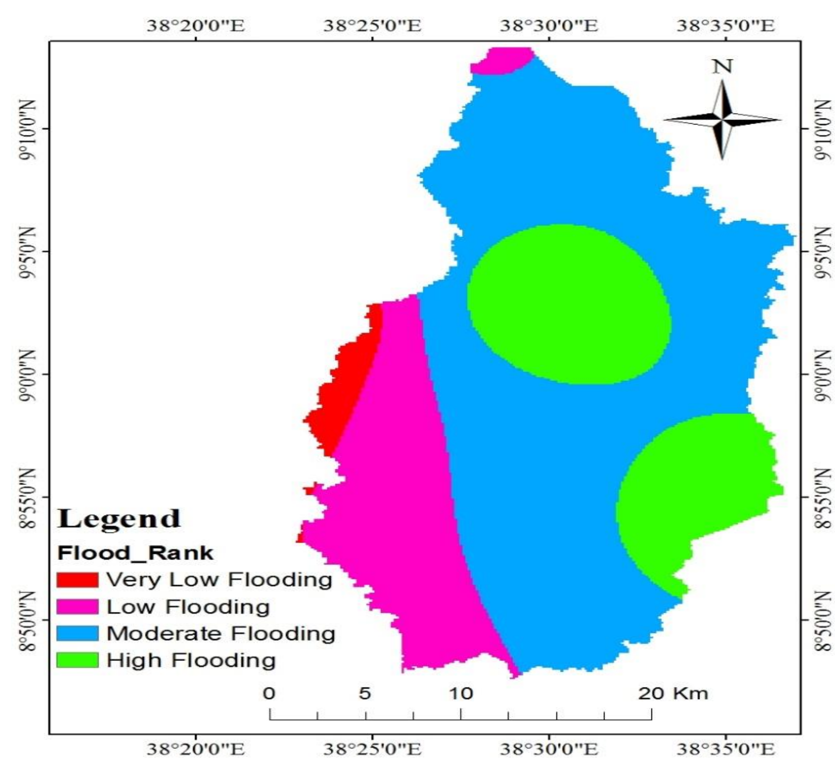


Figure 4-18 Re-classification of rainfall

4.3.6 Watershed delineation

A common task in hydrology is to delineate watershed from topographic map. The DEM store topographic data in the form of grid cells. Using DEM within geographic information system (GIS) the spatial information can be performed like slope, flow length, flow accumulation and stream network. At this stage the flow accumulation and the pour point (interested point or outlet) can perform to give the watershed and boundary. Care should be taken that the pour point lies in the line of flow accumulation. The size of watershed depends on the choosing of pour point along the drainage path (flow accumulation line). For this study, the pour point was selected at the outlet point of the river. The catchment area for upper-downstream Holeta River was estimated about 768.757km^2 using GIS.

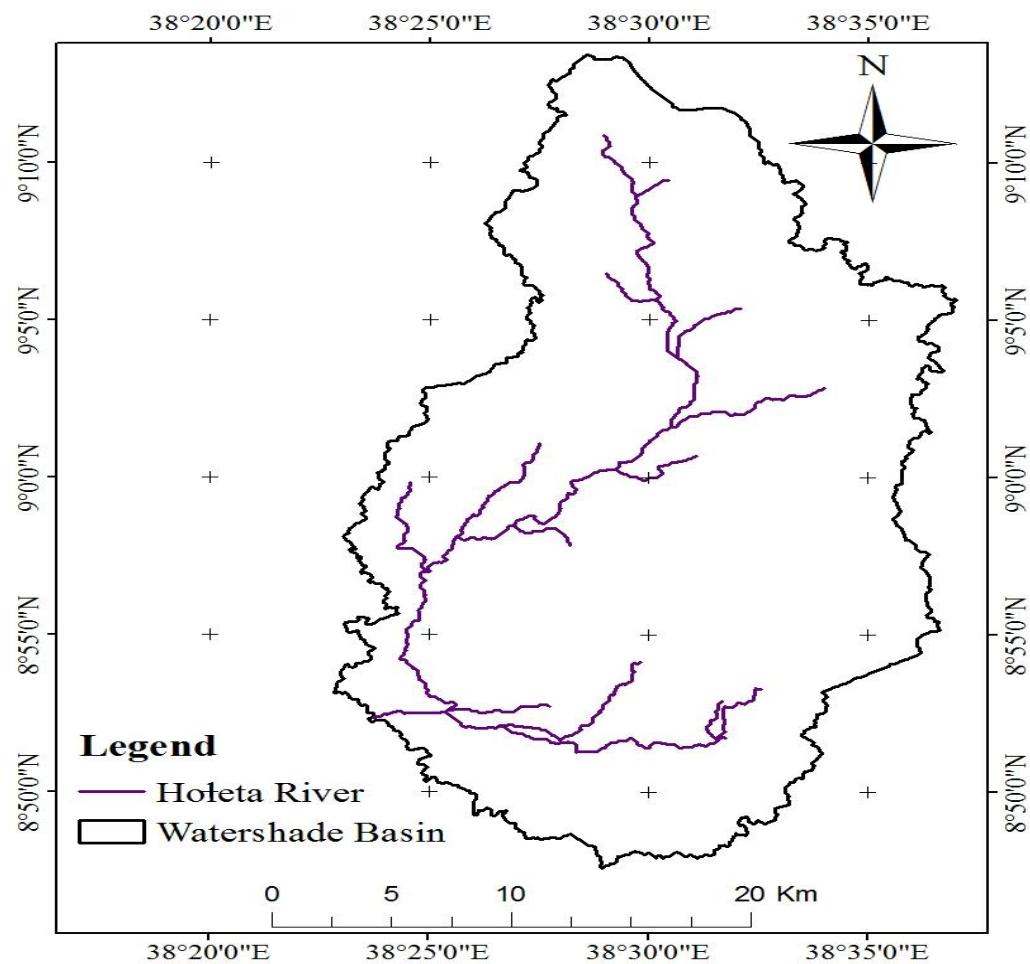


Figure 4-19 Catchment and stream line of Holeta river

4.3.6.1 Flow Direction

The downstream flow (flow direction) in each pixel of DEM depends on the elevation of this point relative to its neighbors (Kafira, 2012). The possible flow directions are eight, namely E, SE, S, SW, W, NW, N and NE (Flow direction calculates the direction of flow for a given matrix. The water that is stored in each cell will flow to the steepest neighboring cells following low altitude. The direction of flow must be known for each cell, because its direction of flow that determines the ultimate destination of water flowing across the surface (Kafira, 2012). The flow direction turned in to the raster below, with a legend of colors, each color corresponds to a number and each number indicates the flow direction between the gauging stations considered.

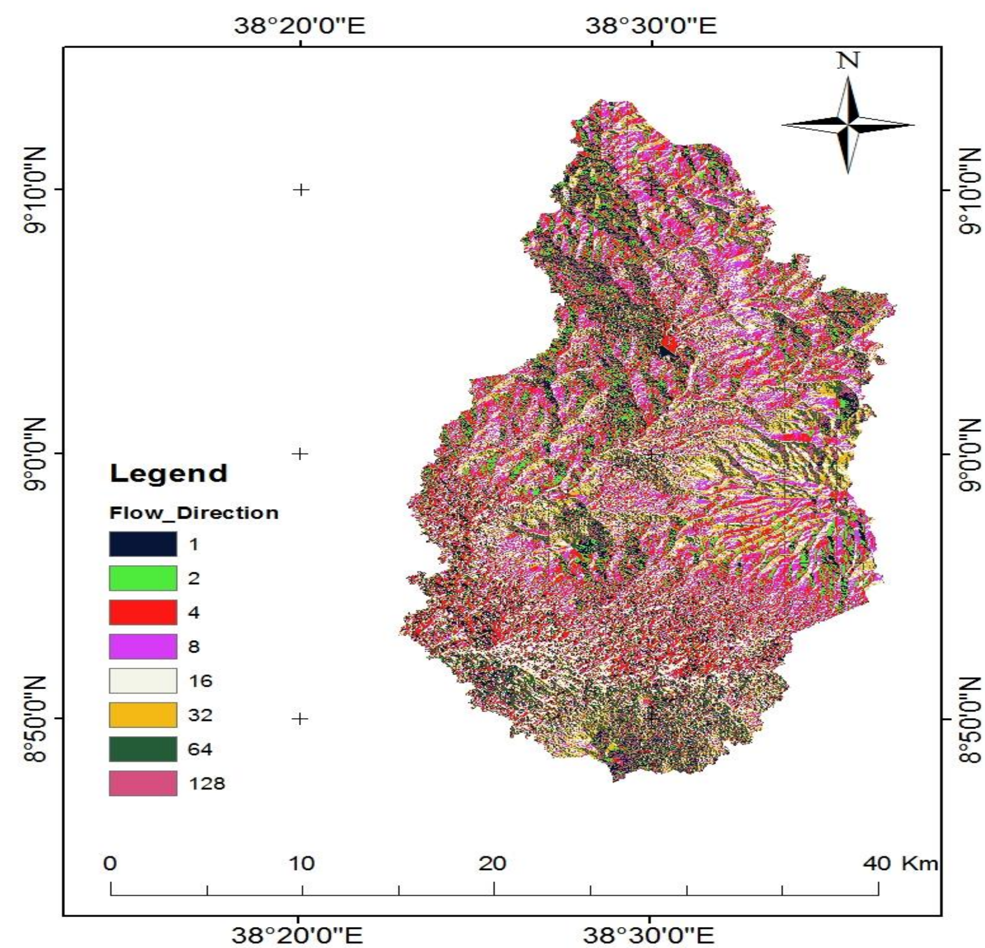


Figure 4-20 Flow direction

4.3.6.2 Flow Accumulation (F)

The accumulation of flow is the quantity of water, which is move to each pixel from its neighbors and eventually accumulated to it (Kafira, 2012). The calculation of total flow that is concentrated in each pixel is possible, based on the flow direction of the neighboring points (Kafira, 2012). The maximum accumulated path gives the drainage path. In this study, using hydrology modeling tools of Arc Map and the DEM of study area the flow direction was calculated for each pixel. The accumulated flow is an important criterion of flood occurrence. It does so by aggregating water flows from uphill to lower elevation at the output raster (Olga, 2017). High values of accumulated flow indicate cells in which the flowing water tends to concentrate (Olga, 2017). Such areas are more prone to the flood hazard. For this study, flow accumulation values are in the range 0–776559 computed by Spatial Analyst Tool (SAT). The figures below show the distribution of the flow in the study area, with the high values only occurring in the tributaries and their outflows.

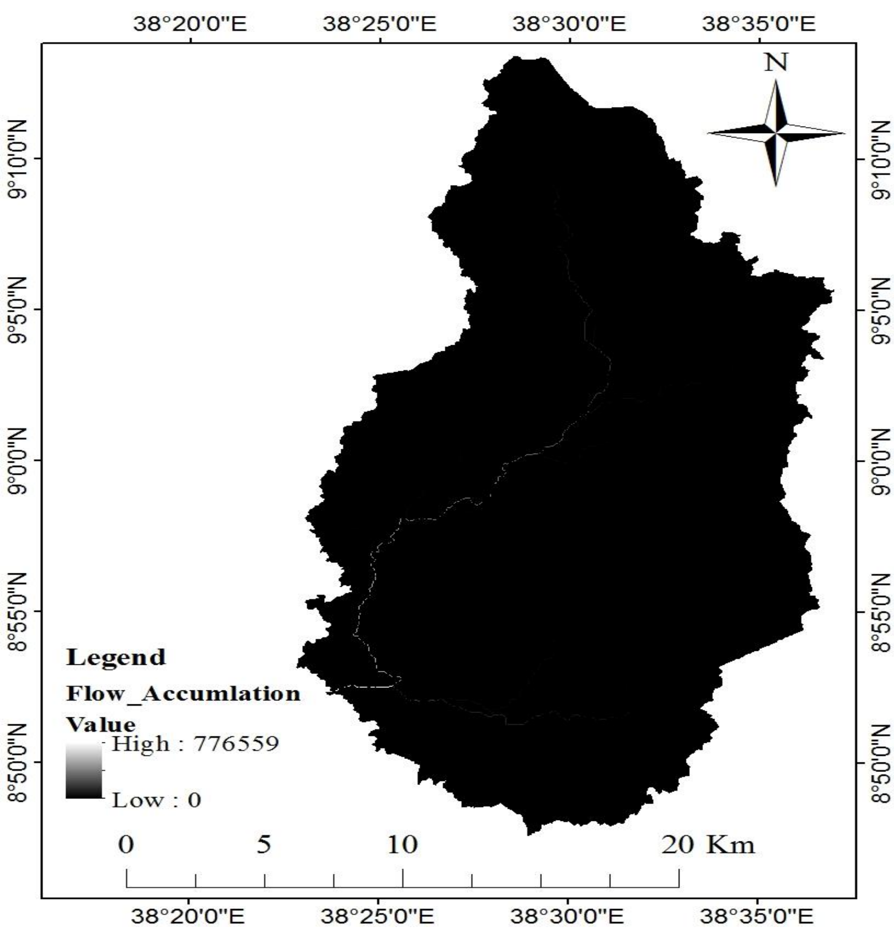


Figure 4-21 Flow accumulation

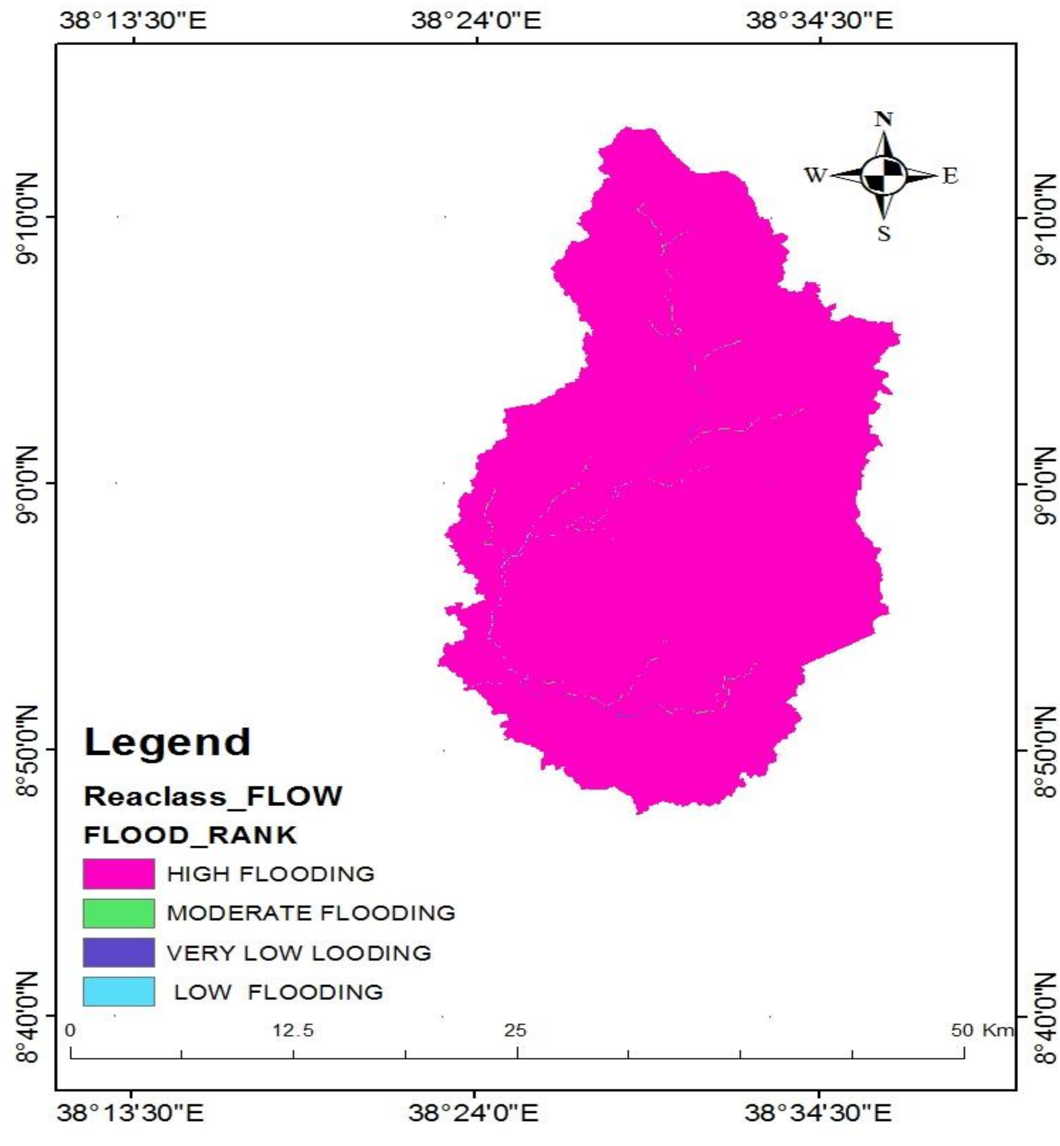


Figure 4-22 Re-classification of flow accumulation

4.3.6.3 Drainage Density (DD)

Drainage Density (DD) was defined by Horton (1945) as the ratio of the total length of streams in a watershed over its contributing area. Drainage Density is higher in arid areas with sparse vegetation cover and increases with increasing probability of heavy rainstorms (Niranjan, 2016). The drainage density also higher, highly branched basins with relatively rapid hydrologic response

(Niranjan, 2016). An increasing drainage density implies that floods peaks. Many methods have been used to find out the drainage density; uses of computer tool (GIS software) give much important. The drainage density for Holeta River sub-basin is estimated about 0.528403 km/sq.km, which indicates that the basin not very high and it tend to flooding.

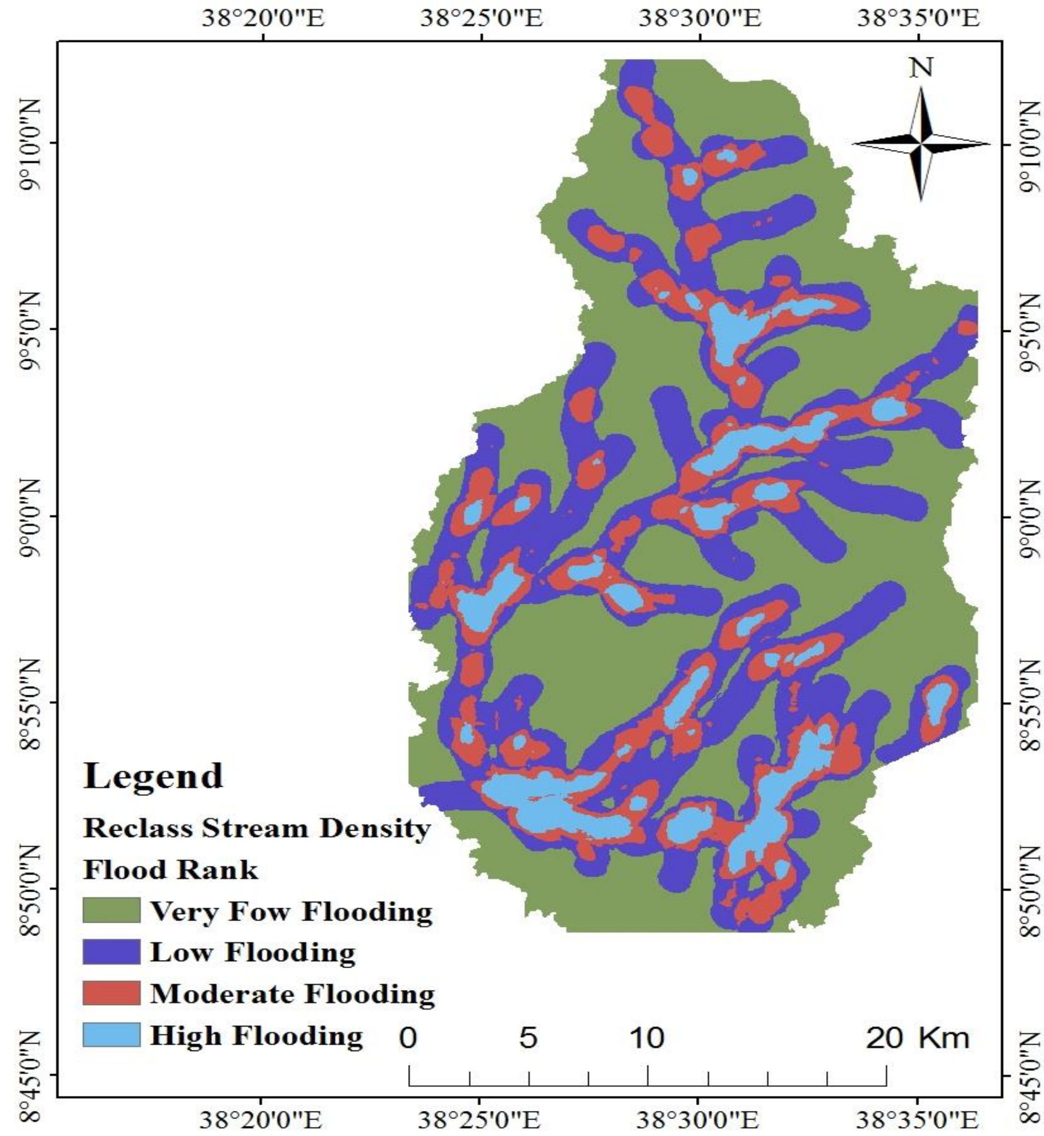


Figure 4-23 Re-class of stream density

4.3.7 Weighted coefficients

The flood generating factors used for this study, their pair wise comparison to calculate priorities to flood hazard and computed using the Analytical Hierarch process (AHP). The pair-wise comparison of one factor to other, following repetition iteration until acceptable consistency ratio becomes less than 10% or 0.1. For this study, the consistency ratio computed as 4.23% or 0.0423 which is less than 10% or 0.1, so that acceptable. The decision matrix gives the resulting weight based on the principal eigenvector.

$$CR=\frac{CI}{RI}\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{Eq4.1}$$

Where CR=Consistency Ratio

CI=Consistency Index

RI=Random Index

Table 4-4 Decision matrix in AHP

Category	Reclass 1	Reclass 2	Reclass 3	Reclass 4	Reclass 5	Reclass 6	Reclass 7
Reclass 1	1	7	3	5	9	2	3
Reclass 2	0.142857	1	0.33	2	3	0.5	0.33
Reclass 3	0.333333	3	1	3	5	1	0.5
Reclass 4	0.2	0.5	0.333	1	1	0.5	0.143
Reclass 5	0.111111	0.333	0.2	1	1	0.11	0.2
Reclass 6	0.5	2	1	2	9	1	0.5
Reclass 7	0.333333	3	2	7	5	2	1

Table 4-5 The resulting weight of priority

These are the resulting weights for the criteria based on my pair wise comparisons

Catagory	Priority	Rank
Re-class_Rainfall	35.71%	1
Re-class_Elevation	6.72%	5
Re-class_Slope	13.65%	4
Re-class_LULC	4.59%	6
Re-class_Soil	3.09%	7
Re-class_Flow Accumulation	14.76%	3
Re-class_ Drainage Density	21.46%	2

4.3.8 Weighted overlay

The weighting methods are used to prioritize the relative importance of each factor relative to another factor. The larger the weight, the more important factor in weighted overlay relative to the other factors. The final flood hazard map produced by overlapping the above seven floods generating with their respective coefficients for Upstream –Downstream Holeta River. Flood Hazard = 0.0672 * Elevation + 0.214 * River Density + 0.147 * Flow Accumulation + 0.137 * slope + 0.3571* Rainfall + 0.0459 * land Use + 0.031 * Soil.

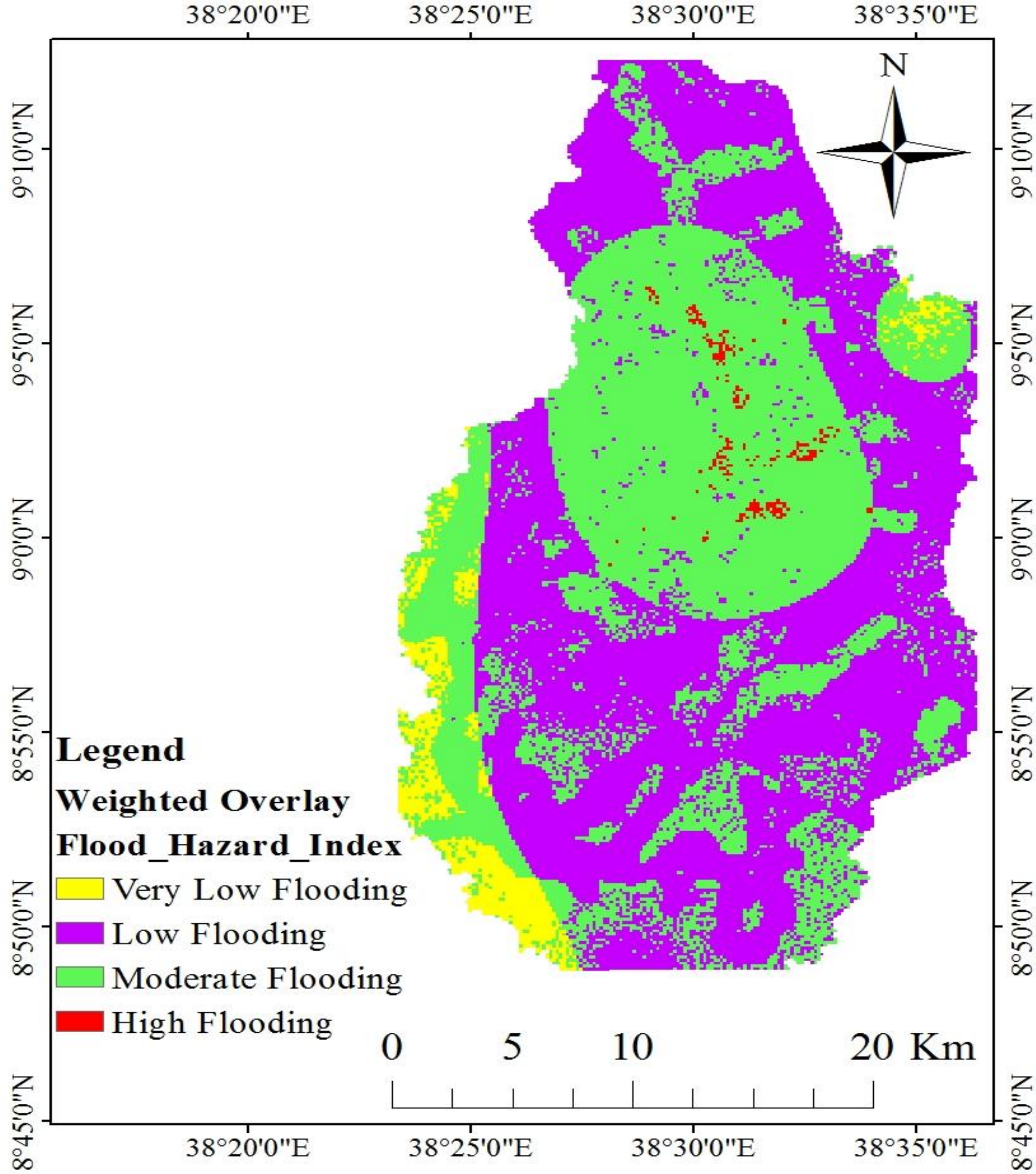


Figure 4-24 Flood Hazard Map of Holeta river catchment

Table 4-6 Areas of Flood for Holeta river catchment

Flood Hazard category	Area of flood prone (km^2)	Percentage (%) area of flood prone
Very low Flooding	77.07	5.84%
Low Flooding	627.01	47.57%
Moderate Flooding	567.05	43.01%
High Flooding	47.07	3.57%

4.4 Mitigation Measurement

Mitigating flood effects requires information on the flooding characteristics and how such characteristics propagate. Information about flood characteristic could be obtained through flood hazard assessment, forecasting, modeling and mapping. Flood inundation mapping are able to simulate flood extents, depths, levels, velocities and timing over distributed model and over the time dimension. Hereby, the flood hazard map developed for upper–Downstream Holeta River at catchment scale indicate the flood prone areas by categorizing in to different flood hazard level from Very low to high flooding. The map shows the middle Holeta River has high flooding rate and care should have necessary to prevent flooding up to possible. Also, information from flood inundation map shows the extent area of flooding from river course.

Traditional approach to floods was dominated by physical flood protection works such as levees and erosion protection consisting of stone rip rap. It is clear that traditional approach towards flood did no longer hold. This study illustrated that the most flood prone areas at a catchment and river scale, as result flood management strategy is very vital in flood protection mechanism. It is better to plan and manage flooding through three approach that, before flooding (preparedness, land use management, community awareness, flood free people's settlement), during flooding (emergency flood alert) and after flooding (training damaged river course, construct engineering structures on the river, resettlement). Information from flood hazard map gives the flood prone areas at catchment scale and inundation mapping gives flood extent areas along Holeta River, so public should have given awareness for community live in flooding zone. Also, weather forecasting Agency should have to provides information about climatology through the time.

As flooding is natural hazard and its frequency is a probability, the response during and after flooding is very essential. This can be improved by ensuring food security, health security, and economy security. Also, the recovery activity has to be done at flood damage areas through resettlement, recover damaged water course and others. Therefore, the research center and the government must be pay special attention and measurement on flood planning and emergency action plan to reduce probability of flood risk problem which causes reductions in agricultural production and economic disruption of the communities as well as the country.

5 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The main contribution of this study is flood inundation mapping and hazard assessment of upstream-Downstream Holeta River, Ethiopia. The overflow of the Holeta River cause series flood problem especially, during summer season. An intensive flood control and mitigation system is required for such flood problem.

By using GIS, HEC-Geo RAS and HEC-RAS flood inundation mapping and hazard assessment was developed. Using GIS and AHP, the selected flood generating factors like elevation, slope, rainfall, land use land cover, soil, drainage density and flow accumulation was classified in to four flood hazard categories based on degree to flooding. The four flood hazard categories are very low flooding, low flood, moderate flood and high flooding. The catchments flood generating parameters susceptibility to flooding the flood prone areas were identified for Holeta River, Ethiopia.

The selected flood generating factors were processed to delineate flood hazard zone using multi criteria evaluation techniques in a GIS environment. Using Spatial Analyst Tool (SAT) in GIS, the weighted methods overlay the ranked flood generating factors to prepare the final flood hazard map. The coefficients of weighted factors were determined by using multi criteria analysis methods done by Analytical Hierarch Process (AHP). The consistency ratio should be less than 10% for pair wise comparisons of criteria acceptable. For this study, the consistency ratio was 4.23% which was less than 10% made iteration terminate. Based on this study, the final flood hazard map gives most of the areas of Upstream-Downstream Holeta river show low and moderate flooding. Some part of the areas was very low flood hazard level and high flood rate very small.

Also, based on probabilistic modeling and hydraulic modeling the flood inundation map gives the extent areas of flood from river. Among the selected probability distribution model for flood frequency analysis, goodness fit test techniques were proceeding others by Easy Fit software. Based on this, for this study log-Pearson type III was used to compute the peak flow for different return period (10,25,50,100). However, there was a limitation of recorded data at downstream.

5.2 Recommendations

Flood hazard-based study is very important and critical, because as flood damage and its consequence is high. This study was deal with flood inundation mapping and hazard assessment for Upstream-Downstream Holeta River, Ethiopia. Ongoing study the following recommendations are made for further studies in the future.

The reliability of the result mainly depends on the input data. Therefore, Higher resolution DEM than 30m*30m resolution is suggested which gives better visualization and more rain gauge stations should be provided. So, the concerned body should pay great attention on the quality of data.

There is no recorded historical flood record information for this study. So, ground truth of flood event is very important like flood level or water surface elevation and existing historical flood map (either inundation or flood prone areas). This can be used for comparison for scenario simulation for flood water surface and prepared flood map. Therefore, historical existing flood events and map will be preferable for comparison prepared flood map from simulation

Development of flood protection structures should be carried out in the upstream and downstream part of the site to reduce the magnitude of flood. Therefore, the responsible bodies such as Holeta municipality office and Institute of Agricultural Research (IAR) should be pay attention to control the impact of the flood.

Finally, I would like to recommend Further studies are needed and require the cooperation of interdisciplinary experts and responsible authorities and decision makers.

References

Alam. (2017). Best-Fit Probability Distribution and return periods for maximum monthly Rainfall in babgladesh. Osaka city University, Japan.

Alemseged. (2013). Loss and damage from flooding in the gambella region, Ethiopia. International journal Global Warming, 5.

Athulya, P. S. and James, K.C. (2017). Best Fit Probability Distributions for Monthly Weather Data. International Journal of Advances in Management, Technology and Engineering Sciences (Vol. Vol.7 (12)).

B.Merz et al. (n.d.). Flood Risk Mapping at The Local Scale : concepts and challenges.

Bedassa. (2016). Evaluation of Extreme Flow Quantiles from Global Reanalysis runoff Data : A Case study of Blue Nile Basin. Hydraulic Engineering, Addis Abeba, Addis Abeba University, Ethiopia.

Bishaw. (2012). Application of GIS and Remote Sensing Techniques for Flood Hazard and Risk Assessment: The case of Dugeda Bora Woreda of Oromiya Regional state, Ethiopia. paper for the 2012 Berlin conference on the Human Dimensions of Global Environmental change.

BMT. (2017). Guide For Flood Studies and Mapping in Queensland.

Brhane. (2011). Hydraulic Modeling and Flood Mapping of Fogera Flood Plain : A Case Study OF Gumera River. Addis Abeba University, school of Graduate study, Civil Engineering Department.

Cowan's. (1956). Guide for Manning Roughness coifficeents for natural channels and flood plains.

Dai, X. (2016). Dam site selection using an integrated method of AHP and GIS for decision making support in Bortala, North west china. Department of physical Geography and Ecosystem Science, Lund University.

Dawit. (2015). Flood Risk Analysis in Illu Floodplain, Upper Awash River Basin, Ethiopia. Master Thesis , Addis Ababa University, Ethiopia.

Dewberry. (2011). Development of Advanced Hydrologic Prediction Service of Flood Inundation Mapping. NOAA partned Guidelines.

Ebrahim et al. (2017). Sustainability -Based Flood Hazard mapping of the Swannanoa River Watershed. Jornal of Sustainability.

Edna. (2007). Floodplain Inundation Simulation Using 2D hydrodynamic modeling Approach International Institute For Geo-Information Science and Earth Observation Enschede, the Netharlands. FAO, (1990, 2006) Guide lines for Soil Description.

FDPPA. (2006). Regional summary of Multi –Agency Flood Impact assessment of 2006. Addis Ababa, Ethiopia.

FEMA. (1997). Hydrologic Hazard. Multi Hazard Identification and Risk Assessment. IN SECURITY, H. (Ed.).

FEMA. (2007). Multi Hazard Identification and Risk management. Hydrologic Hazard.

Getahun and Gebre. (2015). Flood Hazard Assessment and Mapping of flood inundation area of the Awash River Basin in Ethiopia Using GIS and HEC-Geo RAS/ HEC-RAS. Journal of Civil and Environmental Engineering, Vol.5.

Ghosh et al. (2016). Determination of the Best Fit Probability Distribution for Monthly Rainfall Data in Bangladesh. American Journal of Mathematics and Statistics, Vol. 6(4), 170-174. DOI: 10.5923/j.ajms.20160604.05 .

Gilles. (2010). Reviewu of hydraulic Flood Modeling Software. International Perspective in water Resource Management: Hydrosience and Engineering.

Haan. (1977). "Guide-lines for Determining Flood Flow Frequancy, " Bulletin No.17B, Issue, revised 1983. USA: U.S Intreragency Advisory committee.

Harlan. (2002). Frequancy Analysis of Flood Data. Hydrology.

Joy and lu. (2009). GIS -based flood hazard mapping at different administrative scales in Ganget India. Department of Geography. National University of Singapore.

Kafira. (2012). Flood Susceptibility Assessment Using GIS. A case of Kassandara, peninsula, Halkidiki, Greece. Aristotle University of Thessaloniki(AUTH).

Kalkidan. (2015). Flood modeling and Frequancy Analysis in the case of kulifo watershed AbayaCHAMO bASIN. Hydraulic and Water Resource Engineering. Arba-minch University, Ethiopia.

Kamonchat, et all. (2017). Assessment of flood hazard areas using Analytical Hierarchy Process over the Lower Yom Basin, Sukhothai Province. 7th International Conference on Building Resilience; Using scientific knowledge to inform policy and practice in disaster risk reduction.

Karim. (2010). Flood hazard Assessment and Risk - based zoning of tropical flood plain: case study of the Yom River, Thailand. Hydrlogic Sciences Journal.

Kramer Kristian. (1999). Design of a Community Based DAM in Holeta, Ethiopia . Department of Civil Engineering , AAU, ETHIOPIA.

Mati. (2006). Evaluating land use change effects on river flow using USGS Geospatial stream flow model in mara river basin, keniya. Jomo Kenyatta university of Agriculture and Technology.

Maurer, E. (2015). Using HEC-RAS and HEC -GeoRAS for Flood Modeling.

Merwade and olivera, et all. (2008). Uncertainty in flood Inundation Mapping current issues and future Directions. Journal of Hydrologic Engineering, Vol.13 .

Mohammed. (2017). Flood Hazard Mapping of palembang city by using 2D model. Water Resurces Engineering Research Group. American Institute of phyisics.

Moore. (2010). Reviewu of hydraulic Flood Modeling Software International Perspective in water Resource Management: Hydrosience and Engineering.

NDRMC. (2017). Ethiopian Flooding update. The united nation office of coordination of Humanitarian Affirs.

Niranjan. (2016). Links Among Drainage Density, Frequancy And Flooding In Nanoi River Basin, Assam. International Journal Of Interdisciplary Research In Science And Culture(IJIRSSC), Vol.2.

Olga. (2017). Flood Hazard at River Basin Scale with an Index- Based Approach. The case of Mouriki, Greece. .

Raluca-Iustina . (2015). Flood plain Delineation For Calnau Rier Using HEC-RAS Software. Series E. land Reclamation, Earth Observation and Surveying, Environmental Engineering, IV.

Report, Ethiopian Flooding. (2014). Flood Alart.

Samiran. (2012). Guide lines for flood frequancy Estimation under climate change. Water Resource Research Report.

Samson. (2008). Floods and Health in Gambela region, Ethiopia: An Assessment of the strength and weakness of the coping mechanism. Lund University International Master Programme In Environmental studies and Sustainability Science.

Sean, k. A. (2011). Inundation mapping Employing Hydraulic Modeling and GIS. Case Study Tar River During Hurricane Floyd. North Carolina State University, Raleigh.

Senarathne. (2008). Learning to live with FLOODS Natural Hazards and Disasters. Department of Institutional Development National Institute of Education.

Sina. (2010). GIS-Based River Flood Hazard Mapping in urban Area(A case study in Kayu Ara River Basin Malaysia). Water Research Centre, University of South Australia.

Sinafikish. (2013). Causes and Consequences of Flooding in Dire Dawa City, Eastern Ethiopia .

Slobodan. (2009). Hydraulic Modeling and Flood plain Mapping. Water Resources Research Report.

Solomon. (2012). Flood Risk Mapping and Vulnerability Analysis of Megech River Using 2D hydrodynamic Flood Modeling.

Tate et al. (1999). Hydraulics and Floodplain Modeling-managing HEC-RAS cross Section.

Tefera. (2015). Flood mitigation alternatives for selected reachs of awash river from logiya to dubti.

Terakegne. (2014). Disaster Risk management in Ethiopia .

Tesfay. (2018). Flood Risk Assessment in Ethiopia. Journal of civil and Environmental.

Tibebe et al. (2013). Runoff estimation and water management for the Holetta river in Ethiopia. Ethiopian Institute of Water Resources, AAU, Ethiopia .

Ven Te chow. (2010). Applied Hydrology, New york: Mc Graw-Hill.

Vu thanh. (2009). Flood Hazard and Risk Assessment of Hoang Long River Basin, Vietnam. Thesis, Asian institute of technolgy, Thailand.

Wildschut. (2013). Knowledge in plan- making processes on flood hazard maps. Radbound University Nijmegen .

Woubet. (2007). Flood Hazard and Risk Assessment in Fogera Woreda using GIS & Remote Sensing. Department of Earth Sciences GIS and Remote Sensing Program . Addis Ababa University ,Ethiopia.

Zein. (2009). A Community- Based Approach To Flood Hazard And Vulnerability Assessment In Flood Prone Areas. GADJAH MADA UNIVERSITY.

Annex A. Frequency Factors K for Gamma and log-Pearson Type III Distributions (Haan, 1977, Table 7.7) Recurrence Interval In Years

Weighted	1.0101	2	5	10	25	50	100	200
Skew coefficient		Percent Chance (>=) = 1-F						
	99	50	20	10	4	2	1	0.5
3	-0.667	-0.396	0.42	1.18	2.278	3.152	4.051	4.97
2.9	-0.69	-0.39	0.44	1.195	2.277	3.134	4.013	4.904
2.8	-0.714	-0.384	0.46	1.21	2.275	3.114	3.973	4.847
2.7	-0.74	-0.376	0.479	1.224	2.272	3.093	3.932	4.783
2.6	-0.769	-0.368	0.499	1.238	2.267	3.071	3.889	4.718
2.5	-0.799	-0.36	0.518	1.25	2.262	3.048	3.845	4.652
2.4	-0.832	-0.351	0.537	1.262	2.256	3.023	3.8	4.584
2.3	-0.867	-0.341	0.555	1.274	2.248	2.997	3.753	4.515
2.2	-0.905	-0.33	0.574	1.284	2.24	2.97	3.705	4.444
2.1	-0.946	-0.319	0.592	1.294	2.23	2.942	3.656	4.372
2.00	-0.99	-0.307	0.609	1.302	2.219	2.912	3.605	4.298
1.9	-1.037	-0.294	0.627	1.31	2.207	2.881	3.553	4.223
1.8	-1.087	-0.282	0.643	1.318	2.193	2.848	3.499	4.147
1.7	-1.14	-0.268	0.66	1.324	2.179	2.815	3.444	4.069
1.6	-1.197	-0.254	0.675	1.329	2.163	2.78	3.388	3.99
1.5	-1.256	-0.24	0.69	1.333	2.146	2.743	3.33	3.91
1.4	-1.318	-0.225	0.705	1.337	2.128	2.706	3.271	3.828
1.3	-1.383	-0.21	0.719	1.339	2.108	2.666	3.211	3.745
1.2	-1.449	-0.195	0.732	1.34	2.087	2.626	3.149	3.661
1.1	-1.518	-0.18	0.745	1.341	2.066	2.585	3.087	3.575
1.00	-1.588	-0.164	0.758	1.34	2.043	2.542	3.022	3.489
0.9	-1.66	-0.148	0.769	1.339	2.018	2.498	2.957	3.401
0.8	-1.733	-0.132	0.78	1.336	1.993	2.453	2.891	3.312
0.7	-1.806	-0.116	0.79	1.333	1.967	2.407	2.824	3.223
0.6	-1.88	-0.099	0.8	1.328	1.939	2.359	2.755	3.132
0.5	-1.955	-0.083	0.808	1.323	1.91	2.311	2.686	3.041
0.4	-2.029	-0.066	0.816	1.317	1.88	2.261	2.615	2.949
0.3	-2.104	-0.05	0.824	1.309	1.849	2.211	2.544	2.856
0.2	-2.178	-0.033	0.83	1.301	1.818	2.159	2.472	2.763
0.1	-2.252	-0.017	0.836	1.292	1.785	2.107	2.4	2.67
0	-2.326	0	0.842	1.282	1.751	2.054	2.326	2.576
-0.1	-2.4	0.017	0.846	1.27	1.716	2	2.252	2.482
-0.2	-2.472	0.033	0.85	1.258	1.68	1.945	2.178	2.388
-0.3	-2.544	0.05	0.853	1.245	1.643	1.89	2.104	2.294
-0.4	-2.615	0.066	0.855	1.231	1.606	1.834	2.029	2.201
-0.5	-2.686	0.083	0.856	1.216	1.567	1.777	1.955	2.108
-0.6	-2.755	0.099	0.857	1.2	1.528	1.72	1.88	2.016

-0.7	-2.824	0.116	0.857	1.183	1.488	1.663	1.806	1.926
-0.8	-2.891	0.132	0.856	1.166	1.448	1.606	1.733	1.837
-0.9	-2.957	0.148	0.854	1.147	1.407	1.549	1.66	1.749
-1	-3.022	0.164	0.852	1.128	1.366	1.492	1.588	1.664
-1.1	-3.087	0.18	0.848	1.107	1.324	1.435	1.518	1.581
-1.2	-3.149	0.195	0.844	1.086	1.282	1.379	1.449	1.501
-1.3	-3.211	0.21	0.838	1.064	1.24	1.324	1.383	1.424
-1.4	-3.271	0.225	0.832	1.041	1.198	1.27	1.318	1.351
-1.5	-3.33	0.24	0.825	1.018	1.157	1.217	1.256	1.282
-1.6	-3.88	0.254	0.817	0.994	1.116	1.166	1.197	1.216
-1.7	-3.444	0.268	0.808	0.97	1.075	1.116	1.14	1.155
-1.8	-3.499	0.282	0.799	0.945	1.035	1.069	1.087	1.097
-1.9	-3.553	0.294	0.788	0.92	0.996	1.023	1.037	1.044
-2	-3.605	0.307	0.777	0.895	0.959	0.98	0.99	0.995
-2.1	-3.656	0.319	0.765	0.869	0.923	0.939	0.946	0.949
-2.2	-3.705	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	-3.753	0.341	0.739	0.819	0.855	0.864	0.867	0.869
-2.4	-3.8	0.351	0.725	0.795	0.823	0.83	0.832	0.833
-2.5	-3.845	0.36	0.711	0.711	0.793	0.798	0.799	0.8
-2.6	-3.899	0.368	0.696	0.747	0.764	0.768	0.769	0.769
-2.7	-3.932	0.376	0.681	0.724	0.738	0.74	0.74	0.741
-2.8	-3.973	0.384	0.666	0.702	0.712	0.714	0.714	0.714
-2.9	-4.013	0.39	0.651	0.681	0.683	0.689	0.69	0.69
-3	-4.051	0.396	0.636	0.66	0.666	0.666	0.667	0.667

Annex B. Values of Roughness Coefficient (Source: ERA drainage manual)

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

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

Appendix C. Transposing of peak discharge using DAW

year	Q_g	$\frac{Au}{Ag} = \frac{524.75}{244.005}$	$Q_u = Q_{peak} (2.1506)^{0.7}$
1979	43.2012873	2.1506	73.831
1980	56.36805149	2.1506	96.333
1981	77.50029257	2.1506	132.448
1982	71.7331773	2.1506	122.592
1983	68.26155647	2.1506	116.659
1984	76.63779988	2.1506	130.974
1985	67.97132826	2.1506	116.163
1986	79.80046811	2.1506	136.379
1987	96.33469865	2.1506	164.636
1988	114.9801053	2.1506	196.501
1989	123.7571679	2.1506	211.501
1990	116.4534816	2.1506	199.019
1991	129.1082504	2.1506	220.646
1992	136.8952604	2.1506	233.954
1993	140.2176712	2.1506	239.632
1994	146.8367466	2.1506	250.944
1995	131.4452896	2.1506	224.640
1996	163.8583967	2.1506	280.034
1997	154.6717379	2.1506	264.334
1998	157.8320655	2.1506	269.735
1999	150.53189	2.1506	257.259
2000	126.9853716	2.1506	217.018
2001	140.3803394	2.1506	239.910
2002	180.4060854	2.1506	308.314
2003	165.8197776	2.1506	283.386
2004	173.9397308	2.1506	297.263

2005	179.0994734	2.1506	306.081
2006	195.9227618	2.1506	334.832
2007	200.93622	2.1506	343.400
2008	197.9350497	2.1506	338.271
2009	205.5933294	2.1506	351.359

Where Q_g=gauged peak discharge Q_u=ungauged discharge

A_u=ungauged Area=524.75km^2

A_g=gauged Area=244.005km^2

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Appendix D. Peak Discharge computations using Log-Pearson Type-III

Year	Qpeak	Year of Qmax	Qmax (m3/s)	Rank	LogQ	(logQ-avrglogQ)^2	(logQ-avrglogQ)^3	Return Period $T_r=\frac{n+1}{m}$	Excedence Pro=$\frac{1}{Tr}$
1979	73.831	2009	351.359	1	2.545751	0.051443	0.011668	32	0.03125
1980	96.333	2007	343.4	2	2.5358	0.047028	0.010198	16	0.0625
1981	132.448	2008	338.271	3	2.529265	0.044236	0.009304	10.66667	0.09375
1982	122.592	2006	334.832	4	2.524827	0.042389	0.008727	8	0.125
1983	116.659	2002	308.314	5	2.488993	0.028918	0.004918	6.4	0.15625
1984	130.974	2005	306.081	6	2.485836	0.027854	0.004649	5.333333	0.1875
1985	116.163	2004	297.263	7	2.473141	0.023778	0.003667	4.571429	0.21875
1986	136.379	2003	283.386	8	2.452378	0.017805	0.002376	4	0.25
1987	164.636	1996	280.034	9	2.447211	0.016453	0.00211	3.555556	0.28125
1988	196.501	1998	269.735	10	2.430937	0.012543	0.001405	3.2	0.3125
1989	211.501	1997	264.334	11	2.422153	0.010653	0.001099	2.909091	0.34375
1990	199.019	1999	257.259	12	2.410371	0.008359	0.000764	2.666667	0.375
1991	220.646	1994	250.944	13	2.399577	0.006502	0.000524	2.461538	0.40625

1992	233.954	2001	239.91	14	2.380048	0.003734	0.000228	2.285714	0.4375
1993	239.63	1993	239.632	15	2.379545	0.003673	0.000223	2.133333	0.46875
1994	250.944	1992	233.954	16	2.36913	0.002519	0.000126	2	0.5
1995	224.640	1995	224.64	17	2.351487	0.001059	3.45E-05	1.882353	0.53125
1996	280.034	1991	220.646	18	2.343696	0.000613	1.52E-05	1.777778	0.5625
1997	264.334	2000	217.018	19	2.336496	0.000308	5.41E-06	1.684211	0.59375
1998	269.735	1989	211.501	20	2.325312	4.06E-05	2.59E-07	1.6	0.625
1999	257.259	1990	199.019	21	2.298895	0.000402	-8.1E-06	1.52381	0.65625
2000	217.01	1988	196.51	22	2.293365	0.000654	-1.7E-05	1.4545	0.6875
2001	239.910	1987	164.636	23	2.216525	0.010489	-0.00107	1.391304	0.71875
2002	308.314	1986	136.379	24	2.134748	0.033927	-0.00625	1.333333	0.75
2003	283.386	1981	132.448	25	2.122045	0.038768	-0.00763	1.28	0.78125
2004	297.263	1984	130.974	26	2.117185	0.040705	-0.00821	1.230769	0.8125
2005	306.081	1982	122.592	27	2.088462	0.053121	-0.01224	1.185185	0.84375
2006	334.832	1983	116.659	28	2.066918	0.063516	-0.01601	1.142857	0.875

2007	343.400	1985	116.163	29	2.065068	0.064452	-0.01636	1.103448	0.90625
2008	338.271	1980	96.333	30	1.983775	0.112336	-0.03765	1.066667	0.9375
2009	351.359	1979	73.831	31	1.868239	0.203132	-0.09155	1.032258	0.96875
Average			224.453		2.318941	Sum= 0.97142	Sum= -0.13496		

Where N=number of sample data=31 σ=standard deviation
Cs= skweness Y=LogQ avrgY=Average of LogQ

N-1=31-1=30

$\sigma \sqrt{sum(}$=Z-avrgZ)² /(N-1)

$$Cs=\frac{N(Y-avrgY)^3}{(N-1)(N-2)(\sigma)^3}$$

$\sigma=\sqrt{(0.97142)/30}=0.179945$

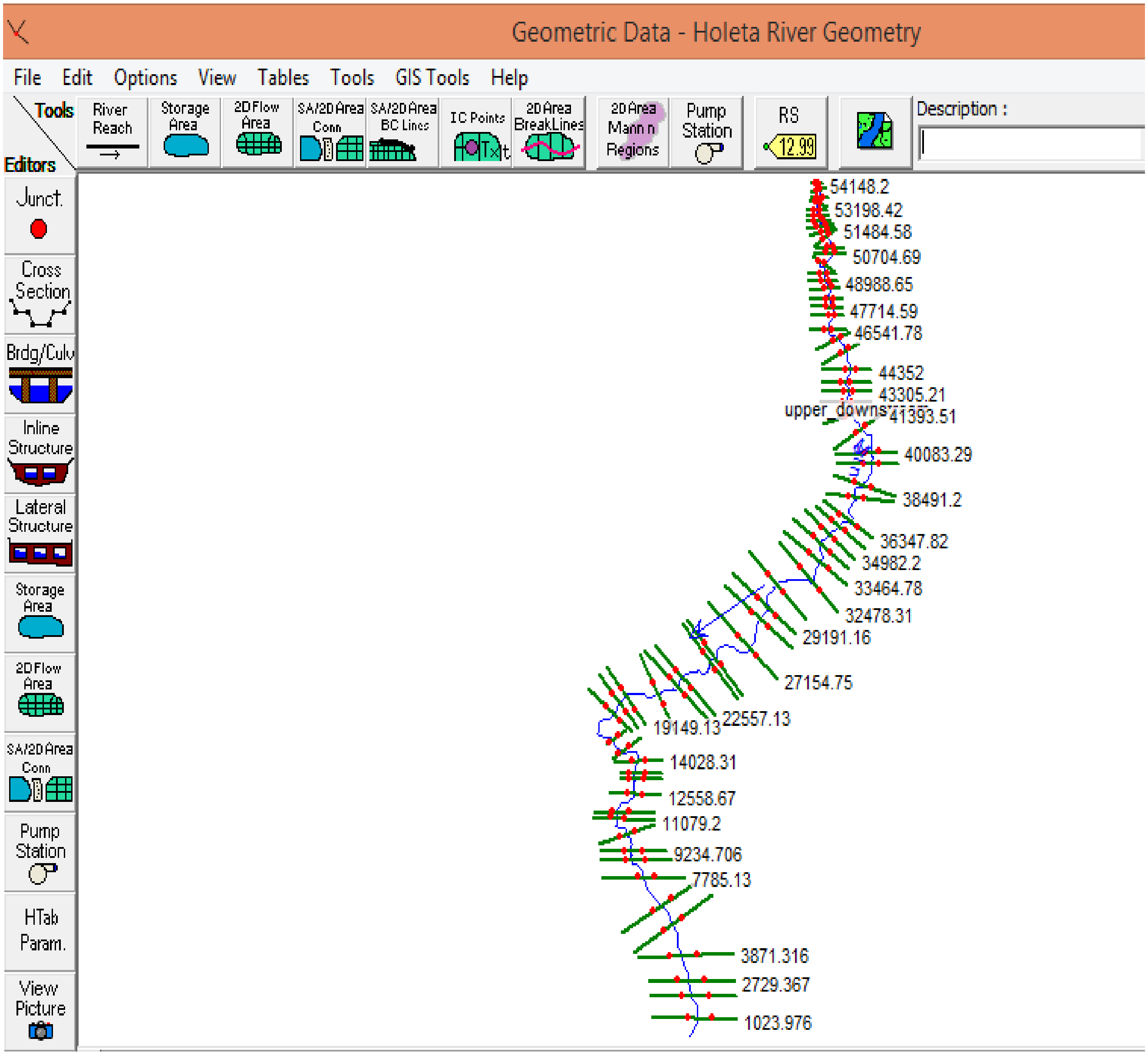
Cs= -0.210259013

Tr (year)	Kt	Avrg (Y)	σ	Z=C3+C2(C4)	$X=10^z(m^3/s)$
C1	C2	C3	C4	C5	C6
10	1.257	2.318941	0.179945	2.545	350.75
25	1.676	2.318941	0.179945	2..621	417.445
50	1.939	2.318941	0.179945	2.668	465.551
100	2.171	2.318941	0.179945	2.709	511.68

Where Tr=Return period X=Peak Discharge
Kt=Factor coefficient
σ =Standard deviation

Appendix E. Summary of HEC-GeoRAS and HEC-RAS output

A. Import RAS Geometry



B. Steady output table profile

HEC-RAS Plan: plan1 River: Main Reach: upper_downstream													
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	54148.2	25years	417.44	2481.77	2481.74	2480.95	2482.02	0.015657		176.50	94.64	0.00
upper_downstream	54148.2	50years	465.55	2481.77	2481.88	2481.08	2482.18	0.015764	0.22	189.74	98.05	0.31
upper_downstream	54148.2	100years	511.68	2481.77	2482.00	2481.19	2482.33	0.015835	0.37	201.98	101.11	0.35
upper_downstream	53831.16	10years	350.75	2469.80	2472.52	2472.52	2473.23	0.056739	3.73	94.01	66.80	1.00
upper_downstream	53831.16	25years	417.44	2469.80	2472.73	2472.73	2473.49	0.055384	3.87	107.93	71.36	1.00
upper_downstream	53831.16	50years	465.55	2469.80	2472.86	2472.86	2473.66	0.054559	3.96	117.70	74.38	1.00
upper_downstream	53831.16	100years	511.68	2469.80	2472.98	2472.98	2473.81	0.053848	4.03	126.87	77.12	1.00
upper_downstream	53475.62	10years	350.75	2459.84	2462.65	2461.78	2462.80	0.010372	1.75	200.22	123.88	0.44
upper_downstream	53475.62	25years	417.44	2459.84	2462.83	2461.94	2463.01	0.010644	1.87	223.66	130.16	0.45
upper_downstream	53475.62	50years	465.55	2459.84	2462.95	2462.03	2463.14	0.010816	1.95	239.00	134.11	0.46
upper_downstream	53475.62	100years	511.68	2459.84	2463.05	2462.14	2463.26	0.010957	2.03	253.44	137.72	0.47
upper_downstream	53198.42	10years	350.75	2458.85	2459.47		2459.57	0.010415	0.59	240.64	200.72	0.34
upper_downstream	53198.42	25years	417.44	2458.85	2459.63		2459.75	0.010327	0.69	274.82	214.21	0.35
upper_downstream	53198.42	50years	465.55	2458.85	2459.74		2459.87	0.010255	0.75	298.91	223.23	0.35
upper_downstream	53198.42	100years	511.68	2458.85	2459.84		2459.97	0.010211	0.80	321.30	231.31	0.36
upper_downstream	52839.74	10years	350.75	2454.30	2456.86		2456.98	0.010427	1.65	231.04	178.79	0.43
upper_downstream	52839.74	25years	417.44	2454.30	2457.03		2457.16	0.010461	1.72	262.83	190.49	0.44
upper_downstream	52839.74	50years	465.55	2454.30	2457.15		2457.28	0.010491	1.77	284.87	198.20	0.44
upper_downstream	52839.74	100years	511.68	2454.30	2457.25		2457.39	0.010513	1.81	305.49	205.15	0.45
upper_downstream	52636.14	10years	350.75	2452.14	2454.59		2454.75	0.011450	1.92	211.57	170.86	0.47
upper_downstream	52636.14	25years	417.44	2452.14	2454.76		2454.94	0.011371	2.01	242.29	182.66	0.47
upper_downstream	52636.14	50years	465.55	2452.14	2454.88		2455.06	0.011323	2.06	263.78	190.47	0.47
upper_downstream	52636.14	100years	511.68	2452.14	2454.98		2455.17	0.011276	2.11	284.00	197.54	0.48
upper_downstream	52421.59	10years	350.75	2449.85	2452.57		2452.66	0.007716	1.36	258.53	188.11	0.37
upper_downstream	52421.59	25years	417.44	2449.85	2452.76		2452.86	0.007608	1.41	296.04	201.16	0.37
upper_downstream	52421.59	50years	465.55	2449.85	2452.89		2453.00	0.007536	1.44	322.38	209.83	0.37
upper_downstream	52421.59	100years	511.68	2449.85	2453.01		2453.12	0.007467	1.47	347.19	217.69	0.37

HEC-RAS Plan: plan1 River: Main Reach: upper_downstream

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	52010.08	10years	350.75	2447.06	2450.00	2448.90	2450.07	0.005327	1.22	294.21	197.94	0.31
upper_downstream	52010.08	25years	417.44	2447.06	2450.19	2449.04	2450.27	0.005382	1.27	334.00	210.80	0.32
upper_downstream	52010.08	50years	465.55	2447.06	2450.32	2449.13	2450.40	0.005438	1.31	361.06	219.12	0.32
upper_downstream	52010.08	100years	511.68	2447.06	2450.43	2449.21	2450.52	0.005501	1.35	385.93	226.50	0.33
upper_downstream	51802.64	10years	350.75	2448.12	2446.03	2446.03	2446.50	0.064355		115.94	124.33	0.00
upper_downstream	51802.64	25years	417.44	2448.12	2446.16	2446.16	2446.66	0.064120		132.23	132.67	0.00
upper_downstream	51802.64	50years	465.55	2448.12	2446.24	2446.24	2446.78	0.063138		144.30	138.52	0.00
upper_downstream	51802.64	100years	511.68	2448.12	2446.33	2446.33	2446.88	0.061660		156.24	144.08	0.00
upper_downstream	51484.58	10years	350.75	2447.94	2442.16	2440.33	2442.19	0.001627		448.51	230.74	0.00
upper_downstream	51484.58	25years	417.44	2447.94	2442.38	2440.47	2442.42	0.001694		502.04	242.58	0.00
upper_downstream	51484.58	50years	465.55	2447.94	2442.53	2440.56	2442.57	0.001740		538.43	250.30	0.00
upper_downstream	51484.58	100years	511.68	2447.94	2442.66	2440.63	2442.70	0.001780		572.31	257.29	0.00
upper_downstream	50980.73	10years	350.75	2448.41	2440.78		2441.00	0.020967		169.41	135.95	0.00
upper_downstream	50980.73	25years	417.44	2448.41	2440.98		2441.21	0.019938		196.71	146.50	0.00
upper_downstream	50980.73	50years	465.55	2448.41	2441.10		2441.34	0.019357		215.86	153.47	0.00
upper_downstream	50980.73	100years	511.68	2448.41	2441.22		2441.46	0.018877		233.90	159.75	0.00
upper_downstream	50704.69	10years	350.75	2446.52	2438.98		2439.06	0.005265		287.23	180.65	0.00
upper_downstream	50704.69	25years	417.44	2446.52	2439.18		2439.27	0.005376		324.73	192.08	0.00
upper_downstream	50704.69	50years	465.55	2446.52	2439.32		2439.41	0.005440		350.85	199.65	0.00
upper_downstream	50704.69	100years	511.68	2446.52	2439.43		2439.53	0.005504		374.96	206.40	0.00
upper_downstream	49975.4	10years	350.75	2437.49	2436.42		2436.50	0.007114		291.49	238.95	0.00
upper_downstream	49975.4	25years	417.44	2437.49	2436.58		2436.66	0.007183		330.94	254.60	0.00
upper_downstream	49975.4	50years	465.55	2437.49	2436.68		2436.77	0.007275		357.44	264.59	0.00
upper_downstream	49975.4	100years	511.68	2437.49	2436.78		2436.87	0.007353		382.15	273.58	0.00
upper_downstream	49314.2	10years	350.75	2429.63	2429.82		2429.91	0.009252	0.25	267.37	243.96	0.26
upper_downstream	49314.2	25years	417.44	2429.63	2429.96		2430.06	0.009210	0.36	302.51	259.50	0.28
upper_downstream	49314.2	50years	465.55	2429.63	2430.06		2430.16	0.009092	0.43	328.46	270.41	0.29
upper_downstream	49314.2	100years	511.68	2429.63	2430.15		2430.26	0.008993	0.48	352.96	280.32	0.30

HEC-RAS Plan: plan1 River: Main Reach: upper_downstream												
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	48988.65	10years	350.75	2425.48	2427.99		2428.04	0.004161	1.02	357.24	284.55	0.27
upper_downstream	48988.65	25years	417.44	2425.48	2428.18		2428.24	0.004022	1.06	412.87	305.92	0.27
upper_downstream	48988.65	50years	465.55	2425.48	2428.30		2428.36	0.003970	1.09	450.71	319.65	0.27
upper_downstream	48988.65	100years	511.68	2425.48	2428.41		2428.47	0.003946	1.11	485.37	331.71	0.27
upper_downstream	48651.51	10years	350.75	2423.50	2425.64		2425.75	0.012915	1.48	236.30	221.19	0.46
upper_downstream	48651.51	25years	417.44	2423.50	2425.70		2425.84	0.015442	1.67	250.74	227.85	0.50
upper_downstream	48651.51	50years	465.55	2423.50	2425.75		2425.91	0.016916	1.78	261.81	232.82	0.53
upper_downstream	48651.51	100years	511.68	2423.50	2425.80		2425.98	0.018048	1.88	273.23	237.85	0.55
upper_downstream	48082.95	10years	350.75	2421.80	2422.96		2423.00	0.002702	0.45	421.01	310.31	0.19
upper_downstream	48082.95	25years	417.44	2421.80	2423.25		2423.29	0.002241	0.48	515.62	343.42	0.18
upper_downstream	48082.95	50years	465.55	2421.80	2423.44		2423.48	0.002019	0.49	582.74	365.09	0.17
upper_downstream	48082.95	100years	511.68	2421.80	2423.61		2423.65	0.001855	0.50	646.62	384.58	0.17
upper_downstream	47714.59	10years	350.75	2424.13	2422.87		2422.88	0.000112		1242.41	395.23	0.00
upper_downstream	47714.59	25years	417.44	2424.13	2423.15		2423.16	0.000125		1355.62	410.15	0.00
upper_downstream	47714.59	50years	465.55	2424.13	2423.34		2423.34	0.000133		1432.15	419.94	0.00
upper_downstream	47714.59	100years	511.68	2424.13	2423.50		2423.51	0.000141		1502.63	428.76	0.00
upper_downstream	47256.39	10years	350.75	2425.46	2422.80		2422.81	0.000339		784.24	284.20	0.00
upper_downstream	47256.39	25years	417.44	2425.46	2423.07		2423.08	0.000372		863.78	298.27	0.00
upper_downstream	47256.39	50years	465.55	2425.46	2423.25		2423.26	0.000393		917.96	307.48	0.00
upper_downstream	47256.39	100years	511.68	2425.46	2423.41		2423.43	0.000412		968.19	315.78	0.00
upper_downstream	46541.78	10years	350.75	2433.18	2422.01		2422.11	0.006866		253.06	160.30	0.00
upper_downstream	46541.78	25years	417.44	2433.18	2422.22		2422.33	0.006883		288.10	171.04	0.00
upper_downstream	46541.78	50years	465.55	2433.18	2422.36		2422.47	0.006914		312.13	178.02	0.00
upper_downstream	46541.78	100years	511.68	2433.18	2422.48		2422.60	0.006914		335.05	184.45	0.00
upper_downstream	45897.34	10years	350.75	2426.81	2419.57	2418.59	2419.69	0.008565		228.80	146.84	0.00
upper_downstream	45897.34	25years	417.44	2426.81	2419.78	2418.74	2419.91	0.008491		261.56	157.00	0.00
upper_downstream	45897.34	50years	465.55	2426.81	2419.93	2418.85	2420.06	0.008427		284.67	163.79	0.00
upper_downstream	45897.34	100years	511.68	2426.81	2420.05	2418.94	2420.20	0.008403		305.89	169.79	0.00

HEC-RAS Plan: plan1 River: Main Reach: upper_downstream

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	45897.34	10years	350.75	2426.81	2419.57	2418.59	2419.69	0.008565		228.80	146.84	0.00
upper_downstream	45897.34	25years	417.44	2426.81	2419.78	2418.74	2419.91	0.008491		261.56	157.00	0.00
upper_downstream	45897.34	50years	465.55	2426.81	2419.93	2418.85	2420.06	0.008427		284.67	163.79	0.00
upper_downstream	45897.34	100years	511.68	2426.81	2420.05	2418.94	2420.20	0.008403		305.89	169.79	0.00
upper_downstream	45244.15	10years	350.75	2424.57	2414.67		2414.78	0.008273		231.88	147.94	0.00
upper_downstream	45244.15	25years	417.44	2424.57	2414.87		2415.00	0.008381		262.93	157.53	0.00
upper_downstream	45244.15	50years	465.55	2424.57	2415.00		2415.14	0.008494		283.92	163.70	0.00
upper_downstream	45244.15	100years	511.68	2424.57	2415.12		2415.27	0.008519		304.43	169.50	0.00
upper_downstream	44352	10years	350.75	2405.66	2395.47	2395.40	2395.89	0.055016		121.95	123.51	0.00
upper_downstream	44352	25years	417.44	2405.66	2395.61	2395.54	2396.06	0.053608		140.31	132.48	0.00
upper_downstream	44352	50years	465.55	2405.66	2395.71	2395.63	2396.18	0.052058		153.95	138.78	0.00
upper_downstream	44352	100years	511.68	2405.66	2395.79	2395.71	2396.28	0.051908		165.44	143.86	0.00
upper_downstream	43734.69	10years	350.75	2394.23	2382.98		2383.07	0.011452		265.15	269.59	0.00
upper_downstream	43734.69	25years	417.44	2394.23	2383.10		2383.20	0.011638		300.31	286.90	0.00
upper_downstream	43734.69	50years	465.55	2394.23	2383.18		2383.29	0.011832		323.89	297.96	0.00
upper_downstream	43734.69	100years	511.68	2394.23	2383.26		2383.37	0.011873		347.23	308.51	0.00
upper_downstream	43305.21	10years	350.75	2381.72	2374.73	2374.68	2375.03	0.059534		142.81	197.61	0.00
upper_downstream	43305.21	25years	417.44	2381.72	2374.83	2374.78	2375.16	0.057557		164.80	212.27	0.00
upper_downstream	43305.21	50years	465.55	2381.72	2374.91	2374.84	2375.25	0.055608		181.18	222.57	0.00
upper_downstream	43305.21	100years	511.68	2381.72	2374.97	2374.90	2375.32	0.055360		194.81	230.79	0.00
upper_downstream	42780.16	10years	350.75	2369.73	2366.29	2365.69	2366.37	0.010427		274.76	274.69	0.00
upper_downstream	42780.16	25years	417.44	2369.73	2366.42	2365.78	2366.51	0.010547		311.74	292.59	0.00
upper_downstream	42780.16	50years	465.55	2369.73	2366.50	2365.85	2366.60	0.010706		336.42	303.95	0.00
upper_downstream	42780.16	100years	511.68	2369.73	2366.58	2365.91	2366.69	0.010700		361.20	314.95	0.00
upper_downstream	42209.61	10years	350.75	2353.81	2355.00	2355.00	2355.31	0.075967	2.44	143.74	241.11	1.01
upper_downstream	42209.61	25years	417.44	2353.81	2355.09	2355.09	2355.41	0.074256	2.53	165.19	258.48	1.01
upper_downstream	42209.61	50years	465.55	2353.81	2355.15	2355.15	2355.49	0.071934	2.57	181.42	270.88	1.00
upper_downstream	42209.61	100years	511.68	2353.81	2355.20	2355.20	2355.55	0.072454	2.63	194.21	280.27	1.01

HEC-RAS Plan: plan1 River: Main Reach: upper_downstream

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	41393.51	10years	350.75	2342.50	2326.88	2326.32	2326.91	0.004757		451.72	527.09	0.00
upper_downstream	41393.51	25years	417.44	2342.50	2326.97	2326.38	2327.00	0.004928		497.89	531.57	0.00
upper_downstream	41393.51	50years	465.55	2342.50	2327.03	2326.42	2327.07	0.004941		532.49	534.90	0.00
upper_downstream	41393.51	100years	511.68	2342.50	2327.08	2326.45	2327.12	0.005238		554.66	537.02	0.00
upper_downstream	40083.29	10years	350.75	2336.03	2318.36	2318.20	2318.58	0.040178		166.17	214.88	0.00
upper_downstream	40083.29	25years	417.44	2336.03	2318.50	2318.30	2318.73	0.035602		197.90	233.97	0.00
upper_downstream	40083.29	50years	465.55	2336.03	2318.57	2318.37	2318.81	0.035097		213.98	238.86	0.00
upper_downstream	40083.29	100years	511.68	2336.03	2318.68	2318.42	2318.91	0.029628		241.53	247.01	0.00
upper_downstream	39549.19	10years	350.75	2327.85	2313.43	2312.37	2313.49	0.005499		304.67	217.28	0.00
upper_downstream	39549.19	25years	417.44	2327.85	2313.59	2312.49	2313.67	0.005711		342.27	230.30	0.00
upper_downstream	39549.19	50years	465.55	2327.85	2313.72	2312.58	2313.80	0.005659		372.70	240.32	0.00
upper_downstream	39549.19	100years	511.68	2327.85	2313.79	2312.66	2313.87	0.006145		387.91	245.17	0.00
upper_downstream	38491.2	10years	350.75	2310.56	2303.03	2302.87	2303.28	0.041890		159.34	198.02	0.00
upper_downstream	38491.2	25years	417.44	2310.56	2303.17	2302.98	2303.42	0.038334		187.70	214.93	0.00
upper_downstream	38491.2	50years	465.55	2310.56	2303.23	2303.05	2303.50	0.039944		200.58	222.18	0.00
upper_downstream	38491.2	100years	511.68	2310.56	2303.37		2303.61	0.032172		233.51	239.72	0.00
upper_downstream	37691.48	10years	350.75	2296.91	2286.93	2286.30	2287.05	0.012169		232.78	201.47	0.00
upper_downstream	37691.48	25years	417.44	2296.91	2287.06	2286.42	2287.20	0.012788		260.36	213.07	0.00
upper_downstream	37691.48	50years	465.55	2296.91	2287.18	2286.50	2287.32	0.012441		285.48	223.11	0.00
upper_downstream	37691.48	100years	511.68	2296.91	2287.20	2286.57	2287.36	0.014309		290.79	225.17	0.00
upper_downstream	36347.82	10years	350.75	2280.29	2278.89	2278.56	2278.96	0.016507		296.68	468.43	0.00
upper_downstream	36347.82	25years	417.44	2280.29	2278.98	2278.63	2279.06	0.015800		343.65	504.15	0.00
upper_downstream	36347.82	50years	465.55	2280.29	2279.03	2278.67	2279.11	0.016604		366.06	520.34	0.00
upper_downstream	36347.82	100years	511.68	2280.29	2279.12	2278.71	2279.20	0.014106		417.72	555.84	0.00
upper_downstream	35620.82	10years	350.75	2271.25	2270.80	2270.56	2270.86	0.019586		324.36	667.41	0.00
upper_downstream	35620.82	25years	417.44	2271.25	2270.86	2270.61	2270.93	0.020759		361.63	704.71	0.00
upper_downstream	35620.82	50years	465.55	2271.25	2270.91	2270.65	2270.98	0.019610		400.92	742.01	0.00
upper_downstream	35620.82	100years	511.68	2271.25	2270.91	2270.68	2270.99	0.024379		396.63	738.02	0.00

C. Unsteady profile output table

HEC-RAS Plan: 10years River: Main Reach: upper_downstream Profile: Max WS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	54148.2	Max WS	10.00	2481.77	2485.58		2485.58	0.000000	0.01	723.01	189.99	0.00
upper_downstream	53831.16	Max WS	1793.58	2469.80	2474.46	2475.12	2476.78	0.090718	6.74	266.03	110.61	1.39
upper_downstream	53475.62	Max WS	176.39	2459.84	2462.91		2462.94	0.001649	0.75	234.29	132.91	0.18
upper_downstream	53198.42	Max WS	-19.40	2458.85	2459.11		2459.11	0.000076	-0.03	174.12	171.44	0.02
upper_downstream	52839.74	Max WS	8.22	2454.30	2456.55		2456.55	0.000011	0.05	179.30	157.91	0.01
upper_downstream	52636.14	Max WS	-11.67	2452.14	2454.71		2454.71	0.000010	-0.06	232.12	178.84	0.01
upper_downstream	52421.59	Max WS	-232.14	2449.85	2452.11		2452.20	0.008980	-1.29	179.42	157.07	0.39
upper_downstream	52010.08	Max WS	-1100.09	2447.06	2450.51		2450.89	0.022641	-2.78	403.11	231.46	0.66
upper_downstream	51802.64	Max WS	-1036.29	2448.12	2446.78	2447.03	2447.83	0.092364		227.77	173.68	0.00
upper_downstream	51484.58	Max WS	10.00	2447.94	2441.78		2441.78	0.000002		366.41	211.29	0.00
upper_downstream	50980.73	Max WS	15965.25	2448.41	2441.09	2447.59	2727.31	23.563650		213.08	152.48	0.00
upper_downstream	50704.69	Max WS	7275.33	2446.52	2437.90	2442.47	2609.52	20.650240		125.40	119.36	0.00
upper_downstream	49975.4	Max WS	92.23	2437.49	2435.23		2435.31	0.017450		76.47	122.46	0.00
upper_downstream	49314.2	Max WS	3037.38	2429.63	2430.59	2431.26	2432.66	0.132097	2.78	486.76	329.20	1.28
upper_downstream	48988.65	Max WS	21376.58	2425.48	2428.54	2433.40	2515.98	5.465323	42.56	529.94	346.62	10.25
upper_downstream	48651.51	Max WS	15454.51	2423.50	2428.83	2430.75	2434.94	0.162778	-11.37	1468.46	551.26	1.97
upper_downstream	48082.95	Max WS	13987.30	2421.80	2424.68	2426.78	2433.02	0.327490	-9.11	1119.25	505.98	2.43
upper_downstream	47714.59	Max WS	80691.12	2424.13	2429.85	2434.13	2443.22	0.090909	-7.59	5293.82	765.64	1.43
upper_downstream	47256.39	Max WS	33827.13	2425.46	2425.78	2430.25	2442.71	0.302242	-2.01	1858.58	437.48	1.61
upper_downstream	46541.78	Max WS	65506.15	2433.18	2429.12	2435.55	2459.64	0.443876		2677.57	521.42	0.00
upper_downstream	45897.34	Max WS	12002.33	2426.81	2430.52		2430.88	0.002619	0.97	4664.15	663.07	0.23
upper_downstream	45244.15	Max WS	70736.22	2424.57	2430.98	2429.92	2434.18	0.014798	3.31	9917.96	1458.35	0.59
upper_downstream	44352	Max WS	7892.51	2405.66	2405.88		2406.02	0.001521	0.11	4798.83	774.80	0.11
upper_downstream	43734.69	Max WS	10.00	2394.23	2389.55		2389.55	0.000000		3661.20	720.51	0.00
upper_downstream	43305.21	Max WS	10.00	2381.72	2389.55		2389.55	0.000000	0.00	13107.43	1347.31	0.00
upper_downstream	42780.16	Max WS	09703.20	2369.73	2381.38	2393.33	2430.87	0.215973	-22.93	17056.10	1678.04	2.61
upper_downstream	42209.61	Max WS	88447.60	2353.81	2379.38		2380.18	0.001871	-4.51	48529.81	2545.03	0.29
upper_downstream	41393.51	Max WS	10.00	2342.50	2352.76		2352.76	0.000000	0.00	31278.15	1855.87	0.00
upper_downstream	40083.29	Max WS	17676.93	2336.03	2355.38		2355.39	0.000008	0.22	57739.17	2886.41	0.02
upper_downstream	39549.19	Max WS	10.00	2327.85	2352.76		2352.76	0.000000	0.00	68408.66	3024.86	0.00
upper_downstream	38491.2	Max WS	55422.92	2310.56	2311.64	2312.37	2315.49	0.048669	1.83	6429.30	1257.93	0.79
upper_downstream	37691.48	Max WS	13328.00	2296.91	2308.61	2338.86	2682.27	1.150644	50.49	25081.84	2091.37	5.96
upper_downstream	36347.82	Max WS	92871.70	2280.29	2291.96	2301.59	2329.51	0.189972	-25.79	29876.40	2848.16	2.57
upper_downstream	35620.82	Max WS	51662.81	2271.25	2284.88		2284.97	0.000394	1.37	38016.90	2963.18	0.12

HEC-RAS Plan: 10years River: Main Reach: upper_downstream Profile: Max WS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	34982.2	Max WS	90558.18	2260.43	2295.10		2295.13	0.000043	0.87	.08184.70	3241.48	0.05
upper_downstream	34339.44	Max WS	96931.30	2248.37	2291.66		2291.77	0.000107	1.58	.33197.60	3426.54	0.08
upper_downstream	33464.78	Max WS	91883.00	2235.51	2250.88	2284.02	2607.59	1.432420	88.17	30243.31	2420.49	7.44
upper_downstream	32478.31	Max WS	15820.70	2219.77	2229.73	2232.09	2237.74	0.066731	13.07	9267.00	1221.31	1.46
upper_downstream	30551.54	Max WS	1086.79	2187.60	2193.26		2193.29	0.000693	0.66	1650.29	582.72	0.12
upper_downstream	29191.16	Max WS	254.28	2154.84	2171.26		2171.26	0.000000	0.02	16464.68	2005.82	0.00
upper_downstream	28575.09	Max WS	50440.88	2135.43	2137.68	2146.13	3376.82	24.781200	155.93	324.33	288.11	45.83
upper_downstream	27154.75	Max WS	89881.40	2096.68	2100.65	2124.43	19207.23	57.031300	601.37	846.63	426.26	132.27
upper_downstream	24853.38	Max WS	121.28	2086.76	2089.63		2089.64	0.000203	0.23	531.00	365.49	0.06
upper_downstream	24512.37	Max WS	39802.20	2086.19	2090.23	2109.28	7442.41	59.851500	324.00	1048.78	514.17	72.44
upper_downstream	22557.13	Max WS	1911.75	2083.52	2085.82	2086.27	2087.23	0.140829	5.26	363.70	306.49	1.54
upper_downstream	22058.27	Max WS	-1833.10	2082.67	2085.21	2085.34	2086.06	0.073984	-4.08	449.36	341.78	1.14
upper_downstream	20914.6	Max WS	290.52	2081.32	2080.82	2081.00	2081.41	0.354035		85.92	280.28	0.00
upper_downstream	19149.13	Max WS	-163.41	2078.06	2077.61		2077.69	0.013349		138.86	196.92	0.00
upper_downstream	18647.69	Max WS	-145.94	2077.11	2076.89		2076.91	0.001628		270.45	243.48	0.00
upper_downstream	18099.75	Max WS	-170.94	2075.90	2077.11		2077.11	0.000034	-0.08	2205.51	2062.92	0.02
upper_downstream	15913.67	Max WS	10.00	2072.10	2076.22		2076.22	0.000000	0.00	3124.48	1124.28	0.00
upper_downstream	15226.27	Max WS	9345.80	2073.68	2076.82		2077.26	0.012403	2.50	3525.73	1701.82	0.51
upper_downstream	14028.31	Max WS	18585.90	2077.44	2079.00	2086.23	2120.77	0.687523	8.79	4204.88	1022.34	3.18
upper_downstream	13458.43	Max WS	4907.15	2078.58	2077.97	2078.45	2079.78	0.085504		822.57	390.35	0.00
upper_downstream	13239.75	Max WS	27548.21	2079.69	2080.25	2084.53	2098.64	0.514668	-3.82	1460.05	513.07	2.31
upper_downstream	12558.67	Max WS	8714.01	2074.91	2071.80	2075.82	2199.88	14.885410		173.86	161.93	0.00
upper_downstream	11342.53	Max WS	-2538.13	2070.29	2070.50	2070.78	2071.38	0.106857	-0.90	618.74	826.67	0.89
upper_downstream	11079.2	Max WS	64006.61	2069.03	2070.46	2073.99	2141.84	5.811309	-29.08	1808.50	1690.98	9.54
upper_downstream	10045.85	Max WS	83168.50	2066.68	2067.65	2077.94	2702.85	26.782490	-39.90	2626.68	1434.56	18.31
upper_downstream	9234.706	Max WS	-1484.20	2066.50	2067.08		2067.10	0.000812	-0.16	2627.01	1481.00	0.09
upper_downstream	8753.816	Max WS	10409.47	2066.46	2067.66		2068.06	0.013674	-1.04	3832.94	1788.70	0.43
upper_downstream	7785.13	Max WS	36691.58	2067.48	2068.21	2068.94	2070.82	0.081249	-1.82	5199.58	2081.05	0.96
upper_downstream	6268.652	Max WS	83168.50	2069.04	2068.02	2077.33	2880.31	29.810840		2243.44	887.39	0.00
upper_downstream	5268.904	Max WS	75527.30	2068.15	2068.07	2074.99	2220.23	8.349316		3213.02	1724.54	0.00
upper_downstream	3871.316	Max WS	2151.65	2067.02	2067.67		2067.70	0.000980	0.19	3374.14	1740.84	0.10
upper_downstream	2729.367	Max WS	3595.80	2067.82	2067.66		2067.72	0.002099		3426.14	1375.77	0.00
upper_downstream	2010.337	Max WS	99355.06	2068.36	2065.64	2072.40	2167.36	4.054193		2224.42	938.25	0.00
upper_downstream	1023.976	Max WS	6523.59	2065.97	2064.18	2062.99	2064.39	0.008682		3237.83	1422.03	0.00

HEC-RAS Plan: 25years River: Main Reach: upper_downstream Profile: Max WS

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
upper_downstream	54148.2	Max WS	10.00	2481.77	2485.58		2485.58	0.000000	0.01	723.01	189.99	0.00
upper_downstream	53831.16	Max WS	107.22	2469.80	2475.08		2475.09	0.000170	0.32	338.76	124.59	0.06
upper_downstream	53475.62	Max WS	137.74	2459.84	2463.21		2463.22	0.000621	0.50	275.46	143.06	0.11
upper_downstream	53198.42	Max WS	13.48	2458.85	2458.04		2458.05	0.001983		39.39	81.71	0.00
upper_downstream	52839.74	Max WS	-2561.59	2454.30	2456.12	2458.34	2480.70	3.429348	-23.83	117.23	128.44	7.44
upper_downstream	52636.14	Max WS	-241.89	2452.14	2454.46		2454.56	0.007205	-1.46	190.13	162.13	0.37
upper_downstream	52421.59	Max WS	-79.71	2449.85	2453.40		2453.40	0.000091	-0.18	437.19	244.08	0.04
upper_downstream	52010.08	Max WS	-16.60	2447.06	2450.96		2450.96	0.000003	-0.03	513.86	261.17	0.01
upper_downstream	51802.64	Max WS	121.53	2448.12	2446.13		2446.17	0.005893		128.29	130.70	0.00
upper_downstream	51484.58	Max WS	10.00	2447.94	2441.78		2441.78	0.000002		366.41	211.29	0.00
upper_downstream	50980.73	Max WS	-449.97	2448.41	2442.36		2442.41	0.002537		450.81	221.78	0.00
upper_downstream	50704.69	Max WS	13959.47	2446.52	2437.85	2444.45	3139.27	37.389430		119.02	116.28	0.00
upper_downstream	49975.4	Max WS	-2912.73	2437.49	2438.51		2438.96	0.015327	-0.99	1002.20	442.75	0.44
upper_downstream	49314.2	Max WS	12414.53	2429.63	2430.52	2434.04	2468.61	2.512374	-11.52	463.87	321.36	5.52
upper_downstream	48988.65	Max WS	41632.48	2425.48	2428.88	2435.97	2645.23	11.832340	-67.26	655.92	385.64	15.35
upper_downstream	48651.51	Max WS	-1780.14	2423.50	2426.12	2426.49	2427.42	0.104345	-5.07	354.75	271.01	1.36
upper_downstream	48082.95	Max WS	-9711.91	2421.80	2426.65		2427.57	0.021268	-3.29	2328.68	696.59	0.67
upper_downstream	47714.59	Max WS	30722.00	2424.13	2429.76	2438.03	2465.71	0.247121	-12.39	5225.89	760.92	2.36
upper_downstream	47256.39	Max WS	17632.42	2425.46	2428.81		2430.27	0.013541	-2.05	3419.50	593.14	0.51
upper_downstream	46541.78	Max WS	-2793.90	2433.18	2444.69		2444.69	0.000004	-0.10	16944.33	1311.59	0.01
upper_downstream	45897.34	Max WS	15870.60	2426.81	2433.74		2434.03	0.001477	-1.10	7042.60	814.82	0.19
upper_downstream	45244.15	Max WS	59739.30	2424.57	2434.96	2439.67	2450.76	0.058429	9.81	17213.75	2094.39	1.29
upper_downstream	44352	Max WS	36521.74	2405.66	2413.91		2414.36	0.001795	1.43	13036.22	1277.09	0.22
upper_downstream	43734.69	Max WS	29106.66	2394.23	2398.10		2398.41	0.001543	0.76	12058.71	1245.12	0.17
upper_downstream	43305.21	Max WS	10.00	2381.72	2389.55		2389.55	0.000000	0.00	13107.43	1347.31	0.00
upper_downstream	42780.16	Max WS	45094.41	2369.73	2381.48		2381.86	0.001643	-2.02	17224.24	1684.31	0.23
upper_downstream	42209.61	Max WS	6194.06	2353.81	2362.81		2362.84	0.000400	0.96	8182.58	1819.76	0.11
upper_downstream	41393.51	Max WS	17520.30	2342.50	2354.86		2355.48	0.001224	-1.63	35297.10	1963.91	0.19
upper_downstream	40083.29	Max WS	08647.70	2336.03	2355.84		2356.57	0.001107	2.60	59081.57	2919.68	0.21
upper_downstream	39549.19	Max WS	98736.90	2327.85	2355.08		2355.48	0.000521	-2.27	75422.08	3024.86	0.15
upper_downstream	38491.2	Max WS	-2119.33	2310.56	2320.29		2320.29	0.000002	-0.06	21916.61	2322.74	0.01
upper_downstream	37691.48	Max WS	72635.00	2296.91	2298.26	2336.19	4770.01	21.567490	44.61	8106.27	1188.91	17.36
upper_downstream	36347.82	Max WS	-2112.59	2280.29	2284.10		2284.10	0.000074	-0.19	7753.61	2395.13	0.04
upper_downstream	35620.82	Max WS	21587.29	2271.25	2284.70		2284.72	0.000072	0.58	37489.46	2963.18	0.05

D. Sample information for Holeta River geometry by HEC-Geo RAS

XSCutLines

Shape *	OID *	Shape_Length	HydroID	Station	River	Reach	LeftBank	RightBank	LLength	ChLength	RLength
Polyline	1	4343.705766	4	53436.91	main	updwnstr	0.34686	0.67251	979.523	1075.25	998.293
Polyline	2	4547.358447	5	52361.66	main	updwnstr	0.37074	0.6958	1077.153	1077.707	764.463
Polyline	3	4948.948975	6	51283.95	main	updwnstr	0.30743	0.64368	405.371	582.23	721.952
Polyline	4	4942.471825	7	50701.72	main	updwnstr	0.28272	0.5694	1270.623	1788.97	1309.777
Polyline	5	5217.690302	8	48912.75	main	updwnstr	0.35453	0.65823	650.383	737.36	691.58
Polyline	6	5260.310486	9	48175.39	main	updwnstr	0.3326	0.61817	617.043	736.595	565.683
Polyline	7	5326.096859	10	47438.8	main	updwnstr	0.32541	0.61161	480.669	552.882	502.579
Polyline	8	5326.079015	11	46885.91	main	updwnstr	0.32121	0.60825	894.062	739.847	570.403
Polyline	9	5542.659993	12	46146.07	main	updwnstr	0.28802	0.64892	1034.357	1453.477	1180.122
Polyline	10	5989.622372	13	44692.59	main	updwnstr	0.25217	0.54464	653.09	704.709	635.522
Polyline	11	6056.351804	14	43987.88	main	updwnstr	0.24677	0.53286	1758.086	1681.641	1337.834
Polyline	12	6942.809664	15	42306.24	main	updwnstr	0.36687	0.61064	2157.196	2503.142	2278.616
Polyline	13	7963.074816	16	39803.1	main	updwnstr	0.30056	0.53761	4870.841	4421.019	2315.014
Polyline	14	7036.347002	17	35382.08	main	updwnstr	0.3411	0.64585	1322.114	1944.552	2277.016
Polyline	15	8052.775923	18	33437.53	main	updwnstr	0.33048	0.60113	3853.762	3499.692	2300.395
Polyline	16	7929.329545	19	29937.83	main	updwnstr	0.37135	0.71416	2434.091	2750.902	2558.365
Polyline	17	9351.053994	20	27186.93	main	updwnstr	0.27118	0.62531	3474.74	4513.109	3105.881
Polyline	18	8934.925112	21	22673.82	main	updwnstr	0.33987	0.636	4465.628	3852.043	2770.587
Polyline	19	3637.780844	22	18821.78	main	updwnstr	0.21203	0.56461	3272.457	4706.754	3898.768
Polyline	20	3067.082494	23	14115.03	main	updwnstr	0.38352	0.70671	644.616	699.493	820.724
Polyline	21	2873.556109	24	13415.53	main	updwnstr	0.44485	0.87694	729.814	723.749	858.396
Polyline	22	3525.03567	25	12691.79	main	updwnstr	0.37803	0.85192	1170.745	1509.309	1197.751
Polyline	23	4507.331934	26	11182.48	main	updwnstr	0.37087	0.82584	1428.733	1839.952	1485.224
Polyline	24	4907.952903	27	9342.523	main	updwnstr	0.35925	0.80354	1660.568	1744.55	1515.529
Polyline	25	6072.559862	28	7597.974	main	updwnstr	0.33436	0.72383	1685.769	1834.171	1499.311
Polyline	26	6614.808264	29	5763.803	main	updwnstr	0.33763	0.64903	1058.335	1222.066	1286.702
Polyline	27	5928.530296	30	4541.736	main	updwnstr	0.34433	0.7123	1879.162	2014.918	2086.423
Polyline	28	4953.292566	31	2526.819	main	updwnstr	0.36714	0.77888	1140.338	1131.743	1006.065
Polyline	29	5126.288971	32	1395.076	main	updwnstr	0.38294	0.71533	1889.867	924.644	756.335
Polyline	30	3458.47266	33	174.2895	main	updwnstr	0.45104	0.82711	325.153	174.29	146.045
Polyline	31	3423.326898	34	470.4313	main	updwnstr	0.45816	0.82921	265.229	296.142	307.406

River3D

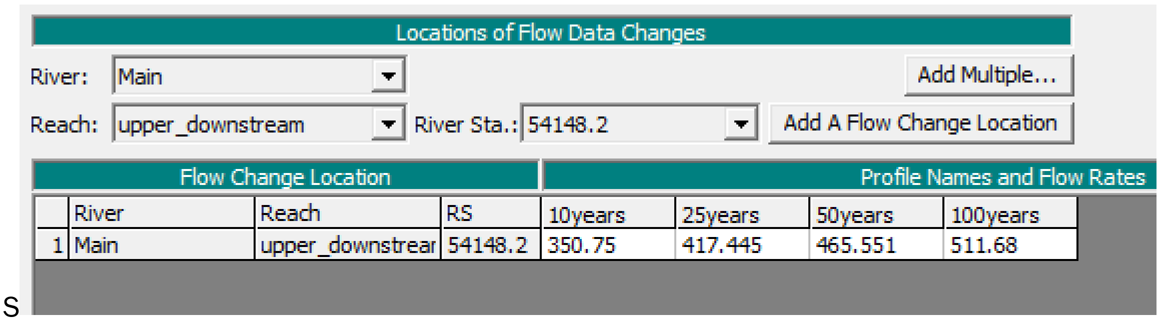
Shape *	OID *	Shape_Length	Riv2DID	HydroID	River	Reach	FromNode	ToNode	ArcLength	FromSta	ToSta
Polyline Z	2	53863.841116	1	98	main	updwnstr	1	2	53863.84	0	53863.84

XSCutLines3D

Shape *	OID *	Shape_Length	XS2DID	HydroID	Station	River	Reach	LeftBank	RightBank	LLength	ChLength	RLength
Polyline Z	63	4343.705766	4	99	53436.91	main	updwnstream	0.34686	0.67251	979.523	1075.25	998.293
Polyline Z	64	4547.358447	5	100	52361.66	main	updwnstream	0.37074	0.6958	1077.153	1077.707	764.463
Polyline Z	65	4948.948975	6	101	51283.95	main	updwnstream	0.30743	0.64368	405.371	582.23	721.952
Polyline Z	66	4942.471825	7	102	50701.72	main	updwnstream	0.28272	0.5694	1270.623	1788.97	1309.777
Polyline Z	67	5217.690302	8	103	48912.75	main	updwnstream	0.35453	0.65823	650.383	737.36	691.58
Polyline Z	68	5260.310486	9	104	48175.39	main	updwnstream	0.3326	0.61817	617.043	736.595	565.683
Polyline Z	69	5326.096859	10	105	47438.8	main	updwnstream	0.32541	0.61161	480.669	552.882	502.579
Polyline Z	70	5326.079015	11	106	46885.91	main	updwnstream	0.32121	0.60825	894.062	739.847	570.403
Polyline Z	71	5542.659993	12	107	46146.07	main	updwnstream	0.28802	0.64892	1034.357	1453.477	1180.122
Polyline Z	72	5989.622372	13	108	44692.59	main	updwnstream	0.25217	0.54464	653.09	704.709	635.522
Polyline Z	73	6056.351804	14	109	43987.88	main	updwnstream	0.24677	0.53286	1758.086	1681.641	1337.834
Polyline Z	74	6942.809664	15	110	42306.24	main	updwnstream	0.36687	0.61064	2157.196	2503.142	2278.616
Polyline Z	75	7963.074816	16	111	39803.1	main	updwnstream	0.30056	0.53761	4870.841	4421.019	2315.014
Polyline Z	76	7036.347002	17	112	35382.08	main	updwnstream	0.3411	0.64585	1322.114	1944.552	2277.016
Polyline Z	77	8052.775923	18	113	33437.53	main	updwnstream	0.33048	0.60113	3853.762	3499.692	2300.395
Polyline Z	78	7929.329545	19	114	29937.83	main	updwnstream	0.37135	0.71416	2434.091	2750.902	2558.365
Polyline Z	79	9351.053994	20	115	27186.93	main	updwnstream	0.27118	0.62531	3474.74	4513.109	3105.881
Polyline Z	80	8934.925112	21	116	22673.82	main	updwnstream	0.33987	0.636	4465.628	3852.043	2770.587
Polyline Z	81	3637.780844	22	117	18821.78	main	updwnstream	0.21203	0.56461	3272.457	4706.754	3898.768
Polyline Z	82	3067.082494	23	118	14115.03	main	updwnstream	0.38352	0.70671	644.616	699.493	820.724
Polyline Z	83	2873.556109	24	119	13415.53	main	updwnstream	0.44485	0.87694	729.814	723.749	858.396
Polyline Z	84	3525.03567	25	120	12691.79	main	updwnstream	0.37803	0.85192	1170.745	1509.309	1197.751
Polyline Z	85	4507.331934	26	121	11182.48	main	updwnstream	0.37087	0.82584	1428.733	1839.952	1485.224
Polyline Z	86	4907.952903	27	122	9342.523	main	updwnstream	0.35925	0.80354	1660.568	1744.55	1515.529
Polyline Z	87	6072.559862	28	123	7597.974	main	updwnstream	0.33436	0.72383	1685.769	1834.171	1499.311
Polyline Z	88	6614.808264	29	124	5763.803	main	updwnstream	0.33763	0.64903	1058.335	1222.066	1286.702
Polyline Z	89	5928.530296	30	125	4541.736	main	updwnstream	0.34433	0.7123	1879.162	2014.918	2086.423
Polyline Z	90	4953.292566	31	126	2526.819	main	updwnstream	0.36714	0.77888	1140.338	1131.743	1006.065
Polyline Z	91	5126.288971	32	127	1395.076	main	updwnstream	0.38294	0.71533	1889.867	924.644	756.335
Polyline Z	92	3458.47266	33	128	174.2895	main	updwnstream	0.45104	0.82711	325.153	174.29	146.045
Polyline Z	93	3423.326898	34	129	470.4313	main	updwnstream	0.45816	0.82921	265.229	296.142	307.406

E. Sample Information for Holeta River geometry by HEC-RAS

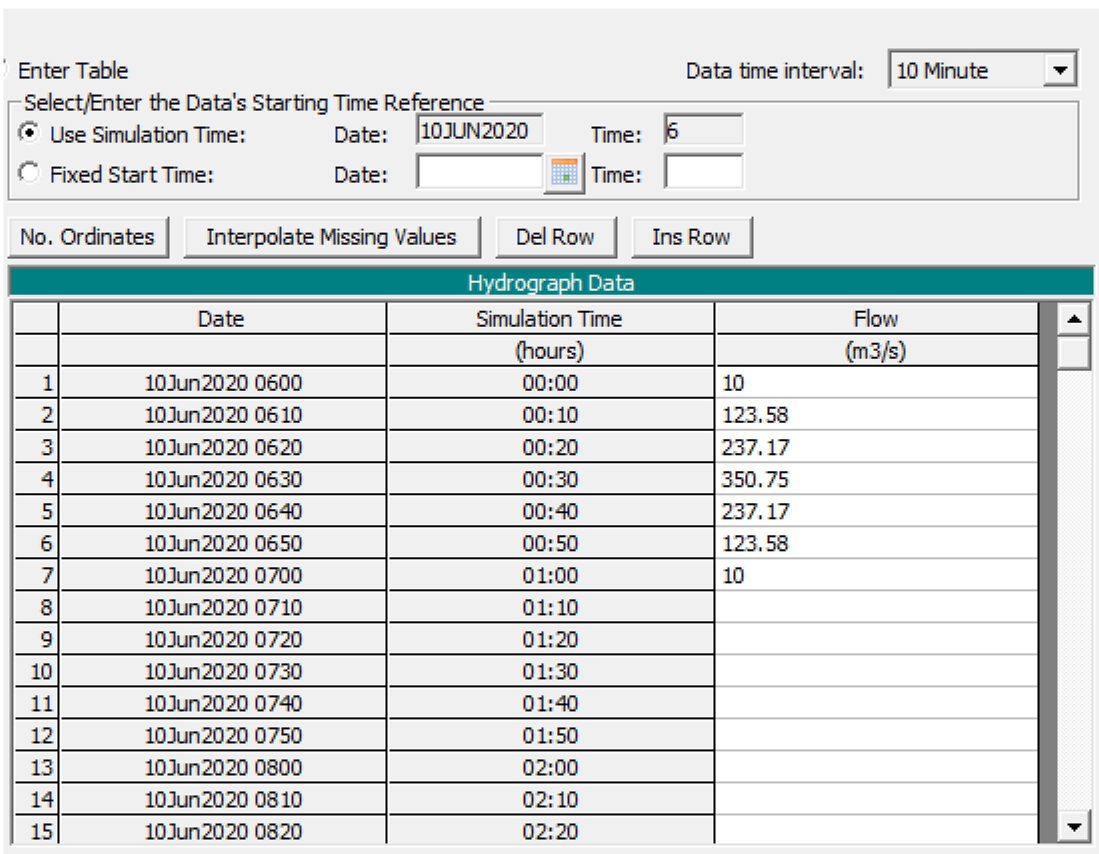
i) Steady Flow Data



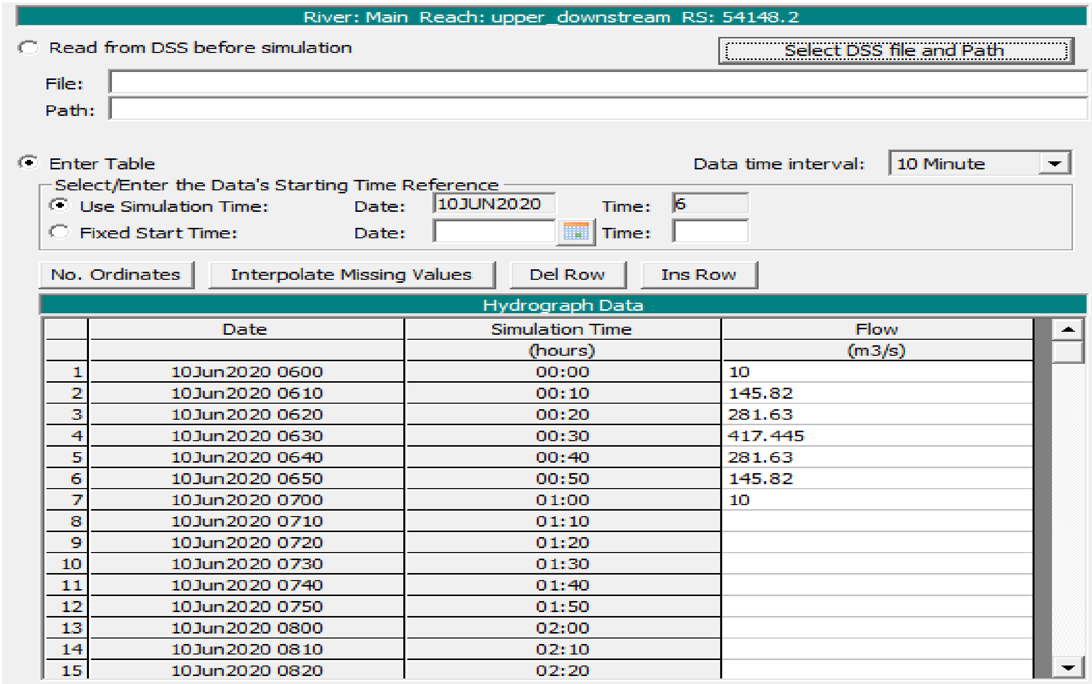
	River	Reach	RS	10years	25years	50years	100years
1	Main	upper_downstrear	54148.2	350.75	417.445	465.551	511.68

S

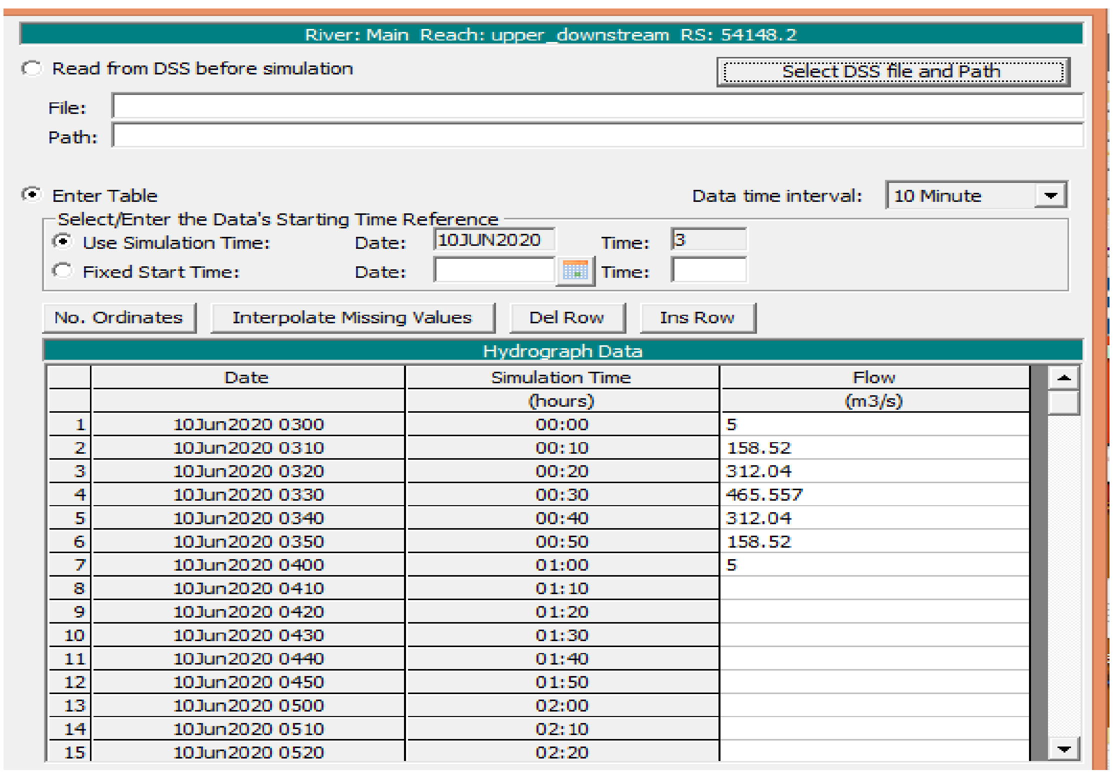
ii) Unsteady Flow Data for 10, 25, 50 and 100 years return periods Respectively



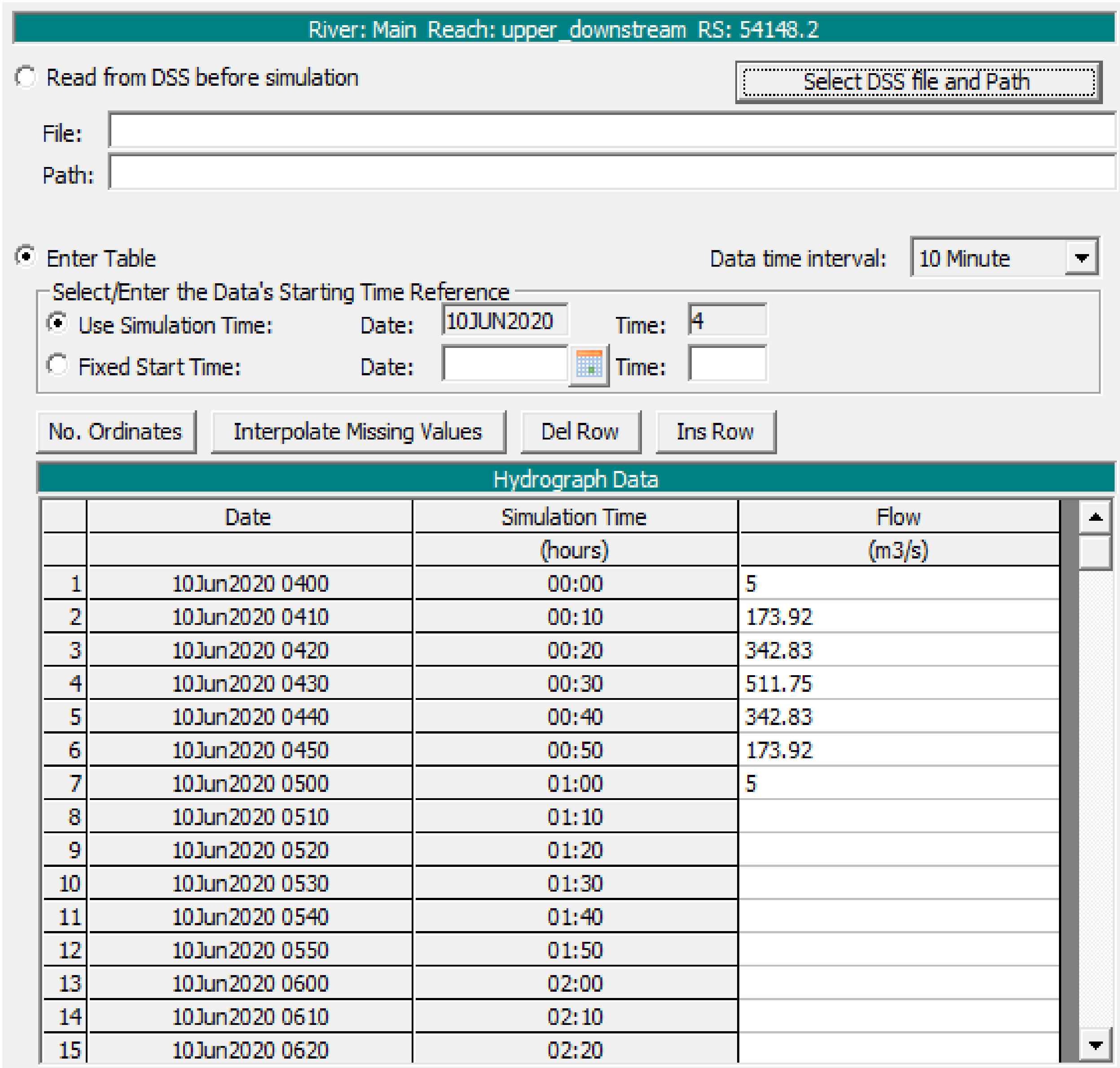
	Date	Simulation Time (hours)	Flow (m3/s)
1	10Jun2020 0600	00:00	10
2	10Jun2020 0610	00:10	123.58
3	10Jun2020 0620	00:20	237.17
4	10Jun2020 0630	00:30	350.75
5	10Jun2020 0640	00:40	237.17
6	10Jun2020 0650	00:50	123.58
7	10Jun2020 0700	01:00	10
8	10Jun2020 0710	01:10	
9	10Jun2020 0720	01:20	
10	10Jun2020 0730	01:30	
11	10Jun2020 0740	01:40	
12	10Jun2020 0750	01:50	
13	10Jun2020 0800	02:00	
14	10Jun2020 0810	02:10	
15	10Jun2020 0820	02:20	



	Date	Simulation Time (hours)	Flow (m3/s)
1	10Jun2020 0600	00:00	10
2	10Jun2020 0610	00:10	145.82
3	10Jun2020 0620	00:20	281.63
4	10Jun2020 0630	00:30	417.445
5	10Jun2020 0640	00:40	281.63
6	10Jun2020 0650	00:50	145.82
7	10Jun2020 0700	01:00	10
8	10Jun2020 0710	01:10	
9	10Jun2020 0720	01:20	
10	10Jun2020 0730	01:30	
11	10Jun2020 0740	01:40	
12	10Jun2020 0750	01:50	
13	10Jun2020 0800	02:00	
14	10Jun2020 0810	02:10	
15	10Jun2020 0820	02:20	

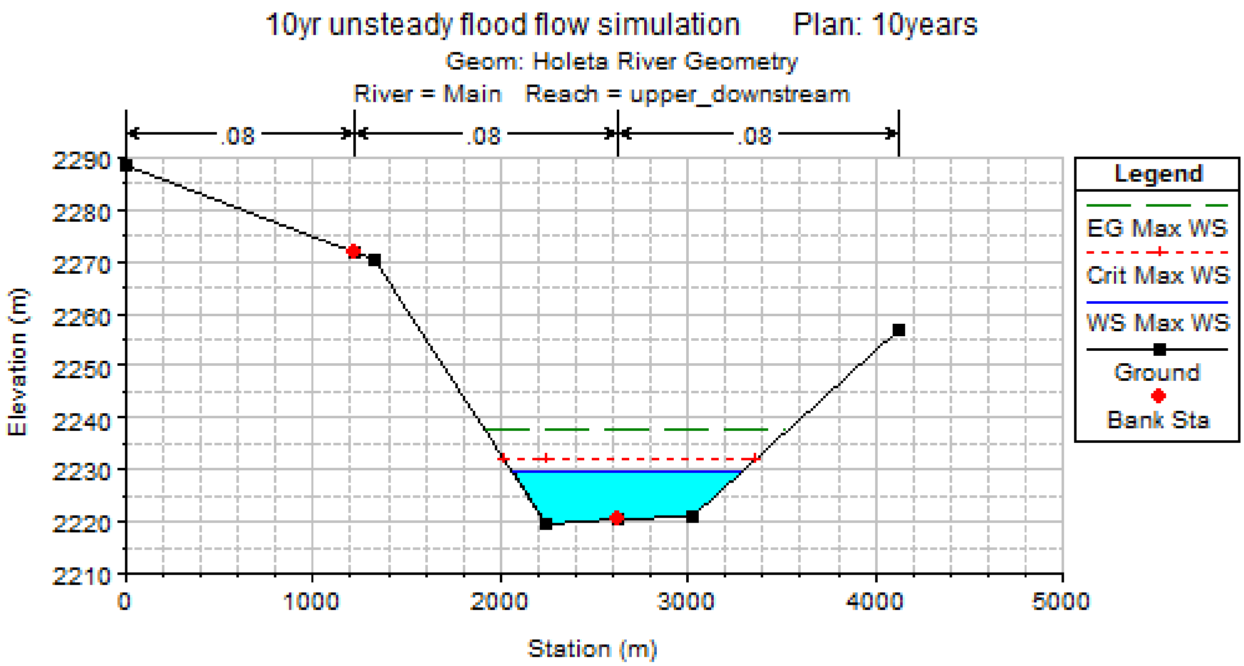


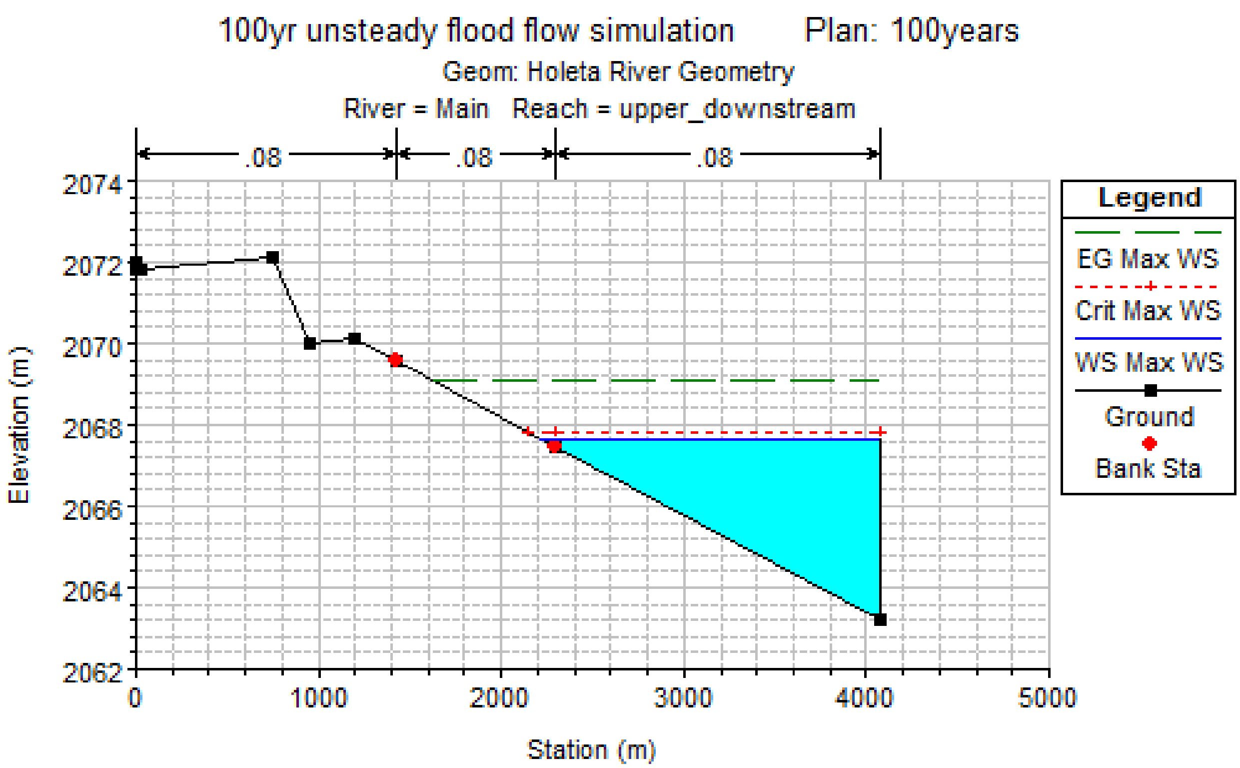
	Date	Simulation Time (hours)	Flow (m3/s)
1	10Jun2020 0300	00:00	5
2	10Jun2020 0310	00:10	158.52
3	10Jun2020 0320	00:20	312.04
4	10Jun2020 0330	00:30	465.557
5	10Jun2020 0340	00:40	312.04
6	10Jun2020 0350	00:50	158.52
7	10Jun2020 0400	01:00	5
8	10Jun2020 0410	01:10	
9	10Jun2020 0420	01:20	
10	10Jun2020 0430	01:30	
11	10Jun2020 0440	01:40	
12	10Jun2020 0450	01:50	
13	10Jun2020 0500	02:00	
14	10Jun2020 0510	02:10	
15	10Jun2020 0520	02:20	

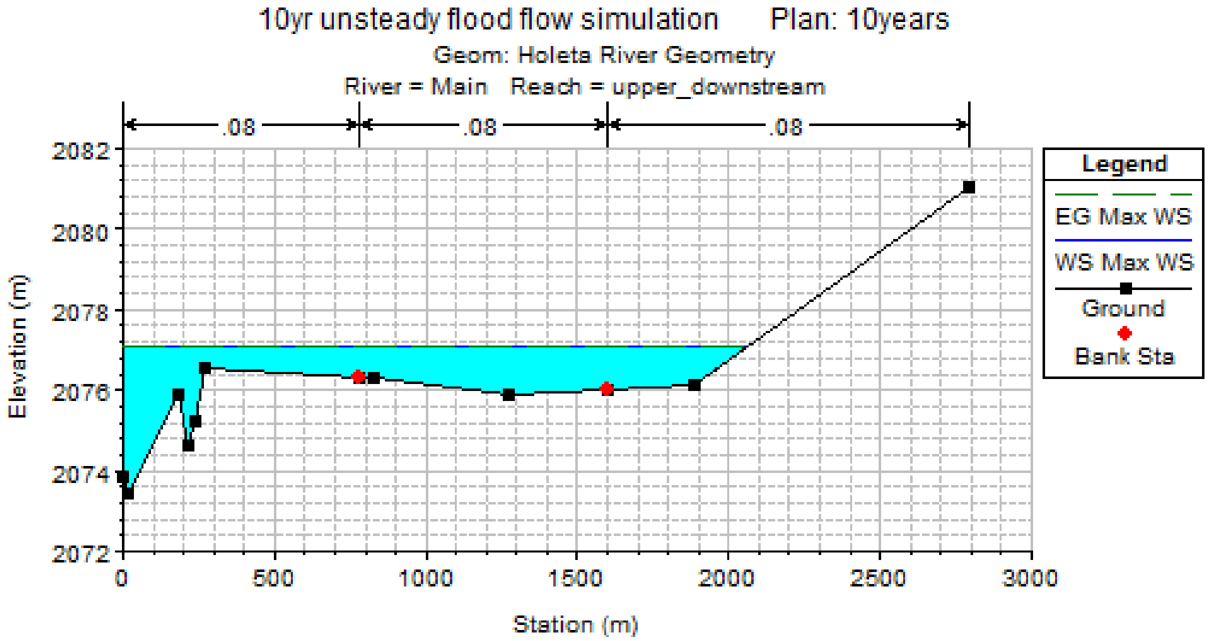


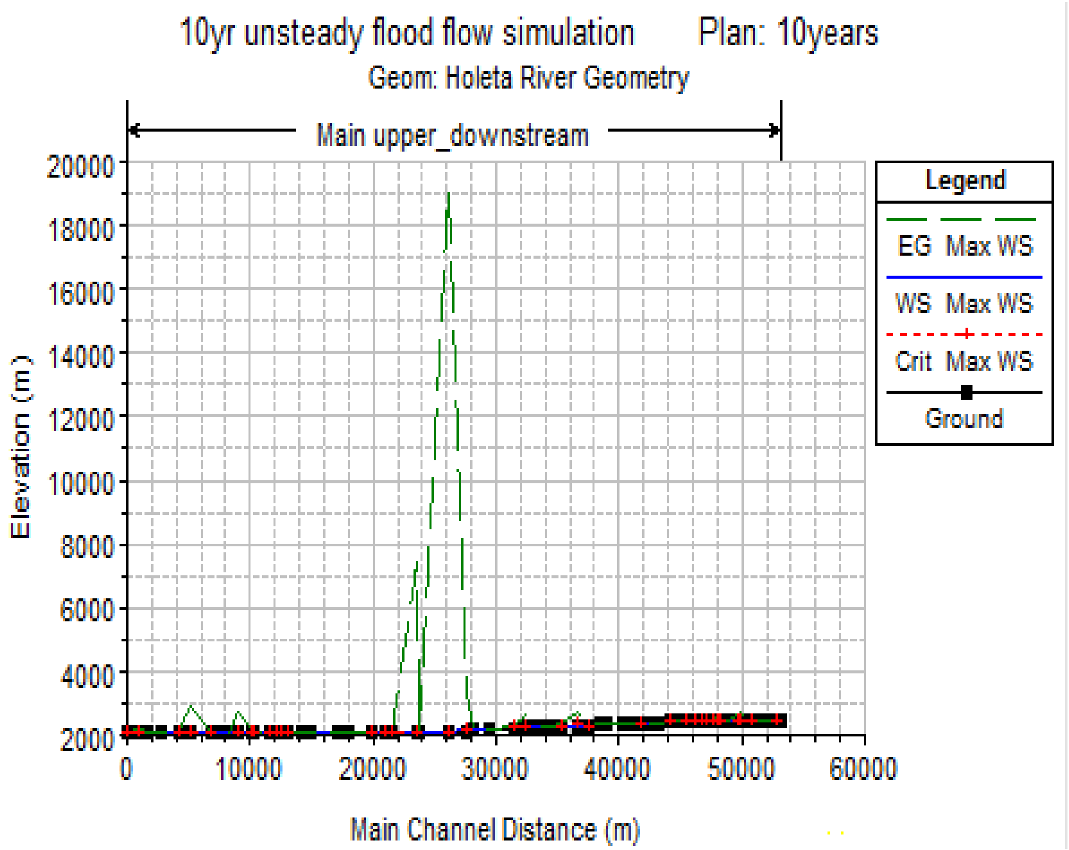
	Date	Simulation Time (hours)	Flow (m3/s)
1	10Jun2020 0400	00:00	5
2	10Jun2020 0410	00:10	173.92
3	10Jun2020 0420	00:20	342.83
4	10Jun2020 0430	00:30	511.75
5	10Jun2020 0440	00:40	342.83
6	10Jun2020 0450	00:50	173.92
7	10Jun2020 0500	01:00	5
8	10Jun2020 0510	01:10	
9	10Jun2020 0520	01:20	
10	10Jun2020 0530	01:30	
11	10Jun2020 0540	01:40	
12	10Jun2020 0550	01:50	
13	10Jun2020 0600	02:00	
14	10Jun2020 0610	02:10	
15	10Jun2020 0620	02:20	

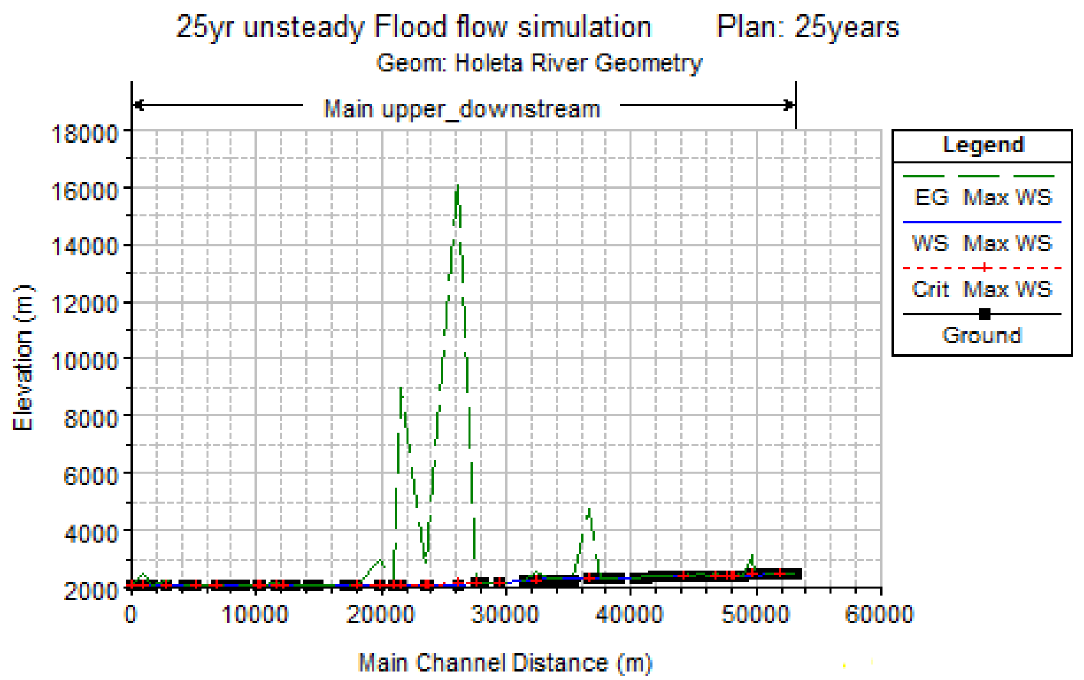
iii) Unsteady cross section

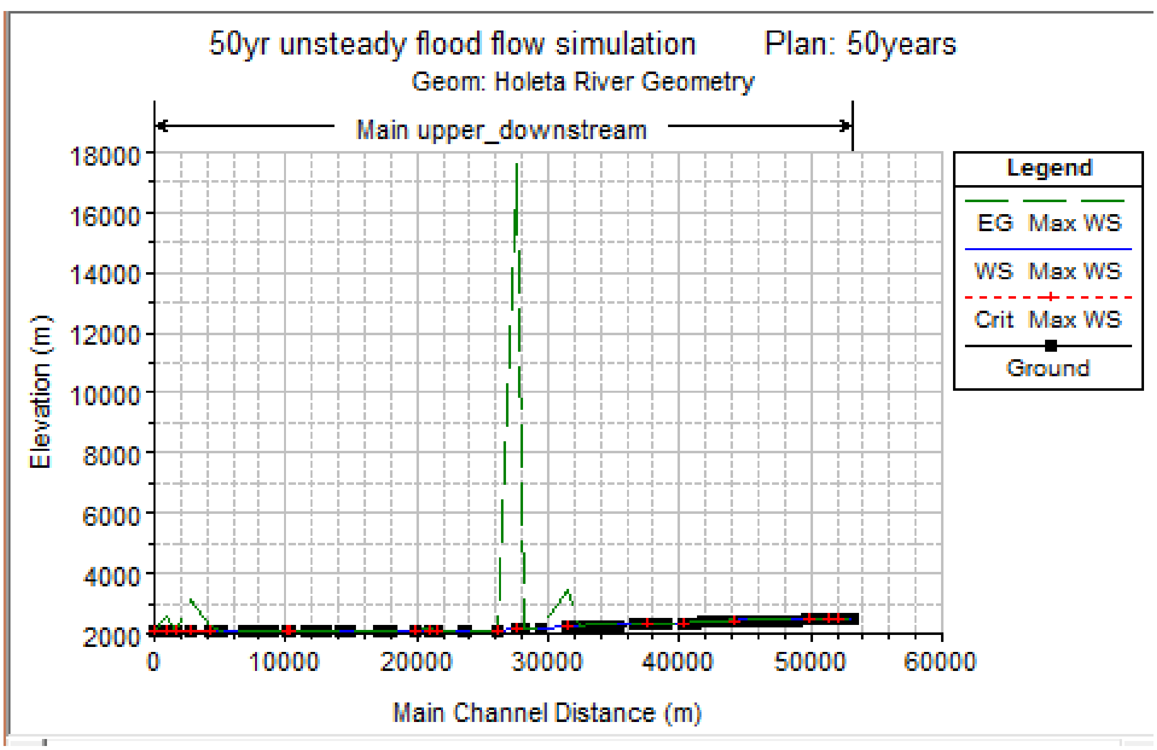


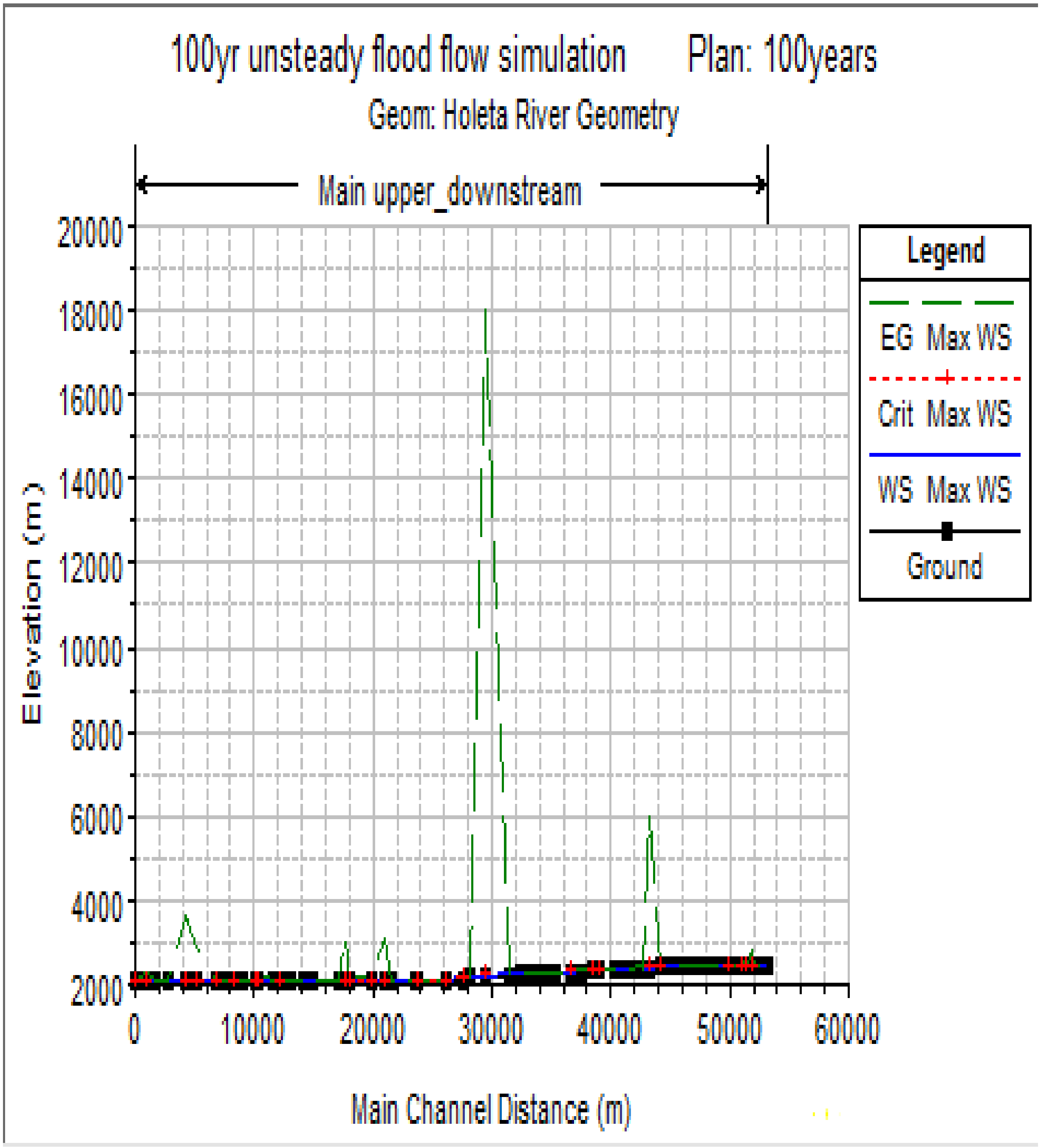



10yr unsteady flood flow simulation Plan: 10years
Geom: Holeta River Geometry
River = Main Reach = upper_downstream
.08
.08
.08
Elevation (m)
2082
2080
2078
2076
2074
2072
0
500
1000
1500
2000
2500
3000
Station (m)
Legend
EG Max WS
WS Max WS
Ground
Bank Sta

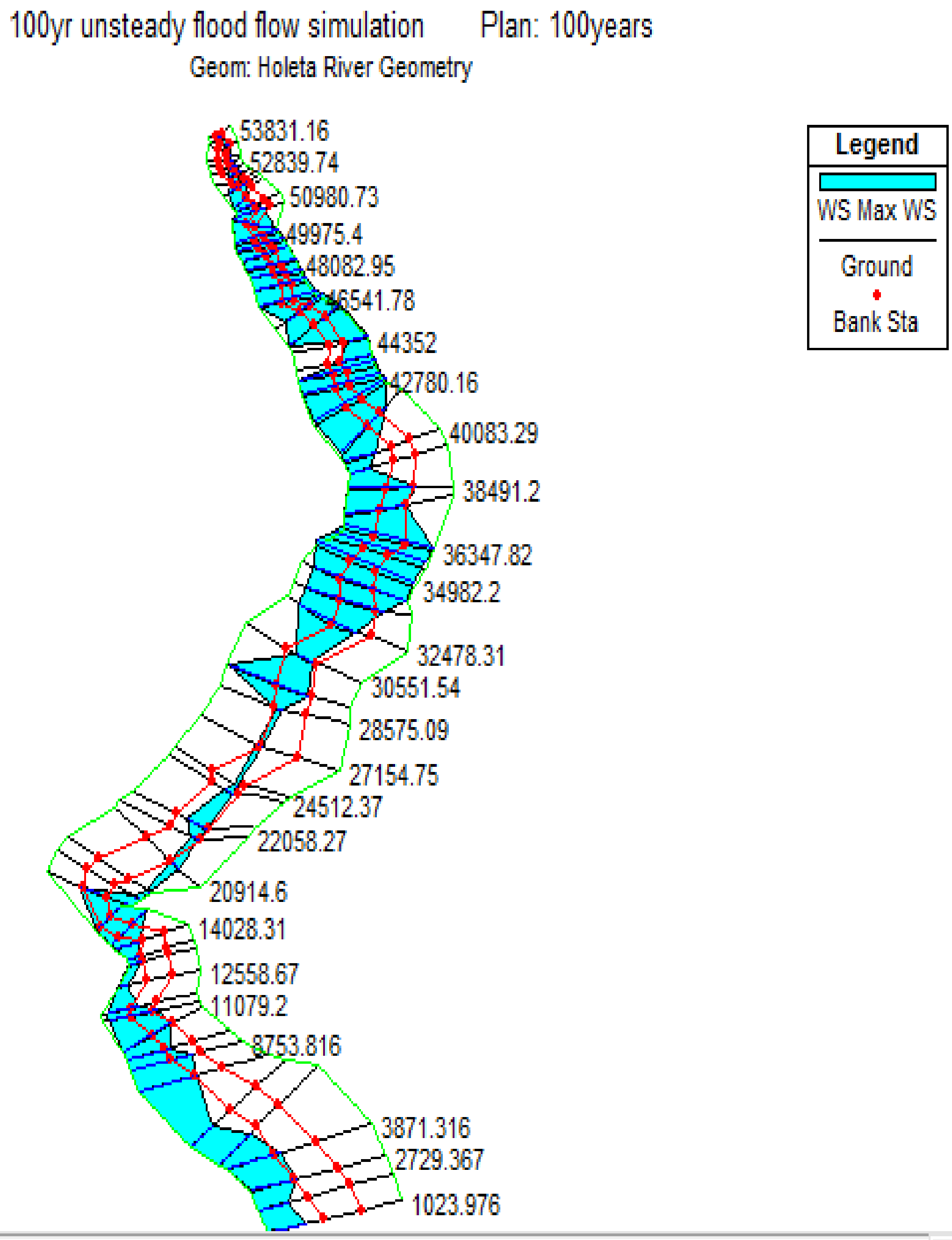

10yr unsteady flood flow simulation Plan: 10years
Geom: Holeta River Geometry
Main upper_downstream
Elevation (m)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)
Legend
EG Max WS
WS Max WS
Crit Max WS
Ground

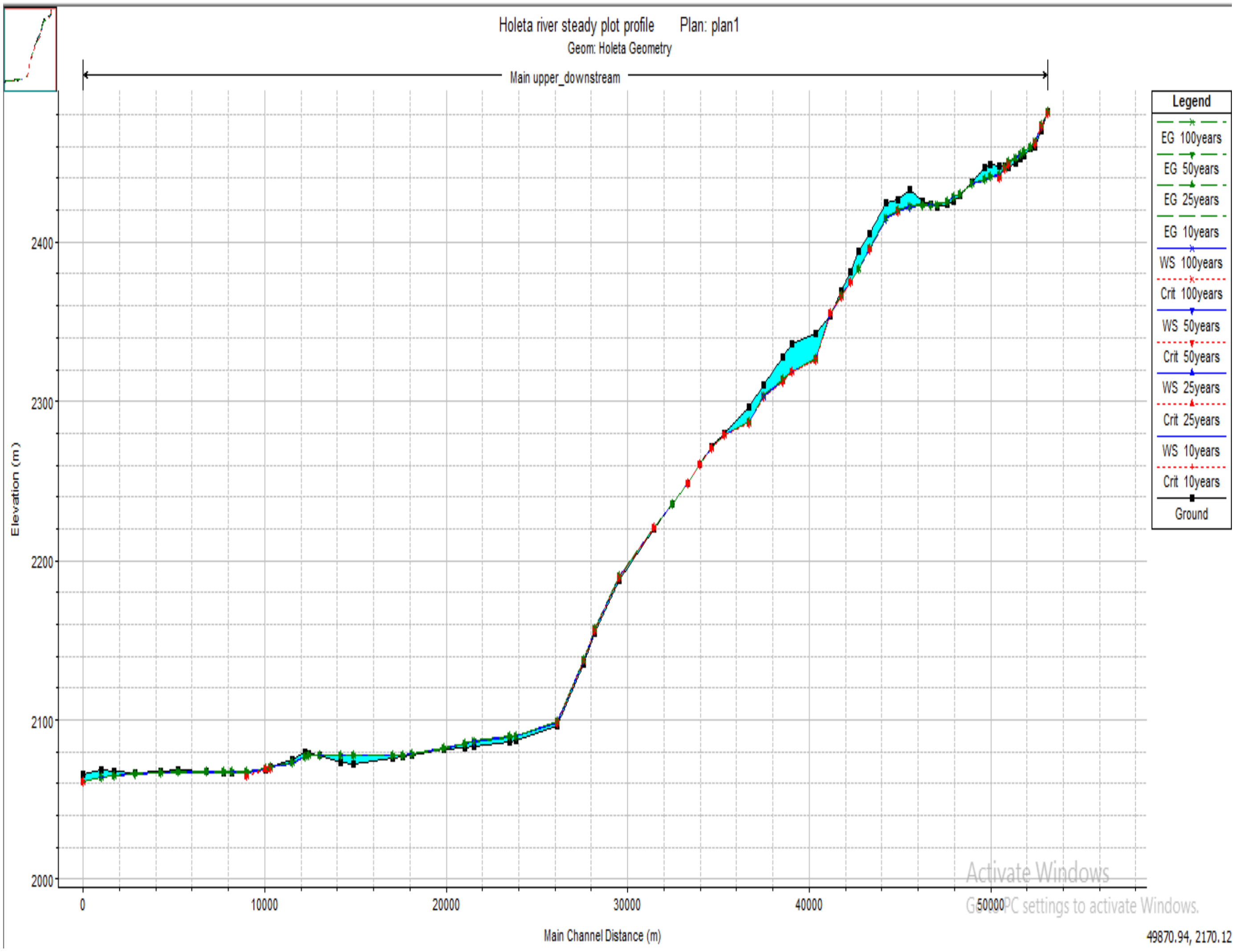

25yr unsteady Flood flow simulation Plan: 25years
Geom: Holeta River Geometry
Main upper_downstream
Legend
EG Max WS
WS Max WS
Crit Max WS
Ground
Elevation (m)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)


50yr unsteady flood flow simulation Plan: 50years
Geom: Holeta River Geometry
Main upper_downstream
Legend
EG Max WS
WS Max WS
Crit Max WS
Ground
Elevation (m)
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)


100yr unsteady flood flow simulation Plan: 100years
Geom: Holeta River Geometry
Main upper_downstream
Legend
EG Max WS
Crit Max WS
WS Max WS
Ground
Elevation (m)
20000
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
10000
20000
30000
40000
50000
60000
Main Channel Distance (m)

iv) X-Y-Z Perspective Plot and River station.





Holeta river steady plot profile Plan: plan1
Geom: Holeta Geometry
Main upper_downstream
Legend
EG 100years
EG 50years
EG 25years
EG 10years
WS 100years
Crit 100years
WS 50years
Crit 50years
WS 25years
Crit 25years
WS 10years
Crit 10years
Ground
Elevation (m)
2400
2300
2200
2100
2000
0
10000
20000
30000
40000
50000
Main Channel Distance (m)
49870.94, 2170.12
Activate Windows
Go to PC settings to activate Windows.