JIMMA UNIVERSITY
SCHOOL OF POST GRADUATE STUDIES
JIMMA INSTITUTE OF TECHNOLOGY
FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING
HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

RIVER MODELLING FOR FLOOD RISK MAP PREDICTION

CASE STUDY ON AWETU RIVER

By: Walabuma Oli

A Thesis submitted to Jimma Institute of Technology Faculty of Civil and Environmental Engineering Hydrology and Hydraulic Engineering Chair in Partial Fulfillment of the requirements for the Degree of Master of Science in Hydraulic Engineering

Jan, 2019
Jimma, Oromiya, Ethiopia

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Main advisor: Dr. Ing. Fikadu Fufa (associate professor)

Co advisor: Mohammed Hussen (m.sc.)

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Finally, I send my precious and honored full thanks to Jimma institute of technology staff and all my friends those who pay contribution from the commencement of this thesis to the end.

DECLARATION

I hereby declare that, this thesis is my original work and has not been presented for any degree in any other university or which has not been accepted for award of any other academic degree of the university, except I have been used their materials as reference with thankful review in the reference of this document.

Walabuma Oli ………………….. ……………………….

Name Signature date

This thesis has been submitted for examination with my approval as university main advisor

Dr.Ing Fikadu Fufa ……………………. ……………………..

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This thesis has been submitted for examination with my approval as university co-advisor

Mohammed Hussen (Msc) …………………… …………………….

Name Signature date

ABSTRACT

Floods are the most critical among all the natural calamities in world causing vast damages to life and property. In Ethiopia many areas are under flood problem and Jimma is like other tropical cities in Ethiopia facing flash flood so flood hazard and risk mapping is important. The HEC-HMS hydrologic modeling system software requires hydrological data for rainfall runoff modeling. The hydrological data of 16 years (i.e. 1995-2011) were collected from Ethiopian meteorological agency and ministry of water, irrigation and energy. Normal ratio method was used for filling missing value of precipitation data and data consistency was checked up using double mass curve. Other parameters like curve number and basin lag time were generated using Hydrologic Engineering Center-Geo spatial Hydrologic Modeling System which is an interface between Arc Geographic Information System and HEC-HMS. Soil Conservation Service-Curve Number, Soil Conservation Service-Unit Hydrograph, monthly constant and Muskingum methods were chosen for precipitation loss modeling, excess precipitation transformation to direct runoff, base flow modeling and flood routing respectively. Among the collected a 16 years hydro-meteorological data for rainfall runoff modeling, 10 events (1995-2005) were used for model calibration and 6 events (2006-2011) were used for model validation. The model performance was evaluated using performance measuring techniques including Nash Sutcliff Efficiency (NSE) and Coefficient of Determination (R^2). Nash Sutcliff Efficiency during calibration and validation was 0.77 and 0.7 respectively whereas coefficient of determination during these two processes was 0.96 and 0.99 respectively. After the evaluation of model performance, it was concluded that HEC-HMS indicated good performance for Awetu sub-basin rainfall runoff modeling. Flood frequency analysis conducted using HEC-HMS' frequency storm method for 25, 50,250 and 500 year return periods. The peak flood for each respective return periods were 13.2, 14.9, 18.9 and 21 m^3/s respectively. Flood inundation mapping was modeled for peak flood of each return period using HEC-RAS and inundation area 58.9ha, 60ha, 60.5ha and 71.7 ha respectively.

Key words: Awetu River, flood hazard map, flood risk map, HEC-HMS, HEC-RAS

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ACRONYMS

CN	Curve Number
DEM	Digital Elevation Model
DMC	Double Mass Curve
DTM	Digital Terrain Model
1D	One Dimension
2D	Two Dimension
ERA	Ethiopian Road Authority
GIS	Geographical Information System
Ha/ha	Hector
HEC-GeoRAS	Hydrologic Engineering Center Geospatial River Analysis System
HEC-HMS	Hydrologic Engineering Center Hydrologic Modeling System
HEC-RAS	Hydrologic Engineering Center River Analysis System
Hrs/hrs	Hours
IDF	Intensity Duration Frequency
MoWIE	Minister of Water, Irrigation and Energy
NMSA	National Meteorological Service Agency
RI	Recurrence Interval
RR	Rainfall Region
SCS	Soil Conservation System
TIN	Triangular Irregular Network
USACE	United State of America Center Engineering
USGS	Unite State Geological Survey

CHAPTER ONE

1 Introduction

1.1 Background

River flooding is a natural process and part of the hydrological cycle of rainfall, surface and groundwater flow and storage. Floods occur whenever the capacity of the natural or manmade drainage system is unable to cope with the volume of water generated by rainfall. Floods vary considerably in size and duration. With prolonged rain falling over wide areas rivers are fed by a network of ditches, streams and tributaries and flows build up to the point where the normal channel is overwhelmed and water floods onto surrounding areas. A flood is a hydrological event which is characterized by high discharges and/or water levels that could lead to inundation of land adjacent to streams, rivers, lakes and other water bodies. Flood events could be caused by of long-lasting rainfall, failure of a dam or embankment system, earthquakes, landslides and by human activities, including the operation of flood control systems. Most countries in the world experience floods and flooding. The risk flood causes is vast. This natural hazards cause damage to life, property and ecosystem [1].

Flooding is one of the major natural hazards in Ethiopia, owing to a national topography of mountainous highlands and lowland plains, with natural drainage systems formed by the principal river basins. Most flooding in the country is caused by river over flow, when prolonged rainfall causes rivers to overflow and inundate lowland plains. Flooding is one of the most destructive natural calamities, responsible for huge economic losses and many deaths. Floods are the most critical among all the natural disasters and nowadays there have been a number of significant riverine floods in the rest of the world, which resulted in tragic loss of life, in enormous infrastructure and the environment all over the world. Floods are excess flows exceeding the transporting capacity of river channel, lakes, ponds, reservoirs, drainage system, dam and any other water bodies, whereby water overwhelm outside water bodies area or flood is a continuous natural and recurring event in floodplains of monsoon rainfall areas like Ethiopia, where over 80% of annual precipitation falls in the four wet months (June -September) [2]. Natural risk is the probability of harmful consequences or expected loss of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged resulting from interactions between natural or human-induced hazards and vulnerable conditions [3].

Flood risk is the combination of the probability of a flood event and of the potential adverse consequences to human health, the environment and economic activity associated with a flood event whereas a flood hazard is a natural phenomenon with certain reoccurrence intervals. The risk is based on both, the hazard and vulnerabilities. Flood hazard maps are detailed flood plain maps complemented with: type of flood, the flood extent; water depths or water level, flow velocity or the relevant water flow direction and flood risk maps indicate potential adverse consequences associated with floods under several probabilities expressed in terms of the indicative number of inhabitants potentially affected; type of economic activity of the area potentially affected and installation which might cause accidental pollution in case of flooding. Flood risk maps can generate awareness in the population and especially among local people to support land-use planners and investors to decrease the overall flood risk. Risk is sometimes taken as synonymous with hazard, but risk has additional implication of the chance and probability a particular hazard actually occurring and hazard refers to the probability of a potentially dangerous phenomenon occurring in a given location within a specified period of time [2]. River flood mapping is the process of determining inundation extents and depth by comparing river water levels with ground elevation. The process requires the understanding of flow dynamics over the river and the adjacent floodplain, topographic relationships and the sound judgments of the modeler. In fact, river flood mapping is the foundation of river flood risk prediction, which can be produced using water depth, flood extent, flow velocity and flood duration maps [4].

For the past 50 years’ flood-related disasters in Africa shows an increasing trend and since 1981, floods account about 50% of the disaster recorded in Sub-Saharan Africa [1]. River flood modelling is a combination of hydrological modelling, hydraulic modelling and river flood visualization using GIS. The complex configuration of a typical urban area introduces uncertainties in the production of flood hazard map and risk map. In this context, cities and towns which concentrate the majority of the economic activity and hence flood impact becomes more severe should have a special treatment for flood risk management plans.

1.2 Statement of the problem

Flooding, as a natural phenomenon, has been occurred in many part of Ethiopia. By the end of August 2006, at least 75 woredas in eight regions had been affected by the flood according to report by Ethiopian government disaster prevention and preparedness agency, more than 500,000 people were vulnerable and about 200,000 people had been affected, with 639 deaths. Thousands of live stocks were killed, 228 tons of harvested crops were washed away, 147 tons of export coffee beans were lost (and machinery ruined), 42,229 ha of crop land were inundated [5]. Traditionally flood risk is analyzed using flood extent parameter only; however, flood extent map does not provide flood risk extent, i.e. flood risk analyzed by flood extent only under estimate flood risk level. With advancement in hydrodynamic flood modeling it is possible to model flood depth, velocity and duration. These results of hydrodynamic model are used in the analysis of flood risk.

River modeling provide better option and flexibility in understanding the flood prone area in flooding process, it requires good representation of topography as an accurate Digital Terrain Model (DTM). Presently; most of the modelling efforts have been made using latest and radar elevation data sources. However medium scale local authorities in developing countries like Ethiopia are in capable of acquiring such data due to financial support and skills involved in pre-processing. With the fast growing of population, floods are the causes of major destruction of property, buildings infrastructures in Ethiopia and this problems is getting worse and worse in urban areas due to high rate of urbanization in country. River flood flow is influenced by several cross-sectional morphology factors, such as the channel slope and the cross-sectional representation of the geometry. This has led to urban flooding due to lack of in adequate drainage system, paved surfaces or asphalts and its effects is high with the higher raindrop intensity on town. The cause of this flood in Ethiopia is heavy rain and mountainous topography. Rivers overflow or burst their banks and inundate downstream plain lands. The heavy rains falling on the upstream highlands cause most rivers to swell and breach their courses, submerging the surrounding floodplains. Jimma town which is surrounded by steep or hilly topography is subject to frequent flooding in rain season .The over flooding of Awetu river by storm and rain water runoff resulting in the heavy rain in the river has leading to overturning (water overwhelm outside water bodies area) happened in Bishishe in the year 2017.Awetu is one of the 13 kebeles of Jimma town located at a lower elevation which is directly affected by surface runoff water from Jiren mountain of Awetu catchment area.

1.3 Objective of the study

1.3.1 General objective

The general object of this study was modelling Awetu River for flood risk map prediction.

1.3.2 Specific objectives

The specific objectives of the study were:-

- to provide consistent information on surface water flood risk ;
- to develop flood hazard and risk map of the Awetu Catchment;
- to identify the areas within a development plan that is at risk of flooding.

1.4 Research questions

The finding was answer the following questions

What are the main surface flood causative factors in Awetu Catchment?

What is flood hazard and risk map?

What areas are most vulnerable to flood risk in Awetu basin, Jimma town?

1.5 Significance of the study

The significance of the study was to modeling flood risk map in flood prone area and the incident of flood on infrastructure, ecosystem, and biotic system and helpful for the planners, decision makers and any concerned bodies to understand the consequences of flood on hydrological and hydraulic variables also to provide the public and other customers with easy access to consistent information on surface flood risk enabling them to make better informed decision. Consequently, it could be a way to secure economic activities and investment. In addition, the most important outcome was improving flood risk management as result of the production good flood risk maps. These flood risk maps can help to decrease the amount of flood damages.

CHAPTER TWO

2 LITERATURE REVIEW

2.1 River Flood

Water is universal concern, interest and the study of its movement and distribution through the hydrological cycle forms the basis of Hydrology. Water is a basic requirement for sustaining life and development of society. Proper management, protection and development of the water resources are challenges imposed by population growth, increasing pressure on the water and land resources by competing usage, and degradation of scarce water resources in many parts of the world. River flood is a high flow that exceeds or over-tops the capacity of the natural or the artificial banks of a stream [6]. Some of the most important factors that determine the features of floods are rainfall event characteristics, depth of the flood, the velocity of the flow, and duration of the rainfall event [7]. Floods are the most damaging phenomena that effect to the social and economic of the population [8].

2.2 Hazard, Vulnerability and Risk

Natural hazards and disasters are the products of an interaction between numerous aspects, such as climatic, social, economic, institutional and technical, that are differently addressed for rural and urban conditions [9]. An environmental approach to flood hazards is based on the view that both social and physical environments influence the creation of flood hazards and disasters. Risk is the product of the threatening natural event including its probability/magnitude of occurrence (Hazard); the values/humans that are present at the location involved (Exposure); and the lack of resistance to damaging/destructive forces (Vulnerability). A hazard does not automatically lead to a harmful outcome, but identification of a hazard does mean that there is a possibility of harm occurring, with the actual harm depending upon the exposure to the hazard and the characteristics of the receptor. Vulnerability to flood disasters comes through various forms: exposure to floods as a result of locating in flood-prone areas, occupying a dwelling which has little resistance to floods, the quality of buildings, lack of protections from floods, weaknesses of the population related to age, gender, health status, infirmity. Inability to avoid or recover from a flood disaster and low levels of protection or assistance are also contributory social factors. Both vulnerability and exposure to floods are viewed as key causal factors of risk: the approach involves evaluating the full range of traditional approaches to flood hazard and disasters as well as modern technological ones. This kind of approach involves viewing the problems of flood hazards, disasters and long-term safety survivability within the context of sustainable development. Sustainable communities are those that are able to weigh up these risks and seek to reduce the vulnerability of their people to natural hazards, so they seek to build social and economical resilience to disaster [10]. Moreover, central to the concept of hazard is the notion that humans interface with floods: a flood is not hazardous unless humans are somehow affected and takes this further by stating that a hazard refers to the potential for damage that exists only in the presence of a vulnerable human community [11]. Flood exposure is a measure of the human population, land uses and investment located in flood zones and at risk of flooding, and increasing exposure is a prime, contributory cause of flood hazards and disasters.

A common method of measuring flood exposure is to count the number of properties of different types that occupy a floodplain or other flood risk area such as flood prone zone. There is substantial evidence from different parts of the world that exposure to floods is growing rapidly as human occupation of floodplains and flood-prone zones intensifies. Floodplains are flood-prone areas they have been sought as sites for urban development because of the facilities they offer, including access to a source of water for a variety of uses. Cities have been permanently developing their water-related infrastructure and discharging their urban waters into the nearest water body [9]. The development of urbanization and activities has continued, although this expansion represents a hazard if the vulnerability of those activities exceeds an acceptable level. The possible interaction between human use of the floodplain and the onset of a flood event potentially creates a natural risk. In fact a disaster exists once a flood occurs, depending on the amount of property damage, disruption and loss of lives. As urban areas grow, both geographically and demographically, the flood hazard and risk increase in part because there is more exposure, but also the process of urbanization itself alters local hydrologic characteristics [12]. The urban sprawl in metropolitan areas along large rivers causes an increasing claim on space that is merely used as floodplain and consequently spread of building activities in places not suitable for building.

This mutual expansion increases the vulnerability of urban areas to flooding and therefore the social and economic damage in case of a disastrous flood event. Consequently, the responsible authorities are required to adapt their policies in order to combine flood management measures, spatial development and new strategies on protection standards. In order to evaluate the changes of risk, it is necessary to examine the increasing exposure to floods and the damage potential losses resulting from these floods [13]. Risk is widely recognized as precisely what it implies as a possibility and often referred in term of probability [3]. Risk also can be defined as the probability of harmful consequences or expected loss of lives, people injured, property, livelihoods, economic activity disrupted or environment damaged resulting from interactions between natural or human-induced hazards and vulnerable conditions. Overbank floods resulting from high flows have important socio-economic consequences all over the world. During the period from 2001 to 2014, more than a billion of the world's people were affected by flooding, and almost 80 thousand died [14].

2.3 Factors Contributing to River Flood and Type of Flood

The most important parameters influencing flood impact are: Water depth, Duration of flooding, Flow velocity, Sediment concentration, Sediment size, Wave or wind action, and Pollution load of flood water and Rate of water rise during flood onset [15] .There are many different types of flooding. The most common types are: river floods, flash floods, coastal floods, urban floods and ice jams. Every year, floods claim many lives and adversely affect around 75 million of people worldwide. The reason lies in the widespread geographical distribution of river floodplains and low-lying coasts, together with their long-standing attractions for human settlement [16].

There is a relationship between urbanization and hydrological characteristics, like decrease of infiltration, increase of overland flow, increase in frequency and height of flood peak, increase in range of discharge variability and decrease lag time. The dangers of floodwaters are associated with a number of different characteristics of the flood such as depth of water, duration, velocity, sediment load, rate of rise and frequency of occurrence [17]. The main hydrologic-hydraulic factors giving rise to flooding are relief, type and intensity of precipitation, vegetation cover, drainage capacity, geology, river morphology with extension of channel and floodplain, channel-floodplain interaction and roughness.

2.4 River Flood Modelling

To minimize the socio-economic impacts of flooding, solutions for preventing/minimizing it have consisted of either structural or non-structural measures. Usually, non-structural measures are financially more viable, focusing on prevention and conservation to give better harmony between the environment and urban areas along the river [18].One of the more widely known non-structural measures was the mapping of areas susceptible to flooding, a financially viable option which is useful in risk studies. Flood risk maps was an intermediate step and flood hazard maps in an initial step prerequisite in order to devise flood management plans. It should be clarified that flood hazard maps are the maps presenting the inundation area with the maximum depths and velocities at every point of the area, whereas flood risk maps are the maps presenting the projected damage losses encountered in the area [19].

Flood mapping commonly uses 1D and 2D hydraulic mathematical models are conceptual or empirical to represent the hydraulic phenomena that determine water-levels (1D and 2D) and flood areas. These hydraulic models can also be coupled to hydrological models to give a complete conceptual representation of all the processes involved [20]. The coupling of hydrological and hydraulic models has been a valuable tool in flood studies because it enables future scenarios to be simulated from limited input data. Hydraulic modelling requires information that adequately represents flooded areas, including data or estimates of flows upstream of the reach of interest and good quality data on regional topography and bathymetry [21]. Lack of adequate topographic and bathymetric data can cause problems for the description of flooded areas given by the hydraulic model, because the channel bed and morphology of the region adjacent to the water-course are inadequately represented [22].

2.5 Computer Models

Geographical Information System (GIS) is a computer system build to capture, store, manipulate, analyze, manage and display all kinds of spatial or geographical data. GIS applications are tools that allow end users to perform spatial query, analysis, edit spatial data and create hard copy maps. GIS is an image that is referenced to the earth or has x and y coordinate and its attribute values are stored in the table. A number of studies are utilized the technique of GIS and DEM or numerically and qualitatively describing the spatial characteristics of drainage basins that are applicable for statistical, comparative and analytical analyses. In this study topographical data, soil data and meteorological data are common inputs for GIS based processing. River flood mapping involves, GIS interface as pre-processor to extract geospatial data and post-processor to visualize model outputs Hydrologic Engineer Center Geospatial Hydrologic System (HEC-GeoHMS) and Hydrologic Engineer Center Geospatial River Analysis

System (HEC-GeoRAS). Hydrological model, which develops rainfall-runoff hydrograph from a design rainfall or historic rainfall event and Hydraulic model, which routes the runoff through river channel to determine water profiles and flow velocity [23].Flood inundation models are required to understand, assess and predict flood events and their impact in the areas. Recent years have shown systematic improvement in the capability of flood inundation modelling and mapping [24]. The results from hydraulic models can be used in flood risk mapping, flood damage assessment, real time flood forecasting, flood related engineering, water resource planning, investigating flood plain erosion and sediment transport, floodplain ecology, river system hydrology [24]. However accurate flood modelling at high spatio-temporal resolutions still remains a significant challenge in any hydrologic and hydraulic studies. This is mainly due to the complex and chaotic nature of flooding and uncertainty associated with the conceptualization of processes and the modelling parameters itself. Good inundation maps could help in designing the flood risk management strategies and their implementations. Preparedness activities and timely response can be undertaken if the forecast information comes with the level of impact of flood. Even for recovery and damage assessment, flood risk mapping plays a crucial role.

CHAPTER THREE

3 MATERIALS AND METHODOLOGY

3.1 Study Area

The study was conducted in Jimma town, Oromiya National Regional State of Ethiopia. The town is located 346 km away from capital city Addis Ababa (Finfine) Ethiopia. The center of the town approximately situate at geographic coordinate of 7^0 $40^{'}$ N latitude and 36^0 49’ $59^{''}$ E longitudes. The town occupies a total area of nearly 4623 hectares, of which about 26% is a residential area. Jimma has a warm and humid climate with daily average temperature of 20^{o}C and mean annual rainfall varying between 1450 and 1800 mm [25]. Topographically it exhibits features of the upper part of the Omo Gibe river basin, made up of gentle slopping. Based on the 2007 Ethiopian Population Census conducted by Central Statistical Agency of Ethiopia, the town has a total population of 120,960 of which 60824 are men and 60136 are women. The main economic activities are commerce, small scale manufacturing enterprises and industries are account 70% [26].

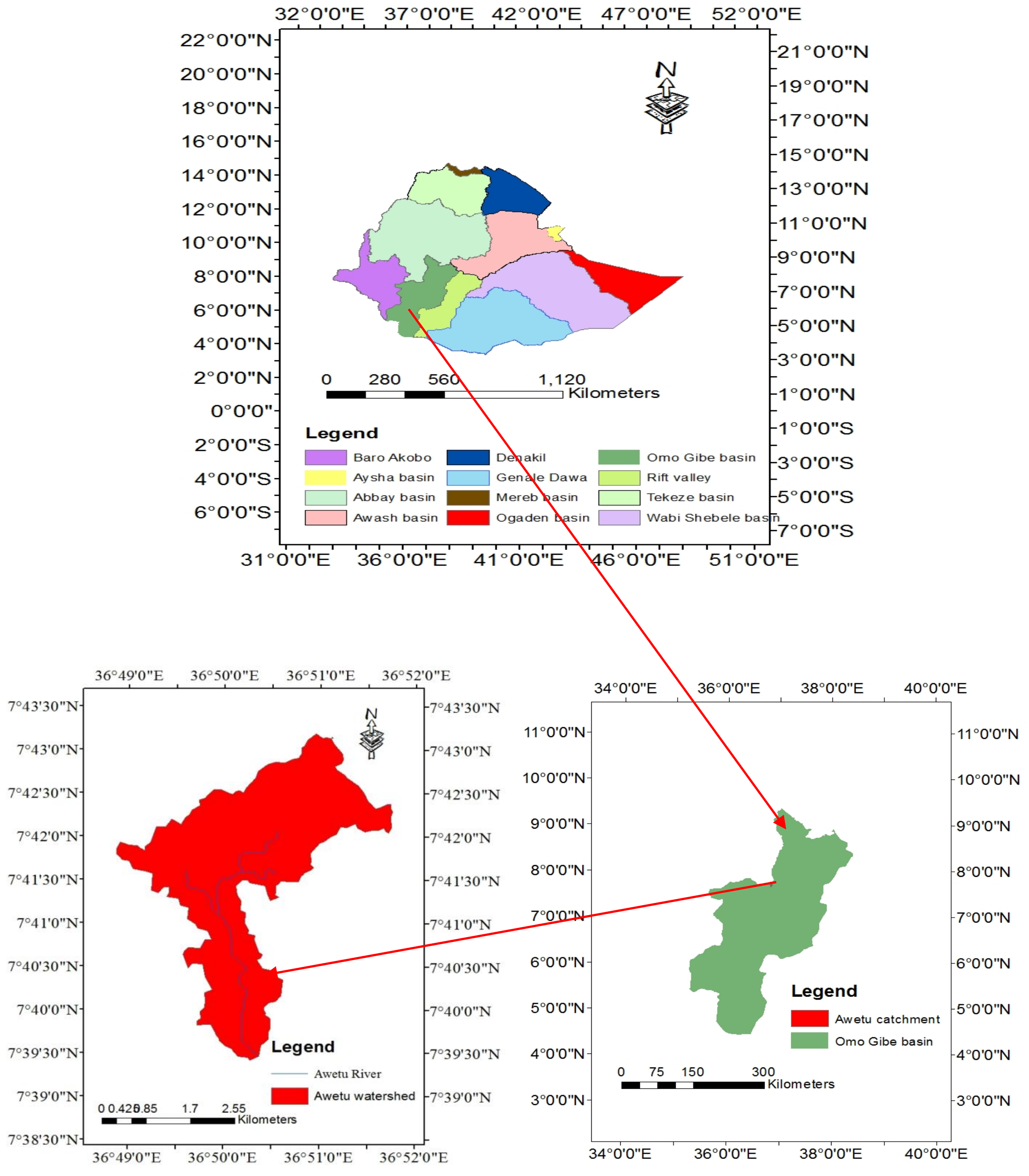


Figure 3.1: Location of Study Area.

3.2 Data Acquisition and Analysis

A good understanding of the topographical, hydrological and climatic condition of the study area and proper set of data defining them are very important for analysing and replicating the actual hydrologic and hydraulic situation. Type of data used and its sources was given in (table 3.1). Further, the quality of data used for modelling directly affects the output, so the collected data should be screened and processed before using them.

Table 3.1: Type of collected data and sources

Data type	Data source	Period	Remark
Stream flow	MoWIE	1995-2011	Full data
LULC and Soil	MoWIE	2013	
Precipitation	NMSA	1995-2011	Some data missing
DEM(30m*30m) resolution	Downloaded from USGS website		

3.2.1 Flow data

Before beginning any hydrological analysis it is important to make sure that data are homogenous, correct, sufficient, and complete with no missing values. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers [27]. Generally, data should be appropriately adjusted for inconsistency, corrected for errors, extended for insufficient, and filled for missing using different techniques. Basically a clear understanding of the hydro-meteorological conditions of the area is one of the basic requirements of any water resource management study. The daily discharge of the study area is collected from the Ministry of Water, Irrigation and Energy. Unlike the daily precipitation, the daily discharge has full data composition for the considered station to represent the study area. The discharge gage is located at out let of Awetu River down side where the downstream end is considered flood prone. For this particular research the stream flow for 16 year (1995-2011) from Minister of water, irrigation and energy and its hydrograph for Awetu River shown in Figure (3.2).

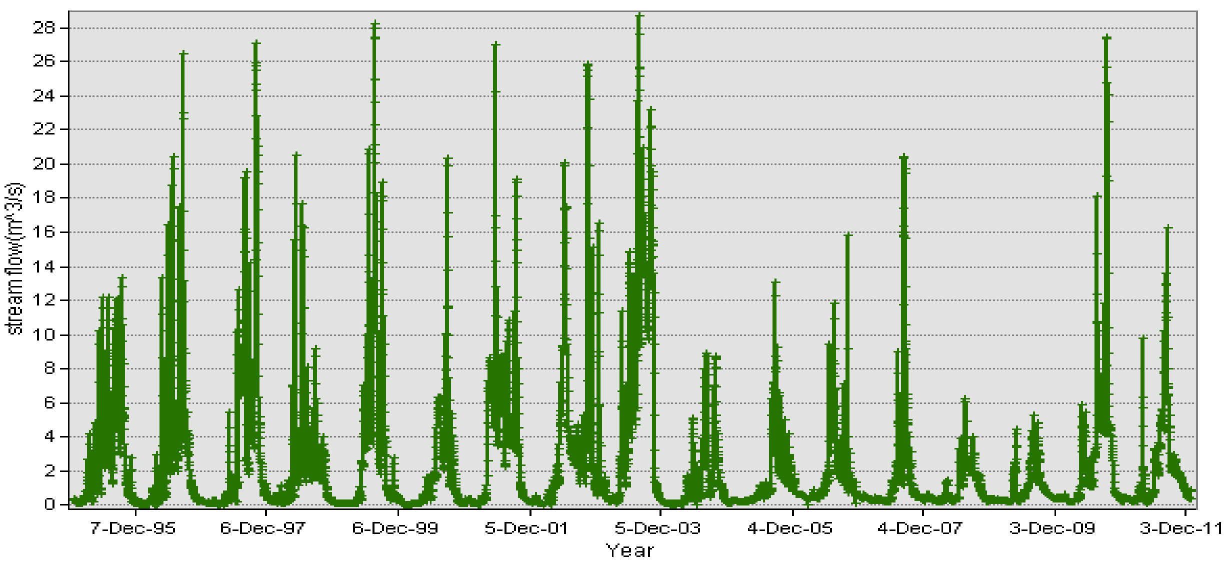


Figure 3.2: Stream flow Hydrograph of Awetu River.

3.2.2 Filling Missing Precipitation

A number of methods have been proposed for estimating missing precipitation. The station average method is the simplest one. The normal ratio and quadrant method provide a weighted mean, with the former biasing the weights on mean annual precipitation at each gauge and the later having weights that depend on the distance between gauges where recorded data are available and the point where the value is required. The Isohyetal method is the fourth alternative. Normal ratio method was used in this research paper. The method is used when the normal annual precipitation of the index stations differ by more than 10% of the missing stations [28]. This is the case for the stations near the study area and their recorded years were given in table (3.2).

Table 3.2: Stations near the study area and their recorded years

S/No.	Station name	Year
1	Jimma	1995-2011
2	Jiren Aba Jifar	1995-2011
3	Seka Coqorsa	1995-2011
4	Limu Genet	1995-2011

The general formula for computing missing precipitation by this method was:

$$P_X = \frac{N_X}{4}\left[\frac{P_1}{1} + \frac{P_2}{2} + \frac{P_3}{3} + \frac{P_4}{4}\right] \qquad \text{……………………………………………………..……3.1}$$

Where P_x = is the precipitation for the station with missing records.

P_1, P_2, P3 and $P_4$are the adjacent stations precipitation values.

N_1, N_2, N_3 and $N_4$are the long-term mean annual precipitation values at the respective stations and 4 is the number of stations surrounding the station X.

3.2.3 Checking the consistency of data

Estimating missing precipitation is one problem that hydrologists need to address. Second problem occurs when the catchment rainfall at rain gages is inconsistent over a period of time and adjustment of the measured data is necessary to provide a consistent record. A consistent record is one where the characteristics of the record have not changed with time. Inconsistency may result from: change in gauge location, exposure, instrumentation, or an observational procedure is not real and on time. To overcome the problem in consistency a technique most widely applied called double mass curve was used. Double-Mass Curve (DMC) analysis is a graphical method for identifying or adjusting inconsistencies in a station record by comparing its time trend with those of other stations nearby [29]. Sometimes a significant change may occur in and around a particular rain gage station. Such a change occurring in a particular year was start affecting the rain gauge data, being reported from that particular station. After a number of years it may be felt that the data of station is not giving consistent rainfall values.

In order to detect any such inconsistency, and to correct and adjust the reported rainfall values a technique, called double mass curve method is generally a doubted. Proportionality between the measurements at the suspect station and those in the region is reflected in a change in the scope of the trend of the plotted points. The data series, which is inconsistent, adjusted to consistent values by proportionality. Double mass curve plot made for all four stations. The curve is a plot of rainfall record of a station and cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region. The data is arranged in the reverse order that is the latest record as the first entry and the oldest record as the last entry in the list. The use of the double-mass curve for checking the consistency of precipitation records is explained by the following example in which the annual records of four precipitation stations. First the annual precipitation data for each year are tabulated and then cumulated in chronological order. The cumulative precipitation for each station is then plotted against the cumulative precipitation of the pattern. Double mass curve plot made for all four metrological stations shown in figure (3.3). From the double mass curve figures the stations were consistent to each other.

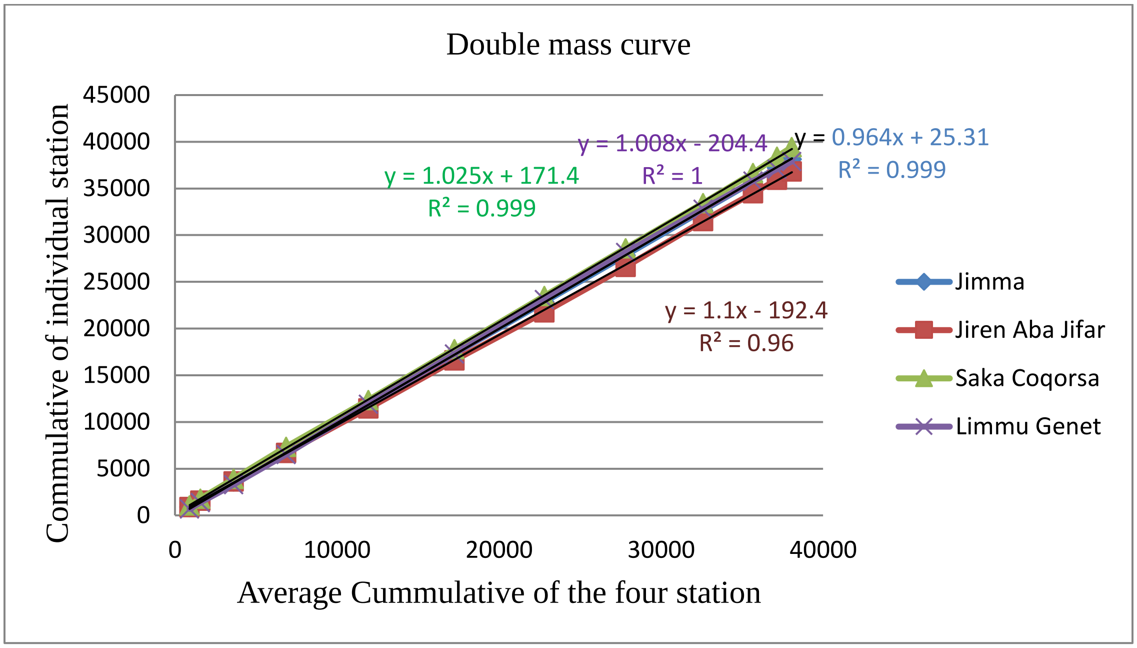


Figure 3.3: Double mass curve for consistency check.

3.2.4 DEM and its processing

Before performing any spatial analysis of a river basin, first prepare a three-dimensional replication of the catchment. DEM is a sampled array of elevations for a number of ground positions at regular spaced intervals. DEM describes the elevation of any point in the study area in digital format and contains the information on drainage, crest and breaks of slopes. DEM is the primary spatial data source based on which GeoHMS extract catchments boundary, topographic variables such as basin geometry, stream networks, slope aspect, flow direction, etc. This study used a 30m resolution DEM show in figure (3.4). Stream and watershed delineation are generated using HEC-GeoHMS extension. A DEM is a specialized database that represents the relief of a surface between points of known elevation.GIS software can use DEM for 3D surface visualization, generating contours, and performing view shed visibility analysis. The DEM was a fundamental dataset used for development of the basin model component in the HEC-HMS model and the geometrical data model in the HEC-RAS model. This dataset was therefore useful in hydrological modeling, hydraulic modeling, and flood hazard and risk map generation.

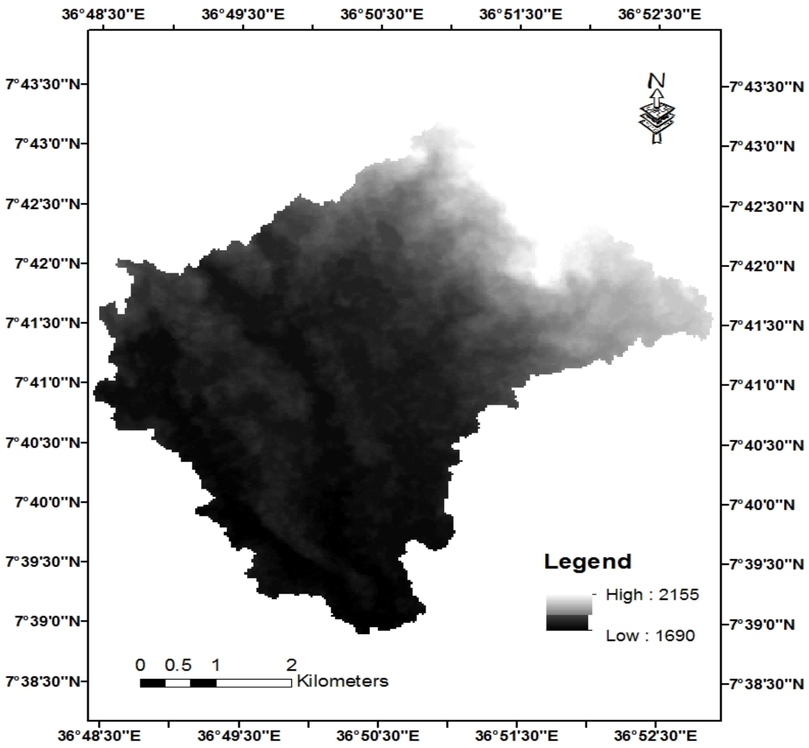


Figure 3.4: 30m*30m resolution Awetu DEM.

3.2.5 Spatial Analysis (Terrain processing)

Terrain processing is used to generate hydrologic parameters using DEM. Hydrologic derivatives including fill sink, flow direction, flow accumulations, watershed sub delineations and stream segmentations, and every stream segment defined by stream segmentation grid and following delineation of corresponding watershed. Based on the above computational steps, three vector layers were created to complete the terrain processing. The first vector layers created were catchment polygon, drainage line and finally adjoin catchment that make the upstream sub-basins are aggregated at any stream confluence. After completing terrain processing the project point or the out let point of the catchment was defined.

Reach parameters were extracted from HEC-GeoRAS. Beside the movement of excess precipitation over the land surface, flow with in a river channel and flood banks are required to predict the rate at which water will flow through a given point in the stream during hydrologic stream routing. Dividing the watershed into sub basins linked with channel reaches were the first step of constructing a semi-distributed model configuration.

In this approach the main stream in each sub basin divided into reaches depending on the slope homogeneity and the length of the reach, the generated discharge from the contributing area in each sub basin is added to the routed stream flow at the end of each channel reach. The physical characteristics of watershed and river like sub-basin area, river length, river slope, stream invert profile, and sub basin centroid location. Elevation, longest flow path for each sub basin length along the stream path from the centroid to the sub basin outlet, channel shape including the principal dimension of channel cross section and channel side slope extracted for implementing model in HEC-HMS. In order to access such physical characteristics of the natural channel, the extension of Arc View GIS developed by USACE, HEC-GeoRAS were used. The study mainly deals with preprocessing and spatial analysis of the DEM for delineation of sub basins and river. GIS extension tools have been used for the extraction of physical characteristics of sub basin and rivers. The geospatial hydrologic modeling (HEC-GeoHMS) extension is software using with GIS for terrain processing and to calculate the physical characteristics of the sub basin. The tool has been used to perform stream and sub basin delineation and calculates many physical character and finally simulate the flow using HEC-HMS.

3.2.6 Study area delineation: HEC-Geo HMS

HEC-GeoHMS extension is software using with GIS for terrain processing and to calculate the physical characteristics of the sub basin. HEC-Geo HMS provides the connection for translating GIS spatial information in to model files for HEC-HMS. The GIS capability is for data formatting, processing and coordinate transformation. Currently, HEC-Geo HMS operates on DEM to derive sub-basin delineation and to prepare a number of hydrologic input files. HEC-HMS supports these hydrologic inputs as starting point for hydrologic modeling. In this study it is intended to derive parameters like: Curve Number, Basin Lag, Time of concentration ,Loss also it used to extract basin characteristics such basin slope, elevation, basin length, river length, stream network, drainage network, longest flow path and finally delineate watershed for the specified study area. HEC-Geo HMS has been developed as a geospatial hydrology tool kit for engineers and hydrologist.

The program is an extension of Arc GIS and allows users to visualize spatial information, document watershed characteristics, perform spatial analysis, delineate sub-basins and streams, construct inputs to hydrologic models, and assist with report preparation. Eight data sets can be derived from DEM that collectively describe the drainage patterns of the watershed [30].

HEC-Geo HMS provides the connection for translating GIS spatial information into hydrologic models. The end result of the GIS processing is a spatial hydrology database that consists of the DEM, soil types, land use information, rainfall, etc. HEC-Geo HMS operates on the DEM to derive sub-basin delineation and to prepare a number of hydrologic inputs. HEC-HMS accepts the hydrologic input files as a starting boundary condition for hydrologic modeling system. HEC-Geo HMS consists of different menus that provide different functions specially, during preprocessing in Arc GIS work environment. These menus are: preprocessing, project setup, basin processing, basin characteristics, basin parameters, HMS and utility, etc. HEC-Geo HMS is an Arc GIS extension that used as a graphical user interface between GIS and HEC-HMS. For this study HEC-Geo HMS 10.2 which is compatible with Arc GIS 10.2 was downloaded from USACE web site. All the menus of HEC-Geo HMS are processed as indicated by the following work flow diagram shown in figure (3.5).

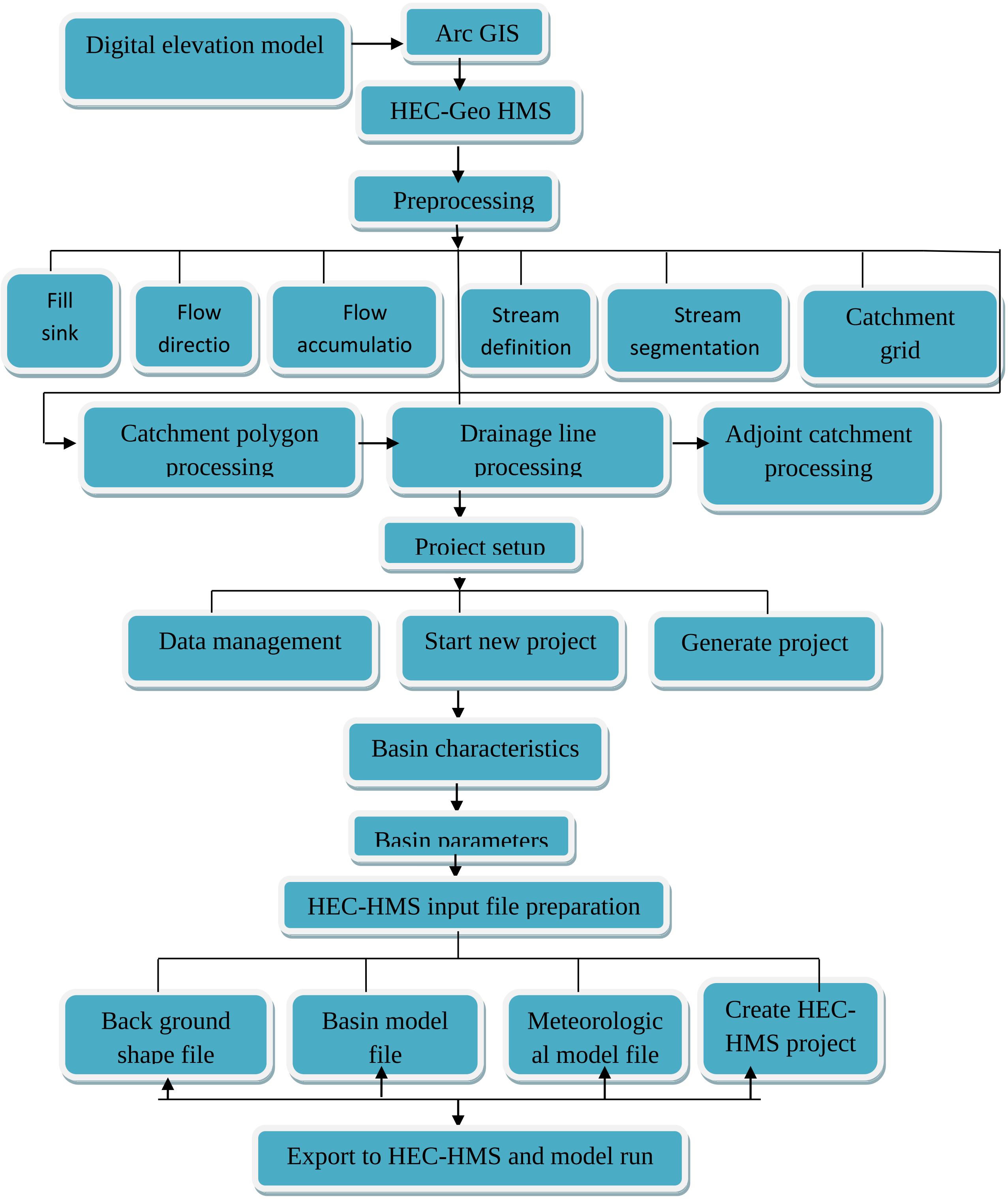


Figure3.5: HEC-GeoHMS preprocessing work flow diagram

After the successful completion of HEC-Geo HMS processing as indicated by the above work flow diagram, back ground shape file, Basin model file, Met model file and Gage model file together with watershed hydrologic elements were exported to HEC-HMS to use as an input file for further analysis as shown in figure (3.6).

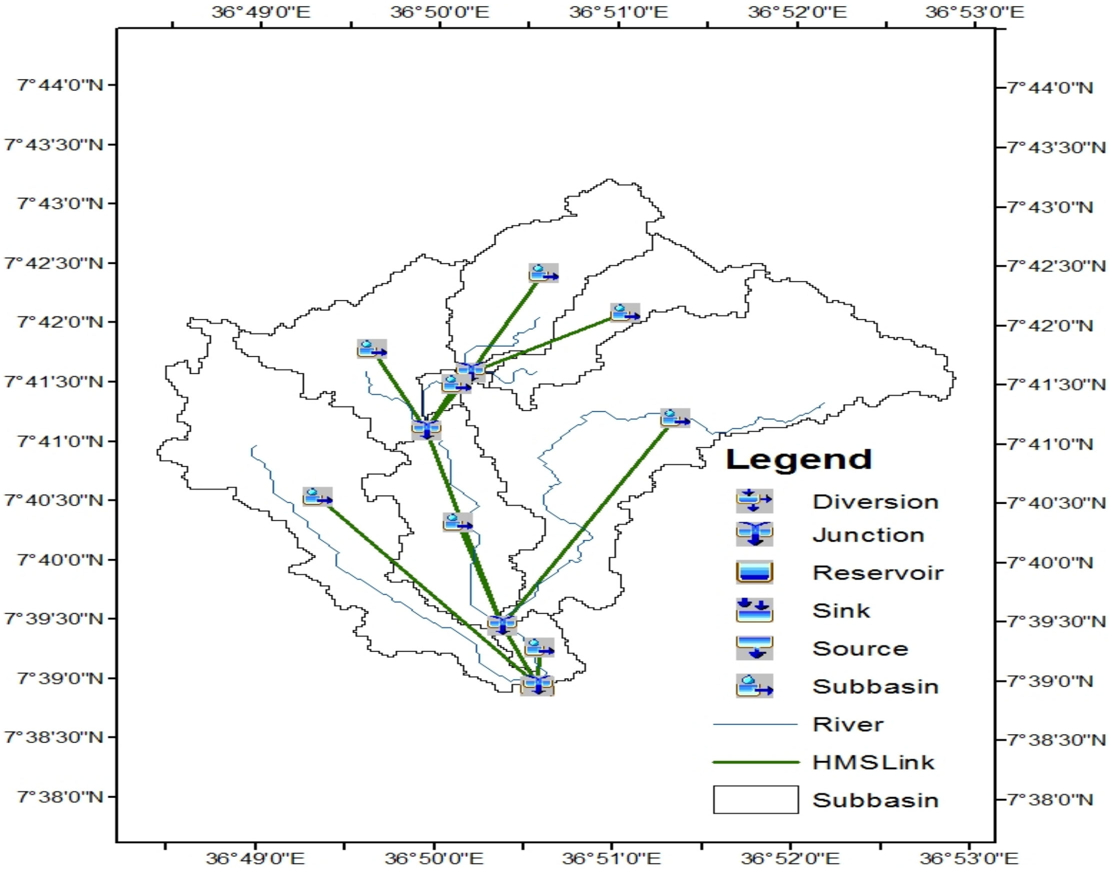
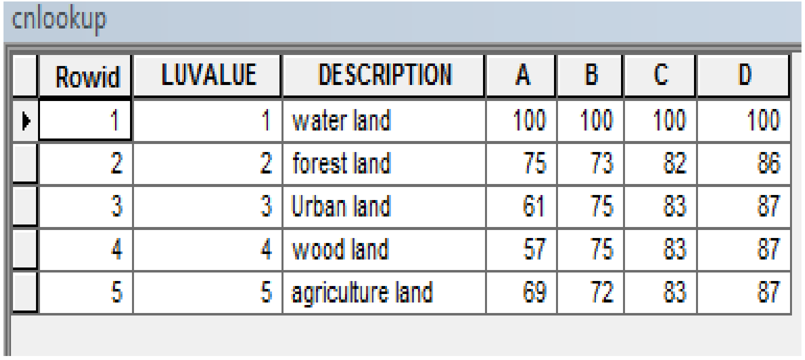


Figure 3.6: Awetu flood plain back ground map file with its elements in HEC-Geo HMS.

3.2.6.1 Generation of curve number grid

The SCS curve number method also known as the Hydrologic Soil Cover Complex Method was based on an empirical equation that estimates land use and soil type, the SCS CN method was also used to estimate excess rainfall and losses [31]. The CN is used to compute the volume of rainfall excess in the HEC-HMS and is therefore used as the description of watershed soil and land use characteristics in this modeling study. The Curve number is calculated in Arc GIS trough the union processing attributes combined to one of the land and Hydrological soil groups. Using the SCS TR55 report from 1986, the creation of the CN table that has curve numbers values for different combinations of soil hydrologic groups and land uses has been made as shown in the table (3.1). The SCS CN table gives CN for different combinations of land use and soil group, the Curve Number parameter is dimensionless and varies from 0 (maximum infiltration) to 100 (zero infiltration) [32]. After elaborating of the data necessary to compute the CN indicator, the CN map has been obtained from the intersection of the soil hydrological group and land use. The values of CN of the Awetu basin are between 82 and 87 in HEC-HMS Curve number grid development for Awetu River.

Table 3.3: CN Lookup table.



cnlookup

Rowid	LUVALUE	DESCRIPTION	A	B	C	D
1	1	water land	100	100	100	100
2	2	forest land	75	73	82	86
3	3	Urban land	61	75	83	87
4	4	wood land	57	75	83	87
5	5	agriculture land	69	72	83	87

Similarly; hydrological soil group was assigned to each soil type based on the criteria for hydrological soil group classification developed by USGS, 2000 and ERA Drainage manual 2013. Basically using these two principal classifications, dominant soil group and its area cover was given in table (3.4). The hydrological soil group was assigned to each main soil type and the Soil map of Awetu Catchment was given in figure (3.7) and the land use land cover of Awetu catchment was assigned with its type and area it cover in table (3.5).

Table 3.4: Dominant soil type and their respective hydrological soil group for study area**.**

Soil Type	Soil Group	Area	% Area
Chromic vertisols	D	0.28	0.84
Dystric Nitosols	B	18.4	58.96
Eutric Fluvisols	B	12.54	40.2

Table 3.5: Dominant Land use land cover and Area it cover with percent for study area**.**

S/No.	LULC Type	Area (km^2)	% Area
1	Agriculture Land	3.2	10.25
2	Forest Land	2.53	8.11
3	Water Land	2.15	6.89
4	Shrub Land	2	6.4
5	Urban Land	21.329	68.35
Total		31.209	100

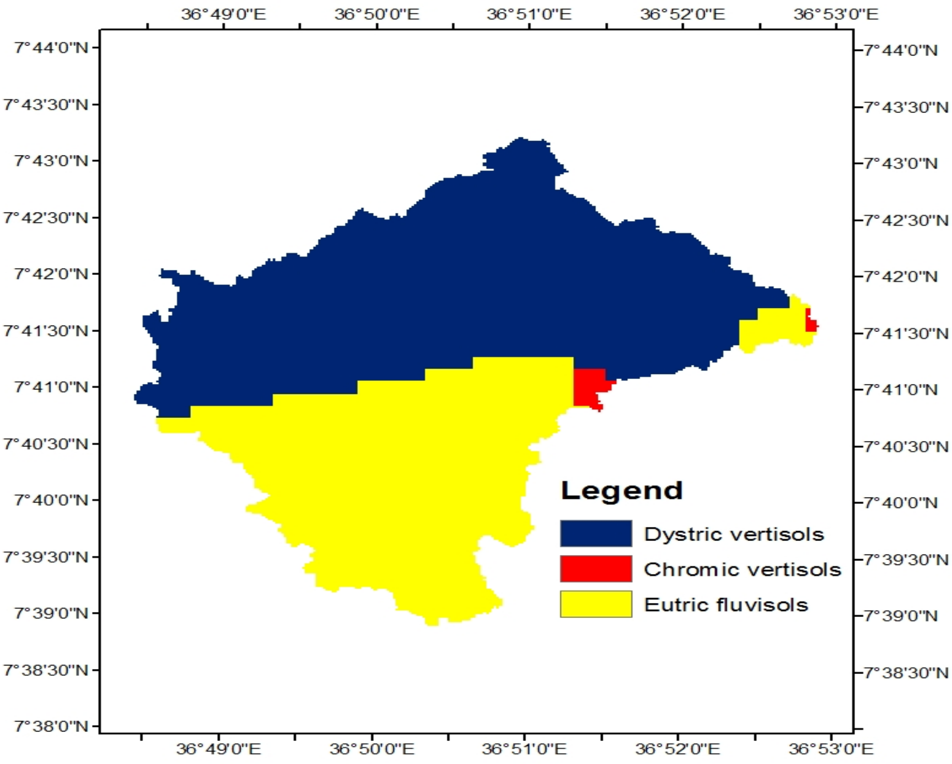


Figure 3.7: Soil map of Awetu Catchment.

3.2.6.2 HEC-HMS Model Setup and Hydrologic Modeling

HEC-GeoHMS is a geospatial hydrology toolkit in ArcGIS to create hydrologic inputs that can be directly used with HEC-HMS. It allows visualizing spatial information, extract watershed physical characteristics from DEM and GIS data, perform spatial analysis, and delineate sub basins and streams to develop hydrologic parameters as well as construct inputs to hydrologic models [33]. HEC-HMS is hydrologic modeling software developed by the US Army Corps of Engineers-Hydrologic Engineering Center (HEC). It is the physically based and conceptual semi distributed model designed to simulate the precipitation-runoff processes in a wide range of geographic areas such as large river basin, water supply and flood hydrology to small urban and natural watershed runoff.

Hydrographs produced by the program can be used directly or in conjunction with other software for studies of water availability, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design, flood damage reduction, floodplain regulation, wetlands hydrology and systems operation. It is an earlier version of HEC-1 that contains many improvements over its predecessor and includes many additional capabilities such as continuous hydrograph simulation over longer periods, distributed runoff computation using a grid cell, graphical user interface (GUI), integrated hydrograph analysis tools, data storage and management tools, graphics and reporting packages. The system encompasses losses, runoff transform, open-channel routing, and analysis of meteorological data, rainfall runoff simulation and parameter estimation. The Hydrologic Modeling System is designed to simulate the precipitation runoff processes of dendritic watershed systems. Its design allows applicability in a wide range of geographic areas for solving diverse problems including large river basin water supply and flood hydrology, and small urban or natural watershed runoff. HEC-HMS uses separate models to represent each component of the runoff process, including models that compute runoff volume, models of direct runoff, and models of base flow. Each model run combines a basin model, meteorological model and control specifications with run options to obtain results.

HEC-HMS Model setup consists of four main model components: basin model, meteorological model, control specifications, and input data (time series, paired data, and gridded data).The Basin model for instance, contains the hydrologic element and their connectivity that represent the movement of water through the drainage system. Hydrologic elements are used to break the watershed into manageable pieces and they are connected together in a dendritic network to form a representation of the stream system [34].The Basin Model contains a schematic consisting of any combination of the six objects (sub-basin, reach, junction, sink, source, and reservoir).In this research paper only the first four components are used. The HEC-HMS model for the Awetu catchment was done considering and dividing the sub-basin in to sub-catchments. Control specifications are one of the main components of in HEC-HMS model set up, even though they do not contain much parameter data. Their principle purpose is to control when simulations start and stop, and what time interval is used in the simulation [30]. In this study the starting date, 01Jan1995 and ending date, 31 December 2005 with a time interval of 1day for calibration and 01Jan2006 starting date and ending date, 31 December 2011 of the same time interval for validation has been used to model Awetu watershed. The meteorological component is also the first computational element by means of which precipitation input is spatially and temporally distributed over the river basin. Meteorological boundary conditions for sub-basins and area contributions of each of the rainfall gauging stations for the sub-basins are the two key purposes of the Metrologic model [29]. The metrological models used this study were Specified hyetograph method for calibration and validation and Frequency storm for frequency analysis.

3.2.6.3 HEC-HMS model input parameter values

The physical basin and river model parameter values were extracted from the attributes table of sub basin and River layers in ArcGIS. Other required input basin and river reach parameter values are as shown in table (3.6).

Table 3.6: Awetu HMS catchment basin model parameters

S/No	Model	Methods	Parameter value required
1	Loss	SCS Curve Number	Initial abstraction(mm),and Curve Number
2	Transform	SCS	Basin lag time(min)
3	Routing	Muskingum	Travel time(K) and Weight factor (X)

3.2.6.4 Modeling by Daily Rainfall Data

HEC-HMS modeling may be taken considering different time series values such as daily, hourly, and even in minute. Accuracy of the model output is high if it is in reverse order (i.e. the model was more performed for hourly data than daily data). Although most flood studies are undertaken considering hourly time steps, there are cases where daily data are taken. For this particular study since hourly data was not available the daily rainfall data was used.

HEC-HMS uses separate models to represent each component of the runoff process, including models that compute losses, runoff volume, models of direct runoff, models of open channel routing and models of base flow [35]. The main input data used for HEC-HMS are: daily precipitation, temperature (optional) Evapo-transpiration (optional), observed flow, base flow and different watershed characteristics obtained from preprocessing using HEC-GeoHMS software in ArcGIS environment.

3.2.6.5 Loss Model

While a sub basin element conceptually represents infiltration, surface runoff, and sub-surface processes interacting together, the actual infiltration calculations are performed by a loss method contained within the sub basin. Interception, infiltration, storage, evaporation, and transpiration collectively are referred to in the HEC-HMS program and documentation as losses. A total of twelve different loss methods are provided [30]. SCS Curve Number loss method, Initial and constant method, deficit and Constant loss method, Exponential loss method, Green and Ampt loss method and soil moisture Accounting loss method are some of the loss models.

In this paper SCS Curve Number loss method was chosen because it simple, predictable, well established and widely accepted many studies throughout the US and has been used for long term simulations. The parameters required for this loss method are Initial abstraction (mm), Curve Number, imperviousness (%). The Initial abstraction parameter values for the sub basins were estimated using the expression shown in equation (3.2).

$$\mathrm{I_a} = 0.2S \ldots\ldots 3.2$$

Where: $\mathrm{I_a}$is initial abstraction (initial loss), and S is potential maximum retention.

The maximum retention S in (mm) and watershed characteristics were related through an intermediate parameter called curve number (CN) as in equation (3.3)

$$S = 25.4\left(\frac{1000}{CN} - 10\right) \ldots\ldots 3.3$$

Basin Curve Number parameter values for each sub basin were estimated during data processing using HEC-GeoHMS software in ArcGIS environment. The values of Sub basin Curve Numbers were then extracted from the attributes table of Sub basin data layer. Percentage imperviousness of sub basin was 45% in the catchment.

3.2.6.6 Transform Model

HEC-HMS computes runoff volume by computing the volume of water that is intercepted infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. While a sub basin element conceptually represents infiltration, surface runoff, and sub-surface processes interacting together, the actual surface runoff calculations were performed by a transform method contained within the sub basin [35]. HEC-HMS computes runoff volume by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired and subtracting it from the precipitation. HEC-HMS considers that all land and water in a watershed can be categorized as either directly-connected impervious surface, or pervious surface. Directly connected impervious surface in a watershed is that portion of the watershed for which all contributing precipitation runs off, with no infiltration, evaporation, or other volume losses. Runoff transformations convert excess precipitation on a sub-basin to direct runoff at the sub-basin outlet. Again, HEC-HMS allows runoff transformation determinations using lumped or linear distributed approaches [36]. Seven different transform methods are provided in HEC-HMS including Clark unit Hydrograph transform, kinematic Wave transform, Mod Clark transform, SCS Unit Hydrograph transform, Snyder Unit Hydrograph transform, User Specified S-Curve transform and user Specified unit Hydrograph transform methods[30]. For this paper SCS unit hydrograph transform method was applied for estimating direct runoff based on data availability and its simplicity. The only parameter value used was basin lag time which were computed during data processing using the HEC-GeoHMS application in ArcGIS environment and stored in the attributes table of sub-basin data layer.

3.2.6.7 Base Flow Model

Subsurface flow in the catchment is illustrated by base flow in HEC-HMS and comprises of interflow and flow in groundwater aquifer. The base flow models simulate the slow subsurface drainage of water. This base flow is the sustained runoff from precipitation that was stored temporarily in the watershed, plus the delayed subsurface runoff from the current storm. The base flow is added to the direct runoff (obtained with the transformation model) to obtain the total flow, which is routed through the stream reach to the outlet. To model the base flow, HEC-HMS offers alternative models, which can be combined with other loss, and direct runoff models. These are: The Constant Monthly- Varying Base Flow Method, the Exponential Recession Model and the Linear Reservoir Model [30]**.** In this study, the Constant Monthly-

Varying Base Flow Method was used because it is the simplest base flow method among the other methods. It represents base flow as a constant flow; may vary monthly. The mean monthly constant which is the minimum monthly flow was adapted for base flow calculation methods for this particular study.

3.2.6.8 Routing model

Flood routing is a technique of determining the flow hydrograph at the downstream point of catchment with sound information regarding hydrograph at its upstream. It is an approach to estimate how the magnitude and celerity of a flood wave varies than that at the inflow point as it moves along the catchment. Flood routing along the catchment is a function of basin characteristics such as slope and length of channel, channel roughness, channel shape, downstream control and initial flow condition [37]. The hydrologic modelling is based on continuity equation while hydraulic modelling is based on combination of continuity and momentum equation which is known as Saint-Venant equations [38]. In this project, Muskingum Cunge method has been used for river routing because of its high accuracy over other methods.

Muskingum Cunge routing method is based on simplification of convective diffusion equation which is combination of continuity equation and momentum equation. The models of channel flow or routing models included in HEC-HMS program are Lag, Muskingum, Modified puls, kinematic-Wave and Muskingum Cunge models. Each of these models computes a downstream hydrograph, given an upstream hydrograph as a boundary condition and solves by the continuity and momentum equations [39].

Muskingum routing model was selected for this particular work since it is well performed in channel routing. The parameter values required for this routing method are Muskingum K and X. The Muskingum K is essentially the travel time through the reach and can be estimated from knowledge of the cross section properties and flow properties or the travel time (K) in Muskingum model = lag time (Δt). Its value ranges between 0.01hr and 150hr. In Muskingum model, X is the dimensionless weight factor ranging between 0.0 and 0.5 (0.0 for a linear reservoir, 0.5 for a pure transmission reach). Most stream reaches require an intermediate value found through calibration.

3.2.6.9 Control Specifications

The other major component in HEC-HMS project is Control specifications model input. Though, unlike the other components, this one does not contain much parameter data, it contains the key step of controlling the time when simulations start and end. In this study the starting date, 01Jan1995and ending date, 31Dec 2005 with a time interval of 1day for calibration and 01Jan2006 and ending date, 31Dec2011 of the same time interval for validation was used to model the Awetu watershed. Generally the methodology used for hydrologic modeling was summarized in figure (3.8).

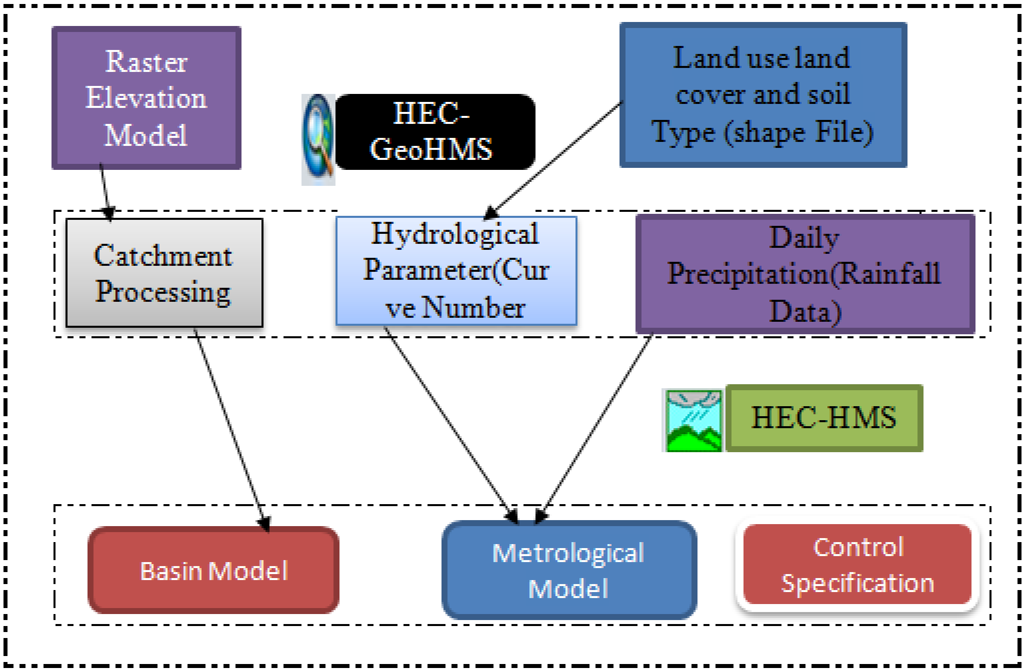


Figure 3.8: Schematization Hydrological Modelling

3.2.6.10 Peak flood estimation

Certain hydrologic procedures use rainfall and rainfall frequency as the basic input instead of flood frequency. It is also commonly assumed that the 10-year rainfall will produce the 10-year flood. Depending on antecedent soil moisture conditions, and other hydrologic parameters, there may not be a direct relationship between rainfall and flood frequency [29]. The frequency with which a given flood can be expected to occur is the reciprocal of the probability or chance that the flood will be equaled or exceeded in a given year. If a flood has a 20% chance of being equaled or exceeded each year, over a long period of time, the flood will be equaled or exceeded on an average of once every five years. This is called the return period or recurrence interval (RI). Thus the expedience probability equals 100/RI. The 5-year flood is not one that will necessarily be equaled or exceeded every 5 years. There is a 20% chance that the flood will be equaled or exceeded in any year; therefore the 5-year flood could conceivably occur in several consecutive years. The same reasoning applies to floods with other return periods [39]. Ethiopian Roads Authority (ERA) divided the country into eight Meteorological regions based on their rainfall pattern similarity as in figure (3.9) and develops intensity-duration frequency curves for 24hr duration rainfall depth for each Meteorological region as a function of the 2,5,10, 25,50 ,100, 200 and 500 years return period of the storm events.

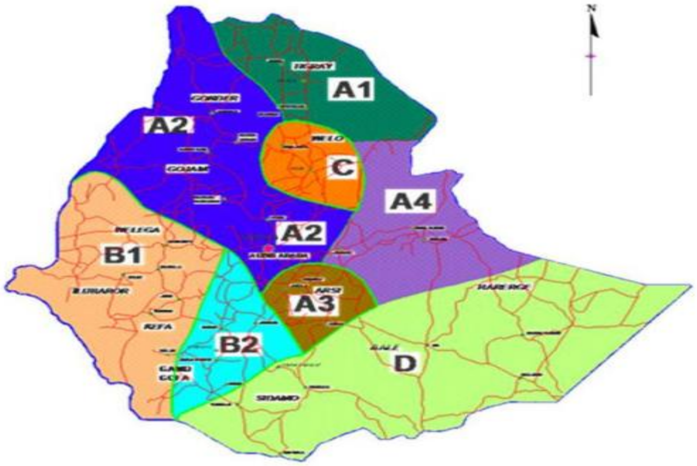


Figure 3.9: IDF Curve of Rainfall Region B1 via Study area [29].

Table 3.7: 24 hr Rainfall Depth Vs Frequency [29]

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

Note: RR- Rainfall Region

Meteorological data required for HEC-HMS model input was the precipitation depths as a function of return period over the river catchment basin obtained from IDF table. The duration of precipitation for frequency analysis in HEC-HMS was chosen as 24 hours (one day). But in addition the software requires a depth of 0.25, 1, 2, 3, 6 and12 hour's duration.

The depth of rainfall for the above durations was computed using the 24 hr rainfall depth, using the equation (3.4).

$$\frac{R_t}{R_{24}} = \frac{t}{24}\frac{(b+24)^n}{(b+t)^n} \ldots\ldots 3.4$$

Where: R_t is rainfall depth in a given duration‘t’; R_{24} is24 hr Rainfall depth; b and n are coefficients (b=0.3, n= (0.78-1.09)).

Table 3.7 shows the input precipitation depths data developed using the equation (3.4) and used as the HEC- HMS model input to frequency analysis.

Table 3.8: Design precipitation depths as a function of return period.

Year	25	50	250	500
Duration(Hr)	Depths(m)	Depths(m)	Depths(m)	Depths(m)
0.25	28.15	30.51	35.84	38.57
1	51.93	56.28	66.1	71.14
2	62.14	67.35	79.12	85.14
3	67.36	73	85.75	92.28
6	75.28	81.59	95.84	103.13
12	82.45	89.36	105	112.96
24	89.35	96.84	113.75	122.41

3.3 Model Calibration and Validation

Hydrological modeling is a complex task and hydrologic models should be well calibrated to increase user confidence in its predictive ability which makes the application of the model effective. The successful application of the hydrologic watershed model depends upon how well the model is calibrated which in turn depends on the technical capability of the hydrological model as well as the quality of the input data [40]. In HEC-HMS modeling of each method, each method needs parameters and values as an input to obtain simulated runoff hydrographs.

The values of the parameters estimated by observation and measurement of stream and basin characteristics, but some of them cannot be estimated. When the required parameters cannot be estimated precisely, the parameters are calibrated [34]. In this study since, Muskingum routing Model was adopted the parameters ‘x’ and ‘k’ can’t be measured directly but can be estimated approximately for limited cases.

How can the appropriate values for the parameters be selected? Since the rainfall and stream flow observations were available, calibration is the answer. Model calibration is the process of adjusting selected model parameters values and other variables in the model in order to match the model outputs with the observed values. Calibration uses observed hydro meteorological data in a systematic search for parameters that yield the best fit of the computed results to the observed runoff. This search is often referred to as optimization. Optimization begins from initial parameter estimates and adjusts them so that the simulated results match the observed stream flow as closely as possible. To compare a computed hydrograph to an observed hydrograph, the program computes an index of the goodness-of-fit. The objective function measures the goodness-of-fit between the computed and observed stream flow at the selected element. Seven different functions are provided in HMS optimization manager. In this Study, the peak-weighted root mean square (PWRMSE) was used to get the finally optimized parameter values since, this function gives more weight to large errors than small errors and it gives a greater overall weight to errors near the peak discharge. Two search methods are available in HEC-HMS model for minimizing the objective functions. Those are the Univariate gradient search Algorithm method (UG) and Nelder and Mead Algorithm method. The UG method was selected for this work because this method evaluates and adjusts one parameter at a time while holding other parameters constant and as it resulted in better and manageable. In order to get the optimum parameter values after manually calibrating the model, an automatic trial and error method applied. Therefore, automated calibration in conjunction with manual calibration was used to determine a practical range of the parameter values preserving the hydrograph shape and minimum error in volume.

Model Validation is the process of testing the model ability to simulate observed data, other than those used for the calibration, within acceptable accuracy. During this process, calibrated model parameter values are kept constant. The quantitative measure of the match is again the degree of variation between computed and observed hydrograph.

3.4 Model performance criteria

Finally the model performance was evaluated for both calibration and validation in different ways including coefficient of determination (R^2) and Nash-Sutcliffe efficiency [41] are used to assess the hydrological modeling performance.

1. By visually inspecting and comparing the calculated and observed hydrograph

2. The Coefficient of Determination(R^2) is a standard correlation statistic designed to determine the strength of the linear relationship between simulated and observed data [42]. This statistic describes the proportion of the total variance in the observed data which can be explained by the model and the ranges is expressed between 0 and 1, with higher values indicating the ability of the model to explain more variance in the observed data and determined by equation (3.5): The Coefficient of Determination indicates how the simulated data correlates to the observed values of data and range from 0 (Unacceptable) to 1(best).

$$\mathrm{R}^2 = \frac{\Sigma(\mathrm{Q_{ob}} - \bar{\mathrm{Q}}_{\mathrm{ob}})2 \quad - \Sigma(\mathrm{Q_{sim}} - \bar{\mathrm{Q}}_{\mathrm{sim}})2}{\Sigma(\mathrm{Q_{ob}} - \bar{\mathrm{Q}}_{\mathrm{ob}})2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.5$$

Where: Q_{ob}=observed discharge; Q_{sim}=simulated discharge; $\bar{\mathrm{Q}}_{\mathrm{ob}}$=mean of observed discharge; $\bar{\mathrm{Q}}_{\mathrm{sim}}$=mean of simulated discharge.

3. Nash-Sutcliffe efficiencies can range from -∞ to 1. An efficiency of ENS=1 corresponds to a perfect match of modeled discharge to the observed data. An efficiency of ENS=0 indicates that the model predictions are as accurate as the mean of the observed data, whereas an efficiency less than zero (-∞<ENS<0) occurs when the observed mean is a better predictor than the model. The closer the model efficiency is to 1, the more accurate the model is [43].

Nash-Sutcliffe efficiencies (ENS) [30].

$$\mathrm{ENs} = \quad 1 - \frac{\sum_{n=1}^{n}(Q_{ob} - Q_{sim})2}{\sum_{n=1}^{n}(Q_{ob} - \overline{Q_{ob}})2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where: Q_{ob}=observed discharge; Q_{sim}=simulated discharge; $\bar{\mathrm{Q}}_{\mathrm{ob}}$=mean of observed discharge; $\bar{\mathrm{Q}}_{\mathrm{sim}}$=mean of simulated discharge.

3.5 Hydraulic Modeling: HEC-RAS

The Hydrologic Engineering Center's Geographical River Analysis System (HEC-GeoRAS) or HEC-RAS has been developed by US Army Corps of Engineers Hydrologic Engineering Center and it is a free downloadable with other supportive documents about how to use the model for flooded area mapping. The HEC-GeoRAS is a GIS extension with a set of procedures, tools, and utilities for the preparation of river geometry GIS data to import into HEC-RAS and it is used to generate the final inundation map. The input data required for the River geometry preparation using the HEC-GeoRAS model are Triangular Irregular Network (TIN), DEM, and land use. The river geometry file and stream flow data are the input files for HEC-RAS to generate the water surface level along the River. The HEC-GeoRAS or HEC-RAS has been used worldwide for inundation mapping, such as in Europe, in the USA, in Africa and in Asia [44].

The technical part for a functioning flood risk management and for preparing a decision basis is risk assessment, which comprises understanding, evaluating and interpreting the perceptions of risk and societal tolerances of risk [45]. Inundation mapping which passed through three steps was performed with the help of HEC-RAS along with HEC-GeoRAS in ArcGIS and risk assessment for floods is based on hazard maps, which are part of the risk analysis process, and methodology to mapping inundation was shown in figure (3.10).

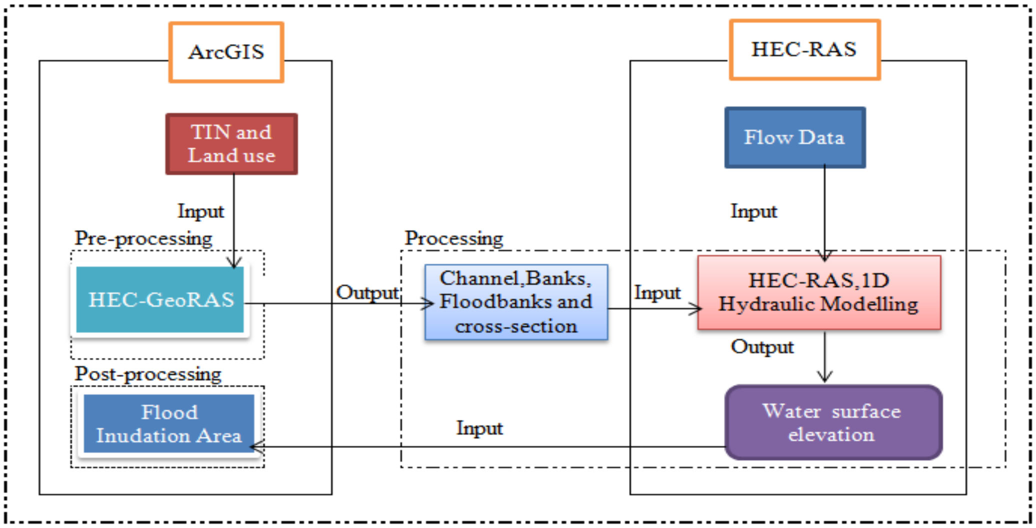


Figure 3.10: Schematic diagram of Modelling for Flood Inundation Map.

It consists of graphical user interface, data storage and management capabilities as well as reporting facilities. The main inputs of HEC-RAS for performing hydraulic analysis are geometric data and flow data. Basic geometric data consists of physical feature of river i.e. channel length, banks, flood banks and cross-sections of the river while additional geometric data defining bridge and culverts, levee alignment, blocked structures, inline structures and storage area can also be incorporated in the software. HEC-RAS has capability of performing one-dimensional and two-dimensional hydraulic calculations. Based on the purpose of the study, HEC-RAS provides different options for performing river analysis which are one-dimensional steady flow for water surface profile computation, one and two-dimensional unsteady flow simulation, quasi unsteady flow for sediment transport computation and water quality analysis [36]. In this thesis, one dimensional (1-D) steady flow analysis has been performed for Awetu river basin and the result has been used to generate flood inundation area. 1-D steady flow analysis is useful for calculating water surface profile. In this analysis, the flow is assumed to be gradually varying along its length. It can calculate the water surface profile for mixed flow condition. Governing equation for calculation of water surface profile is Energy equation which is written as follows;

$$Z_2 + Y_2 + \frac{\alpha_2 V_2{}^2}{2g} = Z_1 + Y_1 + \frac{\alpha_1 V_1{}^2}{2g} + h_e \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.7$$

Where, Z1 and Z2 are elevation of bottom of the channel at cross-section 1 and 2; Y1 and Y2 are depth of water at cross-section 1 and 2; V1 and V2 are velocity of water at cross-section 1 and 2; $\alpha 1$ and $\alpha 2$ are velocity weighing factors; g are acceleration due to gravity; he are energy head loss. Water surface profile between any two cross sections is calculated by solving the energy equation (3.7) in an iterative way. This process is called as standard step method. For the computation of water surface, each cross-section of river is divided into left overbank, main channel and right over bank and the energy is calculated for each section.

The final energy of the channel is the mean of the energy calculated for all three sections [46]. The head loss in the equation (3.7) comprises of loss due to friction and contraction/expansion. The friction loss is given by Manning's equation which is given in equation (3.8):

$\mathrm{h_f} = \mathrm{L}S_\mathrm{f}$……………………………………………………………………………..3.8

Where:- $\mathrm{S_f}$ is representative friction slope (slope of energy grade line)

$\mathrm{S_f} = \frac{Q}{K}$………………………………………………………………………...……..……3.9

Q Flow in the channel length

K = conveyance factor = $\frac{1.486}{n} AR^{2/3}$ ………..………………………………………3.10

n is manning's roughness coefficient ;A is area of the channel; R is hydraulic radius which is calculated as area per wetted perimeter.

L = distance weighted reach length= $\frac{\mathrm{L_{lob}} * \mathrm{Q_{lob}} + \mathrm{L_{ch}} * \mathrm{Q_{ch}} + \mathrm{L_{rob}} * \mathrm{Q_{rob}}}{\mathrm{Q_{lob}} + \mathrm{Q_{ch}} + \mathrm{Q_{rob}}}$ ………………………3.11

$\mathrm{L_{lob}}$, $\mathrm{L_{ch}}$, $\mathrm{L_{rob}}$ are cross-section reach length in left overbank, main channel and right overbank respectively and $\mathrm{Q_{lob}}$, $\mathrm{Q_{ch}}$, $\mathrm{Q_{rob}}$ are average mean flow between sections for left overbank, main channel and right over bank respectively.

The contraction/expansion loss is calculated as:

$\mathrm{h_{ce}} = \mathrm{C}[\ \frac{\alpha_2 \mathrm{V_2}^2}{2\mathrm{g}} - \frac{\alpha_1 \mathrm{V_1}^2}{2\mathrm{g}}\ ]$…………………………………………………..……………3.12

Where, C = Coefficient of contraction/expansion.

Combining friction loss and loss due to contraction/expansion, the total energy loss equation is given below:

$\mathrm{h_f} = LS_f + C[\ \frac{\alpha_2 \mathrm{V_2}^2}{2\mathrm{g}} - \frac{\alpha_1 \mathrm{V_1}^2}{2\mathrm{g}}\ ]$ ……………………………………………………..………3.13

Velocity weighing factor, α is calculated as $\alpha = \frac{\mathrm{Q_1 V_1}^2 + \mathrm{Q_2 V_2}^2}{(\mathrm{Q_1} + \mathrm{Q_2})\mathrm{V}^2}$ ………………..……………3.14

Where, V =mean velocity of the reach length [46].

3.5.1 Generation of water surface TIN

TIN was created from the cross section water surface elevations using HEC-Geo RAS. All four water surface profiles were selected from the window then for each selected water surface profile, a water surface TIN is created without consideration of the terrain model. The TIN was created using the Arc GIS triangulation method. This allowed for the creation of a surface using cut lines as hard break lines with constant elevation. The water surface TIN for 25 year was generated using Arc GIS for flow profile used in HEC-RAS and indicated as in the figure (3.11).

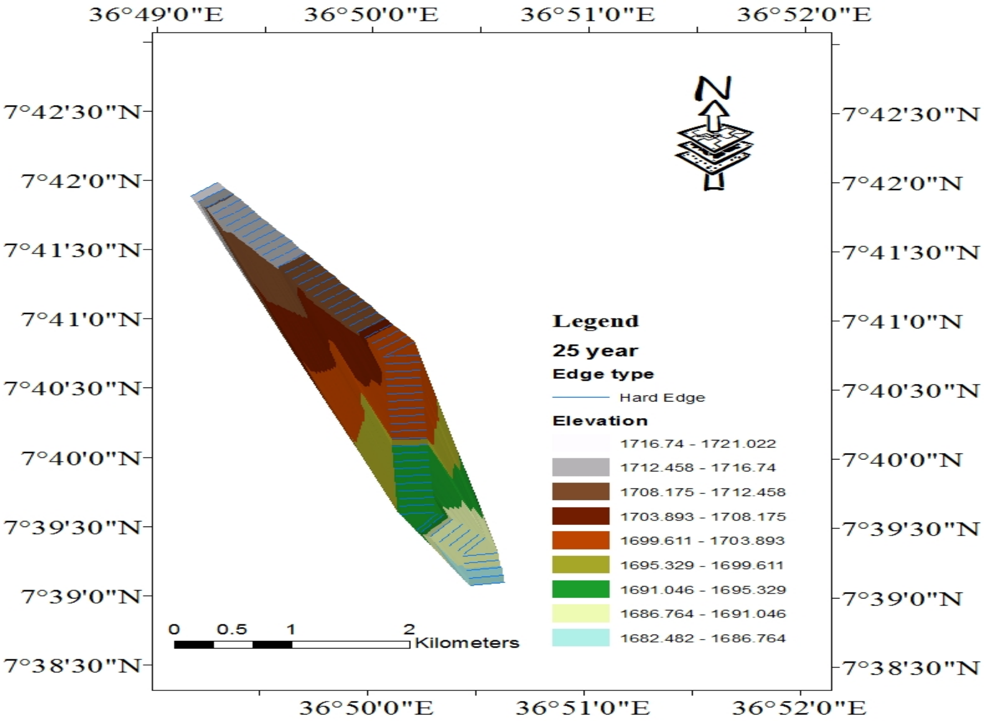


Figure 3.11: water surface TIN for 25 year return period

3.5.2 Flood Hazard Mapping

Flood Hazard Mapping is flood map illustrating the flood hazard, i.e. the intensity of flood situations and their associated accidence 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 distribution of flow velocity [47]. The hazard aspect of the flood risk is related to the hydraulic and the hydrological parameters. Hazard level may be defined by the parameters like flood depth, flood velocity and flood duration. The flood risk assessment consists in evaluating: the causes of the flood hazard, the frequency of flood events, the identification and location of flood prone areas, the depth of floods, the duration of the flood, and its vulnerabilities. In consequence, flood risk assessment should investigate the flood process and this could be done through the following two analysis of Hazard and Vulnerability, consist in analyzing physical, health and social vulnerability to flooding [48]. River flood hazard map shows areas which could be flooded according to different return period with flood extent, water depth or water level and flow velocity and cover the geographical areas which could be flooded. The magnitude of the damage depends on the flood characteristics especially in terms of water depth and flow velocity. For this study, flow velocity and flow depth (water depth) were considered as two main parameters which associate flash flood hazard and in order to model flood hazard map for Awetu River which is the combination of flood depth and river flood velocity the NSW flood development equation was applied [49]. According to this; four flood hazard categories can be determined consists of low, medium, high, and severe and the flood hazard separation line show in figure (3.12). Extreme river flood hazard is defined for the zones with more than 2 m depth or more than 2 m/s velocity. In order to distinguish the other river flood hazard categories for the other class the equation relates to respective categories must be calculated. In this case the following formulas were used to identify each zone of the river flood hazard categories.

The formula of the line separator between medium and high river flood hazard:

$V=-3.333*D+3.333$ ……………………………..…………………………………….3.15

The formula of the line separator between low and medium river flood hazard:

$V=-3.333*D+2.666$ ………………………………..……………………………………..3.16

Where: V is Velocity (m/s) and D is water depth (m).

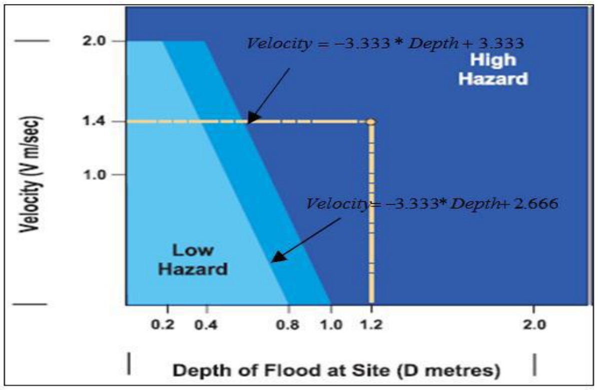


Figure 3.12: Flood hazard classification [49].

The flood depth map and flood velocity map were the essential components for the categorization of the river flood hazard mapping in Awetu river .These maps were created by HEC-RAS 5.0.1.

3.5.2.1 Flood depth

Flood depth information usually presented as maximum depth for each specified period and the presence of flood hazard is clearly explained in both aspects; the size and the degree (Severity) of flood. Flood depth is described as distance between water level and bed level and output files generated by HEC-RAS. The water depth for 25 year with minimum and maximum water depth 0.0027 m and 22.38 m respectively was shown figure (3.13).

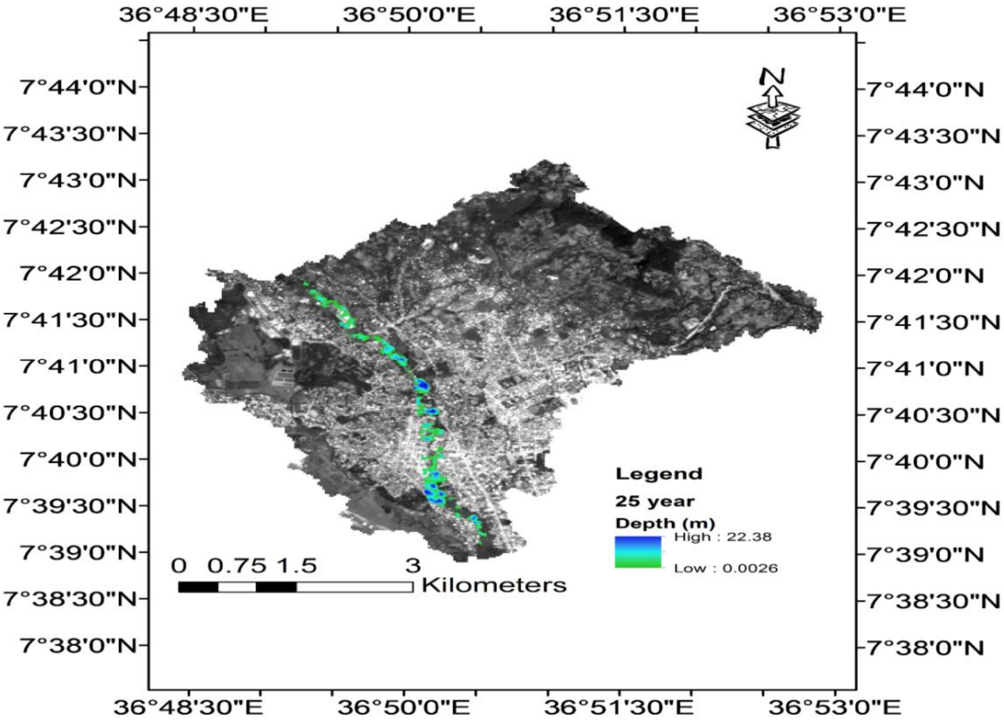


Figure3.13: Water depth for 25 year.

3.5.3 Flood Vulnerability Analysis

Flood hazard map alone cannot completely fulfill the information requirement for flood risk analysis. There is a need to combine flood hazard with other parameter, flood vulnerability, to develop more useful information. Vulnerability generally refers to that characteristic of society which specifies the potential for the damage to occur as a result of different types of hazards. Vulnerability can be defined as the degree to which people, property, environment, social and economical activities are subjected to harm or being exposed to any destructive factors or cause. Flood vulnerability describes the damage or exposure to damage due to flood.

The flood vulnerability is affected by the land use characteristics and slope of the areas under the influence of flood i.e., a flood of same accidence probability will have different levels of vulnerability according to the land use characteristics and potential for damage. The vulnerability analysis, therefore, consists of identifying the land use; slope and infrastructure type of areas under the potential influence of a flood of particular return period was shown in figure (3.14) below.

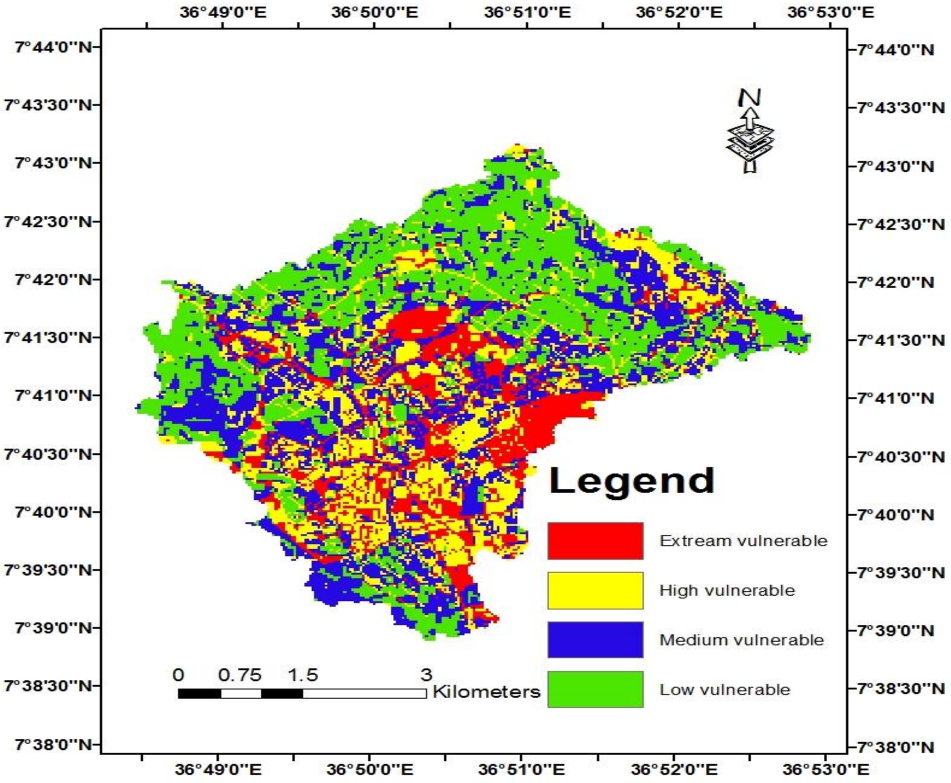


Figure 3.14: Flood Vulnerability map of the study area.

3.6 Flood risk map

Flood risk maps are an important tool for flood prediction and management because they complement the information predicted from hydrological models and allow the development of relief profiles and its is the product of flood hazard map and vulnerability map and modeled by overlay of flood hazard map and vulnerability map. These flood risk maps can serve as a basis for designing measures to minimize the loss of life in the Awetu sub-basin. Figure (3.15) shows the data required and the methodology followed to process the flood risk maps.

The process of flood hazard delineation has been based on DEM/TIN and GIS analysis, and the vulnerability to flood based on the analysis and identification of the land use, slope and the infrastructure (roads, hospital and schools) likely to be inundated. The overlaying of GIS flood hazard and vulnerability maps results in flood risk maps.

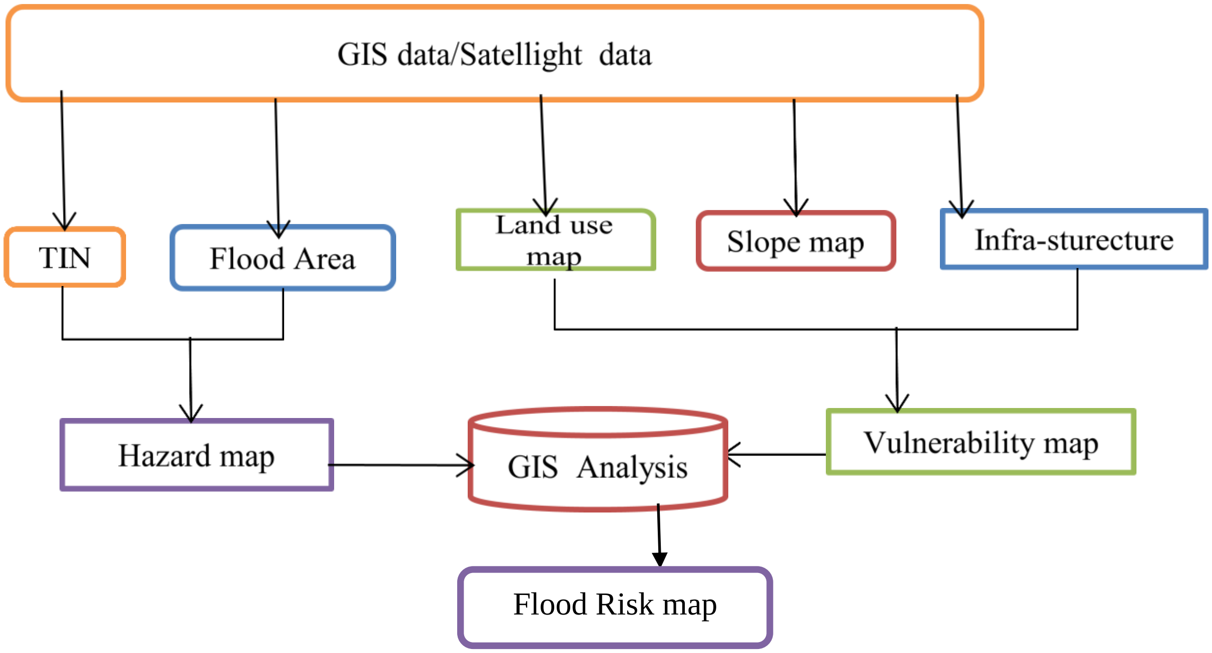


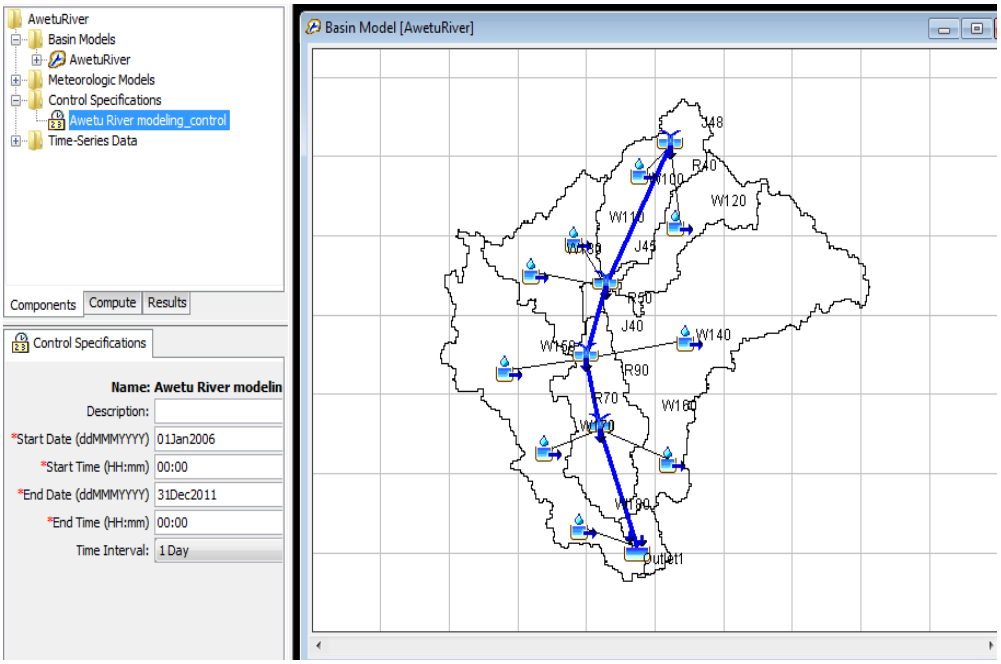
Figure 3.15: Schematization of the flow chart method followed for flood risk maps for the Awetu River.

CHAPTER FOUR

4 RESULT AND DISCUSSION

4.1 Back Ground Map File

The back ground map file represents the physical watershed under consideration. For this study a background map file that contains about 9 Sub-basin was generated using HEC-Geo HMS in Arc GIS was given figure (4.1). It encompasses Basin model file, Met model file, Gage model file those were used as an input in HEC-HMS during rainfall runoff modeling and also it comprises methods for modeling each HEC-HMS components. Basin model file contains sub-watersheds, reaches, junctions, and outlet with methods for precipitation loss modeling, excess precipitation transforming, base flow modeling and channel routing methods.



Name: Awetu River modelin
Description:
*Start Date (ddMMMYYYY) 01Jan2006
*Start Time (HH:mm) 00:00
*End Date (ddMMMYYYY) 31Dec2011
*End Time (HH:mm) 00:00
Time Interval: 1 Day

Figure 4.1: Back ground map file of the Awetu Sub-basin

4.2 Basin Parameters

There are a lot of parameters that can affect the magnitude of flood expected from the particular watershed. This study mainly focused on parameters like curve number, basin lag time, initial abstraction and flood wave travel time (K) because these parameters were more appropriate for the chosen method of precipitation loss modeling, excess precipitation transformation to direct runoff and Muskingum flood routing method. Land use land cover and soil types are the most determinant factors of watershed physical parameters that always impacts watershed surface runoff. The impacts of land use land cover and soil type upon the surface runoff can be represented using curve number. For Awetu River sub-basin curve number was generated using HEC-Geo HMS and it was mapped as shown on figure (4.2). Curve number is one the most essential input parameters for SCS-CN method in order to estimate precipitation loss. According to the land use land cover and soil classification of Awetu sub-basin computed in Arc GIS table (3.5), figure(4.3) and table(3.4),figure (3.7) indicated, about 68.34 % of the Awetu sub-basin land use land cover was Urban which abundantly dominated by Dystric nitisols (58.96% composition). The Dystric nitisols was categorized under hydrological soil group B table (3.4) hence; it has low infiltration and high flood generating capacity. As the generated curve number grid map in figure (4.2) shown, the arctic color was area of Awetu sub-basin that mostly dominated by Urban and it falls in the curve number range of 82-87. Therefore, this area of Awetu sub-basin dominates the total runoff generated due to the received precipitation. The other important basin parameter used for this study was Basin lag time. After the curve number grid incorporating land use land cover, soil type and hydro fill of the Awetu sub-basin was generated, the HEC-HMS automatically extracted the basin lag time for each sub watershed. Initial abstraction that encompasses different losses like infiltration, interception, surface depression and Curve grid generated was given in table (4.1).

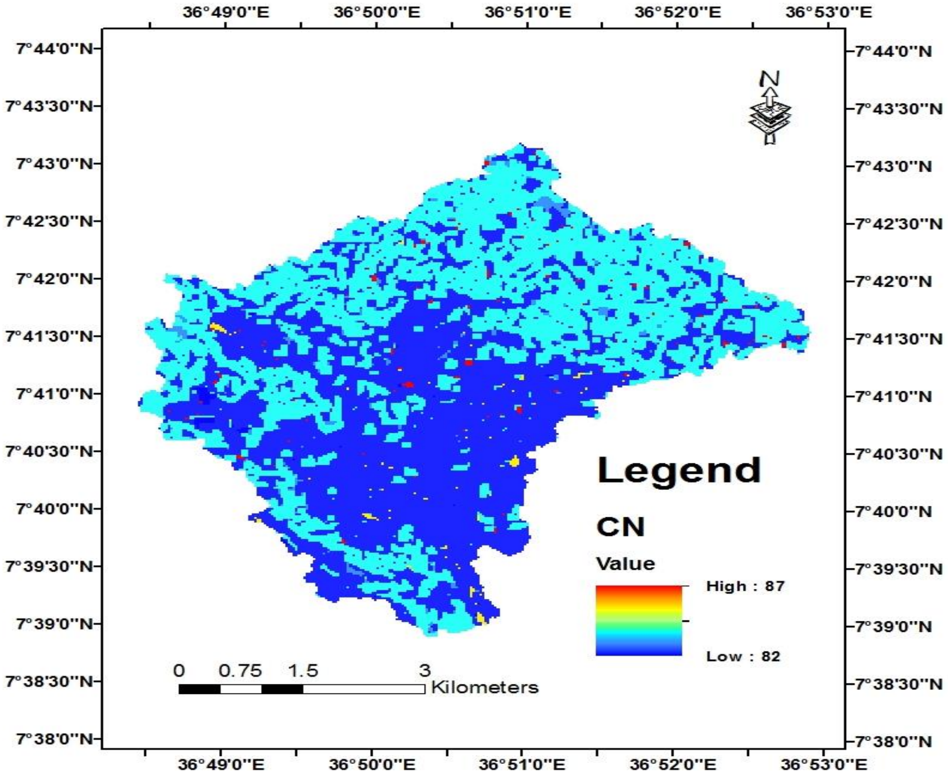


Figure 4.2: Curve number grid map of Awetu Sub-basin

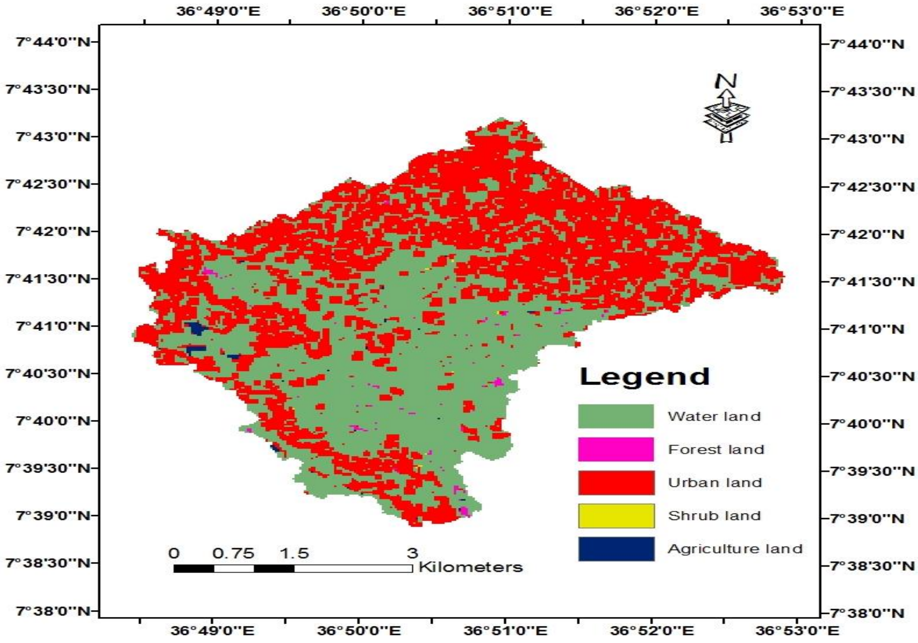


Figure 4.3: Land use land cover map of Awetu Sub-basin

The parameter value used was basin lag time which were computed during data processing using the HEC-GeoHMS application in ArcGIS environment and stored in the attributes table of sub-basin data layer. The basin lag time (T_{lag}) is the parameter of SCS model which is 0.6 times the time of concentration (Tc). The specifications of each sub basin extracted by using HEC Geo-HMS are shown in table(4.1), which clearly indicates that total catchment area of Awetu is about 31.21 km^2.

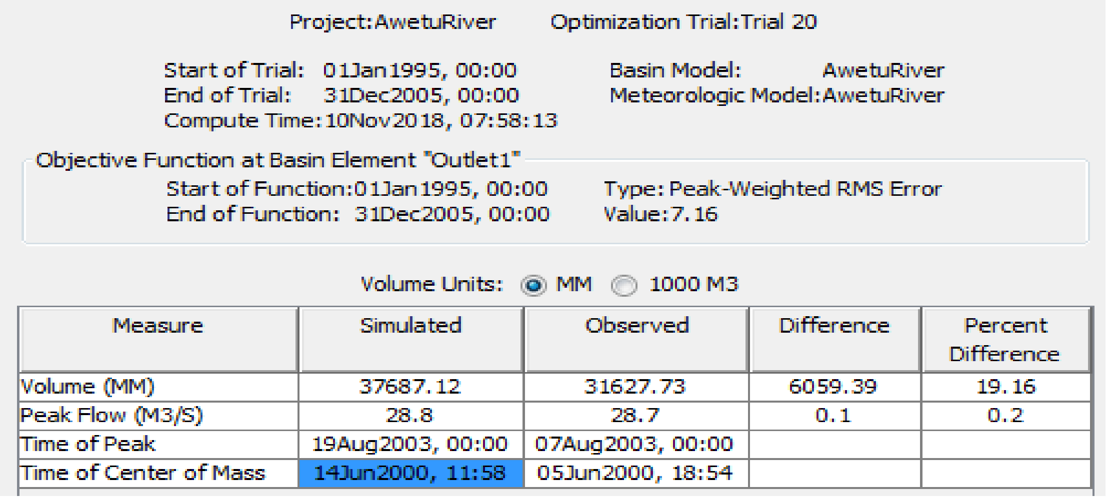
Table 4.1: Curve number, basin lag, Initial abstraction for each sub-watershed of Awetu sub-basin

S/No.	Sub basin name	Area (km^2)	Basin CN	Maximum retention(mm)	Initial Abstraction(mm)	Lag Time(min)	Time of concentration(hr)
1	W_{180}	0.009	87	37.8	7.59	2.71	0.075
2	W_{170}	7.006	83.86	44.4	9.77	67.27	1.87
3	W_{160}	0.63	83	50.8	10.4	20	0.556
4	W_{150}	3.5	82	55.9	11.15	45.45	1.27
5	W_{140}	10.55	83.7	49.3	9.86	77.23	2.15
6	W_{130}	3.43	84.6	45.7	9.22	33.44	0.94
7	W_{120}	2.44	85.1	44.4	8.87	32.86	0.913
8	W_{110}	0.375	85.75	51	10.59	23.7	0.658
9	W_{100}	3.27	85.29	43.9	8.87	30.78	0.855

4.3 Parameter Optimization

Parameter optimization is a systematic process of adjusting model parameter values until the computed model results match acceptably with observed data. The quantitative measure of goodness of fit between the computed result from model and observed flow is called objective function. Objective function measures degree of variation between computed and observed hydrograph. It is equal to zero if hydrographs are exactly identical.

The purpose of parameter optimization is to identify the parameters whose variation causes significant changes in the outputs of the mode. Among the parameters used in HEC-HMS for rainfall runoff model development, flood wave travel time (Muskingum-K) and weighted coefficient of discharge (Muskingum-X) were the most sensitive parameters and the calibration was carried out considering these parameters. In this study, the objective function was to optimize these parameters and to lessen their effect upon the final results of the model.



Project:AwetuRiver Optimization Trial:Trial 20

Start of Trial: 01Jan1995, 00:00
End of Trial: 31Dec2005, 00:00
Compute Time: 10Nov2018, 07:58:13

Basin Model: AwetuRiver
Meteorologic Model: AwetuRiver

Objective Function at Basin Element "Outlet1"

Start of Function: 01Jan1995, 00:00
End of Function: 31Dec2005, 00:00

Type: Peak-Weighted RMS Error
Value: 7.16

Volume Units: ● MM ○ 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	37687.12	31627.73	6059.39	19.16
Peak Flow (M3/S)	28.8	28.7	0.1	0.2
Time of Peak	19Aug2003, 00:00	07Aug2003, 00:00		
Time of Center of Mass	14Jun2000, 11:58	05Jun2000, 18:54		

4.4 Calibration

Calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows. The calibration of HEC-HMS for this particular study area was carried out using Ten years from 1995 to 2005 daily rainfall and daily stream flow data of Awetu River. The coefficient of determination (R^2) during calibration was found to be 0.96 and Nash Sutcliff Efficiency (NSE) was 0.77.

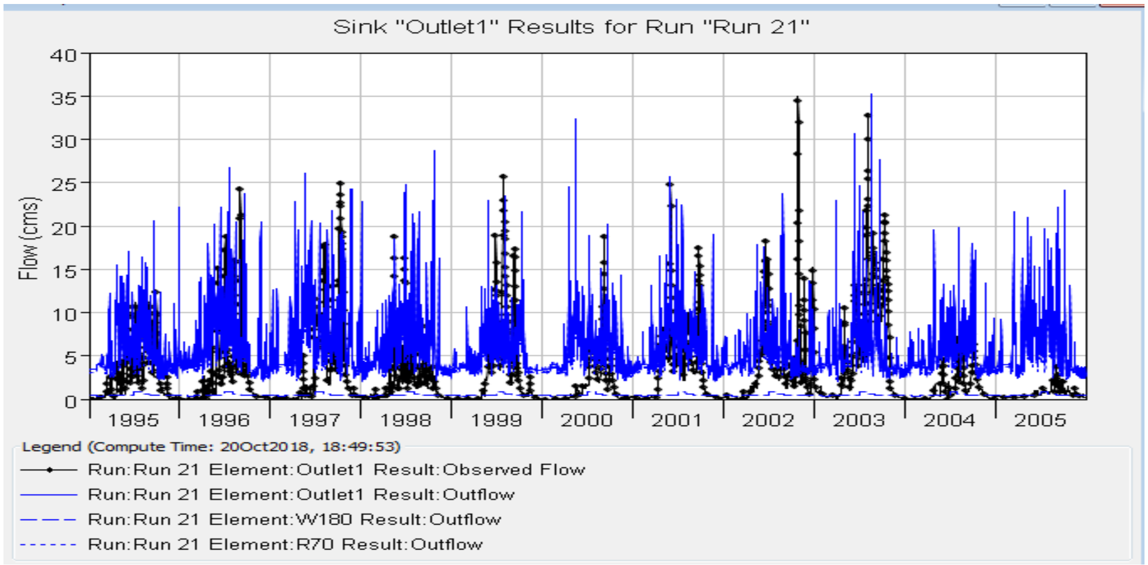


Figure 4.4: Daily simulated and observed flow hydrograph taken from HEC-HMS

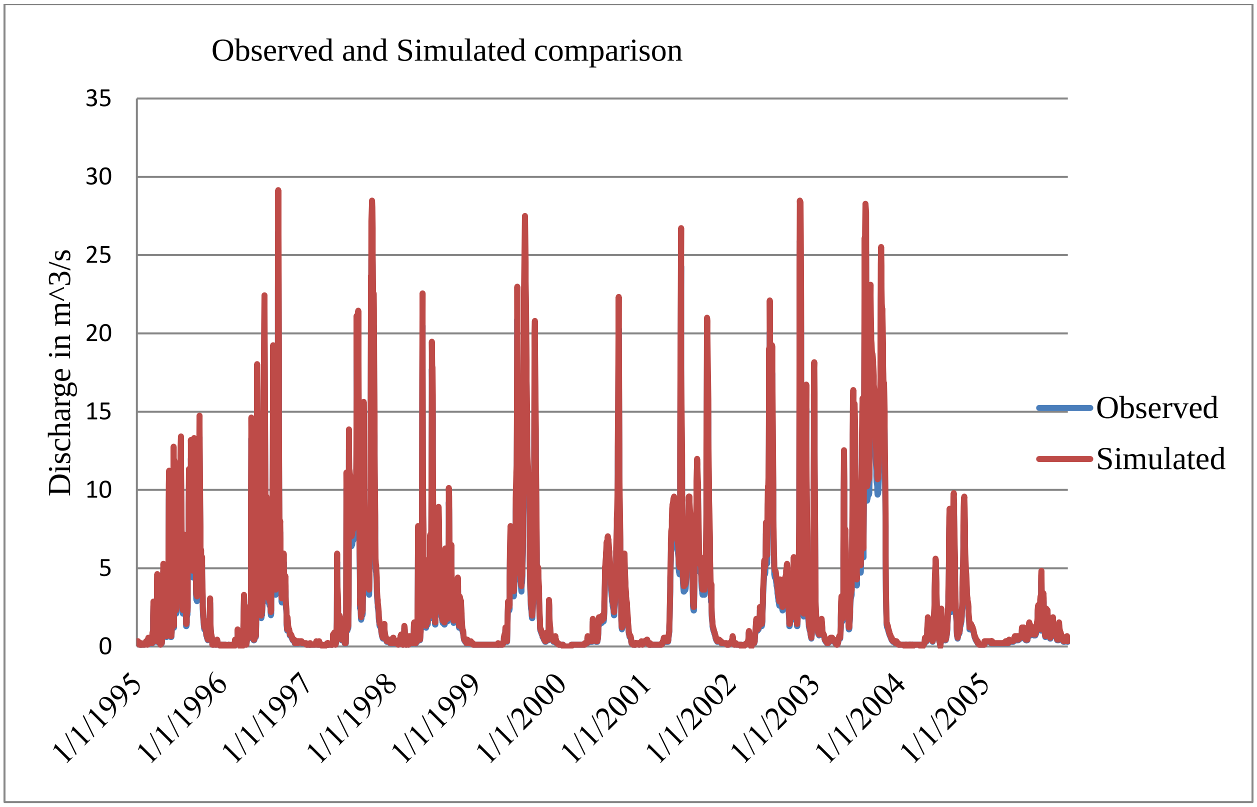


Figure 4.5: Simulated and Observed flow Hydrograph for Calibration (1995-2005)

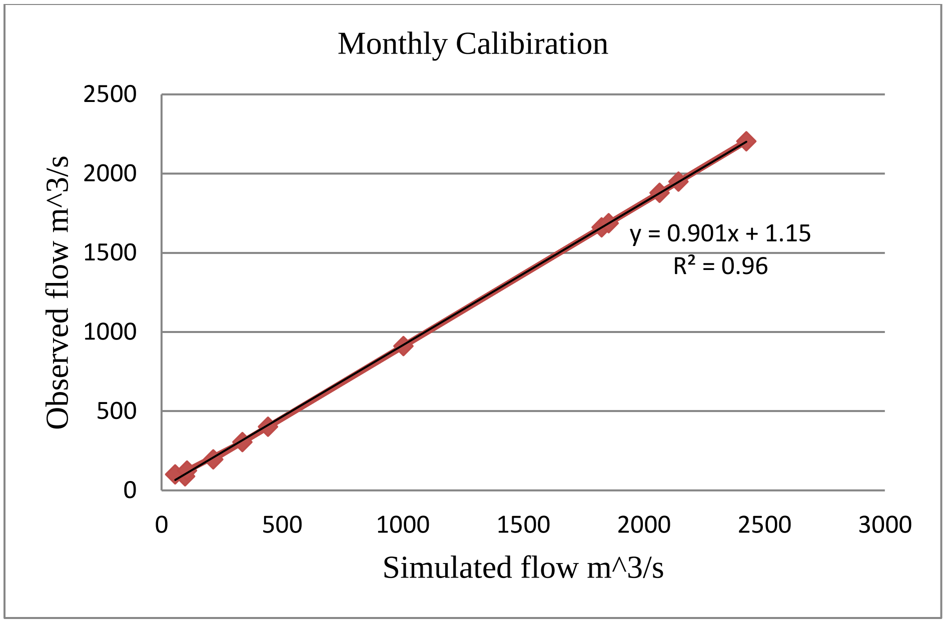


Figure 4.6: Coefficient of determination between simulated and computed flow during calibration

4.5 Validation

After the calibration was completed and all model parameters were adjusted, a 6 years hydro-meteorological data were entered and model validation was carried out to check whether the model with adjusted parameter was valid or not. After processing the input data the model was generated good results without any adjustment of especially, the sensitive parameters. The Nash Sutcliff efficiency and coefficient of determination during the model validation were 0.7 and 0.99 respectively. Coefficient of determination during model validation was shown in figure (4.8).

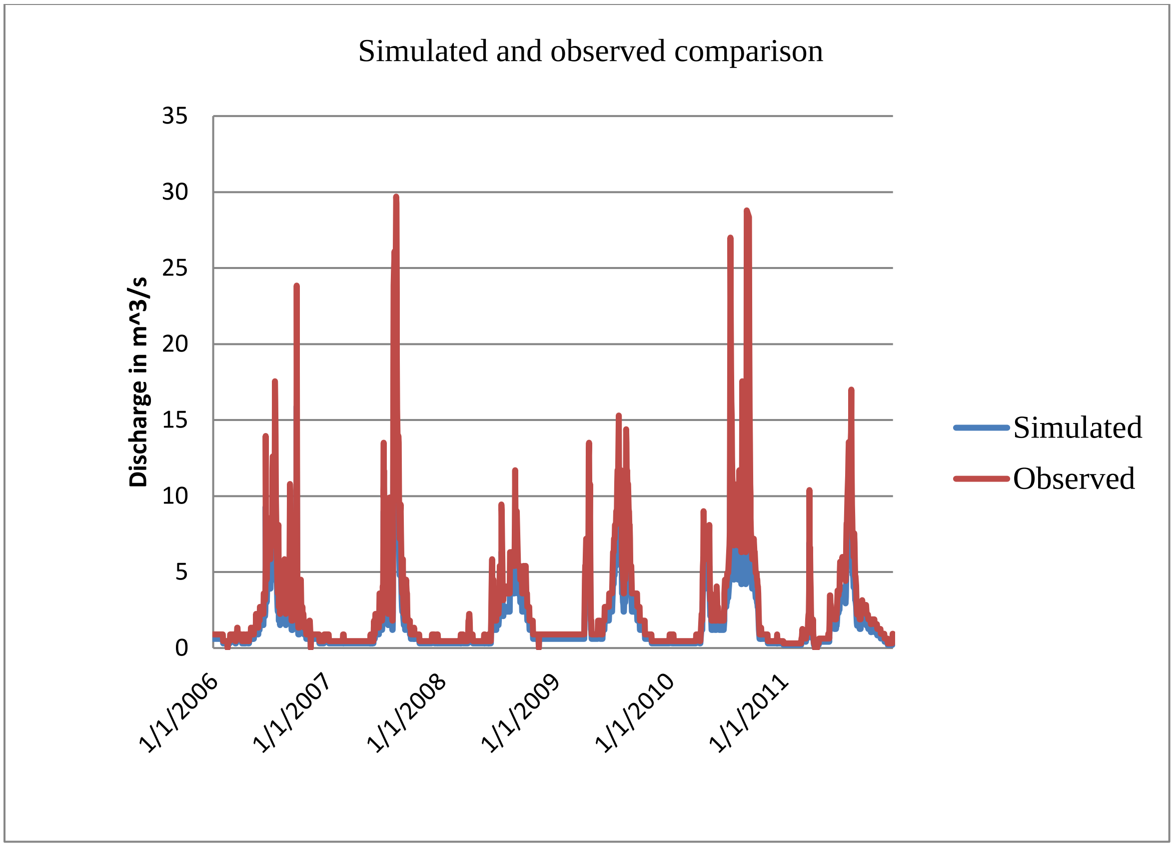


Figure 4.7: Simulated and Observed flow Hydrograph for Validation (2006-2011)

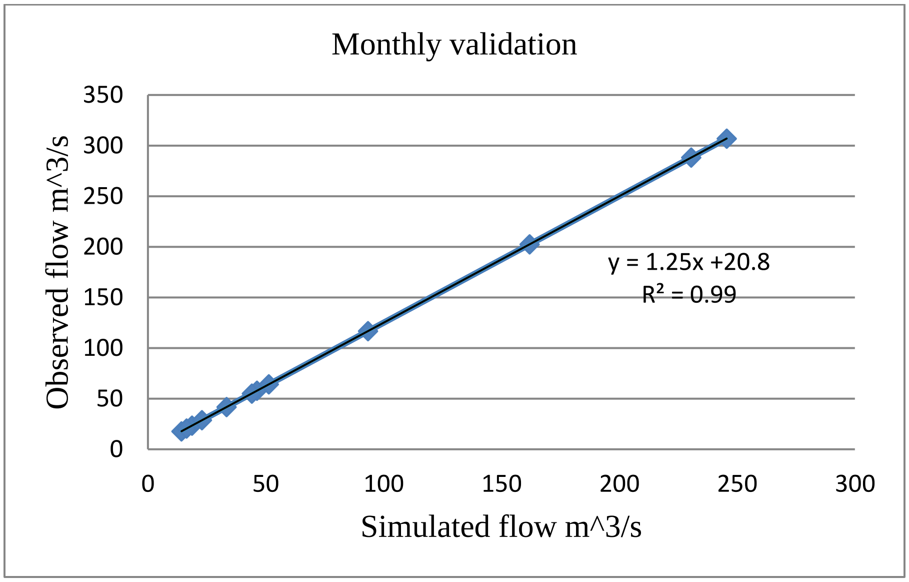


Figure 4.8: Coefficient of determination between simulated and computed flow during validation

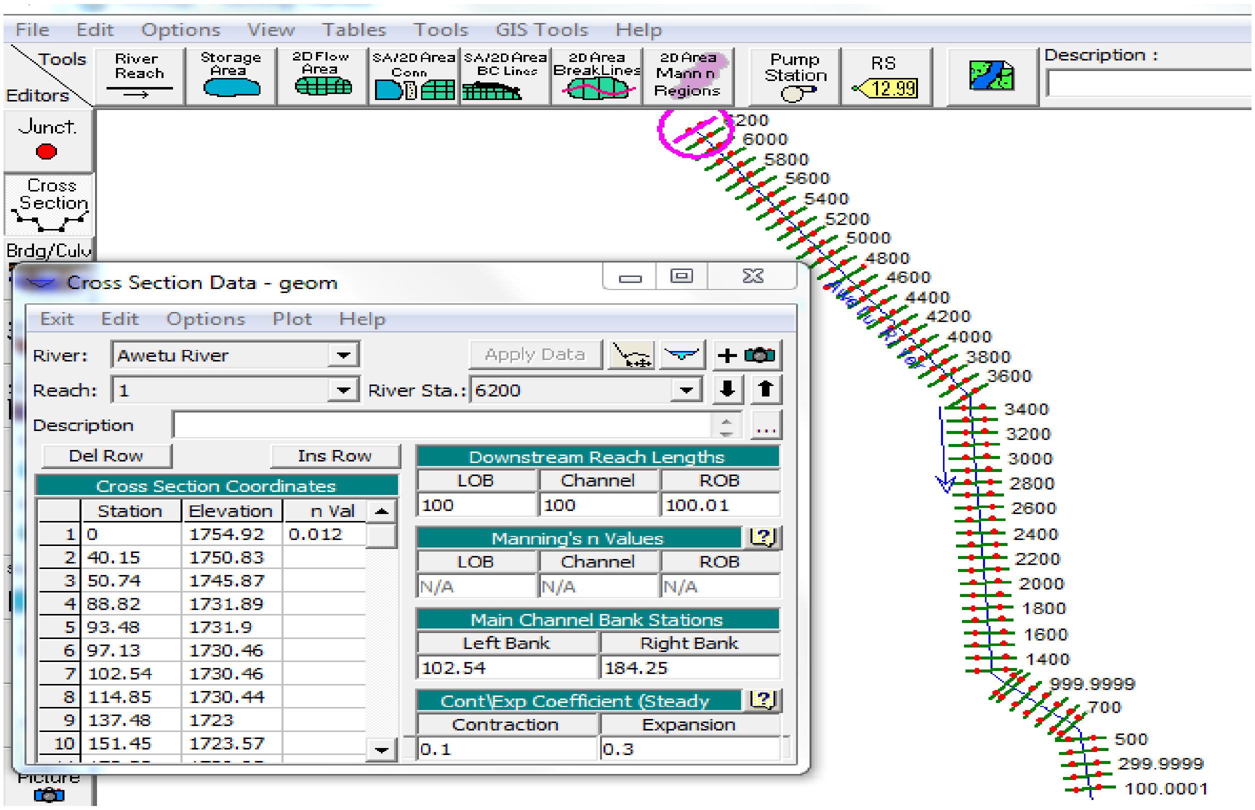
After model setup was adjusted using different parameters and model validation was carried out using daily time series data, a 0.25 hr,1 hr,2 hr,3 hr,6 hr ,12 hr and 24 hr rainfall depth obtained from ERA. IDF curve table was inserted into HEC-HMS for the computation of 25,50,250,and500 years return period and its computed values given in table (4.2).

Table 4.2: 24 hr rainfall depth and its peak flood for different return period developed from HEC-HMS

S/NO.	Return Period(Year)	24 hr Rainfall depth (mm)	Peak discharge(m^3/s)
1	25	89.35	13.2
2	50	96.84	14.9
3	250	113.75	18.9
4	500	122.41	21

4.6 Flood Hazard Mapping

Hydraulic modelling is to determine level of water surface of the river along the flood plain so that it is possible to predict time of over flow and flooding extent of the plain. In this study, rainfall runoff model was developed using HEC-HMS and model calibration and validation was carried out at the specified outlet using the historical flow data obtained from Ethiopian ministry of water, irrigation and energy. After model validity for the proposed study area was approved, then they obtained runoff model peak flood frequency analysis was carried out for different return periods. At the first stage for hydraulic modeling, RAS Geometry was processed using Arc GIS in combination with HEC-Geo RAS and final result was exported to HEC-RAS for final preprocessing as it was indicated by the following figure(4.9).



River: Awetu River

Reach: 1

River Sta.: 6200

Description

Cross Section Coordinates

	Station	Elevation	n Val
1	0	1754.92	0.012
2	40.15	1750.83	
3	50.74	1745.87	
4	88.82	1731.89	
5	93.48	1731.9	
6	97.13	1730.46	
7	102.54	1730.46	
8	114.85	1730.44	
9	137.48	1723	
10	151.45	1723.57	

Downstream Reach Lengths

LOB	Channel	ROB
100	100	100.01

Manning's n Values

LOB	Channel	ROB
N/A	N/A	N/A

Main Channel Bank Stations

Left Bank	Right Bank
102.54	184.25

Cont\Exp Coefficient (Steady

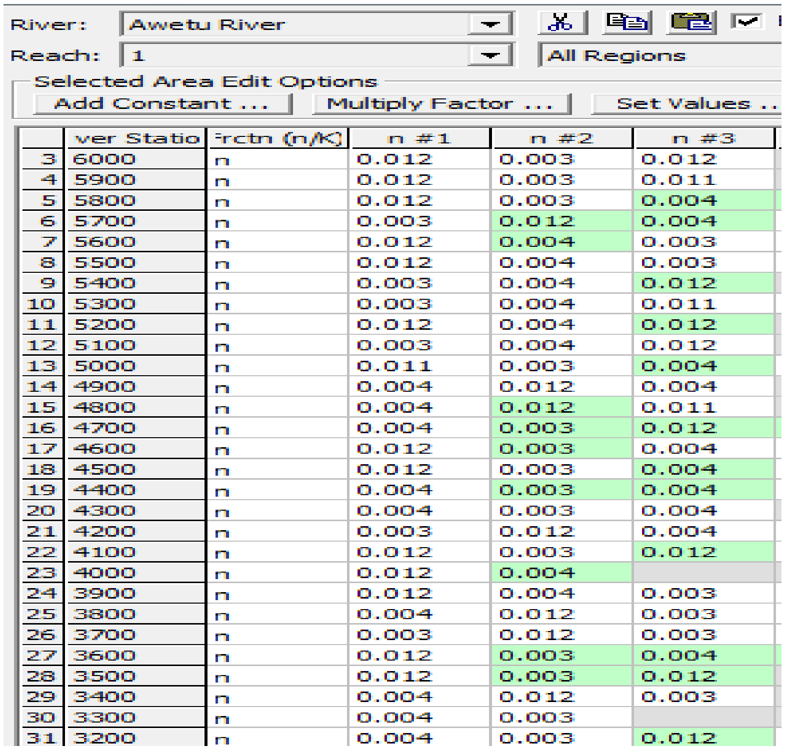
Contraction	Expansion
0.1	0.3

Figure 4.9: Geometric Data, River station and cross section network exported from Arc GIS to HEC-RAS

4.7 Roughness Coefficient Determination of the River and Flood Plain

Manning's n values were used in the model to define roughness for each cross section. Once the land-use was defined for the entire watershed, the representative n-values were assigned to the portion of each cross section that intersects the respective land-use area. These n-values were then extracted from land use and exported to the HEC-RAS model using HEC-GeoRAS as shown table (4.3). Having a peak flood for different return periods from HEC-HMS, river geometry and river cross-section data extracted from digital terrain model as in the figure (4.9), manning's roughness coefficient for right, channel bed and left bank were assigned by HEC-RAS for the specified flood plain and boundary condition (critical depth flow regime for this study), the hydraulic modeling was developed for steady state 1-Dimensional flow condition. Having entering all the necessary data and running the RAS model for mixed flow regime, the river profile elevation along the flood plain was shown as in figure (4.10).

Table 4.3: Roughness Coefficient of right bank, channel bed and left bank



River: Awetu River

Reach: 1

All Regions

	ver Statio	rctn (n/K)	n #1	n #2	n #3
3	6000	n	0.012	0.003	0.012
4	5900	n	0.012	0.003	0.011
5	5800	n	0.012	0.003	0.004
6	5700	n	0.003	0.012	0.004
7	5600	n	0.012	0.004	0.003
8	5500	n	0.012	0.004	0.003
9	5400	n	0.003	0.004	0.012
10	5300	n	0.003	0.004	0.011
11	5200	n	0.012	0.004	0.012
12	5100	n	0.003	0.004	0.012
13	5000	n	0.011	0.003	0.004
14	4900	n	0.004	0.012	0.004
15	4800	n	0.004	0.012	0.011
16	4700	n	0.004	0.003	0.012
17	4600	n	0.012	0.003	0.004
18	4500	n	0.012	0.003	0.004
19	4400	n	0.004	0.003	0.004
20	4300	n	0.004	0.003	0.004
21	4200	n	0.003	0.012	0.004
22	4100	n	0.012	0.003	0.012
23	4000	n	0.012	0.004	
24	3900	n	0.012	0.004	0.003
25	3800	n	0.004	0.012	0.003
26	3700	n	0.003	0.012	0.003
27	3600	n	0.012	0.003	0.004
28	3500	n	0.012	0.003	0.012
29	3400	n	0.004	0.012	0.003
30	3300	n	0.004	0.003	
31	3200	n	0.004	0.003	0.012

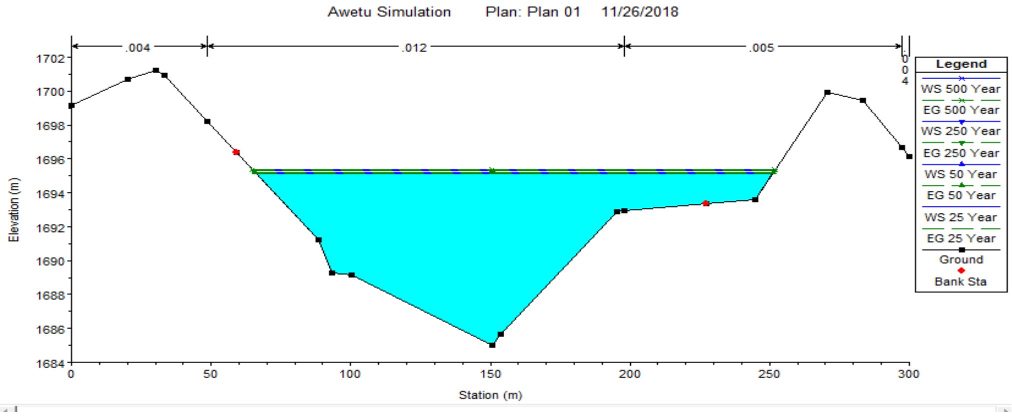


Figure 4.10: River profile and water surface elevation across Awetu flood plain

Besides to water surface elevation, HEC-RAS produces different results such as: Minimum channel elevation, Critical water surface elevation for a model with critical flow regime, Elevation of energy and slope gradient, Channel velocity and flow area, Top width of the channel and Froude number for each river station developed during preprocessing using HEC-

Geo RAS and for each HEC-RAS profile given in (Appendix-G). After all HEC-RAS profiles (flow data, river geometric data, and boundary condition) and other parameters were setup and the data correctness was checked, hydraulic modeling was developed and the RAS result was exported back to HEC-Geo RAS in RASexport.sdf for post processing. At this stage, the RASexport.sdf file was converted to file.xml so that it was easy to process in Arc GIS for the final flood inundation mapping. After converting the file to Arc GIS compatible using ‘Import RAS SDF File’ which is one of the HEC-Geo RAS menus, HEC-Geo RAS layer setup was adjusted and the RAS data was imported and then flood inundation running was take place. The result indicated that a 25 year return period frequency storm inundates 58.9 ha of the total area flood plain with the minimum water depth 0.003m and maximum water depth of 22.38 m.

Maximum flood coverage resulted for 500 years return period frequency storm and it inundates about 71.7ha with a minimum and maximum water depth of 0.0005 m to 22.6 m respectively.

The inundated area and maximum water level given by HEC-RAS during 25, 50,250 and 500-year flood in Awetu basin is tabulated in table (4.4) to have an idea of water level in different design floods.

Table 4.4: Area inundated and Maximum water level in Awetu River.

Return period(year)	Area Inundated (ha)	Maximum water level (m)
25	*58.9*	22.38
50	60	22.44
250	60.5	22.56
500	71.7	22.6

4.8 Flood risk mapping

Flood risk maps are an important tool for flood prediction and management, because they complement the information predicted from hydrological models and allow the development of relief profiles. Mapping is the method used to present risk information and to decide where to spend money on flood risk management measures (and, additionally, to help the water managers and dam operators to enhance their response to flooding). These flood risk maps can serve as a basis for designing measures to minimize loss of life and the flood risk map of 500 return period was given in figure (4.11) where the 25 year, 50 year and 250 year return period were in (Appendix D).

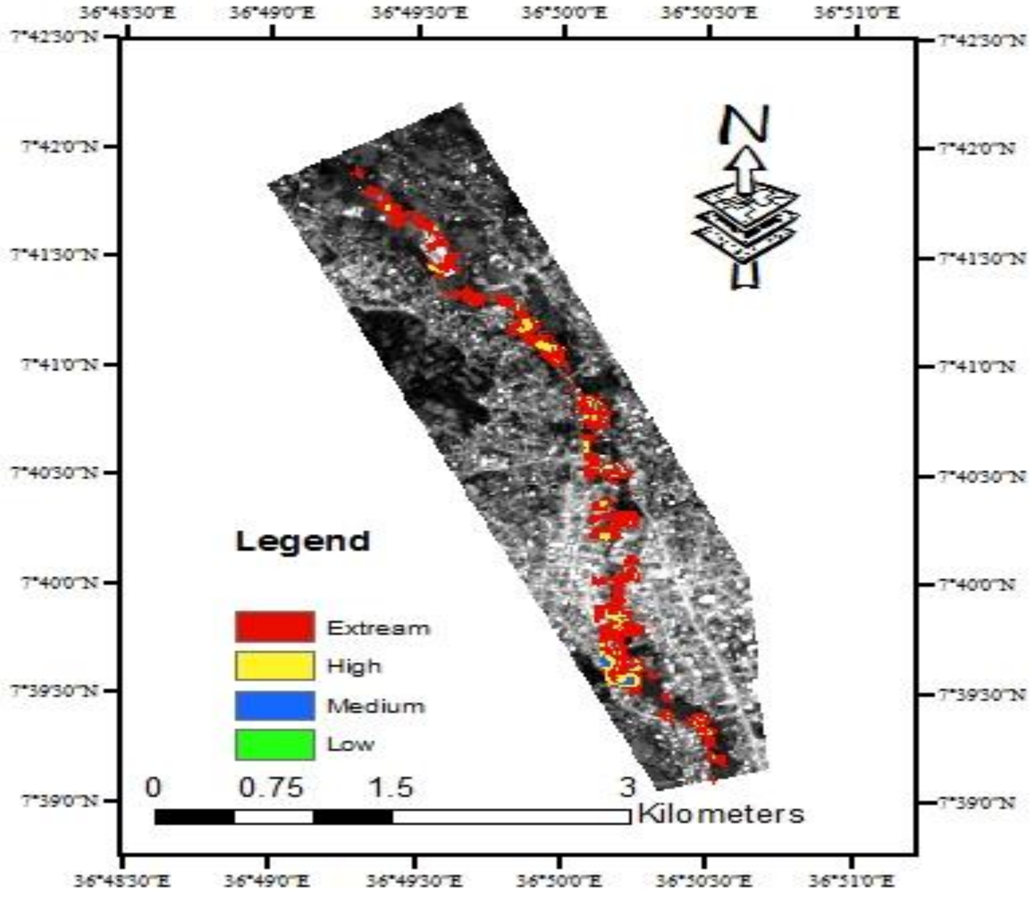


Figure 4.11: Risk map of 500 year return period

CHAPTER FIVE

5 CONCULUTION AND RECOMMEDATION

5.1 CONCLUSION

Flooding is a natural process and its complete control is beyond the capability of human efforts. However, the magnitude of flooding and its impact can be reduced to a certain extent through development of modelling flood hazard, flood risk mapping, effective implementation of land-use zoning and building codes and standards. The problems of increasing risk and vulnerability are not associated with physical features only, but also with socioeconomic conditions.

The importance of flood-hazard, vulnerability mapping and flood risk mapping in developing appropriate disaster-mitigation and management strategies to reduce the impacts of flood hazards has been realized and such activities have been incorporated into National Development Plans. The study in the Awetu Watershed clearly shows that flood-hazard, vulnerability, and flood risk map are economic in terms of both time and money, and a useful tool for developing community's awareness and preparedness in order to reduce the impact from flooding.

River flood water depth and flow velocity were the most important elements of river flood hazard mapping where flood hazard and vulnerability are the most important for flood risk map. The generated river flood hazard pattern distribution is more influenced by water depth in comparison with flow velocity that shows hazard produced by water depth is more considerable than flow velocity during river flood event.

Development of flood risk map is very important in implementing flood risk management especially in flood risk assessment. It provides flood risk information on a specific location and reduces the damage due to floods.

5.2 RECOMMEDATION

There is a need for more accurate and recent data sets as flooding is becoming a more frequently occurring phenomenon. Without appropriate data, flood modelling and prediction is limited, increasing the vulnerability of poor communities that are often without the means to cope with an extreme flood event. The availability of adequate data sets for hydraulic modelling has restricted the scale of flood hazard, risk mapping and the selection of a demonstration area. One-dimension model, HEC-RAS can provide good result in case of proper defined river course. Once it overtops the channel top level, two-dimensional model is required to compute the spread water over flood plain zone.

Flood hazard management can be carried out with two different approaches: soft (non-structure) and hard (structure) approach. The soft approach includes planning and policy making, strategy development, creating awareness and preparedness like river modelling for flood risk map. These seem more effective in long perspective to reduce the effects of flood hazard. Infrastructural development for flood protection which comes under structural or hard approach is a comparatively quick solution but is expensive measures. Thus, thorough planning and implementation of policies and strategies should be integrated with effective structural measures for proper flood risk reduction and protection.

The quality of data collected, and the time span they covered has been checked and day to day river basin management carried out which is vital for the effective management and forecasting of floods. Precipitation data used in hydrologic modelling were daily, and data series had gaps if the data series were complete the accuracy of study would have increased significantly.

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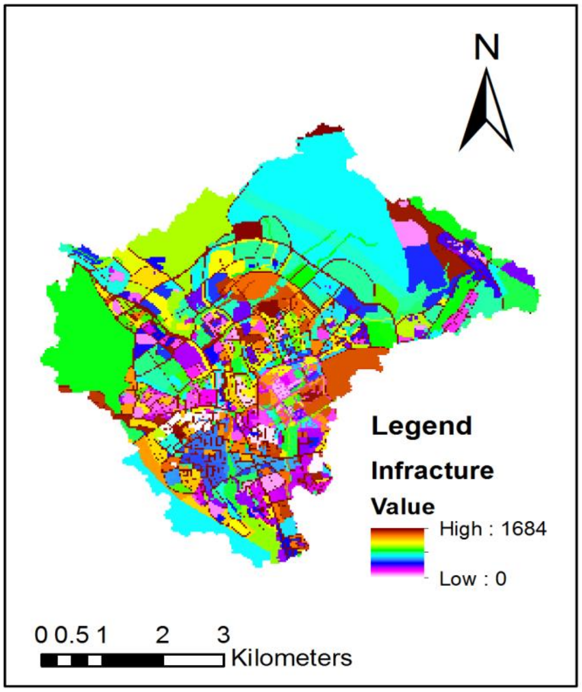
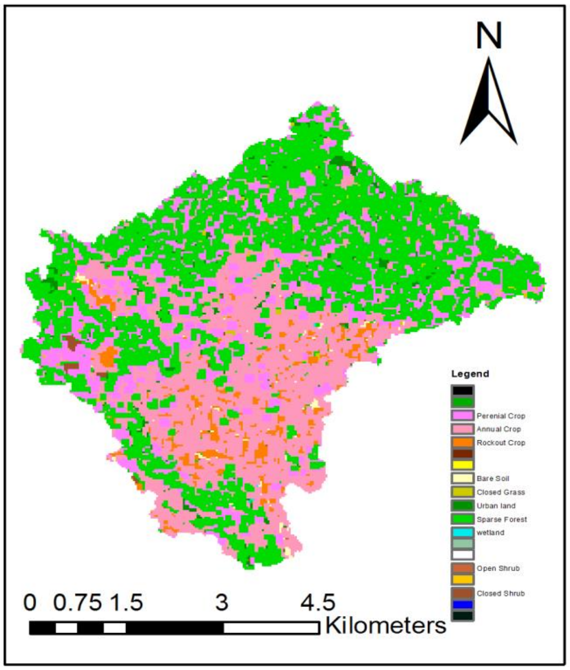
APPENDIXES

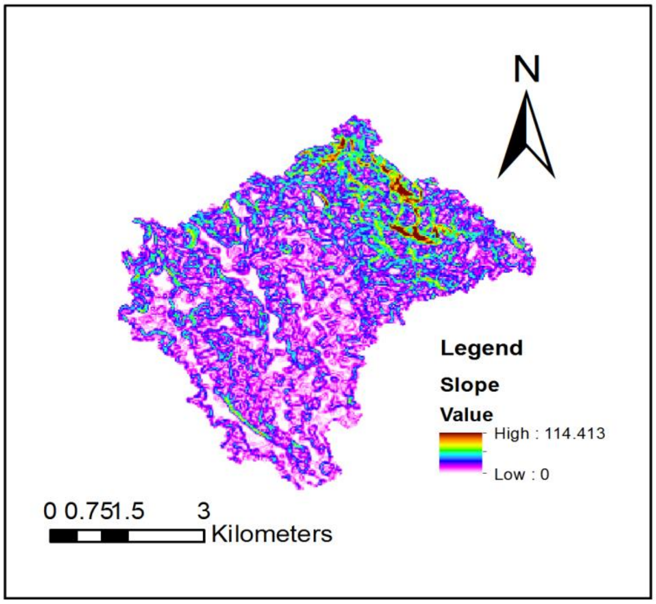
APPENDIX-A: Raw data used for vulnerability mapping



(a) Infra-sturecture map

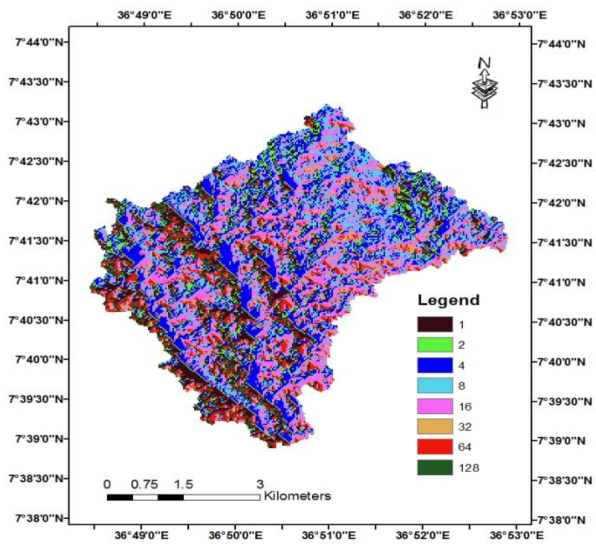


(b) Land use map

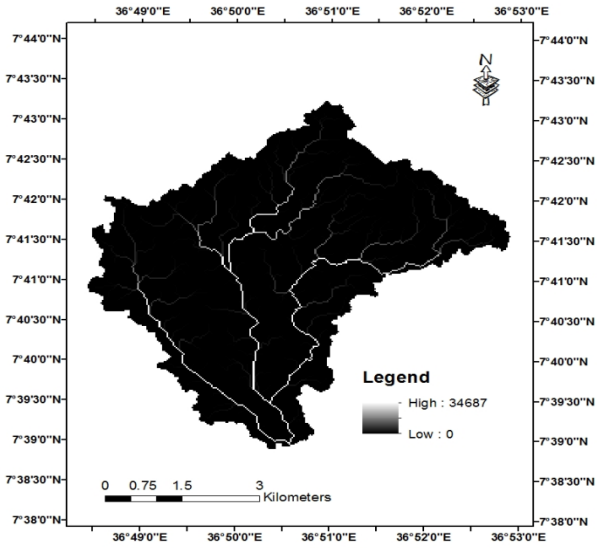


(c) Slope map

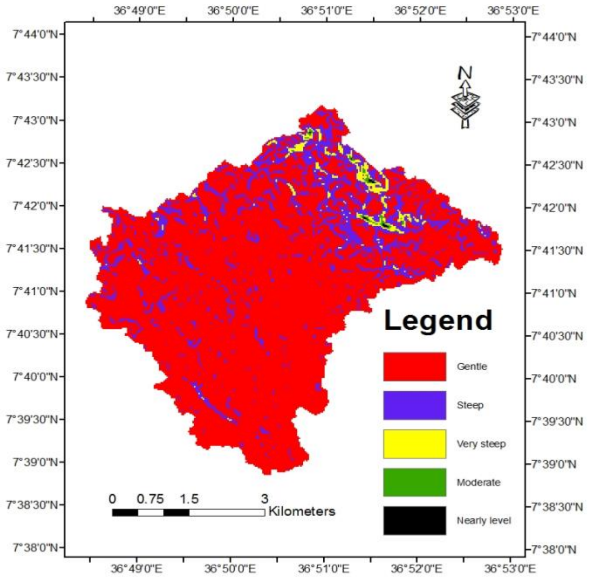
APPENDIX-B :Processed data



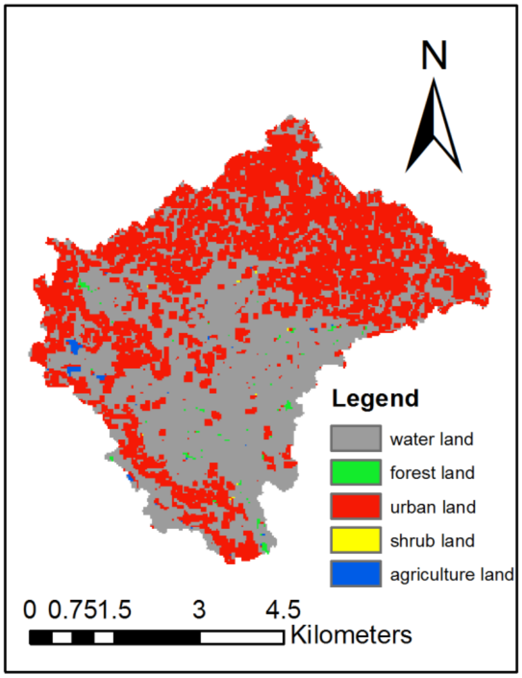
(a) Flow direction



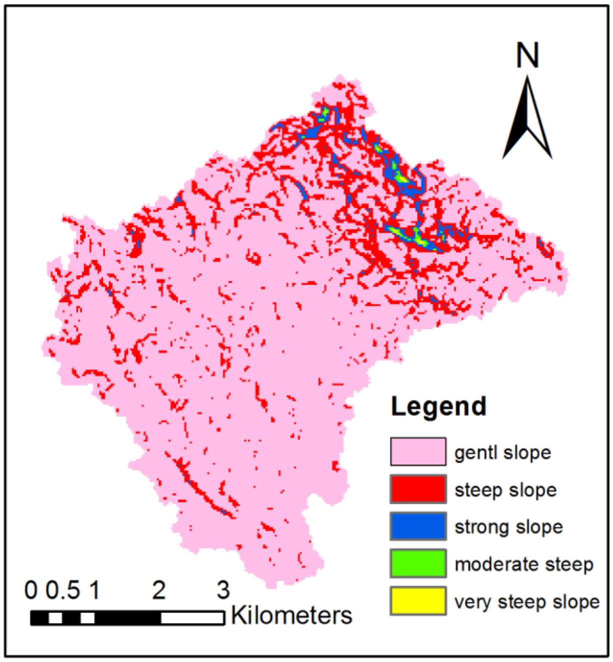
(b) Flow accumulation



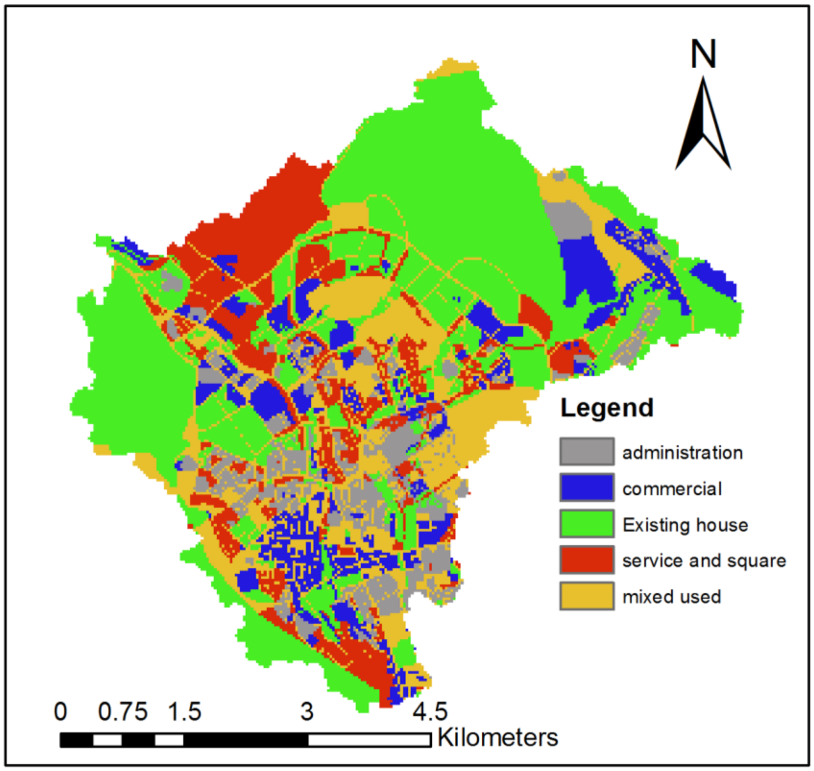
(C) Slope



(a) Landuse classification

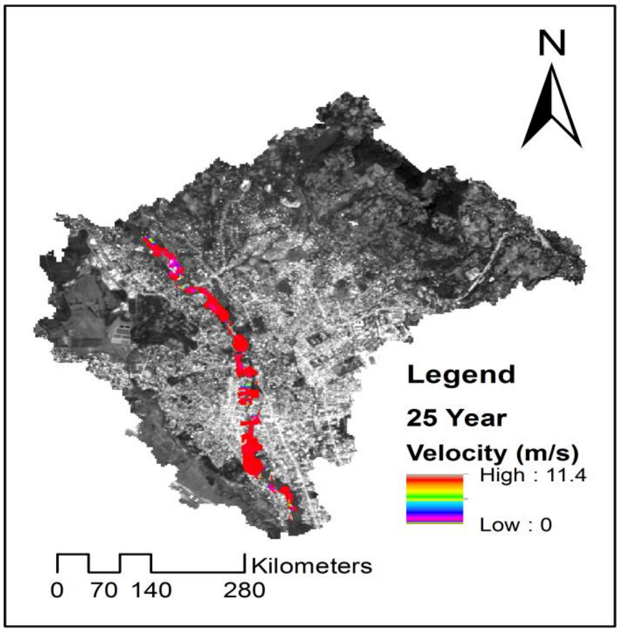


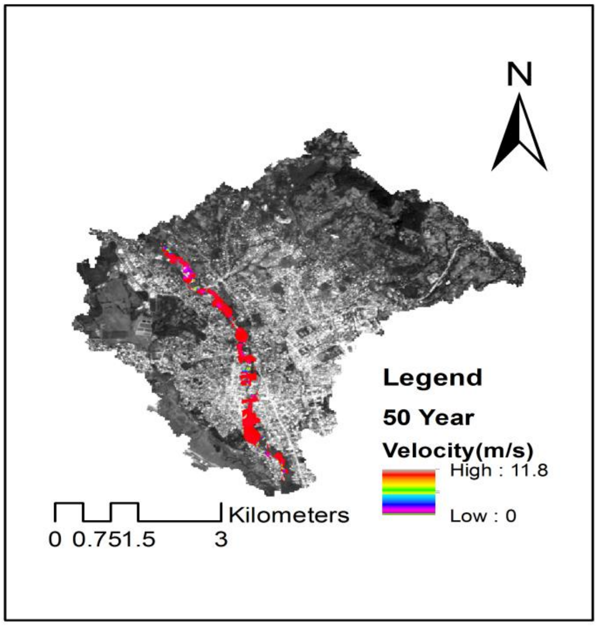
(b) slope classification

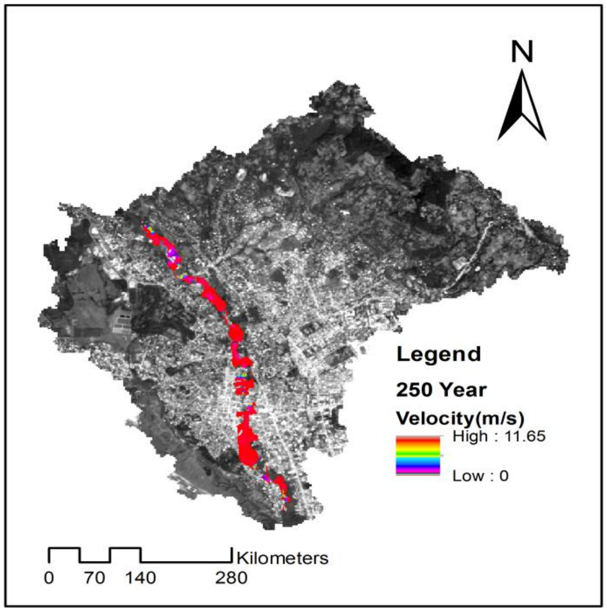


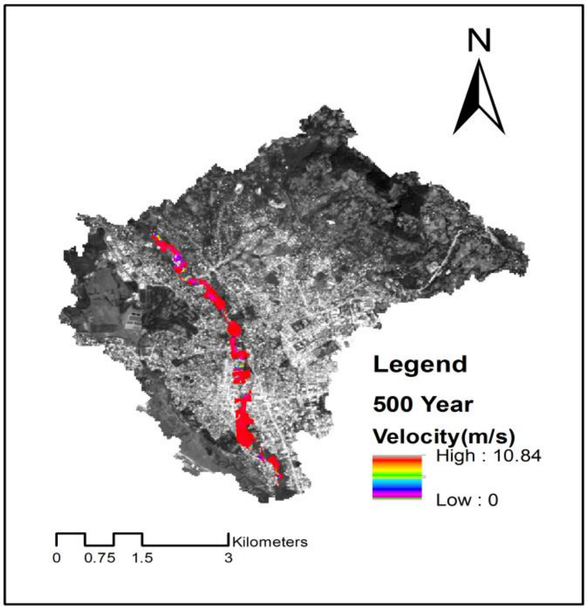
(c) Infra-structure classification

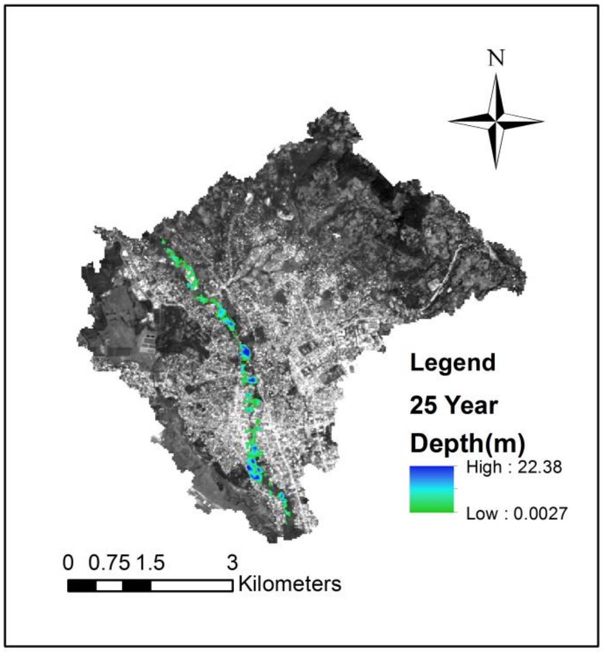
APPENDIX-C: Velocity and Depth for each respective return period.

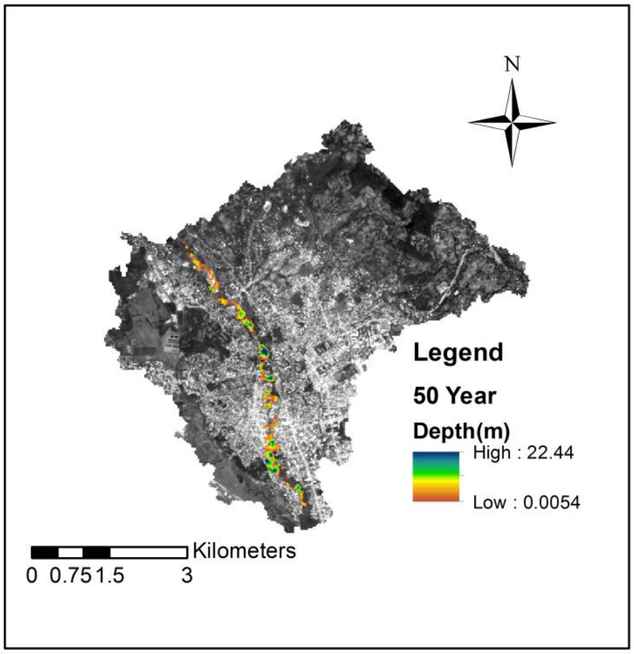


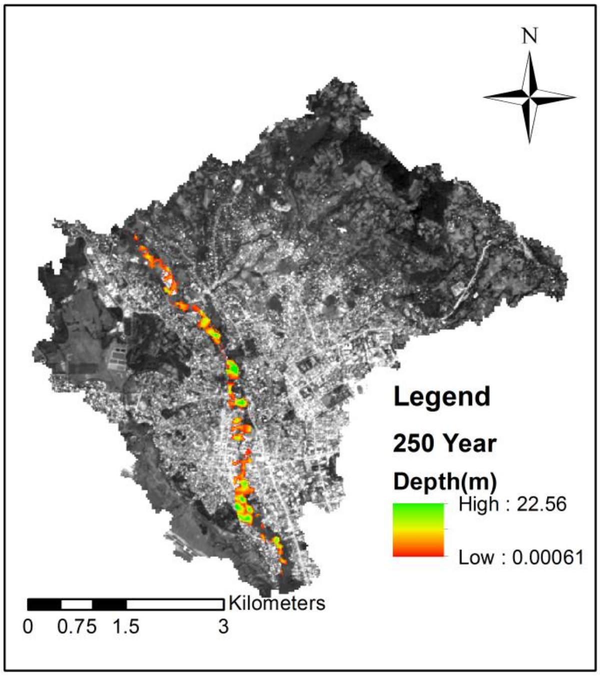


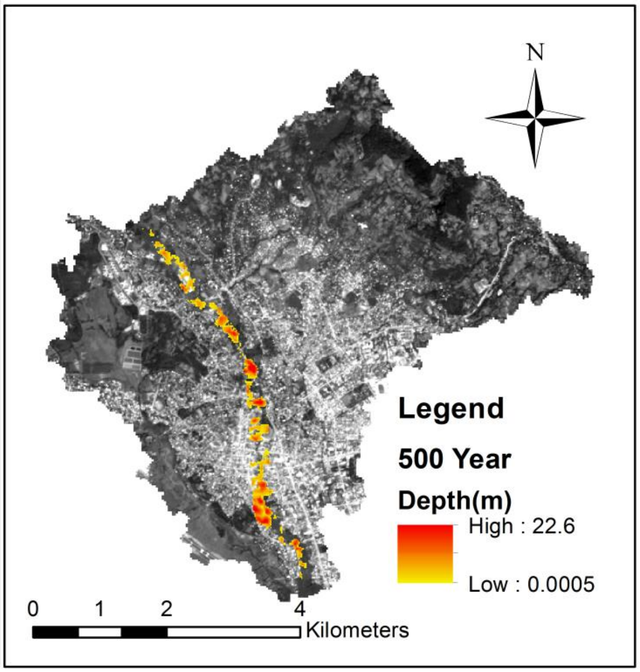




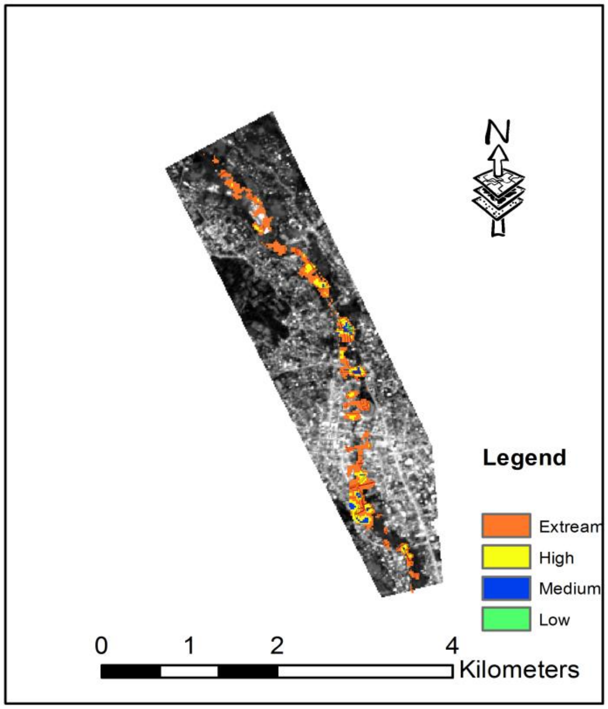

N
Legend
25 Year
Depth(m)
High : 22.38
Low : 0.0027
0 0.75 1.5 3
Kilometers

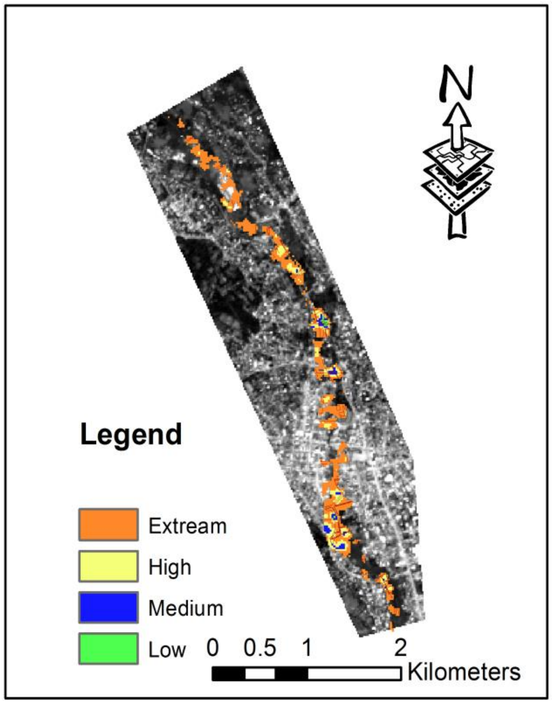

N
Legend
50 Year
Depth(m)
High : 22.44
Low : 0.0054
Kilometers
0 0.75 1.5 3

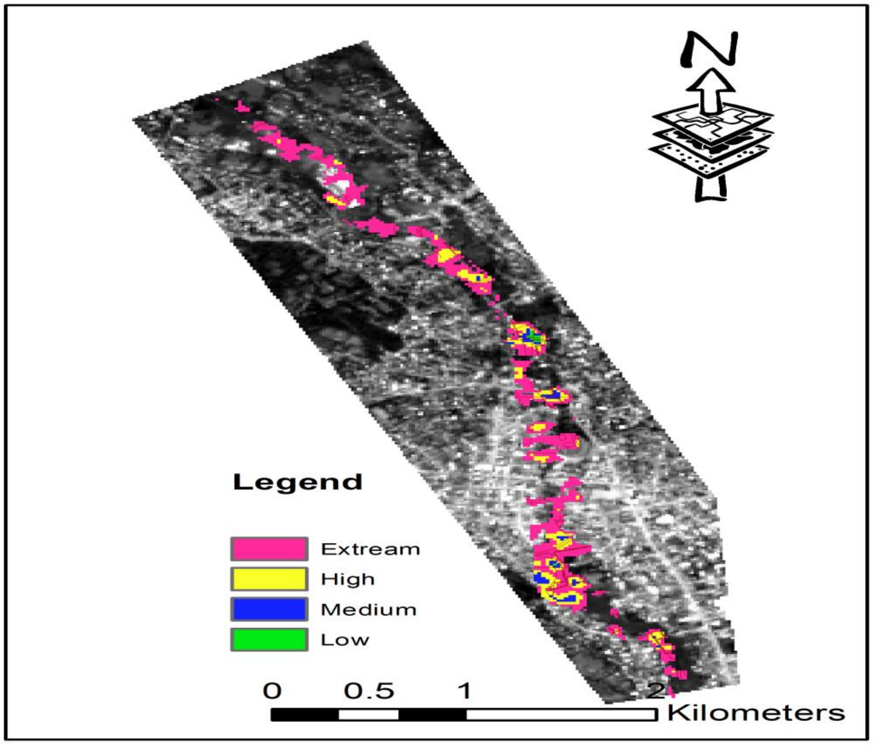

N
Legend
250 Year
Depth(m)
High : 22.56
Low : 0.00061
Kilometers
0 0.75 1.5 3


N
Legend
500 Year
Depth(m)
High : 22.6
Low : 0.0005
0 1 2 4
Kilometers

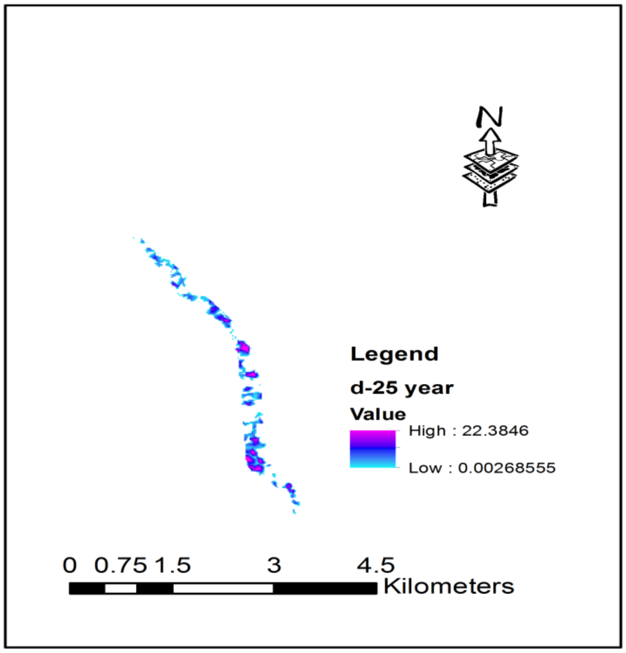
APPENDIX-D: Flood risk map for 25, 50 and 250 year respective return period.

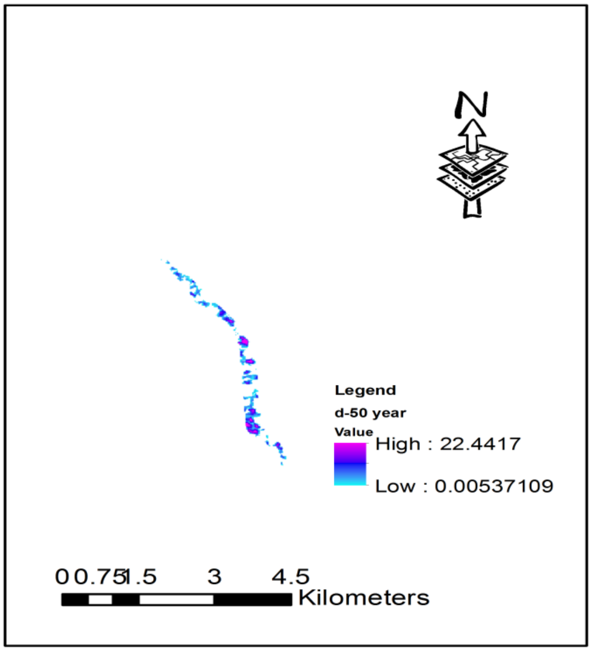


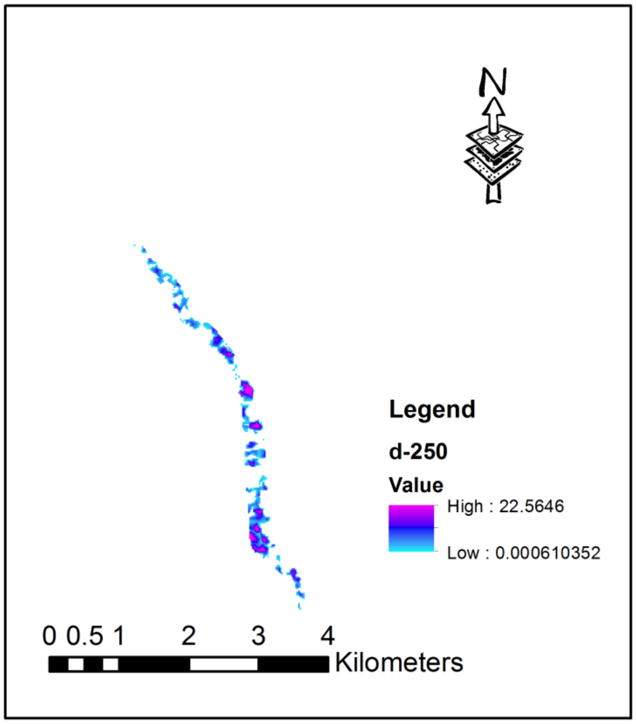


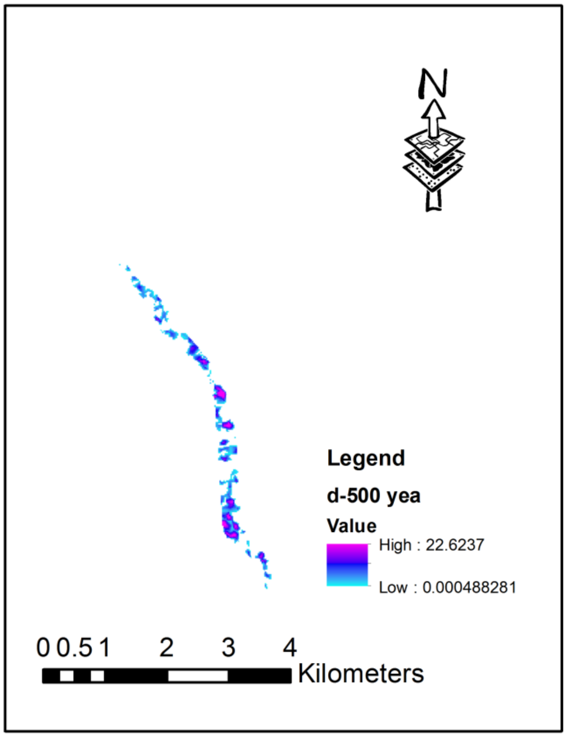


APPENDIX-E: Map of flood inundation area for each respective return period









Appendix -F: X-Y-Z Perspective Plot and River station.

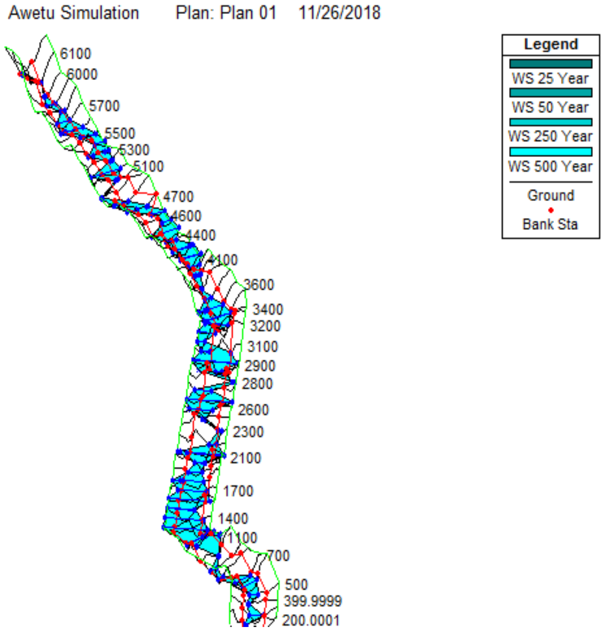
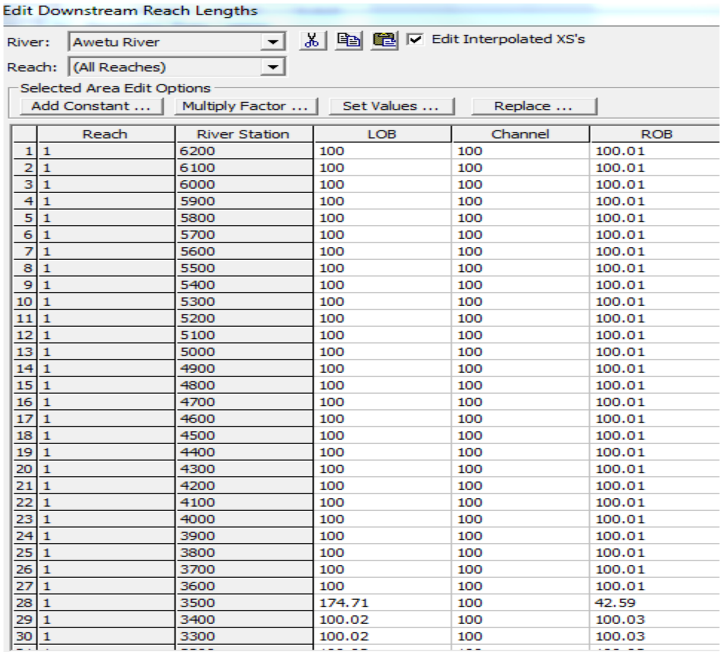


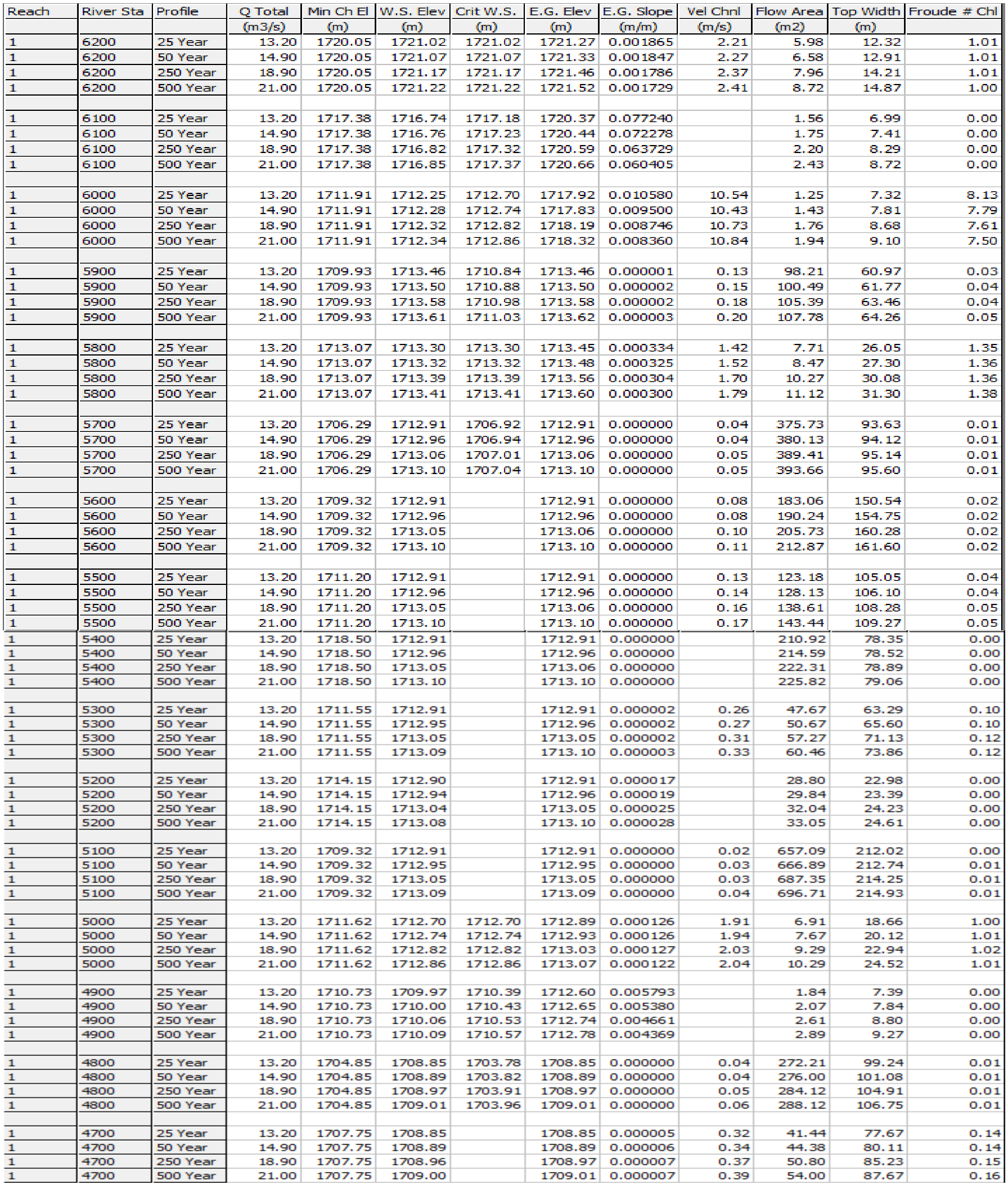
Figure 3D Plan.

Table-a: Rive station of Left, channel and Right Channel

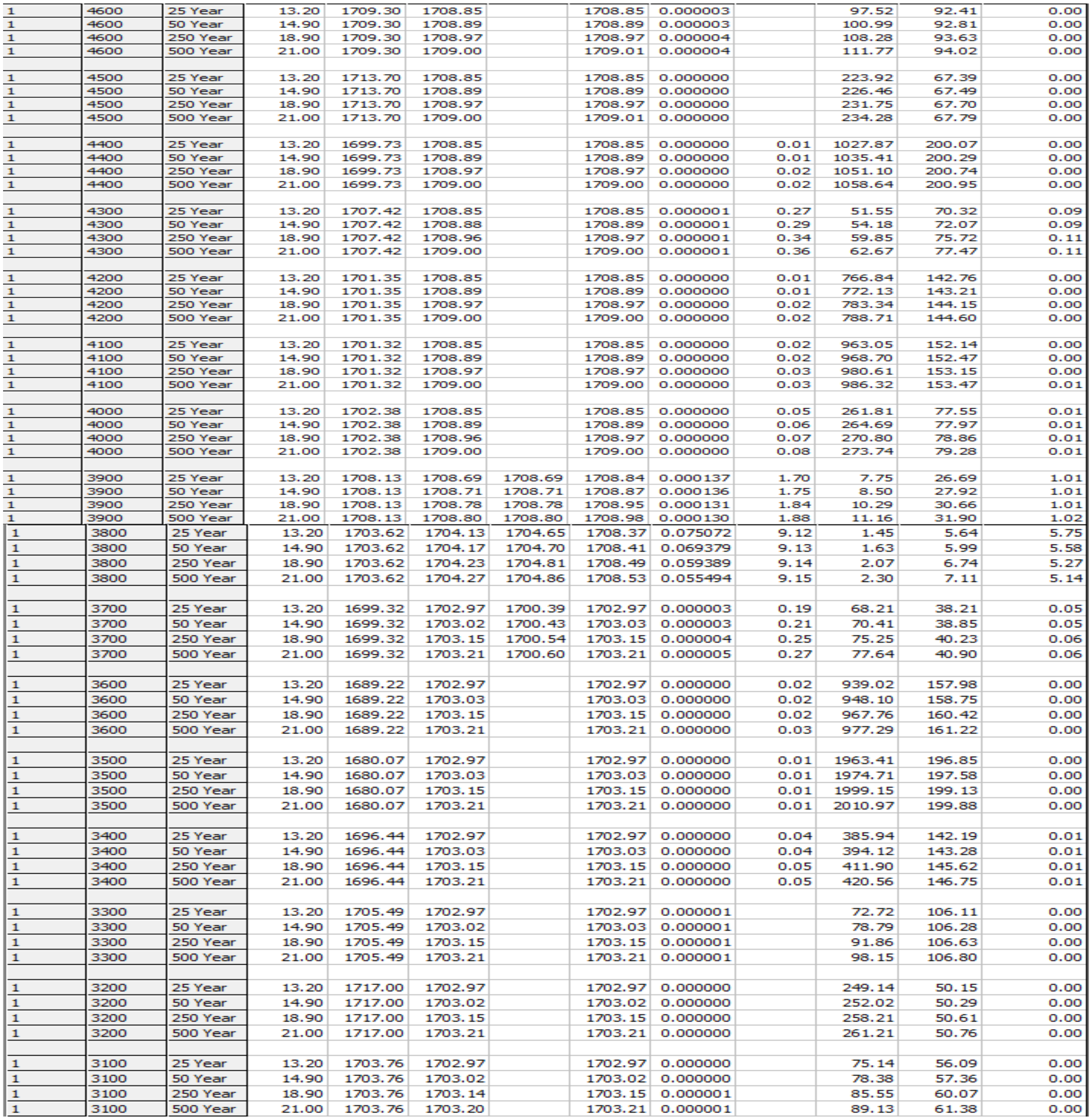


	Reach	River Station	LOB	Channel	ROB
1	1	6200	100	100	100.01
2	1	6100	100	100	100.01
3	1	6000	100	100	100.01
4	1	5900	100	100	100.01
5	1	5800	100	100	100.01
6	1	5700	100	100	100.01
7	1	5600	100	100	100.01
8	1	5500	100	100	100.01
9	1	5400	100	100	100.01
10	1	5300	100	100	100.01
11	1	5200	100	100	100.01
12	1	5100	100	100	100.01
13	1	5000	100	100	100.01
14	1	4900	100	100	100.01
15	1	4800	100	100	100.01
16	1	4700	100	100	100.01
17	1	4600	100	100	100.01
18	1	4500	100	100	100.01
19	1	4400	100	100	100.01
20	1	4300	100	100	100.01
21	1	4200	100	100	100.01
22	1	4100	100	100	100.01
23	1	4000	100	100	100.01
24	1	3900	100	100	100.01
25	1	3800	100	100	100.01
26	1	3700	100	100	100.01
27	1	3600	100	100	100.01
28	1	3500	174.71	100	42.59
29	1	3400	100.02	100	100.03
30	1	3300	100.02	100	100.03

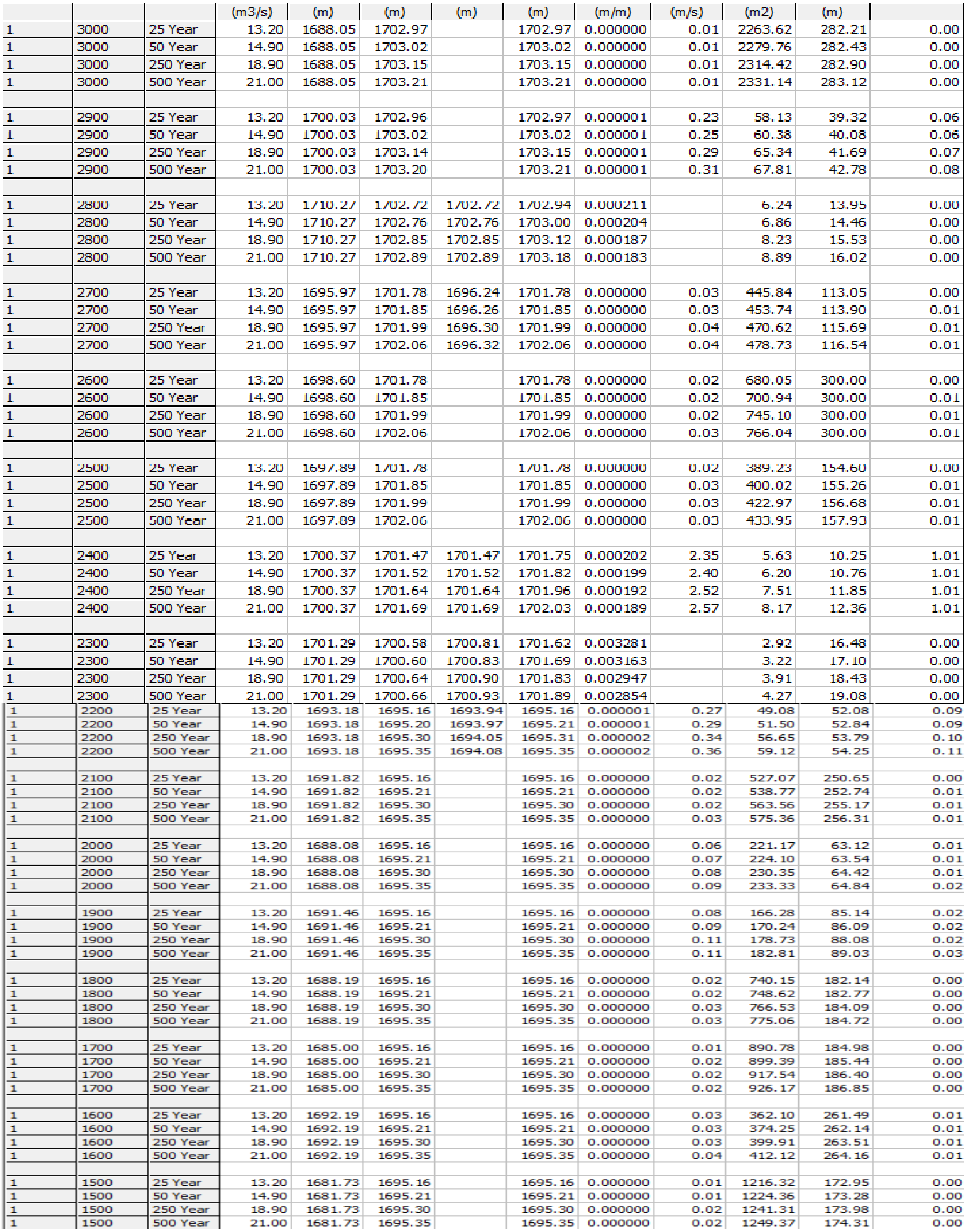
APPENDIX -G: Summary of HEC-RAS output table by profile



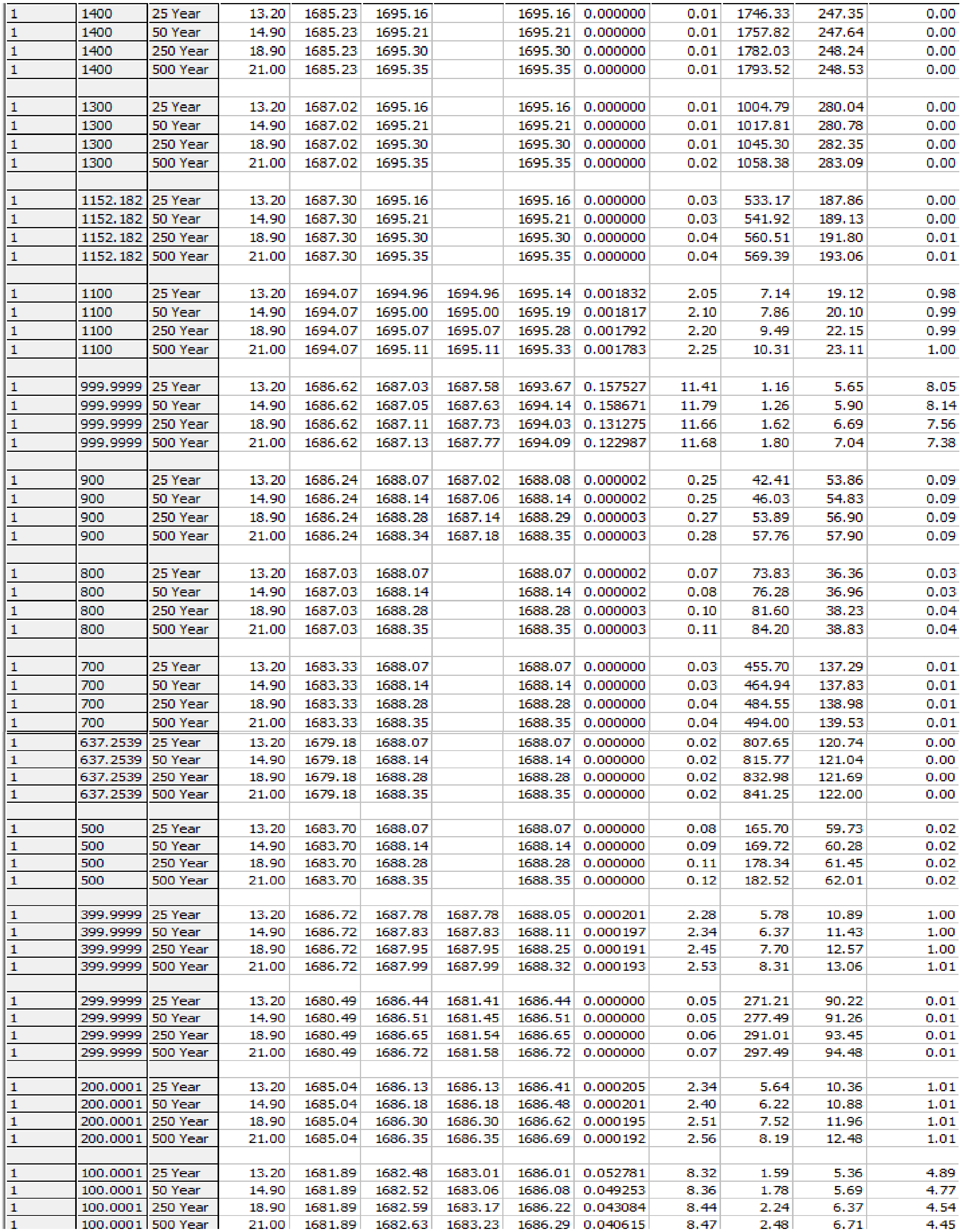
Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	6200	25 Year	13.20	1720.05	1721.02	1721.02	1721.27	0.001865	2.21	5.98	12.32	1.01
1	6200	50 Year	14.90	1720.05	1721.07	1721.07	1721.33	0.001847	2.27	6.58	12.91	1.01
1	6200	250 Year	18.90	1720.05	1721.17	1721.17	1721.46	0.001786	2.37	7.96	14.21	1.01
1	6200	500 Year	21.00	1720.05	1721.22	1721.22	1721.52	0.001729	2.41	8.72	14.87	1.00
1	6100	25 Year	13.20	1717.38	1716.74	1717.18	1720.37	0.077240		1.56	6.99	0.00
1	6100	50 Year	14.90	1717.38	1716.76	1717.23	1720.44	0.072278		1.75	7.41	0.00
1	6100	250 Year	18.90	1717.38	1716.82	1717.32	1720.59	0.063729		2.20	8.29	0.00
1	6100	500 Year	21.00	1717.38	1716.85	1717.37	1720.66	0.060405		2.43	8.72	0.00
1	6000	25 Year	13.20	1711.91	1712.25	1712.70	1717.92	0.010580	10.54	1.25	7.32	8.13
1	6000	50 Year	14.90	1711.91	1712.28	1712.74	1717.83	0.009500	10.43	1.43	7.81	7.79
1	6000	250 Year	18.90	1711.91	1712.32	1712.82	1718.19	0.008746	10.73	1.76	8.68	7.61
1	6000	500 Year	21.00	1711.91	1712.34	1712.86	1718.32	0.008360	10.84	1.94	9.10	7.50
1	5900	25 Year	13.20	1709.93	1713.46	1710.84	1713.46	0.000001	0.13	98.21	60.97	0.03
1	5900	50 Year	14.90	1709.93	1713.50	1710.88	1713.50	0.000002	0.15	100.49	61.77	0.04
1	5900	250 Year	18.90	1709.93	1713.58	1710.98	1713.58	0.000002	0.18	105.39	63.46	0.04
1	5900	500 Year	21.00	1709.93	1713.61	1711.03	1713.62	0.000003	0.20	107.78	64.26	0.05
1	5800	25 Year	13.20	1713.07	1713.30	1713.30	1713.45	0.000334	1.42	7.71	26.05	1.35
1	5800	50 Year	14.90	1713.07	1713.32	1713.32	1713.48	0.000325	1.52	8.47	27.30	1.36
1	5800	250 Year	18.90	1713.07	1713.39	1713.39	1713.56	0.000304	1.70	10.27	30.08	1.36
1	5800	500 Year	21.00	1713.07	1713.41	1713.41	1713.60	0.000300	1.79	11.12	31.30	1.38
1	5700	25 Year	13.20	1706.29	1712.91	1706.92	1712.91	0.000000	0.04	375.73	93.63	0.01
1	5700	50 Year	14.90	1706.29	1712.96	1706.94	1712.96	0.000000	0.04	380.13	94.12	0.01
1	5700	250 Year	18.90	1706.29	1713.06	1707.01	1713.06	0.000000	0.05	389.41	95.14	0.01
1	5700	500 Year	21.00	1706.29	1713.10	1707.04	1713.10	0.000000	0.05	393.66	95.60	0.01
1	5600	25 Year	13.20	1709.32	1712.91		1712.91	0.000000	0.08	183.06	150.54	0.02
1	5600	50 Year	14.90	1709.32	1712.96		1712.96	0.000000	0.08	190.24	154.75	0.02
1	5600	250 Year	18.90	1709.32	1713.05		1713.06	0.000000	0.10	205.73	160.28	0.02
1	5600	500 Year	21.00	1709.32	1713.10		1713.10	0.000000	0.11	212.87	161.60	0.02
1	5500	25 Year	13.20	1711.20	1712.91		1712.91	0.000000	0.13	123.18	105.05	0.04
1	5500	50 Year	14.90	1711.20	1712.96		1712.96	0.000000	0.14	128.13	106.10	0.04
1	5500	250 Year	18.90	1711.20	1713.05		1713.06	0.000000	0.16	138.61	108.28	0.05
1	5500	500 Year	21.00	1711.20	1713.10		1713.10	0.000000	0.17	143.44	109.27	0.05
1	5400	25 Year	13.20	1718.50	1712.91		1712.91	0.000000		210.92	78.35	0.00
1	5400	50 Year	14.90	1718.50	1712.96		1712.96	0.000000		214.59	78.52	0.00
1	5400	250 Year	18.90	1718.50	1713.05		1713.06	0.000000		222.31	78.89	0.00
1	5400	500 Year	21.00	1718.50	1713.10		1713.10	0.000000		225.82	79.06	0.00
1	5300	25 Year	13.20	1711.55	1712.91		1712.91	0.000002	0.26	47.67	63.29	0.10
1	5300	50 Year	14.90	1711.55	1712.95		1712.96	0.000002	0.27	50.67	65.60	0.10
1	5300	250 Year	18.90	1711.55	1713.05		1713.05	0.000002	0.31	57.27	71.13	0.12
1	5300	500 Year	21.00	1711.55	1713.09		1713.10	0.000003	0.33	60.46	73.86	0.12
1	5200	25 Year	13.20	1714.15	1712.90		1712.91	0.000017		28.80	22.98	0.00
1	5200	50 Year	14.90	1714.15	1712.94		1712.96	0.000019		29.84	23.39	0.00
1	5200	250 Year	18.90	1714.15	1713.04		1713.05	0.000025		32.04	24.23	0.00
1	5200	500 Year	21.00	1714.15	1713.08		1713.10	0.000028		33.05	24.61	0.00
1	5100	25 Year	13.20	1709.32	1712.91		1712.91	0.000000	0.02	657.09	212.02	0.00
1	5100	50 Year	14.90	1709.32	1712.95		1712.95	0.000000	0.03	666.89	212.74	0.01
1	5100	250 Year	18.90	1709.32	1713.05		1713.05	0.000000	0.03	687.35	214.25	0.01
1	5100	500 Year	21.00	1709.32	1713.09		1713.09	0.000000	0.04	696.71	214.93	0.01
1	5000	25 Year	13.20	1711.62	1712.70	1712.70	1712.89	0.000126	1.91	6.91	18.66	1.00
1	5000	50 Year	14.90	1711.62	1712.74	1712.74	1712.93	0.000126	1.94	7.67	20.12	1.01
1	5000	250 Year	18.90	1711.62	1712.82	1712.82	1713.03	0.000127	2.03	9.29	22.94	1.02
1	5000	500 Year	21.00	1711.62	1712.86	1712.86	1713.07	0.000122	2.04	10.29	24.52	1.01
1	4900	25 Year	13.20	1710.73	1709.97	1710.39	1712.60	0.005793		1.84	7.39	0.00
1	4900	50 Year	14.90	1710.73	1710.00	1710.43	1712.65	0.005380		2.07	7.84	0.00
1	4900	250 Year	18.90	1710.73	1710.06	1710.53	1712.74	0.004661		2.61	8.80	0.00
1	4900	500 Year	21.00	1710.73	1710.09	1710.57	1712.78	0.004369		2.89	9.27	0.00
1	4800	25 Year	13.20	1704.85	1708.85	1703.78	1708.85	0.000000	0.04	272.21	99.24	0.01
1	4800	50 Year	14.90	1704.85	1708.89	1703.82	1708.89	0.000000	0.04	276.00	101.08	0.01
1	4800	250 Year	18.90	1704.85	1708.97	1703.91	1708.97	0.000000	0.05	284.12	104.91	0.01
1	4800	500 Year	21.00	1704.85	1709.01	1703.96	1709.01	0.000000	0.06	288.12	106.75	0.01
1	4700	25 Year	13.20	1707.75	1708.85		1708.85	0.000005	0.32	41.44	77.67	0.14
1	4700	50 Year	14.90	1707.75	1708.89		1708.89	0.000006	0.34	44.38	80.11	0.14
1	4700	250 Year	18.90	1707.75	1708.96		1708.97	0.000007	0.37	50.80	85.23	0.15
1	4700	500 Year	21.00	1707.75	1709.00		1709.01	0.000007	0.39	54.00	87.67	0.16



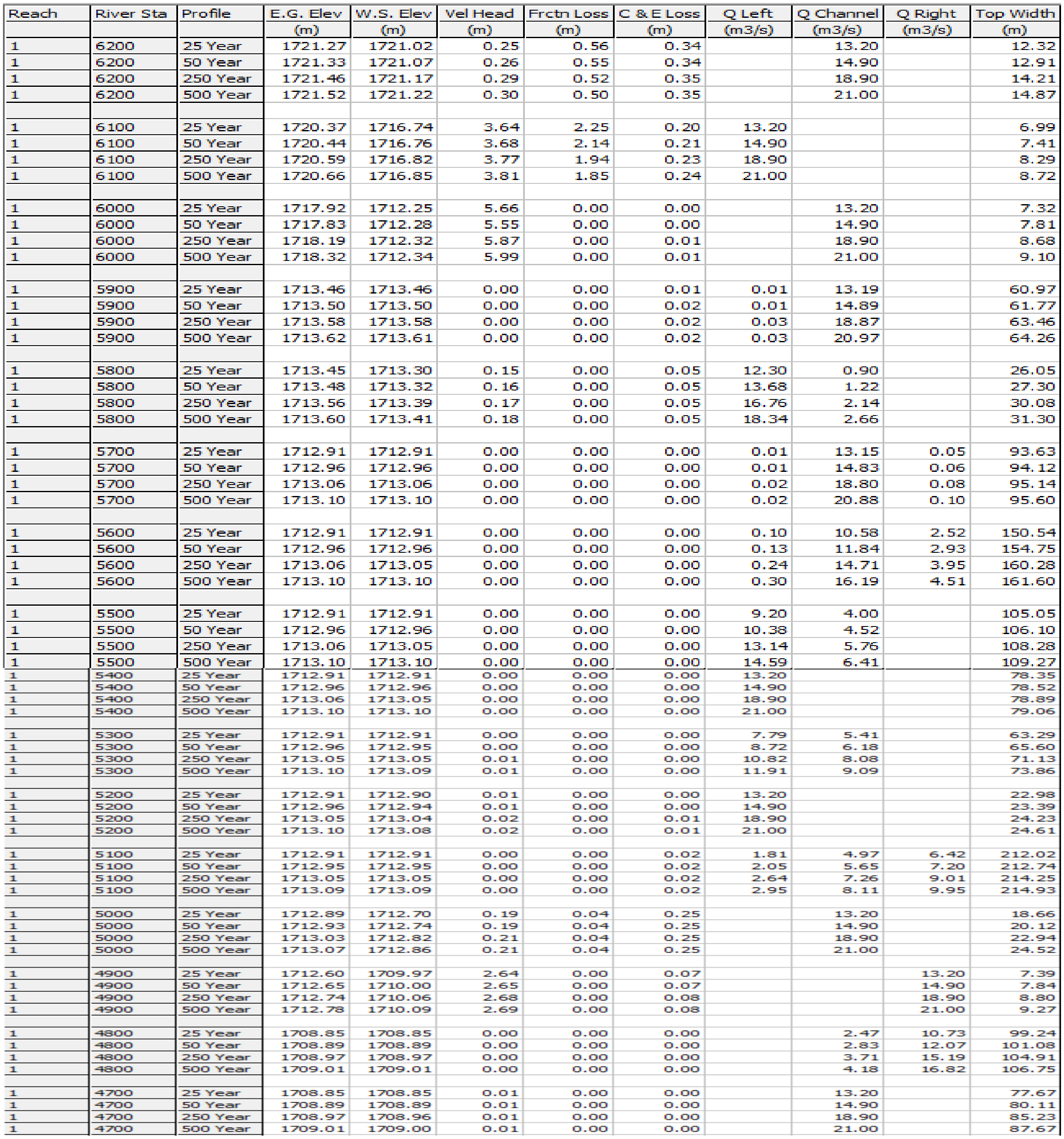
1	4600	25 Year	13.20	1709.30	1708.85		1708.85	0.000003		97.52	92.41	0.00
1	4600	50 Year	14.90	1709.30	1708.89		1708.89	0.000003		100.99	92.81	0.00
1	4600	250 Year	18.90	1709.30	1708.97		1708.97	0.000004		108.28	93.63	0.00
1	4600	500 Year	21.00	1709.30	1709.00		1709.01	0.000004		111.77	94.02	0.00
1	4500	25 Year	13.20	1713.70	1708.85		1708.85	0.000000		223.92	67.39	0.00
1	4500	50 Year	14.90	1713.70	1708.89		1708.89	0.000000		226.46	67.49	0.00
1	4500	250 Year	18.90	1713.70	1708.97		1708.97	0.000000		231.75	67.70	0.00
1	4500	500 Year	21.00	1713.70	1709.00		1709.01	0.000000		234.28	67.79	0.00
1	4400	25 Year	13.20	1699.73	1708.85		1708.85	0.000000	0.01	1027.87	200.07	0.00
1	4400	50 Year	14.90	1699.73	1708.89		1708.89	0.000000	0.01	1035.41	200.29	0.00
1	4400	250 Year	18.90	1699.73	1708.97		1708.97	0.000000	0.02	1051.10	200.74	0.00
1	4400	500 Year	21.00	1699.73	1709.00		1709.00	0.000000	0.02	1058.64	200.95	0.00
1	4300	25 Year	13.20	1707.42	1708.85		1708.85	0.000001	0.27	51.55	70.32	0.09
1	4300	50 Year	14.90	1707.42	1708.88		1708.89	0.000001	0.29	54.18	72.07	0.09
1	4300	250 Year	18.90	1707.42	1708.96		1708.97	0.000001	0.34	59.85	75.72	0.11
1	4300	500 Year	21.00	1707.42	1709.00		1709.00	0.000001	0.36	62.67	77.47	0.11
1	4200	25 Year	13.20	1701.35	1708.85		1708.85	0.000000	0.01	766.84	142.76	0.00
1	4200	50 Year	14.90	1701.35	1708.89		1708.89	0.000000	0.01	772.13	143.21	0.00
1	4200	250 Year	18.90	1701.35	1708.97		1708.97	0.000000	0.02	783.34	144.15	0.00
1	4200	500 Year	21.00	1701.35	1709.00		1709.00	0.000000	0.02	788.71	144.60	0.00
1	4100	25 Year	13.20	1701.32	1708.85		1708.85	0.000000	0.02	963.05	152.14	0.00
1	4100	50 Year	14.90	1701.32	1708.89		1708.89	0.000000	0.02	968.70	152.47	0.00
1	4100	250 Year	18.90	1701.32	1708.97		1708.97	0.000000	0.03	980.61	153.15	0.00
1	4100	500 Year	21.00	1701.32	1709.00		1709.00	0.000000	0.03	986.32	153.47	0.01
1	4000	25 Year	13.20	1702.38	1708.85		1708.85	0.000000	0.05	261.81	77.55	0.01
1	4000	50 Year	14.90	1702.38	1708.89		1708.89	0.000000	0.06	264.69	77.97	0.01
1	4000	250 Year	18.90	1702.38	1708.96		1708.97	0.000000	0.07	270.80	78.86	0.01
1	4000	500 Year	21.00	1702.38	1709.00		1709.00	0.000000	0.08	273.74	79.28	0.01
1	3900	25 Year	13.20	1708.13	1708.69	1708.69	1708.84	0.000137	1.70	7.75	26.69	1.01
1	3900	50 Year	14.90	1708.13	1708.71	1708.71	1708.87	0.000136	1.75	8.50	27.92	1.01
1	3900	250 Year	18.90	1708.13	1708.78	1708.78	1708.95	0.000131	1.84	10.29	30.66	1.01
1	3900	500 Year	21.00	1708.13	1708.80	1708.80	1708.98	0.000130	1.88	11.16	31.90	1.02
1	3800	25 Year	13.20	1703.62	1704.13	1704.65	1708.37	0.075072	9.12	1.45	5.64	5.75
1	3800	50 Year	14.90	1703.62	1704.17	1704.70	1708.41	0.069379	9.13	1.63	5.99	5.58
1	3800	250 Year	18.90	1703.62	1704.23	1704.81	1708.49	0.059389	9.14	2.07	6.74	5.27
1	3800	500 Year	21.00	1703.62	1704.27	1704.86	1708.53	0.055494	9.15	2.30	7.11	5.14
1	3700	25 Year	13.20	1699.32	1702.97	1700.39	1702.97	0.000003	0.19	68.21	38.21	0.05
1	3700	50 Year	14.90	1699.32	1703.02	1700.43	1703.03	0.000003	0.21	70.41	38.85	0.05
1	3700	250 Year	18.90	1699.32	1703.15	1700.54	1703.15	0.000004	0.25	75.25	40.23	0.06
1	3700	500 Year	21.00	1699.32	1703.21	1700.60	1703.21	0.000005	0.27	77.64	40.90	0.06
1	3600	25 Year	13.20	1689.22	1702.97		1702.97	0.000000	0.02	939.02	157.98	0.00
1	3600	50 Year	14.90	1689.22	1703.03		1703.03	0.000000	0.02	948.10	158.75	0.00
1	3600	250 Year	18.90	1689.22	1703.15		1703.15	0.000000	0.02	967.76	160.42	0.00
1	3600	500 Year	21.00	1689.22	1703.21		1703.21	0.000000	0.03	977.29	161.22	0.00
1	3500	25 Year	13.20	1680.07	1702.97		1702.97	0.000000	0.01	1963.41	196.85	0.00
1	3500	50 Year	14.90	1680.07	1703.03		1703.03	0.000000	0.01	1974.71	197.58	0.00
1	3500	250 Year	18.90	1680.07	1703.15		1703.15	0.000000	0.01	1999.15	199.13	0.00
1	3500	500 Year	21.00	1680.07	1703.21		1703.21	0.000000	0.01	2010.97	199.88	0.00
1	3400	25 Year	13.20	1696.44	1702.97		1702.97	0.000000	0.04	385.94	142.19	0.01
1	3400	50 Year	14.90	1696.44	1703.03		1703.03	0.000000	0.04	394.12	143.28	0.01
1	3400	250 Year	18.90	1696.44	1703.15		1703.15	0.000000	0.05	411.90	145.62	0.01
1	3400	500 Year	21.00	1696.44	1703.21		1703.21	0.000000	0.05	420.56	146.75	0.01
1	3300	25 Year	13.20	1705.49	1702.97		1702.97	0.000001		72.72	106.11	0.00
1	3300	50 Year	14.90	1705.49	1703.02		1703.03	0.000001		78.79	106.28	0.00
1	3300	250 Year	18.90	1705.49	1703.15		1703.15	0.000001		91.86	106.63	0.00
1	3300	500 Year	21.00	1705.49	1703.21		1703.21	0.000001		98.15	106.80	0.00
1	3200	25 Year	13.20	1717.00	1702.97		1702.97	0.000000		249.14	50.15	0.00
1	3200	50 Year	14.90	1717.00	1703.02		1703.02	0.000000		252.02	50.29	0.00
1	3200	250 Year	18.90	1717.00	1703.15		1703.15	0.000000		258.21	50.61	0.00
1	3200	500 Year	21.00	1717.00	1703.21		1703.21	0.000000		261.21	50.76	0.00
1	3100	25 Year	13.20	1703.76	1702.97		1702.97	0.000000		75.14	56.09	0.00
1	3100	50 Year	14.90	1703.76	1703.02		1703.02	0.000000		78.38	57.36	0.00
1	3100	250 Year	18.90	1703.76	1703.14		1703.15	0.000001		85.55	60.07	0.00
1	3100	500 Year	21.00	1703.76	1703.20		1703.21	0.000001		89.13	61.38	0.00



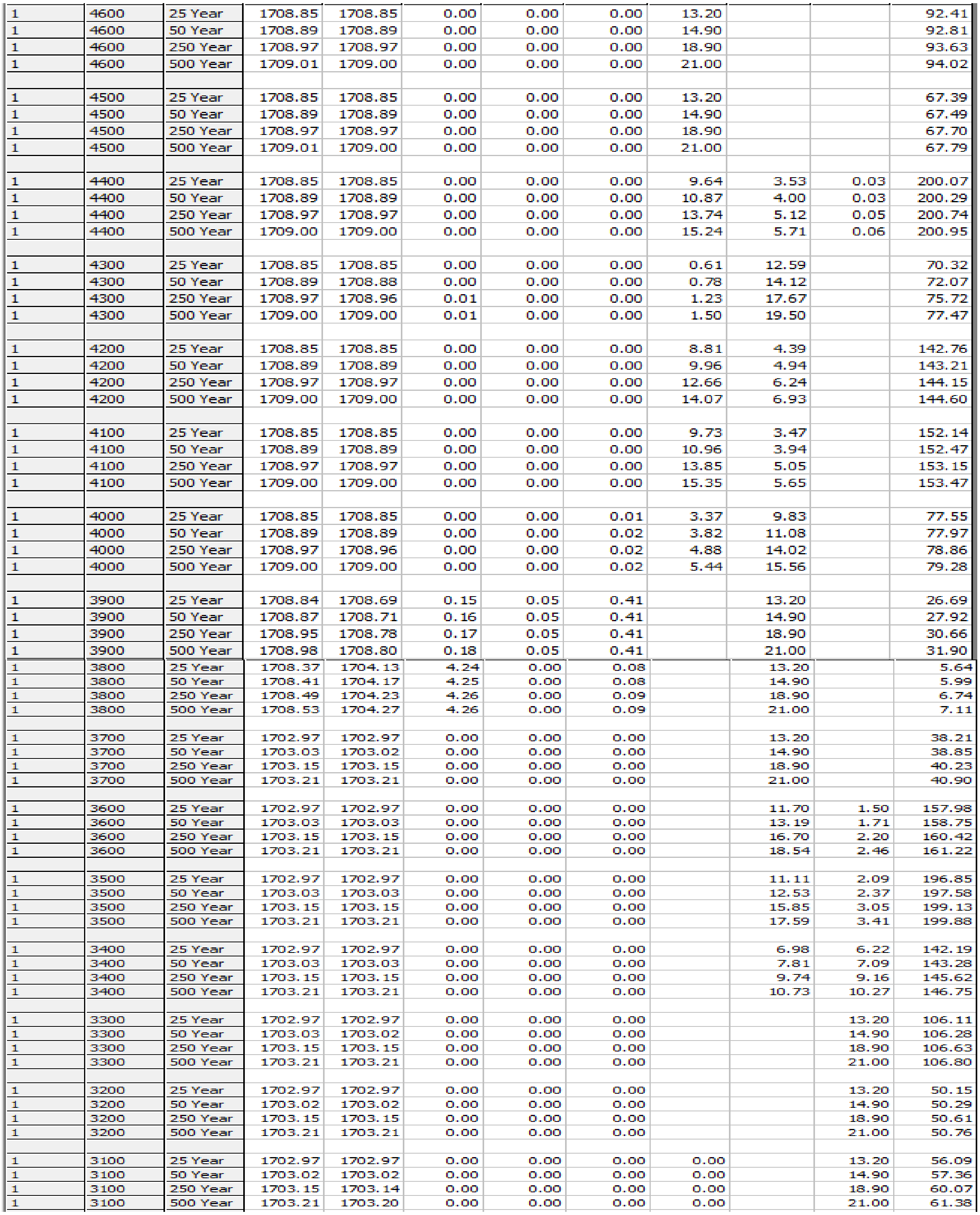
			(m3/s)	(m)	(m)	(m)	(m)	(m/m)	(m/s)	(m2)	(m)	
1	3000	25 Year	13.20	1688.05	1702.97		1702.97	0.000000	0.01	2263.62	282.21	0.00
1	3000	50 Year	14.90	1688.05	1703.02		1703.02	0.000000	0.01	2279.76	282.43	0.00
1	3000	250 Year	18.90	1688.05	1703.15		1703.15	0.000000	0.01	2314.42	282.90	0.00
1	3000	500 Year	21.00	1688.05	1703.21		1703.21	0.000000	0.01	2331.14	283.12	0.00
1	2900	25 Year	13.20	1700.03	1702.96		1702.97	0.000001	0.23	58.13	39.32	0.06
1	2900	50 Year	14.90	1700.03	1703.02		1703.02	0.000001	0.25	60.38	40.08	0.06
1	2900	250 Year	18.90	1700.03	1703.14		1703.15	0.000001	0.29	65.34	41.69	0.07
1	2900	500 Year	21.00	1700.03	1703.20		1703.21	0.000001	0.31	67.81	42.78	0.08
1	2800	25 Year	13.20	1710.27	1702.72	1702.72	1702.94	0.000211		6.24	13.95	0.00
1	2800	50 Year	14.90	1710.27	1702.76	1702.76	1703.00	0.000204		6.86	14.46	0.00
1	2800	250 Year	18.90	1710.27	1702.85	1702.85	1703.12	0.000187		8.23	15.53	0.00
1	2800	500 Year	21.00	1710.27	1702.89	1702.89	1703.18	0.000183		8.89	16.02	0.00
1	2700	25 Year	13.20	1695.97	1701.78	1696.24	1701.78	0.000000	0.03	445.84	113.05	0.00
1	2700	50 Year	14.90	1695.97	1701.85	1696.26	1701.85	0.000000	0.03	453.74	113.90	0.01
1	2700	250 Year	18.90	1695.97	1701.99	1696.30	1701.99	0.000000	0.04	470.62	115.69	0.01
1	2700	500 Year	21.00	1695.97	1702.06	1696.32	1702.06	0.000000	0.04	478.73	116.54	0.01
1	2600	25 Year	13.20	1698.60	1701.78		1701.78	0.000000	0.02	680.05	300.00	0.00
1	2600	50 Year	14.90	1698.60	1701.85		1701.85	0.000000	0.02	700.94	300.00	0.01
1	2600	250 Year	18.90	1698.60	1701.99		1701.99	0.000000	0.02	745.10	300.00	0.01
1	2600	500 Year	21.00	1698.60	1702.06		1702.06	0.000000	0.03	766.04	300.00	0.01
1	2500	25 Year	13.20	1697.89	1701.78		1701.78	0.000000	0.02	389.23	154.60	0.00
1	2500	50 Year	14.90	1697.89	1701.85		1701.85	0.000000	0.03	400.02	155.26	0.01
1	2500	250 Year	18.90	1697.89	1701.99		1701.99	0.000000	0.03	422.97	156.68	0.01
1	2500	500 Year	21.00	1697.89	1702.06		1702.06	0.000000	0.03	433.95	157.93	0.01
1	2400	25 Year	13.20	1700.37	1701.47	1701.47	1701.75	0.000202	2.35	5.63	10.25	1.01
1	2400	50 Year	14.90	1700.37	1701.52	1701.52	1701.82	0.000199	2.40	6.20	10.76	1.01
1	2400	250 Year	18.90	1700.37	1701.64	1701.64	1701.96	0.000192	2.52	7.51	11.85	1.01
1	2400	500 Year	21.00	1700.37	1701.69	1701.69	1702.03	0.000189	2.57	8.17	12.36	1.01
1	2300	25 Year	13.20	1701.29	1700.58	1700.81	1701.62	0.003281		2.92	16.48	0.00
1	2300	50 Year	14.90	1701.29	1700.60	1700.83	1701.69	0.003163		3.22	17.10	0.00
1	2300	250 Year	18.90	1701.29	1700.64	1700.90	1701.83	0.002947		3.91	18.43	0.00
1	2300	500 Year	21.00	1701.29	1700.66	1700.93	1701.89	0.002854		4.27	19.08	0.00
1	2200	25 Year	13.20	1693.18	1695.16	1693.94	1695.16	0.000001	0.27	49.08	52.08	0.09
1	2200	50 Year	14.90	1693.18	1695.20	1693.97	1695.21	0.000001	0.29	51.50	52.84	0.09
1	2200	250 Year	18.90	1693.18	1695.30	1694.05	1695.31	0.000002	0.34	56.65	53.79	0.10
1	2200	500 Year	21.00	1693.18	1695.35	1694.08	1695.35	0.000002	0.36	59.12	54.25	0.11
1	2100	25 Year	13.20	1691.82	1695.16		1695.16	0.000000	0.02	527.07	250.65	0.00
1	2100	50 Year	14.90	1691.82	1695.21		1695.21	0.000000	0.02	538.77	252.74	0.01
1	2100	250 Year	18.90	1691.82	1695.30		1695.30	0.000000	0.02	563.56	255.17	0.01
1	2100	500 Year	21.00	1691.82	1695.35		1695.35	0.000000	0.03	575.36	256.31	0.01
1	2000	25 Year	13.20	1688.08	1695.16		1695.16	0.000000	0.06	221.17	63.12	0.01
1	2000	50 Year	14.90	1688.08	1695.21		1695.21	0.000000	0.07	224.10	63.54	0.01
1	2000	250 Year	18.90	1688.08	1695.30		1695.30	0.000000	0.08	230.35	64.42	0.01
1	2000	500 Year	21.00	1688.08	1695.35		1695.35	0.000000	0.09	233.33	64.84	0.02
1	1900	25 Year	13.20	1691.46	1695.16		1695.16	0.000000	0.08	166.28	85.14	0.02
1	1900	50 Year	14.90	1691.46	1695.21		1695.21	0.000000	0.09	170.24	86.09	0.02
1	1900	250 Year	18.90	1691.46	1695.30		1695.30	0.000000	0.11	178.73	88.08	0.02
1	1900	500 Year	21.00	1691.46	1695.35		1695.35	0.000000	0.11	182.81	89.03	0.03
1	1800	25 Year	13.20	1688.19	1695.16		1695.16	0.000000	0.02	740.15	182.14	0.00
1	1800	50 Year	14.90	1688.19	1695.21		1695.21	0.000000	0.02	748.62	182.77	0.00
1	1800	250 Year	18.90	1688.19	1695.30		1695.30	0.000000	0.03	766.53	184.09	0.00
1	1800	500 Year	21.00	1688.19	1695.35		1695.35	0.000000	0.03	775.06	184.72	0.00
1	1700	25 Year	13.20	1685.00	1695.16		1695.16	0.000000	0.01	890.78	184.98	0.00
1	1700	50 Year	14.90	1685.00	1695.21		1695.21	0.000000	0.02	899.39	185.44	0.00
1	1700	250 Year	18.90	1685.00	1695.30		1695.30	0.000000	0.02	917.54	186.40	0.00
1	1700	500 Year	21.00	1685.00	1695.35		1695.35	0.000000	0.02	926.17	186.85	0.00
1	1600	25 Year	13.20	1692.19	1695.16		1695.16	0.000000	0.03	362.10	261.49	0.01
1	1600	50 Year	14.90	1692.19	1695.21		1695.21	0.000000	0.03	374.25	262.14	0.01
1	1600	250 Year	18.90	1692.19	1695.30		1695.30	0.000000	0.03	399.91	263.51	0.01
1	1600	500 Year	21.00	1692.19	1695.35		1695.35	0.000000	0.04	412.12	264.16	0.01
1	1500	25 Year	13.20	1681.73	1695.16		1695.16	0.000000	0.01	1216.32	172.95	0.00
1	1500	50 Year	14.90	1681.73	1695.21		1695.21	0.000000	0.01	1224.36	173.28	0.00
1	1500	250 Year	18.90	1681.73	1695.30		1695.30	0.000000	0.02	1241.31	173.98	0.00
1	1500	500 Year	21.00	1681.73	1695.35		1695.35	0.000000	0.02	1249.37	174.31	0.00



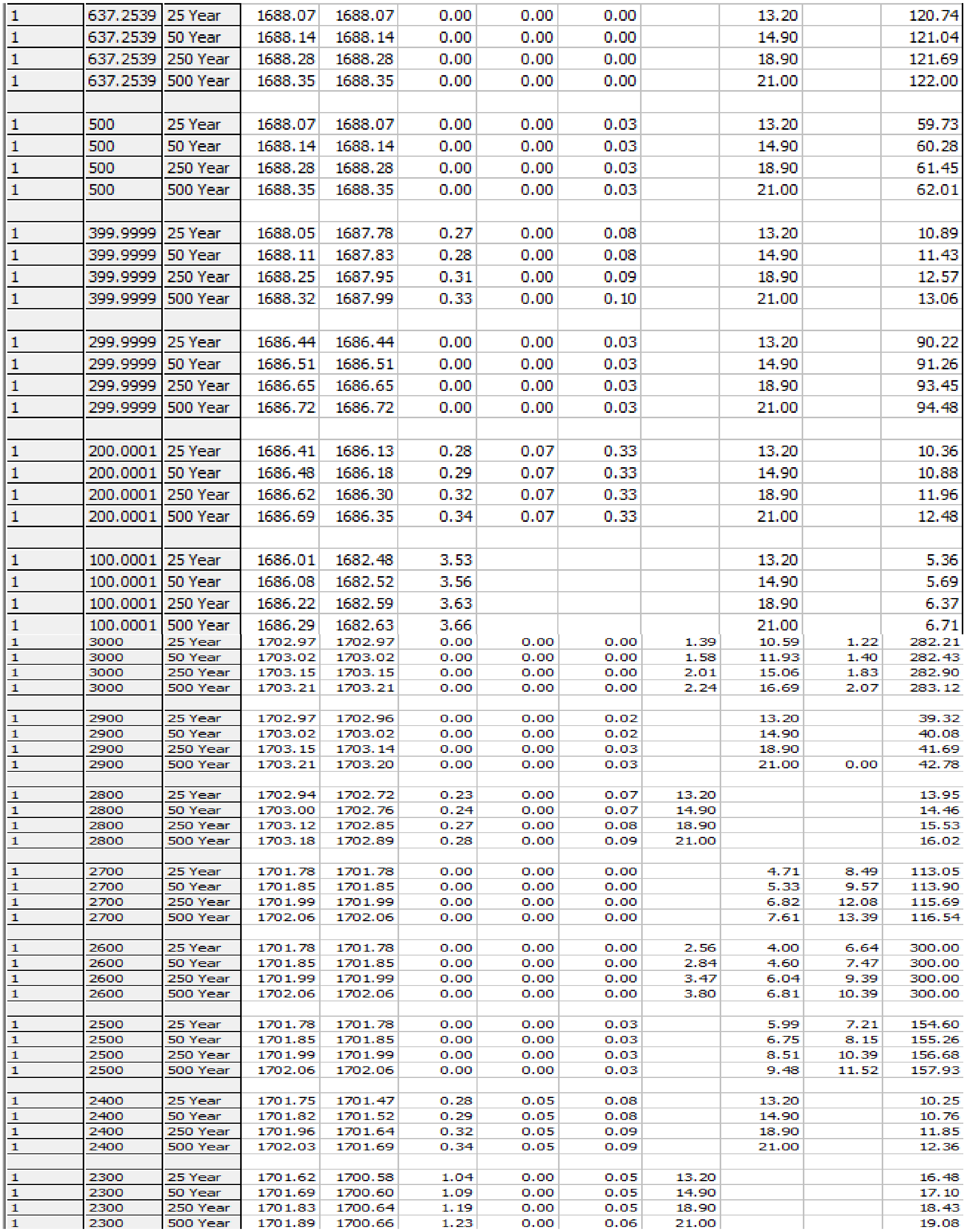
1	1400	25 Year	13.20	1685.23	1695.16		1695.16	0.000000	0.01	1746.33	247.35	0.00
1	1400	50 Year	14.90	1685.23	1695.21		1695.21	0.000000	0.01	1757.82	247.64	0.00
1	1400	250 Year	18.90	1685.23	1695.30		1695.30	0.000000	0.01	1782.03	248.24	0.00
1	1400	500 Year	21.00	1685.23	1695.35		1695.35	0.000000	0.01	1793.52	248.53	0.00
1	1300	25 Year	13.20	1687.02	1695.16		1695.16	0.000000	0.01	1004.79	280.04	0.00
1	1300	50 Year	14.90	1687.02	1695.21		1695.21	0.000000	0.01	1017.81	280.78	0.00
1	1300	250 Year	18.90	1687.02	1695.30		1695.30	0.000000	0.01	1045.30	282.35	0.00
1	1300	500 Year	21.00	1687.02	1695.35		1695.35	0.000000	0.02	1058.38	283.09	0.00
1	1152.182	25 Year	13.20	1687.30	1695.16		1695.16	0.000000	0.03	533.17	187.86	0.00
1	1152.182	50 Year	14.90	1687.30	1695.21		1695.21	0.000000	0.03	541.92	189.13	0.00
1	1152.182	250 Year	18.90	1687.30	1695.30		1695.30	0.000000	0.04	560.51	191.80	0.01
1	1152.182	500 Year	21.00	1687.30	1695.35		1695.35	0.000000	0.04	569.39	193.06	0.01
1	1100	25 Year	13.20	1694.07	1694.96	1694.96	1695.14	0.001832	2.05	7.14	19.12	0.98
1	1100	50 Year	14.90	1694.07	1695.00	1695.00	1695.19	0.001817	2.10	7.86	20.10	0.99
1	1100	250 Year	18.90	1694.07	1695.07	1695.07	1695.28	0.001792	2.20	9.49	22.15	0.99
1	1100	500 Year	21.00	1694.07	1695.11	1695.11	1695.33	0.001783	2.25	10.31	23.11	1.00
1	999.9999	25 Year	13.20	1686.62	1687.03	1687.58	1693.67	0.157527	11.41	1.16	5.65	8.05
1	999.9999	50 Year	14.90	1686.62	1687.05	1687.63	1694.14	0.158671	11.79	1.26	5.90	8.14
1	999.9999	250 Year	18.90	1686.62	1687.11	1687.73	1694.03	0.131275	11.66	1.62	6.69	7.56
1	999.9999	500 Year	21.00	1686.62	1687.13	1687.77	1694.09	0.122987	11.68	1.80	7.04	7.38
1	900	25 Year	13.20	1686.24	1688.07	1687.02	1688.08	0.000002	0.25	42.41	53.86	0.09
1	900	50 Year	14.90	1686.24	1688.14	1687.06	1688.14	0.000002	0.25	46.03	54.83	0.09
1	900	250 Year	18.90	1686.24	1688.28	1687.14	1688.29	0.000003	0.27	53.89	56.90	0.09
1	900	500 Year	21.00	1686.24	1688.34	1687.18	1688.35	0.000003	0.28	57.76	57.90	0.09
1	800	25 Year	13.20	1687.03	1688.07		1688.07	0.000002	0.07	73.83	36.36	0.03
1	800	50 Year	14.90	1687.03	1688.14		1688.14	0.000002	0.08	76.28	36.96	0.03
1	800	250 Year	18.90	1687.03	1688.28		1688.28	0.000003	0.10	81.60	38.23	0.04
1	800	500 Year	21.00	1687.03	1688.35		1688.35	0.000003	0.11	84.20	38.83	0.04
1	700	25 Year	13.20	1683.33	1688.07		1688.07	0.000000	0.03	455.70	137.29	0.01
1	700	50 Year	14.90	1683.33	1688.14		1688.14	0.000000	0.03	464.94	137.83	0.01
1	700	250 Year	18.90	1683.33	1688.28		1688.28	0.000000	0.04	484.55	138.98	0.01
1	700	500 Year	21.00	1683.33	1688.35		1688.35	0.000000	0.04	494.00	139.53	0.01
1	637.2539	25 Year	13.20	1679.18	1688.07		1688.07	0.000000	0.02	807.65	120.74	0.00
1	637.2539	50 Year	14.90	1679.18	1688.14		1688.14	0.000000	0.02	815.77	121.04	0.00
1	637.2539	250 Year	18.90	1679.18	1688.28		1688.28	0.000000	0.02	832.98	121.69	0.00
1	637.2539	500 Year	21.00	1679.18	1688.35		1688.35	0.000000	0.02	841.25	122.00	0.00
1	500	25 Year	13.20	1683.70	1688.07		1688.07	0.000000	0.08	165.70	59.73	0.02
1	500	50 Year	14.90	1683.70	1688.14		1688.14	0.000000	0.09	169.72	60.28	0.02
1	500	250 Year	18.90	1683.70	1688.28		1688.28	0.000000	0.11	178.34	61.45	0.02
1	500	500 Year	21.00	1683.70	1688.35		1688.35	0.000000	0.12	182.52	62.01	0.02
1	399.9999	25 Year	13.20	1686.72	1687.78	1687.78	1688.05	0.000201	2.28	5.78	10.89	1.00
1	399.9999	50 Year	14.90	1686.72	1687.83	1687.83	1688.11	0.000197	2.34	6.37	11.43	1.00
1	399.9999	250 Year	18.90	1686.72	1687.95	1687.95	1688.25	0.000191	2.45	7.70	12.57	1.00
1	399.9999	500 Year	21.00	1686.72	1687.99	1687.99	1688.32	0.000193	2.53	8.31	13.06	1.01
1	299.9999	25 Year	13.20	1680.49	1686.44	1681.41	1686.44	0.000000	0.05	271.21	90.22	0.01
1	299.9999	50 Year	14.90	1680.49	1686.51	1681.45	1686.51	0.000000	0.05	277.49	91.26	0.01
1	299.9999	250 Year	18.90	1680.49	1686.65	1681.54	1686.65	0.000000	0.06	291.01	93.45	0.01
1	299.9999	500 Year	21.00	1680.49	1686.72	1681.58	1686.72	0.000000	0.07	297.49	94.48	0.01
1	200.0001	25 Year	13.20	1685.04	1686.13	1686.13	1686.41	0.000205	2.34	5.64	10.36	1.01
1	200.0001	50 Year	14.90	1685.04	1686.18	1686.18	1686.48	0.000201	2.40	6.22	10.88	1.01
1	200.0001	250 Year	18.90	1685.04	1686.30	1686.30	1686.62	0.000195	2.51	7.52	11.96	1.01
1	200.0001	500 Year	21.00	1685.04	1686.35	1686.35	1686.69	0.000192	2.56	8.19	12.48	1.01
1	100.0001	25 Year	13.20	1681.89	1682.48	1683.01	1686.01	0.052781	8.32	1.59	5.36	4.89
1	100.0001	50 Year	14.90	1681.89	1682.52	1683.06	1686.08	0.049253	8.36	1.78	5.69	4.77
1	100.0001	250 Year	18.90	1681.89	1682.59	1683.17	1686.22	0.043084	8.44	2.24	6.37	4.54
1	100.0001	500 Year	21.00	1681.89	1682.63	1683.23	1686.29	0.040615	8.47	2.48	6.71	4.45



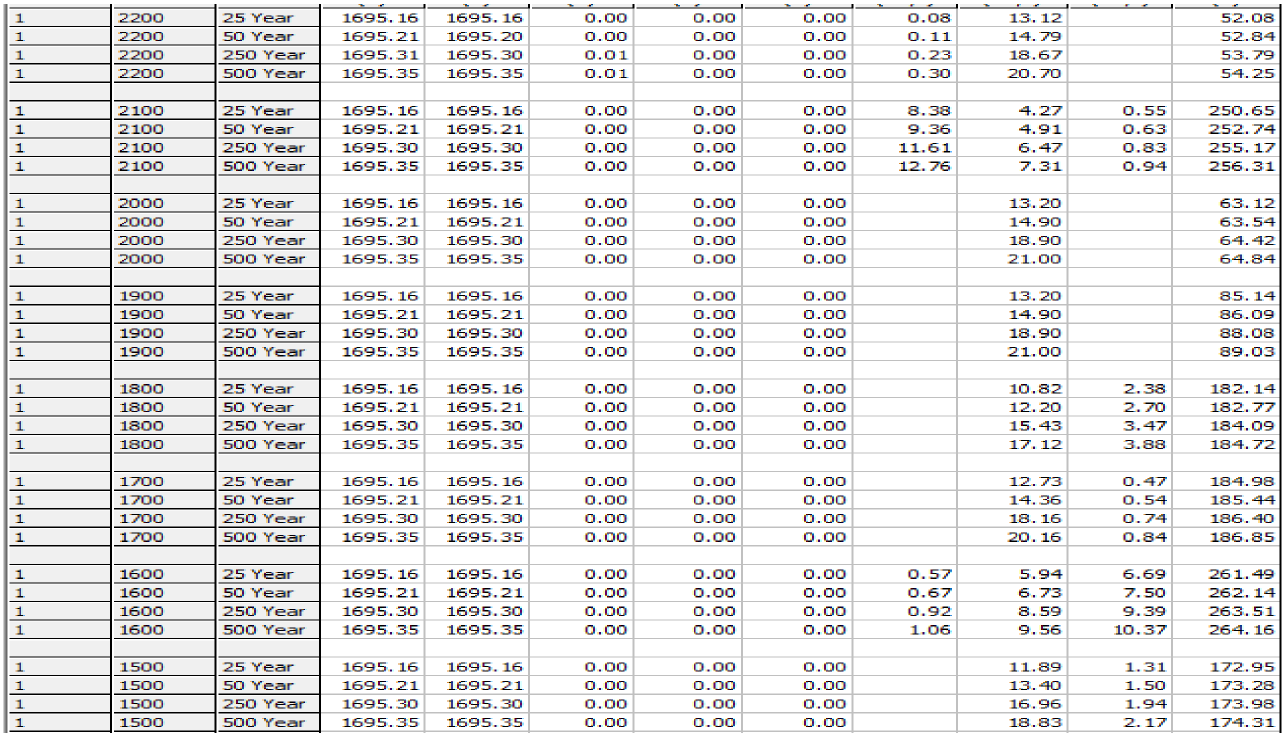
Reach	River Sta	Profile	E.G. Elev	W.S. Elev	Vel Head	Frctn Loss	C & E Loss	Q Left	Q Channel	Q Right	Top Width
			(m)	(m)	(m)	(m)	(m)	(m3/s)	(m3/s)	(m3/s)	(m)
1	6200	25 Year	1721.27	1721.02	0.25	0.56	0.34		13.20		12.32
1	6200	50 Year	1721.33	1721.07	0.26	0.55	0.34		14.90		12.91
1	6200	250 Year	1721.46	1721.17	0.29	0.52	0.35		18.90		14.21
1	6200	500 Year	1721.52	1721.22	0.30	0.50	0.35		21.00		14.87
1	6100	25 Year	1720.37	1716.74	3.64	2.25	0.20	13.20			6.99
1	6100	50 Year	1720.44	1716.76	3.68	2.14	0.21	14.90			7.41
1	6100	250 Year	1720.59	1716.82	3.77	1.94	0.23	18.90			8.29
1	6100	500 Year	1720.66	1716.85	3.81	1.85	0.24	21.00			8.72
1	6000	25 Year	1717.92	1712.25	5.66	0.00	0.00		13.20		7.32
1	6000	50 Year	1717.83	1712.28	5.55	0.00	0.00		14.90		7.81
1	6000	250 Year	1718.19	1712.32	5.87	0.00	0.01		18.90		8.68
1	6000	500 Year	1718.32	1712.34	5.99	0.00	0.01		21.00		9.10
1	5900	25 Year	1713.46	1713.46	0.00	0.00	0.01	0.01	13.19		60.97
1	5900	50 Year	1713.50	1713.50	0.00	0.00	0.02	0.01	14.89		61.77
1	5900	250 Year	1713.58	1713.58	0.00	0.00	0.02	0.03	18.87		63.46
1	5900	500 Year	1713.62	1713.61	0.00	0.00	0.02	0.03	20.97		64.26
1	5800	25 Year	1713.45	1713.30	0.15	0.00	0.05	12.30	0.90		26.05
1	5800	50 Year	1713.48	1713.32	0.16	0.00	0.05	13.68	1.22		27.30
1	5800	250 Year	1713.56	1713.39	0.17	0.00	0.05	16.76	2.14		30.08
1	5800	500 Year	1713.60	1713.41	0.18	0.00	0.05	18.34	2.66		31.30
1	5700	25 Year	1712.91	1712.91	0.00	0.00	0.00	0.01	13.15	0.05	93.63
1	5700	50 Year	1712.96	1712.96	0.00	0.00	0.00	0.01	14.83	0.06	94.12
1	5700	250 Year	1713.06	1713.06	0.00	0.00	0.00	0.02	18.80	0.08	95.14
1	5700	500 Year	1713.10	1713.10	0.00	0.00	0.00	0.02	20.88	0.10	95.60
1	5600	25 Year	1712.91	1712.91	0.00	0.00	0.00	0.10	10.58	2.52	150.54
1	5600	50 Year	1712.96	1712.96	0.00	0.00	0.00	0.13	11.84	2.93	154.75
1	5600	250 Year	1713.06	1713.05	0.00	0.00	0.00	0.24	14.71	3.95	160.28
1	5600	500 Year	1713.10	1713.10	0.00	0.00	0.00	0.30	16.19	4.51	161.60
1	5500	25 Year	1712.91	1712.91	0.00	0.00	0.00	9.20	4.00		105.05
1	5500	50 Year	1712.96	1712.96	0.00	0.00	0.00	10.38	4.52		106.10
1	5500	250 Year	1713.06	1713.05	0.00	0.00	0.00	13.14	5.76		108.28
1	5500	500 Year	1713.10	1713.10	0.00	0.00	0.00	14.59	6.41		109.27
1	5400	25 Year	1712.91	1712.91	0.00	0.00	0.00	13.20			78.35
1	5400	50 Year	1712.96	1712.96	0.00	0.00	0.00	14.90			78.52
1	5400	250 Year	1713.06	1713.05	0.00	0.00	0.00	18.90			78.89
1	5400	500 Year	1713.10	1713.10	0.00	0.00	0.00	21.00			79.06
1	5300	25 Year	1712.91	1712.91	0.00	0.00	0.00	7.79	5.41		63.29
1	5300	50 Year	1712.96	1712.95	0.00	0.00	0.00	8.72	6.18		65.60
1	5300	250 Year	1713.05	1713.05	0.01	0.00	0.00	10.82	8.08		71.13
1	5300	500 Year	1713.10	1713.09	0.01	0.00	0.00	11.91	9.09		73.86
1	5200	25 Year	1712.91	1712.90	0.01	0.00	0.00	13.20			22.98
1	5200	50 Year	1712.96	1712.94	0.01	0.00	0.00	14.90			23.39
1	5200	250 Year	1713.05	1713.04	0.02	0.00	0.01	18.90			24.23
1	5200	500 Year	1713.10	1713.08	0.02	0.00	0.01	21.00			24.61
1	5100	25 Year	1712.91	1712.91	0.00	0.00	0.02	1.81	4.97	6.42	212.02
1	5100	50 Year	1712.95	1712.95	0.00	0.00	0.02	2.05	5.65	7.20	212.74
1	5100	250 Year	1713.05	1713.05	0.00	0.00	0.02	2.64	7.26	9.01	214.25
1	5100	500 Year	1713.09	1713.09	0.00	0.00	0.02	2.95	8.11	9.95	214.93
1	5000	25 Year	1712.89	1712.70	0.19	0.04	0.25		13.20		18.66
1	5000	50 Year	1712.93	1712.74	0.19	0.04	0.25		14.90		20.12
1	5000	250 Year	1713.03	1712.82	0.21	0.04	0.25		18.90		22.94
1	5000	500 Year	1713.07	1712.86	0.21	0.04	0.25		21.00		24.52
1	4900	25 Year	1712.60	1709.97	2.64	0.00	0.07			13.20	7.39
1	4900	50 Year	1712.65	1710.00	2.65	0.00	0.07			14.90	7.84
1	4900	250 Year	1712.74	1710.06	2.68	0.00	0.08			18.90	8.80
1	4900	500 Year	1712.78	1710.09	2.69	0.00	0.08			21.00	9.27
1	4800	25 Year	1708.85	1708.85	0.00	0.00	0.00		2.47	10.73	99.24
1	4800	50 Year	1708.89	1708.89	0.00	0.00	0.00		2.83	12.07	101.08
1	4800	250 Year	1708.97	1708.97	0.00	0.00	0.00		3.71	15.19	104.91
1	4800	500 Year	1709.01	1709.01	0.00	0.00	0.00		4.18	16.82	106.75
1	4700	25 Year	1708.85	1708.85	0.01	0.00	0.00		13.20		77.67
1	4700	50 Year	1708.89	1708.89	0.01	0.00	0.00		14.90		80.11
1	4700	250 Year	1708.97	1708.96	0.01	0.00	0.00		18.90		85.23
1	4700	500 Year	1709.01	1709.00	0.01	0.00	0.00		21.00		87.67



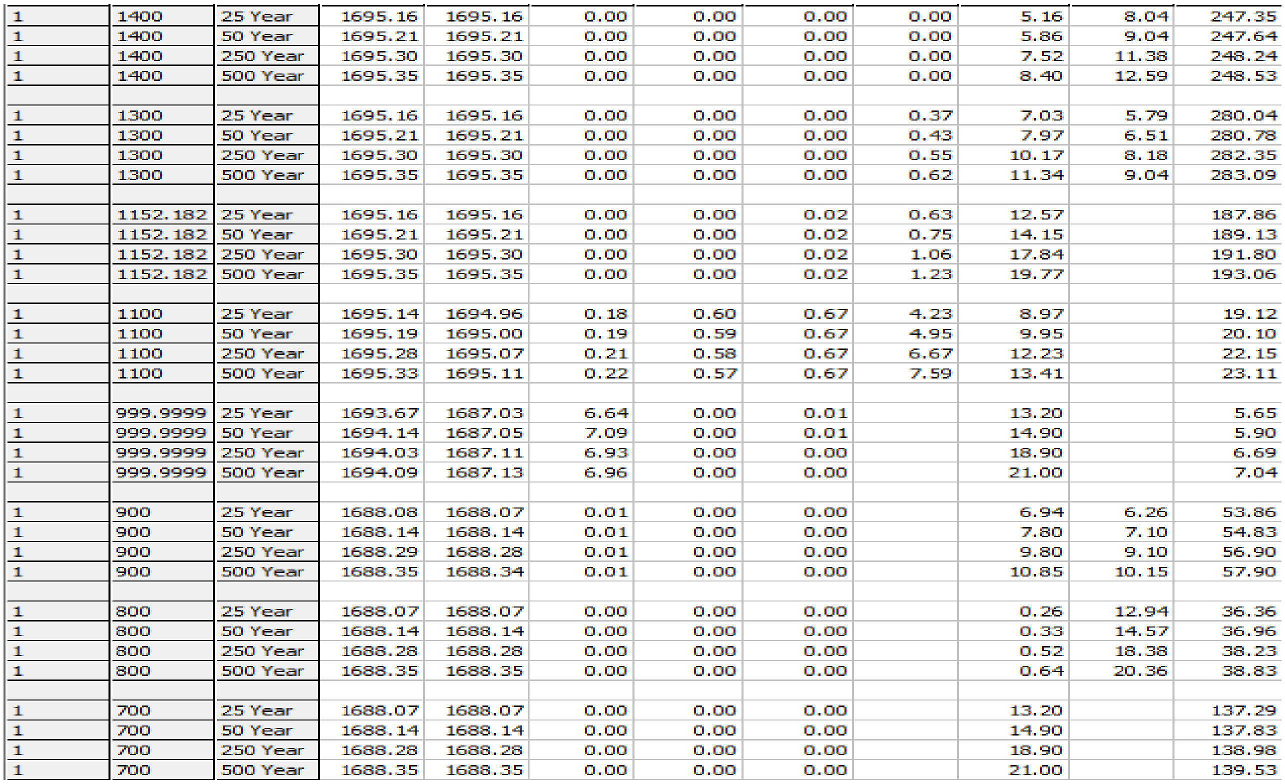
1	4600	25 Year	1708.85	1708.85	0.00	0.00	0.00	13.20			92.41
1	4600	50 Year	1708.89	1708.89	0.00	0.00	0.00	14.90			92.81
1	4600	250 Year	1708.97	1708.97	0.00	0.00	0.00	18.90			93.63
1	4600	500 Year	1709.01	1709.00	0.00	0.00	0.00	21.00			94.02
1	4500	25 Year	1708.85	1708.85	0.00	0.00	0.00	13.20			67.39
1	4500	50 Year	1708.89	1708.89	0.00	0.00	0.00	14.90			67.49
1	4500	250 Year	1708.97	1708.97	0.00	0.00	0.00	18.90			67.70
1	4500	500 Year	1709.01	1709.00	0.00	0.00	0.00	21.00			67.79
1	4400	25 Year	1708.85	1708.85	0.00	0.00	0.00	9.64	3.53	0.03	200.07
1	4400	50 Year	1708.89	1708.89	0.00	0.00	0.00	10.87	4.00	0.03	200.29
1	4400	250 Year	1708.97	1708.97	0.00	0.00	0.00	13.74	5.12	0.05	200.74
1	4400	500 Year	1709.00	1709.00	0.00	0.00	0.00	15.24	5.71	0.06	200.95
1	4300	25 Year	1708.85	1708.85	0.00	0.00	0.00	0.61	12.59		70.32
1	4300	50 Year	1708.89	1708.88	0.00	0.00	0.00	0.78	14.12		72.07
1	4300	250 Year	1708.97	1708.96	0.01	0.00	0.00	1.23	17.67		75.72
1	4300	500 Year	1709.00	1709.00	0.01	0.00	0.00	1.50	19.50		77.47
1	4200	25 Year	1708.85	1708.85	0.00	0.00	0.00	8.81	4.39		142.76
1	4200	50 Year	1708.89	1708.89	0.00	0.00	0.00	9.96	4.94		143.21
1	4200	250 Year	1708.97	1708.97	0.00	0.00	0.00	12.66	6.24		144.15
1	4200	500 Year	1709.00	1709.00	0.00	0.00	0.00	14.07	6.93		144.60
1	4100	25 Year	1708.85	1708.85	0.00	0.00	0.00	9.73	3.47		152.14
1	4100	50 Year	1708.89	1708.89	0.00	0.00	0.00	10.96	3.94		152.47
1	4100	250 Year	1708.97	1708.97	0.00	0.00	0.00	13.85	5.05		153.15
1	4100	500 Year	1709.00	1709.00	0.00	0.00	0.00	15.35	5.65		153.47
1	4000	25 Year	1708.85	1708.85	0.00	0.00	0.01	3.37	9.83		77.55
1	4000	50 Year	1708.89	1708.89	0.00	0.00	0.02	3.82	11.08		77.97
1	4000	250 Year	1708.97	1708.96	0.00	0.00	0.02	4.88	14.02		78.86
1	4000	500 Year	1709.00	1709.00	0.00	0.00	0.02	5.44	15.56		79.28
1	3900	25 Year	1708.84	1708.69	0.15	0.05	0.41		13.20		26.69
1	3900	50 Year	1708.87	1708.71	0.16	0.05	0.41		14.90		27.92
1	3900	250 Year	1708.95	1708.78	0.17	0.05	0.41		18.90		30.66
1	3900	500 Year	1708.98	1708.80	0.18	0.05	0.41		21.00		31.90
1	3800	25 Year	1708.37	1704.13	4.24	0.00	0.08		13.20		5.64
1	3800	50 Year	1708.41	1704.17	4.25	0.00	0.08		14.90		5.99
1	3800	250 Year	1708.49	1704.23	4.26	0.00	0.09		18.90		6.74
1	3800	500 Year	1708.53	1704.27	4.26	0.00	0.09		21.00		7.11
1	3700	25 Year	1702.97	1702.97	0.00	0.00	0.00		13.20		38.21
1	3700	50 Year	1703.03	1703.02	0.00	0.00	0.00		14.90		38.85
1	3700	250 Year	1703.15	1703.15	0.00	0.00	0.00		18.90		40.23
1	3700	500 Year	1703.21	1703.21	0.00	0.00	0.00		21.00		40.90
1	3600	25 Year	1702.97	1702.97	0.00	0.00	0.00		11.70	1.50	157.98
1	3600	50 Year	1703.03	1703.03	0.00	0.00	0.00		13.19	1.71	158.75
1	3600	250 Year	1703.15	1703.15	0.00	0.00	0.00		16.70	2.20	160.42
1	3600	500 Year	1703.21	1703.21	0.00	0.00	0.00		18.54	2.46	161.22
1	3500	25 Year	1702.97	1702.97	0.00	0.00	0.00		11.11	2.09	196.85
1	3500	50 Year	1703.03	1703.03	0.00	0.00	0.00		12.53	2.37	197.58
1	3500	250 Year	1703.15	1703.15	0.00	0.00	0.00		15.85	3.05	199.13
1	3500	500 Year	1703.21	1703.21	0.00	0.00	0.00		17.59	3.41	199.88
1	3400	25 Year	1702.97	1702.97	0.00	0.00	0.00		6.98	6.22	142.19
1	3400	50 Year	1703.03	1703.03	0.00	0.00	0.00		7.81	7.09	143.28
1	3400	250 Year	1703.15	1703.15	0.00	0.00	0.00		9.74	9.16	145.62
1	3400	500 Year	1703.21	1703.21	0.00	0.00	0.00		10.73	10.27	146.75
1	3300	25 Year	1702.97	1702.97	0.00	0.00	0.00			13.20	106.11
1	3300	50 Year	1703.03	1703.02	0.00	0.00	0.00			14.90	106.28
1	3300	250 Year	1703.15	1703.15	0.00	0.00	0.00			18.90	106.63
1	3300	500 Year	1703.21	1703.21	0.00	0.00	0.00			21.00	106.80
1	3200	25 Year	1702.97	1702.97	0.00	0.00	0.00			13.20	50.15
1	3200	50 Year	1703.02	1703.02	0.00	0.00	0.00			14.90	50.29
1	3200	250 Year	1703.15	1703.15	0.00	0.00	0.00			18.90	50.61
1	3200	500 Year	1703.21	1703.21	0.00	0.00	0.00			21.00	50.76
1	3100	25 Year	1702.97	1702.97	0.00	0.00	0.00	0.00		13.20	56.09
1	3100	50 Year	1703.02	1703.02	0.00	0.00	0.00	0.00		14.90	57.36
1	3100	250 Year	1703.15	1703.14	0.00	0.00	0.00	0.00		18.90	60.07
1	3100	500 Year	1703.21	1703.20	0.00	0.00	0.00	0.00		21.00	61.38



1	637.2539	25 Year	1688.07	1688.07	0.00	0.00	0.00		13.20		120.74
1	637.2539	50 Year	1688.14	1688.14	0.00	0.00	0.00		14.90		121.04
1	637.2539	250 Year	1688.28	1688.28	0.00	0.00	0.00		18.90		121.69
1	637.2539	500 Year	1688.35	1688.35	0.00	0.00	0.00		21.00		122.00
1	500	25 Year	1688.07	1688.07	0.00	0.00	0.03		13.20		59.73
1	500	50 Year	1688.14	1688.14	0.00	0.00	0.03		14.90		60.28
1	500	250 Year	1688.28	1688.28	0.00	0.00	0.03		18.90		61.45
1	500	500 Year	1688.35	1688.35	0.00	0.00	0.03		21.00		62.01
1	399.9999	25 Year	1688.05	1687.78	0.27	0.00	0.08		13.20		10.89
1	399.9999	50 Year	1688.11	1687.83	0.28	0.00	0.08		14.90		11.43
1	399.9999	250 Year	1688.25	1687.95	0.31	0.00	0.09		18.90		12.57
1	399.9999	500 Year	1688.32	1687.99	0.33	0.00	0.10		21.00		13.06
1	299.9999	25 Year	1686.44	1686.44	0.00	0.00	0.03		13.20		90.22
1	299.9999	50 Year	1686.51	1686.51	0.00	0.00	0.03		14.90		91.26
1	299.9999	250 Year	1686.65	1686.65	0.00	0.00	0.03		18.90		93.45
1	299.9999	500 Year	1686.72	1686.72	0.00	0.00	0.03		21.00		94.48
1	200.0001	25 Year	1686.41	1686.13	0.28	0.07	0.33		13.20		10.36
1	200.0001	50 Year	1686.48	1686.18	0.29	0.07	0.33		14.90		10.88
1	200.0001	250 Year	1686.62	1686.30	0.32	0.07	0.33		18.90		11.96
1	200.0001	500 Year	1686.69	1686.35	0.34	0.07	0.33		21.00		12.48
1	100.0001	25 Year	1686.01	1682.48	3.53				13.20		5.36
1	100.0001	50 Year	1686.08	1682.52	3.56				14.90		5.69
1	100.0001	250 Year	1686.22	1682.59	3.63				18.90		6.37
1	100.0001	500 Year	1686.29	1682.63	3.66				21.00		6.71
1	3000	25 Year	1702.97	1702.97	0.00	0.00	0.00	1.39	10.59	1.22	282.21
1	3000	50 Year	1703.02	1703.02	0.00	0.00	0.00	1.58	11.93	1.40	282.43
1	3000	250 Year	1703.15	1703.15	0.00	0.00	0.00	2.01	15.06	1.83	282.90
1	3000	500 Year	1703.21	1703.21	0.00	0.00	0.00	2.24	16.69	2.07	283.12
1	2900	25 Year	1702.97	1702.96	0.00	0.00	0.02		13.20		39.32
1	2900	50 Year	1703.02	1703.02	0.00	0.00	0.02		14.90		40.08
1	2900	250 Year	1703.15	1703.14	0.00	0.00	0.03		18.90		41.69
1	2900	500 Year	1703.21	1703.20	0.00	0.00	0.03		21.00	0.00	42.78
1	2800	25 Year	1702.94	1702.72	0.23	0.00	0.07	13.20			13.95
1	2800	50 Year	1703.00	1702.76	0.24	0.00	0.07	14.90			14.46
1	2800	250 Year	1703.12	1702.85	0.27	0.00	0.08	18.90			15.53
1	2800	500 Year	1703.18	1702.89	0.28	0.00	0.09	21.00			16.02
1	2700	25 Year	1701.78	1701.78	0.00	0.00	0.00		4.71	8.49	113.05
1	2700	50 Year	1701.85	1701.85	0.00	0.00	0.00		5.33	9.57	113.90
1	2700	250 Year	1701.99	1701.99	0.00	0.00	0.00		6.82	12.08	115.69
1	2700	500 Year	1702.06	1702.06	0.00	0.00	0.00		7.61	13.39	116.54
1	2600	25 Year	1701.78	1701.78	0.00	0.00	0.00	2.56	4.00	6.64	300.00
1	2600	50 Year	1701.85	1701.85	0.00	0.00	0.00	2.84	4.60	7.47	300.00
1	2600	250 Year	1701.99	1701.99	0.00	0.00	0.00	3.47	6.04	9.39	300.00
1	2600	500 Year	1702.06	1702.06	0.00	0.00	0.00	3.80	6.81	10.39	300.00
1	2500	25 Year	1701.78	1701.78	0.00	0.00	0.03		5.99	7.21	154.60
1	2500	50 Year	1701.85	1701.85	0.00	0.00	0.03		6.75	8.15	155.26
1	2500	250 Year	1701.99	1701.99	0.00	0.00	0.03		8.51	10.39	156.68
1	2500	500 Year	1702.06	1702.06	0.00	0.00	0.03		9.48	11.52	157.93
1	2400	25 Year	1701.75	1701.47	0.28	0.05	0.08		13.20		10.25
1	2400	50 Year	1701.82	1701.52	0.29	0.05	0.08		14.90		10.76
1	2400	250 Year	1701.96	1701.64	0.32	0.05	0.09		18.90		11.85
1	2400	500 Year	1702.03	1701.69	0.34	0.05	0.09		21.00		12.36
1	2300	25 Year	1701.62	1700.58	1.04	0.00	0.05	13.20			16.48
1	2300	50 Year	1701.69	1700.60	1.09	0.00	0.05	14.90			17.10
1	2300	250 Year	1701.83	1700.64	1.19	0.00	0.05	18.90			18.43
1	2300	500 Year	1701.89	1700.66	1.23	0.00	0.06	21.00			19.08



1	2200	25 Year	1695.16	1695.16	0.00	0.00	0.00	0.08	13.12		52.08
1	2200	50 Year	1695.21	1695.20	0.00	0.00	0.00	0.11	14.79		52.84
1	2200	250 Year	1695.31	1695.30	0.01	0.00	0.00	0.23	18.67		53.79
1	2200	500 Year	1695.35	1695.35	0.01	0.00	0.00	0.30	20.70		54.25
1	2100	25 Year	1695.16	1695.16	0.00	0.00	0.00	8.38	4.27	0.55	250.65
1	2100	50 Year	1695.21	1695.21	0.00	0.00	0.00	9.36	4.91	0.63	252.74
1	2100	250 Year	1695.30	1695.30	0.00	0.00	0.00	11.61	6.47	0.83	255.17
1	2100	500 Year	1695.35	1695.35	0.00	0.00	0.00	12.76	7.31	0.94	256.31
1	2000	25 Year	1695.16	1695.16	0.00	0.00	0.00		13.20		63.12
1	2000	50 Year	1695.21	1695.21	0.00	0.00	0.00		14.90		63.54
1	2000	250 Year	1695.30	1695.30	0.00	0.00	0.00		18.90		64.42
1	2000	500 Year	1695.35	1695.35	0.00	0.00	0.00		21.00		64.84
1	1900	25 Year	1695.16	1695.16	0.00	0.00	0.00		13.20		85.14
1	1900	50 Year	1695.21	1695.21	0.00	0.00	0.00		14.90		86.09
1	1900	250 Year	1695.30	1695.30	0.00	0.00	0.00		18.90		88.08
1	1900	500 Year	1695.35	1695.35	0.00	0.00	0.00		21.00		89.03
1	1800	25 Year	1695.16	1695.16	0.00	0.00	0.00		10.82	2.38	182.14
1	1800	50 Year	1695.21	1695.21	0.00	0.00	0.00		12.20	2.70	182.77
1	1800	250 Year	1695.30	1695.30	0.00	0.00	0.00		15.43	3.47	184.09
1	1800	500 Year	1695.35	1695.35	0.00	0.00	0.00		17.12	3.88	184.72
1	1700	25 Year	1695.16	1695.16	0.00	0.00	0.00		12.73	0.47	184.98
1	1700	50 Year	1695.21	1695.21	0.00	0.00	0.00		14.36	0.54	185.44
1	1700	250 Year	1695.30	1695.30	0.00	0.00	0.00		18.16	0.74	186.40
1	1700	500 Year	1695.35	1695.35	0.00	0.00	0.00		20.16	0.84	186.85
1	1600	25 Year	1695.16	1695.16	0.00	0.00	0.00	0.57	5.94	6.69	261.49
1	1600	50 Year	1695.21	1695.21	0.00	0.00	0.00	0.67	6.73	7.50	262.14
1	1600	250 Year	1695.30	1695.30	0.00	0.00	0.00	0.92	8.59	9.39	263.51
1	1600	500 Year	1695.35	1695.35	0.00	0.00	0.00	1.06	9.56	10.37	264.16
1	1500	25 Year	1695.16	1695.16	0.00	0.00	0.00		11.89	1.31	172.95
1	1500	50 Year	1695.21	1695.21	0.00	0.00	0.00		13.40	1.50	173.28
1	1500	250 Year	1695.30	1695.30	0.00	0.00	0.00		16.96	1.94	173.98
1	1500	500 Year	1695.35	1695.35	0.00	0.00	0.00		18.83	2.17	174.31



1	1400	25 Year	1695.16	1695.16	0.00	0.00	0.00	0.00	5.16	8.04	247.35
1	1400	50 Year	1695.21	1695.21	0.00	0.00	0.00	0.00	5.86	9.04	247.64
1	1400	250 Year	1695.30	1695.30	0.00	0.00	0.00	0.00	7.52	11.38	248.24
1	1400	500 Year	1695.35	1695.35	0.00	0.00	0.00	0.00	8.40	12.59	248.53
1	1300	25 Year	1695.16	1695.16	0.00	0.00	0.00	0.37	7.03	5.79	280.04
1	1300	50 Year	1695.21	1695.21	0.00	0.00	0.00	0.43	7.97	6.51	280.78
1	1300	250 Year	1695.30	1695.30	0.00	0.00	0.00	0.55	10.17	8.18	282.35
1	1300	500 Year	1695.35	1695.35	0.00	0.00	0.00	0.62	11.34	9.04	283.09
1	1152.182	25 Year	1695.16	1695.16	0.00	0.00	0.02	0.63	12.57		187.86
1	1152.182	50 Year	1695.21	1695.21	0.00	0.00	0.02	0.75	14.15		189.13
1	1152.182	250 Year	1695.30	1695.30	0.00	0.00	0.02	1.06	17.84		191.80
1	1152.182	500 Year	1695.35	1695.35	0.00	0.00	0.02	1.23	19.77		193.06
1	1100	25 Year	1695.14	1694.96	0.18	0.60	0.67	4.23	8.97		19.12
1	1100	50 Year	1695.19	1695.00	0.19	0.59	0.67	4.95	9.95		20.10
1	1100	250 Year	1695.28	1695.07	0.21	0.58	0.67	6.67	12.23		22.15
1	1100	500 Year	1695.33	1695.11	0.22	0.57	0.67	7.59	13.41		23.11
1	999.9999	25 Year	1693.67	1687.03	6.64	0.00	0.01		13.20		5.65
1	999.9999	50 Year	1694.14	1687.05	7.09	0.00	0.01		14.90		5.90
1	999.9999	250 Year	1694.03	1687.11	6.93	0.00	0.00		18.90		6.69
1	999.9999	500 Year	1694.09	1687.13	6.96	0.00	0.00		21.00		7.04
1	900	25 Year	1688.08	1688.07	0.01	0.00	0.00		6.94	6.26	53.86
1	900	50 Year	1688.14	1688.14	0.01	0.00	0.00		7.80	7.10	54.83
1	900	250 Year	1688.29	1688.28	0.01	0.00	0.00		9.80	9.10	56.90
1	900	500 Year	1688.35	1688.34	0.01	0.00	0.00		10.85	10.15	57.90
1	800	25 Year	1688.07	1688.07	0.00	0.00	0.00		0.26	12.94	36.36
1	800	50 Year	1688.14	1688.14	0.00	0.00	0.00		0.33	14.57	36.96
1	800	250 Year	1688.28	1688.28	0.00	0.00	0.00		0.52	18.38	38.23
1	800	500 Year	1688.35	1688.35	0.00	0.00	0.00		0.64	20.36	38.83
1	700	25 Year	1688.07	1688.07	0.00	0.00	0.00		13.20		137.29
1	700	50 Year	1688.14	1688.14	0.00	0.00	0.00		14.90		137.83
1	700	250 Year	1688.28	1688.28	0.00	0.00	0.00		18.90		138.98
1	700	500 Year	1688.35	1688.35	0.00	0.00	0.00		21.00		139.53