JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

HYDROLOGY AND HYDRAULIC ENGINEERING CHAIR

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

# Flood Inundation Mapping and Hazard Assessment using GIS and HEC-RAS Model for Bilate River, Rift valley, Ethiopia

**By: Assefa Erimeko**

A Research Thesis Submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science Program in Hydraulic Engineering.

May, 2020 G.C

Jimma, Ethiopia

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Main Advisor: Mamuye Busier (Ass. Prof.)
Co-Advisor: Mahmud Mustefa (MSc.)

May, 2020 G.C
Jimma, Ethiopia

# DECLARATION

I declare that this thesis is my own work and it has not been presented for any degree award either by me or others. All ideas and materials used for the thesis organization are cited properly and acknowledged. If there is mistake it is my responsibility.

Mr. Assefa Erimeko

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As a university master's research advisors, we have read and evaluate this MSc. thesis done under our supervisor-ship. Therefor we declare that this thesis is full authorized by the researcher.

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# APPROVAL PAGE

This thesis work done under the title "Food inundation mapping and Hazard assessment using GIS and HEC-RAS models for Bilate River, Rift valley, Ethiopia" done by Assefa Erimeko has been approved by the following parties in the partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering.

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## *ABSTRACT*

*Flood is a natural disaster that occurs suddenly which runs from hilly land to low land area of river banks when runoff exceeds the capacity of the natural or artificial water conveyance structures. Currently, the hazard of flood is common in some parts of Ethiopia including Bilate watershed and cause heart breaking losses in terms of property and even human life in flat river flood plains due to elevation difference and climatic factors. The main cause of flood disaster vulnerability is due to unavailability of proper river and watershed management. Hence, the intended aim of this research is to carryout inundation mapping and hazard assessment of Bilate River flood plain. The required data for this analysis were, Digital Elevation Model, streamflow data, soil type and land use land cover map. These data were collected from Ministry of Water, Irrigation and Electricity in legal request. Hydraulic Engineering Center- Geographic River Analysis System (HEC-GeoRAS 10.3) was used to prepare RAS import file for steady flow analysis on Hydraulic Engineering Center-River Analysis System(HEC-RAS5.0.1). Stream flow data was checked for outlier, consistency and homogeneity at different significance level using Grubbs and Beck(G-B) test, double mass curve method and Mann-Whitney tests respectively. For flood frequency analysis parameter estimation of worldwide used distribution functions was done by three important parameter estimation methods such as: method of moment, probability weight method and maximum likelihood method. Best fitted Pearson type distribution function was selected by linear moment(L-moment), D-index, root mean square and correlation coefficient methods. The estimated peak floods in Bilate at Tena Bilate gauging station for 5, 10, 50, 100 and 200 years return periods were 153.2, 193.2, 273.6, 305.3 and 335.9 $m^3$/s respectively. Mapping of flood inundation was processed with inter connection of GIS extension tool HEC-GeoRAS and HEC-RAS software. The flood inundations for 5,10,50,100 and 200 years return period were 6840.244, 7284, 8029.13, 8270.031 and 8463 ha respectively. Flood hazard map were prepared by reclassifying depth grid and its area bounding polygon. Also the assessment of hazard lever with integrating flood causative agent land use land cover map with hazard map prepared after post-RAS processing.* Area inundated at sever to moderate hazard is ranges between 4% to 10.3% and around 58% was very low hazard area and out of these *shrub land, cultivation area and grass land covers large portion of delineated flood area 44%, 25-28% and 13-15% respectively in all return periods. Hence, the result of the level of hazard indicates that there is significant potential of flood and the consequence risk on livelihood in study area. It is recommended that, the watershed management party or any stakeholder, should use this research finding to take appropriate measure and reduce flood disaster.*

***Keywords****: Bilate Watershed, Flood Frequency, Flood hazard, Flood inundation, HEC-GeoRAS, HEC-RAS.*

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## ACRONNOMY AND ABBREVIATION

| | |
|---|---|
| DEM | Digital Elevation Model |
| DG | Depth Grid |
| DHM | Department of Hydrology and Meteorology |
| DMC | Double Mass Curve |
| DPPA | Disaster Prevention and Preparedness Agency |
| DTM | Digital Train Model |
| ENMA | Ethiopian national Metrologic agency |
| ERA | Ethiopian Rod Authority |
| ERVLB | Ethiopian Rift Valley Lakes Basin |
| ESRI | Environmental Systems Research Institute |
| Geo-RAS | Geometrical River Analysis |
| GIS | Geographic Information System |
| GPS | Geographic Positioning System |
| GUI | Graphical User Interface |
| HEC-RAS | Hydraulic Engineering Center-River Analysis System |
| HHEC | Hydrology and Hydraulic Engineering Chair |
| ILWIS | Integrated Land and Water Information System |
| IPCC | Intergovernmental Panel on Climate Change |
| IWRM | Integrated Water Resources Management |
| JU | Jimma University |
| JIT | Jimma Institute of Technology |
| LULCC | Land Use Land Cover Condition |
| MoWIE | Ministry of water, irrigation and electricity |
| MLM | Methods of maximum likelihood |
| MOM | Method of moment |
| NDRMC | National Disaster Risk Management Commission |
| PWM | Probability of weight method |
| SNNPRS | Southern Nations Nationality & People Regional State |

| | |
|---|---|
| TIN | Triangulated Irregular Network |
| USACE | US Army Corps of Engineers |
| USGS | United States Geographic Survey |
| USWRC | United State Water Resources Council |
| VA | Vulnerable area |
| WECS | Water and Energy Commission Secretariat |
| XS | Cross-Section |
| Yrs | Years |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Water has long historical back ground in relation to its use. “Every life in the world cannot with stand alive in the absence of water’’. Due to these strong dependences on the water, all human activities and life time hosting follows the river path and river systems since from the beginning. Entire River roots and their adjacent floodplain serve a variety of functions both as part of the natural ecosystem and for a variety of human uses with in life existence (Manandhar, 2010). Most of the civilizations in ancient historical time was developed around or near the rivers flood plain flat area. According to the estimation by Wrachien, Mambretti & Schultz (2011) at the middle of the present century, about 80% of the world’s population will live in flood prone areas.

Even though the floodplains have great importance in its positive side, there is also negative impact like damage to houses, civil infrastructure, agriculture, water supply and natural ecosystems (Barrientosa and Swain, 2014). Thus flood is defined as the inundation of water outside the artificial or natural water carrying body to the river banks or nearby plain area which may cause flood disaster on the nature and human activities on the earth’s surface. Flood hazard is unexpected happening occur due to natural impacts heavy rain, snow melt or manmade impacts like dam failure and land use land cover change. From the most common global hazards river flooding is one that causes serious phenomenal losses throughout human life history, on properties and lives and caused more economic losses than any other natural hazards.

The cause of occurrence of flood inundation proneness in different country is different. Ethiopia's topographic characteristic has made the country prone to flood and resulting devastation (Enyew, 2014). In most of the time floods occur in the Ethiopia as a result of continuing for long time heavy rainfall which causing river flow go over the sides and inundate flood plain along the river banks in lowland. Among the major river flood prone areas identified parts of Oromia and Afar regions lying along the upper, middle and downstream plains of the Awash River; parts of Somali region along the Wabe Shebelle, Genale and Dawa Rivers; low-lying areas of Gambella along the Baro, Gilo, Alwero and Akobo Rivers; down-stream areas along the Omo and Bilate Rivers in SNNPR and the extensive floodplains surrounding Lake Tana and the banks of Gumera, Rib and Megech Rivers in Amhara (NDRMC, 2018)

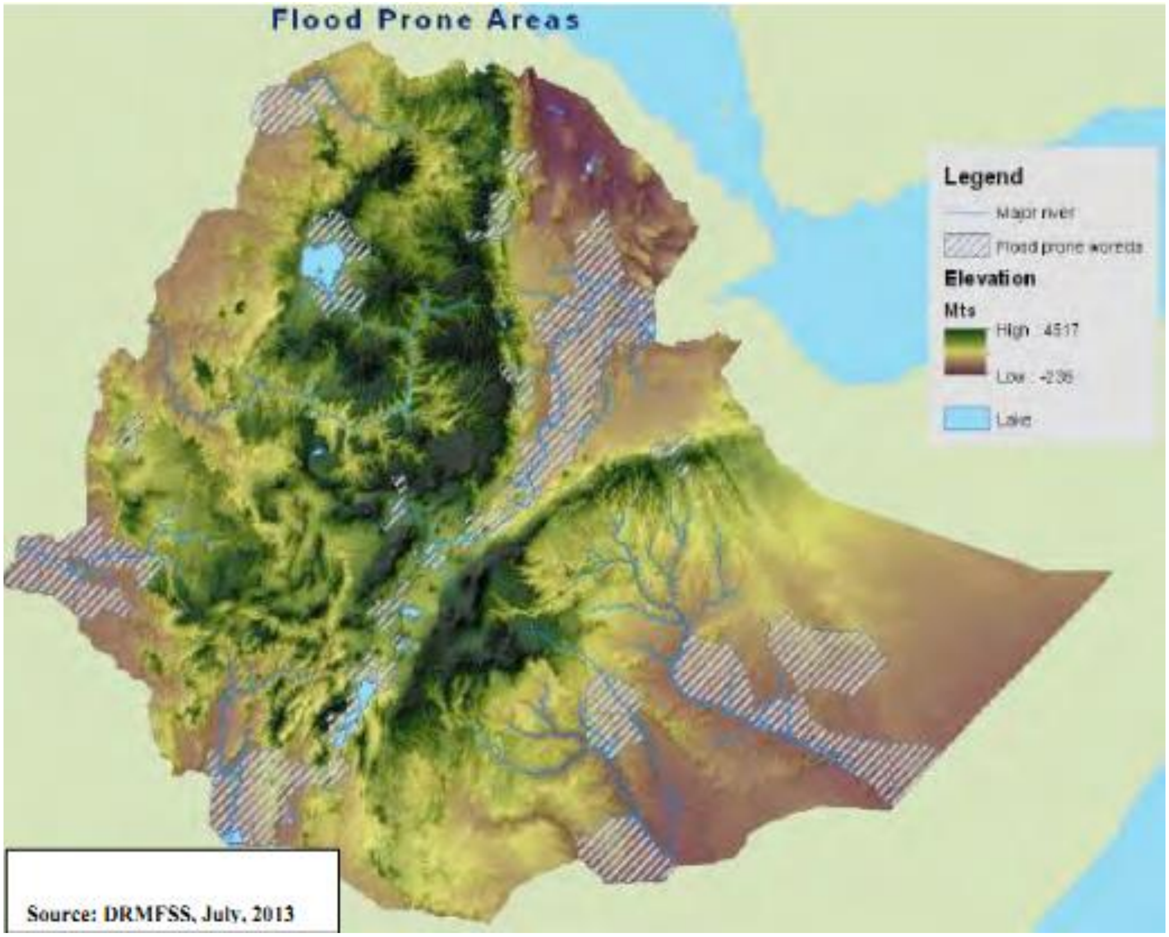



Figure 1.1 Flood Prone Area in Ethiopia

Source (NDRMC, 2018)

Particularly the rift valley regions of the Ethiopian are prone to floods due to its connection with the highland system bounding the rift valley basin in both directions (Kefeyale , 2003). This high elevation difference contributes to significance erosion at higher altitude and deposition at lower altitude which consequences high flooding processes at lower altitude. Bilate watershed is natural disasters prone area, mainly water induced disaster such as flood, landslides, even currently some significant measures of earthquake (Tesfaye, 2015). Climate change in the study area is also another important factor for unexpected occurrence of the flood magnitude and its hazard in this watershed (Demissie,Negash and Behailu, 2016).

As side to natural factors human activities are also other factors that cause unexpected flood happening in natural river system or manmade water conveyance structures. Unplanned rapid settlement development, uncontrolled construction of buildings in general and major land use changes can influence the spatial and temporal pattern of hazards level in fact (Elias, 2015). Currently Bilate watershed is one which in the line of LULC change due to the urbanization effect and some level of deforestation that cause high runoff and soil degradation in and deposition in general.

To reduce the damage of life and destruction of property due to flood, river system analysis and taking remedy action by appropriate method is mandatory. Controlling flood hazard will be accomplished by knowing peak magnitude of flood and assessing related hazard for different return period. To estimate the magnitude of peak flood different alternative methods are available like rational method, empirical method, unit hydrograph method and flood frequency studies depending up on the desired objectives, data availability and importance of the project to be done (Subramanya, 2008). Watershed management also needs different sophisticated tools which been developed with in recent decades like GIS and Remote sensing with important contribution (Mohamed, 2015). There are different software model packages to analyze and manage watershed in the world. HEC-RAS and HEC-GeoRAS are most current accurate methods of river flood inundation mapping in the world (Yirga, 2016). EC-RAS software, in addition to calculating one-dimensional profile of water surface instable rivers, it is also used for simulating unstable flow in rivers, calculating delivered sediment load and water quality analysis (Ahmad, Alam,Bhat and Ahmad, 2016).

This study basically aims to work on flood inundation mapping and hazard assessment for Bilate river flood plain to fill the gap where there is no longer study have done around. In this study flood frequency analysis method by statically distribution functions analysis was used to determine peak magnitude. Also inundation due to this peak flood was mapped and assessed for the severity of hazard level in delineated area using GIS tools and HEC-RAS models.

## 1.2 Statements of Problem

Flood is the most widespread and frequently occurring natural hazard that devastates human life and property in the world. Currently different studies show that climatic effect and land use land caver changes are the main causes for the increase in frequency and magnitude of flood in river system for last decades that result negative impact on human life and activity in Ethiopia (Zewde, 2004). High land area of Ethiopia is affected by human activities like urbanization, population settlement and life activities which causes environmental degradation and decreases infiltration. Then flooding occurs at prone area of low land by river channel filling with soil disposition and overfills of heavy seasonal rainfall from high land.

Land topographic condition like high relief, steep slopes, complex geological structures and variable climate effected by great LULCC and seasonality in rainfall, all combine to make Bilate watershed natural disasters prone area, mainly water induced disaster such as flood, landslides, even currently some significant measures of earthquake (Tesfaye, 2015). Most of the time huge amount of property, agricultural land and even human life is destructed due to peak occurrence of flood in sudden. To take the remedy action for flood inundation and its hazard probability either structurally or non-structurally it is necessary to estimate the magnitude of the peak flood in the river system.

The area has been suffering with water logging problem for a long time and farmers of the lowland area in Bilate Watershed have been facing crop failures and declining agricultural production due to inundation of river flood plain. This water logging can also reduce the agricultural and economic value of land causing yield reductions or at a time, total crop failures. Thus Bilate river plain is exposed to flood hazard and even hazard level also increase from place to place due to flood causative factors like elevation, slope, land use land cover change, drainage density and hydraulic parameters.

## 1.3 Objective of the Research

### 1.3.1 General Objective

The general objective of this study is to conduct flood inundation mapping and flood hazard assessment of Bilate river flood plain, Ethiopian Rift Valley Lakes Basin using worldwide watershed management tools ArcGIS and hydrodynamic river analysis system model HEC-RAS.

### 1.3.2 Specific Objectives

Three specific objectives are addressed based on the main goal of the research work. These are:

1. To estimate peak flood of different return period in the river;
2. To delineate inundation map for these peak flood;
3. To assess severity of flood hazard and preparation of its map in adjacent plain of Bilate River.

## 1.4 Research Questions

The relevant questions were formulated to meet the specific objectives of this research study efficiently. These are:

1. How much will be the flood magnitude quantitatively for different return period in the river?
2. what will be the flood inundation delineated for depth grids of water surface in the river flood plain?
3. What will be the flood hazard level assessed and mapped for different return periods?

## 1.5 Significance of the Study

Mapping of flood inundation and assessment of its hazard in this research is significant to reduce direct devastates of life and property by delineating and mapping flood inundation, to reduce the crop failure and direct land use for in season by mapping flood hazard area and give information to control flooding in important crop production period. Also this research is very important as information for designers as well as managers of the water resources structure in Bilate watershed and also gives a guidance to flood related river system management researchers.

## 1.6 Scope of the Study

This research is geographically limited to Bilate watershed which is one of the watersheds of Ethiopian rift valley river lakes basin (ERVLB) that runs from high lands of Gurage zone in the north west to lowest tip of watershed at Lake Abaya in the south. The research area is also bounded around an area of 5356.76 $km^2$ as it was delineated from the DEM and calculated. Even though the models used are multcriteria analysis methods, the study covers only preparation of flood inundation mapping and assessment of flood hazard for the inundated area using ArcGIS and HEC-RAS

## 1.7 Limitation

Cross-section data was extracted from TIN that have some drawback in representing exact river geometry. Hydraulic model(HEC-RAS) also assume a channel boundary as stationary during runoff event to be modeled. Assumptions in 1D models like HEC-RAS cannot account a flow pattern in with the cross section. These all have some effect on the consistency of outcome in study of 1D river analysis of Bilate river flood plain by GIS and HEC-RAS model.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Flood

The term flood is used in a broad sense to cover several river activities that causes damage that means inundation of floodplains and in probably. Flood is unusual maximum stage in the river, normally the level at which the river overfills and inundates the adjoining area (Subramanya, 2008). River flooding is defined as a naturally occurring event and one part of hydrologic cycle of surface and subsurface or ground water flow and storage beyond the carrying capacity of river (Tolera and Fayera, 2019).

Flood is the most among the natural hazards in the world which has high significant damage or destruction on human life as well as property depending up on the characteristics of the river and river system. Moreover, demography, geography, urbanization, industrialization, are the major factor for flood ( Pathan and Agnihotri, 2019). Both climatic and topographic condition make Ethiopia as well Bilate watershed flood prune area (Enyew, 2014; Demissie,Negash and Behailu, 2016).

## 2.2 Peak Flood

Peak flood is a magnitude of water level at natural or man-made channel that occurs in extreme value in probable of time. Peak flood estimation in river analysis is the first and essential step (V.Chow, 1987). Actually, there is no methodology available that can determine the strict amount of flood magnitude in the catchment. But there are some methods which are based on either probability or empirical equation. To estimate the magnitude of a peak flood in the river, different alternative methods are available like rational method, empirical method, unit-hydrograph method and flood frequency studies depends up on desired objective, data availability and importance of the project. Further rational formula is applicable for small size project ($<50km^2$) catchment and unit-hydrograph method is restricted to moderate sized catchment with area $<5000km^2$ (Subramanya, 2008).

## 2.3 Flood Frequency Study

One of the biggest challenges for hydrologists is the reliable estimation of extreme flood events (Lešˇcešen and Dolinaj, 2019). The flood frequency analysis is one of the important studies of river hydrology. In flood frequency analysis the objective is to estimate a flood magnitude corresponding to any required return period of occurrence (Demissie,Negash and Behailu, 2016). It is essential to interpret the past record of flood events in order to evaluate future possibilities of such occurrences. The results of flood flow frequency analysis can be used for many engineering purposes for the design of dams, bridges, culverts, and flood control structures, to determine the economic value of flood control projects and to delineate flood plains and determine the effect of encroachments on the flood plain (V.Chow, 1987).

The estimation of the frequencies of flood is essential for the quantitative assessment of the flood problem. The knowledge of magnitude and probable frequency of such recurrence is also required for proper planning, design and location of hydraulic structures and for other related studies in water works design and assessments (Vivekanandan, 2015)

Most frequency distributions applicable in hydrologic study can be expressed by the following equation 2.1 which is known as the general equation of hydrologic frequency analysis.

$$X_T = \overline{X} + K\sigma \qquad \text{2.1}$$

Where, $X_T$ is the value of variate X of a random hydrologic series return period T, $\overline{X}$ is the mean of variate X, σ is the standard deviation of variate X and K is the frequency factor which depends on return period T and assumed frequency distribution method.

## 2.4 Distribution Functions

Frequency analysis study needs statically distribution functions to estimate the peak flood magnitude of occurrence in the watershed for structural design either flood hazard remedy action or any design purposes. There are number of different statically distribution functions and parameter estimation methods with their procedures which was tested and recommended whole over the world are summarized by (Cunnane, 1989). As cited by Rahman (2010) Some of the widely used distributions for modeling annual maximum flood series includes Extreme Value Type I(EV1), General Extreme Value(GEV), Extreme Value Type I (EV2), Two component Extreme Value, Normal, Log Normal (LN), Pearson Type III (P3), Log Pearson Type III(LP3), Gamma, Exponential, Weibull, Generalized Pareto and Wakeby. Each distribution is site fitted depending up on the hydrologic data property in the gauging station for analysis.

## 2.5 Parameter Estimation Methods

In distribution function there are parameters like scale, shape, location parameters depend up on the type of PDF which should have been estimated before the computation of peak flood occurrence in different return period. In current watershed study there are a number of parameter estimation methods like method of moment(MOM), method of maximum likelihood(MLM), the probability weight method(PWM), the least square method(LS), maximum entropy(ENT), mixed moment(MIX), generalized method of moment(GMM), incomplete means method(ICM) and from those three namely MOM,MLM and PWM are most common ones (Hamed, 1998).

### 2.5.1 Method of Moment

This method is natural and relatively easy parameter estimation method however estimates are less efficient for distributions with higher parameters. Estimates of parameters are found by equating the moment of samples with the moments of probability distribution functions. For a k parameter distribution function with a $\alpha_1$, $\alpha_2$ $\alpha_3 \ldots \alpha_k$ parameters which are to be estimated, the first k is set equals to corresponding population moments that are given in terms of unknown parameter. This means that the method is a technique to construct estimators of parameters that is based on matching the sample moments with the corresponding distribution moments (Vivekanandan, 2015). The $j^{th}$ central moment $\mu_j$ about the center of random variable can be given by:

$$\mu_j = \int (Q - \bar{Q})^j) f(Q) dQ \quad \ldots\ldots\ldots\ldots\ldots \quad 2.2$$

where Q is contentious variable, $\bar{Q}$ is mean value of Q, $f(Q)$ is a PDF of random variable continues variable Q.

### 2.5.2 Methods of Maximum Likelihood

This method is considered as most efficient method since it provides the smallest sampling variance of estimated parameters and quantiles. However, for some cases like Pearson(3P) this leads to inferior quality (Bobee and Ashar, 1991). MLM involves the choice of parameter estimation that produce a maximum probably of observation occurrence. For distribution density function determined as a function f(x) and parameters $\alpha_1$, $\alpha_2$ $\alpha_3 \ldots \alpha_k$ likelihood function is defined as:

$$L(\alpha_1, \alpha_2\ \alpha_3 \ldots \alpha_k) = \prod_{i=1}^{n} f(X_{i;} \alpha_1, \alpha_2\ \alpha_3 \ldots \alpha_k) \quad \text{...2.3}$$

Partial derivation with respect to parameters are computed and equated to zero to maximize the likelihoods function. Then the resulting equation is solved simultaneously to obtain value of parameters.

$$\frac{\partial L(\alpha_1,\ \alpha_2\ \alpha_3 \ldots \alpha k)}{\partial x_i} \quad \text{...2.4}$$

### 2.5.3 Probability Weight Methods

In this method parameters are estimated, as in the case of method of moment by equating moment of distribution with the corresponding sample moments. For distribution with parameter k $\alpha_1$, $\alpha_2 \ldots \alpha_k$ which are to be estimated the first sample moments are equals to the corresponding population moments. The resulting equations are solved simultaneously for unknown parameters $\alpha_1$, $\alpha_2 \ldots \alpha_k$ (Hamed, 1998).

Table 2-1 PDs and their Parameters

Source (Rizwan, Guo, Xiong and Yin, 2018)

| Number | Distribution | Probability Density Function | Parameters |
|---|---|---|---|
| 1 | EXP | $F(x) = 1 - \exp\{-(x-\xi)/\alpha\}$ | scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 2 | GAM | $F(x) = \frac{x^{\alpha-1}\exp\left(\frac{-x}{\beta}\right)}{\beta^{\alpha}\Gamma(\alpha)}$<br>$\Gamma$ is the gamma function | shape parameter = $\alpha$<br>scale parameter = $\beta$ |
| 3 | GEV | $F(x) = \exp\{-\exp(-y)\}$<br>$y = \kappa^{-1}\log\{1-\kappa(x-\xi)/\alpha\}$ | shape parameter = $\kappa$<br>scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 4 | GLO | $F(x) = \frac{1}{\{1+\exp(-y)\}}$<br>$y = -\kappa^{-1}\log\{1-k(x-\xi)/\alpha\}$ | shape parameter = $\kappa$<br>scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 5 | GNO | $F(x) = \phi(y)$<br>$y = -\kappa^{-1}\log\{1-k(x-\xi)/\alpha\}$ | shape parameter = $\kappa$<br>scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 6 | GPA | $F(x) = 1 - \exp(-y)$<br>$y = -k^{-1}\log\left\{1-\frac{\kappa(x-\xi)}{\alpha}\right\}$ | shape parameter = $\kappa$<br>scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 7 | GUM | $F(x) = \exp[-\exp\{-(x-\xi)/\alpha\}]$ | scale parameter = $\alpha$<br>location parameter = $\xi$ |
| 8 | NOR | $F(x) = \frac{1}{\sigma\sqrt{2\pi}}\exp\left\{-\frac{(x-\mu)^2}{(2\sigma^2)}\right\}$ | scale parameter = $\sigma$<br>location paramete = $\mu$ |
| 9 | P3 | $F(x) = \frac{\lvert x-\varepsilon\rvert^{\alpha-1}\exp(-\lvert x-\varepsilon\rvert/\beta)}{\beta^{\alpha}\Gamma(\alpha)}$<br>If $\gamma \neq 0$, then let $\alpha = \frac{4}{\gamma^2}, \beta = \frac{1}{2}\sigma\lvert\gamma\rvert$, and $\xi = \mu - 2\sigma/\gamma$ | scale parameter = $\sigma$<br>shape parameter = $\gamma$<br>location parameter = $\mu$ |
| 10 | WEI | $F(x) = 1 - \exp\left[-\{(x-\zeta)/\beta\}^{\delta}\right]$ | scale parameter = $\beta$<br>shape parameter = $\delta$<br>location parameter = $\zeta$ |

## 2.6 Tools and Models for Floodplain Analysis and Mapping

There are a number of commercial and non-commercial software tools available for numerical modeling and analysis in GIS. Based on information on the lateral distribution of flow across a cross section the models can be further divided into one-dimensional and two-dimensional model. There are also different models like HEC-RAS, HEC-HMS and Remote sensing models are used in watershed flood plain analysis.

### 2.6.1 Geographic Information System

Currently, GIS tool is very rapidly developing tool regarding to its applications in different field of studies. Geographical information system is defined as computer systems capable of assembling, storing, manipulating and displaying geographically referenced information (ESRI, 1990). It encompasses not only to the GIS package but all the software used for databases, drawings, statistics, and imaging and functionality of the software used to manage the GIS determines the type of problems that the GIS may be used to solve. The soft wares must match the needs and skills of end user. GIS is powerful, easy to use, point and click graphical user interface that makes easy loading of spatial and tabular data to display the data as maps, tables and charts (Murayama and Estoque, 2010).

All the activities GIS are organized in a project, which may consist of views, tables, charts, layouts, and scripts. Using Avenue, we can customize ArcView's menus, buttons, and tools for specific applications. There are different extensions, add-on programs HEC-GeoRAS, HEC-GeoHMS ,Arc Hydro and the likes can provide advanced functionality in GIS (ESRI, 1996). This tool can assist the flood plain managers to identify the flood inundation area in their community.

### 2.6.2 HEC-RAS Model and Its Application

Hydraulic engineering center river analysis system is an integrated system of software which was designed for interactive use in a multitasking environment. The system is comprised of a graphical user interface (GUI), separate hydraulic analysis components, data storage and management capabilities, graphics and reporting facilities (ShahiriParsa et al, 2016). The software replaces the HEC-2 river hydraulics package which was one of the oldest method dimensional steady flow water surface profiles program.

This numerical hydrodynamic model has four important possibilities in flood plain analysis. These are possibility of calculating water surface profile for steady gradually varied flow, capability of the simulation 1D/2D and combination 1D/2D unsteady flow of along open channel, floodplains and alluvial fans, simulations of 1D sediment transport or movable boundary calculation resulting from scoured and deposition over a moderate long period of time and analysis of riverine water quality. Therefore, HEC-RAS model is designed to perform 1D hydraulic analysis for a full network of natural and artificial channels and flood plains. The latest versions of HEC-RAS enables to analysis steady and unsteady flow water surface profile calculations, perform sediment transport simulation and perform water quality simulation for the user (USACE, 2016).

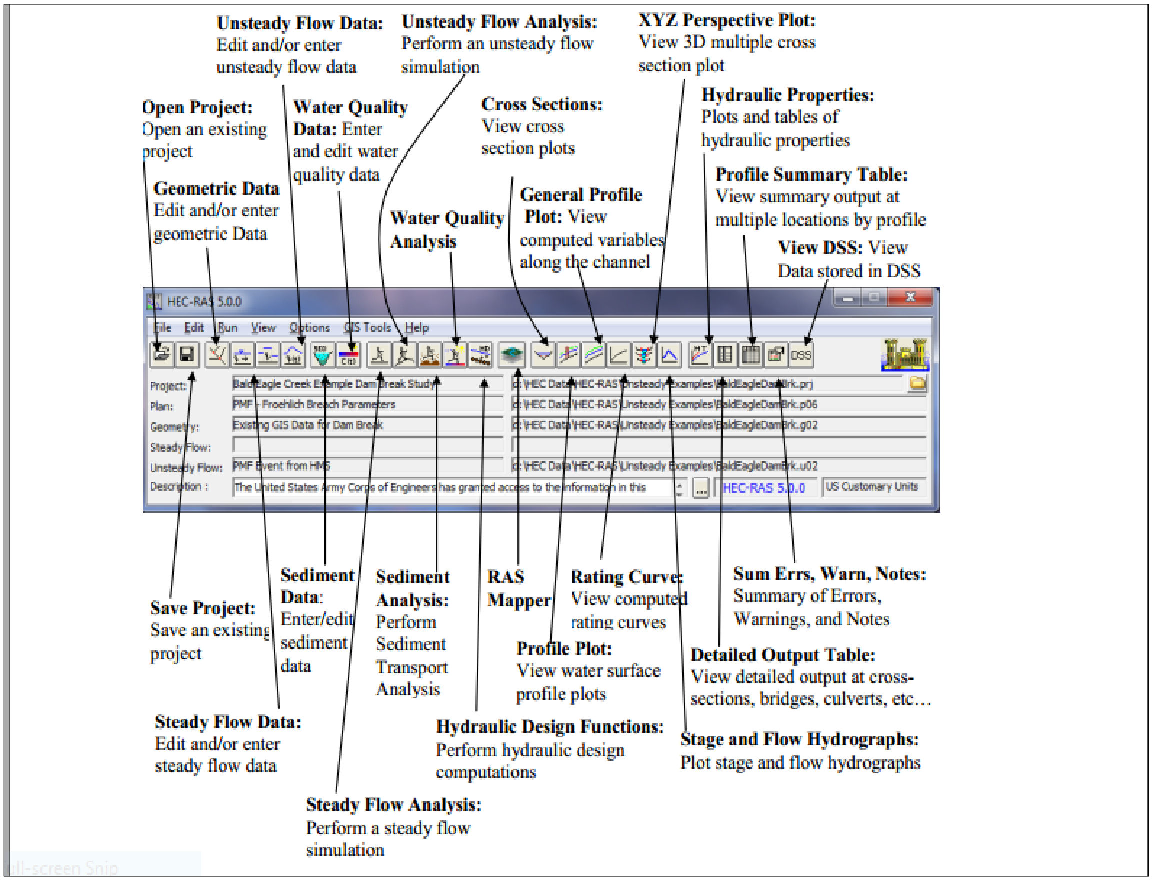



Figure 2.1 Component Parts of HEC-RAS Menu

Source (USACE, 2016)

### 2.6.2.1 Steady flow water surface profiles

Understanding of the flow dynamics in a river system is an important step towards the satisfaction of the water needs (Traore, 2015). There are different basic equations which are applicable in the environment of HEC-RAS algorithm to compute water surface elevations. In steady flow simulation water surface profiles are computed from one cross-section to the next by solving the energy equation with an iterative procedure. Energy equation is based on principle of conservation of the energy and it states that the sum of the kinetic energy and potential energy at a particular cross-section is equal to the sum of the potential and kinetic energy at any other cross section plus or minus energy loss or gains between the sections. The energy equation can be written as follows:

$$z_2 + y_2 + \frac{\alpha_2 V_2^2}{2g} = z_1 + y_1 + \frac{\alpha_1 v_1^2}{2g} + h_e \quad \text{……………………………………………..2.5}$$

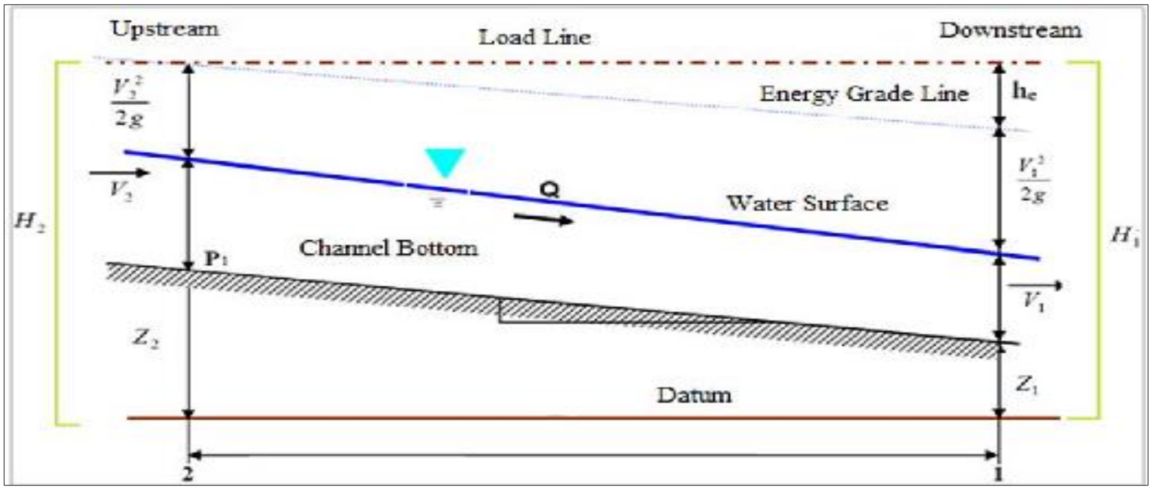



Figure 2.2 Representations of Terms in the Energy Equation

(Source: (Traore, 2015))

Where; $z_1$ and $z_2$ are elevations of main channel, $z_2$ are $y_2$ are depth of water across channel, $V_1$ and $v_2$ are average velocities, $\alpha_1$ and $\alpha_2$ are velocity weighing coefficients and g is gravitational acceleration.

$$h_e = LS_f + C\left(\frac{\alpha_2 V_2^2}{2g} - \frac{\alpha_1 v_1^2}{2g}\right) \quad \text{……………………………………………..2.6}$$

Where; $h_e$ is energy head loss between two sections, L is discharge weighted reach length, $S_f$ is representative friction slope between two section and C is expansion or contraction loss coefficient.

The distance weighted reach length, L, is calculated as:

$$L = \frac{(L_{lob}Q_{lob} + L_{mch}Q_{mch} + L_{rob}Q_{rob})}{(Q_{lob} + Q_{mch} + Q_{rob})} \quad \text{……………………………………………..2.7}$$

Where $L_{lob}$, $L_{mch}$ and $L_{rob}$ are x-section reach length specified for flow in the left overbank, main channel and right overbank respectively and $Q_{lob}$, $Q_{mch}$ and $Q_{rob}$ are arithmetic average of the flows between sections for the left overbank, main channel and right over bank respectively.

### 2.6.3 HEC-GeoRAS and Its Application

HEC-GeoRAS is an Arc GIS extension tool specifically designed to process geo-spatial data for use with interconnection of the hydrodynamic model HEC-RAS (Cameron and Ackerman, 2012). This extension tool enables Modelers of river to pre-process HEC-RAS import file containing geometric attribute data form an existing digital terrain model and complementary data sets. When using the HEC-GeoRAS extension, the data can be easily inserted into the equation, and the results can be exposed through maps of hydrological risk (Merwade , 2012).

Here the result of water surface profile also processed to visualize flood inundation depths and bounding boundaries. HEC-GeoRAS extension for ArcView GIS used an interface method to provide a direct link to transfer information between the ArcView GIS and the HEC-RAS as shown in Figure 2.4 below.

HEC-GeoRAS version10.3 requires GIS10.3 or higher version with 3D Analyst 1.0 extension. GeoRAS10.2, extension provides the user with a set of procedures, tools, and utilities for the preparation of GIS data for import into RAS and generation of GIS data form RAS output. These tasks are organized as pre-processing (pre-RAS) and post-processing (post-RAS) facilitated by menu and buttons.

#### 2.6.3.1 Pre-RAS processing

In order to create the import file for HEC-RAS model, the digital terrain model or digital elevation model of the river system in the form of TIN format is needed. The other important data used for the pre-processing includes series of line themes are stream centerlines, flow path centerlines, main channel banks, and cross section cut lines referred as the RAS themes. 3D streamline and cut lines themes are created using 2D RAS themes and TIN. The RAS import file consists of geometric attribute data necessary to perform hydraulic computations in HEC-RAS model. The cross-sectional geometric data is developed from DTM of the channel and surrounding land surface, while the cross-sectional attributes are derived from points of inter-section of RAS themes. Additional RAS themes may be created / used to extract additional geometric data for import in HEC-RAS. These themes include LULC, Levee Alignment, Ineffective Flow Areas, and Storage

Areas. Expansion or contraction coefficients, hydraulic structure data such as bridges and culverts are not written to the RAS GIS import file and need to be added to the model through the RAS interface (USACE, 2016).

#### 2.6.3.2 RAS-Processing

Flood modeling is one of the engineering tools which provides the accurate information of the flood profile through processing of appropriate model (Ahmad, Alam,Bhat and Ahmad, 2016). Hydrodynamic HEC-RAS model processing is another important step in river plain analysis to simulate either steady or unsteady state flow profile. HEC-RAS model was used by (Traore, 2015) based on hydraulic routing to describe the hydraulic behavior of this river basin by performing steady flow calculations in order to generate water surface profiles for different discharges.

#### 2.6.3.3 Post- RAS processing

Post-Processing (post-RAS) facilitates the automated floodplain delineation based on the data contained in the RAS GIS output file and the original terrain TIN. Based on the RASGIS export file, cross-sections theme (with water levels for each modeled profile as attributes) and bounding polygon (to the edge of the modeled cross-sections) can be generated. The water surface Tin is generated using these cross-sections and bounding polygon themes. With the water surface TIN and the original terrain TIN, inundated depth grids and floodplain polygons can be automatically generated. Apart from this, HEC-GeoRAS can also generate the velocity TIN and grid (ESRI, 1997).

## 2.7 Triangulated Irregular Network (TIN)

Triangulated irregular network is a surface representation derived from interconnected and non-overlapping triangles. The vertices of the triangles are formed by irregularly spaced sample points. Each point has x, y coordinate and a surface or z- coordinates (ESRI, 1997). Any floodplain model needs information about the elevation of the ground points inside the flood prone areas. Since the TIN model is the three dimensional presentation to the terrain, they become very important information to floodplain modeling. Thus the TIN model can be considered as the backbone of the flood hazard occurrence predictions. These kinds of models enable computer processing to solve problems faster and better than dealing with the natural ground.

## 2.8 Flood Plain Analysis

Flood plain is defined adjoining dry land area of the river or any other water carrying body that is inundated during flood event happening. As cited by Ahmad, Alam, Bhat and Ahmad (2016) floodplain modelling can focus on several different areas, including preparation of comprehensive floodplain studies, design of transportation feature, or other facilities like floodway development and structural or nonstructural solutions to flood problems in the watershed. Once the peak flood for desired return period has been estimated the next task is to determine the water surface profile of the river channel. This process can be done by assuming the steady, gradually varied 1D or 2D models. One dimensional models allow the flow properties for long stream whereas 2D model accounts the changes across the channel (V.Chow, 1987). HEC-RAS model can do this as it designed to perform the 2D/1D hydraulic calculations in full networked natural or constructed channel (USACE, 2016).

## 2.9 Flood Hazard Assessment

Hazard is defined as threatening event, or the probability of occurrence of a potentially damaging phenomenon within a given time period and area (Brooks, 2003). The hazard assessment includes the assessment of risks posed by a flood event in terms of tangible and intangible damages. After identifying the potential hazards, the next step in the assessment process includes the estimation of extent and severity of the damages in terms of hazard exposure analysis, usually defined by flood water depth and the velocity. The damage assessment involves estimating the impact of the likely exposure in terms of the costs of replacing and restoring the affected areas.

The flood hazard and exposure assessment can be undertaken as outlined in the three approaches by Rejewski (1993) as cited (Awal, 2003). In the first approach, a simple binary model, describes the hazard as either present or absent. The second approach, spatial coexistence model is represented by a weighted model, which involves ranking locations within the hazard area according to the severity of the hazard. The third approach is the quantitative interval ratio model that assigns numbers to locations that quantify the unit hazard factor.

## 2.10 Previous Study in Ethiopia

Currently flood, is common phenomenon in the low land areas of Ethiopia like ERVLB due to its topographic and human-effect causes. Bilate watershed is one lie in ERVLB which has consecutive flooding. In the higher reaches of watershed, the problem is mainly confined to landslides, debris flows and river bank undercutting, whereas in the low lying areas and the flat areas of the watershed across the river bank. The floods generally overflow the bank and cause bank erosion, inundation and fields are filled with sediments every year during the monsoon (June- September) in the numerous streams and rivers (Kefyalew, 2003).

Natural hazard assessment in Ethiopia is still nearly in initial stage and less concern is given to assess flood hazard and mapping flood inundation area. Flood hazard assessment still needs research in Ethiopia. Even though some flood protection work has carried out at some part, it is more without planning and mapping in basin scale. Some relevant literatures carried out in Ethiopia reviewed for this study are discussed here.

(Solomon, 2012); worked on Flood risk mapping and Vulnerability Analysis of Megech River using 2D hydrodynamic flood modeling. The study was generated flood risk map by weighting flood depth, flow velocity and flood duration using HEC-RAS hydraulic model. Then prepared flood map for different return periods.

Flood Risk Analysis in Illu Floodplain, Upper Awash River Basin, Ethiopia by (Dawit, 2015) as carried out to analysis risk on crop. After the study he recommend that in order to minimize the amount of flood damage, it is recommended that areas inundated by the 100 year return period flood should not be used for agricultural activities, infrastructure development, settlement and other investment projects on the wet season because has high probability occurrence in the study area.

Flood hazard and risk assessment using GIS and remote sensing in lower awash sub basin, Ethiopia was studied by (Yirga, 2016). The major finding indicated that 107,145.01 ha (5%), 522,116.92 ha (23%), 897388.95 ha (39%) and 763045.31 ha (33%) of the area considered in Lower Awash Sub-basin were subjected respectively to low, moderate, high and very high flood hazards. The recommendation of the paper says that "A limitation that can be pointed to this method of flood hazard and risk mapping is that the GIS result is not combined with an applicable hydrologic/hydraulic method for estimating stages. As a result of this, the study is conducted without any hydrodynamic simulation and estimation of flood depth inundation. Therefore, in the future research on developing flood hazard map that can indicate the depth of inundation through hydrodynamic simulation should be done for the Lower Awash Sub-basin."

As cited by Yirga(2016) in Ethiopia most flood hazard studies have been concentrated in Tana sub-basin (Assefa et al, 2008; Mossie, 2008; Hagos, 2011; Wubet & Dagnachew, 2011; Zelalem, 2011 Yalelet, 2013), in Dire Dawa (Daniel, 2007) and in Middle and Upper Awash sub-basin (Alemayehu, 2007; Sifan, 2012). These studies are done by out of GIS based technique to analysis flood hazard area.

Floodplain modeling for Awitu River sub-basin, Oromia, Ethiopia was done by (Tolera and Fayera, 2019). They used HEC-RAS model and HEC-GeoRAS ArcGIS tool to conclude that upstream and downstream right banks are more exposed to flood inundation with their finding of 130.7 ha and 185 ha for the return periods of 5 and 1000 Yrs respectively.

As Demissie,Negash and Behailu(2016) are work together on assessment of climate change impact on flood frequency of Bilate river basin, Ethiopia using HEC-HMS model and HEC-SSP software, their study concludes that precipitation and temperature of the study area have changed, hence there is flooding in the basin for the next 30 years.

Floodplain modeling for Awitu River sub-basin, Oromia, Ethiopia was done by (Tolera and Fayera, 2019). They used HEC-RAS model and HEC-GeoRAS ArcGIS tool to conclude that upstream and downstream right banks are more exposed to flood inundation with their finding of 130.7 ha and 185 ha for the return periods of 5 and 1000 Yrs respectively.

Flood inundation mapping in Gelana, Rift valley in Ethiopia was done by (Bucha and Selvaraj, 2019)  was done using HEC-RAS model and GIS tool. Their finding show 3.99, 2.32, 2.21, 2.13, 2.04 ha which is very small finding in relation to watershed size respectively to very high, high, moderate, low and very low flood hazards

Mapping flood prone areas of Bilate watershed using integration of multcriteria analysis and GIS techniques was carried out by (Muse,Getaneh and Abiy, 2018). The final result produced using Weighted overlay function of the five criterions developed identified three flood prone areas in the watershed as high, moderate and low flood prone areas covering 28.5% (1603.16 $Km^2$), 61.4% (3453.82 $Km^2$) and 10.1% (568.14 $Km^2$) area from the watershed respectively. A gap found here is that flood hazard and risk mapping using multcriteria analysis and GIS result is not combined with an applicable hydrologic /hydraulic method for estimating flood hazard relative to stages the area itself is also over estimated.

Therefore, the studying on the river plain flood inundation mapping and hazard assessment using GIS and HEC-RAS is current research area. Bilate river plain analysis using the GIS tool and hydrodynamic model HEC-RAS model was done as no more research in this area.

# CHAPTER 3

# MATERIALS AND METHODS

## 3.1 Description of Research Area

### 3.1.1 Location

The study area (Bilate sub-basin) is situated in the southwest of Addis Ababa, between around 6°30'10''and 8°24'0''N latitude and 37°46'50''and 38'31'55''E longitude. It forms part of the Main Ethiopian Rift valley, which is part of an active rift system of the Great Rift Valley. The Bilate River watershed, which is chosen to be the area of study, forms the north western part of the ERVLB. The catchment covers the area between Gurage highlands to Lake Abaya shore and includes the portions of SNNPRS regional zones Hadiya, Kembata Tembaro, Gurage, Silte, Wolyita, Sidama, Alaba zone and small parts of the South-central Oromia regional states. The total area coverage is around 5356.76$km^2$ based on watershed delineation.

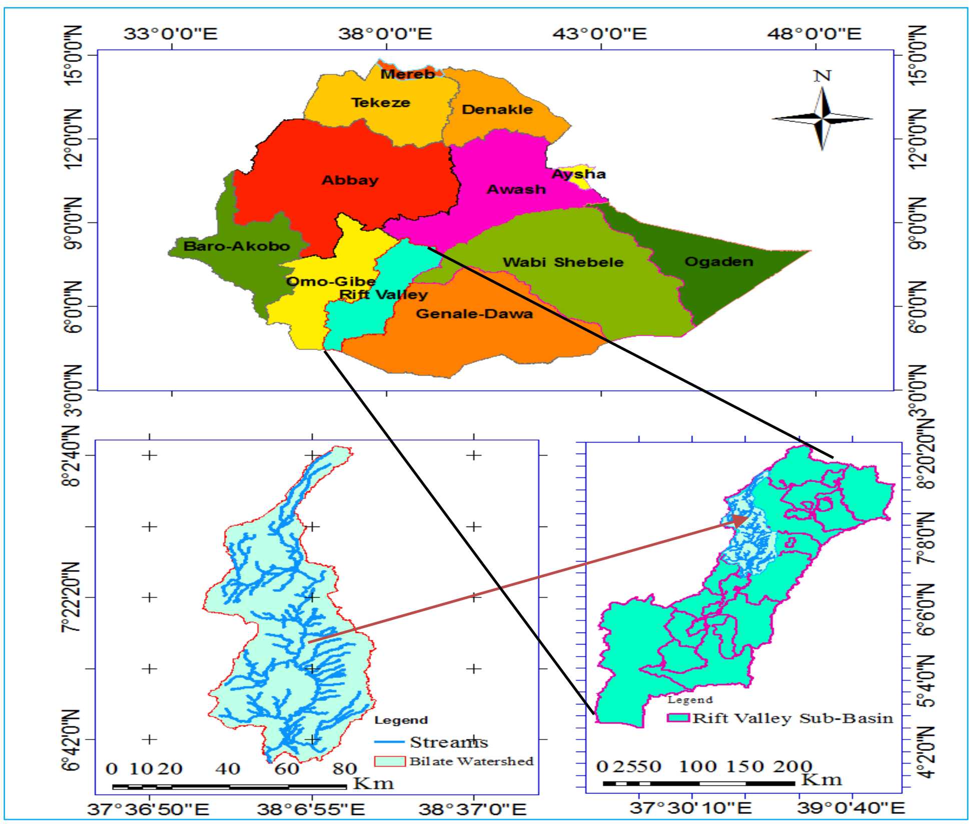



Figure 3.1 Location Map of Research Area

### 3.1.2 Hydro-Metrological Condition

Climatic condition of the study area ranged between sub-tropical to temperate at lower and higher altitudes respectively. The annual rain fall study watershed ranged between 769mm to 1516mm and annual maximum and minimum temperature varies between 11℃ and 30℃ (Demissie,Negash and Behailu, 2016). The maximum and minimum stream flow record Bilate near Alaba Kulito, Bilate near Tena Bilate, Weira near Fonko, Batena Near Hossana and Ferfero near Wulbarag were 283.54 to 0.206,283.5 to 0,239.48 to 0.449,101.3 to 0.003 and 104.366 to 0 $m^3/s$ respectively.

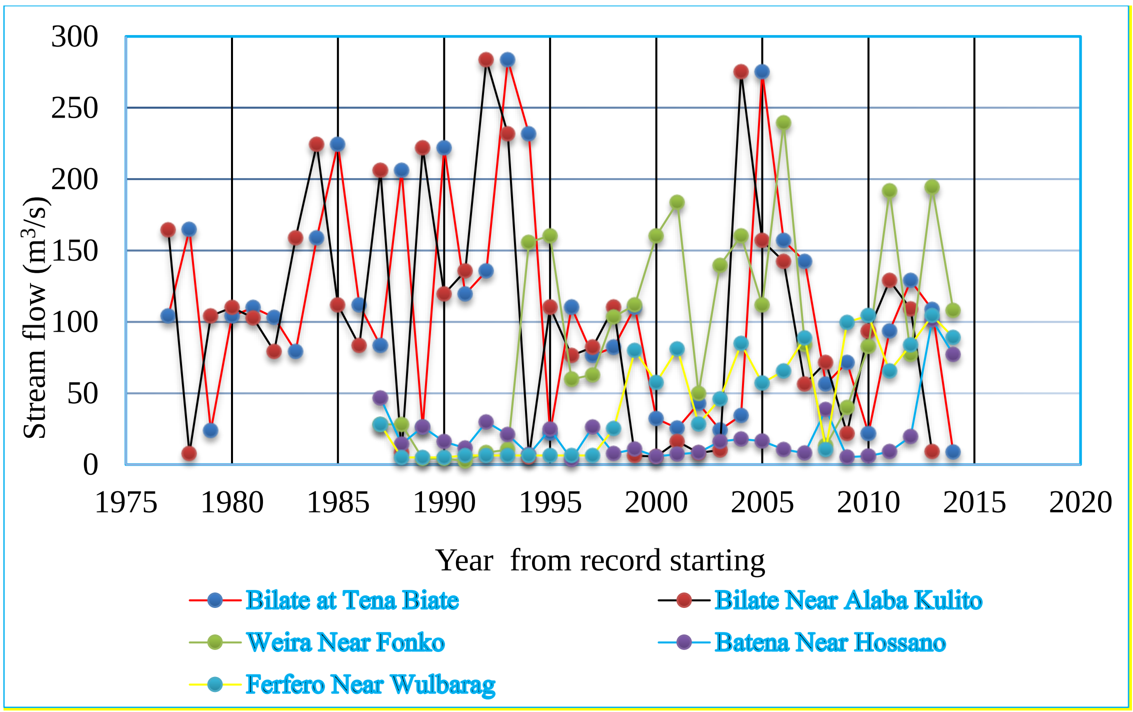



Figure 3.2 Yearly Maximum Stream Flow at Gaging Stations in Bilate Watershed

### 3.1.3 Land Use Land Cover Map of Research Area

The LULC of watershed also has an impact on flood and also impacted itself by flood. That means when there is density in land use land cover the infiltration rate is high and low in runoff rata. Bilate watershed consists of nine land use land cover type namely crop plantation land, cultivation land, wood land, state farm, swamps, grass land, water body, forest area and shrub land. The area under shrub land comprises more than 46% therefore there is an indication of soil degradation at high land area and deposition at low land area which reduces the river water carrying capacity.

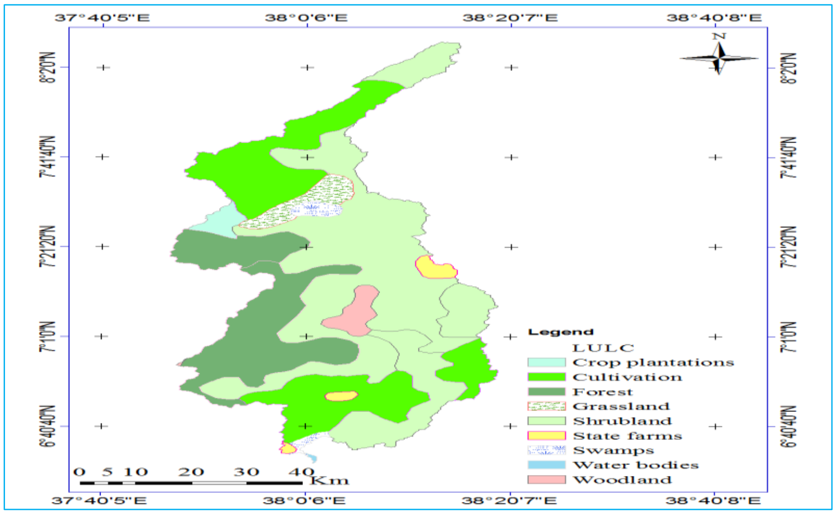



Figure 3.3 LULC Map of the Research Area

### 3.1.4 Soil Map of Research area

Soil type in the watershed has also great impact in the occurrence of the river flooding and its hazard. The soil type also impacted by the flood due to the degradation in high land deposition in lowland when the area inundated. As the soil type near the river bank is very poor to resist the pressure of water, the bank will be degraded and filled in the channel. Then this leads for inundation in river plain due to the peak flood holding capacity retardation in river. Bilate watershed has about sixteen types of soil based on the soil Ethiopian soil map as shown in Figure 3.4 below.

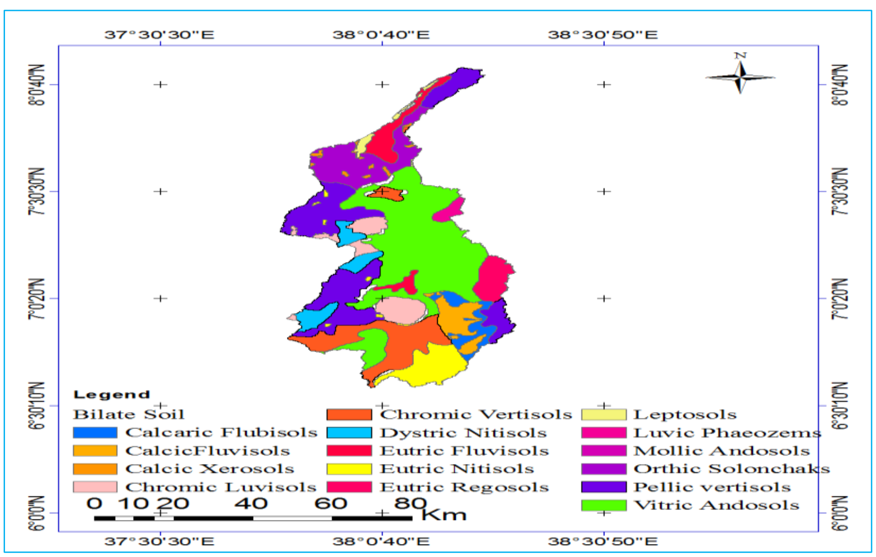



Figure 3.4 Soil Map of the Research Area

### 3.1.5 Topography of Research Area

The topographic condition of the watershed like elevation, slope, drainage density and aspect has a great roll in flood hazard occurrence in river system. The elevation of the Bilate watershed varies between 1153m and 3331m above mean sea level as it was extracted from the DEM of 30m resolution. But majority of the Catchment area forms an elevation between 1160m and 2000m above mean sea level. Slop has also great contribution river flood happening in river system. The slope of the of Bilate watershed was classified from DEM 30 as shown on the figure 3.6 below and its majority falls under the slope category of 0-15% rises. This elevation variation and slope variation also has great in indication for the occurrence of river flooding.

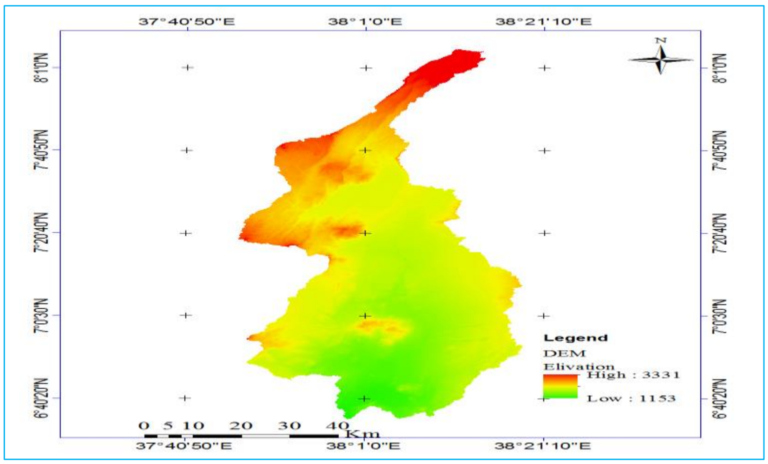



Figure 3.5 DEM of the Research Area

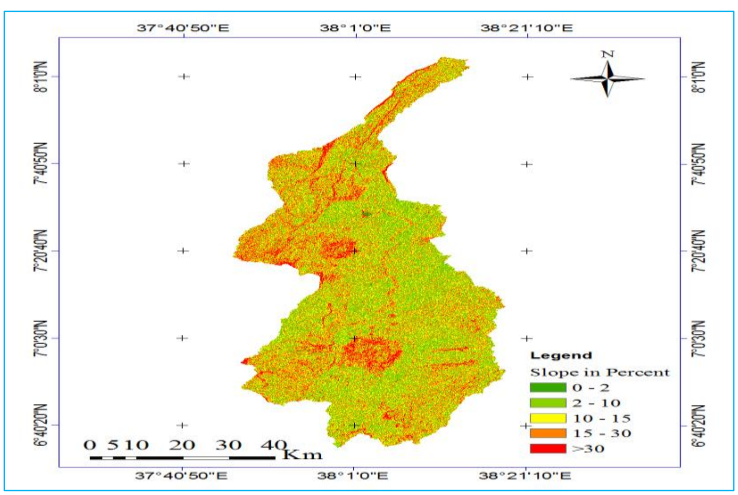



Figure 3.6 Slop Map of Research Area

## 3.2 Materials Used

Before interring to the research work it is important to know what materials are necessary required for the selected title. For this case the chosen study area is to analyze the river plain which needs GIS based tools and hydraulic models. Thus to accomplish the study properly and effectively with in a short period of time different basic equipment, materials and software were used for data collection, processing, analysis and flood map preparation are tabulated with their source and purpose as following Table 3-1.

Table 3-1 Table showing the materials used for flood plain analysis

| S. No | Material | Source | Purpose |
|---|---|---|---|
| 1 | ArcGIS10.4 | Sharing it from JIT instructors | For geospatial data processing and floodplain mapping of the research area |
| 2 | HEC-GeoRAS12.3 | Downloaded from the Website: www.hec.usace.army.mail | To interface between GIS and HEC-RAS model |
| 3 | HEC-RAS5.0.1 | Downloaded from the Website: www.hec.usace.army.mail | To calculate water surface profiles and steady flow analysis |

## 3.3 Data Used and Sources

All the necessary data for river plain flood inundation mapping and hazard assessment using HEC-RAS model and GIS tools are stream flow data, DEM and LULC. Stream flow data of five gauging stations namely Bilate near Tena Bilate, Bilate near Alaba kulito, Batena near Hossana, Ferfero near Wulbarag and Weira near Fonko was gathered from Ministry of Water, Irrigation and Electricity(MoWIE) in legally way. Digital Elevation Model (DEM) 30m resolution of Ethiopian rift valley lake basin which is very important in flood modeling and land use land cover(LULC) map was also collected from MoWIE by kindly request.

## 3.4 Study Procedures

The following diagram shows the core path that the flood plain analysis in this study using GIS and HEC-RAS model was conducted. Each steps shown on the work flow diagram was done step by step and carefully to come up with best results of this research objectives.

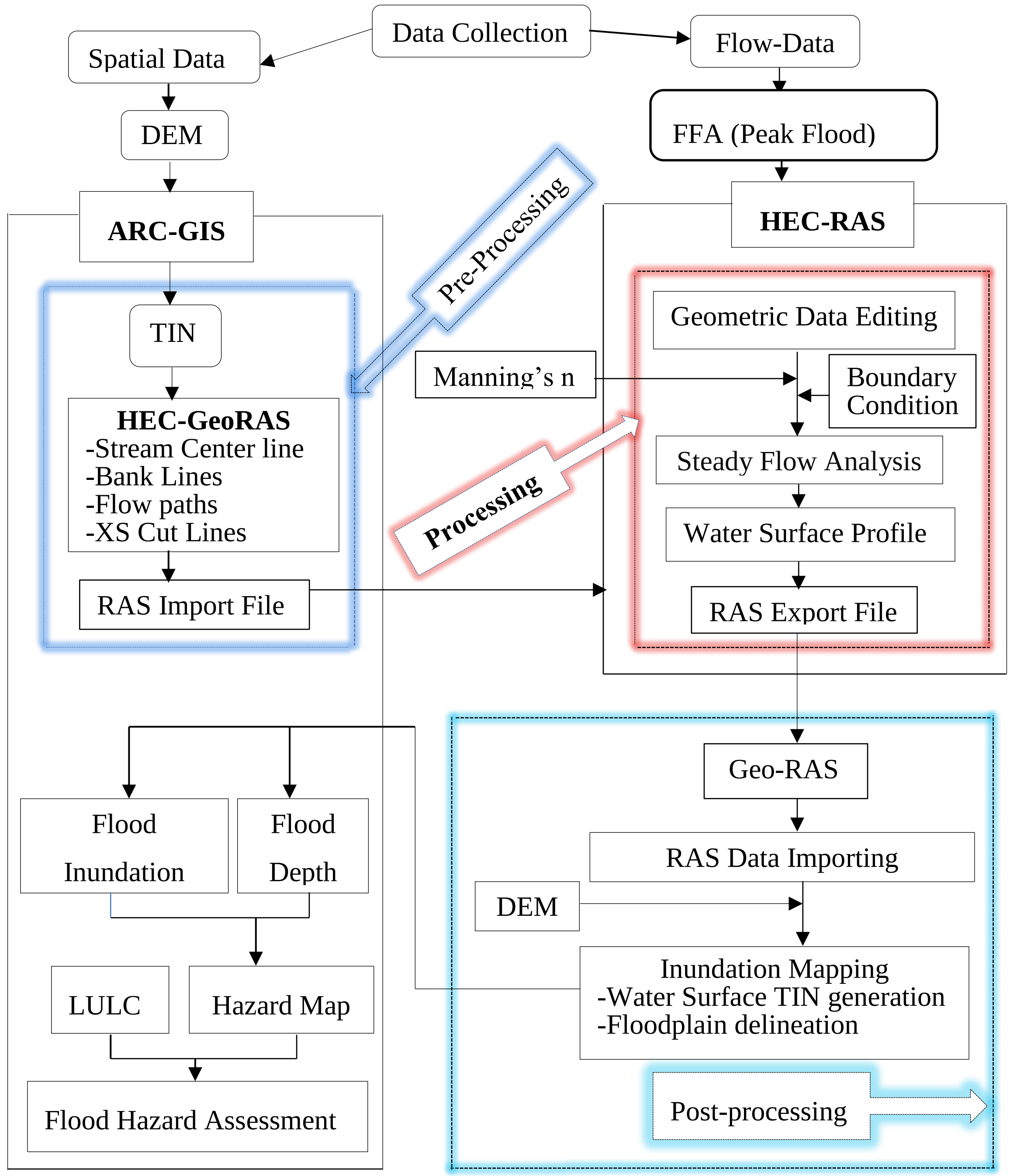



Figure 3.7 Conceptual Work Flow of Flood Plain Analysis Using GIS and HEC-RAS

## 3.5 Data Preparation and Analysis

After all the data have been collected, the next step of the study followed as preparation and analysis of the raw data to make it useful for the research purpose. The data preparation and analysis phase of flood inundation mapping and hazard assessment for the study area consists of; Identifying and filling missing stream flow data, Checking the consistency and homogeneity of data, Analysis of stream flow data, Preparation of LULC and soil Map and reclassification and Topographic data preparation.

### 3.5.1 Identifying and Filling Missing Data

Before starting hydrologic analysis, it is important to check whether the data series is sufficient and complete with no missing or not. Errors resulting from lack of appropriate data processing are serious because they lead to bias in the final answers (Vedula, 2005). In general data should be adjusted for homogeneity and inconsistence, extended for insufficiency and filled for missing using appropriate methods.

There are different techniques to fill missing data in hydrological analysis such as simple average (Station area Average), linear or multiple regression, normal-ratio, coefficient of correlation, and inverse distance weighting method are commonly used to fill the missing records (Gomez, 2007). The regression analysis is most frequently used method to solve the missing data problem in many river flows (Mfwango, Salim ,Kazumba , 2018).

For this study the stream flow data gap was filled using linear regression. analysis. Linear Regression analysis for two relative variables $Q_m$ and $Q_o$ the linear regression equation is given as equation 3.1 below.

$Q_m = \alpha * Q_o + \beta$…………………………………………………………………… 3.1

Where $Q_m$ is missed stream flow, $Q_o$ is observed stream flow of neighboring station, α is slop of the linear function and β is the intercept of $Q_m$ axis, that means y-intercept.

### 3.5.2 Test on Outlier

Outlier in the data can be happen due to the depart of the single data from the general trend of the other data in the record station. This problem usually occurs due to the observation error made during record data collection or any other natural error like failure of structures adds inspected reading of gauge.

There are two groups of methods of outlier test of data like interval and statically tests of data. Interval method considers interval of data after observation and traditionally concerns mean plus or minus three times standard deviation ($\overline{X} \pm 3S$). The data out of this range is termed as outlier data. Box plot method is also other interval method of outlier test of data which consider the data between $X_i < Q_1 + 1.5IQR$ or $X_i > Q_1 + 1.5IQR$ as weak outlier and $X_i < Q_1 + 3IQR$ or $X_i > Q_1 + 3IQR$ equalities are taken as strong outlier data. In this equalities $Q_1$, $Q_3$ and IQR are first quartile, the third quartile, and interquartile range ($IQR = Q_3 - Q_1$), respectively (Garcia, 2012). This method is to show position, dispersion and skewness of data, which is frequently used to detect outlier data. Statically methods like Grubbs test, Grubbs and Beck test are basic methods to detect outlier of data. For this study Grubbs and Beck (G-B) test was used.

#### 3.5.1.1 Grubbs and Beck (G-B) test

This method is also another statically method to detect an outlier of data in stream flow record before estimating peak flood for any water related design. Quintiles bound not to be or to be outlier using G-B test method can be computed as equations 3.2 and 3.3.

$$X_H = \exp(\overline{X} + K_N.S) \quad \text{.......3.2}$$

$$X_L = \exp(\overline{X} - K_N.S) \quad \text{.......3.3}$$

$$K_N = -3.62201 + 6.28446N^{1/4} - 2.49835N^{1/4} + 0.491436N^{1/4} - 0.037911N^{1/4} \quad \text{.......3.4}$$

Where X and S are the mean and standard deviation of the natural logarithms of the sample, respectively, and $K_N$ is the G-B statistic tabulated for various sample sizes and significance levels by Grubbs and Beck at the 10% significance level. Sample values greater than $X_H$ are considered to be high outliers while those less than $X_L$ are considered to be low outliers.

### 3.5.3 Checking for Data Accuracy

The daily flow data collected from MoWIE for the study area was filled using regression analysis and extended for the shortage of data by using satisfactory correlation coefficient for the common data period of neighboring station. It is very important to check the data for consistency and homogeneity before using the data to frequency analysis for different design (Hamed, 1998). In flood frequency analysis both consistency and homogeneity are important parameters to be considered for data accuracy. Therefore, the consistency and homogeneity test was done by using the method of DMC and Mann-Whitney (1947) (M-W) test statically methods respectively.

#### 3.5.3.1 Consistency test

Inconsistency of the data that faced to hydrologists in any river and hydrologic system analysis are due to inefficiency of the missing data filling technique, due to fault of reader and change of recording material. The most widely used technique for evaluating a time series data record, such as rainfall or stream flow, for consistency is the double mass curve (Bras 1990). Double mass curve ware computed as cumulative of stations and targeted station and it is scatter plotted as shown in appendix Figure 1.

Table 3-2 Double mass curve fitting table for Bilate stream flow gauging station

| S. No | Station Name | Equation | $R^2$ |
|---|---|---|---|
| 1 | Bilate at Tena Bilate | $Y = 2.376X - 71.06$ | 0.988 |
| 2 | Bilate Near Alaba Kulito | $Y = 1.356X + 13.72$ | 0.974 |
| 2 | Weira Near Fonko | $Y = 0.859X + 0.886$ | 0.982 |
| 3 | Batena Near Hossana | $Y = 0.384X + 43.61$ | 0.954 |
| 4 | Ferfero Near Wulbarag | $Y = 0.478X - 4.608$ | 0.965 |
| Where X is cumulative of four and Y is cumulative of each | | | |

#### 3.5.3.2 Homogeneity test

For flood frequency analysis of …In this test two samples of size p and q with p is less than or equal to q are compared. The combined data set of size N = p + q is ranked in increasing order. The Mann-Whitney (1947) (M-W) test considers the quantities V and W in the following form (Hamed, 1998).

$$V = R - \frac{(p\,(p+1))}{2} \qquad (3.5)$$

$$w = pq - v \qquad (3.6)$$

where R is the sum of the ranks of the elements of the firs sample of size p in the combine series (size p), v represents the number of times an item in the sample 1 follows an item in the sample 2 in ranking. The hypothesis for this method is tested with the statically defined equation for significant level α.

$$u = (U - \overline{U})/(var(U)^{\frac{1}{2}}) \qquad (3.7)$$

Where U is the smaller of v and w, $\overline{U}$ is equals to $pq/2$ approximately and variance is given as:

$$\mathrm{var(U)} = \left[\frac{\mathrm{pq}}{\mathrm{N(N-1)}}\right]\left[\frac{\mathrm{N^3-N}}{12} - \sum \mathrm{T}\right] \quad \text{………………..……………………..……..…..3.8}$$

Where $\mathrm{T} = (\mathrm{J}^3 - \mathrm{J})/12$ , J the number of observation tied at a given rank of samples both in p and q.

### 3.5.4 Flood Frequency Analysis

Flooding is among the most threatening natural disasters in the world and its mitigation and management are pivotal for the design of enormous hydraulic structures, according to regulations administered by flood frequency analysis (Rizwan, Guo, Xiong and Yin, 2018). Flood frequency analysis which is one of the peak flow estimation method was used to analyze the flood plain in study river gauging station. There are many probability functions which represent random occurrence of variable to analyze flood frequency in river and river system. Here are some of the statically distribution functions which are graphically best fitted for the station are discussed.

#### 3.5.4.1 Pearson type III method

Pearson III distribution method is one of the three parameter gamma family distribution function to estimate peak flood occurrence in the watershed. Quantile estimation of these three parameter distribution function is given by the Equation 3.9.

$$X_T = \alpha\beta + \gamma K_T\sqrt{\alpha^2\beta} \quad \text{……………………………………………………….…..3.9}$$

Where α, β and γ are parameters and $K_T$ is frequency factor for the return period and computed by different imperial formulas based on the value of coefficient of skewness. For these case $C_s$ is greater than zero and Wilson-Hilferty transformation (Wilson and Hilferty 1931) equation was used.

$$K_T = \frac{2}{C_s}\left[\left\{\frac{C_s}{6}\left(u - \frac{C_s}{6}\right) + 1\right\}^3 - 1\right] \text{…………………………………………………..…3.10}$$

where $C_s > 0$ and u is standard normal variate.

#### 3.5.4.2 Gumbel’s method (distribution)

Gumbel statically distribution is the most widely used probability distribution function for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls and maximum wind speeds (Subramanya, 2008). For practical use in

Gumbel’s method the general equation of hydrologic frequency analysis for finite length records of data for finite N is given by:

$X_T = \overline{X} + K\sigma_{n-1}$ ……………………………...……………………………………..….3.11

Where, $\sigma_{n-1}$ is standard deviation sample of size, N is sample size and K is frequency factor.

$N = \sqrt{\frac{\sum(X-\overline{X})^2}{N-1}}$ ……...…………………………………..…………………………..3.12

$K = \frac{y_T - \overline{y}_n}{S_n}$ …....................................................................................................... 3.13

Where, $y_T$ is reduced variate as a function of T and given by the equation 2.5 as:

$y_T = -[\ln \ln \frac{T}{T-1}]$…………………………...…………………………….……..……......3.14

Where $\overline{y}_n$ is reduced mean as function of N and $S_n$ is a reduced standard deviation as function of N.

### 3.5.4.3 Log Pearson III method (distribution)

This distribution is extensively used in USA for projects sponsored by the US governments (Subramanya, 2008). In this distribution method first variate X is converted to log 10 and the transformed data is analyzed. For X variate random hydrologic series Z variate series is given by:

$Z = \log X$ ……………………………………………….………..…….…………3.15

Then reduced Z series $Z_T = \overline{Z} + K_Z\sigma_Z$ ........................................................................3.16

Where $K_Z$ is frequency factor as function of T and coefficient of skew of variate Z, $C_s$ and Standard deviation of variate Z, $\overline{Z}$ is means of Z value, N is sample size or number of records year of data

$\sigma_Z = \sqrt{\frac{\sum(Z-\overline{Z})^2}{N-1}}$……………………………………………….…...………..…....3.17

Coefficient of skew of variate Z, $C_s = \frac{N(\sum(Z-\overline{Z})^3}{(N-1)(N-2)(\sigma_Z)^3}$ …………………...………..…....3.18

$K_Z$ is found from $f(C_s, T)$ from table or given by computation equation and after computing $Z_T$, $X_T$ can be computed as $X_T$ equals to an $\text{ant}\log\ (Z_T)$.

### 3.5.4.4 Log Normal method (distribution)

when the skew is zero that means Cs is zero the Log –Person Type III distribution is reduced to Lognormal distribution (Subramanya, 2008). In this method all the procedures flow the Log-Person Type III distribution for zero skewness.

### 3.5.4.5 Exponential distributions

Exponential distribution is one of the spatial form of gamma family which include three parameter Pearson and log Pearson, one and two parameter gamma and generalized gamma distribution (Hamed, 1998).

$X_T= \varepsilon+\alpha+\alpha*K_T$……………………………………..….……………………………3.19

Where KT is frequency factor giver by $K_T= \log_{(T)} -1$, ε and α are parameters estimated by methods of parameter estimation.

### 3.5.4.6 Gamma (2p) distribution

This distribution is also an other special form of Pearson (3) distribution with ε is equals to zero and its quantile of T-year is given by

$X_T=\alpha\beta+ K_T\sqrt{\alpha\beta}$ …………………………………...……………...……..…..……..3.20

Where α and β are parameters and $K_T$ is frequency factor computed by different empirical formulas based on coefficient of skewness (Hamed, 1998).

### 3.5.4.7 Generalized extreme value

GEV is also another form of distribution method which is depends up on the sing of parameters when k in distribution function is negative it is reduced to GEV (2) and suitable for bounded parameters. T-year flood is given by the equation as follows:

$X_T= u+ \frac{\alpha}{k} [1-\{-\log(1- \frac{1}{T})\}\hat{}k]$ ……………………….……………………………..…3.21

Where u, α and k are parameters commuted by parameter estimation methods.

### 3.5.4.8 Best fit selection numerically and graphically

Fitting of distribution function for a given watershed or station must be done through both graphically and analytically for best result. Graphically like L-Moment ratio and MRD and analytically D-index, RMS and CC was used for commonly used functions to identify best fit distribution function for the catchment. Side to side parameter estimation was done for graphically selected best distribution methods during analytical solution using parameter estimation methods like MOM, PWM and MLM which are mostly applicable methods in flood frequency analysis. Here for this study L-moments was used.

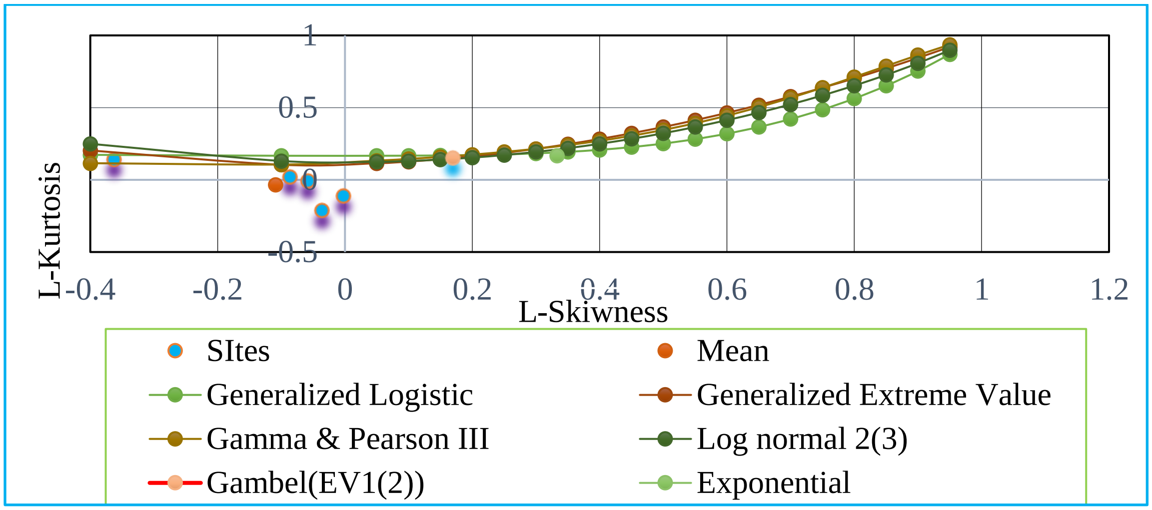



Figure 3.8 Graphical Methods to Select Best Fit Parent Distribution

Based on L-moment diagram Pearson type three distribution function is best fitted because the site moments and site mean are migrating around it. But is impossible for different engineers come up with similar distribution function by a simple visualization of graph reading. Therefore, supporting by some numerical results should be mandatory to be real. In this study analytically using D-index, RMSE and CC methods and three of mostly used parameter estimation methods are used to select best fitted statically distribution function for stream flow data of Bilate near Tena Bilate gauging station.

### 3.5.4.9 D-Index method

D-Index Method this method for the comparison of upper limit of the data is given as;

D-Index = $\frac{1}{\bar{X}} * \sum |X_i - \bar{X}_i|$ ……………...……………………..……………..…………………3.22

Where $X_i$ and $\bar{X}_i$ are the highest observed and simulated value for the distributions and smallest value is taken as best fit distribution. D-Index method was computed following the steps 1) selecting six highest values from both observed and calculated data 2) ranking from 1 to 6 highest to least order 3) computing probability here p is given by m/(N+1), N as data record length and m as a rank order 4) computing corresponding z value 5) calculating $X_T$ value 6) computing absolute value of the deference of observed and calculated data 7) finally compute D-Index. The distribution having the least D-index is identified as the better suited distribution for estimation of probable maximum flood (USWRC, 1981).

### 3.5.2.10 Correlation coefficient

Correlation coefficient ($R^2$) is also another analytical method to judge distribution function is best fitted, if it has largest value. Method was accomplishing by scatter plotting of observed data vs computed data by different graphically selected and commonly used distribution functions.

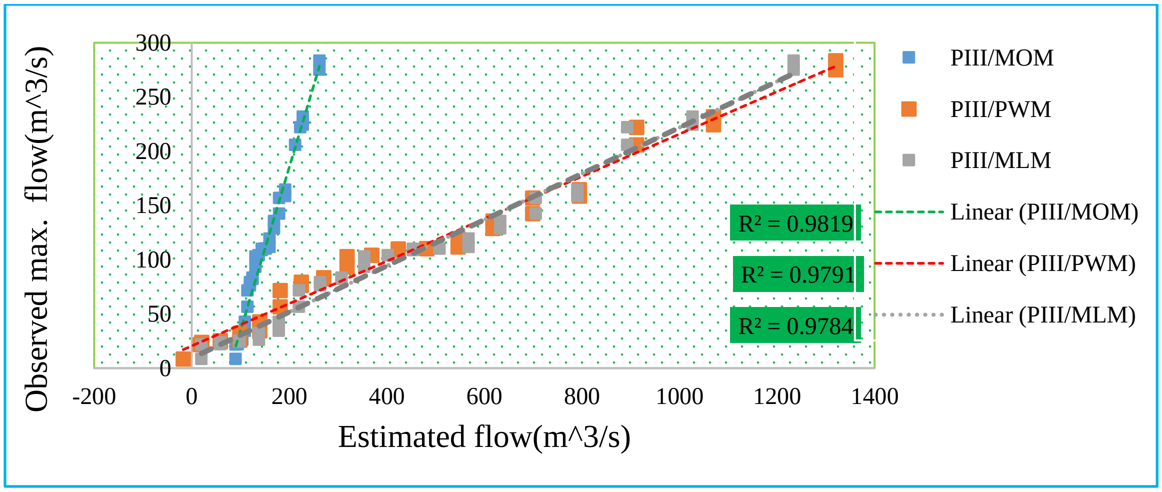



Figure 3.9 Scatter Plot of Estimated Vs Observed Flow at Study Station

### 3.5.2.11 Root mean square error method

Root mean square method is another analytical best fit selection method which is widely directed for the use of probability distribution identifications for the station. Here this method was applied in the study of frequency analysis. The equation is given by:

$$\text{RMSE} = \left(\frac{\sum \mathbf{Q_{oi}-Q_{mi}}}{\mathbf{N-m}}\right)^{\mathbf{1/2}} \quad \text{.......................................................................3.23}$$

Where $Q_{oi}$ is observed data, $Q_{mi}$ estimated flow, N is number of record year and n is the number of parameter for distribution used.

## 3.6 Flood Plain Analysis

Spatial data preparation for flood plain analysis and flood plain analysis after steady state flow simulation was carried out using GIS10.4.1 in this study. Powerful hydraulic model for river analysis HEC-RAS 5.0.1 was also used to calculate water surface profiles of the Bilate river flood plain. Hydraulic Engineering Center Geographic River Analysis System version13.1 which is one of the extension tools of GIS was used to circuit between HEC-RAS and ArcGIS. These model software's and tools were used in this study why because they are most worldwide applicable in river flood plain analysis and data processing, very accurate in 1D flood plain analysis and freely available.

### 3.6.1 Flood Plain Analysis Procedure

The general method adopted for flood plain analysis and hazard assessment in this study was basically shown in work flow diagram of 1D hydraulic river flood plain analysis above. Here the detail of these like watershed delineation, Preparation of TIN, LULC and soil Map on GIS tool, GeoRAS Pre-processing to generate HEC-RAS import file, Running of HEC-RAS to calculate water surface profiles, Post-processing of HEC-RAS results and floodplain mapping and hazard and assessment discussed.

#### 3.6.1.1 Watershed delineation

Delineating study area is the first thing to be done in watershed related research. The study watershed Bilate was delineated from DEM 30m resolution using GIS. Procedural steps have been done for any watershed research area delineation are fill, flow direction, flow accumulation, map calculation, flow sink, stream order, stream to feature create, snapping outlet point, watershed creating, conversion to polygon and clipping polygon in progressive order.

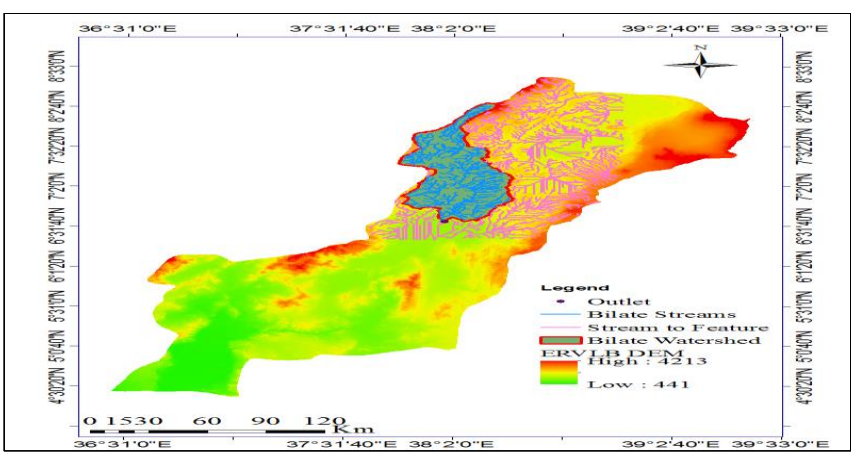



Figure 3.10 Delineated Watershed of Research Area

#### 3.6.1.2 LULC Map Preparation

LULC map of the Bilate watershed was developed and reclassified from LULC map of Ethiopia collected from MoWIE which have 9 classes with use verification. This activity was accomplished by clipping the Ethiopian LULC map by the watershed polygon developed in section 3.6.1.1 above. From these output topo-sheet map each occupied by reclassifying LULC of total watershed 5356.763 km2 area were tabulated in Table 3-3 below.

Table 3-3 LULC share for each type in study area

| Name | Area($km^2$) | % Each |
|---|---|---|
| Crop Plantation | 73.998 | 1.381 |
| Cultivation | 1335.816 | 24.94 |
| Forest | 1049.022 | 19.58 |
| Grass Land | 147.8328 | 2.76 |
| Shrub Land | 2492.308 | 46.53 |
| State Farms | 74.4942 | 1.391 |
| Swamps | 68.17936 | 1.273 |
| Woodland | 111.9478 | 2.09 |
| Water Body | 3.16497 | 0.059 |
| Total | 5356.763 | 100 |

#### 3.6.1.3 Manning's coefficient

In the hydraulics of HEC-RAS flood model Manning's n value have great role to determine the flow property. Based on the land use land cover table creation the GeoRAS environment Manning's value for each cross section was entered. According's to the (Chow, 1959) Manning value n for different land use was prepared as 0.035 for crop plantation area, state farm and grass land , 0.1 for forest land , 0.05 for shrub land, 0.04 for swamp and water body and 0.07 for wood land.

#### 3.6.1.4 Preparation of TIN

TIN which is the back bone for river flood analysis was pre-processed for HEC-RAS Model using DEM 30m*30m resolution for this study. It shows best specific river bed and banks which is very important parameters are in flood plain hydraulics. There are different tools to generate TIN like GIS and RAS Mapper. Here for this thesis GIS was used as a tool to create TIN Passing the steps:  GIS new project, add DEM to GIS window, go to Arc Toolbox, 3D analysis tool, Conversion, raster to TIN, call DEM to raster to TIN menu then output was delivered.

#### 3.6.1.5  Geo-RAS pre-processing

All the RAS import files are pre-processed on the GeoRAS before the start of RAS analysis for river system. The basic river layer parameters like stream centerline, Bank lines, XS Cutline and flow path centerline was prepared from TIN of the Watershed. These step was done based on as per criteria of the USACE manual.

### 3.6.2  HEC-RAS Processing

Hydraulic Engineering Center River analysis system (HEC-RAS) model is very powerful model for flood inundation mapping with interconnection to GIS tools has procedural steps to simulate flow analysis. These are setting up new project, importing geometric file, editing geometric data, inputting flow data, setting boundary conditions and running steady flow data analysis. Finally, the processed data was exported to GIS tool for post processing as form of SDF file format.

#### 3.6.2.1  HEC-RAS project setup and geometric data importing

HEC-RAS model was setup before importing RAS import file as creating new project, saving in folder and converting the measurement system US customary units to SI units for this research work. Once the projected sated up the next step was importing geometric data which was prepared on HEC-GeoRAS. To import file going to View/edit geometric data on HEC-RAS menu, import geometry file, select folder then the data has been imported as a GIS data format.

Both GIS and its extension HEC-GeoRAS tools were effectively used to create RAS import file as GIS data. TIN was extracted from DEM raster and XS data was pre-processed passing challenging steps of HEC-GeoRAS.

#### 3.6.2.2 Editing geometric data

After import of geometric data to edit the following steps was done; going to tools XS points were filtered for all reaches, going to table manning's n value was interred and LOB, ROB, reach lengths was edited. contraction and expansion coefficient was sated by the model itself.

#### 3.6.2.3 Flow data imputing and steady flow analysis

Finally, Stream flow data computed using Pearson(III) statically distribution method for return periods of 5,10,50,100,200Yrs was interred. Then selecting normal depth boundary condition of slope 0.001 and 0.003 from downstream to upstream respectively which was average computed from both ends of ground profile of study area. Finally, the steady flow analysis was carried out successfully as shown in appendix Figure 3.

### 3.6.3 Post-RAS Processing

These stage started after the successful simulation of steady flow in HEC-RAS and exported as RASexport SDF file. Then post-RAS was analyzed by steps like changing SDF file to XML file, RAS Mapping menu, layer setup, import RAS data and inundation mapping. SDF file was converted by calling the converter in RAS mapping tool then going to folder that RASexport file exist and adding it changes the data to XML file which is familiar on GIS environment. RAS map was set for steady flow analysis in this study by creating folder, adding RASexport file, adding TIN, setting cell size 20 as it was and running the tool accomplished. Then post RAS was done for water surface generation and inundation mapping using raster as show in appendix Figure 8.

## 3.7 Flood Hazard Assessment and Mapping

Flood hazard was assessed based on the depth grids that was generated during flood plain map delineation using raster with intersection of land use land cover map clipped by depth grid bound polygon. The hazard aspects of flood are related to hydraulic(depth, velocity, slope, boundary condition and elevation) and the hydrological parameters(stream flow or rain fall) (Glard, 1996). As magnitude of flood increases the depth increase, then the study was done reclassifying the depth grids in to six depth level in hazard map indicating very low to sever level.

After the reclassification of the depth grid it was intersected with land use land cover and finally the resulted attribute table in GIS environment was assessed for hazard level. Hazard maps for selected return periods was done by reclassifying the depth grid raster as rang of less than one is very low, one to one and half is low, one and half to two moderate, two to two and half is high, two and half to three is very high and more than three is sever flood magnitude.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Flood Frequency Analysis

### 4.1.1 Determination of Stream Flow Accuracy

Using G-B test the higher quantile and lower quantile was 727.38 $m^3$/s and 8.334 $m^3$/s respectively, which is highly outlier for the station with maximum and minimum of the yearly maximum discharge 283.5$m^3$/s and 8.539$m^3$/s respectively. That mean the station stream flow data was not have an outlier data during the record or missing data filling time.

Double mass curve analysis was done for five stream flow gauging stations and the cumulative of average yearly stream flow for selected station verses accumulated average of the other four station was drown on excel as scatter plot. As the result shown in in appendix Figure1 and Table3.2 there are no significant slop drop on the data and therefore there is no need of adjustments. These result indicates that the method of missing data and the recorded data was accurate enough for flood frequency analysis.

Homogeneity and stationarity test value for stream flow for this study in Bilate gauging station using Manny-Whitney was u = 1.28 which is less than critical value $u_{0.025}$ = 1.96 at 5% significance and homogeneity was accepted. Therefor the stream flow data used for this study in Bilate at Tena Bilate station was acceptable.

### 4.1.2 Determination of Peak Flood

Determination of peak flood for 5, 10, 50, 100 and 200Yrs was achieved by using statistical methods of best fitted probability functions numerically and. To select the best fit statistical model graphical and numerical methods were used. Graphical analysis was done for some worldwide recommended probability distributions and six of best fitted distribution functions were analytically solved for best of best. As the result shown in Table 4.1, 4.2 and 4.3 Pearson Type III is the appropriate method to estimate peak flood magnitude in Bilate watershed of Bilate at Tena Bilate gauging station for this study. The estimated peak floods were tabulated in the Table 4-4 below.

Table 4-1 Correlation coefficient for best fit selection

| | Method of Parameter estimation | | | | |
|---|---|---|---|---|---|
| Distribution Type | MOM | PWM | MLM | Max | Remark(Selected) |
| PIII(3P) | **0.9819** | 0.9791 | 0.9784 | **0.9819** | MOM |
| EXP(2P) | 0.9546 | 0.6773 | 0.6773 | 0.9546 | MOM |
| EV1(Gumbel) | 0.7334 | 0.9711 | 0.7334 | 0.9711 | PWM |
| LN(3P) | 0.8845 | 0.9776 | 0.9812 | 0.9812 | MLM |
| Gamma(2P) | 0.9772 | 0.9738 | N/A | 0.9772 | MOM |
| GEV3(3P) | 0.9546 | 0.9546 | 0.9073 | 0.9546 | PWM |
| | | | Grand Max. | **0.9819** | Take: PIII/MOM |

Table 4-2 RMS method of best fit estimate

| | | Method of Parameter/Quantile Estimation | | | |
|---|---|---|---|---|---|
| S. No | Name of Distributions | MOM | PWM | MLM | Max. of Min. Count |
| 1 | PIII(3P) | **30** | 0 | 8 | 30 |
| 2 | EXP(2P) | 19 | 19 | 0 | 19 |
| 3 | EV1(Gumbel) | 23 | 9 | 6 | 23 |
| 4 | LN(3P) | 1 | 16 | 21 | 21 |
| 5 | Gamma(2P) | 28 | 10 | 0 | 28 |
| 6 | GEV3(3P) | 20 | 18 | 0 | 20 |
| | | | | Grand Max. Take: PIII/MOM | **30** |

Table 4-3 D-Index Methods

| | Method Of Parameter Estimation | | | | |
|---|---|---|---|---|---|
| Distribution Type | MOM | PWM | MLM | Min. | Remark(Selected) |
| PIII(3P) | **1.532** | 2.379 | 1.674 | **1.532** | MOM |
| EXP(2P) | 6.326 | 7.283 | 6.155 | 6.155 | MLM |
| EV1(Gumbel) | 10.5 | 8.455 | 8.885 | 8.455 | PWM |
| LN(3P) | 6.462 | 9.354 | 6.08 | 6.08 | MLM |
| Gamma(2P) | 1.708 | 2.862 | N/A | 1.708 | MOM |
| GEV3(3P) | 2.043 | 10.95 | 7.872 | 2.043 | MOM |
| | | | Grand Min. | **1.532** | Take: PIII/MOM |

Table 4-4 Peak discharge for different return period at Bilate at Tena Bilate station

| α = 27.8834 | β= 6.8136 | γ = -81.6376 |
|---|---|---|
| T | $K_T$ | $Q_T\,(m^3/s)$ |
| 5 | 0.61623 | 153.2 |
| 10 | 1.16515 | 193.2 |
| 50 | 2.27075 | 273.6 |
| 100 | 2.70612 | 305.3 |
| 200 | 3.126 | 335.9 |

These results indicate that severity of flood magnitude increases from year to year of return period. These peak flood discharge increase is due to the increase in return period which can receive different flood causative agent like LULCC, urbanization, soil degradation and elevation changes.

## 4.2 Preparation of TIN

TIN which is the back bone for river flood analysis was pre-processed for HEC-RAS Model using DEM 30m*30m resolution for this study. It shows best specific river bed and banks which is very important parameters are in flood plain hydraulics. TIN was reclassified in to nine class from peak elevation 3331m to lowest elevation 1153m above mean sea level.

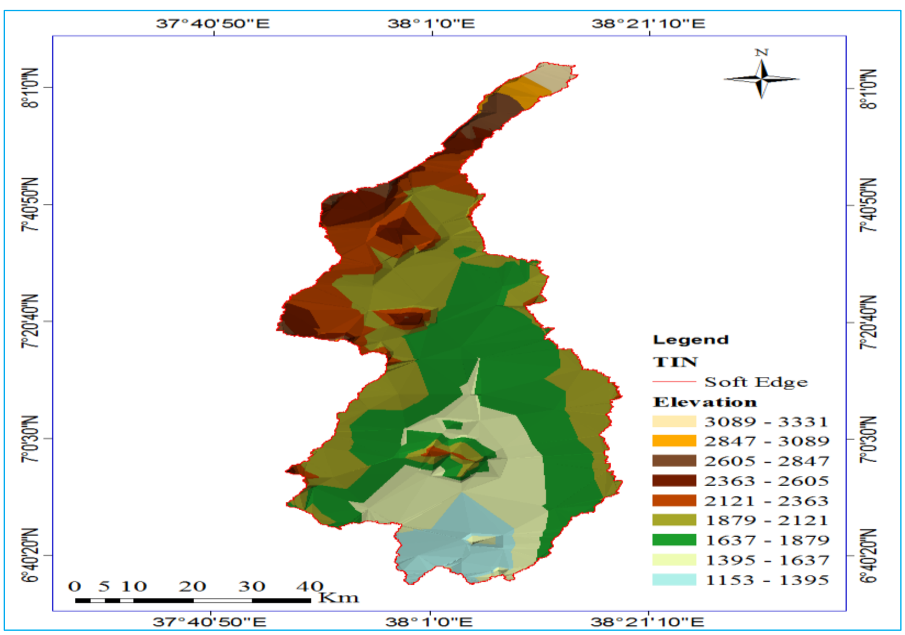



Figure 4.1 TIN of Bilate

## 4.3 HEC-RAS pre-processing

### 4.3.1 Stream centerline layer

Stream centerline which is one of the required RAS layer was created on GeoRAS geometry processing menu. The stream network was created on reach basis starting from upper reach to lower reach and represents the river and reach network of Bilate River. Stream center line is used to assign river stations to XS and imported in HEC-RAS as schematic to define main channel flow path.

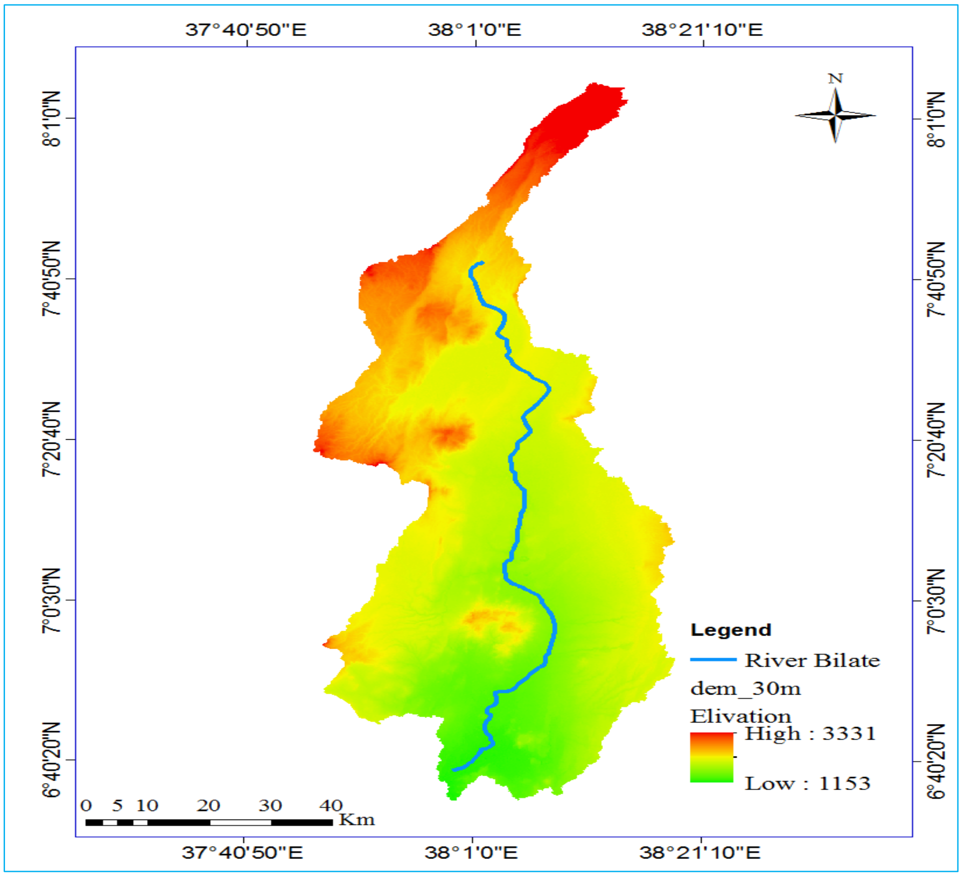



Figure 4.2 Stream Center Line

### 4.3.2 Bank lines layer

The bank lines are optional RAS layer that differentiates the main channel flow from two overbank flows. Stations of the bank were assigned to each XS based on the intersection of bank lines with cut lines. The two bank lines are exactly intersected with each cut lines and drown from upstream to downstream in this study.

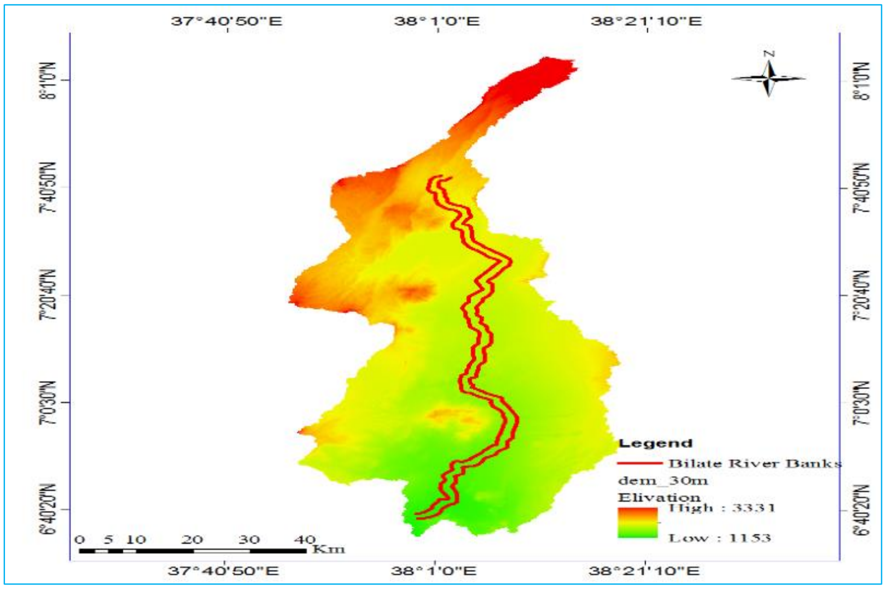



Figure 4.3 River Bank Line

### 4.3.3 Flow path centerlines layer

The flow path center lines layer are RAS layers used to identify the hydraulic flow path in the left over bank, main channel and right over bank by identifying the center mass of flow in each region. Creating the flow path center lines assists in proper laying out the X-sectional cut lines. The path center lines were drawn in the direction of flow that means upstream to downstream in this study.

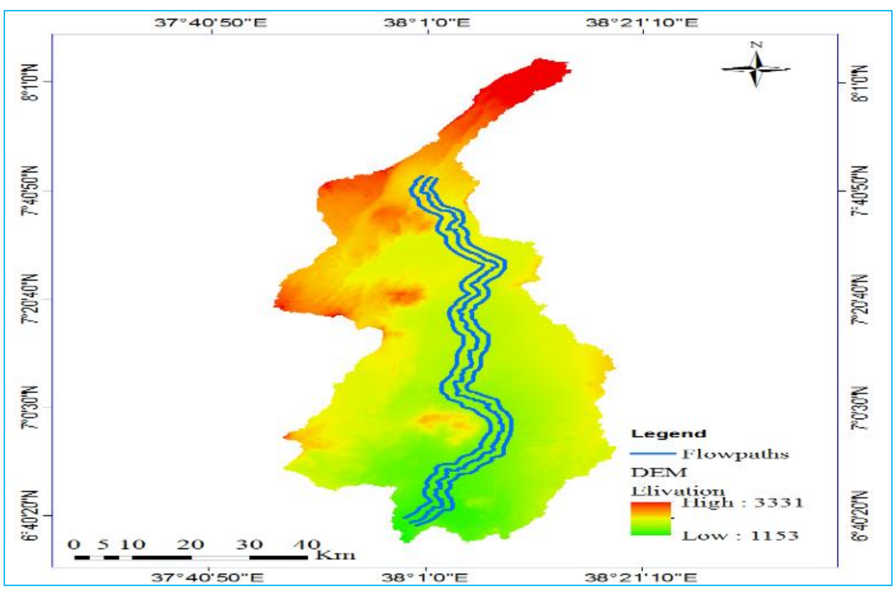



Figure 4.4 Flow Path Line

### 4.3.4 Cross section cut lines layer

Cross section cut lines are another required RAS layer which was drowns in perpendicular direction of flow from left overbank to right overbank when looking to downstream. Cut lines of this study represent location, position and extents of XS of the Bilate River.

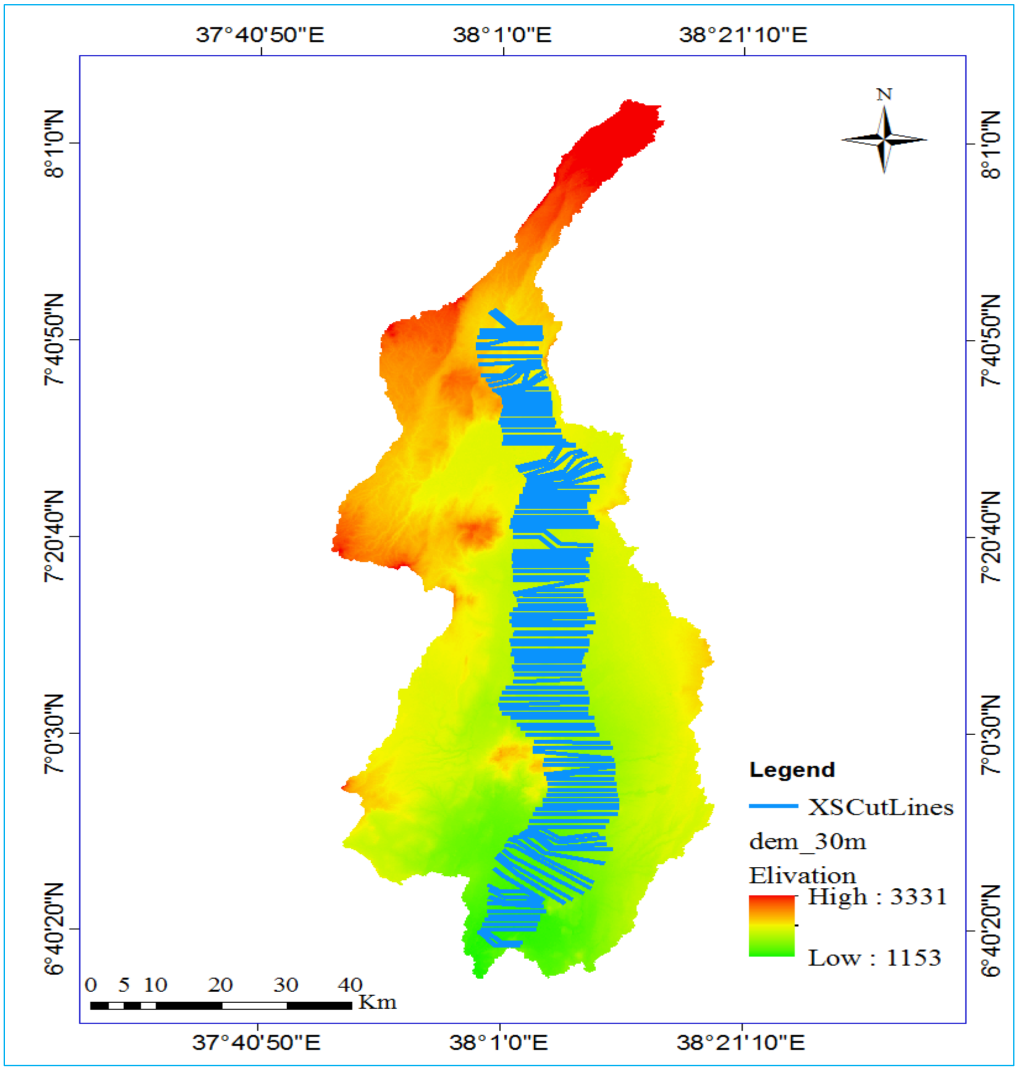



Figure 4.5 Cross Section Cut Line

### 4.3.5 RAS-Import File

Geometric data which is basic impute for steady flow simulation was prepared on Geo-RAS tool. This data was imported to HEC-RAS and edited for best results in simulation of steady flow. In this research four basic RAS-layers was added on HEC-GeoRAS tool and processed to results the geometric data as given in Figure 4.6 below.

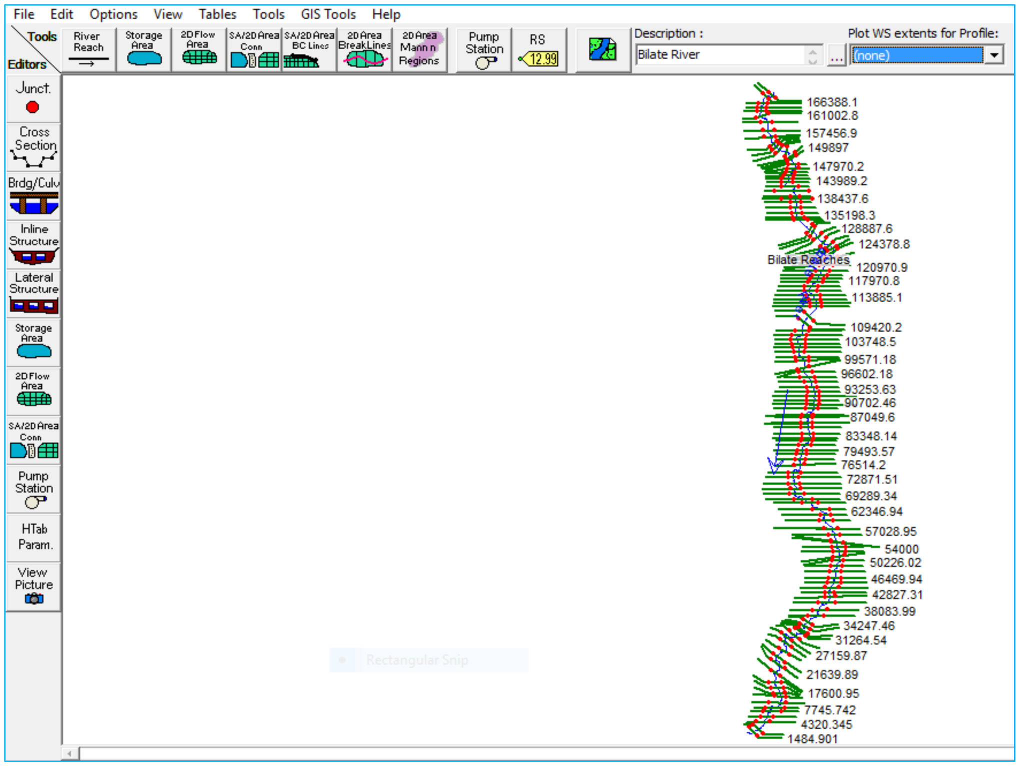
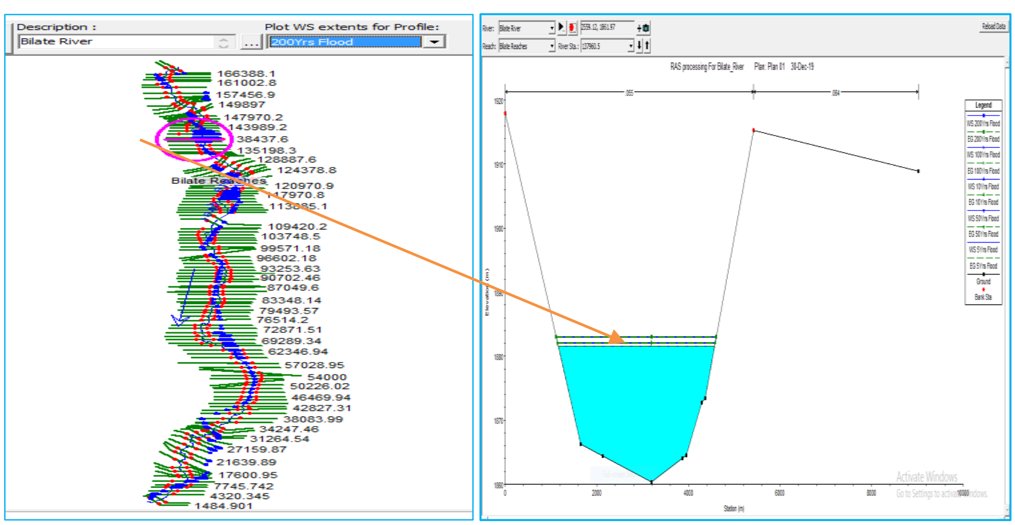



Figure 4.6 RAS Import Geometry File from HEC-RAS Menu for 200 Yrs Return Period.

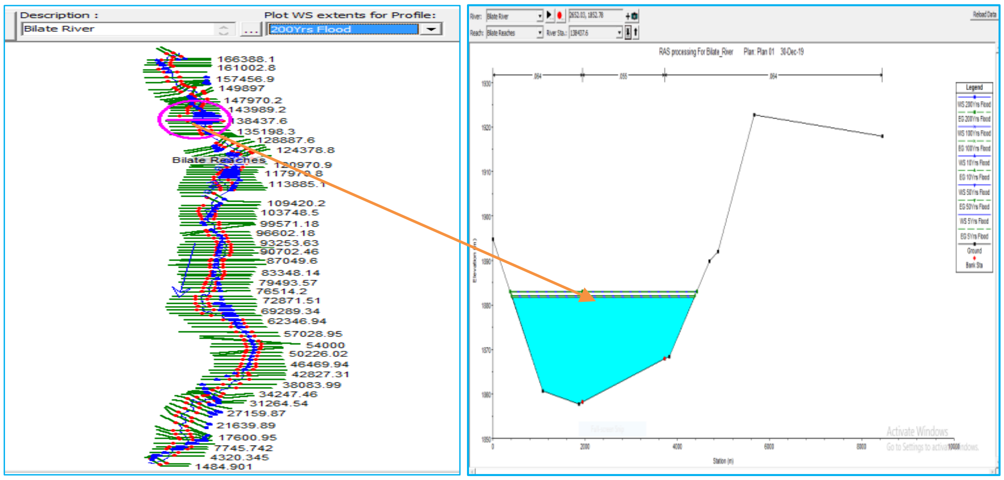
## 4.4 Steady Flow Simulation

Using geometric data and peak flood resulted from flood frequency analysis, steady state flow was simulated successively. Water surface profile at different stations as a sample for a peak flood discharge of return period 200 Yrs was drawn as shown below Figure 4.7.

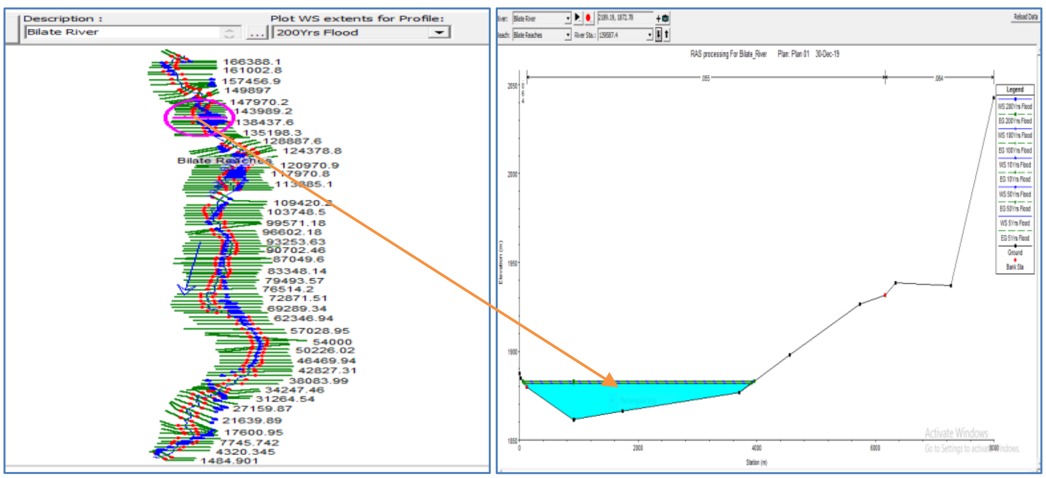
A.



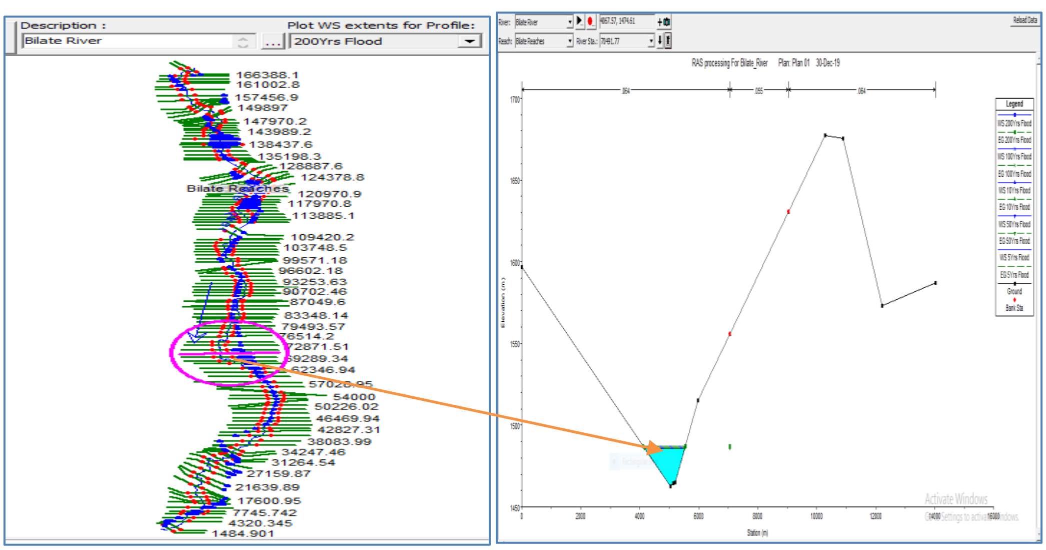
B.


Description :
Bilate River
Plot WS extents for Profile:
200Yrs Flood
166388.1
161002.8
157456.9
149897
147970.2
143989.2
38437.6
135198.3
128887.6
124378.8
Bilate Reaches
120970.9
117970.8
113885.1
109420.2
103748.5
99571.18
96602.18
93253.63
90702.46
87049.6
83348.14
79493.57
76514.2
72871.51
69289.34
62346.94
57028.95
54000
50226.02
46469.94
42827.31
38083.99
34247.46
31264.54
27159.87
21639.89
17600.95
7745.742
4320.345
1484.901
RAS processing For Bilate_River Plan: Plan 01 30-Dec-19

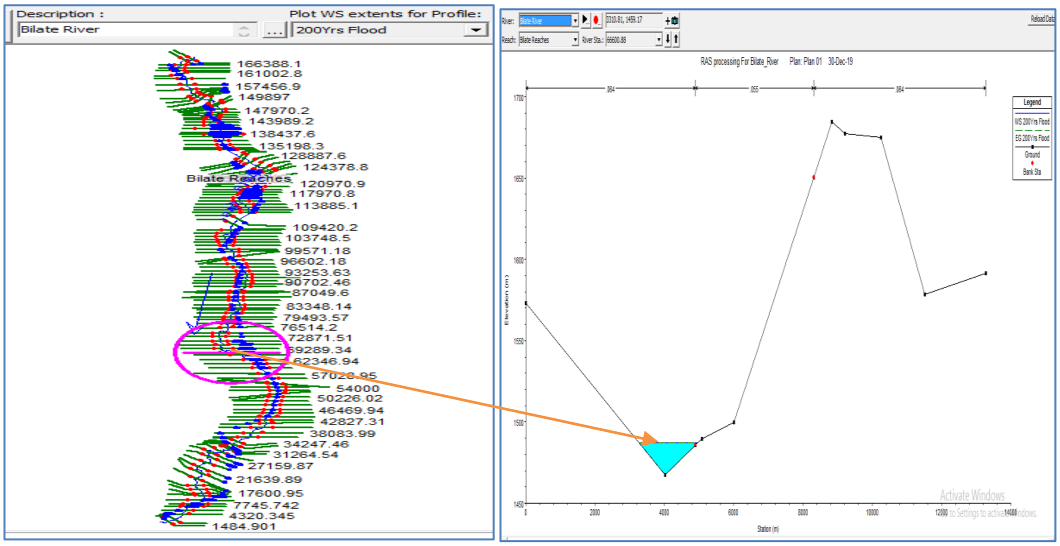
C.


Description :
Bilate River
Plot WS extents for Profile:
200Yrs Flood
166388.1
161002.8
157456.9
149897
147970.2
143989.2
138437.6
135198.3
128887.6
124378.8
Bilate Reaches
120970.9
117970.8
113885.1
109420.2
103748.5
99571.18
96602.18
93253.63
90702.46
87049.6
83348.14
79493.57
76514.2
72871.51
69289.34
62346.94
57028.95
54000
50226.02
46469.94
42827.31
38083.99
34247.46
31264.54
27159.87
21639.89
17600.95
7745.742
4320.345
1484.901
RAS processing For Bilate_River Plan: Plan 01 30-Dec-19

D.


Description :
Bilate River
Plot WS extents for Profile:
200Yrs Flood
166388.1
161002.8
157456.9
149897
147970.2
143989.2
138437.6
135198.3
128887.6
124378.8
Bilate Reaches
120970.9
117970.8
113885.1
109420.2
103748.5
99571.18
96602.18
93253.63
90702.46
87049.6
83348.14
79493.57
76514.2
72871.51
69289.34
62346.94
57028.95
54000
50226.02
46469.94
42827.31
38083.99
34247.46
31264.54
27159.87
21639.89
17600.95
7745.742
4320.345
1484.901
RAS processing For Bilate_River Plan: Plan 01 30-Dec-19

E.




F.

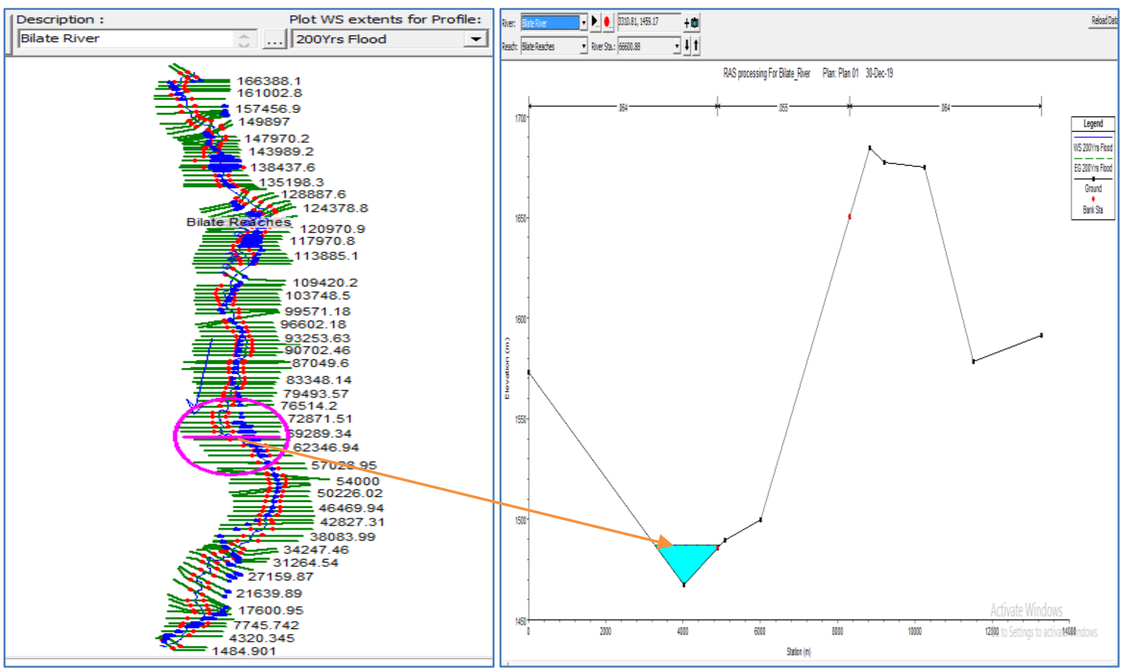



Figure 4.7 A - F Showing Different Water Surface Profiles Simulated on HEC-RAS

The steady flow simulated from HEC-RAS analysis for Bilate watershed at different sections was delineated for a given boundary conditions. Among these water surfaces the most severe than other water surface level in the river cross section are also tabulated as Table 4-5 below. Station 138437.6 receives the deepest level in all return periods with slight increase obviously due to increase in flood discharge cavers large area and depth.

Table 4-5 Maximum water level at most severe stations

| Stations | Return Period | Max. water level |
|---|---|---|
| 138437.6 | 5 | 23.90 |
| | 10 | 24.43 |
| | 50 | 24.27 |
| | 100 | 25.23 |
| | 200 | 25.41 |
| 70491.77 | 5 | 23.32 |
| | 10 | 23.72 |
| | 50 | 23.52 |
| | 100 | 24.65 |
| | 200 | 24.87 |
| 137960.5 | 5 | 21.27 |
| | 10 | 21.80 |
| | 50 | 21.64 |
| | 100 | 22.60 |
| | 200 | 22.78 |
| 69289.34 | 5 | 20.82 |
| | 10 | 21.22 |
| | 50 | 21.03 |
| | 100 | 22.16 |
| | 200 | 22.37 |
| 139587 | 5 | 20.54 |
| | 10 | 21.07 |
| | 50 | 20.91 |
| | 100 | 21.87 |
| | 200 | 22.05 |
| 66600.88 | 5 | 18.35 |
| | 10 | 18.72 |
| | 50 | 18.35 |
| | 100 | 19.66 |
| | 200 | 19.87 |

## 4.5 Post-RAS Analysis

### 4.5.1 Water Surface TIN

TIN with big profile that means "t200" for this study was generated for all other water surface profiles based on elevations of waster surface at each XS and bounding polygon extracted during importing RASexport file. For Bilate river flood inundation mapping enough water surface TIN was generated because it covers the outside of area possibly.

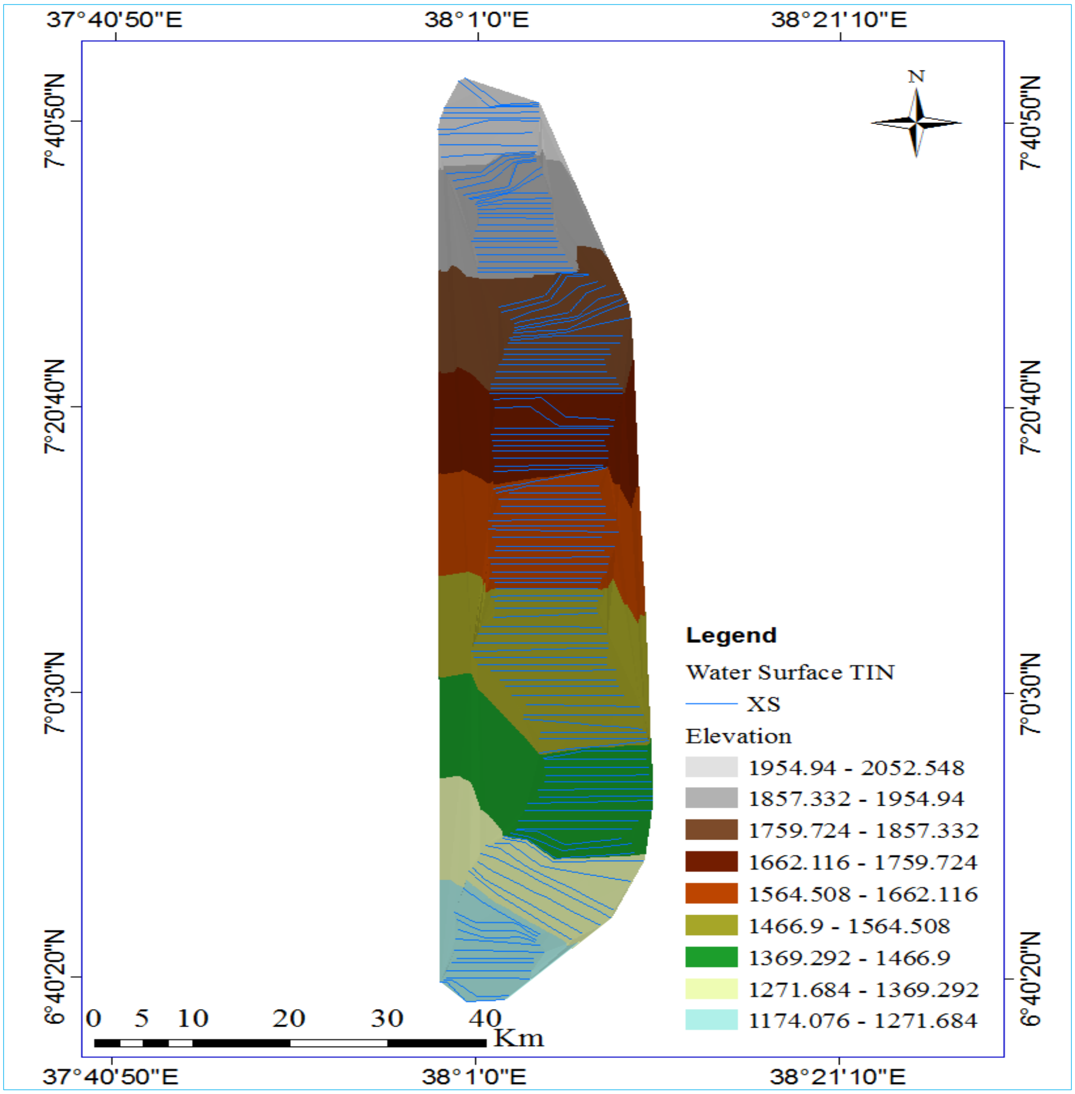



Figure 4.8 Water Surface TIN Generated

### 4.5.2 Flood Inundation

After the steady flow analysis in HEC-RAS for different discharges of respective return period, inundation in study area was delineated using GIS extension tool HEC-GeoRAS as raster. Then area inundated was computed from bounding polygons of these raster for return period of peak discharge and the result is tabulated in next Table 4-5. Inundation map for each return period was overlapped on bounding polygon of post-RAS processing for more visualization as shown in Figure 4.4 to 4.8 below.

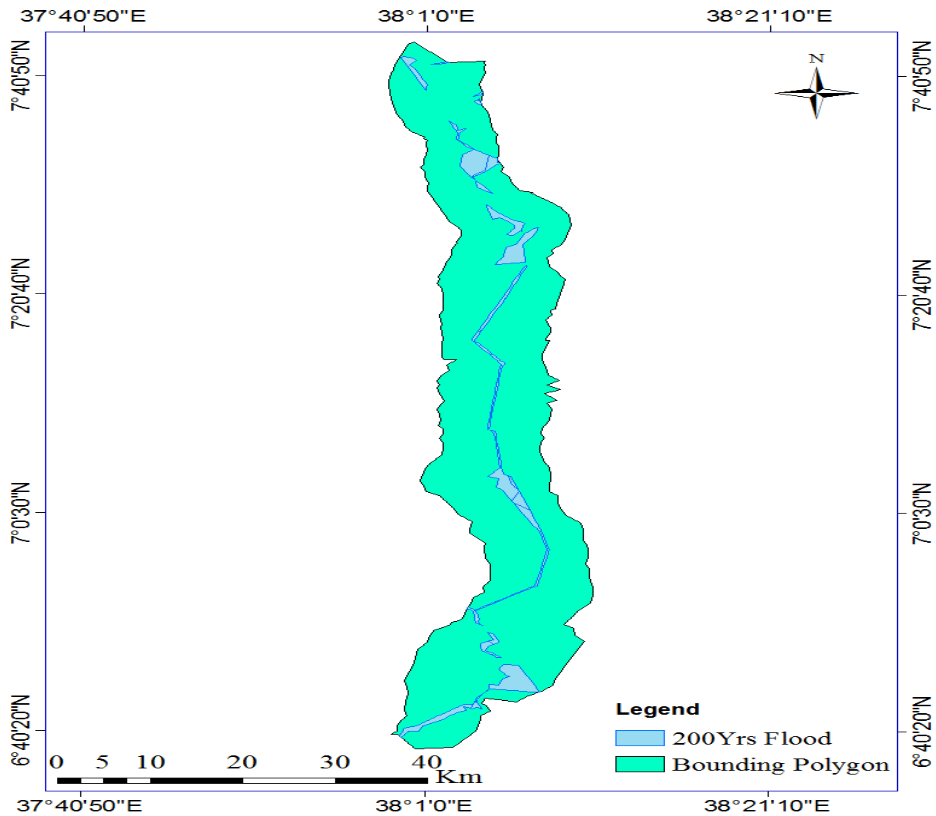



Figure 4.9 Flood Inundation Map For 200 Yrs Return Period

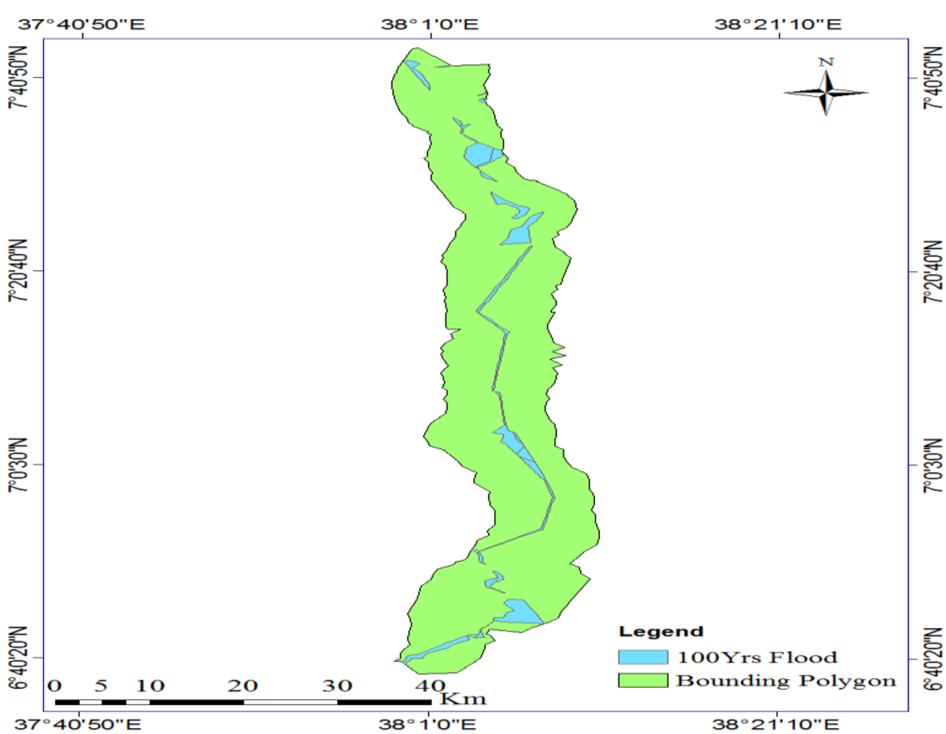



Figure 4.10 Flood Inundation Map for 100 Yrs Return Period

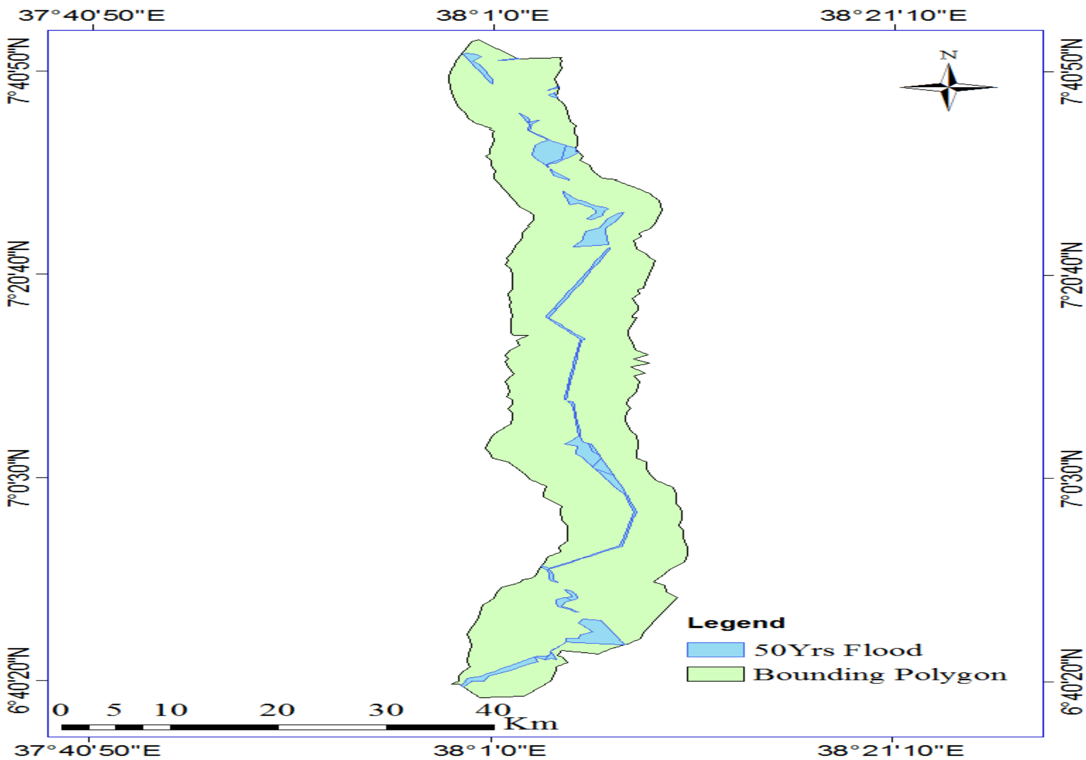



Figure 4.11 Flood Inundation Map for 50 Yrs Return Period

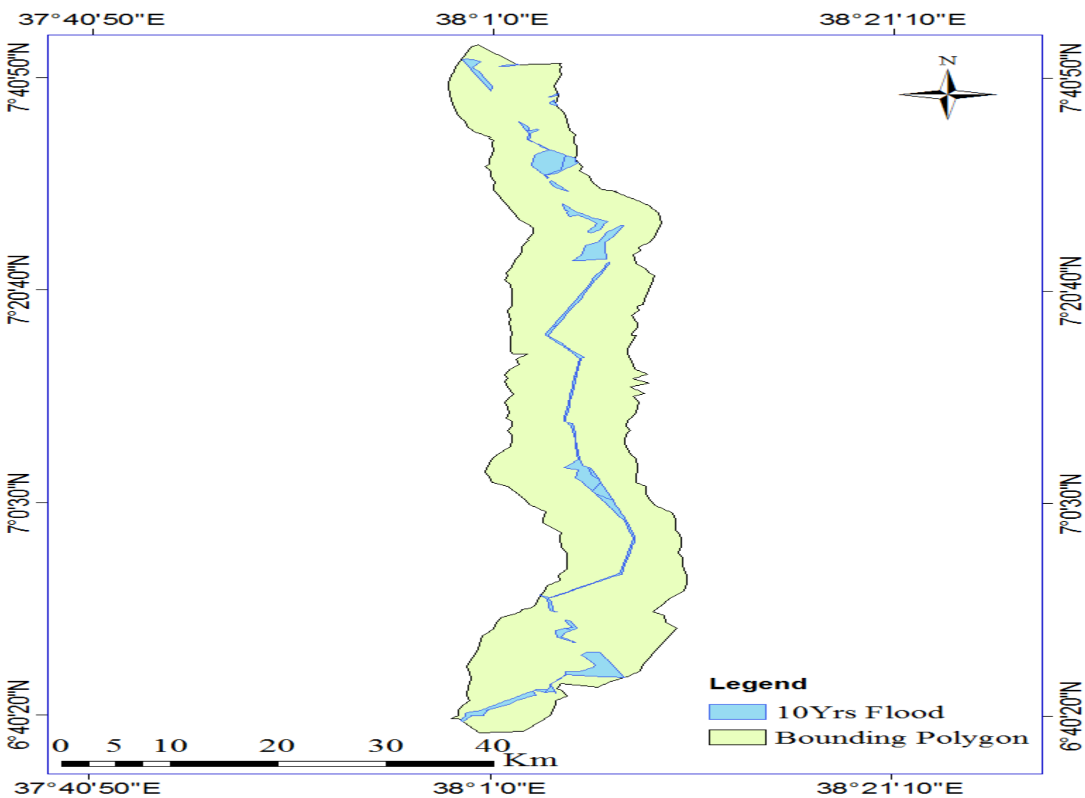



Figure 4.12 Flood Inundation Map for 10 Yrs Return Period

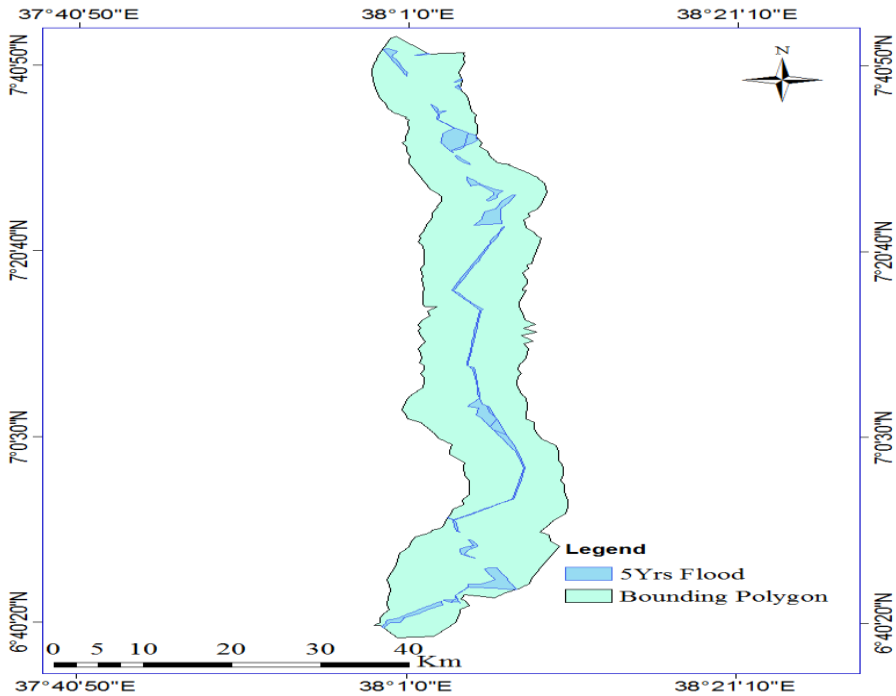



Figure 4.13 Flood Inundation Map for 5 Yrs Return Period

Table 4-6 Flood inundation at different return period

| Return period | Peak discharge(m^3/s) | Area(ha) | % per Catchment |
|---|---|---|---|
| 5 | 153.199 | 6840.244 | 1.3 |
| 10 | 193.152 | 7284 | 1.4 |
| 50 | 273.621 | 8029.13 | 1.5 |
| 100 | 305.31 | 8270.031 | 1.55 |
| 200 | 335.87 | 8463 | 1.6 |

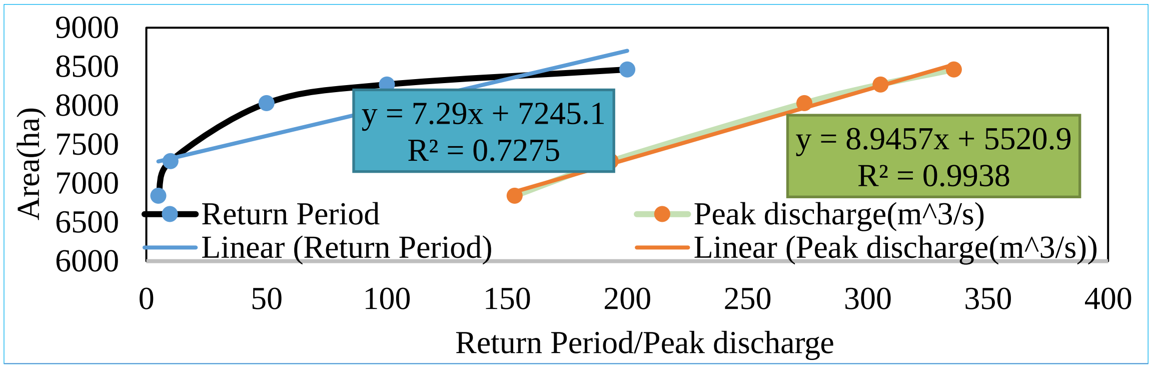



Figure 4.14 Area Vs Return Period/Peak Discharge Relationship

Both from the Figure 4.9 and Table 4-5 above we observe that inundated area delineated using the model for different return period discharge was increase slightly due to increase in flood magnitude and return period.

### 4.5.2 Flood Hazard Mapping and Analysis

Flood hazard maps was prepared for return periods of 5,10,50,100 and 200Yrs by overlapping the water surface grid depth generated during inundation mapping with TIN of study area as shown in Figure 4.6 for 200Yrs flood and the rest are at Appendix Figure 9.

Hazard aspect of flood is basically expressed by the severity of effect related to hydraulic and hydrologic parameters flood. Depth one of hydraulic parameter was taken for this study by reclassifying water depth grid generated from post-RAS analysis as very low, low, moderate, high, very high and sever to prepare map and flood hazard level assessment for each return.

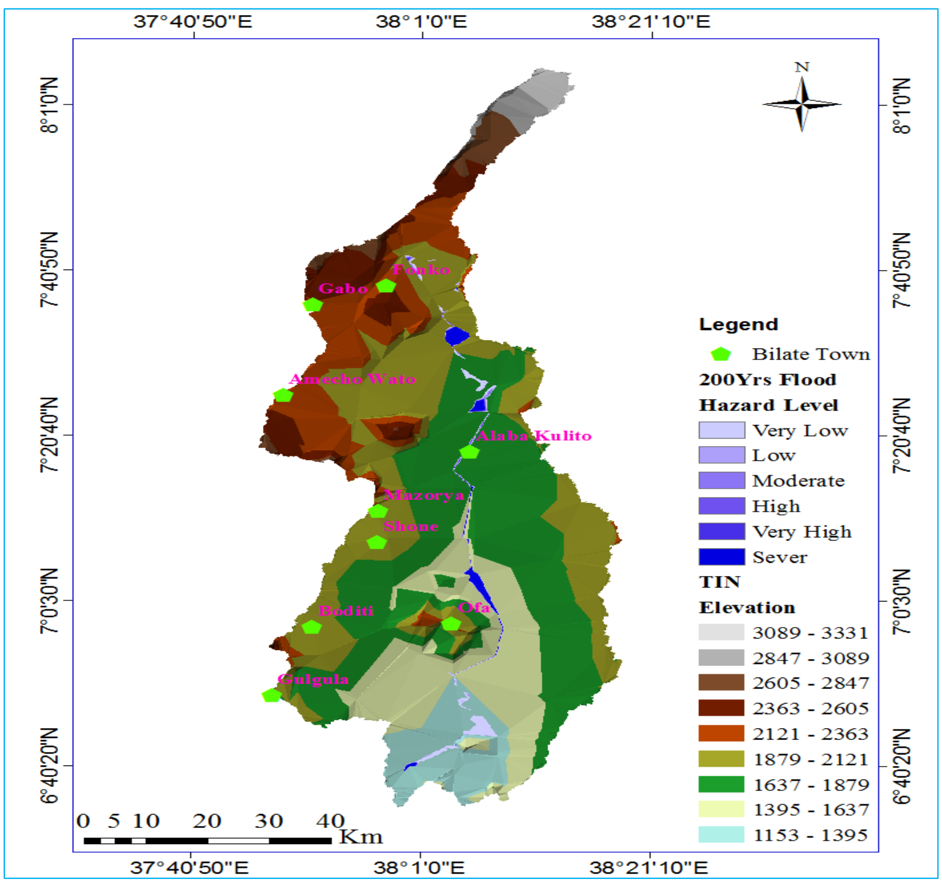



Figure 4.15 Flood Hazard Map

Table 4-7 Flood hazard for different return period

Flood hazard Area(ha) In relation to water surface depth grid

| Level of Hazard | 5Yrs Flood | | 10Yrs Flood | | 50Yrs Flood | | 100YrsFlood | | 200Yrs flood | |
|---|---|---|---|---|---|---|---|---|---|---|
| | % | Area | % | Area | % | Area | % | Area | % | Area |
| Very Low | 56.5 | 3864.25 | 57.3 | 4177.2 | 57.4 | 4609.4 | 57.6 | 4762.5 | 57.6 | 4871.1 |
| Low | 15.6 | 1066.06 | 15.5 | 1130 | 16.7 | 1343.6 | 17 | 1402.2 | 17.2 | 1457.1 |
| Moderate | 10.3 | 706.535 | 10 | 731.25 | 9.59 | 769.83 | 9.44 | 780.61 | 9.36 | 792.48 |
| High | 7.11 | 486.34 | 6.9 | 502.57 | 6.67 | 535.68 | 6.55 | 541.61 | 6.47 | 547.95 |
| Very high | 6.07 | 415.075 | 5.84 | 425.58 | 5.46 | 438.71 | 5.37 | 443.87 | 5.29 | 447.86 |
| Sever | 4.41 | 301.978 | 4.35 | 316.99 | 4.11 | 329.95 | 4.04 | 334.18 | 4 | 338.23 |
| Total | 100 | 6840.24 | 100 | 7284 | 100 | 8029.1 | 100 | 8269 | 100 | 8462.8 |

Area inundated at sever level to moderate hazard is ranges between 4% to 10.3% respectively for all return periods whereas around 58% of inundated area was fall under very low flood hazard level and all the value for return periods 5,10,50,100,200Yrs was tabulated in Table 4-6 above.

Land use land cover map was intersected by the depth grid result assessed from the attribute table of hazard map and assessed for severity of hazard in river flood plain. The result indicates that, the area under all land use except State farm and forest receive flood hazard of high to sever level as tabulated blow Table 4-8 to 4-12.

Table 4-8 5Yrs return period flood hazard

| | LULC | | | | | |
|---|---|---|---|---|---|---|
| Level of Hazard | Cultivation | Forest | Grass Land | Shrub Land | State Farm | Woodland |
| Very Low | 1574.387 | 89.618 | 171.896 | 1688.233 | 125.086 | 173.821 |
| Low | 78.855 | 12.956 | 138.337 | 624.350 | 0 | 170.426 |
| Moderate | 43.557 | 0 | 171.072 | 352.022 | 0 | 139.577 |
| High | 2.275 | 0 | 196.111 | 136.934 | 0 | 151.170 |
| Very high | 0 | 0 | 214.971 | 52.570 | 0 | 147.836 |
| Sevier | 0 | 0 | 155.576 | 74.935 | 0 | 71.322 |
| **Total** | 1699.073 | 102.574 | 1047.963 | 2929.049 | 125.086 | 854.151 |

Table 4-9 10Yrs return period flood hazard

| | | | LULC | | | |
|---|---|---|---|---|---|---|
| Level of Hazard | Cultivation | Forest | Grass Land | Shrub Land | State Farm | Woodland |
| Very Low | 1730.372 | 92.185 | 176.487 | 1859.913 | 134.922 | 175.498 |
| Low | 79.775 | 19.414 | 137.515 | 700.2885 | | 191.621 |
| Moderate | 46.305 | | 171.917 | 371.7841 | | 141.240 |
| High | 2.650 | | 200.085 | 144.5839 | | 155.059 |
| Very high | 0 | | 219.120 | 55.09168 | | 151.420 |
| Sevier | 0 | | 167.473 | 76.67635 | | 72.870 |
| **Total** | 1859.101 | 111.60 | 1072.615 | 3208.338 | 134.922 | 887.698 |

Table 4-10 50 Years return period flood hazard

| | | | LULC | | | |
|---|---|---|---|---|---|---|
| Level of Hazard | Cultivation | Forest | Grass Land | Shrub Land | State Farm | Woodland |
| Very Low | 1730.723 | 92.185 | 177.207 | 1861.406 | 134.908 | 177.8593 |
| Low | 80.145 | 19.420 | 137.516 | 700.294 | | 191.6245 |
| Moderate | 46.305 | | 171.917 | 371.784 | | 141.2354 |
| High | 2.650 | | 200.086 | 144.584 | | 155.0593 |
| Very high | | | 219.138 | 55.092 | | 151.4153 |
| Sevier | 0 | | 167.473 | 76.676 | | 72.8652 |
| **Total** | 1859.823 | 111.605 | 1073.337 | 3209.836 | 134.908 | 890.059 |

Table 4-11 100 Years return period flood hazard

| | | LULC | | | | |
|---|---|---|---|---|---|---|
| Level of Hazard | Cultivation | Forest | Grass Land | Shrub Land | State Farm | Woodland |
| Very Low | 2135.973 | 91.516 | 185.561 | 2020.084 | 156.569 | 168.1633 |
| Low | 86.996 | 39.999 | 148.111 | 897.306 | | 229.8891 |
| Moderate | 51.587 | | 172.890 | 409.258 | | 145.9426 |
| High | 4.313 | | 209.338 | 164.313 | | 164.0288 |
| Very high | 0 | | 225.675 | 60.538 | | 157.8136 |
| Sevier | 0 | | 178.045 | 78.364 | | 77.98089 |
| **Total** | 2278.869 | 131.516 | 1119.620 | 3629.862 | 156.569 | 943.8183 |

Table 4-12 200 Years return period flood hazard

| LULC | | | | | | |
|---|---|---|---|---|---|---|
| Level of Hazard | Cultivation | Forest | Grass Land | Shrub Land | State Farm | Woodland |
| Very Low | 2196.442 | 92.939 | 188.212 | 2061.368 | 160.017 | 167.88 |
| Low | 88.950 | 43.511 | 150.481 | 939.160 | | 229.8891 |
| Moderate | 53.022 | | 173.663 | 416.927 | | 148.1385 |
| High | 4.842 | | 210.653 | 167.722 | | 165.2618 |
| Very high | 0 | | 226.935 | 61.938 | | 159.2848 |
| Sevier | 0 | | 180.480 | 78.700 | | 79.43034 |
| **Total** | 2343.256 | 136.450 | 1130.424 | 3725.815 | 160.017 | 949.8845 |

As these tabular result and the Figure 4.10 shows Bilate river plain receiver the Hazard level from Sevier to low level. Specially the area at upper watershed near Fonko, midle watershed near Alaba Kulito and lower watershed near Ofa Town receives hazard level of sever to moderate hazard.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

This study basically focused on peak flood estimation for different return period at station, flood inundation area delineation and preparation of flood hazard map and its hazard level using hydraulic model HEC-RAS and GIS based extension tools HEC-GeoRAS. Both spatial data and hydrological data at Bilate gaging station with the appropriate accuracy checked was used for flood plain analysis. GIS as spatial data analysis tool, HEC-GeoRAS GIS extension tool to data circuit between GIS and HEC-RAS model and 1D numerical hydraulic model HEC-RAS to simulate steady state flow.

Using these models and tools results efficient outputs with in short period because of the high accuracy in analysis and the models use DEM as an input data instead of DTM which takes long time for survey.

Stream flow data from Bilate at Tena Bilate gauging station was accurate and enough long that was checked during data preparation. These results good frequency analysis output of 153.2, 193.2, 273.6, 305.3 and 335.9 $m^3/s$ for 5, 10, 50, 100 and 200 Yrs return period respectively. This was done by Pearson III distribution function that is highly fitted by the correlation coefficient R2 = 0.982 for estimate and observed flow using method of moment parameter estimation method with the list D-index value than others which is 1.532. Therefore, using these peak discharge result for steady flow simulation in HEC-RAS model gives good result.

Each path of the work during application of models was done step by step procedure carefully and giving consideration of standards for best result of the study. Simulation of steady state flow was done and results maximum water surface depths of 23.90, 24.43, 24.27, 25.23 and 25.41m for 5, 10, 50, 100 and 200 Yrs return periods respectively at the most severe station 138437.6.

From the result of inundation area mapping generated during post-RAS processing there is significant flood inundation of 6840.244, 7284, 8029.13, 8270.031 and 8463 ha. Area inundated shows slight increase from 5Yrs to 200Yrs due to increase in peak flood, water surface depth grid and flood velocity and variation land use.

Map of hazard was prepared for all return period flood and assessment was done for each by reclassifying the resulted depth grid polygon and land use land cover change map. As a result of map assessment watershed is in flood hazard from sever to very low level and around 86% of delineated area covered by shrub, cultivation and grass land. From this significance its fact to say that the research area is in hazard because the land use cultivation and grass land is very familiar with different lives.

## 5.2 Recommendation

Based on the result of the Bilate river flood plain analysis the following recommendations are forwarded.

- Especially the area under sever hazard shown on map should not be used for settlement because it occurs even for small discharge return period which is not expectable.
- The responsible party of the government should give priority for these area during implementation of planning watershed management include awareness creation for community how to use land use in flood prune area.
- As a master’s research flood hazard assessment was done using flood depth and land use land cover parameter, it is recommended to do further research including other flood risk properties and use of new technologies to generate TIN like DEM 10m resolution, RAS mapper and LIDAR which give best quality.
- Stream flow data at one station was used for this research included the others and comparing the results as well as studying mitigation measure is also future research direction.
- Modification of natural conveyance by constructing mitigation structure like retain wall at the weak banks of the river side, modification of the river and keeping the land use land cover management in upstream as well as whole over the shade is an engineering recommendations.

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# APPENDICES

## APPENDIX TABLES

Appendix Table 1 Stream flow data

| | Station Name : Bilate @Tena Bilte | | | | Time-Series Type : Flow (cumecs) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Station Code: 082005 | | | | Elevation : 2030.0 metres | | | | Area : 5518.0 km2 | | | | | | |
| | Monthly max. and min. | | | | | | | | | | | | | | |
| Years | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Annual Max. | Annual min. | Annual av. |
| 1977 | 0.702 | 0.703 | 19.82 | 15.76 | 16.92 | 7.182 | 104.1 | 65.31 | 67.09 | 40.6 | 10.97 | 8.874 | 104.1 | 0.702 | 33.06 |
| 1978 | 1.244 | 1.083 | 3.962 | 6.27 | 13.24 | 129 | 164.7 | 59.31 | 67.99 | 49.8 | 28.57 | 3.962 | 164.7 | 1.083 | 49.64 |
| 1979 | 0.63 | 0.631 | 0.272 | 0.286 | 0.451 | 0.368 | 14.87 | 22.48 | 23.84 | 19.99 | 9.858 | 10.31 | 23.84 | 0.272 | 9.15 |
| 1980 | 4.662 | 0.936 | 0.622 | 11.28 | 35.49 | 28.57 | 84.41 | 36.73 | 104.1 | 54.43 | 14.29 | 2.896 | 104.1 | 0.622 | 34.51 |
| 1981 | 1.008 | 1.418 | 34.27 | 12.56 | 15.76 | 9.793 | 24.45 | 110.1 | 63.56 | 27.5 | 6.717 | 1.418 | 110.1 | 1.008 | 29.98 |
| 1982 | 0.622 | 1.807 | 29.66 | 44.71 | 26.46 | 33.08 | 103 | 67.09 | 95.06 | 74.5 | 0.622 | 0 | 103 | 0 | 41.4 |
| 1983 | 0 | 0 | 1.605 | 5.232 | 21.6 | 1.51 | 10.97 | 79.36 | 39.94 | 8.169 | 33.08 | 3.545 | 79.36 | 0 | 20.31 |
| 1984 | 6.686 | 29.56 | 24.41 | 64.33 | 50.14 | 68.52 | 98.93 | 128.9 | 132.2 | 158.8 | 153.2 | 18.09 | 158.8 | 6.686 | 78.52 |
| 1985 | 2.057 | 11.29 | 42.73 | 22.84 | 18.09 | 34.04 | 83.4 | 146 | 186.6 | 224.5 | 14.05 | 51.9 | 224.5 | 2.057 | 76 |
| 1986 | 28.36 | 111.8 | 35.4 | 38.95 | 46.75 | 94.88 | 63.31 | 85.87 | 88.38 | 96.22 | 16.81 | 3.545 | 111.8 | 3.545 | 58.97 |
| 1987 | 2.269 | 4.858 | 19.9 | 38.22 | 45.11 | 83.4 | 41.95 | 17.13 | 43.43 | 39.82 | 5.143 | 1.059 | 83.4 | 1.059 | 30.48 |
| 1988 | 0.664 | 1.675 | 174.3 | 128.9 | 23.88 | 32.72 | 156.9 | 80.99 | 206 | 190.8 | 30.8 | 1.588 | 206 | 0.664 | 88.28 |
| 1989 | 0.426 | 0.429 | 5.47 | 9.654 | 9.912 | 10.86 | 16.41 | 24.81 | 26.3 | 25.86 | 17.4 | 16.93 | 26.3 | 0.426 | 13.66 |
| 1990 | 2.269 | 7.876 | 50.14 | 80.99 | 137.3 | 120.9 | 55.53 | 172.3 | 222.1 | 176.3 | 43.51 | 2.989 | 222.1 | 2.269 | 92.61 |
| 1991 | 1.196 | 0.995 | 1.196 | 1.588 | 27.19 | 15.19 | 41.95 | 100.3 | 119.4 | 33.37 | 3.545 | 2.859 | 119.4 | 0.995 | 33.51 |
| 1992 | 2.612 | 0.713 | 8.389 | 76.29 | 114.8 | 19.5 | 53.7 | 47.58 | 32.72 | 27.19 | 135.6 | 24.95 | 135.6 | 0.713 | 48.6 |
| 1993 | 1.268 | 11.95 | 24.95 | 27.77 | 83.4 | 149.6 | 283.5 | 168.3 | 164.5 | 132.2 | 162.6 | 34.71 | 283.5 | 1.268 | 109.3 |
| 1994 | 4.504 | 3.259 | 5.231 | 47.58 | 26.62 | 231.7 | 105.9 | 30.8 | 34.71 | 67.46 | 48.43 | 4.333 | 231.7 | 3.259 | 60.39 |
| 1995 | 0.333 | 1.121 | 4.354 | 5.353 | 4.46 | 4.522 | 12.52 | 15.93 | 22.19 | 15.8 | 6.033 | 6.056 | 22.19 | 0.333 | 8.657 |
| 1996 | 1.344 | 110.3 | 19.9 | 85.87 | 42.73 | 56.47 | 22.84 | 41.19 | 101.7 | 107.4 | 2.748 | 2.772 | 110.3 | 1.344 | 50.49 |
| 1997 | 2.771 | 2.765 | 1.799 | 2.097 | 1.599 | 1.799 | 25.89 | 66.4 | 67.46 | 76.29 | 10.06 | 8.389 | 76.29 | 1.599 | 24.66 |
| 1998 | 4.504 | 22.84 | 82.19 | 34.71 | 71.78 | 71.78 | 53.7 | 65.36 | 71.78 | 11.95 | 13.32 | 23.36 | 82.19 | 4.504 | 43.85 |
| 1999 | 60.31 | 49.28 | 59.34 | 46.75 | 37.5 | 78.61 | 76.29 | 89.66 | 110.3 | 110.3 | 96.22 | 1.878 | 110.3 | 1.878 | 66.33 |
| 2000 | 2.079 | 1.953 | 3.367 | 2.874 | 3.015 | 3.51 | 31.95 | 31.16 | 30.75 | 32.19 | 4.341 | 4.388 | 32.19 | 1.953 | 13.27 |
| 2001 | 4.407 | 4.415 | 3.132 | 4.346 | 4.77 | 3.791 | 25.44 | 24.28 | 24.53 | 25.45 | 3.79 | 3.811 | 25.45 | 3.132 | 11.48 |
| 2002 | 3.819 | 3.828 | 20.48 | 10.06 | 20.91 | 38.67 | 38.76 | 35.93 | 39.14 | 42.8 | 3.239 | 3.257 | 42.8 | 3.239 | 21.92 |
| 2003 | 3.267 | 3.279 | 1.551 | 1.849 | 1.586 | 1.861 | 14.33 | 24.38 | 15.57 | 23.72 | 19.36 | 21.53 | 24.38 | 1.551 | 11.3 |
| 2004 | 21.65 | 21.65 | 6.452 | 8.456 | 6.498 | 6.164 | 28.62 | 34.36 | 29.3 | 31.55 | 9.203 | 9.442 | 34.36 | 6.164 | 18.13 |
| 2005 | 9.541 | 9.653 | 2.449 | 275.3 | 21.83 | 22.84 | 22.84 | 192.9 | 85.87 | 61.3 | 20.85 | 3.848 | 275.3 | 2.449 | 71.93 |
| 2006 | 2.269 | 1.503 | 6.463 | 3.545 | 8.654 | 14.8 | 46.75 | 64.33 | 156.9 | 144.2 | 38.95 | 3.545 | 156.9 | 1.503 | 46.45 |
| 2007 | 2.161 | 1.344 | 1.196 | 36.09 | 97.57 | 15.59 | 23.88 | 117.8 | 34.71 | 142.4 | 26.06 | 8.389 | 142.4 | 1.196 | 46.48 |
| 2008 | 3.545 | 3.545 | 37.5 | 21.83 | 27.19 | 45.11 | 35.4 | 30.18 | 56.47 | 53.7 | 8.389 | 3.545 | 56.47 | 3.545 | 27.6 |
| 2009 | 6.913 | 14.8 | 71.78 | 18.98 | 19.9 | 12.62 | 13.32 | 53.7 | 19.9 | 9.482 | 4.504 | 19.9 | 71.78 | 4.504 | 24.43 |
| 2010 | 16.39 | 11.95 | 15.99 | 21.83 | 19.9 | 19.9 | 21.34 | 21.83 | 21.83 | 20.85 | 5.102 | 5.122 | 21.83 | 5.102 | 16.35 |
| 2011 | 5.131 | 5.138 | 10.67 | 21.34 | 20.85 | 10.98 | 93.56 | 51.01 | 89.66 | 85.87 | 5.622 | 7.384 | 93.56 | 5.131 | 36.14 |
| 2012 | 8.13 | 7.146 | 17.23 | 46.75 | 49.28 | 18.98 | 128.9 | 74.01 | 34.71 | 37.5 | 48.43 | 3.848 | 128.9 | 3.848 | 43.4 |
| 2013 | 2.494 | 10.36 | 37.5 | 46.75 | 41.19 | 20.85 | 40.43 | 108.8 | 63.31 | 29.56 | 12.97 | 9.769 | 108.8 | 2.494 | 38.23 |
| 2014 | 6.65 | 6.65 | 6.64 | 6.6 | 6.64 | 6.62 | 6.1 | 6.1 | 6.2 | 6.21 | 8.54 | 8.53 | 8.54 | 6.1 | 6.866 |
| | | | | | | | | | | | | Grand Max | 283.5 | | |
| | | | | | | | | | | | | Grand Min | | 0 | |

Appendix Table 2 Best fit selection computation

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Qav=108.348 | | S=72.78 | | N=38 | | | | | |
| Ditribution Type | Selected Max | Rank | T | F | p<0.5 | 1/p^2 | w | u | KT | QT | /Q-Q*/ |
| Pearson(3P)/MOM | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 2.032 | 256.267 | 27.233 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.611 | 225.615 | 49.685 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 1.347 | 206.418 | 25.282 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 1.15 | 192.058 | 32.442 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.99 | 180.4 | 25.6 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.854 | 170.475 | 5.7745 |
| | | | | | | | | | | **Sum** | **166.02** |
| | | | | | | | | | | **D=** | **1.5323** |
| Pearson(3P)/PWM | Selected Max | Rank | T | F | p<0.5 | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 2.032 | 229.823 | 53.677 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.611 | 204.706 | 70.594 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 1.347 | 188.975 | 42.725 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 1.15 | 177.208 | 47.292 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.99 | 167.655 | 38.345 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.854 | 159.522 | 5.1778 |
| | | | | | | | | | | **Sum** | **257.81** |
| | | | | | | | | | | **D=** | **2.3795** |
| Pearson(3P)/MLM | Selected Max | Rank | T | F | p<0.5 | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 2.032 | 251.28 | 32.22 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.611 | 221.662 | 53.638 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 1.347 | 203.112 | 28.588 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 1.15 | 189.236 | 35.264 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.99 | 177.971 | 28.029 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.854 | 168.38 | 3.6801 |
| | | | | | | | | | | **Sum** | **181.42** |
| | | | | | | | | | | **D=** | **1.6744** |
| Gamma(2P)/MOM | Selected Max | Rank | T | F | p | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 2.111 | 261.976 | 21.524 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.58 | 223.387 | 51.913 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 1.265 | 200.42 | 31.28 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 1.038 | 183.875 | 40.625 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.859 | 170.86 | 35.14 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.711 | 160.081 | 4.6191 |
| | | | | | | | | | | **Sum** | **185.1** |
| | | | | | | | | | | **D=** | **1.7084** |
| Gamma(2P)/MLM | Selected Max | Rank | T | F | p | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 2.17 | 222.226 | 61.274 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.668 | 195.868 | 79.432 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 1.362 | 179.833 | 51.867 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 1.138 | 168.092 | 56.408 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.96 | 158.727 | 47.273 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.81 | 150.876 | 13.824 |
| | | | | | | | | | | **Sum** | **310.08** |
| | | | | | | | | | | **D=** | **2.8619** |
| LNIII/MOM | Selected Max | Rank | T | F | p | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 0.22 | 124.331 | 123.36 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 0.166 | 120.403 | 119.45 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 0.131 | 117.856 | 116.93 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 0.104 | 115.902 | 115 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.082 | 114.284 | 113.41 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.062 | 112.883 | 112.04 |
| | | | | | | | | | | **Sum** | **700.2** |
| | | | | | | | | | | **D=** | **6.4625** |
| LNIII/PWM | Selected Max | Rank | T | F | p | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 1.741 | 235.054 | 234.08 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 1.134 | 190.875 | 189.93 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 0.815 | 167.667 | 166.74 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 0.604 | 152.298 | 151.4 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.448 | 140.97 | 140.1 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.326 | 132.082 | 131.24 |
| | | | | | | | | | | **Sum** | **1013.5** |
| | | | | | | | | | | **D=** | **9.354** |
| LNIII/MLM | Selected Max | Rank | T | F | p | 1/p^2 | w | u | KT | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.026 | 1521 | 2.707 | 1.837 | 0.056 | 112.4 | 111.43 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.051 | 380.25 | 2.437 | 1.513 | 0.042 | 111.416 | 110.47 |
| | 231.7 | 3 | 13 | 0.92 | 0.077 | 169 | 2.265 | 1.301 | 0.033 | 110.774 | 109.85 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.103 | 95.063 | 2.134 | 1.138 | 0.027 | 110.28 | 109.38 |
| | 206 | 5 | 7.8 | 0.87 | 0.128 | 60.84 | 2.027 | 1.002 | 0.021 | 109.869 | 109 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.154 | 42.25 | 1.935 | 0.884 | 0.016 | 109.511 | 108.67 |
| | | | | | | | | | | **Sum** | **658.79** |
| | | | | | | | | | | **D=** | **6.0803** |

cont.…

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Exp(2P)/MOM | Selected Max | Rank | T | KT | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 1.59 | 151.4 | 132.13 | | |
| | 275.3 | 2 | 19.5 | 1.29 | 129.5 | 145.84 | | |
| | 231.7 | 3 | 13 | 1.11 | 116.6 | 115.06 | | |
| | 224.5 | 4 | 9.75 | 0.99 | 107.5 | 116.95 | | |
| | 206 | 5 | 7.8 | 0.89 | 100.5 | 105.51 | | |
| | 164.7 | 6 | 6.5 | 0.81 | 94.73 | 69.969 | | |
| | | | | | **Sum** | **685.46** | | |
| | | | | | **D=** | **6.3265** | | |
| Exp(2P)/PWM | Selected Max | Rank | T | KT | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 1.59 | 62.46 | 221.04 | | |
| | 275.3 | 2 | 19.5 | 1.29 | 85.83 | 189.47 | | |
| | 231.7 | 3 | 13 | 1.11 | 99.5 | 132.2 | | |
| | 224.5 | 4 | 9.75 | 0.99 | 109.2 | 115.3 | | |
| | 206 | 5 | 7.8 | 0.89 | 116.7 | 89.275 | | |
| | 164.7 | 6 | 6.5 | 0.81 | 122.9 | 41.828 | | |
| | | | | | **Sum** | **789.11** | | |
| | | | | | **D=** | **7.2831** | | |
| Exp(2P)/MLM | Selected Max | Rank | T | KT | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 1.59 | 167.3 | 116.16 | | |
| | 275.3 | 2 | 19.5 | 1.29 | 137.3 | 138 | | |
| | 231.7 | 3 | 13 | 1.11 | 119.7 | 111.98 | | |
| | 224.5 | 4 | 9.75 | 0.99 | 107.3 | 117.25 | | |
| | 206 | 5 | 7.8 | 0.89 | 97.58 | 108.42 | | |
| | 164.7 | 6 | 6.5 | 0.81 | 89.68 | 75.024 | | |
| | | | | | **Sum** | **666.83** | | |
| | | | | | **D=** | **6.1545** | | |
| EV1(Gumbel)/MOM | Selected Max | Rank | T | F | (-log(F) | log(-log( | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.011 | -1.948 | 76.23 | 207.3 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.023 | -1.641 | 76.89 | 198.4 |
| | 231.7 | 3 | 13 | 0.92 | 0.035 | -1.459 | 77.57 | 154.1 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.047 | -1.328 | 0.195 | 224.3 |
| | 206 | 5 | 7.8 | 0.87 | 0.06 | -1.225 | 6.047 | 200 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.073 | -1.139 | 10.9 | 153.8 |
| | | | | | | | **Sum** | **1138** |
| | | | | | | | **D=** | **10.5** |
| EV1(Gumbel)/PWM | Selected Max | Rank | T | F | (-log(F) | log(-log( | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.011 | -1.948 | 450.1 | 166.6 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.023 | -1.641 | 408.6 | 133.3 |
| | 231.7 | 3 | 13 | 0.92 | 0.035 | -1.459 | 383.9 | 152.2 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.047 | -1.328 | 366.2 | 141.7 |
| | 206 | 5 | 7.8 | 0.87 | 0.06 | -1.225 | 352.3 | 146.3 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.073 | -1.139 | 340.7 | 176 |
| | | | | | | | **Sum** | **916** |
| | | | | | | | **D=** | **8.455** |
| EV1(Gumbel)/MLM | Selected Max | Rank | T | F | (-log(F) | log(-log( | Q* | /Q-Q*/ |
| | 283.5 | 1 | 39 | 0.97 | 0.011 | -1.948 | 72.5 | 211 |
| | 275.3 | 2 | 19.5 | 0.95 | 0.023 | -1.641 | 71.7 | 203.6 |
| | 231.7 | 3 | 13 | 0.92 | 0.035 | -1.459 | 70.91 | 160.8 |
| | 224.5 | 4 | 9.75 | 0.9 | 0.047 | -1.328 | 70.11 | 154.4 |
| | 206 | 5 | 7.8 | 0.87 | 0.06 | -1.225 | 69.31 | 136.7 |
| | 164.7 | 6 | 6.5 | 0.85 | 0.073 | -1.139 | 68.52 | 96.18 |
| | | | | | | | **Sum** | **962.7** |
| | | | | | | | **D=** | **8.885** |
| GEV(3P)/MOM | Selected Max | Rank | T | 1-1/T | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 0.97 | 210.7 | 72.836 | | |
| | 275.3 | 2 | 19.5 | 0.95 | 210.2 | 65.107 | | |
| | 231.7 | 3 | 13 | 0.92 | 209.7 | 21.992 | | |
| | 224.5 | 4 | 9.75 | 0.9 | 209.2 | 15.289 | | |
| | 206 | 5 | 7.8 | 0.87 | 208.7 | 2.6982 | | |
| | 164.7 | 6 | 6.5 | 0.85 | 208.2 | 43.471 | | |
| | | | | | **Sum** | **221.39** | | |
| | | | | | **D=** | **2.0434** | | |
| GEV(3P)/PWM | Selected Max | Rank | T | 1-1/T | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 0.97 | 36.19 | 247.31 | | |
| | 275.3 | 2 | 19.5 | 0.95 | 35.02 | 240.28 | | |
| | 231.7 | 3 | 13 | 0.92 | 33.81 | 197.89 | | |
| | 224.5 | 4 | 9.75 | 0.9 | 32.57 | 191.93 | | |
| | 206 | 5 | 7.8 | 0.87 | 31.3 | 174.7 | | |
| | 164.7 | 6 | 6.5 | 0.85 | 29.98 | 134.72 | | |
| | | | | | **Sum** | **1186.8** | | |
| | | | | | **D=** | **10.954** | | |
| GEV(3P)/MLM | Selected Max | Rank | T | 1-1/T | Q* | /Q-Q*/ | | |
| | 283.5 | 1 | 39 | 0.97 | 89.7 | 193.8 | | |
| | 275.3 | 2 | 19.5 | 0.95 | 89.35 | 185.95 | | |
| | 231.7 | 3 | 13 | 0.92 | 88.99 | 142.71 | | |
| | 224.5 | 4 | 9.75 | 0.9 | 88.63 | 135.87 | | |
| | 206 | 5 | 7.8 | 0.87 | 88.25 | 117.75 | | |
| | 164.7 | 6 | 6.5 | 0.85 | 87.86 | 76.839 | | |
| | | | | | **Sum** | **852.92** | | |
| | | | | | **D=** | **7.872** | | |

Appendix Table 3 RMS computation for best fit

| Distribution/Methods | PIII(3P) | | | | EVI | | | | LN(3P) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | MOM | PWM | MLM | Min. | MOM | PWM | MLM | Min. | MOM | PWM | MLM | Min. |
| 1 | 2.5387 | 13.1467 | **0.1153** | 0.1153 | 0.5395 | 4.6703 | **0.3254** | 0.3254 | 1.1601 | 2.2695 | **1.0406** | 1.0406 |
| 2 | 2.3837 | 12.1097 | **0.0206** | 0.0206 | 0.576 | 4.7574 | **0.4195** | 0.4195 | 1.1393 | 1.9539 | **1.0355** | 1.0355 |
| 3 | 2.1473 | 10.3303 | **0.4261** | 0.4261 | 0.464 | 4.4904 | **0.3606** | 0.3606 | 1.1103 | 1.6885 | **1.0282** | 1.0282 |
| 4 | 1.9872 | 9.12 | **0.4149** | 0.4149 | 0.4061 | 4.3523 | **0.3398** | 0.3398 | 1.0894 | 1.5201 | **1.0229** | 1.0229 |
| 5 | 1.8458 | 8.03457 | **0.879** | 0.879 | 0.3469 | 4.2113 | **0.3111** | 0.3111 | 1.0707 | 1.3885 | **1.0181** | 1.0181 |
| 6 | 1.7305 | 7.14426 | **0.8775** | 0.8775 | 0.3073 | 4.117 | **0.2968** | 0.2968 | 1.0547 | 1.2863 | **1.014** | 1.014 |
| 7 | 1.6268 | 6.33703 | **1.3623** | 1.3623 | **0.2717** | 4.0321 | 0.2834 | 0.2717 | 1.04 | 1.2007 | **1.0103** | 1.0103 |
| 8 | 1.5684 | 5.90689 | **1.3903** | 1.3903 | **0.3238** | 4.1562 | 0.3573 | 0.3238 | 1.0282 | 1.1359 | **1.0072** | 1.0072 |
| 9 | **1.4852** | 5.25815 | 1.9513 | 1.4852 | **0.3201** | 4.1476 | 0.3739 | 0.3201 | 1.0147 | 1.0686 | **1.0038** | 1.0038 |
| 10 | **1.444** | 4.97822 | 2.0737 | 1.444 | **0.4468** | 4.4496 | 0.5271 | 0.4468 | 1.0016 | 1.0071 | **1.0004** | 1.0004 |
| 11 | **1.4393** | 5.04749 | 3.1593 | 1.4393 | **0.778** | 5.2392 | 0.9021 | 0.778 | 0.984 | 0.9299 | **0.9959** | 0.9299 |
| 12 | **1.461** | 5.43118 | 4.0634 | 1.461 | **1.4569** | 6.8579 | 1.6625 | 1.4569 | 0.9528 | **0.8** | 0.9878 | 0.8 |
| 13 | **1.351** | 4.63265 | 5.8313 | 1.351 | **1.733** | 7.5163 | 1.9991 | 1.733 | 0.9194 | **0.6677** | 0.9792 | 0.6677 |
| 14 | **1.2041** | 3.51227 | 6.343 | 1.2041 | **1.9505** | 8.0348 | 2.2773 | 1.9505 | 0.8822 | **0.5272** | 0.9695 | 0.5272 |
| 15 | **1.0309** | 2.17847 | 8.617 | 1.0309 | **2.1945** | 8.6168 | 2.5907 | 2.1945 | 0.8386 | **0.3686** | 0.9582 | 0.3686 |
| 16 | **0.8354** | 0.6067 | 8.9864 | 0.6067 | **2.2749** | 8.8085 | 2.7241 | 2.2749 | 0.7992 | **0.2337** | 0.948 | 0.2337 |
| 17 | **0.401** | 2.33508 | 17.598 | 0.401 | **4.4052** | 13.888 | 5.2172 | 4.4052 | 0.6088 | **0.4569** | 0.8985 | 0.4569 |
| 18 | **1.5191** | 15.4347 | 46.895 | 1.5191 | **13.63** | 35.884 | 16.018 | 13.63 | **0.2247** | 3.4534 | 0.6821 | 0.2247 |
| 19 | **3.2305** | 28.593 | 70.188 | 3.2305 | **17.038** | 44.008 | 20.217 | 17.038 | 0.72 | 5.1097 | **0.5532** | 0.5532 |
| 20 | **3.2305** | 28.593 | 70.188 | 3.2305 | **16.671** | 43.135 | 20.016 | 16.671 | 0.72 | 5.1097 | **0.5532** | 0.5532 |
| 21 | **30.813** | 49.4999 | 62.86 | 30.813 | **63.799** | 87.176 | 96.747 | 63.799 | 15.494 | 53.704 | **4.7617** | 4.7617 |
| 22 | **6.0561** | 29.152 | 36.037 | 6.0561 | **42.165** | 97.155 | 51.039 | 42.165 | 4.3024 | 13.298 | **1.8564** | 1.8564 |
| 23 | **3.1034** | 6.02699 | 23.917 | 3.1034 | **37.227** | 85.379 | 45.518 | 37.227 | 3.5669 | 10.795 | **1.6651** | 1.6651 |
| 24 | **0.5853** | 14.7931 | 23.917 | 0.5853 | **36.526** | 83.709 | 45.134 | 36.526 | 3.1626 | 9.461 | **1.5599** | 1.5599 |
| 25 | **0.7141** | 20.0974 | 32.045 | 0.7141 | **20.702** | 45.979 | 25.745 | 20.702 | 1.9889 | 4.9703 | **1.2558** | 1.2558 |
| 26 | **0.0182** | 9.53718 | 40.555 | 0.0182 | **7.0361** | 13.393 | 8.6643 | 7.0361 | 1.2338 | 1.9639 | **1.0604** | 1.0604 |
| 27 | **0.1797** | 6.88443 | 24.517 | 0.1797 | **4.184** | 6.5922 | 5.0876 | 4.184 | 1.0839 | 1.3559 | **1.0217** | 1.0217 |
| 28 | **0.1638** | 6.70501 | 18.244 | 0.1638 | **3.3554** | 4.6165 | 4.0576 | 3.3554 | 1.0305 | 1.1334 | **1.0079** | 1.0079 |
| 29 | **0.1452** | 6.65787 | 16.55 | 0.1452 | **2.8491** | 3.4091 | 3.4273 | 2.8491 | 0.997 | **0.9864** | 0.9992 | 0.9864 |
| 30 | **0.2605** | 5.48898 | 11.309 | 0.2605 | 2.272 | **2.0331** | 2.6888 | 2.0331 | 0.9775 | **0.8954** | 0.9942 | 0.8954 |
| 31 | **0.142** | 6.40704 | 12.523 | 0.142 | 2.2005 | **1.8627** | 2.6123 | 1.8627 | 0.9575 | **0.7949** | 0.9891 | 0.7949 |
| 32 | **0.0873** | 6.77069 | 11.107 | 0.0873 | 2.054 | **1.5133** | 2.4321 | 1.5133 | 0.9417 | **0.7078** | 0.985 | 0.7078 |
| 33 | **0.3799** | 4.21595 | 7.0356 | 0.3799 | 1.5963 | **0.422** | 1.8199 | 0.422 | 0.9536 | **0.757** | 0.9881 | 0.757 |
| 34 | **0.3756** | 4.1927 | 5.8983 | 0.3756 | 1.5018 | **0.1965** | 1.6983 | 0.1965 | 0.9478 | **0.7132** | 0.9866 | 0.7132 |
| 35 | **0.2818** | 4.90783 | 6.9092 | 0.2818 | 1.4816 | **0.1483** | 1.6785 | 0.1483 | 0.935 | **0.6216** | 0.9834 | 0.6216 |
| 36 | **0.1987** | 5.51696 | 6.4475 | 0.1987 | 1.4442 | **0.0593** | 1.6338 | 0.0593 | 0.9229 | **0.5191** | 0.9803 | 0.5191 |
| 37 | **0.283** | 4.75726 | 5.7453 | 0.283 | 1.3214 | **0.2336** | 1.4646 | 0.2336 | 0.9278 | **0.5057** | 0.9816 | 0.5057 |
| 38 | **0.1232** | 5.92172 | 5.4295 | 0.1232 | 1.2999 | **0.285** | 1.4393 | 0.285 | 1.0189 | **0.2766** | 0.9769 | 0.2766 |
| **Count of Min./Methods** | **30** | 0 | 8 | 38 | **23** | 9 | 6 | 38 | 1 | 16 | **21** | 38 |

cont.…

| Distribution/Methods | GAM(2P) | | | GEV3(3) | | | | EXP(2P) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | MOM | PWM | Min. | MOM | PWM | MLM | Min. | MOM | PWM | MLM | Min. |
| 1 | **0.76339** | 2.26948 | 0.76339 | 2.02509 | **0.44818** | 8.89146 | 0.44818 | 1.43102 | **0.54026** | 2.46231 | 0.54026 |
| 2 | **0.72704** | 1.95387 | 0.72704 | 2.1771 | **0.65708** | 10.0502 | 0.65708 | 1.24399 | **0.73975** | 8.86456 | 0.73975 |
| 3 | **0.77361** | 1.68849 | 0.77361 | 2.17637 | **0.65001** | 10.0328 | 0.65001 | 1.09626 | **0.89733** | 15.1102 | 0.89733 |
| 4 | **0.76919** | 1.52006 | 0.76919 | 2.19341 | **0.66755** | 10.1512 | 0.66755 | **0.99053** | 1.0101 | 28.7938 | 0.99053 |
| 5 | **0.81864** | 1.3885 | 0.81864 | 2.19496 | **0.66308** | 10.1501 | 0.66308 | **0.90647** | 1.09976 | 18.5585 | 0.90647 |
| 6 | **0.81629** | 1.2863 | 0.81629 | 2.20398 | **0.66869** | 10.2057 | 0.66869 | **0.83574** | 1.17521 | 17.7352 | 0.83574 |
| 7 | **0.86882** | 1.20069 | 0.86882 | 2.2098 | **0.66947** | 10.2359 | 0.66947 | **0.77465** | 1.24036 | 15.5778 | 0.77465 |
| 8 | **0.85868** | 1.13586 | 0.85868 | 2.29596 | **0.78023** | 10.8778 | 0.78023 | **0.7018** | 1.31807 | 13.433 | 0.7018 |
| 9 | **0.91784** | 1.06863 | 0.91784 | 2.32609 | **0.81293** | 11.0905 | 0.81293 | **0.64274** | 1.38107 | 13.8474 | 0.64274 |
| 10 | **0.90726** | 1.00707 | 0.90726 | 2.48765 | **1.0236** | 12.2999 | 1.0236 | **0.54593** | 1.48433 | 12.8 | 0.54593 |
| 11 | 0.97796 | **0.92994** | 0.92994 | 2.86764 | **1.52705** | 15.1599 | 1.52705 | **0.3682** | 1.6739 | 24.7923 | 0.3682 |
| 12 | 0.96873 | **0.79995** | 0.79995 | 3.6319 | **2.54127** | 20.9155 | 2.54127 | **0.02847** | 2.03626 | 37.4283 | 0.02847 |
| 13 | 1.12739 | **0.66769** | 0.66769 | 3.98126 | **2.98764** | 23.5127 | 2.98764 | **0.18712** | 2.26623 | 21.6008 | 0.18712 |
| 14 | 1.14088 | **0.52722** | 0.52722 | 4.27296 | **3.35039** | 25.6619 | 3.35039 | **0.39366** | 2.48652 | 18.9841 | 0.39366 |
| 15 | 1.36901 | **0.36864** | 0.36864 | 4.59933 | **3.75235** | 28.0589 | 3.75235 | **0.6278** | 2.73627 | 23.8996 | 0.6278 |
| 16 | 1.38691 | **0.23365** | 0.23365 | 4.7436 | **3.90775** | 29.075 | 3.90775 | **0.78853** | 2.9077 | 20.876 | 0.78853 |
| 17 | 2.05664 | **0.45692** | 0.45692 | 7.26222 | **7.14724** | 47.8414 | 7.14724 | **2.1469** | 4.35659 | 16.5507 | 2.1469 |
| 18 | 3.21722 | **2.45337** | 2.45337 | 18.1612 | **21.1451** | 29.0107 | 18.1612 | **8.03935** | 10.6417 | 26.7428 | 8.03935 |
| 19 | 5.1982 | **5.09669** | 5.09669 | **22.401** | 26.3738 | 60.1625 | 22.401 | **10.7823** | 13.5674 | 37.52 | 10.7823 |
| 20 | 5.1982 | **5.09669** | 5.09669 | **22.1865** | 25.8423 | 58.0649 | 22.1865 | **11.164** | 13.9745 | 18.1524 | 11.164 |
| 21 | **63.4562** | 53.7042 | 53.7042 | **26.0394** | 48.0647 | 54.7094 | 26.0394 | 38.7606 | **34.6075** | 45.5864 | 34.6075 |
| 22 | **15.6264** | 13.2981 | 13.2981 | **49.2465** | 63.2937 | 68.8303 | 49.2465 | **32.2155** | 32.2956 | 38.1119 | 32.2155 |
| 23 | **17.906** | 10.795 | 10.795 | **43.5464** | 55.5436 | 57.8387 | 43.5464 | **29.7369** | 29.6518 | 47.5772 | 29.6518 |
| 24 | **17.906** | 9.46101 | 9.46101 | **42.9591** | 54.0881 | 61.6264 | 42.9591 | 30.4261 | **30.3869** | 40.9521 | 30.3869 |
| 25 | **12.2113** | 4.97026 | 4.97026 | **23.502** | 30.1392 | 26.1039 | 23.502 | 18.013 | **17.1467** | 24.1369 | 17.1467 |
| 26 | **3.12637** | 1.96392 | 1.96392 | **6.53374** | 9.80601 | 64.3024 | 6.53374 | 6.42594 | **4.7875** | 46.1137 | 4.7875 |
| 27 | **1.70146** | 1.35594 | 1.35594 | **2.98214** | 5.56403 | 34.4357 | 2.98214 | 3.97588 | **2.17417** | 37.1487 | 2.17417 |
| 28 | **1.0373** | 1.13337 | 1.0373 | **1.9464** | 4.30139 | 25.9555 | 1.9464 | 3.28643 | **1.43878** | 65.577 | 1.43878 |
| 29 | **0.97039** | 0.98639 | 0.97039 | **1.30831** | 3.51891 | 20.7517 | 1.30831 | 2.86241 | **0.98651** | 51.9235 | 0.98651 |
| 30 | **0.38194** | 0.89541 | 0.38194 | **0.58039** | 2.67111 | 14.3768 | 0.58039 | 2.32828 | **0.41678** | 31.0889 | 0.41678 |
| 31 | **0.60695** | 0.79492 | 0.60695 | **0.47941** | 2.50541 | 13.9107 | 0.47941 | 2.2988 | **0.38534** | 19.6399 | 0.38534 |
| 32 | **0.4387** | 0.70779 | 0.4387 | **0.28243** | 2.24348 | 12.4474 | 0.28243 | 2.18062 | **0.25929** | 14.8241 | 0.25929 |
| 33 | **0.0122** | 0.75695 | 0.0122 | **0.28799** | 1.64808 | 6.81482 | 0.28799 | 1.69126 | **0.26268** | 12.3128 | 0.26268 |
| 34 | **0.13106** | 0.71322 | 0.13106 | **0.41723** | 1.4858 | 5.75433 | 0.41723 | 1.60172 | **0.35819** | 17.2505 | 0.35819 |
| 35 | **0.06338** | 0.62162 | 0.06338 | **0.4634** | 1.39119 | 5.65812 | 0.4634 | 1.59717 | **0.36303** | 54.8205 | 0.36303 |
| 36 | **0.00131** | 0.51911 | 0.00131 | **0.53614** | 1.26569 | 5.30916 | 0.53614 | 1.56954 | **0.39251** | 46.4939 | 0.39251 |
| 37 | **0.01188** | 0.50568 | 0.01188 | **0.70042** | 1.08939 | 3.69001 | 0.70042 | 1.42599 | **0.54563** | 18.5277 | 0.54563 |
| 38 | **0.05814** | 0.27659 | 0.05814 | **0.78473** | 0.911 | 3.49689 | 0.78473 | 1.41086 | **0.56177** | 23.9123 | 0.56177 |
| Count of Min./Methods | **28** | 10 | 38 | 20 | **18** | 0 | 38 | 19 | **19** | 0 | 38 |

Appendix Table 4 HEC-RAS profile output table sample

| Reach | River Sta | Q Total | Min Ch El | W.S. Elev | Crit W.S. | E.G. Elev | E.G. Slop | Vel Chnl | Flow Area | Top Width |
|---|---|---|---|---|---|---|---|---|---|---|
| | | (m3/s) | (m) | (m) | (m) | (m) | (m/m) | (m/s) | (m2) | (m) |
| Bilate Reaches | 162674 | 153.2 | 2007.36 | 2007.69 | 2006.92 | 2007.69 | 0.00091 | 0.16 | 362.45 | 494.01 |
| Bilate Reaches | 162674 | 193.15 | 2007.36 | 2007.81 | 2006.98 | 2007.82 | 0.0009 | 0.2 | 427.39 | 536.22 |
| Bilate Reaches | 162674 | 173.62 | 2007.36 | 2007.75 | 2006.95 | 2007.76 | 0.00091 | 0.18 | 395.98 | 516.24 |
| Bilate Reaches | 162674 | 305.31 | 2007.36 | 2008.11 | 2007.14 | 2008.12 | 0.00088 | 0.28 | 599.56 | 634.67 |
| Bilate Reaches | 162674 | 335.87 | 2007.36 | 2008.18 | 2007.17 | 2008.19 | 0.00087 | 0.29 | 644.87 | 658.14 |
| Bilate Reaches | 161986 | 153.2 | 2001.6 | 2003 | | 2003.01 | 0.00086 | 0.43 | 359.41 | 500.42 |
| Bilate Reaches | 161986 | 193.15 | 2001.6 | 2003.14 | | 2003.15 | 0.00083 | 0.45 | 431.59 | 548.27 |
| Bilate Reaches | 161986 | 173.62 | 2001.6 | 2003.07 | | 2003.08 | 0.00084 | 0.44 | 396.75 | 525.72 |
| Bilate Reaches | 161986 | 305.31 | 2001.6 | 2003.45 | | 2003.46 | 0.00079 | 0.49 | 621.4 | 657.69 |
| Bilate Reaches | 161986 | 335.87 | 2001.6 | 2003.53 | | 2003.54 | 0.00078 | 0.5 | 670.59 | 683.2 |
| Bilate Reaches | 161003 | 153.2 | 1995.14 | 1997.08 | 1995.92 | 1997.09 | 0.00042 | 0.37 | 409.91 | 405.11 |
| Bilate Reaches | 161003 | 193.15 | 1995.14 | 1997.27 | 1996.01 | 1997.27 | 0.00042 | 0.4 | 486.62 | 441.29 |
| Bilate Reaches | 161003 | 173.62 | 1995.14 | 1997.18 | 1995.97 | 1997.19 | 0.00042 | 0.39 | 449.53 | 424.18 |
| Bilate Reaches | 161003 | 305.31 | 1995.14 | 1997.67 | 1996.2 | 1997.68 | 0.00042 | 0.45 | 682.24 | 522.32 |
| Bilate Reaches | 161003 | 335.87 | 1995.14 | 1997.77 | 1996.24 | 1997.78 | 0.00043 | 0.46 | 731.93 | 540.98 |
| Bilate Reaches | 159009 | 153.2 | 1987.9 | 1989.11 | | 1989.12 | 0.00178 | 0.57 | 271.02 | 427.86 |
| Bilate Reaches | 159009 | 193.15 | 1987.9 | 1989.22 | | 1989.24 | 0.00181 | 0.6 | 320.45 | 464.97 |
| Bilate Reaches | 159009 | 173.62 | 1987.9 | 1989.17 | | 1989.18 | 0.00179 | 0.58 | 296.95 | 447.71 |
| Bilate Reaches | 159009 | 305.31 | 1987.9 | 1989.47 | 1988.76 | 1989.49 | 0.00186 | 0.68 | 446.69 | 548.47 |
| Bilate Reaches | 159009 | 335.87 | 1987.9 | 1989.53 | 1988.8 | 1989.55 | 0.00187 | 0.7 | 478.84 | 567.78 |
| Bilate Reaches | 147970 | 153.2 | 1912.8 | 1913.77 | 1913.39 | 1913.79 | 0.00439 | 0.74 | 235.29 | 475.44 |
| Bilate Reaches | 147970 | 193.15 | 1912.8 | 1913.85 | 1913.44 | 1913.88 | 0.00462 | 0.8 | 274.82 | 513.83 |
| Bilate Reaches | 147970 | 173.62 | 1912.8 | 1913.82 | 1913.42 | 1913.84 | 0.00445 | 0.77 | 257.3 | 497.17 |
| Bilate Reaches | 147970 | 305.31 | 1912.8 | 1914.04 | 1913.58 | 1914.08 | 0.00476 | 0.91 | 382.96 | 606.55 |
| Bilate Reaches | 147970 | 335.87 | 1912.8 | 1914.09 | 1913.61 | 1914.12 | 0.00475 | 0.93 | 411.64 | 628.86 |
| Bilate Reaches | 144661 | 153.2 | 1896.28 | 1898.83 | 1897.7 | 1898.86 | 0.0015 | 0.83 | 185.08 | 145.34 |
| Bilate Reaches | 144661 | 193.15 | 1896.28 | 1899.1 | 1897.84 | 1899.14 | 0.00138 | 0.85 | 227.34 | 161.08 |
| Bilate Reaches | 144661 | 173.62 | 1896.28 | 1898.96 | 1897.78 | 1899 | 0.00146 | 0.84 | 205.5 | 153.15 |
| Bilate Reaches | 144661 | 305.31 | 1896.28 | 1899.67 | 1898.15 | 1899.71 | 0.00131 | 0.93 | 327.36 | 193.29 |
| Bilate Reaches | 144661 | 335.87 | 1896.28 | 1899.79 | 1898.23 | 1899.84 | 0.0013 | 0.95 | 351.97 | 200.43 |
| Bilate Reaches | 143989 | 153.2 | 1888.79 | 1891.78 | 1890.22 | 1891.8 | 0.00065 | 0.6 | 253.84 | 169.94 |
| Bilate Reaches | 143989 | 193.15 | 1888.79 | 1892.17 | 1890.36 | 1892.18 | 0.00067 | 0.58 | 330.24 | 237.14 |
| Bilate Reaches | 143989 | 173.62 | 1888.79 | 1891.95 | 1890.29 | 1891.97 | 0.00065 | 0.61 | 283.49 | 187.34 |
| Bilate Reaches | 143989 | 305.31 | 1888.79 | 1892.78 | 1890.66 | 1892.8 | 0.00069 | 0.59 | 517.42 | 375.32 |
| Bilate Reaches | 143989 | 335.87 | 1888.79 | 1892.89 | 1890.74 | 1892.91 | 0.00069 | 0.6 | 561.97 | 401.27 |
| Bilate Reaches | 136193 | 153.2 | 1877.08 | 1881.59 | | 1881.6 | 0.0003 | 0.53 | 287.61 | 128.9 |
| Bilate Reaches | 136193 | 193.15 | 1877.08 | 1882.12 | | 1882.13 | 0.00026 | 0.54 | 360.12 | 144.71 |
| Bilate Reaches | 136193 | 173.62 | 1877.08 | 1881.96 | | 1881.97 | 0.00025 | 0.51 | 337.49 | 139.97 |
| Bilate Reaches | 136193 | 305.31 | 1877.08 | 1882.91 | | 1882.93 | 0.0003 | 0.63 | 484 | 168.33 |
| Bilate Reaches | 136193 | 335.87 | 1877.08 | 1883.08 | | 1883.1 | 0.00031 | 0.65 | 513.53 | 173.49 |
| Bilate Reaches | 135198 | 153.2 | 1874.47 | 1875.74 | | 1875.76 | 0.00226 | 0.66 | 233.08 | 351.69 |
| Bilate Reaches | 135198 | 193.15 | 1874.47 | 1875.65 | | 1875.69 | 0.00563 | 0.96 | 201.79 | 343.03 |
| Bilate Reaches | 135198 | 173.62 | 1874.47 | 1875.58 | | 1875.63 | 0.0063 | 0.97 | 178.51 | 322.64 |
| Bilate Reaches | 135198 | 305.31 | 1874.47 | 1875.87 | | 1875.93 | 0.00493 | 1.08 | 281.71 | 360.14 |
| Bilate Reaches | 135198 | 335.87 | 1874.47 | 1875.94 | | 1876 | 0.00468 | 1.1 | 304.45 | 364.02 |
| Bilate Reaches | 134291 | 153.2 | 1866.65 | 1868.42 | | 1868.42 | 0.00041 | 0.34 | 453.98 | 514.01 |
| Bilate Reaches | 134291 | 193.15 | 1866.65 | 1868.71 | | 1868.71 | 0.00029 | 0.31 | 615.94 | 598.71 |
| Bilate Reaches | 134291 | 173.62 | 1866.65 | 1868.64 | | 1868.64 | 0.00028 | 0.3 | 573.91 | 577.93 |
| Bilate Reaches | 134291 | 305.31 | 1866.65 | 1869.09 | | 1869.1 | 0.00029 | 0.35 | 867.07 | 710.36 |
| Bilate Reaches | 134291 | 335.87 | 1866.65 | 1869.18 | | 1869.18 | 0.00029 | 0.36 | 928.16 | 734.96 |

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| Bilate Reaches | 133632 | 153.2 | 1860.71 | 1862.16 | 1861.45 | 1862.17 | 0.00117 | 0.5 | 305.32 | 421.86 |
| Bilate Reaches | 133632 | 193.15 | 1860.71 | 1862 | 1861.52 | 1862.04 | 0.00339 | 0.79 | 244.02 | 377.14 |
| Bilate Reaches | 133632 | 173.62 | 1860.71 | 1861.93 | 1861.49 | 1861.97 | 0.00369 | 0.8 | 218.09 | 356.54 |
| Bilate Reaches | 133632 | 305.31 | 1860.71 | 1862.22 | 1861.69 | 1862.26 | 0.00371 | 0.92 | 332.46 | 440.21 |
| Bilate Reaches | 133632 | 335.87 | 1860.71 | 1862.28 | 1861.72 | 1862.33 | 0.00365 | 0.93 | 359.52 | 457.78 |
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| Bilate Reaches | 122554 | 153.2 | 1791.18 | 1792.15 | | 1792.15 | 0.001 | 0.35 | 432.93 | 895.05 |
| Bilate Reaches | 122554 | 193.15 | 1791.18 | 1792.27 | | 1792.27 | 0.00085 | 0.35 | 546.05 | 1005.21 |
| Bilate Reaches | 122554 | 173.62 | 1791.18 | 1792.21 | | 1792.22 | 0.00091 | 0.35 | 491.67 | 953.84 |
| Bilate Reaches | 122554 | 305.31 | 1791.18 | 1792.54 | | 1792.54 | 0.00066 | 0.36 | 850.03 | 1254.17 |
| Bilate Reaches | 122554 | 335.87 | 1791.18 | 1792.6 | | 1792.61 | 0.00062 | 0.36 | 930.03 | 1311.86 |
| | | | | | | | | | | |
| Bilate Reaches | 120971 | 153.2 | 1784.73 | 1786.4 | | 1786.41 | 0.00025 | 0.26 | 595.08 | 711.21 |
| Bilate Reaches | 120971 | 193.15 | 1784.73 | 1786.53 | | 1786.53 | 0.00028 | 0.28 | 686.63 | 763.97 |
| Bilate Reaches | 120971 | 173.62 | 1784.73 | 1786.47 | | 1786.47 | 0.00027 | 0.27 | 642.46 | 738.98 |
| Bilate Reaches | 120971 | 305.31 | 1784.73 | 1786.8 | | 1786.8 | 0.00033 | 0.34 | 909.42 | 879.21 |
| Bilate Reaches | 120971 | 335.87 | 1784.73 | 1786.86 | | 1786.87 | 0.00034 | 0.35 | 963.86 | 905.15 |
| | | | | | | | | | | |
| Bilate Reaches | 119912 | 153.2 | 1779.86 | 1781.15 | | 1781.16 | 0.00103 | 0.44 | 351.87 | 545.89 |
| Bilate Reaches | 119912 | 193.15 | 1779.86 | 1781.31 | | 1781.32 | 0.00086 | 0.43 | 447.28 | 615.47 |
| Bilate Reaches | 119912 | 173.62 | 1779.86 | 1781.24 | | 1781.25 | 0.00093 | 0.43 | 401.52 | 583.14 |
| Bilate Reaches | 119912 | 305.31 | 1779.86 | 1781.69 | | 1781.7 | 0.00063 | 0.43 | 709.27 | 775.04 |
| Bilate Reaches | 119912 | 335.87 | 1779.86 | 1781.78 | | 1781.79 | 0.00059 | 0.43 | 779.2 | 812.35 |
| | | | | | | | | | | |
| Bilate Reaches | 118818 | 153.2 | 1775.5 | 1781.14 | | 1781.14 | 1E-06 | 0.02 | 6201.73 | 1891.74 |
| Bilate Reaches | 118818 | 193.15 | 1775.5 | 1781.3 | | 1781.3 | 1E-06 | 0.03 | 6502.88 | 1922.52 |
| Bilate Reaches | 118818 | 173.62 | 1775.5 | 1781.22 | | 1781.22 | 1E-06 | 0.03 | 6362.62 | 1908.25 |
| Bilate Reaches | 118818 | 305.31 | 1775.5 | 1781.66 | | 1781.66 | 1E-06 | 0.04 | 7203.49 | 1992.28 |
| Bilate Reaches | 118818 | 335.87 | 1775.5 | 1781.74 | | 1781.74 | 1E-06 | 0.05 | 7369.61 | 2008.47 |
| | | | | | | | | | | |
| Bilate Reaches | 117971 | 153.2 | 1771.74 | 1781.14 | | 1781.14 | 1E-06 | 0.01 | 10820.6 | 2081.29 |
| Bilate Reaches | 117971 | 193.15 | 1771.74 | 1781.3 | | 1781.3 | 1E-06 | 0.02 | 11150.4 | 2111.95 |
| Bilate Reaches | 117971 | 173.62 | 1771.74 | 1781.22 | | 1781.22 | 1E-06 | 0.02 | 10996.9 | 2097.74 |
| Bilate Reaches | 117971 | 305.31 | 1771.74 | 1781.65 | | 1781.65 | 1E-06 | 0.03 | 11914.9 | 2181.37 |
| Bilate Reaches | 117971 | 335.87 | 1771.74 | 1781.73 | | 1781.73 | 1E-06 | 0.03 | 12095.4 | 2197.44 |
| | | | | | | | 1E-06 | | | |
| Bilate Reaches | 117250 | 153.2 | 1772.19 | 1781.14 | | 1781.14 | 1E-06 | 0.01 | 12757.7 | 2282.87 |
| Bilate Reaches | 117250 | 193.15 | 1772.19 | 1781.29 | | 1781.29 | 1E-06 | 0.02 | 13118.8 | 2312.07 |
| Bilate Reaches | 117250 | 173.62 | 1772.19 | 1781.22 | | 1781.22 | 1E-06 | 0.01 | 12951 | 2298.55 |
| Bilate Reaches | 117250 | 305.31 | 1772.19 | 1781.65 | | 1781.65 | 1E-06 | 0.02 | 13951.8 | 2378.09 |
| Bilate Reaches | 117250 | 335.87 | 1772.19 | 1781.73 | | 1781.73 | 1E-06 | 0.02 | 14147.8 | 2393.35 |
| | | | | | | | | | | |
| Bilate Reaches | 116165 | 153.2 | 1777.89 | 1781.14 | | 1781.14 | 1E-06 | 0.03 | 5300.45 | 2835.7 |
| Bilate Reaches | 116165 | 193.15 | 1777.89 | 1781.29 | | 1781.29 | 1E-06 | 0.04 | 5747.14 | 2864.85 |
| Bilate Reaches | 116165 | 173.62 | 1777.89 | 1781.22 | | 1781.22 | 1E-06 | 0.04 | 5539.98 | 2851.37 |
| Bilate Reaches | 116165 | 305.31 | 1777.89 | 1781.65 | | 1781.65 | 2E-06 | 0.05 | 6771.82 | 2930.63 |
| Bilate Reaches | 116165 | 335.87 | 1777.89 | 1781.73 | | 1781.73 | 2E-06 | 0.05 | 7012.33 | 2945.86 |
| | | | | | | | | | | |
| Bilate Reaches | 115105 | 153.2 | 1784.9 | 1781.08 | 1780.4 | 1781.11 | 0.00318 | | 195.96 | 234.54 |
| Bilate Reaches | 115105 | 193.15 | 1784.9 | 1781.23 | 1780.5 | 1781.26 | 0.00322 | | 232.04 | 255.21 |
| Bilate Reaches | 115105 | 173.62 | 1784.9 | 1781.16 | 1780.45 | 1781.19 | 0.00319 | | 215.04 | 245.69 |
| Bilate Reaches | 115105 | 305.31 | 1784.9 | 1781.56 | 1780.72 | 1781.6 | 0.00331 | | 323.93 | 301.55 |
| Bilate Reaches | 115105 | 335.87 | 1784.9 | 1781.63 | 1780.76 | 1781.68 | 0.00333 | | 347.22 | 312.2 |
| | | | | | | | | | | |
| Bilate Reaches | 113885 | 153.2 | 1779.43 | 1772.54 | 1772.54 | 1772.79 | 0.05101 | | 69.24 | 139.46 |
| Bilate Reaches | 113885 | 193.15 | 1779.43 | 1772.64 | 1772.64 | 1772.91 | 0.04946 | | 83.34 | 153 |
| Bilate Reaches | 113885 | 173.62 | 1779.43 | 1772.59 | 1772.59 | 1772.86 | 0.051 | | 76.06 | 146.17 |
| Bilate Reaches | 113885 | 305.31 | 1779.43 | 1772.86 | 1772.86 | 1773.19 | 0.0464 | | 120.34 | 183.85 |
| Bilate Reaches | 113885 | 335.87 | 1779.43 | 1772.91 | 1772.91 | 1773.25 | 0.04576 | | 129.94 | 191.04 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Bilate Reaches | 113065 | 153.2 | 1768.24 | 1767.5 | 1766.74 | 1767.52 | 0.00252 | | 213.99 | 245.05 |
| Bilate Reaches | 113065 | 193.15 | 1768.24 | 1767.67 | 1766.84 | 1767.7 | 0.00241 | | 258.91 | 269.54 |
| Bilate Reaches | 113065 | 173.62 | 1768.24 | 1767.59 | 1766.79 | 1767.62 | 0.00246 | | 237.04 | 257.91 |
| Bilate Reaches | 113065 | 305.31 | 1768.24 | 1768.07 | 1767.05 | 1768.11 | 0.00219 | | 378.11 | 325.74 |
| Bilate Reaches | 113065 | 335.87 | 1768.24 | 1768.17 | 1767.1 | 1768.2 | 0.00214 | | 409.67 | 339.06 |
| | | | | | | | | | | |
| Bilate Reaches | 112488 | 153.2 | 1761.13 | 1763.63 | 1762.12 | 1763.64 | 0.00025 | 0.36 | 439.52 | 351.08 |
| Bilate Reaches | 112488 | 193.15 | 1761.13 | 1763.86 | 1762.22 | 1763.87 | 0.00025 | 0.39 | 521.9 | 382.58 |
| Bilate Reaches | 112488 | 173.62 | 1761.13 | 1763.75 | 1762.17 | 1763.76 | 0.00025 | 0.37 | 482.31 | 367.78 |
| Bilate Reaches | 112488 | 305.31 | 1761.13 | 1764.36 | 1762.44 | 1764.37 | 0.00026 | 0.44 | 732.98 | 453.4 |
| Bilate Reaches | 112488 | 335.87 | 1761.13 | 1764.48 | 1762.49 | 1764.49 | 0.00026 | 0.45 | 786.13 | 469.55 |
| | | | | | | | | | | |
| Bilate Reaches | 111753 | 153.2 | 1755.41 | 1757.31 | | 1757.33 | 0.00118 | 0.6 | 253.98 | 267.21 |
| Bilate Reaches | 111753 | 193.15 | 1755.41 | 1757.47 | | 1757.5 | 0.00121 | 0.64 | 299.48 | 290.16 |
| Bilate Reaches | 111753 | 173.62 | 1755.41 | 1757.4 | | 1757.42 | 0.0012 | 0.63 | 277.44 | 279.28 |
| Bilate Reaches | 111753 | 305.31 | 1755.41 | 1757.84 | | 1757.87 | 0.00126 | 0.74 | 414.87 | 341.51 |
| Bilate Reaches | 111753 | 335.87 | 1755.41 | 1757.93 | | 1757.96 | 0.00127 | 0.76 | 444.83 | 353.63 |
| | | | | | | | | | | |
| Bilate Reaches | 109420 | 153.2 | 1734.55 | 1736.23 | | 1736.26 | 0.00211 | 0.74 | 206.49 | 246.33 |
| Bilate Reaches | 109420 | 193.15 | 1734.55 | 1736.39 | | 1736.42 | 0.00205 | 0.78 | 248.47 | 270.21 |
| Bilate Reaches | 109420 | 173.62 | 1734.55 | 1736.31 | | 1736.34 | 0.00207 | 0.76 | 228.35 | 259.04 |
| Bilate Reaches | 109420 | 305.31 | 1734.55 | 1736.76 | | 1736.8 | 0.00193 | 0.85 | 358.11 | 324.4 |
| Bilate Reaches | 109420 | 335.87 | 1734.55 | 1736.84 | | 1736.88 | 0.00192 | 0.87 | 385.31 | 336.49 |
| | | | | | | | | | | |
| Bilate Reaches | 107883 | 153.2 | 1723.29 | 1725.61 | | 1725.62 | 0.00041 | 0.41 | 376.77 | 324.69 |
| Bilate Reaches | 107883 | 193.15 | 1723.29 | 1725.82 | | 1725.83 | 0.00041 | 0.43 | 447.04 | 353.67 |
| Bilate Reaches | 107883 | 173.62 | 1723.29 | 1725.72 | | 1725.73 | 0.00041 | 0.42 | 413.03 | 339.95 |
| Bilate Reaches | 107883 | 305.31 | 1723.29 | 1726.27 | | 1726.28 | 0.00042 | 0.49 | 621.5 | 417.03 |
| Bilate Reaches | 107883 | 335.87 | 1723.29 | 1726.37 | | 1726.38 | 0.00042 | 0.51 | 662.11 | 430.45 |
| | | | | | | | | | | |
| Bilate Reaches | 106035 | 153.2 | 1716.5 | 1718.59 | | 1718.6 | 0.00071 | 0.5 | 306.91 | 293.65 |
| Bilate Reaches | 106035 | 193.15 | 1716.5 | 1718.78 | | 1718.8 | 0.00071 | 0.53 | 365.78 | 320.58 |
| Bilate Reaches | 106035 | 173.62 | 1716.5 | 1718.69 | | 1718.71 | 0.00071 | 0.51 | 337.67 | 308.02 |
| Bilate Reaches | 106035 | 305.31 | 1716.5 | 1719.22 | | 1719.23 | 0.0007 | 0.59 | 518.42 | 381.66 |
| Bilate Reaches | 106035 | 335.87 | 1716.5 | 1719.32 | | 1719.34 | 0.0007 | 0.6 | 557.41 | 395.75 |
| | | | | | | | | | | |
| Bilate Reaches | 105083 | 153.2 | 1709.86 | 1712.15 | | 1712.15 | 0.00044 | 0.42 | 366.56 | 320.79 |
| Bilate Reaches | 105083 | 193.15 | 1709.86 | 1712.35 | | 1712.36 | 0.00044 | 0.44 | 436.19 | 349.93 |
| Bilate Reaches | 105083 | 173.62 | 1709.86 | 1712.26 | | 1712.26 | 0.00044 | 0.43 | 402.44 | 336.12 |
| Bilate Reaches | 105083 | 305.31 | 1709.86 | 1712.82 | | 1712.83 | 0.00044 | 0.5 | 614.24 | 415.25 |
| Bilate Reaches | 105083 | 335.87 | 1709.86 | 1712.93 | | 1712.94 | 0.00044 | 0.51 | 659.8 | 430.38 |
| | | | | | | | | | | |
| Bilate Reaches | 103749 | 153.2 | 1703.53 | 1705.65 | | 1705.66 | 0.00066 | 0.48 | 315.94 | 297.88 |
| Bilate Reaches | 103749 | 193.15 | 1703.53 | 1705.84 | | 1705.86 | 0.00066 | 0.51 | 375.28 | 324.65 |
| Bilate Reaches | 103749 | 173.62 | 1703.53 | 1705.75 | | 1705.77 | 0.00066 | 0.5 | 346.99 | 312.18 |
| Bilate Reaches | 103749 | 305.31 | 1703.53 | 1706.27 | | 1706.29 | 0.00067 | 0.58 | 526.93 | 384.7 |
| Bilate Reaches | 103749 | 335.87 | 1703.53 | 1706.37 | | 1706.39 | 0.00067 | 0.59 | 565.64 | 398.57 |
| | | | | | | | | | | |
| Bilate Reaches | 102739 | 153.2 | 1696.9 | 1699.13 | | 1699.14 | 0.0005 | 0.44 | 349.84 | 313.33 |
| Bilate Reaches | 102739 | 193.15 | 1696.9 | 1699.34 | | 1699.35 | 0.0005 | 0.46 | 417.76 | 342.4 |
| Bilate Reaches | 102739 | 173.62 | 1696.9 | 1699.24 | | 1699.25 | 0.0005 | 0.45 | 384.76 | 328.6 |
| Bilate Reaches | 102739 | 305.31 | 1696.9 | 1699.81 | | 1699.82 | 0.00049 | 0.51 | 593.22 | 408.02 |
| Bilate Reaches | 102739 | 335.87 | 1696.9 | 1699.92 | | 1699.93 | 0.00048 | 0.53 | 638.56 | 423.32 |
| | | | | | | | | | | |
| Bilate Reaches | 102000 | 153.2 | 1691.52 | 1693.82 | 1692.51 | 1693.83 | 0.00043 | 0.41 | 372.04 | 323.13 |
| Bilate Reaches | 102000 | 193.15 | 1691.52 | 1694.03 | 1692.61 | 1694.04 | 0.00043 | 0.44 | 441.1 | 351.85 |
| Bilate Reaches | 102000 | 173.62 | 1691.52 | 1693.93 | 1692.56 | 1693.94 | 0.00043 | 0.43 | 408.07 | 338.42 |
| Bilate Reaches | 102000 | 305.31 | 1691.52 | 1694.48 | | 1694.5 | 0.00044 | 0.5 | 616.57 | 415.99 |
| Bilate Reaches | 102000 | 335.87 | 1691.52 | 1694.59 | | 1694.6 | 0.00044 | 0.51 | 660.73 | 430.63 |
| | | | | | | | | | | |
| Bilate Reaches | 101087 | 153.2 | 1683.8 | 1685.67 | 1684.79 | 1685.69 | 0.00128 | 0.62 | 246.34 | 263.07 |
| Bilate Reaches | 101087 | 193.15 | 1683.8 | 1685.85 | 1684.89 | 1685.87 | 0.00127 | 0.66 | 293.72 | 287.25 |
| Bilate Reaches | 101087 | 173.62 | 1683.8 | 1685.76 | 1684.84 | 1685.78 | 0.00128 | 0.64 | 270.56 | 275.69 |
| Bilate Reaches | 101087 | 305.31 | 1683.8 | 1686.24 | 1685.11 | 1686.26 | 0.00125 | 0.73 | 416.92 | 342.23 |
| Bilate Reaches | 101087 | 335.87 | 1683.8 | 1686.33 | 1685.16 | 1686.36 | 0.00124 | 0.75 | 448.89 | 355.11 |

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|---|---|---|---|---|---|---|---|---|---|---|
| Bilate Reaches | 99571.2 | 153.2 | 1675.58 | 1677.39 | 1676.28 | 1677.4 | 0.00084 | 0.49 | 310.97 | 295.41 |
| Bilate Reaches | 99571.2 | 193.15 | 1675.58 | 1677.58 | 1676.38 | 1677.6 | 0.00082 | 0.52 | 371.76 | 323 |
| Bilate Reaches | 99571.2 | 173.62 | 1675.58 | 1677.49 | 1676.33 | 1677.51 | 0.00083 | 0.51 | 342.78 | 310.15 |
| Bilate Reaches | 99571.2 | 305.31 | 1675.58 | 1678.02 | 1676.59 | 1678.04 | 0.00081 | 0.59 | 527.43 | 384.73 |
| Bilate Reaches | 99571.2 | 335.87 | 1675.58 | 1678.12 | 1676.64 | 1678.14 | 0.00081 | 0.61 | 566.73 | 398.81 |
| | | | | | | | | | | |
| Bilate Reaches | 99009.8 | 153.2 | 1672.9 | 1670.96 | 1670.96 | 1671.23 | 0.04955 | | 66.84 | 124.9 |
| Bilate Reaches | 99009.8 | 193.15 | 1672.9 | 1671.06 | 1671.06 | 1671.36 | 0.04815 | | 80.38 | 136.97 |
| Bilate Reaches | 99009.8 | 173.62 | 1672.9 | 1671.01 | 1671.01 | 1671.3 | 0.04964 | | 73.36 | 130.86 |
| Bilate Reaches | 99009.8 | 305.31 | 1672.9 | 1671.3 | 1671.3 | 1671.65 | 0.0461 | | 115.18 | 163.96 |
| Bilate Reaches | 99009.8 | 335.87 | 1672.9 | 1671.35 | 1671.35 | 1671.72 | 0.04547 | | 124.36 | 170.37 |
| | | | | | | | | | | |
| Bilate Reaches | 97494 | 153.2 | 1655.27 | 1657.94 | 1656.43 | 1657.95 | 0.00042 | 0.45 | 338.77 | 253.6 |
| Bilate Reaches | 97494 | 193.15 | 1655.27 | 1658.18 | 1656.54 | 1658.19 | 0.00043 | 0.48 | 400.91 | 275.87 |
| Bilate Reaches | 97494 | 173.62 | 1655.27 | 1658.07 | 1656.49 | 1658.08 | 0.00042 | 0.47 | 371.1 | 265.42 |
| Bilate Reaches | 97494 | 305.31 | 1655.27 | 1658.7 | 1656.8 | 1658.71 | 0.00044 | 0.55 | 557.54 | 325.33 |
| Bilate Reaches | 97494 | 335.87 | 1655.27 | 1658.82 | 1656.86 | 1658.83 | 0.00045 | 0.56 | 597.19 | 336.7 |
| | | | | | | | | | | |
| Bilate Reaches | 96602.2 | 153.2 | 1647.83 | 1649.78 | | 1649.8 | 0.0013 | 0.65 | 237.31 | 243.2 |
| Bilate Reaches | 96602.2 | 193.15 | 1647.83 | 1649.96 | | 1649.99 | 0.0013 | 0.68 | 283.01 | 265.58 |
| Bilate Reaches | 96602.2 | 173.62 | 1647.83 | 1649.88 | | 1649.9 | 0.0013 | 0.67 | 260.74 | 254.92 |
| Bilate Reaches | 96602.2 | 305.31 | 1647.83 | 1650.37 | | 1650.4 | 0.00126 | 0.76 | 402.99 | 316.92 |
| Bilate Reaches | 96602.2 | 335.87 | 1647.83 | 1650.47 | | 1650.5 | 0.00125 | 0.77 | 433.74 | 328.79 |
| | | | | | | | | | | |
| Bilate Reaches | 95315.4 | 153.2 | 1637.49 | 1639.67 | | 1639.68 | 0.00072 | 0.52 | 295.98 | 271.48 |
| Bilate Reaches | 95315.4 | 193.15 | 1637.49 | 1639.87 | | 1639.88 | 0.00072 | 0.55 | 351.93 | 296.03 |
| Bilate Reaches | 95315.4 | 173.62 | 1637.49 | 1639.78 | | 1639.79 | 0.00072 | 0.53 | 325.27 | 284.6 |
| Bilate Reaches | 95315.4 | 305.31 | 1637.49 | 1640.3 | | 1640.32 | 0.00074 | 0.62 | 493.17 | 350.43 |
| Bilate Reaches | 95315.4 | 335.87 | 1637.49 | 1640.41 | | 1640.43 | 0.00074 | 0.63 | 529.17 | 363 |
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| Bilate Reaches | 94347 | 153.2 | 1630.14 | 1633.88 | | 1633.9 | 0.00054 | 0.58 | 265.31 | 164.62 |
| Bilate Reaches | 94347 | 193.15 | 1630.14 | 1634.27 | | 1634.29 | 0.0005 | 0.58 | 335.26 | 199.33 |
| Bilate Reaches | 94347 | 173.62 | 1630.14 | 1634.09 | | 1634.11 | 0.00052 | 0.58 | 301.54 | 183.42 |
| Bilate Reaches | 94347 | 305.31 | 1630.14 | 1635.04 | | 1635.06 | 0.00044 | 0.59 | 516.44 | 269.17 |
| Bilate Reaches | 94347 | 335.87 | 1630.14 | 1635.21 | | 1635.23 | 0.00043 | 0.6 | 563.16 | 284.41 |
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| Bilate Reaches | 93253.6 | 153.2 | 1625.9 | 1630.07 | | 1630.09 | 0.00026 | 0.48 | 321.76 | 154.17 |
| Bilate Reaches | 93253.6 | 193.15 | 1625.9 | 1630.39 | | 1630.4 | 0.00028 | 0.52 | 372.19 | 165.81 |
| Bilate Reaches | 93253.6 | 173.62 | 1625.9 | 1630.24 | | 1630.25 | 0.00027 | 0.5 | 347.95 | 160.32 |
| Bilate Reaches | 93253.6 | 305.31 | 1625.9 | 1631.11 | | 1631.13 | 0.00031 | 0.61 | 501.55 | 192.48 |
| Bilate Reaches | 93253.6 | 335.87 | 1625.9 | 1631.28 | | 1631.3 | 0.00032 | 0.63 | 534.71 | 198.74 |
| | | | | | | | | | | |
| Bilate Reaches | 92341.6 | 153.2 | 1622.23 | 1625.61 | | 1625.63 | 0.0008 | 0.73 | 210.41 | 124.67 |
| Bilate Reaches | 92341.6 | 193.15 | 1622.23 | 1626.06 | | 1626.08 | 0.00065 | 0.71 | 270.26 | 141.29 |
| Bilate Reaches | 92341.6 | 173.62 | 1622.23 | 1625.85 | | 1625.87 | 0.00071 | 0.72 | 241.3 | 133.5 |
| Bilate Reaches | 92341.6 | 305.31 | 1622.23 | 1627.05 | | 1627.08 | 0.00048 | 0.71 | 428.92 | 177.99 |
| Bilate Reaches | 92341.6 | 335.87 | 1622.23 | 1627.28 | | 1627.3 | 0.00045 | 0.71 | 470.4 | 186.4 |
| | | | | | | | | | | |
| Bilate Reaches | 91500 | 153.2 | 1618.47 | 1624.09 | | 1624.1 | 5.2E-05 | 0.26 | 585.47 | 208.23 |
| Bilate Reaches | 91500 | 193.15 | 1618.47 | 1624.53 | | 1624.53 | 5.6E-05 | 0.28 | 679.83 | 224.38 |
| Bilate Reaches | 91500 | 173.62 | 1618.47 | 1624.32 | | 1624.33 | 5.4E-05 | 0.27 | 634.59 | 216.79 |
| Bilate Reaches | 91500 | 305.31 | 1618.47 | 1625.5 | | 1625.51 | 6.3E-05 | 0.33 | 915.39 | 260.37 |
| Bilate Reaches | 91500 | 335.87 | 1618.47 | 1625.73 | | 1625.73 | 6.5E-05 | 0.34 | 974.47 | 268.64 |
| | | | | | | | | | | |
| Bilate Reaches | 91472.1 | 153.2 | 1618.36 | 1622.68 | | 1622.69 | 0.00021 | 0.44 | 345.14 | 159.81 |
| Bilate Reaches | 91472.1 | 193.15 | 1618.36 | 1623.03 | | 1623.04 | 0.00022 | 0.48 | 403.39 | 172.77 |
| Bilate Reaches | 91472.1 | 173.62 | 1618.36 | 1622.86 | | 1622.88 | 0.00022 | 0.46 | 375.26 | 166.63 |
| Bilate Reaches | 91472.1 | 305.31 | 1618.36 | 1623.84 | | 1623.86 | 0.00024 | 0.55 | 555.61 | 202.76 |
| Bilate Reaches | 91472.1 | 335.87 | 1618.36 | 1624.03 | | 1624.05 | 0.00024 | 0.56 | 595.28 | 209.87 |
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| Bilate Reaches | 90702.5 | 153.2 | 1615.18 | 1619.11 | | 1619.13 | 0.00035 | 0.54 | 285.71 | 145.3 |
| Bilate Reaches | 90702.5 | 193.15 | 1615.18 | 1619.57 | | 1619.59 | 0.00031 | 0.54 | 356.41 | 162.28 |
| Bilate Reaches | 90702.5 | 173.62 | 1615.18 | 1619.36 | | 1619.37 | 0.00033 | 0.54 | 322.23 | 154.3 |
| Bilate Reaches | 90702.5 | 305.31 | 1615.18 | 1620.59 | | 1620.61 | 0.00026 | 0.56 | 540.54 | 199.85 |
| Bilate Reaches | 90702.5 | 335.87 | 1615.18 | 1620.82 | | 1620.84 | 0.00025 | 0.57 | 587.81 | 208.41 |

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| Bilate Reaches | 90000 | 153.2 | 1612.2 | 1617.97 | | 1617.97 | 4.6E-05 | 0.25 | 610.85 | 211.85 |
| Bilate Reaches | 90000 | 193.15 | 1612.2 | 1618.41 | | 1618.41 | 0.00005 | 0.27 | 707.3 | 227.96 |
| Bilate Reaches | 90000 | 173.62 | 1612.2 | 1618.2 | | 1618.2 | 4.8E-05 | 0.26 | 661.03 | 220.38 |
| Bilate Reaches | 90000 | 305.31 | 1612.2 | 1619.37 | | 1619.38 | 5.8E-05 | 0.32 | 945.41 | 263.56 |
| Bilate Reaches | 90000 | 335.87 | 1612.2 | 1619.6 | | 1619.6 | 5.9E-05 | 0.33 | 1004.4 | 271.65 |
| | | | | | | | | | | |
| Bilate Reaches | 89989.3 | 153.2 | 1612.16 | 1616.83 | | 1616.84 | 0.00014 | 0.38 | 400.72 | 171.57 |
| Bilate Reaches | 89989.3 | 193.15 | 1612.16 | 1617.18 | | 1617.19 | 0.00016 | 0.42 | 463.02 | 184.43 |
| Bilate Reaches | 89989.3 | 173.62 | 1612.16 | 1617.02 | | 1617.03 | 0.00015 | 0.4 | 433.24 | 178.4 |
| Bilate Reaches | 89989.3 | 305.31 | 1612.16 | 1617.96 | | 1617.97 | 0.00018 | 0.49 | 617.35 | 212.96 |
| Bilate Reaches | 89989.3 | 335.87 | 1612.16 | 1618.14 | | 1618.15 | 0.00019 | 0.51 | 655.68 | 219.47 |
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| Bilate Reaches | 89141.5 | 153.2 | 1608.49 | 1610.62 | | 1610.79 | 0.00928 | 1.83 | 83.91 | 78.73 |
| Bilate Reaches | 89141.5 | 193.15 | 1608.49 | 1611.1 | | 1611.22 | 0.00497 | 1.53 | 126.22 | 96.56 |
| Bilate Reaches | 89141.5 | 173.62 | 1608.49 | 1610.88 | | 1611.02 | 0.00646 | 1.64 | 105.63 | 88.33 |
| Bilate Reaches | 89141.5 | 305.31 | 1608.49 | 1612.12 | | 1612.2 | 0.00216 | 1.26 | 243.22 | 134.03 |
| Bilate Reaches | 89141.5 | 335.87 | 1608.49 | 1612.35 | | 1612.42 | 0.00189 | 1.22 | 274.65 | 142.43 |
| | | | | | | | | | | |
| Bilate Reaches | 87049.6 | 153.2 | 1603.06 | 1608.68 | | 1608.69 | 5.3E-05 | 0.26 | 583.98 | 207.77 |
| Bilate Reaches | 87049.6 | 193.15 | 1603.06 | 1609.13 | | 1609.13 | 5.6E-05 | 0.28 | 680.06 | 224.21 |
| Bilate Reaches | 87049.6 | 173.62 | 1603.06 | 1608.92 | | 1608.92 | 5.4E-05 | 0.27 | 634.09 | 216.5 |
| Bilate Reaches | 87049.6 | 305.31 | 1603.06 | 1610.11 | | 1610.12 | 6.2E-05 | 0.33 | 918.98 | 260.63 |
| Bilate Reaches | 87049.6 | 335.87 | 1603.06 | 1610.34 | | 1610.34 | 6.4E-05 | 0.34 | 978.8 | 268.98 |
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| Bilate Reaches | 87000 | 153.2 | 1602.84 | 1607.82 | | 1607.82 | 0.0001 | 0.33 | 458.48 | 184.17 |
| Bilate Reaches | 87000 | 193.15 | 1602.84 | 1608.21 | | 1608.22 | 0.00011 | 0.36 | 533.69 | 198.7 |
| Bilate Reaches | 87000 | 173.62 | 1602.84 | 1608.03 | | 1608.03 | 0.0001 | 0.35 | 497.71 | 191.89 |
| Bilate Reaches | 87000 | 305.31 | 1602.84 | 1609.09 | | 1609.1 | 0.00012 | 0.42 | 722.26 | 231.15 |
| Bilate Reaches | 87000 | 335.87 | 1602.84 | 1609.29 | | 1609.3 | 0.00012 | 0.44 | 770.08 | 238.68 |
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| Bilate Reaches | 86584 | 153.2 | 1601.01 | 1604.09 | | 1604.12 | 0.00132 | 0.88 | 174.57 | 113.55 |
| Bilate Reaches | 86584 | 193.15 | 1601.01 | 1604.52 | | 1604.56 | 0.00103 | 0.85 | 227.89 | 129.74 |
| Bilate Reaches | 86584 | 173.62 | 1601.01 | 1604.32 | | 1604.36 | 0.00115 | 0.86 | 201.96 | 122.14 |
| Bilate Reaches | 86584 | 305.31 | 1601.01 | 1605.5 | | 1605.53 | 0.0007 | 0.82 | 372.03 | 165.77 |
| Bilate Reaches | 86584 | 335.87 | 1601.01 | 1605.72 | | 1605.76 | 0.00065 | 0.82 | 409.93 | 174.01 |
| | | | | | | | | | | |
| Bilate Reaches | 85509.7 | 153.2 | 1596.8 | 1602.31 | | 1602.31 | 5.8E-05 | 0.27 | 562.07 | 204 |
| Bilate Reaches | 85509.7 | 193.15 | 1596.8 | 1602.75 | | 1602.75 | 6.2E-05 | 0.29 | 654.94 | 220.21 |
| Bilate Reaches | 85509.7 | 173.62 | 1596.8 | 1602.54 | | 1602.55 | 0.00006 | 0.28 | 610.43 | 212.6 |
| Bilate Reaches | 85509.7 | 305.31 | 1596.8 | 1603.72 | | 1603.73 | 6.9E-05 | 0.34 | 886.13 | 256.14 |
| Bilate Reaches | 85509.7 | 335.87 | 1596.8 | 1603.94 | | 1603.95 | 0.00007 | 0.36 | 943.88 | 264.36 |
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| Bilate Reaches | 85500 | 153.2 | 1596.75 | 1601.03 | | 1601.04 | 0.00022 | 0.45 | 339.83 | 158.72 |
| Bilate Reaches | 85500 | 193.15 | 1596.75 | 1601.42 | | 1601.44 | 0.00022 | 0.48 | 404.7 | 173.21 |
| Bilate Reaches | 85500 | 173.62 | 1596.75 | 1601.24 | | 1601.25 | 0.00022 | 0.46 | 373.49 | 166.4 |
| Bilate Reaches | 85500 | 305.31 | 1596.75 | 1602.29 | | 1602.31 | 0.00022 | 0.54 | 569.64 | 205.5 |
| Bilate Reaches | 85500 | 335.87 | 1596.75 | 1602.49 | | 1602.51 | 0.00022 | 0.55 | 611.23 | 212.87 |
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| Bilate Reaches | 84575.8 | 153.2 | 1592.95 | 1596.9 | | 1596.91 | 0.00035 | 0.53 | 287.48 | 145.73 |
| Bilate Reaches | 84575.8 | 193.15 | 1592.95 | 1597.22 | | 1597.24 | 0.00036 | 0.57 | 337.2 | 157.83 |
| Bilate Reaches | 84575.8 | 173.62 | 1592.95 | 1597.07 | | 1597.08 | 0.00036 | 0.55 | 313.24 | 152.12 |
| Bilate Reaches | 84575.8 | 305.31 | 1592.95 | 1597.97 | | 1597.99 | 0.00038 | 0.66 | 464.65 | 185.27 |
| Bilate Reaches | 84575.8 | 335.87 | 1592.95 | 1598.14 | | 1598.16 | 0.00039 | 0.68 | 497.41 | 191.69 |
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| Bilate Reaches | 83348.1 | 153.2 | 1588.27 | 1591.99 | | 1592.01 | 0.00048 | 0.6 | 255.29 | 137.3 |
| Bilate Reaches | 83348.1 | 193.15 | 1588.27 | 1592.38 | | 1592.4 | 0.00044 | 0.62 | 312.11 | 151.81 |
| Bilate Reaches | 83348.1 | 173.62 | 1588.27 | 1592.2 | | 1592.22 | 0.00046 | 0.61 | 284.61 | 144.97 |
| Bilate Reaches | 83348.1 | 305.31 | 1588.27 | 1593.27 | | 1593.29 | 0.00039 | 0.66 | 460.88 | 184.48 |
| Bilate Reaches | 83348.1 | 335.87 | 1588.27 | 1593.47 | | 1593.49 | 0.00038 | 0.67 | 499.03 | 191.96 |
| | | | | | | | | | | |
| Bilate Reaches | 82336.5 | 153.2 | 1584.6 | 1589.34 | | 1589.34 | 0.00013 | 0.37 | 414.05 | 174.89 |
| Bilate Reaches | 82336.5 | 193.15 | 1584.6 | 1589.73 | | 1589.73 | 0.00014 | 0.4 | 485.25 | 189.33 |
| Bilate Reaches | 82336.5 | 173.62 | 1584.6 | 1589.54 | | 1589.55 | 0.00013 | 0.38 | 451.1 | 182.55 |
| Bilate Reaches | 82336.5 | 305.31 | 1584.6 | 1590.59 | | 1590.6 | 0.00015 | 0.46 | 662.67 | 221.25 |
| Bilate Reaches | 82336.5 | 335.87 | 1584.6 | 1590.79 | | 1590.8 | 0.00015 | 0.47 | 708.28 | 228.74 |

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| Bilate Reaches | 81761 | 153.2 | 1582.23 | 1584.44 | | 1584.59 | 0.00767 | 1.7 | 90.15 | 81.6 |
| Bilate Reaches | 81761 | 193.15 | 1582.23 | 1584.64 | | 1584.81 | 0.00765 | 1.8 | 107.37 | 89.06 |
| Bilate Reaches | 81761 | 173.62 | 1582.23 | 1584.55 | | 1584.7 | 0.00765 | 1.75 | 99.12 | 85.57 |
| Bilate Reaches | 81761 | 305.31 | 1582.23 | 1585.09 | 1584.46 | 1585.3 | 0.0075 | 2.02 | 150.78 | 103.19 |
| Bilate Reaches | 81761 | 335.87 | 1582.23 | 1585.23 | 1584.55 | 1585.44 | 0.0075 | 2.02 | 166.53 | 114.68 |
| Bilate Reaches | 80581.7 | 153.2 | 1558.75 | 1561.59 | 1560.22 | 1561.61 | 0.00099 | 0.72 | 212.8 | 150.06 |
| Bilate Reaches | 80581.7 | 193.15 | 1558.75 | 1561.84 | 1560.36 | 1561.87 | 0.00099 | 0.76 | 253.36 | 163.74 |
| Bilate Reaches | 80581.7 | 173.62 | 1558.75 | 1561.72 | 1560.29 | 1561.75 | 0.00099 | 0.74 | 233.77 | 157.28 |
| Bilate Reaches | 80581.7 | 305.31 | 1558.75 | 1562.42 | 1560.69 | 1562.46 | 0.00099 | 0.86 | 357.08 | 194.39 |
| Bilate Reaches | 80581.7 | 335.87 | 1558.75 | 1562.56 | 1560.75 | 1562.6 | 0.00099 | 0.88 | 383.47 | 201.45 |
| Bilate Reaches | 59123.3 | 153.2 | 1476.98 | 1485.75 | | 1485.75 | 1E-06 | 0.05 | 3304.57 | 753.74 |
| Bilate Reaches | 59123.3 | 193.15 | 1476.98 | 1486.15 | | 1486.15 | 1E-06 | 0.05 | 3611.23 | 787.93 |
| Bilate Reaches | 59123.3 | 173.62 | 1476.98 | 1485.96 | | 1485.96 | 1E-06 | 0.05 | 3461.77 | 771.46 |
| Bilate Reaches | 59123.3 | 305.31 | 1476.98 | 1487.07 | | 1487.07 | 2E-06 | 0.07 | 4376.42 | 867.4 |
| Bilate Reaches | 59123.3 | 335.87 | 1476.98 | 1487.28 | | 1487.28 | 2E-06 | 0.07 | 4561.92 | 885.6 |
| Bilate Reaches | 57029 | 153.2 | 1480.23 | 1485.72 | | 1485.72 | 1.1E-05 | 0.12 | 1316.11 | 479.19 |
| Bilate Reaches | 57029 | 193.15 | 1480.23 | 1486.12 | | 1486.12 | 1.2E-05 | 0.13 | 1510.82 | 513.41 |
| Bilate Reaches | 57029 | 173.62 | 1480.23 | 1485.93 | | 1485.93 | 1.1E-05 | 0.12 | 1415.33 | 496.92 |
| Bilate Reaches | 57029 | 305.31 | 1480.23 | 1487.03 | | 1487.03 | 1.4E-05 | 0.15 | 2015.33 | 592.97 |
| Bilate Reaches | 57029 | 335.87 | 1480.23 | 1487.24 | | 1487.24 | 1.4E-05 | 0.16 | 2140.96 | 611.17 |
| Bilate Reaches | 57014.1 | 153.2 | 1480.27 | 1485.54 | | 1485.54 | 1.3E-05 | 0.13 | 1210.19 | 459.2 |
| Bilate Reaches | 57014.1 | 193.15 | 1480.27 | 1485.92 | | 1485.92 | 1.5E-05 | 0.14 | 1387.88 | 491.76 |
| Bilate Reaches | 57014.1 | 173.62 | 1480.27 | 1485.73 | | 1485.73 | 1.4E-05 | 0.13 | 1300.1 | 475.95 |
| Bilate Reaches | 57014.1 | 305.31 | 1480.27 | 1486.8 | | 1486.8 | 1.7E-05 | 0.16 | 1854.8 | 568.49 |
| Bilate Reaches | 57014.1 | 335.87 | 1480.27 | 1487 | | 1487 | 1.7E-05 | 0.17 | 1971.21 | 586.06 |
| Bilate Reaches | 55517.7 | 153.2 | 1482.95 | 1484.62 | 1484.5 | 1484.92 | 0.02302 | 2.43 | 62.97 | 75.9 |
| Bilate Reaches | 55517.7 | 193.15 | 1482.95 | 1485.09 | | 1485.26 | 0.0098 | 1.85 | 104.42 | 100.09 |
| Bilate Reaches | 55517.7 | 173.62 | 1482.95 | 1484.88 | | 1485.09 | 0.01374 | 2.05 | 84.57 | 89.33 |
| Bilate Reaches | 55517.7 | 305.31 | 1482.95 | 1485.99 | | 1486.09 | 0.00363 | 1.42 | 215.55 | 146.4 |
| Bilate Reaches | 55517.7 | 335.87 | 1482.95 | 1486.19 | | 1486.28 | 0.00311 | 1.37 | 245.54 | 156.57 |
| Bilate Reaches | 54000 | 153.2 | 1477.55 | 1482.33 | | 1482.33 | 5.6E-05 | 0.24 | 630.38 | 263.87 |
| Bilate Reaches | 54000 | 193.15 | 1477.55 | 1482.71 | | 1482.71 | 5.9E-05 | 0.26 | 735.3 | 284.98 |
| Bilate Reaches | 54000 | 173.62 | 1477.55 | 1482.53 | | 1482.53 | 5.8E-05 | 0.25 | 685.08 | 275.08 |
| Bilate Reaches | 54000 | 305.31 | 1477.55 | 1483.56 | | 1483.57 | 6.5E-05 | 0.31 | 997.42 | 331.91 |
| Bilate Reaches | 54000 | 335.87 | 1477.55 | 1483.75 | | 1483.76 | 6.7E-05 | 0.32 | 1062.88 | 342.63 |
| Bilate Reaches | 53909.7 | 153.2 | 1477.18 | 1480.65 | | 1480.66 | 0.00032 | 0.47 | 325.82 | 188 |
| Bilate Reaches | 53909.7 | 193.15 | 1477.18 | 1480.98 | | 1480.99 | 0.00032 | 0.49 | 390.92 | 205.93 |
| Bilate Reaches | 53909.7 | 173.62 | 1477.18 | 1480.82 | | 1480.83 | 0.00032 | 0.48 | 359.58 | 197.51 |
| Bilate Reaches | 53909.7 | 305.31 | 1477.18 | 1481.72 | | 1481.73 | 0.0003 | 0.55 | 558.31 | 246.1 |
| Bilate Reaches | 53909.7 | 335.87 | 1477.18 | 1481.89 | | 1481.9 | 0.0003 | 0.56 | 601.07 | 255.35 |
| Bilate Reaches | 52990.4 | 153.2 | 1473.46 | 1477.13 | | 1477.14 | 0.00026 | 0.44 | 350.92 | 191.03 |
| Bilate Reaches | 52990.4 | 193.15 | 1473.46 | 1477.44 | | 1477.46 | 0.00027 | 0.47 | 412.7 | 207.16 |
| Bilate Reaches | 52990.4 | 173.62 | 1473.46 | 1477.3 | | 1477.31 | 0.00026 | 0.45 | 382.95 | 199.56 |
| Bilate Reaches | 52990.4 | 305.31 | 1473.46 | 1478.14 | | 1478.15 | 0.00028 | 0.54 | 569.28 | 243.31 |
| Bilate Reaches | 52990.4 | 335.87 | 1473.46 | 1478.3 | | 1478.32 | 0.00028 | 0.55 | 609.06 | 251.67 |
| Bilate Reaches | 51893 | 153.2 | 1469.82 | 1472.9 | | 1472.92 | 0.00066 | 0.62 | 246.01 | 159.98 |
| Bilate Reaches | 51893 | 193.15 | 1469.82 | 1473.21 | | 1473.23 | 0.00063 | 0.65 | 298.15 | 176.12 |
| Bilate Reaches | 51893 | 173.62 | 1469.82 | 1473.06 | | 1473.08 | 0.00064 | 0.64 | 272.97 | 168.52 |
| Bilate Reaches | 51893 | 305.31 | 1469.82 | 1473.91 | | 1473.93 | 0.00058 | 0.7 | 434.61 | 212.63 |
| Bilate Reaches | 51893 | 335.87 | 1469.82 | 1474.07 | | 1474.1 | 0.00057 | 0.71 | 469.75 | 221.06 |
| Bilate Reaches | 50985.8 | 153.2 | 1464.6 | 1468.31 | | 1468.32 | 0.00028 | 0.46 | 334.27 | 180.44 |
| Bilate Reaches | 50985.8 | 193.15 | 1464.6 | 1468.62 | | 1468.63 | 0.00029 | 0.49 | 392.81 | 195.6 |
| Bilate Reaches | 50985.8 | 173.62 | 1464.6 | 1468.47 | | 1468.48 | 0.00029 | 0.48 | 364.61 | 188.45 |
| Bilate Reaches | 50985.8 | 305.31 | 1464.6 | 1469.31 | | 1469.33 | 0.00031 | 0.56 | 540.7 | 229.49 |
| Bilate Reaches | 50985.8 | 335.87 | 1464.6 | 1469.47 | | 1469.49 | 0.00031 | 0.58 | 577.86 | 237.24 |

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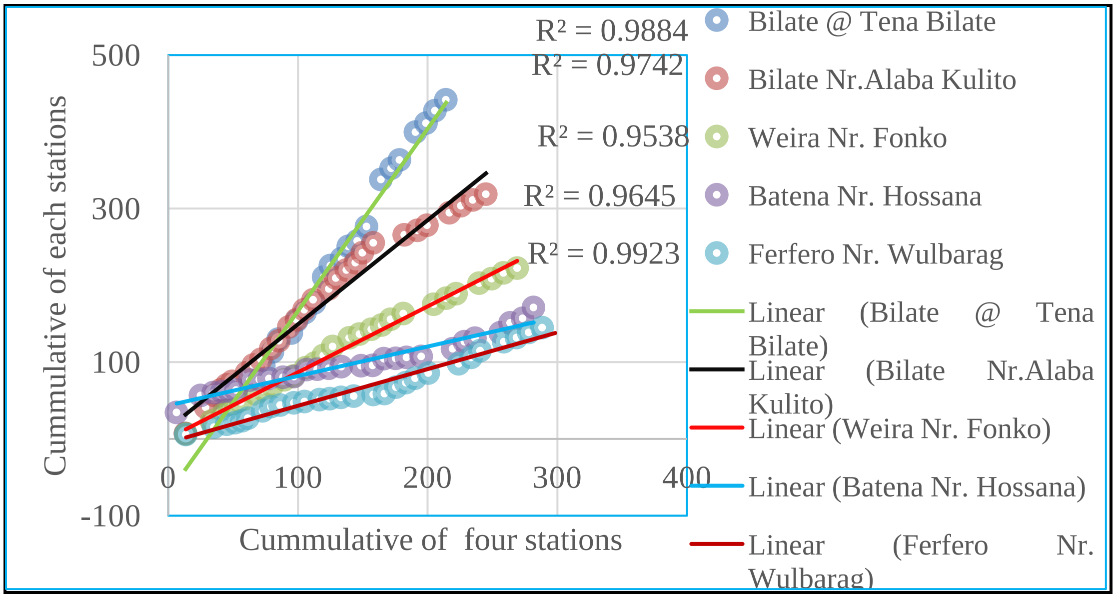
| Bilate Reaches | 50226 | 153.2 | 1459.48 | 1462.23 | | 1462.27 | 0.00142 | 0.85 | 180.79 | 131.56 |
| Bilate Reaches | 50226 | 193.15 | 1459.48 | 1462.51 | | 1462.55 | 0.00135 | 0.88 | 219.62 | 145 |
| Bilate Reaches | 50226 | 173.62 | 1459.48 | 1462.38 | | 1462.42 | 0.00138 | 0.86 | 200.88 | 138.68 |
| Bilate Reaches | 50226 | 305.31 | 1459.48 | 1463.15 | | 1463.19 | 0.00121 | 0.95 | 322.04 | 175.59 |
| Bilate Reaches | 50226 | 335.87 | 1459.48 | 1463.3 | | 1463.35 | 0.00119 | 0.96 | 348.81 | 182.74 |
| | | | | | | | | | | |
| Bilate Reaches | 48834.7 | 153.2 | 1451.17 | 1454.62 | | 1454.64 | 0.00042 | 0.54 | 285.21 | 165.26 |
| Bilate Reaches | 48834.7 | 193.15 | 1451.17 | 1454.92 | | 1454.93 | 0.00044 | 0.58 | 335.67 | 179.28 |
| Bilate Reaches | 48834.7 | 173.62 | 1451.17 | 1454.78 | | 1454.79 | 0.00043 | 0.56 | 311.44 | 172.69 |
| Bilate Reaches | 48834.7 | 305.31 | 1451.17 | 1455.57 | | 1455.59 | 0.00046 | 0.66 | 462.74 | 210.5 |
| Bilate Reaches | 48834.7 | 335.87 | 1451.17 | 1455.72 | | 1455.74 | 0.00047 | 0.68 | 494.43 | 217.59 |
| | | | | | | | | | | |
| Bilate Reaches | 47632.5 | 153.2 | 1444.32 | 1447.02 | | 1447.06 | 0.00156 | 0.88 | 174.83 | 129.38 |
| Bilate Reaches | 47632.5 | 193.15 | 1444.32 | 1447.3 | | 1447.34 | 0.00148 | 0.91 | 211.82 | 142.41 |
| Bilate Reaches | 47632.5 | 173.62 | 1444.32 | 1447.17 | | 1447.21 | 0.00152 | 0.9 | 193.93 | 136.26 |
| Bilate Reaches | 47632.5 | 305.31 | 1444.32 | 1447.92 | | 1447.97 | 0.00135 | 0.99 | 309.6 | 172.16 |
| Bilate Reaches | 47632.5 | 335.87 | 1444.32 | 1448.06 | | 1448.12 | 0.00132 | 1 | 335.35 | 179.18 |
| | | | | | | | | | | |
| Bilate Reaches | 46469.9 | 153.2 | 1436.29 | 1439.82 | | 1439.83 | 0.00038 | 0.51 | 297.73 | 168.88 |
| Bilate Reaches | 46469.9 | 193.15 | 1436.29 | 1440.12 | | 1440.14 | 0.00038 | 0.55 | 352.01 | 183.63 |
| Bilate Reaches | 46469.9 | 173.62 | 1436.29 | 1439.98 | | 1439.99 | 0.00038 | 0.53 | 325.92 | 176.7 |
| Bilate Reaches | 46469.9 | 305.31 | 1436.29 | 1440.81 | | 1440.83 | 0.0004 | 0.62 | 489.43 | 216.53 |
| Bilate Reaches | 46469.9 | 335.87 | 1436.29 | 1440.97 | | 1441 | 0.0004 | 0.64 | 525.41 | 225.58 |
| | | | | | | | | | | |
| Bilate Reaches | 45248.1 | 153.2 | 1430.41 | 1433.28 | 1431.93 | 1433.31 | 0.00116 | 0.76 | 201.2 | 147.6 |
| Bilate Reaches | 45248.1 | 193.15 | 1430.41 | 1433.55 | 1432.08 | 1433.58 | 0.00115 | 0.8 | 241.77 | 163.91 |
| Bilate Reaches | 45248.1 | 173.62 | 1430.41 | 1433.42 | 1432.01 | 1433.45 | 0.00116 | 0.78 | 222.19 | 156.25 |
| Bilate Reaches | 45248.1 | 305.31 | 1430.41 | 1434.12 | | 1434.16 | 0.00113 | 0.88 | 346.65 | 200 |
| Bilate Reaches | 45248.1 | 335.87 | 1430.41 | 1434.25 | | 1434.29 | 0.00113 | 0.9 | 373.23 | 208.15 |
| | | | | | | | | | | |
| Bilate Reaches | 44062.9 | 153.2 | 1423.45 | 1425.88 | 1424.51 | 1425.89 | 0.00045 | 0.44 | 351.04 | 289.43 |
| Bilate Reaches | 44062.9 | 193.15 | 1423.45 | 1426.09 | 1424.61 | 1426.1 | 0.00045 | 0.47 | 415.1 | 314.73 |
| Bilate Reaches | 44062.9 | 173.62 | 1423.45 | 1425.99 | 1424.56 | 1426 | 0.00045 | 0.45 | 384.31 | 302.83 |
| Bilate Reaches | 44062.9 | 305.31 | 1423.45 | 1426.56 | 1424.84 | 1426.58 | 0.00047 | 0.53 | 577.48 | 371.22 |
| Bilate Reaches | 44062.9 | 335.87 | 1423.45 | 1426.67 | 1424.9 | 1426.69 | 0.00047 | 0.54 | 618.68 | 384.23 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Bilate Reaches | 32082 | 153.2 | 1369.65 | 1370.84 | 1370.14 | 1370.85 | 0.00044 | 0.28 | 573.87 | 961.97 |
| Bilate Reaches | 32082 | 193.15 | 1369.65 | 1370.95 | 1370.19 | 1370.95 | 0.00045 | 0.3 | 678.46 | 1045.97 |
| Bilate Reaches | 32082 | 173.62 | 1369.65 | 1370.9 | 1370.17 | 1370.9 | 0.00044 | 0.29 | 628.51 | 1006.73 |
| Bilate Reaches | 32082 | 305.31 | 1369.65 | 1371.18 | 1370.3 | 1371.19 | 0.00046 | 0.33 | 946.71 | 1235.55 |
| Bilate Reaches | 32082 | 335.87 | 1369.65 | 1371.24 | 1370.33 | 1371.24 | 0.00046 | 0.34 | 1016.16 | 1280.07 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Bilate Reaches | 10494.9 | 153.2 | 1209.25 | 1209.88 | | 1209.89 | 0.00167 | 0.38 | 411.99 | 1303.65 |
| Bilate Reaches | 10494.9 | 193.15 | 1209.25 | 1209.94 | | 1209.95 | 0.00164 | 0.41 | 486.72 | 1418.09 |
| Bilate Reaches | 10494.9 | 173.62 | 1209.25 | 1209.91 | | 1209.92 | 0.00165 | 0.4 | 450.6 | 1363.97 |
| Bilate Reaches | 10494.9 | 305.31 | 1209.25 | 1210.07 | | 1210.08 | 0.00161 | 0.48 | 683.17 | 1682.19 |
| Bilate Reaches | 10494.9 | 335.87 | 1209.25 | 1210.07 | | 1210.08 | 0.00188 | 0.53 | 692.46 | 1693.66 |
| | | | | | | | | | | |
| Bilate Reaches | 7745.74 | 153.2 | 1195.83 | 1196.67 | 1196.25 | 1196.67 | 0.00125 | 0.36 | 426.18 | 1019.16 |
| Bilate Reaches | 7745.74 | 193.15 | 1195.83 | 1196.74 | 1196.29 | 1196.75 | 0.00127 | 0.38 | 503.58 | 1107.85 |
| Bilate Reaches | 7745.74 | 173.62 | 1195.83 | 1196.71 | 1196.27 | 1196.71 | 0.00126 | 0.37 | 466.37 | 1066.14 |
| Bilate Reaches | 7745.74 | 305.31 | 1195.83 | 1196.9 | 1196.38 | 1196.91 | 0.00132 | 0.44 | 700.11 | 1306.26 |
| Bilate Reaches | 7745.74 | 335.87 | 1195.83 | 1196.97 | 1196.4 | 1196.98 | 0.00115 | 0.42 | 791.77 | 1389.14 |
| | | | | | | | | | | |
| Bilate Reaches | 6955.07 | 153.2 | 1188.02 | 1188.94 | 1188.44 | 1188.94 | 0.00077 | 0.3 | 510.54 | 1114.39 |
| Bilate Reaches | 6955.07 | 193.15 | 1188.02 | 1189.02 | 1188.48 | 1189.03 | 0.00076 | 0.32 | 611.44 | 1219.56 |
| Bilate Reaches | 6955.07 | 173.62 | 1188.02 | 1188.98 | 1188.46 | 1188.99 | 0.00076 | 0.31 | 562.81 | 1170.05 |
| Bilate Reaches | 6955.07 | 305.31 | 1188.02 | 1189.22 | 1188.57 | 1189.23 | 0.00073 | 0.35 | 873.52 | 1457.68 |
| Bilate Reaches | 6955.07 | 335.87 | 1188.02 | 1189.23 | | 1189.24 | 0.00083 | 0.37 | 896.67 | 1476.87 |
| | | | | | | | | | | |
| Bilate Reaches | 5481.34 | 153.2 | 1173.66 | 1173.96 | 1173.96 | 1174.07 | 0.04721 | 1.12 | 110.33 | 517.35 |
| Bilate Reaches | 5481.34 | 193.15 | 1173.66 | 1174 | 1174 | 1174.12 | 0.04617 | 1.2 | 132.48 | 567.08 |
| Bilate Reaches | 5481.34 | 173.62 | 1173.66 | 1173.98 | 1173.98 | 1174.1 | 0.04625 | 1.16 | 122.18 | 544.52 |
| Bilate Reaches | 5481.34 | 305.31 | 1173.66 | 1174.09 | 1174.09 | 1174.24 | 0.0442 | 1.38 | 190.14 | 679.67 |
| Bilate Reaches | 5481.34 | 335.87 | 1173.66 | 1174.23 | | 1174.3 | 0.01528 | 1.08 | 289.76 | 737.85 |

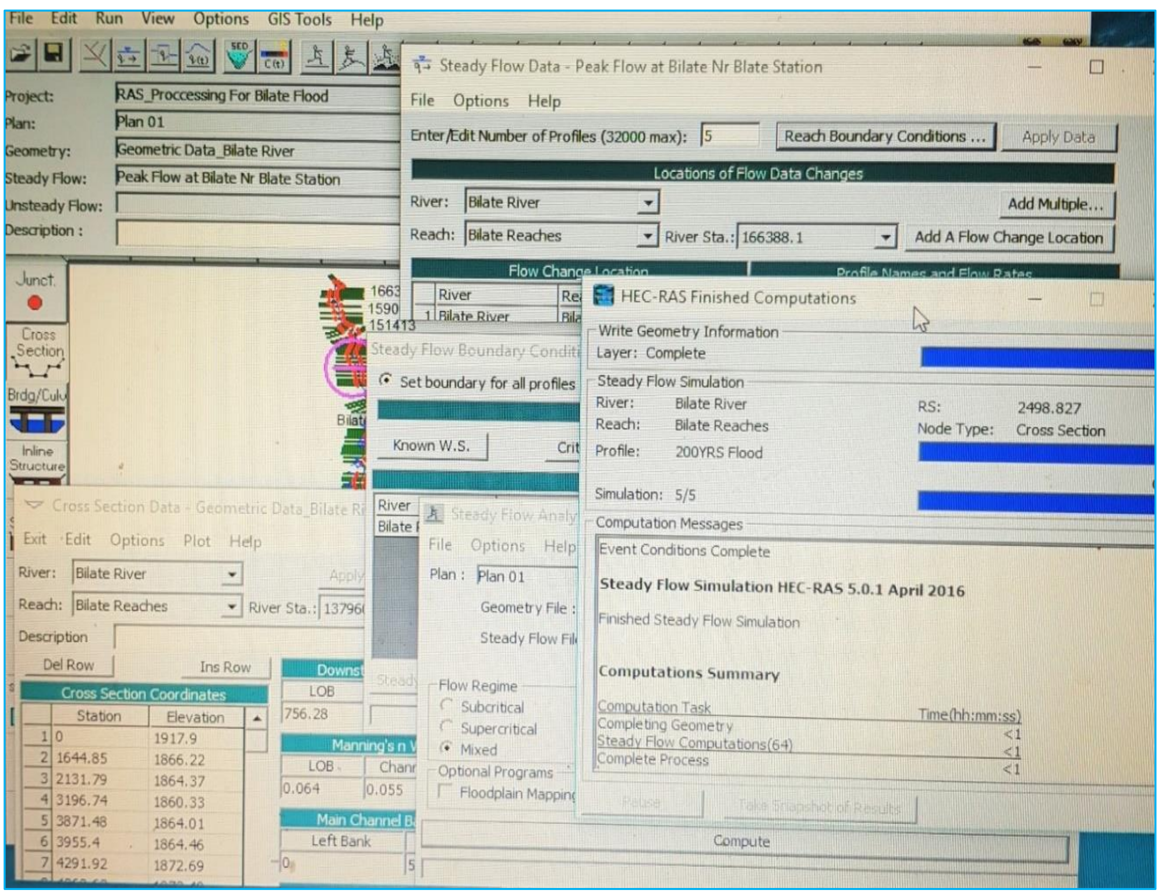
cont.…

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Bilate Reaches | 50226 | 153.2 | 1459.48 | 1462.23 | | 1462.27 | 0.00142 | 0.85 | 180.79 | 131.56 |
| Bilate Reaches | 50226 | 193.15 | 1459.48 | 1462.51 | | 1462.55 | 0.00135 | 0.88 | 219.62 | 145 |
| Bilate Reaches | 50226 | 173.62 | 1459.48 | 1462.38 | | 1462.42 | 0.00138 | 0.86 | 200.88 | 138.68 |
| Bilate Reaches | 50226 | 305.31 | 1459.48 | 1463.15 | | 1463.19 | 0.00121 | 0.95 | 322.04 | 175.59 |
| Bilate Reaches | 50226 | 335.87 | 1459.48 | 1463.3 | | 1463.35 | 0.00119 | 0.96 | 348.81 | 182.74 |
| | | | | | | | | | | |
| Bilate Reaches | 48834.7 | 153.2 | 1451.17 | 1454.62 | | 1454.64 | 0.00042 | 0.54 | 285.21 | 165.26 |
| Bilate Reaches | 48834.7 | 193.15 | 1451.17 | 1454.92 | | 1454.93 | 0.00044 | 0.58 | 335.67 | 179.28 |
| Bilate Reaches | 48834.7 | 173.62 | 1451.17 | 1454.78 | | 1454.79 | 0.00043 | 0.56 | 311.44 | 172.69 |
| Bilate Reaches | 48834.7 | 305.31 | 1451.17 | 1455.57 | | 1455.59 | 0.00046 | 0.66 | 462.74 | 210.5 |
| Bilate Reaches | 48834.7 | 335.87 | 1451.17 | 1455.72 | | 1455.74 | 0.00047 | 0.68 | 494.43 | 217.59 |
| | | | | | | | | | | |
| Bilate Reaches | 47632.5 | 153.2 | 1444.32 | 1447.02 | | 1447.06 | 0.00156 | 0.88 | 174.83 | 129.38 |
| Bilate Reaches | 47632.5 | 193.15 | 1444.32 | 1447.3 | | 1447.34 | 0.00148 | 0.91 | 211.82 | 142.41 |
| Bilate Reaches | 47632.5 | 173.62 | 1444.32 | 1447.17 | | 1447.21 | 0.00152 | 0.9 | 193.93 | 136.26 |
| Bilate Reaches | 47632.5 | 305.31 | 1444.32 | 1447.92 | | 1447.97 | 0.00135 | 0.99 | 309.6 | 172.16 |
| Bilate Reaches | 47632.5 | 335.87 | 1444.32 | 1448.06 | | 1448.12 | 0.00132 | 1 | 335.35 | 179.18 |
| | | | | | | | | | | |
| Bilate Reaches | 46469.9 | 153.2 | 1436.29 | 1439.82 | | 1439.83 | 0.00038 | 0.51 | 297.73 | 168.88 |
| Bilate Reaches | 46469.9 | 193.15 | 1436.29 | 1440.12 | | 1440.14 | 0.00038 | 0.55 | 352.01 | 183.63 |
| Bilate Reaches | 46469.9 | 173.62 | 1436.29 | 1439.98 | | 1439.99 | 0.00038 | 0.53 | 325.92 | 176.7 |
| Bilate Reaches | 46469.9 | 305.31 | 1436.29 | 1440.81 | | 1440.83 | 0.0004 | 0.62 | 489.43 | 216.53 |
| Bilate Reaches | 46469.9 | 335.87 | 1436.29 | 1440.97 | | 1441 | 0.0004 | 0.64 | 525.41 | 225.58 |
| | | | | | | | | | | |
| Bilate Reaches | 45248.1 | 153.2 | 1430.41 | 1433.28 | 1431.93 | 1433.31 | 0.00116 | 0.76 | 201.2 | 147.6 |
| Bilate Reaches | 45248.1 | 193.15 | 1430.41 | 1433.55 | 1432.08 | 1433.58 | 0.00115 | 0.8 | 241.77 | 163.91 |
| Bilate Reaches | 45248.1 | 173.62 | 1430.41 | 1433.42 | 1432.01 | 1433.45 | 0.00116 | 0.78 | 222.19 | 156.25 |
| Bilate Reaches | 45248.1 | 305.31 | 1430.41 | 1434.12 | | 1434.16 | 0.00113 | 0.88 | 346.65 | 200 |
| Bilate Reaches | 45248.1 | 335.87 | 1430.41 | 1434.25 | | 1434.29 | 0.00113 | 0.9 | 373.23 | 208.15 |
| | | | | | | | | | | |
| Bilate Reaches | 44062.9 | 153.2 | 1423.45 | 1425.88 | 1424.51 | 1425.89 | 0.00045 | 0.44 | 351.04 | 289.43 |
| Bilate Reaches | 44062.9 | 193.15 | 1423.45 | 1426.09 | 1424.61 | 1426.1 | 0.00045 | 0.47 | 415.1 | 314.73 |
| Bilate Reaches | 44062.9 | 173.62 | 1423.45 | 1425.99 | 1424.56 | 1426 | 0.00045 | 0.45 | 384.31 | 302.83 |
| Bilate Reaches | 44062.9 | 305.31 | 1423.45 | 1426.56 | 1424.84 | 1426.58 | 0.00047 | 0.53 | 577.48 | 371.22 |
| Bilate Reaches | 44062.9 | 335.87 | 1423.45 | 1426.67 | 1424.9 | 1426.69 | 0.00047 | 0.54 | 618.68 | 384.23 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Bilate Reaches | 32082 | 153.2 | 1369.65 | 1370.84 | 1370.14 | 1370.85 | 0.00044 | 0.28 | 573.87 | 961.97 |
| Bilate Reaches | 32082 | 193.15 | 1369.65 | 1370.95 | 1370.19 | 1370.95 | 0.00045 | 0.3 | 678.46 | 1045.97 |
| Bilate Reaches | 32082 | 173.62 | 1369.65 | 1370.9 | 1370.17 | 1370.9 | 0.00044 | 0.29 | 628.51 | 1006.73 |
| Bilate Reaches | 32082 | 305.31 | 1369.65 | 1371.18 | 1370.3 | 1371.19 | 0.00046 | 0.33 | 946.71 | 1235.55 |
| Bilate Reaches | 32082 | 335.87 | 1369.65 | 1371.24 | 1370.33 | 1371.24 | 0.00046 | 0.34 | 1016.16 | 1280.07 |
| | | | | | | | | | | |
| | | | | | | | | | | |
| Bilate Reaches | 10494.9 | 153.2 | 1209.25 | 1209.88 | | 1209.89 | 0.00167 | 0.38 | 411.99 | 1303.65 |
| Bilate Reaches | 10494.9 | 193.15 | 1209.25 | 1209.94 | | 1209.95 | 0.00164 | 0.41 | 486.72 | 1418.09 |
| Bilate Reaches | 10494.9 | 173.62 | 1209.25 | 1209.91 | | 1209.92 | 0.00165 | 0.4 | 450.6 | 1363.97 |
| Bilate Reaches | 10494.9 | 305.31 | 1209.25 | 1210.07 | | 1210.08 | 0.00161 | 0.48 | 683.17 | 1682.19 |
| Bilate Reaches | 10494.9 | 335.87 | 1209.25 | 1210.07 | | 1210.08 | 0.00188 | 0.53 | 692.46 | 1693.66 |
| | | | | | | | | | | |
| Bilate Reaches | 7745.74 | 153.2 | 1195.83 | 1196.67 | 1196.25 | 1196.67 | 0.00125 | 0.36 | 426.18 | 1019.16 |
| Bilate Reaches | 7745.74 | 193.15 | 1195.83 | 1196.74 | 1196.29 | 1196.75 | 0.00127 | 0.38 | 503.58 | 1107.85 |
| Bilate Reaches | 7745.74 | 173.62 | 1195.83 | 1196.71 | 1196.27 | 1196.71 | 0.00126 | 0.37 | 466.37 | 1066.14 |
| Bilate Reaches | 7745.74 | 305.31 | 1195.83 | 1196.9 | 1196.38 | 1196.91 | 0.00132 | 0.44 | 700.11 | 1306.26 |
| Bilate Reaches | 7745.74 | 335.87 | 1195.83 | 1196.97 | 1196.4 | 1196.98 | 0.00115 | 0.42 | 791.77 | 1389.14 |
| | | | | | | | | | | |
| Bilate Reaches | 6955.07 | 153.2 | 1188.02 | 1188.94 | 1188.44 | 1188.94 | 0.00077 | 0.3 | 510.54 | 1114.39 |
| Bilate Reaches | 6955.07 | 193.15 | 1188.02 | 1189.02 | 1188.48 | 1189.03 | 0.00076 | 0.32 | 611.44 | 1219.56 |
| Bilate Reaches | 6955.07 | 173.62 | 1188.02 | 1188.98 | 1188.46 | 1188.99 | 0.00076 | 0.31 | 562.81 | 1170.05 |
| Bilate Reaches | 6955.07 | 305.31 | 1188.02 | 1189.22 | 1188.57 | 1189.23 | 0.00073 | 0.35 | 873.52 | 1457.68 |
| Bilate Reaches | 6955.07 | 335.87 | 1188.02 | 1189.23 | | 1189.24 | 0.00083 | 0.37 | 896.67 | 1476.87 |
| | | | | | | | | | | |
| Bilate Reaches | 5481.34 | 153.2 | 1173.66 | 1173.96 | 1173.96 | 1174.07 | 0.04721 | 1.12 | 110.33 | 517.35 |
| Bilate Reaches | 5481.34 | 193.15 | 1173.66 | 1174 | 1174 | 1174.12 | 0.04617 | 1.2 | 132.48 | 567.08 |
| Bilate Reaches | 5481.34 | 173.62 | 1173.66 | 1173.98 | 1173.98 | 1174.1 | 0.04625 | 1.16 | 122.18 | 544.52 |
| Bilate Reaches | 5481.34 | 305.31 | 1173.66 | 1174.09 | 1174.09 | 1174.24 | 0.0442 | 1.38 | 190.14 | 679.67 |
| Bilate Reaches | 5481.34 | 335.87 | 1173.66 | 1174.23 | | 1174.3 | 0.01528 | 1.08 | 289.76 | 737.85 |
| | | | | | | | | | | |
| Bilate Reaches | 4320.35 | 153.2 | 1173.9 | 1173.3 | 1165.41 | 1173.3 | 2E-06 | 0.01 | 2505.47 | 564.83 |
| Bilate Reaches | 4320.35 | 193.15 | 1173.9 | 1173.54 | 1165.54 | 1173.54 | 3E-06 | 0.01 | 2656.25 | 690.14 |
| Bilate Reaches | 4320.35 | 173.62 | 1173.9 | 1173.42 | 1165.48 | 1173.42 | 2E-06 | 0.01 | 2581.2 | 630.88 |
| Bilate Reaches | 4320.35 | 305.31 | 1173.9 | 1174.08 | 1165.82 | 1174.08 | 5E-06 | 0.01 | 3118.96 | 999.29 |
| Bilate Reaches | 4320.35 | 335.87 | 1173.9 | 1174.21 | | 1174.21 | 5E-06 | 0.01 | 3250.63 | 1069.61 |
| | | | | | | | | | | |
| Bilate Reaches | 1484.9 | 153.2 | 1170.76 | 1173.23 | 1172 | 1173.25 | 0.001 | 0.68 | 254.55 | 206.33 |
| Bilate Reaches | 1484.9 | 193.15 | 1170.76 | 1173.46 | 1172.12 | 1173.48 | 0.001 | 0.72 | 302.98 | 225.11 |
| Bilate Reaches | 1484.9 | 173.62 | 1170.76 | 1173.35 | 1172.06 | 1173.37 | 0.001 | 0.7 | 279.58 | 216.24 |
| Bilate Reaches | 1484.9 | 305.31 | 1170.76 | 1173.96 | 1172.39 | 1173.99 | 0.001 | 0.81 | 427.42 | 267.37 |
| Bilate Reaches | 1484.9 | 335.87 | 1170.76 | 1174.08 | 1172.44 | 1174.1 | 0.001 | 0.82 | 459.12 | 277.11 |

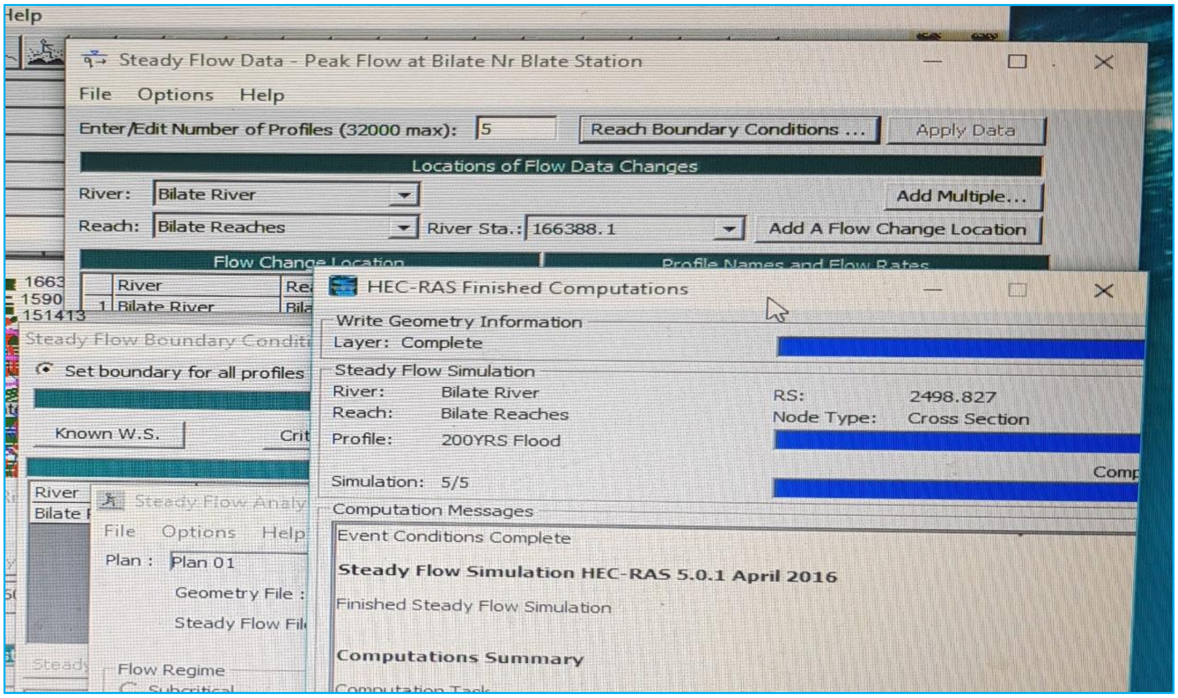
## APPENDIX FIGURE



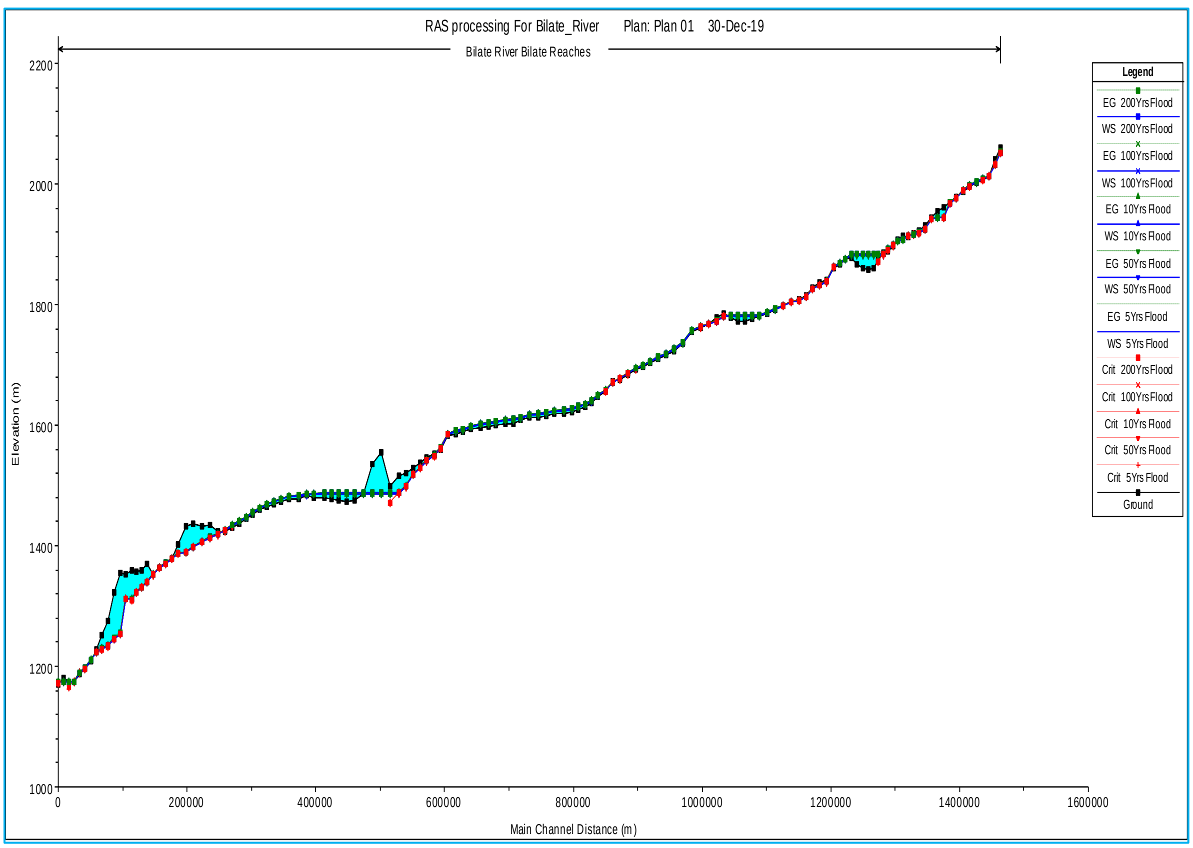

Appendix Figure 1 Double Mass Curve For Bilate at Tena Bilata Station



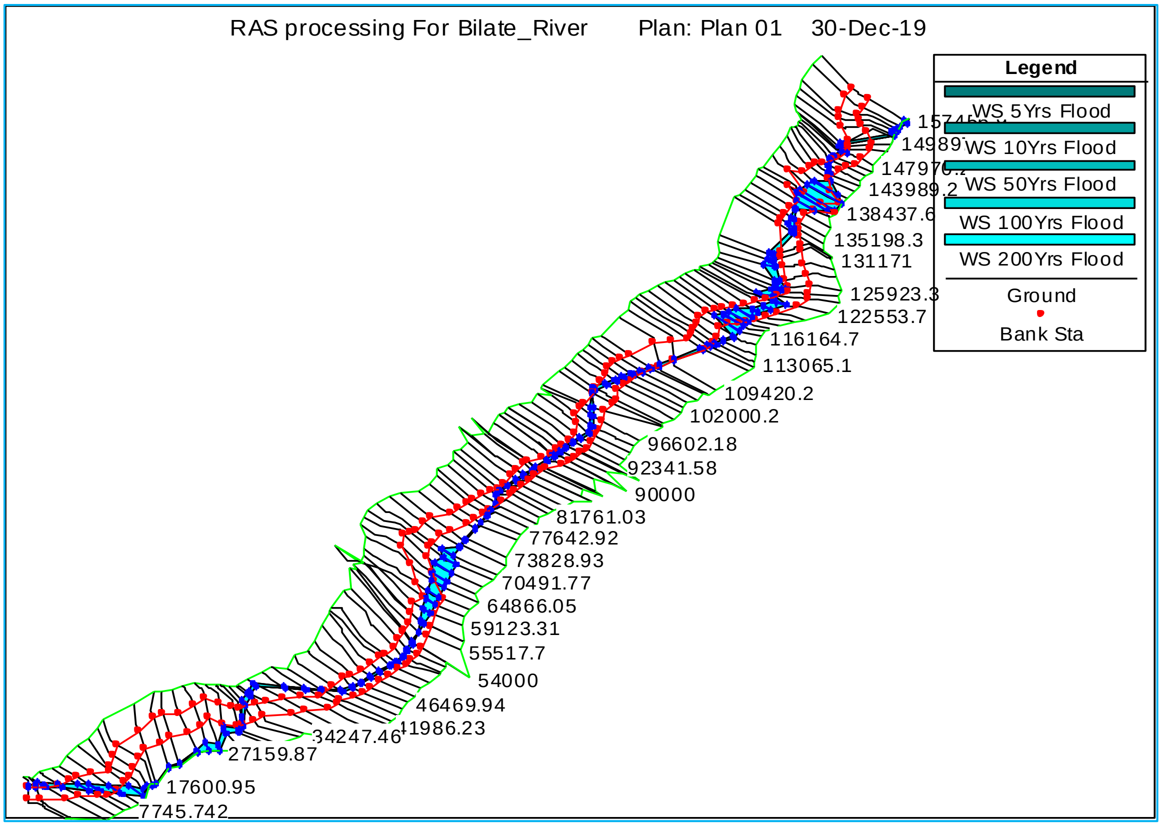

Appendix Figure 2 RAS Process at Research Station



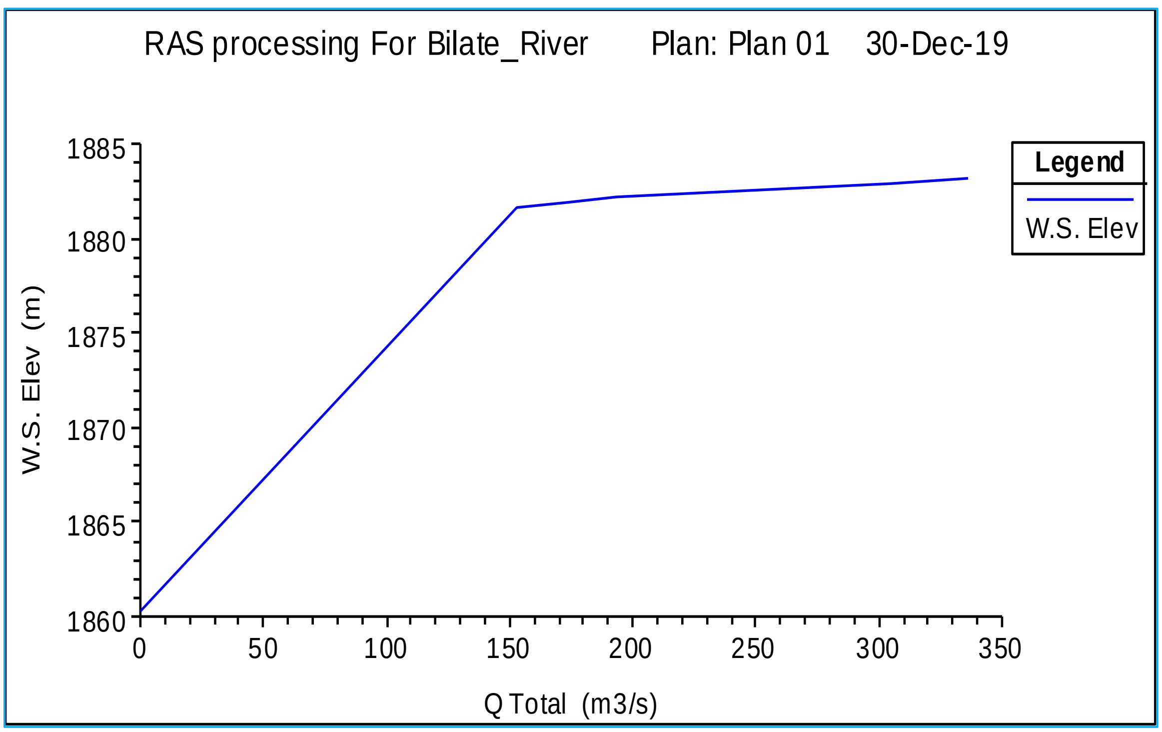

Appendix Figure 3 Steady Flow Simulation



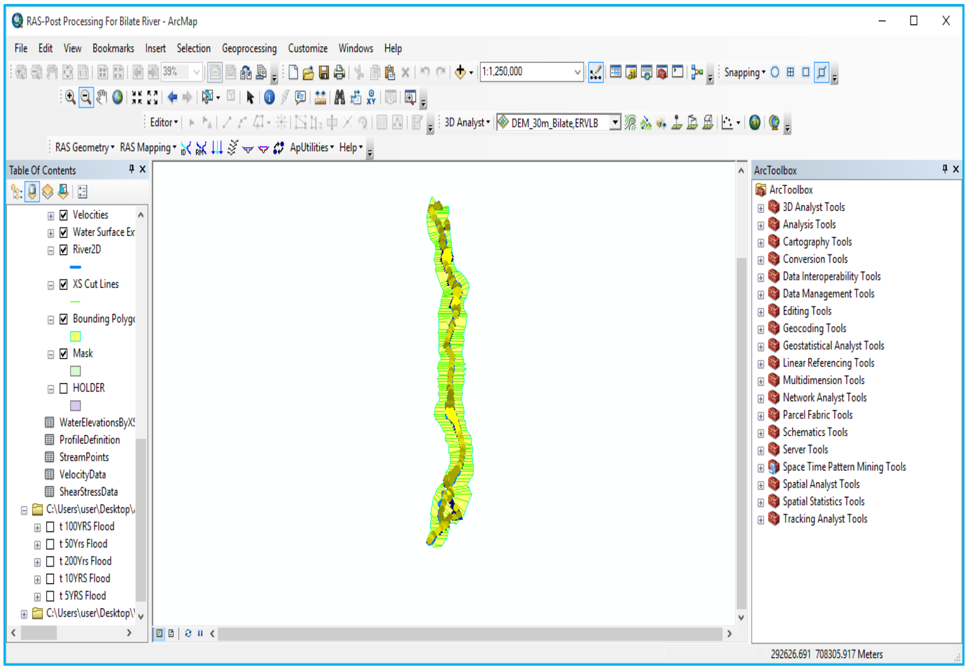

Appendix Figure 4 Water Surface Profile Plots of Different Return Period




Appendix Figure 5 X-Y-Z Perspective Plot

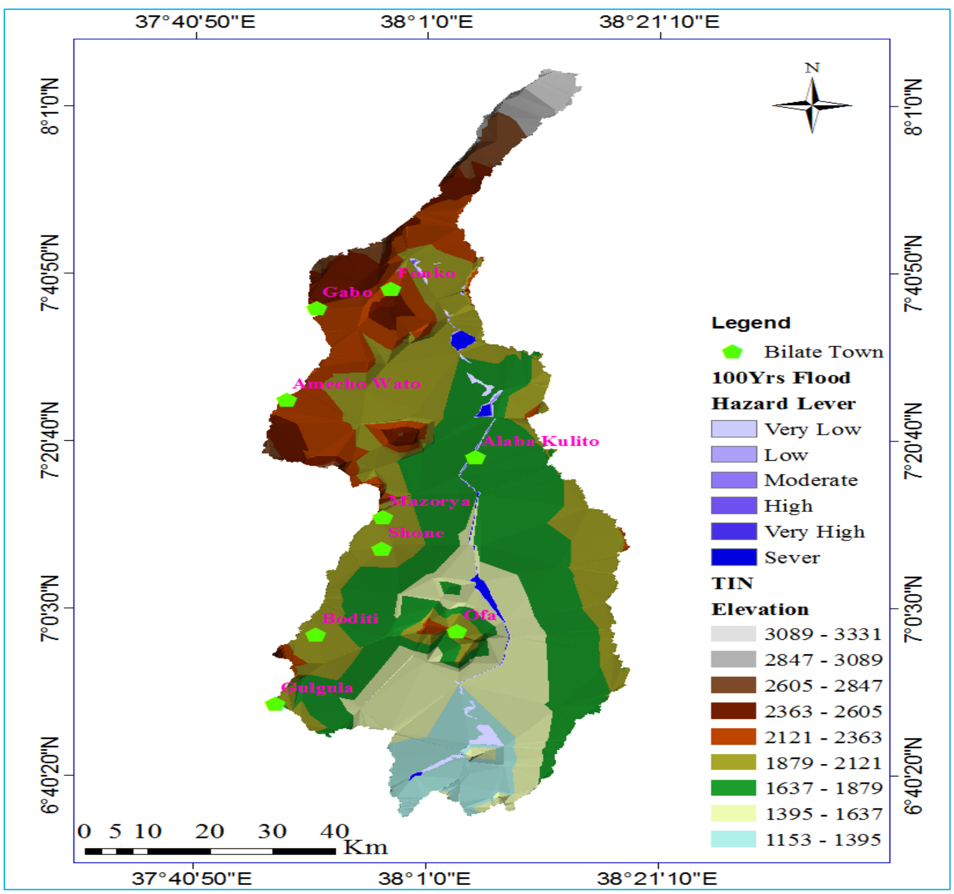



Appendix Figure 6 Sample Rating Curve at Station 137960.5

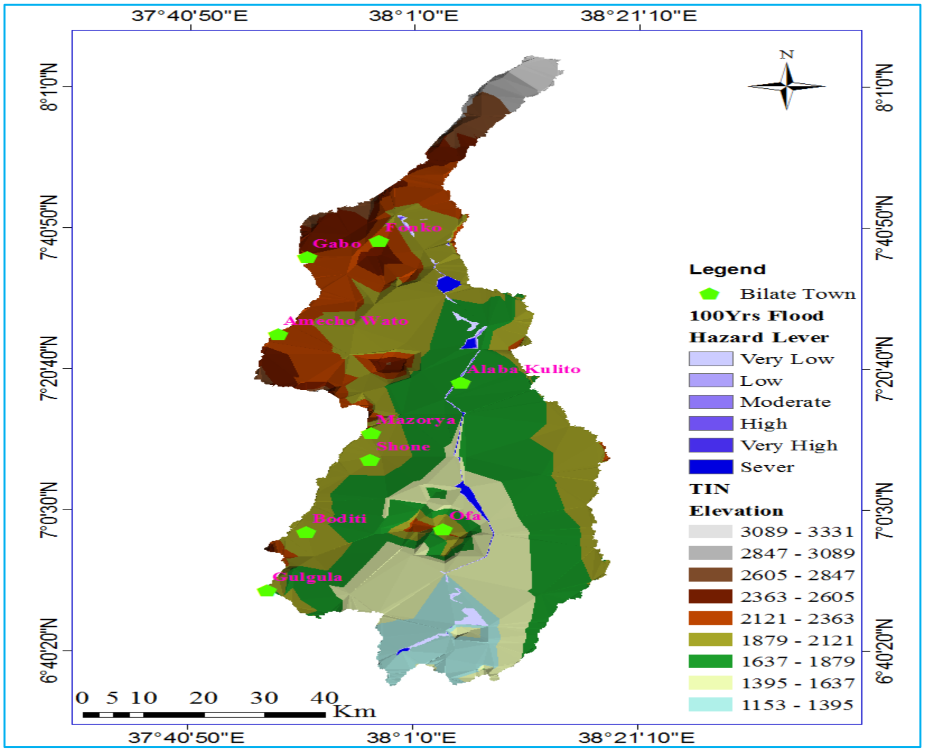



Appendix Figure 7 Post-RAS Processing

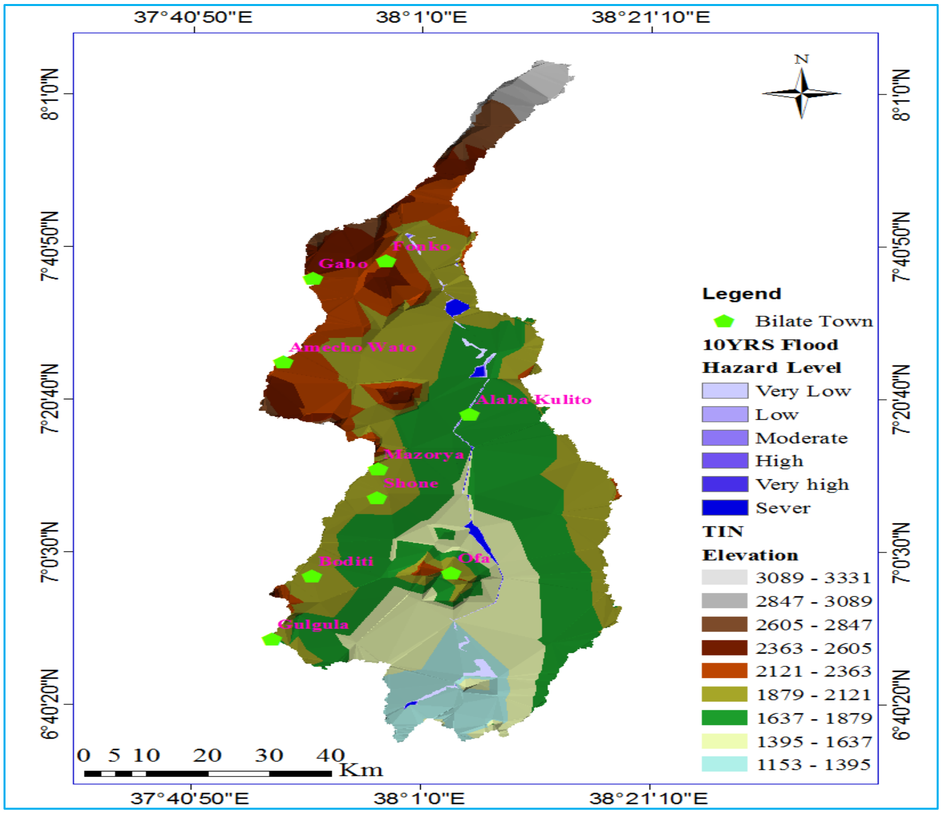
A.



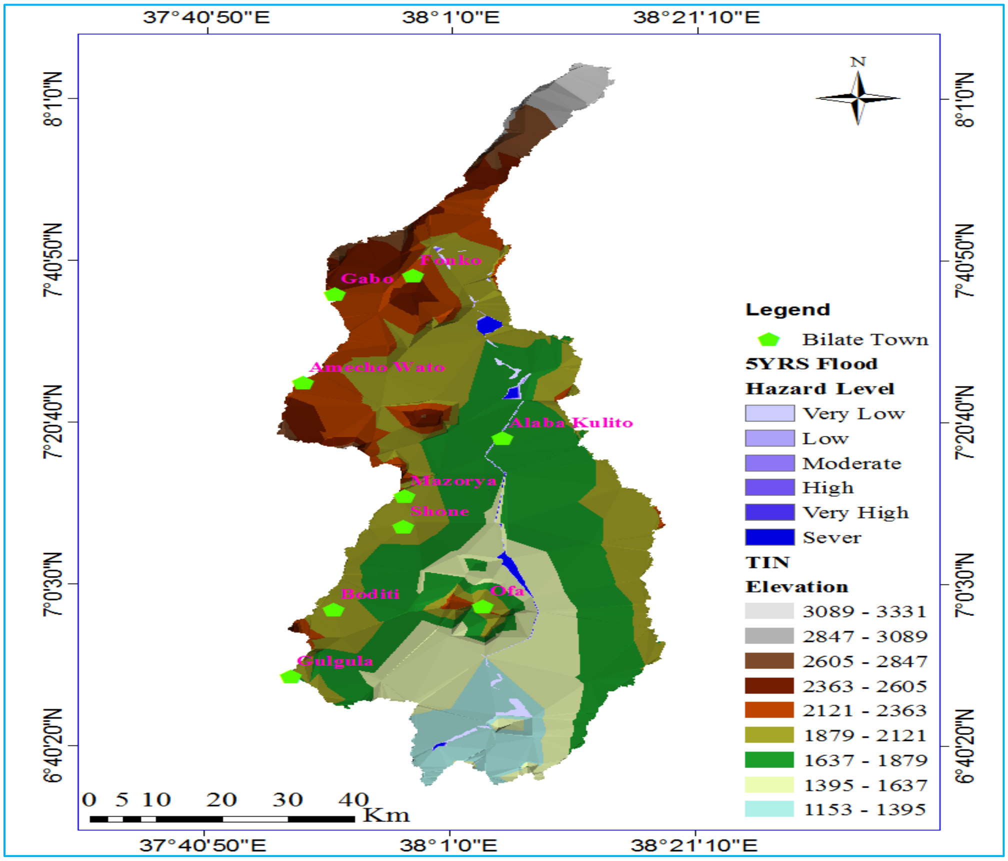
B.


37°40'50"E
38°1'0"E
38°21'10"E
8°1'0"N
7°40'50"N
7°20'40"N
7°0'30"N
6°40'20"N
N
Fonko
Gabo
Amecho Wato
Alaba Kulito
Mazorya
Shone
Boditi
Ofa
Gulgula
Legend
Bilate Town
100Yrs Flood
Hazard Lever
Very Low
Low
Moderate
High
Very High
Sever
TIN
Elevation
3089 - 3331
2847 - 3089
2605 - 2847
2363 - 2605
2121 - 2363
1879 - 2121
1637 - 1879
1395 - 1637
1153 - 1395
0 5 10 20 30 40
Km

C.


37°40'50"E
38°1'0"E
38°21'10"E
8°1'0"N
7°40'50"N
7°20'40"N
7°0'30"N
6°40'20"N
N
Fonko
Gabo
Amecho Wato
Alaba Kulito
Mazorya
Shone
Boditi
Ofa
Gulgula
Legend
Bilate Town
10YRS Flood
Hazard Level
Very Low
Low
Moderate
High
Very high
Sever
TIN
Elevation
3089 - 3331
2847 - 3089
2605 - 2847
2363 - 2605
2121 - 2363
1879 - 2121
1637 - 1879
1395 - 1637
1153 - 1395
0 5 10 20 30 40
Km

D.




Appendix Figure 8 A, B, C And D Showing Hazard Maps of Different Return Period

Appendix Figure 9 Flood Hazard in study area,2019