TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
CENTRAL CAMPUS PULCHOWK

# FLASH FLOOD EARLY WARNING SYSTEM

By:

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# LETTER OF APPROVAL

The undersigned hereby certify that they have read, and recommended to the Institute of Engineering for acceptance, this project report entitled "Flash Flood Early Warning System" submitted by Pramithas Dhakal, Suraj Pandey, Suraj Subedi and Saurab Dulal in partial fulfilment of the requirements for the Bachelor’s Degree in Computer Engineering.

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# Abstract

Floods occur in many parts of the country every year claiming the life and property that worth millions of rupees. Early warning about the flood occurrence could be very useful to minimize this loss in terms of lives and money. Our project FFEWS is concerned with solving the similar problem.

Our project is Flash Flood Early Warning System (FFEWS). FFEWS project, as its name suggests, is an early warning system for flash flood. Our project will include the basic features of following parts: Information Database, Data Collection and Forecasts, Communication and Warning, Disaster Information, Flood Map Generation. Various hydrological data, satellite forecast data, inundation models, digital terrain data etc will be used in the project. Our project is supposed to help the related agencies and authorities to solve the disaster problem. In overall, our project is assumed help the mankind in whole.

Keywords: Flash Flood, Flood Map Generation, Forecast data, Inundation model, Digital Terrain data, Satellite Forecast data.

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# List of Abbreviations

| | |
|---|---|
| ALERT | Automated Local Evaluation in Real Time |
| API | Application Programming Interface |
| CAMI | Central America Mitigation Initiative, |
| CDMA | Code Division Multiple Access |
| DEM | Digital Elevation Model |
| DHM | Department of Hydrology and Meteorology |
| DOECE | Department of Electronics and Computer Engineering |
| DRR | Disaster Risk Reduction |
| DTM | Digital Terrain Model |
| DWIDP | Department of Water Induced Disaster Prevention |
| ET | Evapo-Transpiration |
| EWS | Early Warning System |
| FFA | Flood Frequency Analysis |
| FFEWS | Flash Flood Early Warning System |
| FFG | Flash Flood Guidance |
| FFMP | Flash Flood Monitoring and Prediction |
| GIS | Geographical Information System |
| GPS | Global Positioning System |

| | |
|---|---|
| HEC | Hydrologic Engineering Center |
| HTML | Hyper-Text Markup Language |
| ICIMOD | International Centre for Integrated Mountain Development |
| IDE | Integrated Development Environment |
| IPCC | Intergovernmental Panel on Climate Change |
| JSON | JavaScript Object Notation |
| MAR | Mean Area Rainfall |
| NESDIS | National Environmental Satellite Data Information Service |
| NOAA | National Oceanic and Atmospheric Administration |
| NWS | National Weather Service |
| OFDA | Office of Foreign Disaster Assistance |
| PHP | PHP: Hypertext Preprocessor |
| RAS | River Analysis System |
| SQL | Structured Query Language |
| SRE | Satellite Rainfall Estimate |
| UI | User Interface |
| UNDP | United Nations Development Programme |
| USGS | United States Geological Survey |
| UX | User Experience |
| VDC | Village Development Committee |

# Chapter One - Introduction

## 1.1 Definition of "Flash Flood"

World Meteorological Organization**:** a flood of short duration with a relatively high peak discharge. (Grabs, 2010)

U.S. National Weather Service: a rapid and extreme flow of high water into a normally dry area, or a rapid water level rise in a stream or creek above a predetermined flood level, beginning within six hours of the causative event (e.g., intense rainfall, dam failure, ice jam). However, the actual time threshold may vary in different parts of the country. Ongoing flooding can intensify to flash flooding in cases where intense rainfall results in a rapid surge of rising flood waters. (Konarik et al., n.d.)

## 1.2 What is flash flood early warning system (FFEWS)?

In 2006, the United Nations released its *Global Survey of Early Warning Systems* which identified four elements (United Nations [UN], 2006) in natural hazard early warning systems:

1. Risk Knowledge – systematic assessment of hazards and vulnerabilities, and mapping of their patterns and trends.
2. Monitoring & Warning Service – accurate and timely forecasting of hazards using reliable, scientific methods and technologies.
3. Dissemination & Communication – clear and timely distribution of warnings to those at risk.
4. Response Capability – national and local capacities and knowledge to act correctly when warnings are communicated.

## 1.3 Background

The abundance of water resources and diversity in natural topography of Nepal are considered to be the boon of nature. These valued gifts of nature have always served Nepal for its all-around development and prosperity.

But, several times this very nature has turned into a violent and devastating disaster. Almost every year, we hear of a number of massive disasters affecting the life and habitat of different parts of the country. Among various catastrophic forms of nature, flood and landslides are the most prevalent ones in Nepal. According to UNDP report “Reducing Disaster Risk: A challenge for development”, Nepal ranks $12^{th}$ in the world in terms of the proportion of its population exposed to the threat of flood annually (23.74%) (UNDP, 2004). And the Terai region, the lowermost belt of Nepal running east to west with almost 50% of the total population is under the high risk of these disasters.

Among different nature of flood, flash flood is the most dangerous one. Most of the times, flash floods occur due to the outburst of the glaciers, lakes etc. Since, this kind of outbursts result in immediate rise in water levels and overflow of regular rivers, they immediately take the form of flood. Unlike regular flood, flash flood takes place within a short interval of time, leaving the victims very less time to react.

Flood occur in many parts of the country every year claiming the life and property that worth million of rupees. On 5 May 2012, flash flood occurred in the Kaski district of Nepal and it resulted in the death of at least 31 people. Dozens of people went missing. People lost their homes, businesses, crops, and livestock. To summarize, it caused a great loss of lives and property. It is believed to be due to the outburst of a landslide-dammed lake. Most of the damage and loss of life was near Sardi Khola.

Similarly, when Koshi River erupted in 2012, about 107,200 people’s life was affected. As per a survey, (44,000 – 70,000) people were displaced by the flooding incident. It was tagged as the country’s worst flooding in 50 years. Over 9,000 hectares of rice paddy, sugar cane, corn and jute had been destroyed. In Sunsari District, the VDC’s of Sripur, Haripur, and West Kusah were totally destroyed. The VDCs of Laukahi and Narsingh were partially destroyed. It was even worst in Bihar (State of India) where around 2.5 million people were displaced temporally.

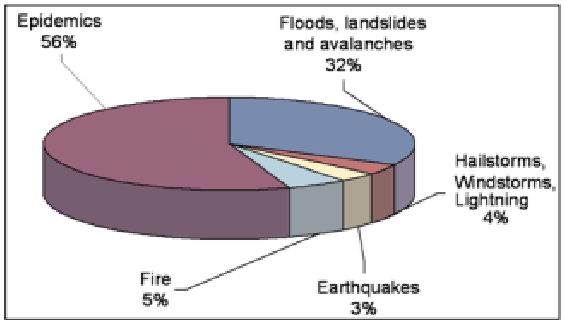



**Figure 1.1 :- Families affected by Natural Disasters**

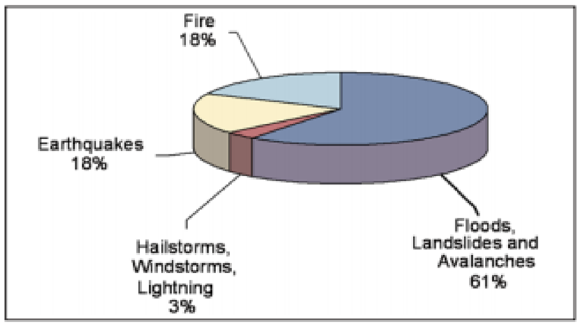



**Figure 1.2:- Estimated loss of life**

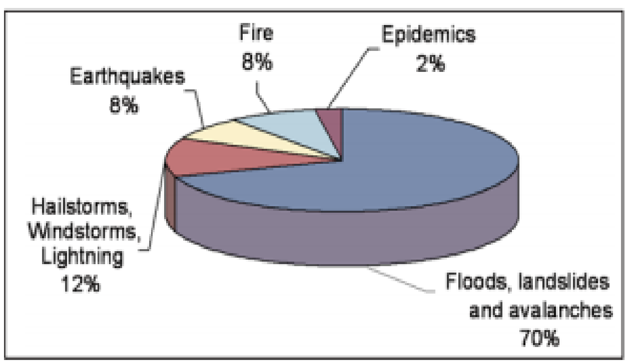



**Figure 1.3:- Estimated amount of property loss, 1983-2005**

Note:-The above data is taken in between the year 1983-2005

Thus, these examples and figures are just representative incidents out of many flash flood incidents that occur in our nation in yearly basis. And due to the absence of any effective flash flood early warning systems, the damages have been worse than they ought to be. In the Koshi flood incident mentioned above, people escaped with just the clothes they were wearing. The death toll would have increased if the flood had occurred at night. If there had been some early warning system, the disaster would have certainly been minimized.

Our project is concerned with solving the similar problem. Our project is Flash Flood Early Warning System (FFEWS).

## 1.4 Problem Statement

“Flooding cannot be wholly prevented. The occurrence of a flood need not be considered a 'failure' and, conversely, minimization of losses may constitute a 'success'. There are lessons to be learned from every flood and it is important to use them in preparing for the next flood. Once we accept that no flood protection measures can guarantee complete safety, a general change of paradigm is needed to reduce human vulnerability to floods. The attitude of 'living with floods' and accommodating them in planning seems more sustainable than hopelessly striving to eradicate them”. (Kundzewicz, n.d.)

Problems statements can be stated as follow:-

1. Nepal being a Himalayan country is regularly exposed natural calamities and flood is one the major problem, which is also shown in graph above.
2. The poor economic condition of people has made them migrate on the floodplains areas for the food security.
3. Terai region, the lowermost belt of Nepal running east to west with almost 50% of the total population is under the high risk.
4. Lack of accurate and statistical data, no inference system and even unavailability of sensing device to these big rivers turns out to be one of the major problems,
5. Absence of EWS in risk exposed area.

### 1.4.1 Basic System flow information table

<table>
<tr><th>Risk Information</th><th>Hazard Data and Forecast</th><th>Communication and Dissemination</th><th>Preparedness and Response</th></tr>
<tr><td>Risk Assessment</td><td>Monitoring Network</td><td>Dissemination Timely Warning</td><td>Community Based Emergency Planning</td></tr>
<tr><td>Hazard Database</td><td>Detect and Analyze</td><td>First Responder Voice and Data Networks</td><td>Education and Outreach</td></tr>
<tr><td>Hazard Statistics</td><td>IT Infrastructure</td><td>Broadcasting Media</td><td>Preparedness Training and drills</td></tr>
<tr><td>Analysis Tools</td><td>Flash Flood prediction</td><td rowspan="3">Alarm and Sirens</td><td>Flood Insurance</td></tr>
<tr><td>Science and Research</td><td rowspan="2">Issue Warning</td><td>Land Stabilization and Reinforcement</td></tr>
<tr><td>Risk Information Warning</td><td>Reconstruction and Settlements</td></tr>
<tr><td colspan="4">Flash Flood Early Warning System(FFEWS)</td></tr>
</table>

**Table 1.1: Basic System Flow Information Table**

## 1.5 Objectives

The objectives of FFEWS are:

1. Collection and storage of flood related data for the analysis and research purpose.
2. Encourage automated warning system implementations in highly risked areas of Nepal.
3. Help public, private and government sectors working in the related field in disaster management.

## 1.6 Scope of the work

FFEWS project, as its name suggests, is an early warning system for flash flood. The fully featured and detailed project of FFEWS would be very large and its accomplishment period would exceed the time-frame of one year. So, we have limited our project to include the basic features of following parts:

1. Information Database
2. Data Collection and Forecasts
3. Communication and Warning
4. Flood Map Prediction

### 1.6.1 Information Database

This part is the input system of the project. All the data, information, statistics related to the hazard is stored in this system. Also, the entire geological database, hydro-meteorological information is fed in this part of the project.

### 1.6.2 Data Collection and Forecasts

This includes the continuous real-time data collection from the hydrological sensors, storage of data, processing of data for anomaly detection and early forecasts based on the acquired information. This will also make use of the information database for the data processing and forecast purpose.

### 1.6.3 Communication and Warning

This part consists of mechanism of information distribution during the disaster. Our system uses the SMS-based information dissemination to provide warning to the probable victims through concerned authorities.

### 1.6.4 Flood map Prediction

This part consists of prediction of flood map. Flood map generation is used to estimate the probable region affected by the flood. The concerned authorities of the vulnerable sites are provided warning message by observing the flood map.

## 1.7 Organization of Report

This report is divided into nine chapters. Each chapter contains various aspects of the project. A brief synopsis of each of the chapter is discussed below:

The first chapter discusses the basic introduction of the project. It describes the background scenario which brought the motivation of the development of the project. The objectives of the project, a brief overview of the project are shown in this chapter.

Second chapter provides a review of literature related to the project. It introduces the reader with various terms and technologies used in the project. It also provides a understanding of data used in the project.

Third chapter includes the research works performed during the project. It explains about the various similar existing systems and current scenario of flash flood in Nepal.

The theoretical backgrounds of the project are discussed in the fourth chapter. Various theories on the technologies and algorithms used on the project are discussed in this chapter.

The technical aspects of the above mentioned theories are discussed in the fifth chapter. It includes the technical aspects of implementation of technologies used in the project. The mathematical expressions, technical aspects are discussed in this chapter.

Sixth chapter provides a wide description of the system. The functional specification of the system, the modular explanation and their working are discussed in this chapter.

Chapter seven discussed the methodology of the project development. It includes the explanation of the methods and processes used in the project development. The implementation details are discussed in this chapter.

In the eighth chapter, the results and outputs of the projects are included. This chapter shows the product of the project.

The ninth chapter is about the tools and technologies we used during the development of the project and the final chapter i.e. the tenth chapter is the conclusion of the report.

# Chapter Two – Literature Review

## 2.1. Data Requirement for Flood Inundation Models

Flood inundation models are a major tool for mitigating the effects of flooding. They provide predictions of flood extent and depth that are used in the development of spatially accurate hazard maps. There have been significant advances in flood inundation modelling over the past decade**.** Progress has been made in the understanding of the processes controlling runoff and flood wave propagation, in simulation techniques, in low cost high power computing, in uncertainty handling, and in the provision of new data sources.

The acquisition of the vast majority of these new data has been made possible by developments in the field of remote sensing (Mason, n.d.). Remote sensing, from both satellites and aircraft, allows the collection of spatially distributed data over large areas rapidly and reduces the need for costly ground survey. The data required for the flood inundation model fall into four distinct categories:

(a) Topographic data of the channel and floodplain

(b) Time series of bulk flow rates and stage data to provide model input and output boundary conditions

The basic topographic data requirement is for a high quality Digital Terrain Model (DTM) representing the ground surface with surface objects removed. For rural floodplain modelling, modellers require that the DTM has vertical accuracy of about 0.5m and a spatial resolution of at least 10m. There are various kinds of DTM data collected from different methods. The choice of data type depends upon the application of the data in flood inundation modelling.

Flood inundation models also require discharge and stage data to provide model boundary conditions. The data are usually acquired from gauging stations spaced 10-60km apart on the river network, which provide input to flood warning systems.

Estimates of bottom roughness coefficients in the channel and floodplain are also required. This data is related to the friction coefficients of the surface which affects the flow of water. This data is useful in reducing the error in the inundation model.

A final requirement is for suitable data for model calibration, validation. If a model can be successfully validated using independent data, this gives confidence in its predictions for future events of similar magnitude under similar conditions. Record from the previous data is used for the model calibration and validation.

## 2.2. Satellite Rainfall Estimation

Precipitation is a crucial link in the hydrologic cycle, and its spatial and temporal variations are enormous. Knowledge of the amount of regional rainfall is essential to the welfare of society. (Geerts, n.d.) Rainfall also drives the hydrological cycle, and to improve weather and climate predictions, an accurate global coverage of rainfall records is necessary. Rain gauge data are available on land only, mainly in densely populated areas, and little offshore information exists.

Rainfall can be estimated remotely, either from ground-based weather radars or from satellite. Radars are active devices, emitting radiation at wavelengths ranging between 1 and 10 cm, and receiving the echo from targets such as raindrops. The maximum range of radars is only about 300 km, so offshore coverage is limited. Also, radars are prohibitively expensive in the Third World. Satellite-based measurements offer global coverage or a good part thereof.

## 2.3 Flood Map

Flood mapping is a crucial element of flood risk management. Different kinds of flood mapping are:

- **Flood hazard maps** showing the extent and expected water depths/levels of an area flooded in three scenarios, a low probability scenario or extreme events, in a medium probability scenario (at least with a return period of 100 years) and if appropriate a high probability scenario.

- **Flood risk maps** are the maps for the areas flooded under these scenarios showing potential population, economic activities and the environment at potential risk from flooding, and other information that authorities may find useful to include, for instance other sources of pollution.

## 2.4 DEM Data

Digital Elevation Models (DEMs) are a type of raster GIS layer. Raster GIS represents the world as a regular arrangement of locations. In a DEM, each cell has a value corresponding to its elevation. The fact that locations are arranged regularly permits the raster GIS to infer many interesting associations among locations: Which cells are upstream from other cells? Which locations are visible from a given point? Where are the steep slopes? These various questions can be answered using the DEM data. (Harvard University, n.d.)

The USGS Digital Elevation Model (DEM) data files are digital representations of elevation information in a raster or grid form. DEMs consist of a sampled array of elevations for a number of ground positions at regularly spaced intervals. These digital cartographic/geographic data files are produced by the U.S. Geological Survey (USGS) as part of the National Mapping Program and are available for the entire US from the **USGS National Map.**

The entire United States has DEM coverage at 30 meter resolution (1 arc second), and much of the country is available at 10 meter resolution (1/3 arc second). The **National Elevation Dataset** (NED) is a regularly updated composite of the latest DEM data for the country, and represents the most current and highest resolution DEM data available that USGS has produced. Often DEMs may be found which are tiled by 7.5 minute quadrangles or some other tiling scheme.

# Chapter Three- Research

Floods are the most common natural disasters that affect societies around the world and are considered being one of the most dangerous natural disasters in Nepal. Dilley (2005) estimated that more than one-third of the world’s land area is flood prone affecting some 82 percent of the world’s population. About 196 million people in more than 90 countries are exposed to catastrophic flooding, and that some 170,000 deaths were associated with floods worldwide between 1980 and 2000 UNDP (2004). These figures show that flooding is a major concern in many regions of the world. Globally, the economic cost of extreme weather events and flood catastrophes is severe, and if it rises owing to climate change, it will hit poorest nations the hardest consequently; the poorest section of people will bear the brunt of it. The number of major flood disasters in the world has risen relentlessly over recent time. There were six in the 1950s; seven in the 1960s; eight in 1970s; eighteen in the 1980s; and twenty six in the 1990s (UNDP, 2004).

Nepal, the central part of the Hindu-Kush Himalayan, has more than 6,000 rivers and rivulets. Floods and landslides, which are triggered by heavy precipitation, cause 29% of the total annual deaths and 43% of the total loss of properties in Nepal (DWIDP, 2004).The Terai amounting to only 17% of the total area of the country is regarded as the granary of Nepal and the problem of flooding in this region is of utmost concern. In recent years, between 1981 and 1998, three events of extreme precipitation with extensive damage have been reported. In the context of global warming, the probability of potentially damaging floods occurring is likely to increase as a consequence of the increase in the intensity of extreme precipitation events and the status of glacial lakes in high mountain areas.

| Year | Loss of lives | Year | Loss of lives |
|---|---|---|---|
| 1983 | 293 | 1996 | 258 |
| 1984 | 363 | 1997 | 83 |
| 1985 | 420 | 1998 | 273 |
| 1986 | 315 | 1999 | 193 |
| 1987 | 391 | 2000 | 173 |
| 1988 | 328 | 2001 | 196 |
| 1989 | 680 | 2002 | 441 |
| 1990 | 307 | 2003 | 232 |
| 1991 | 93 | 2004 | 131 |
| 1992 | 71 | 2005 | 141 |
| 1993 | 1336 | 2006 | 114 |
| 1994 | 49 | 2007 | 216 |
| 1995 | 203 | 2008 | 134 |

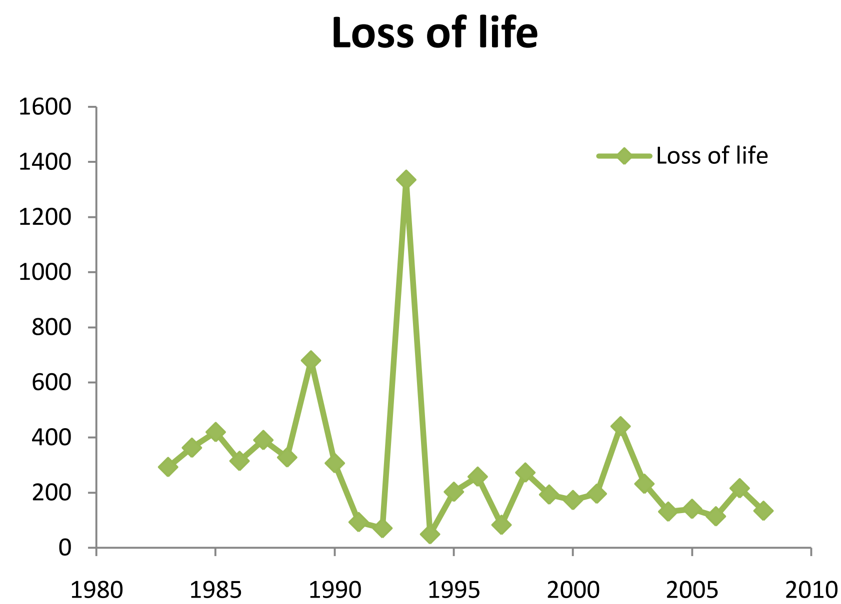



**Figure 3.1: Loss of lives due to flood and landslides**

**Table 3.1 : Loss of lives due to flood and landslides**

The monsoon precipitation pattern is changing too; with fewer days of rain and more high-intensity and incessant rainfall events. Various definitions of vulnerability have been provided in the context of natural hazards and climate change. From these definitions, vulnerability can be viewed from the perspective of the physical, spatial or locational, and socioeconomic characteristics of a region. In recent years, a number of studies have recognized the importance of estimating people's vulnerability to natural hazards, rather than retaining a narrow focus on the physical processes of the hazard itself. Some experts argued that natural disaster is a function of both natural hazard and vulnerable people. They emphasized the need to understand the interaction between hazard and people's vulnerability. Nepal's vulnerability to climate-related disasters is likely to be increased by the increase in the intensity and frequency of weather hazards induced by anthropogenic climate change (IPCC, 2007). Vulnerability to flood hazards is likely to increase unless effective flood mitigation and management activities are implemented. An important prerequisite for developing management strategies for the mitigation of extreme flood events is to identify areas of potentially high risk to such events, thus accurate information on the extent of floods is essential for flood monitoring, and relief (Smith, 1997). The main objective of this project is to integrate flood simulation model. Flooding is a serious, common, and costly hazard that many countries face regularly. Identification and mapping of flood prone areas are valuable for risk reduction. The project is concern with the analysis of floods from the past data and generating the flood maps. It also visualizes the time series data which helps experts in analysis and prediction.

## 3.1 Existing System

### 3.1.1 Existing Systems outside Nepal

#### 3.1.1.1 United States Flash Flood EWS

There are numerous locally operated ALERT networks but no national *flash flood* rain gauge/stream flow network in the United States. At the national level, precipitation monitoring is primarily accomplished via a network of weather radars deployed by the National Weather Service in cooperation with the Federal Aviation Administration and the Department of Defense. Weather surveillance radars are extensively used to collect the data. The WSR-88D reflectivity data is converted to high resolution precipitation estimates and mapped to individual basins across the country by NWS computer software called Flash Flood Monitoring and Prediction (FFMP). Local forecasters are alerted by FFMP when the observed rainfall or rainfall rate exceeds a basin's Flash Flood Guidance (FFG). Also at the national level, the WSR-88D data provided to the local forecaster is augmented by satellite precipitation estimates produced by the National Weather Service's sister NOAA agency, the National Environmental Satellite Data Information Service (NESDIS).

The end purpose of radar and satellite precipitation estimates is to detect when flash flood producing rainfall is occurring so that forecasters can issue warnings with sufficient lead time for actions to be taken to protect lives and property. Greatest warning success is achieved, however, when the NWS is able to partner with local agencies and groups that deploy ALERT networks.

#### 3.1.1.2 Central America Flash Flood Guidance System

Following the catastrophic flooding of Hurricane Mitch in 1998 in Central America, the United States Agency for International Development (USAID) provided funding for the reconstruction of damaged infrastructure. The National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS) provided technology transfer, training, and technical assistance to the meteorological and hydrologic services in the countries hardest hit (Honduras, Nicaragua, El Salvador, and Guatemala). The USAID/Office of Foreign Disaster Assistance (OFDA) also initiated a supplemental project in 2000 (known as the Central America Mitigation Initiative, CAMI) to have NWS coordinate the implementation of an early warning system for flash floods in the region. NWS worked with the Hydrologic Research Center (HRC), a public-benefit non-profit research, technology transfer, and training corporation in San Diego, California, to implement the HRC-developed Flash Flood Guidance system for the region.

The system implemented, Central America Flash Flood Guidance (CAFFG), provides operational meteorological and hydrological services in seven Central American countries (Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua, and Panama) with timely guidance for those NMHSs to issue effective flash flood warnings for small river basins. Unique characteristics of the CAFFG system include:

(1) The world's first regional flash flood guidance system – operational dissemination of both regional and small scale products for all countries throughout Central America
(2) Fully automated real-time operation – data acquisition, ingest, quality control, model processing, output publication, and data management are all automated
(3) A regional center at the National Meteorological Institute in San Jose, Costa Rica, for the centralized acquisition, standardization, and archiving of a variety of real-time data products throughout the entire region

(4) All products are disseminated to each country via the internet, requiring the countries to acquire and maintain only a PC and internet connection.

### 3.1.1.3 Forecasting subsystem Central America

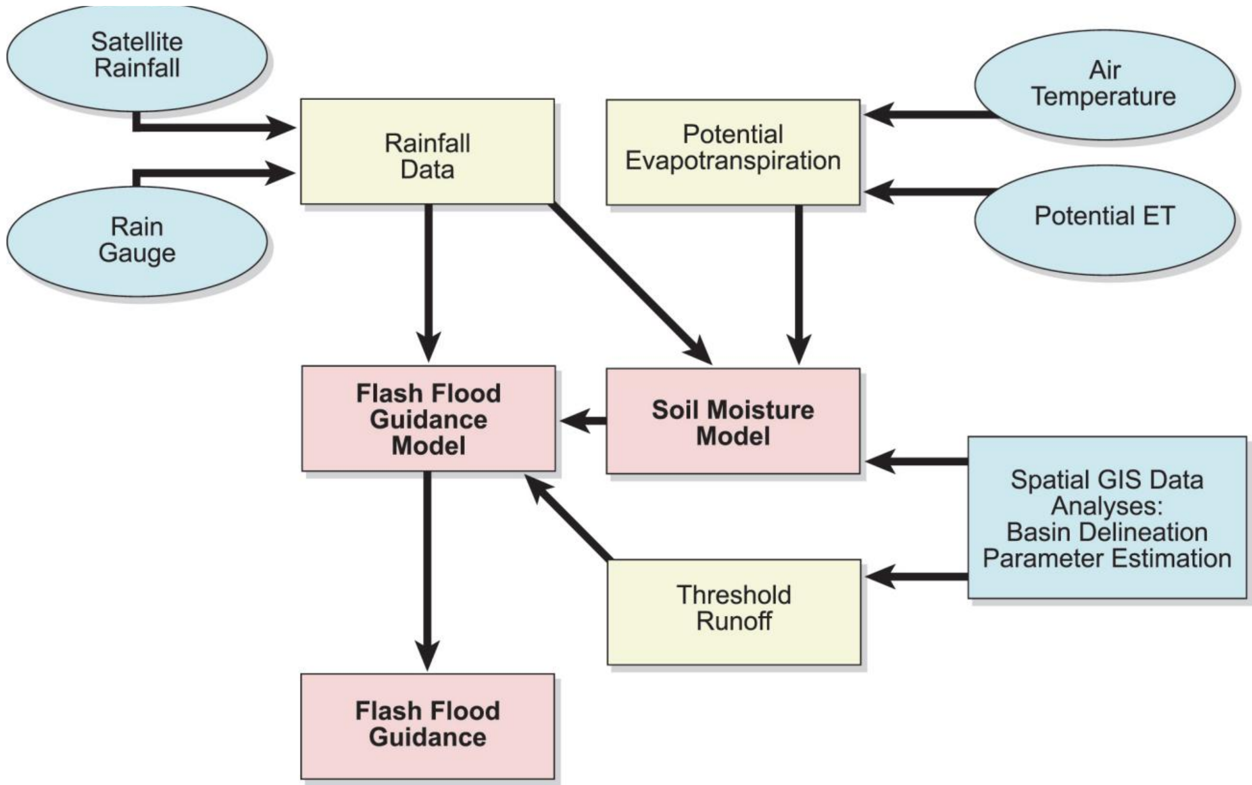



**Figure 3.2: Programmatic flow diagram for CAFFG subsystem.**

A "potential ET" processor uses daily temperature and climate information on evapotranspiration (ET) to provide daily potential ET input to the soil moisture model. The soil moisture model runs on a 6 hourly basis and determines the real-time soil moisture conditions to allow estimation of rainfall abstractions (such as actual ET and deep groundwater flow) and of the volume of surface runoff.

Threshold runoff is computed on the basis of geomorphologic theory from watershed and land characteristics. Soil moisture deficits and threshold runoff estimates are used in the flash flood guidance model to produce the volume of rainfall of a given duration that is necessary to initiate flooding in the small watersheds, that is, FFG. Threshold runoff is defined as the volume of effective rainfall of a given duration over the watershed of a small stream that is just enough to cause bank full flow at the watershed outlet.

The real-time rainfall data pass through a quality control model, as depicted in figure below, which identifies data with impossible values and adjusts for biases in the remotely sensed data on the basis of real-time and daily on-site rain gauge information. The result of this model is a merged hourly rainfall product, estimated as a mean areal rainfall value over the small watersheds that cover the Central America region.

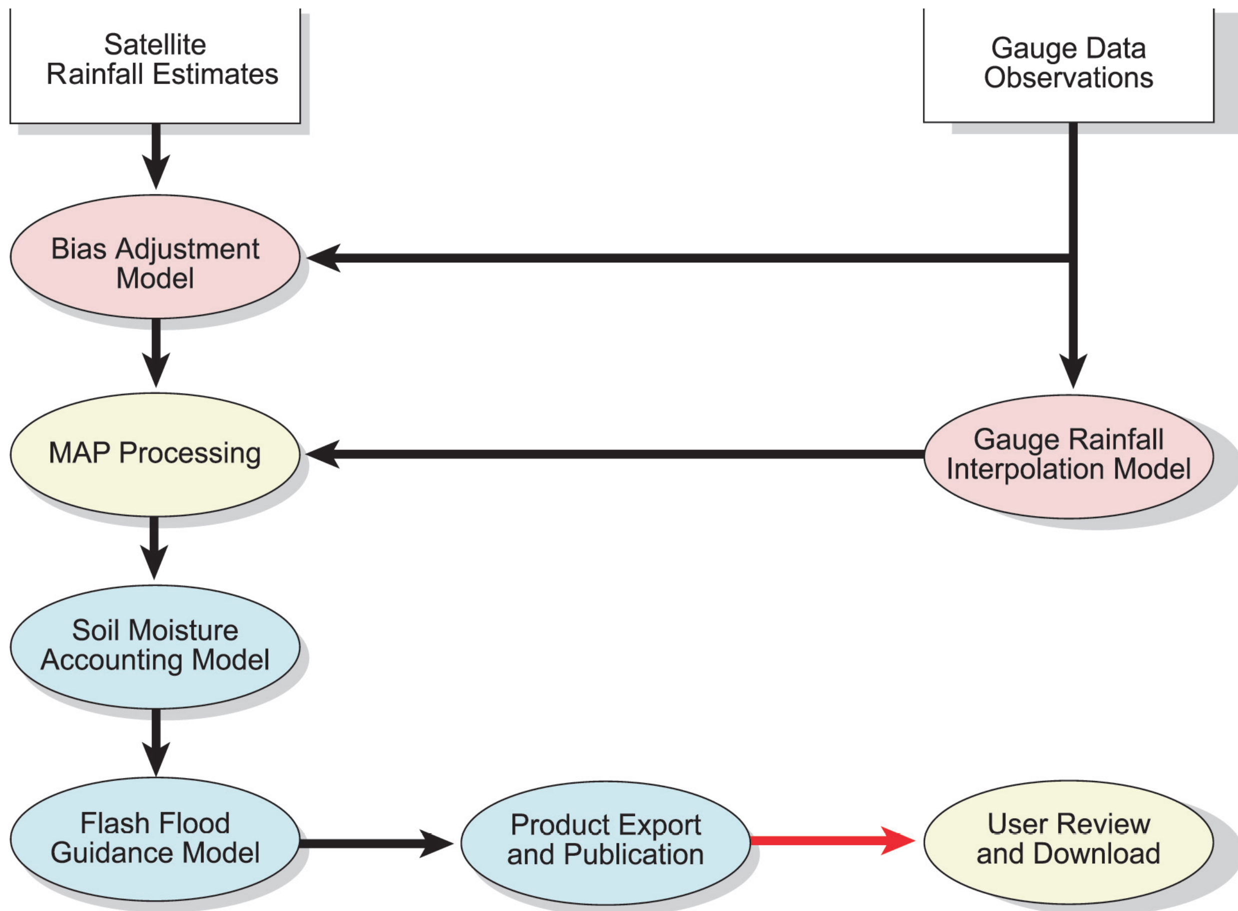



**Figure 3.3: Processing of real-time rainfall in CAFFG**

***CAFFG hardware:***

(1) CAFFG Processing Server (CPS).

(2) CAFFG Dissemination Server (CDS)

**Dissemination**:

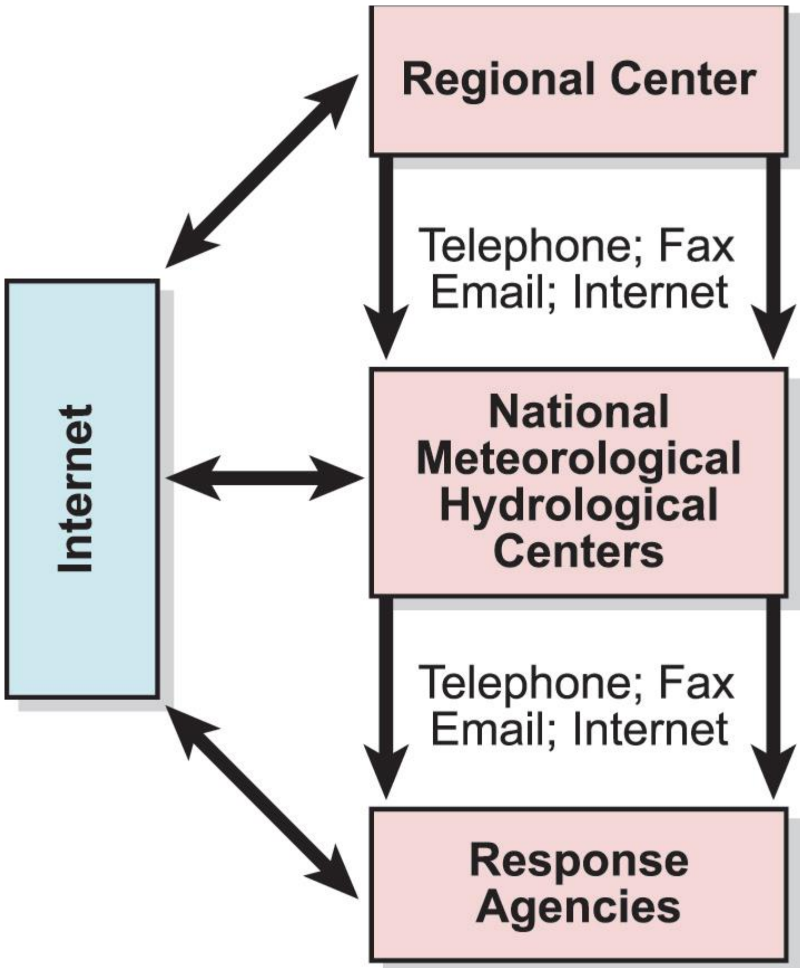



**Figure 3.4: Warning dissemination of CAFFG**

CAFFG System products are developed at the regional center in Costa Rica and disseminated to the national meteorological and hydrological services (NMHSs) and response agencies as appropriate.

### 3.1.2 Existing System in NEPAL

In Nepal early warning systems have been established by Mercy's corps in some place.

#### 3.1.2.1 Early Warning System in Kailali

Kailali District covers 3,235 Km² of which 59.7% lie in the plains (known as the Terai). It contains three major rivers. The Karnali, marking its eastern border, the Mohana running along its western and then southern border with India, and the Kandra, running north-south, through its centre. The Karnali, being snow fed, carries a significant flow throughout the year, while the two others, originating in the adjacent Churia range, carry significant flows only between June and September. During this period the annual monsoon swells their banks and brings regular floods to the district. The Karnali, rises hundreds of kilometers upstream in the Himalayas, passes through a number of gauging/recording points and also through a number of populated areas. As such it is both more predictable and more easily covered by warning. For this reason Mercy Corps chose to work on the Mohana river initially and then moved on to the Kandra, representing as they do both the greatest threat to the poorest and most vulnerable communities in Kailali and also the most difficult rivers, technically, in terms of establishing early warning.

The Mohana river starts in the Churia hills with its seven main tributaries gaining most of their dry season flow from springs. This flow is greatly increased during the monsoon however when surface runoff from the district catchment flows into the tributaries and routinely overwhelms their carrying capacity. Floods develop quickly, with little warning, resulting in disastrous consequences particularly for communities lying along the Indian border.

Prior to this effort, communities had traditional means of predicting floods - they took readings from the clouds, noted differences in the smell and color of the water, watched animal behavior closely – they acknowledged these indicators did not provide reliable or timely information, especially at night when flood most regularly occurred. They were therefore often left to evacuate when it was far too late and consequently lost lives, belongings and livestock.

## Setup

The work started started with a detailed assessment both of the community situation and possible institutional arrangements which could assist in broadening the information available to them. This assessment concentrated on the four stages of EWS - Knowledge of the risks; Monitoring, analysis and forecasting of the hazards; Communication or dissemination of alerts and Warnings; Local capacities to respond to the warnings received.

As a full Community Based Disaster Risk Reduction (CBDRR) programme was envisaged it was anticipated the first and fourth elements would be addressed through this (i.e. raising awareness and building capacities to respond). What were less clear were how warnings might be communicated and, critically, how monitoring, analysis and forecasting could be achieved at the community level. As such initial work concentrated on these two key elements.

Consultative meetings were held with the Department of Hydrology & Meteorology (DHM) at national, regional and district level. This was to establish what institutional capacity existed in terms of river and rainfall monitoring, whether this could be incorporated into an EWS and whether formal collaboration with DHM could be possible. At the same time, at District level, talks were held with the District Administration Office and District Development Committee to gauge their interest in and support for an EWS. Discussions at both levels were positive and as such a district assessment was carried out. This resulted in the following technical findings.

» For the Mohana watershed existing DHM rainfall monitoring stations existed at Godavari, Garva Darbar, Chaumala, Attaria and Sitapur. These could be utilised in any future EWS without the need for any additional support.

» Stream (river level, or ‘staff’) gauge stations on the Mohana river (at Malakheti), Khutiya river (at Mudi Bhavar), Guraha river (at Khereti) and the Kataini river (at Manikapur) could also all be incorporated into an EWS.

The assessment of resources also included discussion with existing DHM guage readers responsible for carrying our rainfall and river flow readings. Discussion covered the present functioning of the exisiting recording and reporting system, challenges faced by the readers, and their opinions on how and where improvements could be made. The opportunity was also taken to confirm all locations by GPS reading. As a result of these discussions various recommendations were made to the local authorities and DHM. These included:

» The need for the provision of CDMA phones to recording stations with communications difficulties.

» The need to offer additional payments, for additional work during peak rainfall periods, to DHM employees.

» The need to offer a package of additional awareness activities, training and incentives to DHM staff.

» The need to recruit volunteer readers within the communities themselves, who would go through the same capacity building program as the DHM staff.

### Dissemination

The final stage in communication system development was to formalize communication protocols, clarify communication routes and make public the communication network. To facilitate this number of workshops took place during which community members, gauge readers, DHM staff and district stakeholders collectively produced a communication tree. This clearly identified those responsible in each location and at every stage, by name and telephone number. Copies of this were subsequently produced in banner form for hanging in police posts, government offices, and community centers. It was also printed as part of a diary, for community members, so all critical numbers could be carried at all times.

In parallel with these planning activities a broad awareness, capacity building and skills training program was carried out at community level, as part of a community based DRR (CBDRR) program. As part of these task forces for search and rescue, first aid and early warning were established, with appropriate equipment distributed to match. In terms of EWS hand sirens were distributed as past experience indicated these were far more reliable and equally affective as powered ones. These would sound general warnings over a wide area. Additionally battery powered hand microphones were given, as ideal for relaying specific spoken messages.

# Chapter Four – Theoretical Background

## 4.1 Satellite Rainfall Estimates

Rain gauges provide a direct measurement of rainfall; however, the spatial density of rain gauge networks (especially of gauges whose data are available in real time) is typically far too coarse to capture the spatial variability of rainfall at small scales. Radar provides an indirect measurement of rainfall, but only for regions within a few hundred km of a radar unit - and even less in mountainous regions due to blockage of the beam. Estimates of rainfall from satellite data are less direct and less accurate than either gauges or radar, but have the advantage of high spatial resolution (4 km) and complete coverage over oceans, mountainous regions, and sparsely populated areas where other sources of rainfall data are not available. Since flash flood events often originate with heavy rainfall in sparsely instrumented areas that goes undetected, satellite-derived rainfall can be a critical tool for identifying hazards from smaller-scale rainfall and flood events.

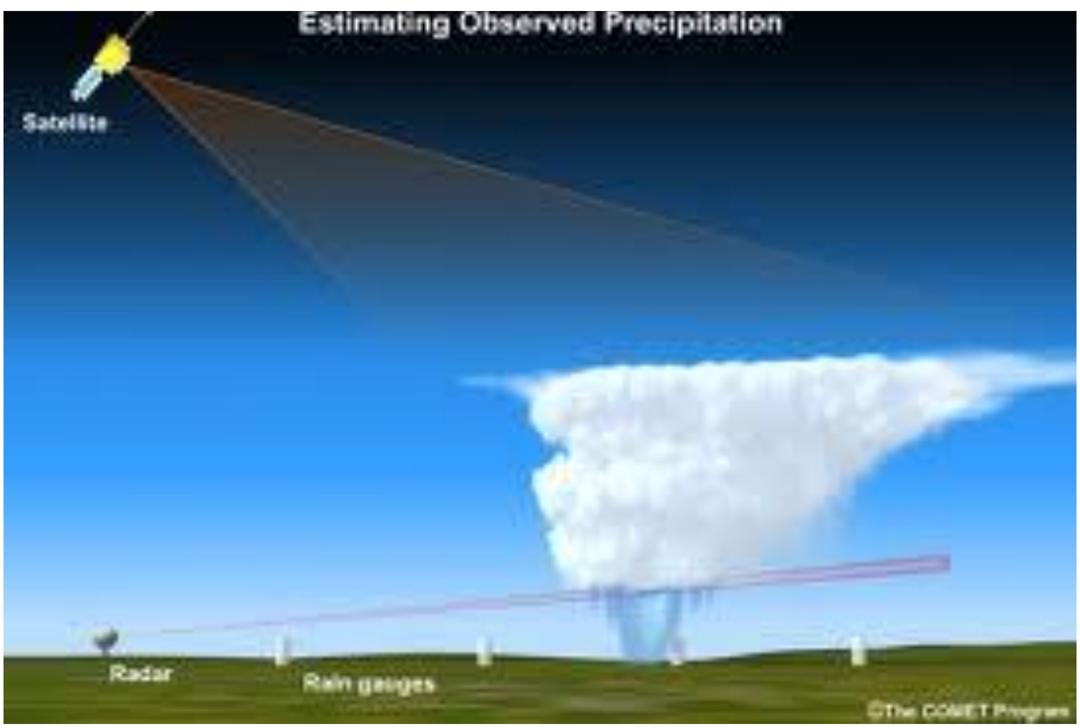



**Figure 4.1: SRE Mechanism**

### 4.1.1 Why estimating rainfall from space?

Precipitation is a crucial link in the hydrologic cycle, and its spatial and temporal variations are enormous. Knowledge of the amount of regional rainfall is essential to the welfare of society. Rainfall also drives the hydrological cycle, and to improve weather and climate predictions, an accurate global coverage of rainfall records is necessary. Raingauge data are available on land only, mainly in densely populated areas, and little offshore information exists.

Rainfall can be estimated remotely, either from ground-based weather radars or from satellite. Radars are active devices, emitting radiation at wavelengths ranging between 1 and 10 cm, and receiving the echo from targets such as raindrops. The maximum range of radars is only about 300 km, so offshore coverage is limited. Also, radars are prohibitively expensive in the Third World. Satellite-based measurements offer global coverage or a good part thereof.

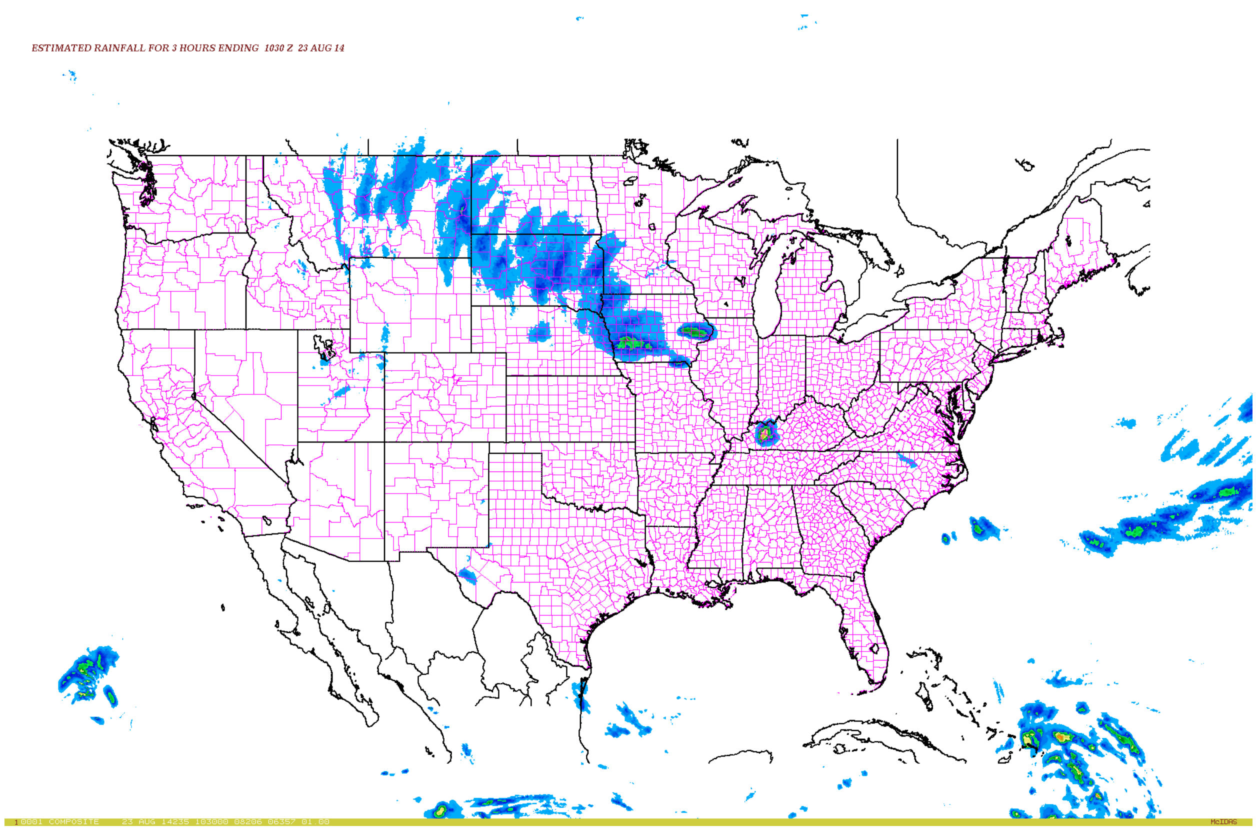



**Figure 4.2: SRE map showing atmosphere temperature**

## 4.2 Introduction to Flood Frequency Analysis

Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedence probability.

Flood frequency distributions can take on many forms according to the equations used to carry out the statistical analyses. Four of the common forms are:

- Normal Distribution
- Log-Normal Distribution
- Gumbel Distribution
- Log-Pearson Type III Distribution

Each distribution can be used to predict design floods; however, there are advantages and disadvantages of each technique. The choice of method depends on the various other supportive analyses such as nature of the river, geographical condition, peak discharge and many more.

## 4.3 Data Collection

FFA can be done on both discharge data and rainfall data. These data were collected from DHM (Department of Hydrology and Meteorology).

### Discharge Data

We collected discharge data for all the stations (e.g. station 681, Hampuachuwa) of Koshi Basin from DHM and some discharge date were also collected from internet for testing. Those data contains information about average discharge value in $m^3$ /s for each day of a year. Data of about 10 years from 1998 to 2008 A.D were collected.

### Rainfall Data

Rainfall data were also collected for DHM. Data collected were from the places surrounding the Koshi Basin such as of Dharan, Chatara and soon. The dataset was for the consecutive year from 1998 to 2008 A.D. The Dataset was formatted and had no missing values. The dataset had following columns.

1. Year

2. Day

3. Place

4. Min Precipitations

5. Max Precipitations

Similarly other data such as disaster data were collected from ICIMOD. The basic format of data collected from DHM is shown in Annex below.

## 4.4 Data Extraction

Once we have collected our required data from the source, we extract the actual information from it. Since the data provided from DHM were well formatted and in .txt format it was quite easy to extract the required field. A simple python script was written to extract each file from the folder. We had about more than 20 files in each more than 100 folders thus we develop folder extraction script.

## 4.5 Data Storage

The extracted data was saved in database. We have used My-SQL as our primary database and some temporary file systems (.txt, .xls) were also used to store some temporary information's during the simulation process. We have designed our database as per our requirement and also to make the retrieve process easy.

Maximum and minimum parameters for both discharge and precipitation were stored in database for frequency analysis.

### Average Discharge

For the calculation of frequency analysis we need to feed the average discharge for each year so we have to calculate average discharge for each year from the data stored.

### Construction parameter

The stored data contains information about the average daily discharge in $m^3/s$. We had data from 1986 to 2008/9. We summed up the individual discharge for each day of a month and similarly we found average discharge for a year. In this way average discharge for 10 year is found and fed in the system from the database. The average discharge calculation was done through SQL query.

Example:-

$$\text{Average Discharge for a year (Q)} = \sum_{n=0}^{365} \text{Average Daily Discharge}(q)$$

Similarly, in this way average discharge for each stored year was calculated.

### Average Precipitation

Frequency analysis is done for the rainfall data as well so average precipitation for each year is obtained from the stored.

### Construction Parameter

Obtained data contains the precipitation for the places surrounding Koshi basin. Precipitation data contain max and min values (in mm)but our concert were only average maximum precipitation values so we extract all the max values for each day and sum up to obtain for the year.

Example:-

$$\text{Average Precipitation for a year (P)} = \sum_{n=0}^{365} \text{Average Daily Precipitation}(p)$$

Thus, in this way average precipitation were calculated for each stored year.

## 4.5 Data Analysis

Flood frequency analysis of 1.101, 2, 10, 25, 50, 100 and 200-Years Return Period was calculated by Gumbel’s, and Log-PearsonIII. This program intended to assist in frequency analysis of rainfall or discharge data. The procedures used are based on Gumbel's distribution and log-distribution. Similarly,floods of different return periods were calculated. All the statistical data was entered and analyzed using corresponding algorithm and programming.

# Chapter 5 – Technical Background

## 5.1 Satellite-based rainfall estimation

With the advent of geostationary weather satellites in the 1960s and 70's, positioned above the equator at 5-6 positions around the globe to provide complete coverage, various techniques have been developed to estimate rainfall from visible and infrared (IR) radiation upwelling from the Earth into space. The higher the cloud albedo, the more droplets and/or ice crystals it contains and the deeper it tends to be, so the more likely rainfall is on the ground. And the lower the IR brightness temperature, the higher the cloud top, and the more likely the rainfall. A combination of both channels works best. Imagine a fair day with cirrus clouds, for instance. The IR channel may flag this as wet, because of the cold cloud tops; however cirrus is optically thin, so in the visible channel it is dry.

The visible/IR rain retrieval algorithms work best at low latitudes, because at higher latitudes the view is more slanted, confusion arises with high-albedo surfaces of snow or ice, and deep-convective precipitation is less common. Another problem is incomplete pixel filling for small cumulonimbus clouds.

At night no visible imagery is available. One can then use an empirical relationship between cloud-top temperature (deduced from the outgoing radiation in the 10.7-micron waveband), the simultaneous precipitation rate inferred from surface radar reflectivity, and the humidity profile (derived from radiosonde data). The rainfall rate (R mm/h) depends on the cloud-top temperature (T degrees Kelvin) thus:

$$R = 1.1183 \times 10^{11} \times \exp(-3.6382 \times 10^{-2} \times T^{0.5}) \qquad (5.1)$$

Adjustments are then made according to the perceptible water and surface relative humidity. The rate of change of cloud-top temperature can be used as well. It indicates the speed of cloud growth, and hence the areas of heavy rainfall.

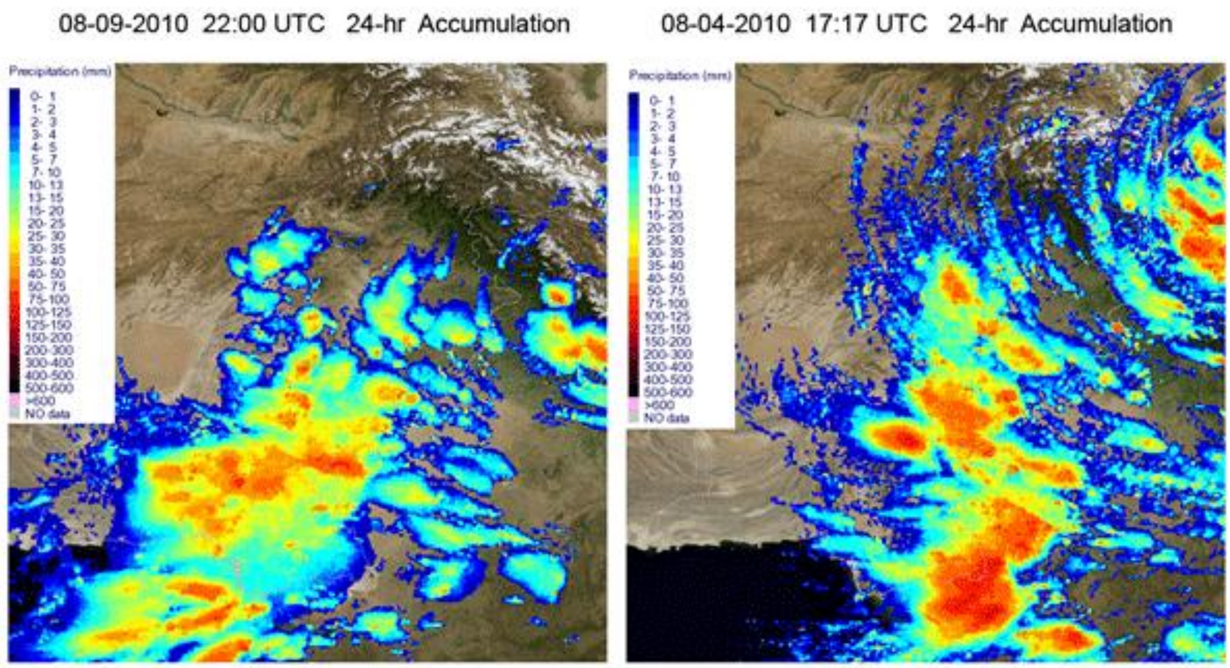



**Figure 5.1: Estimating MAR from SRE map**

In practice, the procedure allows useful estimates over 6 hours' periods. However, it overestimates rainfalls over 24-hours in the case of slowly moving thunderstorms with a broad anvil, by exaggerating the area of rainfall. On the other hand it underestimates rainfall from warm-top stratus, especially near coastlines and in mountainous terrain. In short, quantitative precipitation estimates from geostationary satellites can yield cumulative rainfall and thus flood warnings, for instance, because of the continuous coverage, but large discrepancies with rain gauge data occur.

## 5.2 Flood Flow Analysis

### 5.2.1 Introduction

In hydrological analysis, high floods are required to be computed for designing and predicting possible outcome.

Finding out of the design flood in different return period are very important for the evaluation, design and prediction of any water resource projects such as design of hydropower, design of culverts and bridges, and also for the early warning systems. The flood flow analysis is carried out to obtain the worst flood that can occur during the 200 years time so that we can carry out our worst case analysis of the given period. Frequency analysis along with time series data can be very useful in early warning system. With frequency analysis we too can statistically predict the losses of lives and property with the reference of available disaster data.

Flood frequency analysis uses historical records of peak flows to produce guidance about the expected behavior of future flooding.

Two primary applications of flood frequency analyses are:

1. To predict the possible flood magnitude over a certain time period
2. To estimate the frequency with which floods of a certain magnitude may occur

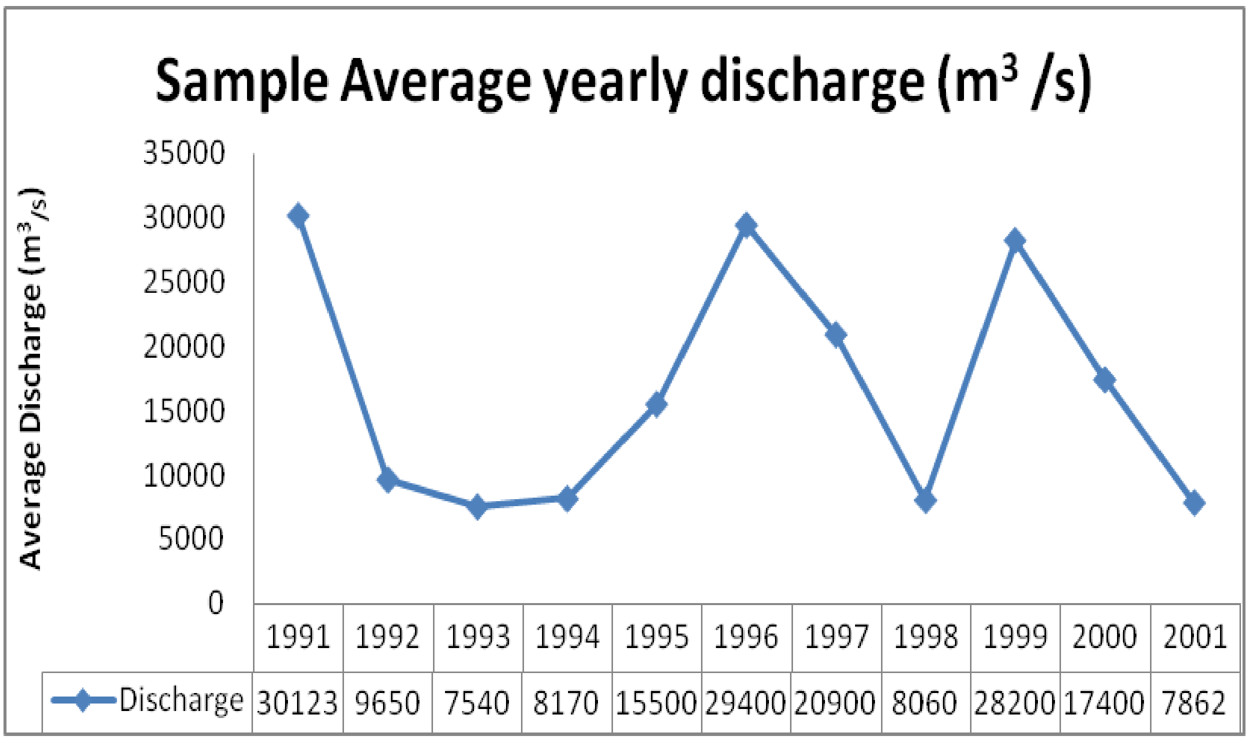



**Figure 5.1: Sample average discharge per year data**

### 5.2.2 Importance of Flood Flow Analysis

The flood flow analysis is of supreme importance as failure to predict the flood flow correctly may cause the immature demise of the whole project due to unforeseen flood. Reliable flood estimates are essential as the viability of a project depends on the economy of hydraulic structures.

### 5.2.3 Method for Flood Flow Analysis

For Ungauged Basin:

1. Regional Methods
   - PCJ method
   - MHSP
   - WECS/DHM
2. Empirical Method
   - Snyder's Method
   - B. D. Richard's Method
   - Modified Dicken's Method

For Gauged Basin

- Gumbel Method
- Log Pearson Type III Distribution

#### 5.2.3.1 Empirical Methods

#### Snyder's Method

Snyder's method was used for flood flow estimation by deriving a synthetic unit hydrograph based on known physical characteristics of the basin. In this method, the peak discharge $Q_{PR}$, in $m^3/s$, was computed as

$$Q_{PR} = q_{PR} C_A AR \qquad \text{.........(5.2)}$$

where $q_{PR}$ is the peak discharge per square km of the drainage area due to 1 cm of effective rainfall for rainfall duration of $t_r$ in $m^3$/s/sq. km., $C_A$ is an aerial reduction factor that accounts for the fact that the average rainfall intensity over a large area is smaller than that over a small area, $R$ is the rainfall in cm for duration $t_R$ derived from the 24-hour rainfall with the reduction for area. For use $q_{PR}$ shall be computed from the relation

$$q_{PR} = 2.78 \frac{C_P}{t_{PR}} \qquad \text{.........(5.3)}$$

where $C_P$ is a coefficient depending upon basin characteristics and $t_{PR}$ is the lag time in hours for rainfall duration $t_R$, calculated as

$$t_{PR} = t_{pr} + .25(t_R - t_r) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.4)$$

In the above equation, $t_r$ is the standard duration of effective rainfall in hours given by

$$t_r = \frac{t_{pr}}{5.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.5)$$

and $t_{pr}$ is the lag time from the midpoint of effective rainfall of duration $t_r$ to the peak of a unit hydrograph in hours, computed as

$$t_{pr} = 0.75 C_t (L L_c)^{0.3} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.6)$$

where $C_t$ is a coefficient depending upon basin characteristics, $L$ is the length of stream from the station to the upstream limit of the drainage area in km and $L_c$ is the distance along the main stream from the basin outlet to a point on the stream which is nearest to the centroid of the basin in km.

The coefficients $C_t$ and $C_P$ shall be determined from analysis of some known hydrographs in the region. In the absence of hydrographs, the values of $C_t$ and $C_P$ may be adopted as 1.5 and 0.62, respectively.

## B.D. Richard's Method

B. D. Richard's method was used for flood estimation using rainfall and basin characteristics. The method consists of computing the flood discharge Q in m$^3$/s using the equation.

$$Q = 0.222 AIF \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(5.7)$$

where $A$ is basin area in sq. km., $I$ is the rainfall intensity corresponding to the time of concentration $T_c$ and $F$ is an aerial reduction factor given by

$$F = 1.09352 - 0.6628 \ln(A) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.8)$$

The value of $I$ shall be estimated through an iterative procedure in which an initial value of $T_c$ in hours shall be assumed and the following computations performed in sequence:

$$D = 1.102 \frac{L^2}{S} F \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots...(5.9)$$

$$R_{TC} = 0.22127 R_T T_c^{0.476577} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5.10)$$

$$I = \frac{R_{TC}}{T_C} \quad \text{.............................................................(5.11)}$$

$$K_R = 0.65I(T_c + 1) \quad \text{....................................................(5.12)}$$

$$C_{KR} = \frac{0.95632}{K_R^{1.4806}} \quad \text{.......................................................(5.13)}$$

$$T_{c3} = DC_{KR}$$

$$T_{c2} = \left(\frac{T_{c3}}{0.585378}\right)^{\frac{1}{2.17608}} \quad \text{...............................................(5.14)}$$

where $L$ is the basin length in km, $S$ is the basin slope, $R_T$ is the 24 hour rainfall for return period $T$ in mm and $T_{c2}$ is the second estimate of the time of concentration. The iterations shall be repeated with $T_c$ = $T_{c2}$ till the difference between the assumed $T_c$ and the resulting second estimate $T_{c2}$ is less than 5%.

## Modified Dicken's Method

Using Dicken's method, the T year Flood discharge $Q_T$ in $m^3/s$ shall be determined as

$$Q_T = C_T A^{0.7}$$

Where A is the total basin area in $km^2$ and $C_T$ the modified Dicken's constant proposed by the Irrigation Research Institute, Roorkee, India, based on frequency studies on Himalayan

rivers. This constant shall be computed as

$$C_T = 2.342\log(0.6T)\log\left(\frac{1185}{p}\right) + 4 \quad \text{........................................(5.15)}$$

$$p = 100\left(\frac{a+6}{A+a}\right) \text{.........................................................(5.16)}$$

where a is the perpetual snow area in $km^2$ and T is return period in years.

The flood flows for different return periods were obtained by B.D.Richard's method is presented in tabular form in Appendix A

### 5.2.4 For Gauged River Basin (GRB):

#### 5.2.4.1 Gumbel's Method :

This extreme value distribution was introduced by Gumbel (1914) and is commonly known as Gumbel's distribution. It is one of the most widely used probability- distribution functions for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc.

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value of $x_0$

$$P(X \geq x_0) = 1 - e^{-e^{-y}}$$

in which $y$ is a dimensionless variable given by

$$y = \alpha(x - a)$$

$$a = \bar{x} - 0.45005\sigma_x$$

Thus $$y = \frac{1.2825(x - \bar{x})}{\sigma_x} + 0.577 \qquad \text{.......................................................(5.17)}$$

where $\bar{x}$ = mean and $\sigma_x$ = standard deviation of the variate $X$. In practice it is the value of $X$ for a given P that is required and the eqn. is transposed as

$$Y_p = -\ln[-\ln(1 - P)]$$

Noting that return period T=1/P and designating $Y_T$= the value of y, commonly called the reduced variate, for a given T,

$$Y_T = -\left[\ln \ln \frac{T}{T-1}\right]$$

$$Y_T = -\left[0.834 + 2.303 \log \log \frac{T}{T-1}\right] \qquad \text{..............................................(5.18)}$$

So, the value of variate X with a return period T is

$$x_T = \bar{x} + K\sigma_x$$

$$where, \; K = \frac{(y_T - 0.577)}{1.2825}$$

In this way Gumbel's method can be use for frequency analysis.

### 5.2.4.2 Log –Pearson Type III Distribution

In this method the variant is first transformed into logarithmic form (base10) and the transformed data is then analyzed. If X is variant of random hydrologic series, then the series of z variants Where,

$$z = \log x$$

For z series, for any recurrence interval T

$$z_T = \bar{z} + K_z \sigma_z \quad \ldots\ldots(5.19)$$

Where $K_z$ = a frequency factor is function of recurrence interval T and coefficient of skew $C_s$

$\sigma_z$ = Standard deviation of the Z variant sample

$$\sigma_z = \sqrt{\frac{\sum (z-\bar{z})^2}{(N-1)}}$$

$C_{s=}$ coefficient of skew of variant Z

$$C_s = \frac{N\sum (z-\bar{z})}{(N-1)(N-2)\sigma_z{}^3} \quad \ldots\ldots(5.20)$$

The variations of $K_z$ =f ($C_s$, T) is given in table.

The corresponding value of $x_T$=antilog ($z_T$)

## 5.2.5 Low Flow Analysis:

This method is developed for predicting the river flows for catchment areas larger than 100 sq km. of ungauged rivers based on hydrological theories, empirical equations and statistics. In this method, the total catchment area, areas between 5000 m to 3000 m are required as input. Flow contribution per unit area for 5000 m to 3000 m and from lower elevations i.e. below 3000 m is assumed to be in different proportion during flood. However, for long term average monthly flows all areas below 5000 m are assumed to contribute flows equally per sq. km. area. The average monthly flows can be calculated by the equation:

$Q_{mean,[month]}$=C * (Area of basin)$^{A1}$ * (Area below 5000 m +1)$^{A2}$ * (mean monsoon precipitation)$^{A3}$ ..........................................................................(5.21)

Where, $Q_{mean,[month]}$is the mean flow for a particular month in m$^3$/s, C, A1, A2 and A3 are coefficients of the different months.

The discharge for the different return period can be calculated by the following formulae:

$Q_2$=0.09299 + 0.09269*(Area of catchment below 5000 m + 1)$^{0.5}$

$Q_{10}$= -0.00749 + 0.0848*(Area of catchment below 5000 m + 1)$^{0.5}$

$Q_{20}$= -0.03059 + 0.08248*(Area of catchment below 5000 m + 1)$^{0.5}$

The WECS also developed a regression equation to obtain the 2, 10 and 20 year low flows. The above equations can be used to obtain the values and these values are the lowest for the year and not specific to a month. If the resulting value of Q is negative then the value is replaced by zero as the flow cannot be negative.

Thus, above mentioned are some of the methodologies of flood frequency analysis, all of the above mentioned methods are not implemented in our project rather two of them (Gumbels and Log-PearsonIII) are implemented.

# Chapter Six - System Description

## 6.1 Requirement Specification

The system requirement specification of the project gives the overall requirements of the system. The functional and non-functional aspects of requirements are given by the requirement specification. The requirements of the project were based on the functional requirements provided by ICIMOD.

### 6.1.2 High Level Requirement

The system FFEWS is developed as a tool for flash flood analysis and early warning system. The system will provide different functionalities for flood analysis through the use of past flood data. Similarly, the system will provide a warning mechanism based on continuous monitoring of flood sites as well as forecast mechanisms. The system will also be able to predict the vulnerability the sites through flood mapping. Besides, the system will be able to visualize the past flood data for easy understanding and analysis of flood data.

### 6.1.3 Functional Requirements

The functional requirements of our project are discussed below:

#### 6.1.3.1 Flood Frequency Analysis

Flood frequency analyses are used to predict design floods for sites along a river. The technique involves using observed annual peak flow discharge data to calculate statistical information such as mean values, standard deviations, skewness, and recurrence intervals. These statistical data are then used to construct frequency distributions, which are graphs and tables that tell the likelihood of various discharges as a function of recurrence interval or exceedence probability.

#### 6.1.3.2 Satellite Rainfall Estimation (SRE)

Satellite Rainfall Estimation is a technique through which the precipitation level can be predicted based on the satellite images captured by geostationary satellites. The image pattern observed in a given sequence of time is analyzed to extrapolate the future image and estimate the level of precipitation based on it. The rainfall amount can be calculated from this extrapolation and this number can be used to compare with the critical rainfall level for flood initiation.

The system acquires the satellite images for different time-intervals from the satellite image server and calculates the precipitation level. The equivalent rainfall amount is estimated and compared with the critical rainfall amount required for triggering a flood. The warning message is generated based on the different warning levels.

#### 6.1.3.3 Real-time River level Monitoring

The real-time water-level data of various stations are continuously collected from the monitoring page of Nepal Government, Ministry of Science Technology and Environment, Department of Hydrology. The data so collected are compared with the different critical levels of water level. And the warnings are generated accordingly.

#### 6.1.3.4 Real-time Rainfall Monitoring

The real-time precipitation level data of various stations is continuously collected from the monitoring page of Nepal Government, Ministry of Science Technology and Environment, Department of Hydrology. The data so collected are compared with the different critical levels of rainfall required to trigger a flood. Then the warnings are generated accordingly based on the output obtained.

#### 6.1.3.5 Flood Map Generation

Flood map is the map showing inundation of water flow plotted in a given area-map. The flood map shows the prediction of vulnerable areas which can be possibly reached by the forecasted flood. The flood map is generated by the system based on the Digital Terrain Model (DTM) data and the discharge level data. The DTM data is fed as input and the discharge level data is taken as the boundary condition for the flood-mapping.

#### 6.1.3.6 Data Visualization

The system is also able to show the graphical visualization of the past flood data. The visualization is interactive and can be viewed in different forms. It helps the user to get the intuition about the past data and helps in the analysis of the data.

## 6.2 System Architecture

Our project, for simplification, has been categorized into three modules.

1. Prediction module
2. Warning Message Transfer module
3. Visualizing module

### 6.2.1 System Architecture Diagram

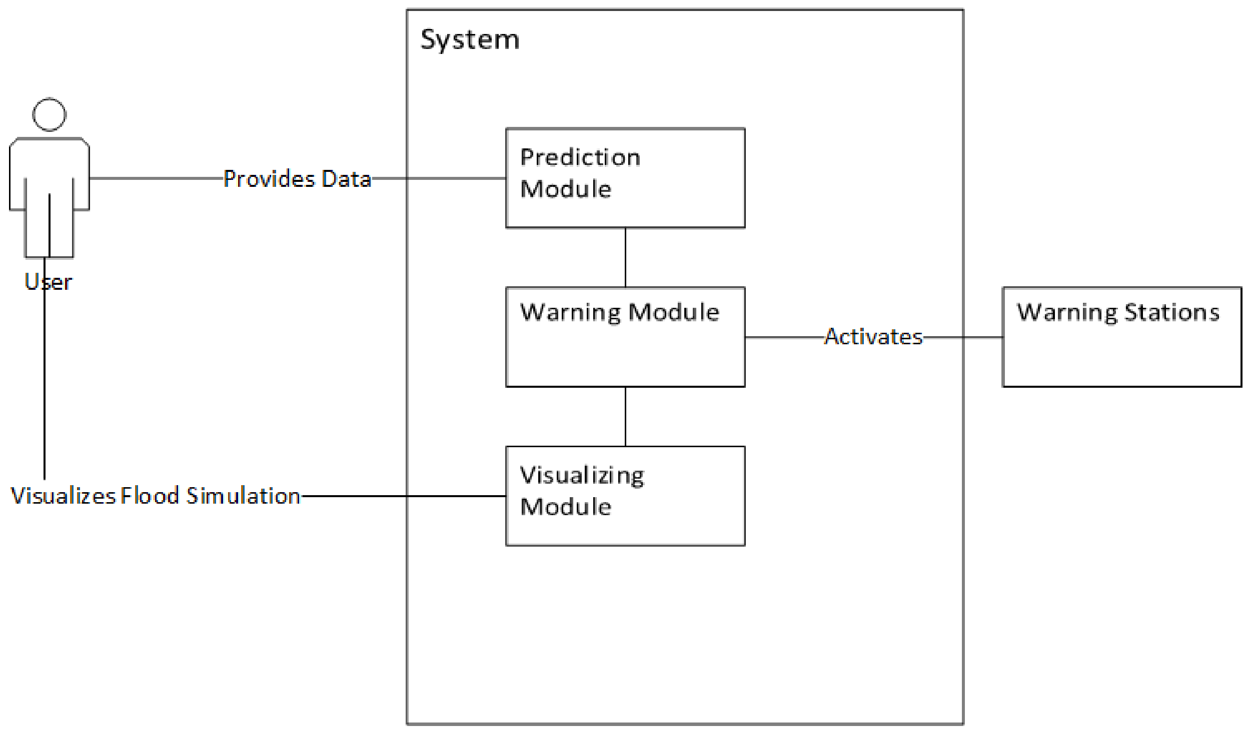



Figure 6.1: System Architecture Diagram

## 6.3 System Description

Different hydrological stations are established in various parts of the country. These hydrological stations continuously collect real time data of water-level of the rivers, discharge rate of the rivers and rainfall of the site. These real time data are continuously provided by the servers of the

DHM. These data are collected and brought to the system. Then the data is processed to determine the warning level of various stations.

SRE data is the satellite image map collected from satellite stations. The link to fileserver for SRE image was provided by ICIMOD. The satellite image is downloaded from the image server and then is processed for the generation of equivalent precipitation amount for the given site. The temperature shown in the map is converted to the predicted rainfall amount by processing the pixels of the map.

Historical data is the database of the past hydrological data. The database contains the past data of rainfall and discharge levels of different rivers collected from different hydrological stations. The data was collected from the DHM. The day-wise rainfall and discharge level data of past ten years from different stations were collected and stored in the database. The database was used for the flood frequency analysis and data visualization purpose.

This is the main module of the project. All the data collected from different sources are processed in this module. The data from real-time data servers are processed to determine warning levels for each river stations. Similarly the data collected from SRE data server is processed to generate precipitation amount. The pixel mapping is used to generate the precipitation amount from the temperature map. So obtained rainfall amount estimation is used to determine the warning level of the respective river site.

The data collected from DHM contained some unformatted files and unformatted data. The data file format was fixed and values were converted into usable formats. Then the database was created using these values. These values were then used for the flood frequency analysis and visualization.

Flood map generation is one major task in the project. The DTM data of the river site is fed into the system. Then the river-line is generated from the given data. After that, the cross section of the river line is drawn using the Hec-Ras tool. Then the discharge level of the river is provided as the boundary condition for the flood-map generation. Finally, using the DTM model and the boundary conditions, the flood map is generated using the ArcGIS and Hec-Ras plugin.

Thus produced flood map can be used to calculate the vulnerability of the site and habitat residing in the site and hence can be warned beforehand.

The system can produce different kinds of warning message based on the real-time station monitoring and forecasted rainfall prediction. Based on the different risk levels, different warning messages are generated. Similarly the system user can provide early warning to the vulnerable habitants by observing the flood map resulting from the different estimations.

This visualization module of the project is used for easy understanding and analysis of the past hydrological datasets. The visualization tools give an intuitive understanding of the flood related data of different monitoring stations.

## 6.4 System Diagrams

### 6.4.1 Use Case Diagram

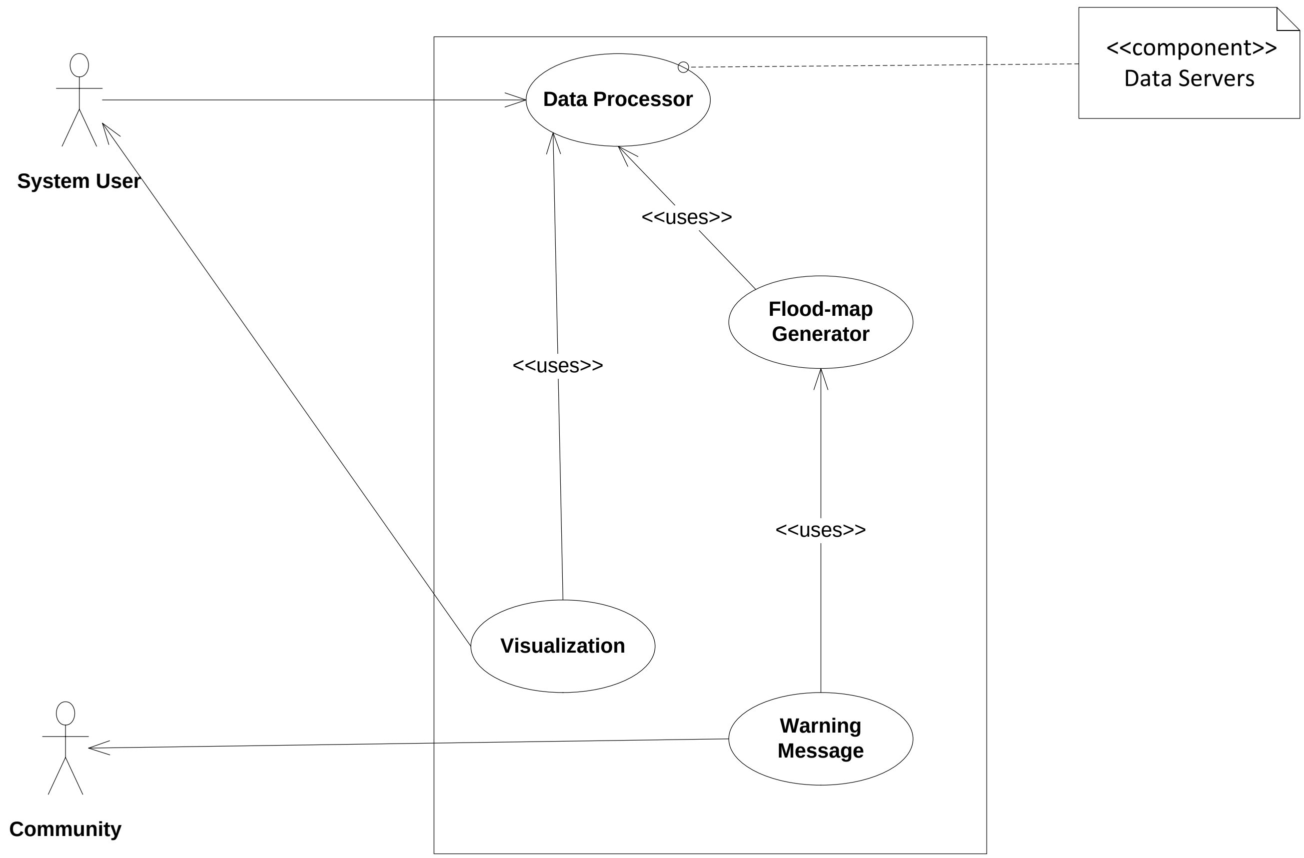



**Figure 6.2: Use-case Diagram**

### 6.4.2 Collaboration Diagram

### 6.4.2 Collaboration Diagram

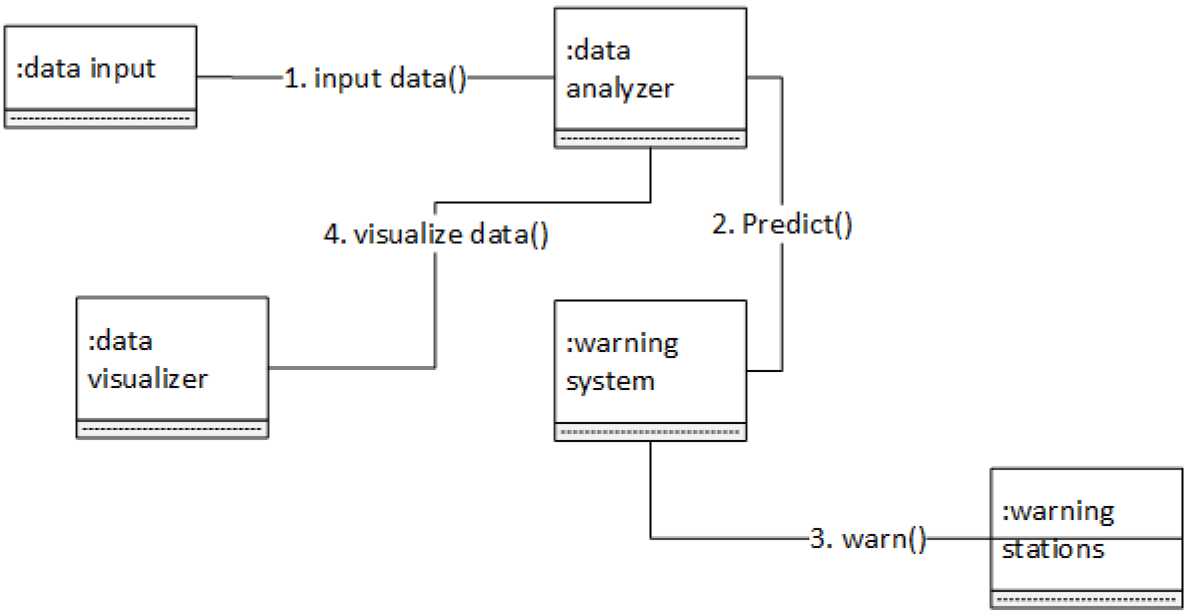



Figure 6.3: Collaboration Diagram

### 6.4.3 Activity Diagram

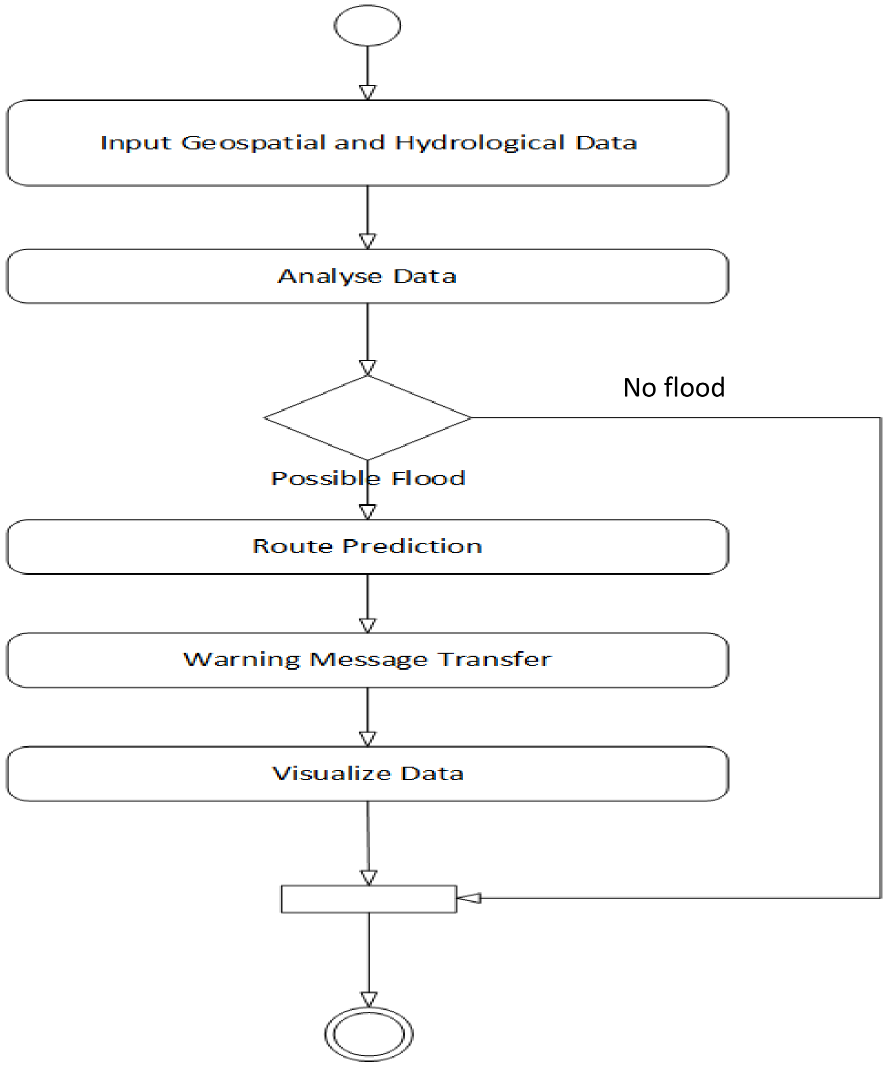



**Figure 6.1: Activity Diagram**

# Chapter Seven – Methodology

## 7.1 System Design

The overall system design of FFEWS can be shown in the following block diagram:

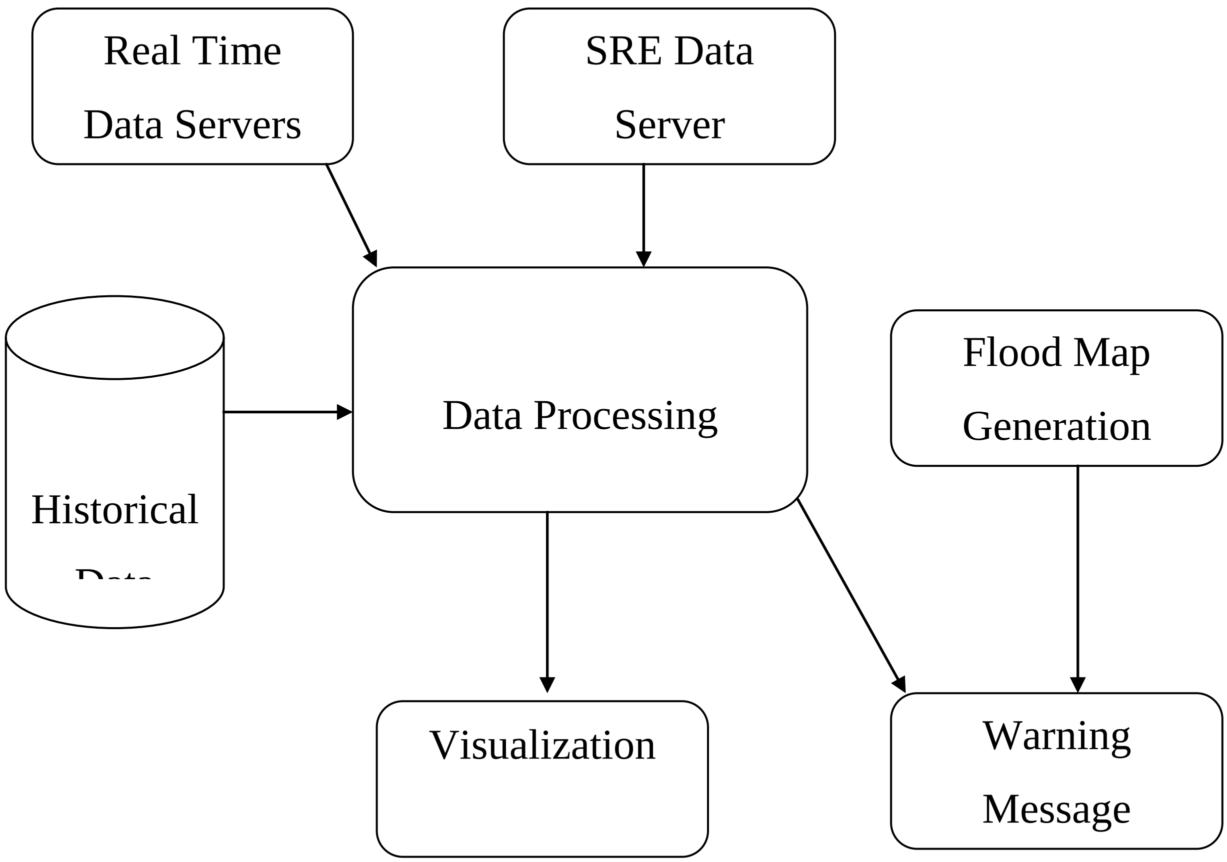



**Figure 7.1: System Block Diagram**

The block diagram of the FFEWS System is shown in the above figure. It consists of different modules. Each of the modules was developed separately. The components of the projects were altered a few times based on the feasibility of the system. The implementation methodology of each of these modules is discussed in the sections below.

## 7.2 System Development

### 7.2.1 Satellite Rainfall Estimation

#### SRE Data Download

SRE data is the satellite image map data collected by various organization and authorities working on this field. The map data is found for different regions of the world. The map data we collected was provided by a data server whose link was provided to us by ICIMOD. The data is downloaded from the server and stored in our local database for processing.

Ajax was used to routinely download the SRE Data required for processing. Then the downloaded map data was processed using python script.

#### Rainfall Data Extraction

When the map is obtained from the data server, each pixel of the map is processed to generate the rainfall amount shown by the pixel of the map grid. Each cell in the grid shows the area in the earth's surface and the temperature value of each pixel gives the equivalent rainfall amount for that area.

The pixel value of the map gives the temperature of the atmosphere. Then we use an empirical relationship between cloud-top temperatures, the simultaneous precipitation rate inferred from surface radar reflectivity, and the humidity profile. The rainfall rate (R mm/h) depends on the cloud-top temperature (T degrees Kelvin).

### 7.2.2 Data Scraping From Real Time Data Servers

The real time rainfall data, river discharge data and water level data are continuously collected by the various hydrological stations setup in the river sites. These data are continuously provided by the servers of DHM. These data are routinely collected from the data-serving site and checked for the warning level. The various warning levels are set for the different stations. The acquired data is compared with the critical data values required for warning. If the collected data is above the warning level, then the warnings are generated.

### 7.2.3 Flood Map Generation

Flood map is a visualization of, to what extent the flood will affect any area. It is generated over an aerial imagery and shows the flow of water across the river and also displays the flow of water beyond river banks. The overlap area between water flow and the aerial imagery thus helps to determine the affected region for a particular value of discharge. Thus measuring the discharge at a certain point in the river can help predict the amount of water flow below that point and thus generate a flood map. This generated flood map can be used to determine the region which probably will be affected by that amount of discharge in the river.

#### 7.2.3.1 Generation Technique

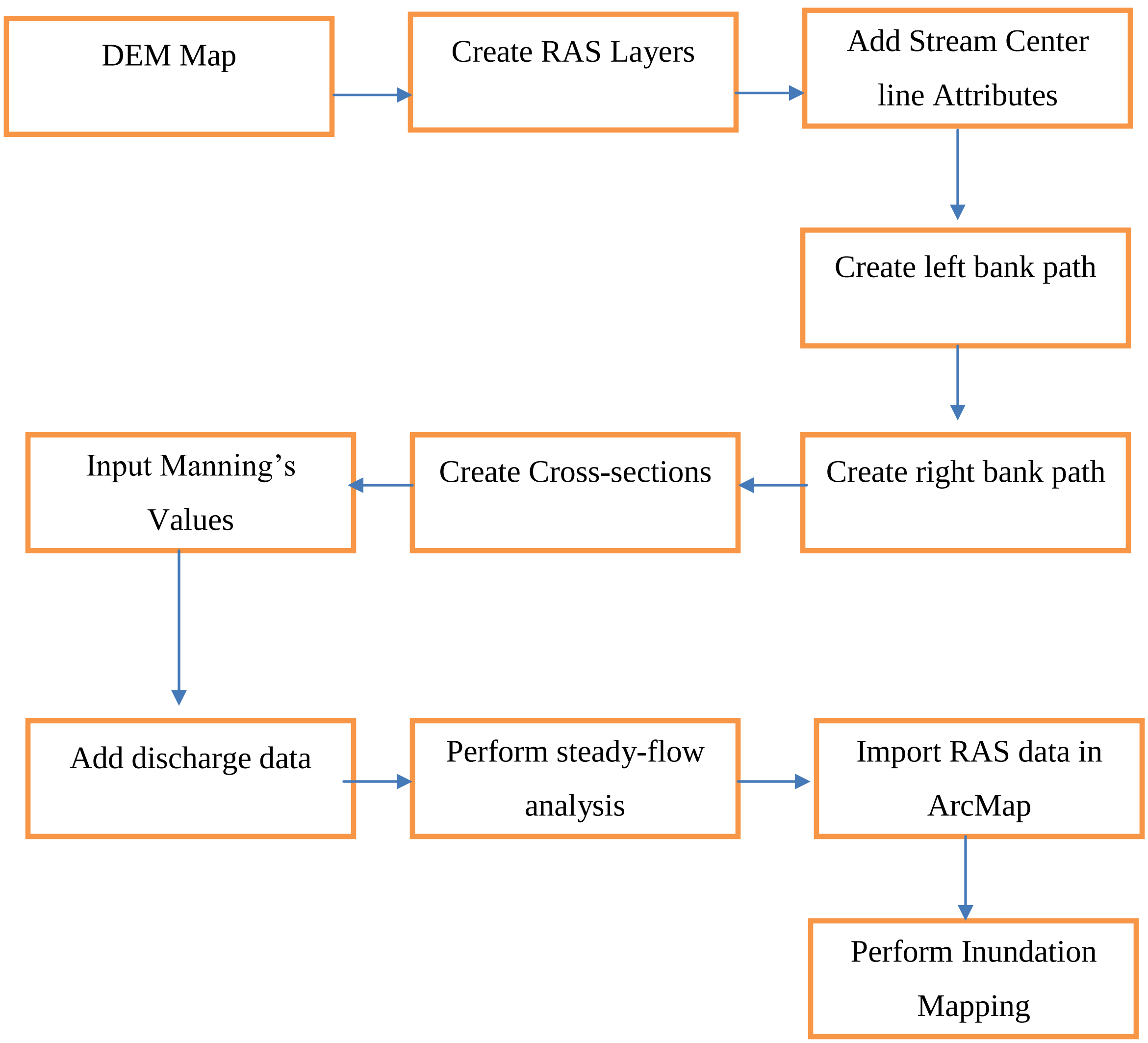



Figure 7.2: Flood Map Generation Technique in Block Diagram

#### 7.2.3.2 Phases of Generation

### Phase I (Creation of RAS Geometry)

DEM data is taken and along the river path, cross-sections are generated. Cross-sections are the lines perpendicular to the line generated along the river path. These perpendicular lines join the left bank to the right bank denoting the extent of river.

Generation of cross-sections is done using ArcMap. ArcMap provides an advanced UI to generate cross-sections where each cross-section line width are specified. After these lines are generated, a geo-spatial reference is added so that a co-ordinate system is assigned to our map.

As water flows through the river, the flow experiences some resistance from the river geo-structure. This resistance is low at the center of the river and more at the sideways i.e. the banks. This resistance is due to vegetation and uneven structure of the soil. To represent this resistance, manning values are provided. An entire map is divided into polygons and each polygon is provided with a certain manning value. This manning value represents the amount of resistance it will provide to the water flow.

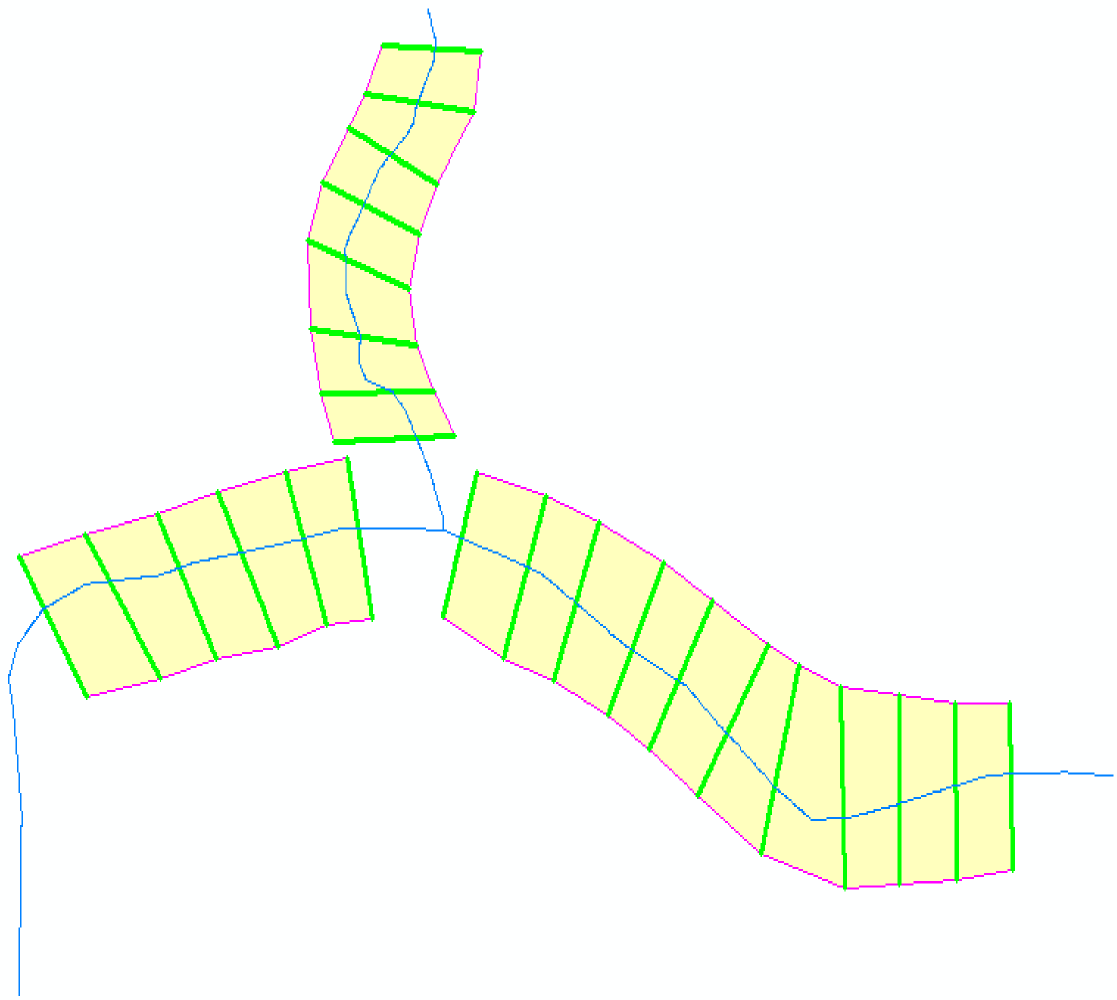


**Figure 7.3: Cross Sections in the River Line**

### Phase II (Steady Flow Analysis)

Thus generated cross-section data is exported to Hec-RAS. Hec-RAS is a tool to perform steady flow analysis. For a certain value of discharge and a certain cross-section data, it performs steady flow analysis and thus generates RAS Mapper data. This generated RAS Mapper data is exported in DEM format and then import in ArcMap to perfrom RAS Mapping.

### Phase III (RAS Mapping)

To perform RAS Mapping, a certain layer is setup importing the DEM data exported through Hec-RAS. Then inundation mapping is performed using imported RAS data. Inundation mapping includes two steps. The first step is **Water Surface Generation**. A layer of water data is generated over the DEM map. Then the second step is **Flood Plain Delineation using Raster**. In this step a flood plain is aligned with the imported DEM map.

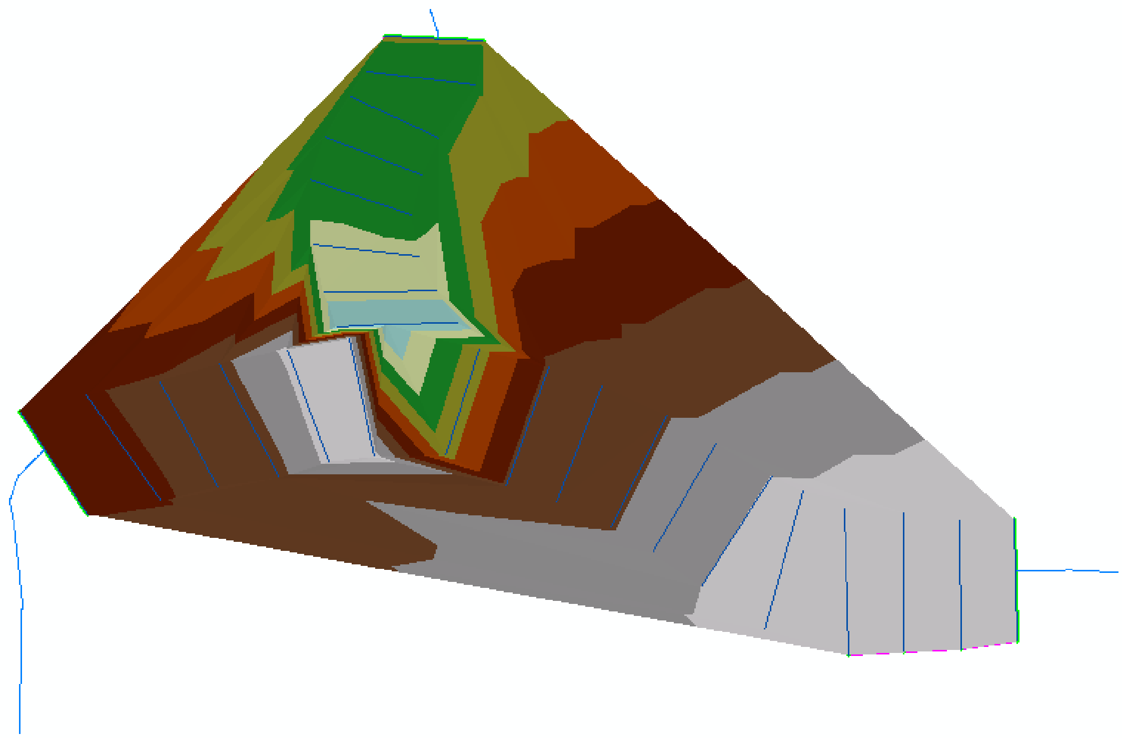


**Figure 7.4: DEM data imported from Hec-RAS**

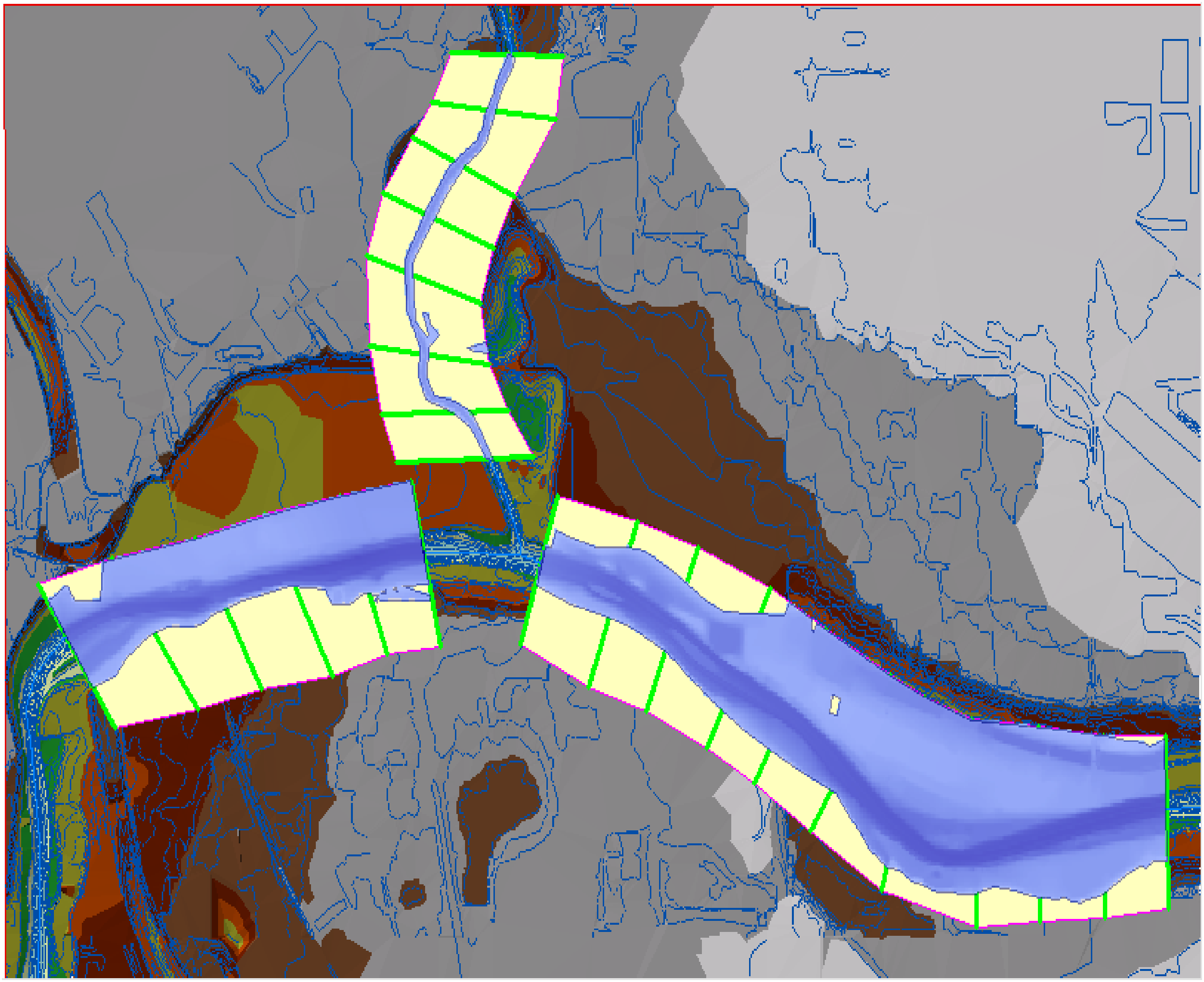


**Figure 7.5: Water Surface Generated over DEM Map**

### Phase IV (Addition of Aerial Image)

Flood map generation is completed in Phase III. This last step is done to help visualize the effect of flood discharge over residential area. For this, an aerial imagery is added over the same DEM and flood map under the same geo-spatial reference thus displaying the region where flood will affect.

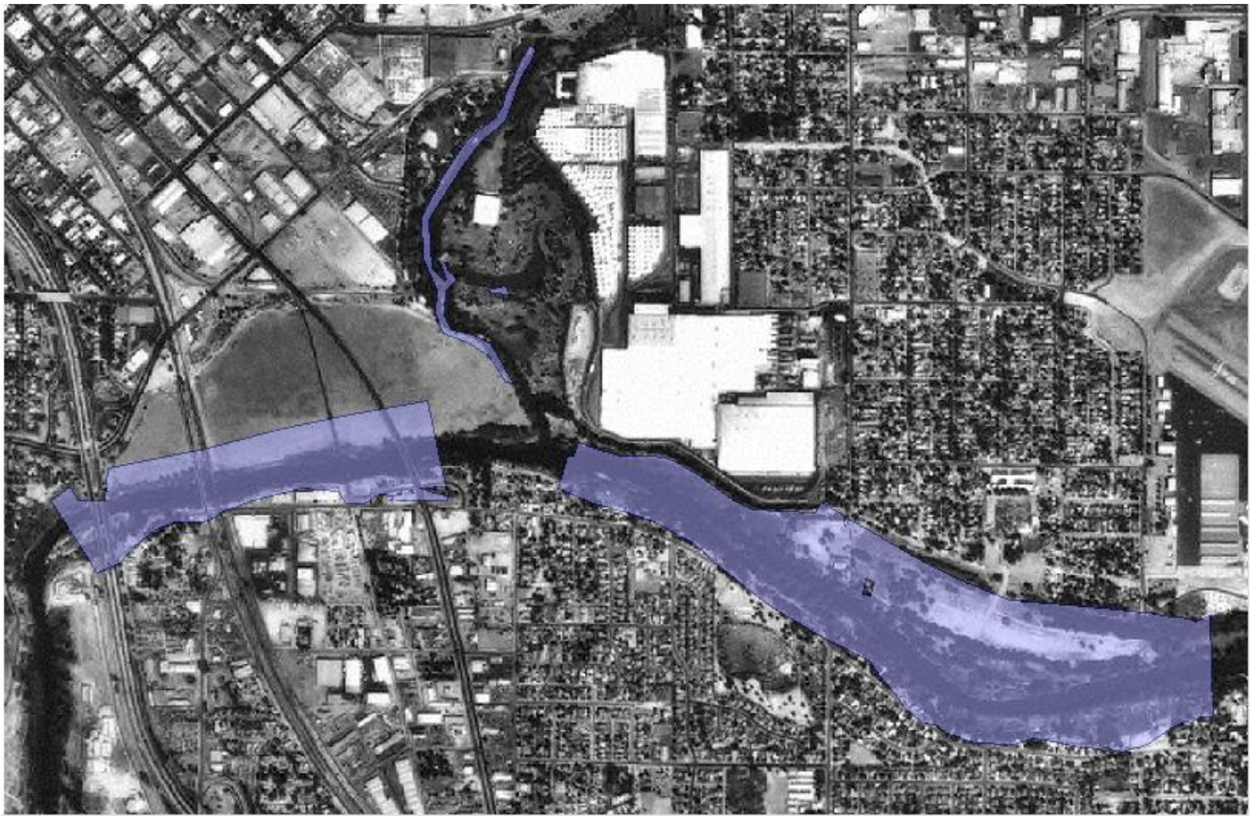


Figure 7.6: Flood map with imagery included

### 7.2.4 Flood Frequency Analysis

Overall methodology for frequency analysis of rainfall and discharge data is represented in block diagram below

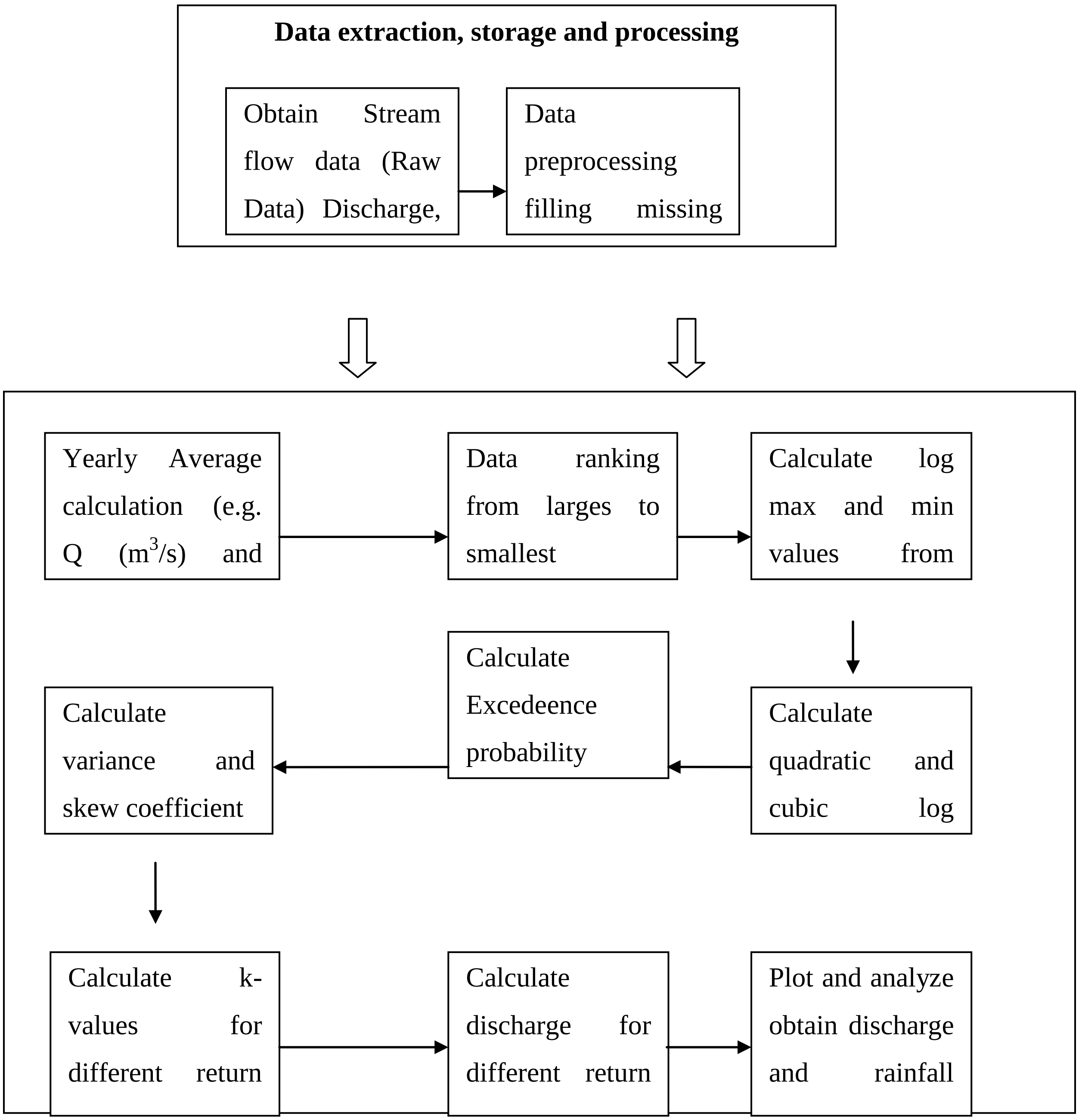



Figure 7.7: Frequency Analysis methods and process

Above block diagram explains a complete mechanism for frequency analysis. There are several mechanism for doing frequency analysis. Some methods are explained in brief [4, 5] in this report as well. Among mentioned methodologies we have implemented tow or them i.e. Gumbel's and Log-PearsonII. The choice of method was carried out by some simple research and accuracy result found in different papers and website listed under references [e.g. Oregon State University].

The above presented block diagram is explained below.

#### 7.2.4.1 Data extraction storage and processing

##### Data extraction and processing

Testing data were gathered from DHM, ICIMOD. Those obtained data were in .txt format thus, we wrote simple python script for extracting .txt format data .Extracted data were stored in msysql database and further processing was done such as data smoothing and filling missing values. These processes were carried out during data search for frequency analysis. Most of the data provided by DHM was well formatted so, data pre-processing task become quite easy.

##### Frequency analysis method and process

##### Yearly average calculation

The step involved for frequency analysis is calculating yearly average from the available data set. As we had don frequency analysis for both rainfall data and discharge data thus, we calculated yearly average for both types of data set.

Mathematically,

$$\text{Average Discharge for a year (Q)} = \sum_{n=0}^{365} \text{Average Daily Discharge(q)}$$

$$\text{Average Precipitation for a year (P)} = \sum_{n=0}^{365} \text{Average Daily Precipitation(p)}$$

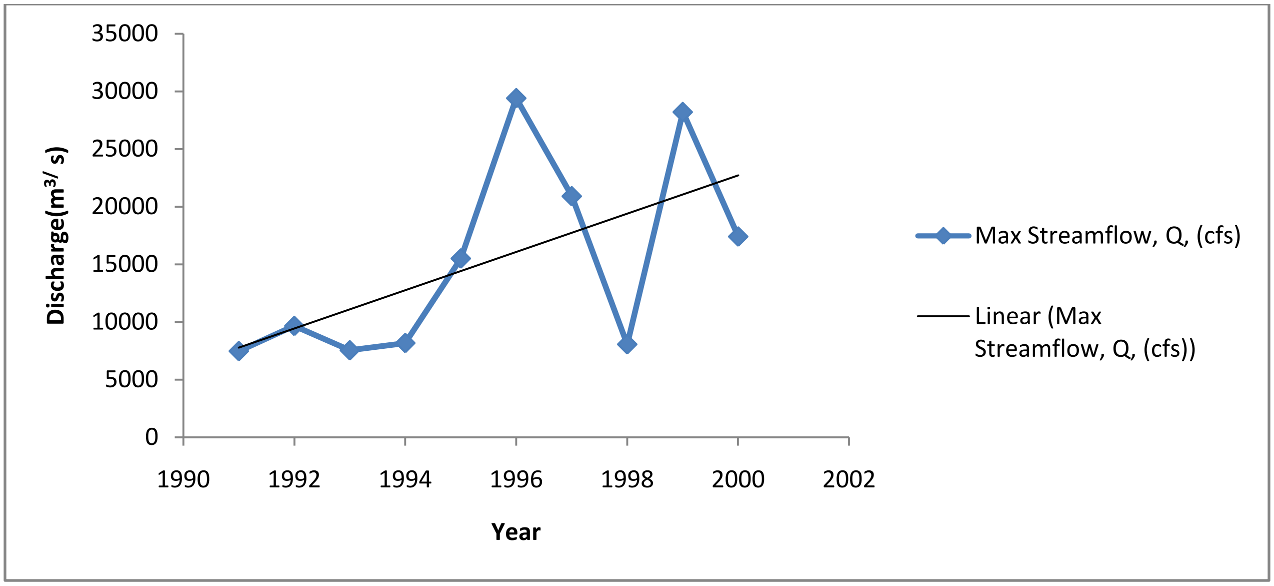



**Figure 7.8: Sample output average discharge**

## Ranking and log min, max calculation

Obtained data (max discharge/rainfall) value is provided rank according to descending order of max value. Logarithm of average discharge is calculated after ranking them.

| Rank | Water Year | Ranked Max Stream flow, Q (cfs) | log Q (cfs) |
|---|---|---|---|
| 1 | 1996 | 29400 | 4.468 |
| 2 | 1999 | 28200 | 4.450 |
| 3 | 1997 | 20900 | 4.320 |
| 4 | 2000 | 17400 | 4.241 |
| 5 | 1995 | 15500 | 4.190 |
| 6 | 1992 | 9650 | 3.985 |
| 7 | 1994 | 8170 | 3.912 |
| 8 | 1998 | 8060 | 3.906 |
| 9 | 1993 | 7540 | 3.877 |
| 10 | 1991 | 7470 | 3.873 |

**Table 7.1: Ranking on the basis of max discharge**

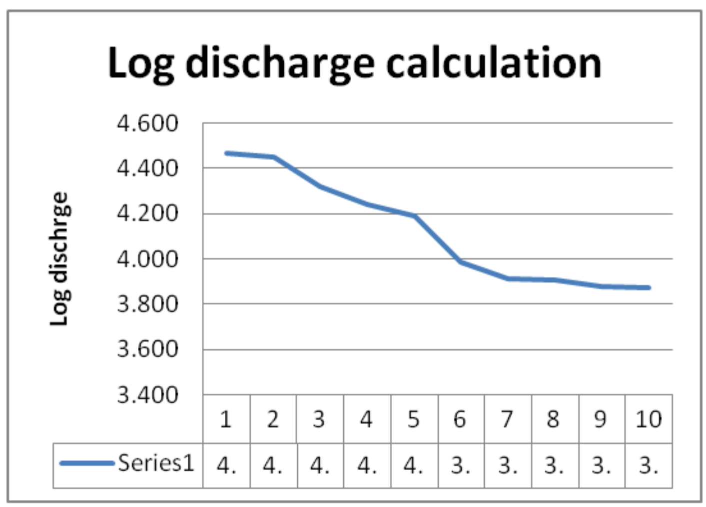



**Figure 7.9: Log discharge value from max stream flow**

Average value for both stream line flow and log discharge is calculated as well.

### Calculation of variance and cubic variance

Calculate (log Q -avg(logQ))^2 and (log Q -avg(logQ))^3 value as well average for each of them for the calculation of variance and skew coefficient.

### Calculation of exceedence probability

Return Period = (n+1)/m …………………………………… (7.1)

Where n = no of values in the data set and m = rank ………... (7.2)

Exceedence Probability(Pe) = 1/Tr(Return back period) …… (7.3)

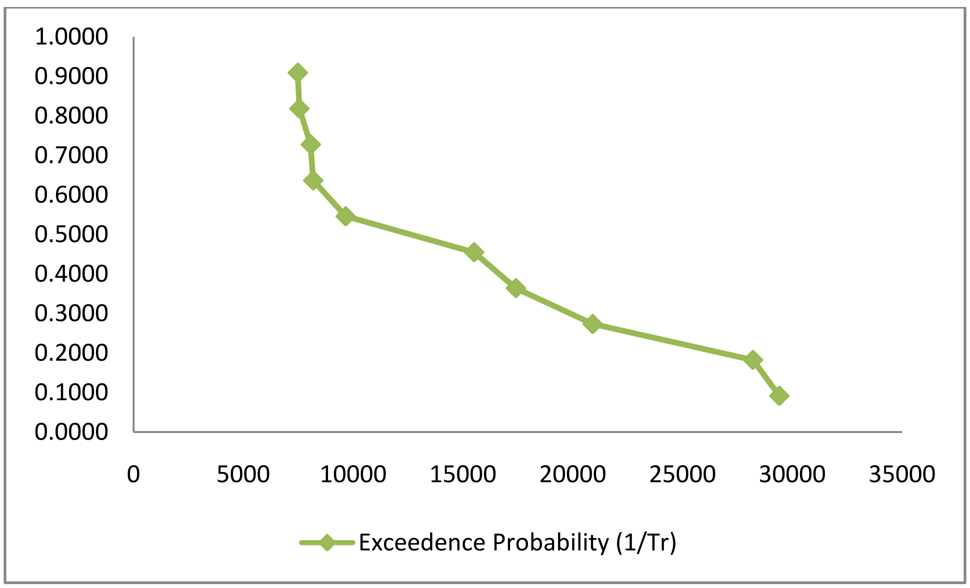



**Figure 7.10: Excceedence probability versus Discharge value**

The graph above shows as the discharge increases the probability of occurrence decreases

### Log-PearsonIII

### Calculation of skew coefficient

Before calculating skew coefficient variance and standard deviation are calculated. Standard deviation is useful in calculating skew coefficient.

$$\text{Variance}(q) = \sum_{k=0}^{n} \frac{(\log\ Q - \text{avg}\ (\log Q\ ))\string^2}{(n-1)} \ldots\ldots\ldots\ldots\ldots\ldots\ (7.4)$$

$$\text{Standard deviation} = q \log (Q) = \sqrt{\text{Variance}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots...\ (7.5)$$

Now skew coefficient is calculated

$$\text{Skew coefficient (Se)} = \frac{n * \sum_{k=0}^{n} (\log\ Q - \text{avg}\ (\log Q\ ))\string^3}{(n-1)(n-2) q \log\ (Q)\ \string^2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (7.6)$$

Where ‘Q’ is the average discharge value and ‘q’ is variance

## Calculation of ‘k’ values for different return back period

Use the ***frequency factor table***(refer annex for the table) and the skew coefficient to find the **k *values*** for the 1.01,2,5,10,25,50,100, and 200 ***recurrence intervals***.

Note: - If the skew coefficient is between two given skew coefficients in the table than you can linearly extrapolate between the two numbers to get the appropriate k value.

## Discharge calculation

Now using k values, average log discharge, variance and a standard equation, We calculate average return back discharge for different time interval.

Average discharge ($Q^1$) = log (Q) $T_r$+[K($T_{r,}$ $C_s$)]*x*q*log(Q)………….. (7.7)

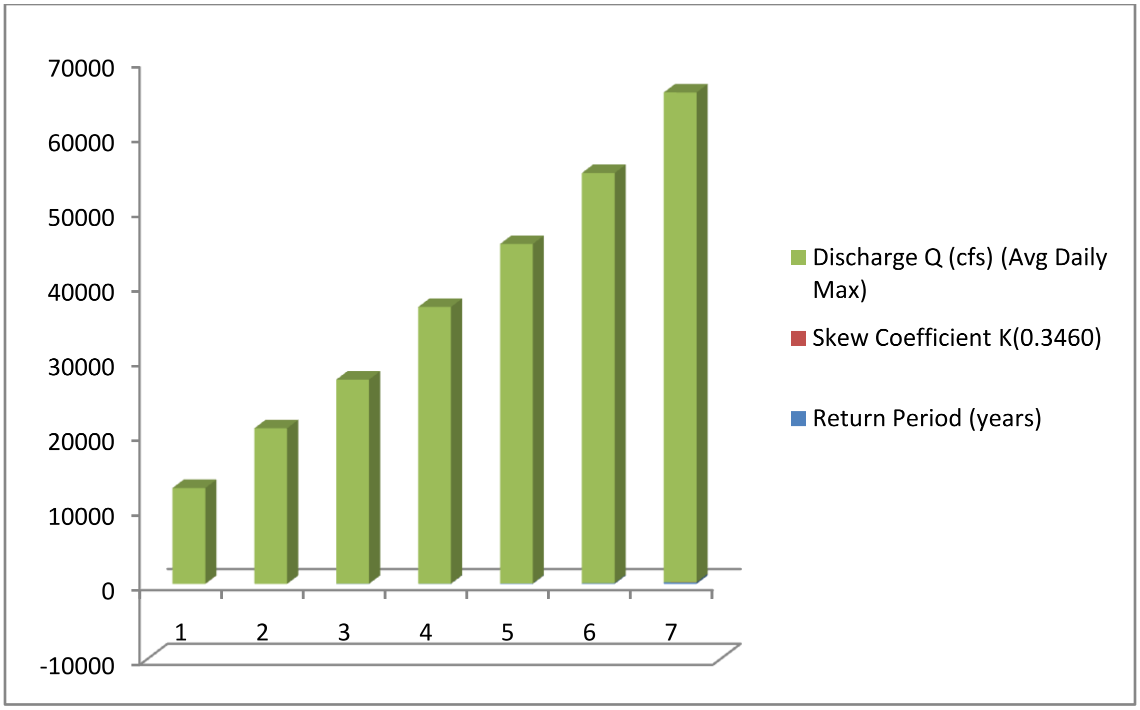



**FIgure 7.11: Average Discharge for different return back period**

## Gumbel's Method:

This extreme value distribution was introduced by Gumbel (1914) and is commonly known as Gumbel's distribution. It is one of the most widely used probability- distribution functions for extreme values in hydrologic and meteorological studies for prediction of flood peaks, maximum rainfalls, maximum wind speed, etc.

Gumbel defined a flood as the largest of the 365 daily flows and the annual series of flood flows constitute a series of largest values of flows. According to his theory of extreme events, the probability of occurrence of an event equal to or larger than a value of $x_0$

$$P(X \geq x_0) = 1 - e^{-e^{-y}} \qquad \text{.................................................} \quad (7.8)$$

in which $y$ is a dimensionless variable given by

$$\begin{aligned} y &= \alpha(x - a) \\ a &= \bar{x} - 0.45005\sigma_x \end{aligned} \qquad \text{.......................................................} \quad (7.9)$$

Thus $y = \dfrac{1.2825\left(x - \bar{x}\right)}{\sigma_x} + 0.577$ ……………………………………… (7.10)

where $\bar{x}$ = mean and $\sigma_x$ = standard deviation of the variate *X*. In practice it is the value of *X* for a given P that is required and the eqn. is transposed as

$Y_p = -\ln\left[-\ln\left(1 - P\right)\right]$ ………………………………………………… (7.11)

Noting that return period T=1/P and designating $Y_T$= the value of y, commonly called the reduced variate, for a given T,

$$\begin{aligned} Y_T &= -\left[\ln \ln \frac{T}{T-1}\right] \\ Y_T &= -\left[0.834 + 2.303 \log \log \frac{T}{T-1}\right] \end{aligned} \quad \text{……………………………… (7.12)}$$

So, the value of variate X with a return period T is

$$\begin{aligned} x_T &= \bar{x} + K\sigma_x \\ where,\ K &= \frac{\left(y_T - 0.577\right)}{1.2825} \end{aligned} \quad \text{………………………………………….. (7.13)}$$

In this way Gumbel's method is used for frequency analysis.

### 7.2.5 Visualization with jqplot library

After all the data is collected and processed for analysis, then the output is visualized in the graphs and charts using the jqplot library. Jqplot library gives a wide range of functionalities to effectively visualize the datasets.

# Chapter Eight - Results, Visualization and Analysis of the Data

## 8.1 Flood Frequency Analysis

### 8.1.1 Gumbel's Method

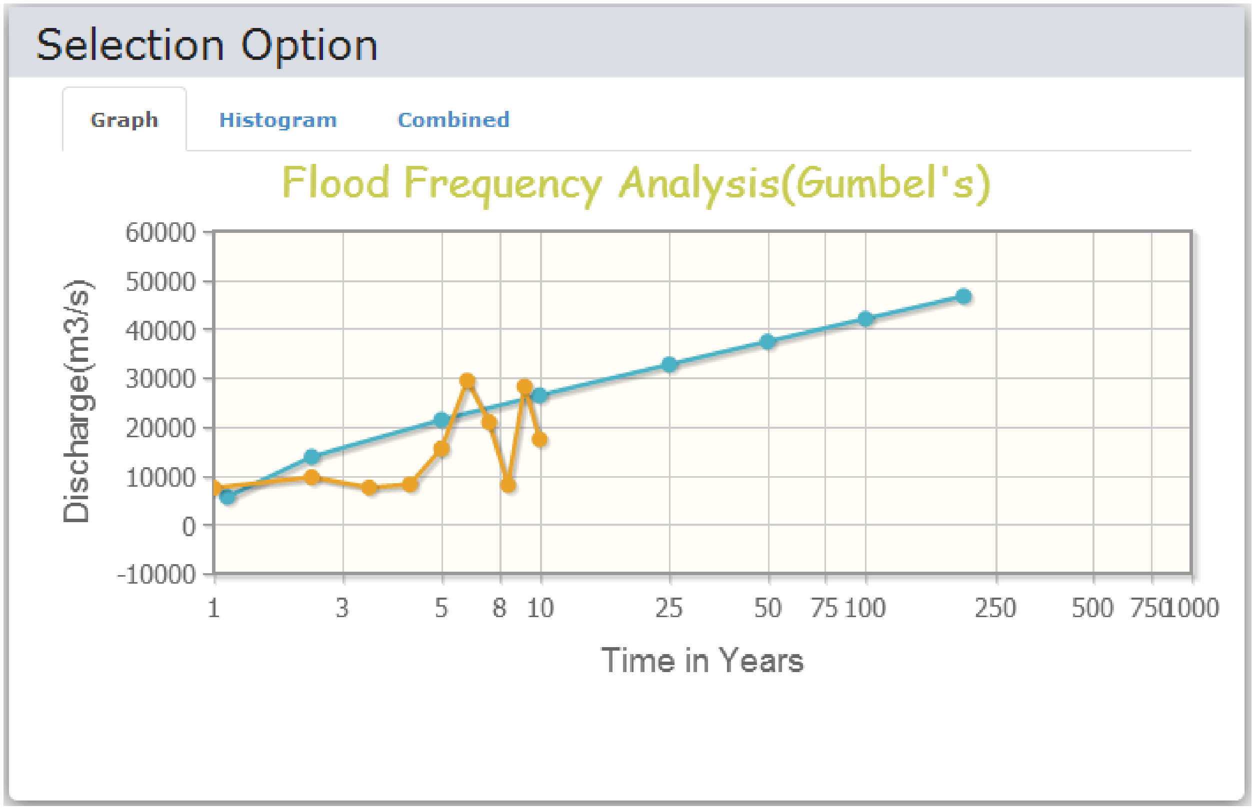



**Figure 8.1: Flood Frequency Analysis Gumbel's Method**

The graph below show the average discharge value(m$^3$/s) for the different return period. The blue line represent average return back discharge predicted by Gumbel's method and the orange line represent the actual average data we have in the database.

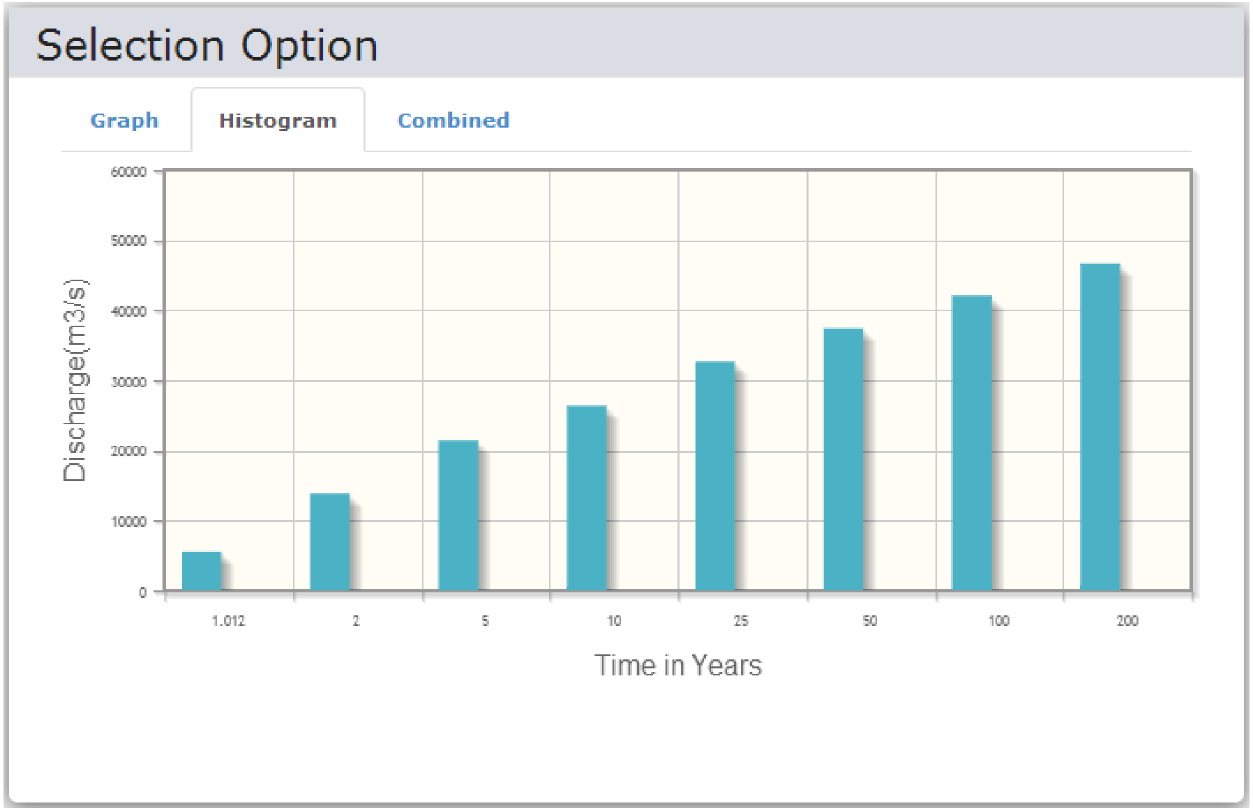



Figure 8.2: Gumbel's Method FFA Histogram

Same average return back discharge for different time interval predicted by Gumbel's method is plotted in histogram.

### 8.1.2 Log-Pearson III Analysis

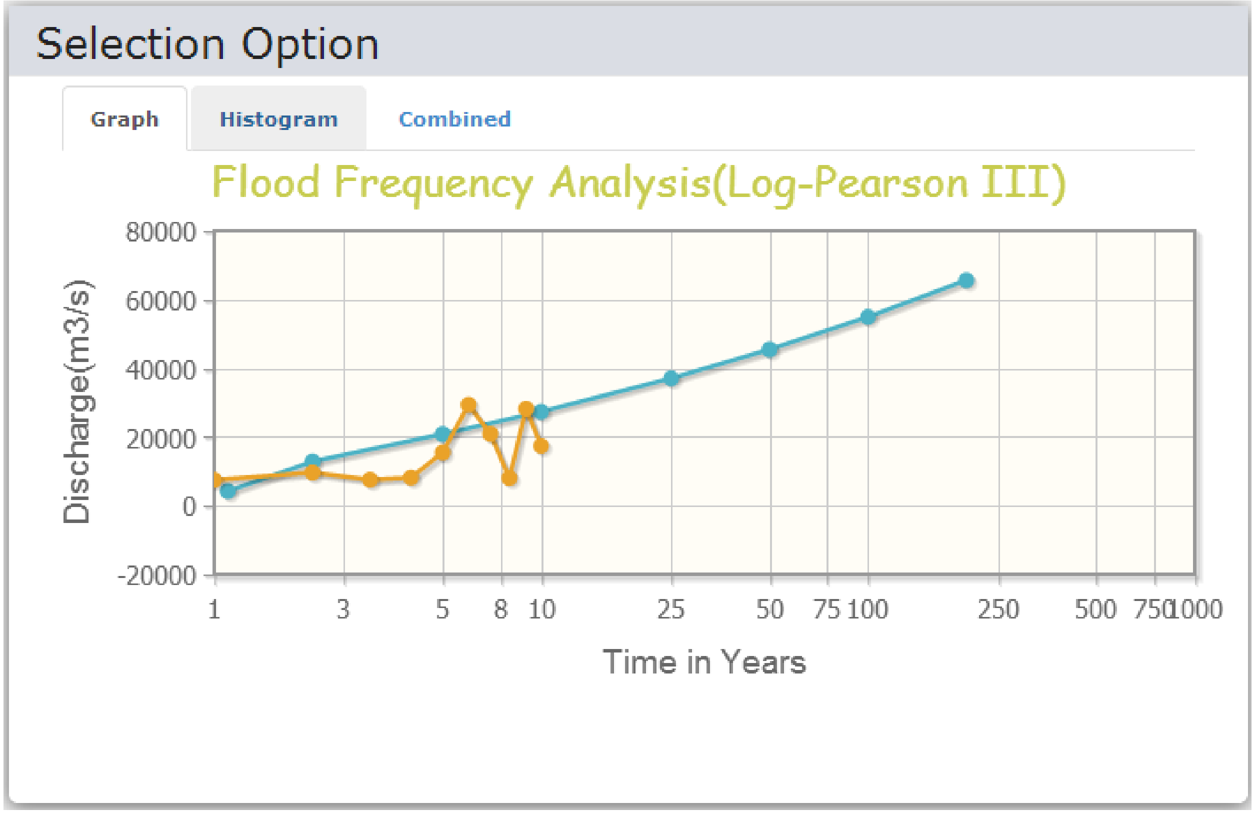



**Figure 8.3: FFA Log Pearson III Method**

The graph above show the flood frequency analysis by Log-Pearson III method. Using this method average return back discharge (plotted in blue) for different time interval is plotted along with actual discharge value shown in orange plot.

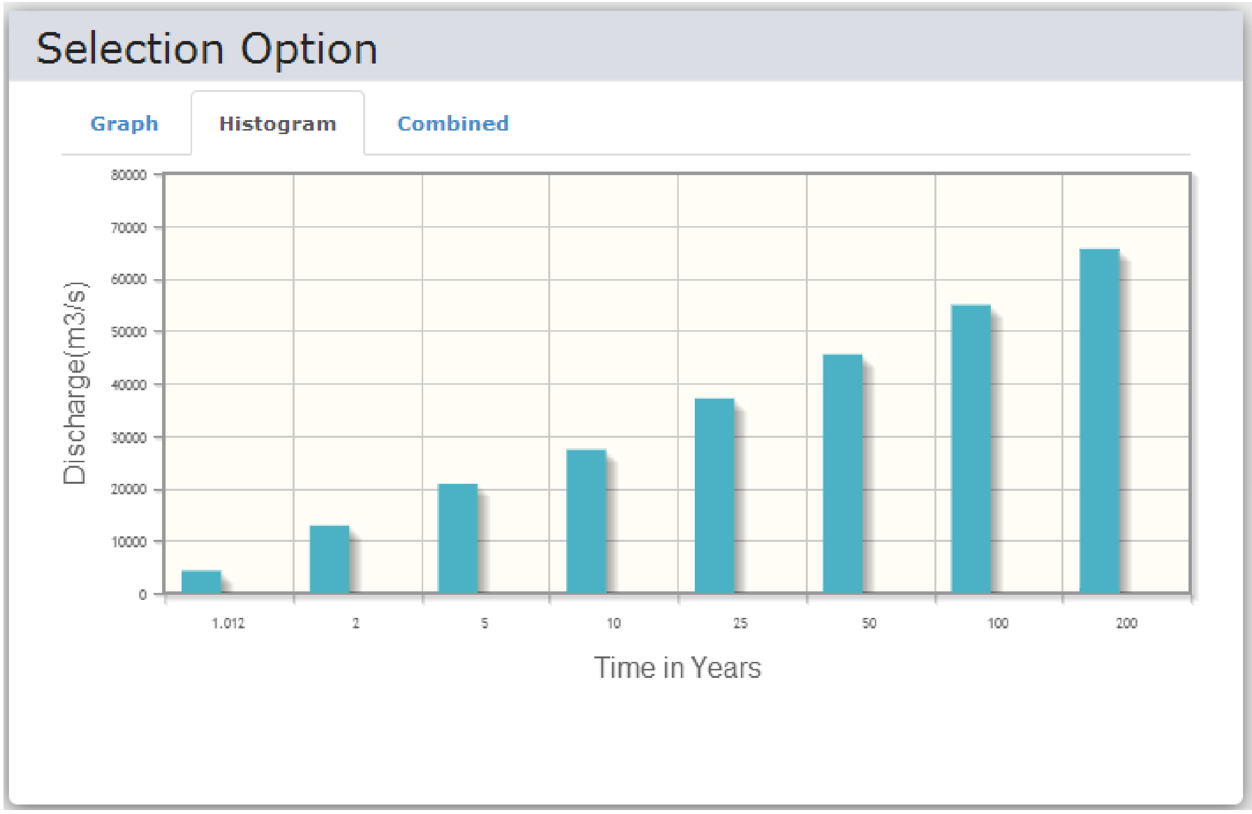



**Figure 8.4: FFA Log Pearson III Method Histogram**

Above output represent the average return back discharge for different time interval by Log-PearsonIII method in histogram.

### 8.1.3 Combined Analysis

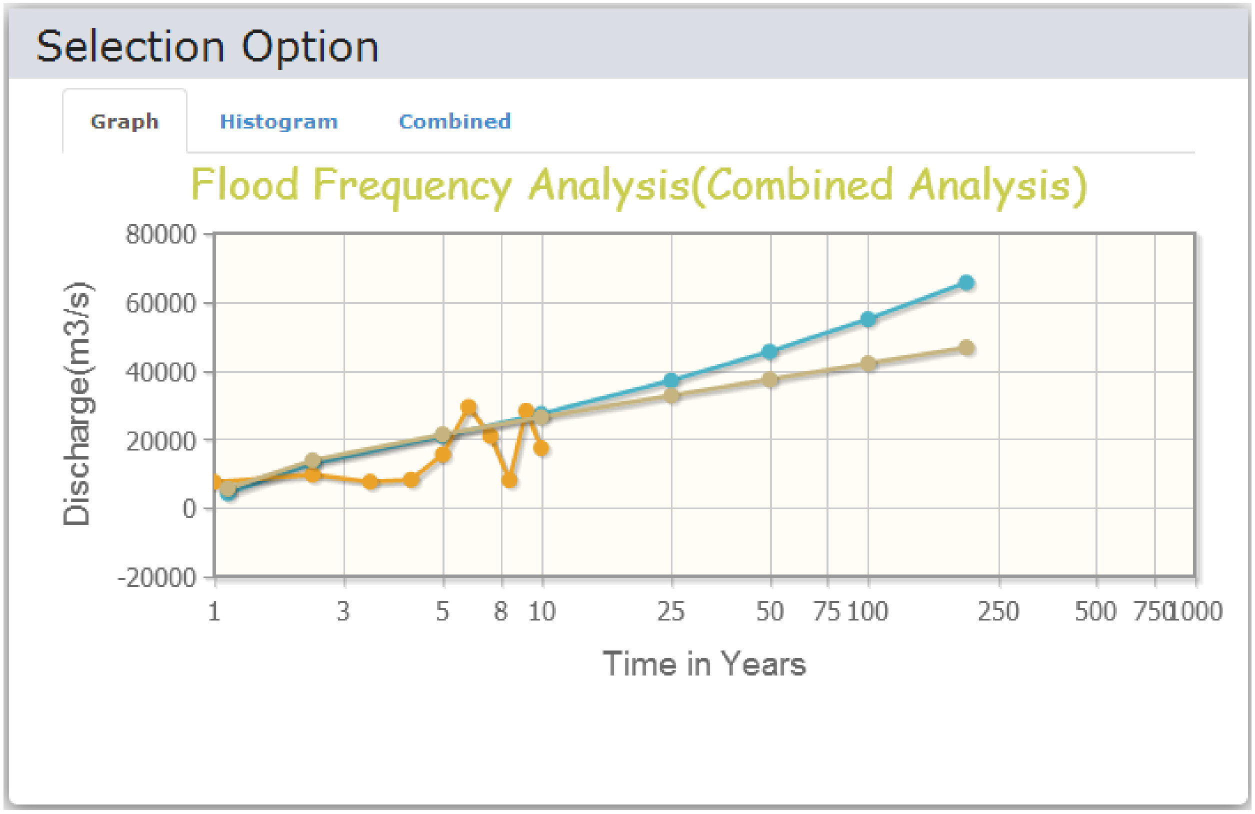



**Figure 8.5: Combined plot of FFA using Gumbel's Method and Log Pearson III Method**

Above graph shows the comparative analysis of both the method we adopted for flood frequency analysis (Gumbels and Log-Pearson).Blue line represent the predicted discharge by Log-Pearson while brown line represent average return-back discharge and finally orange line represent actual discharge value.

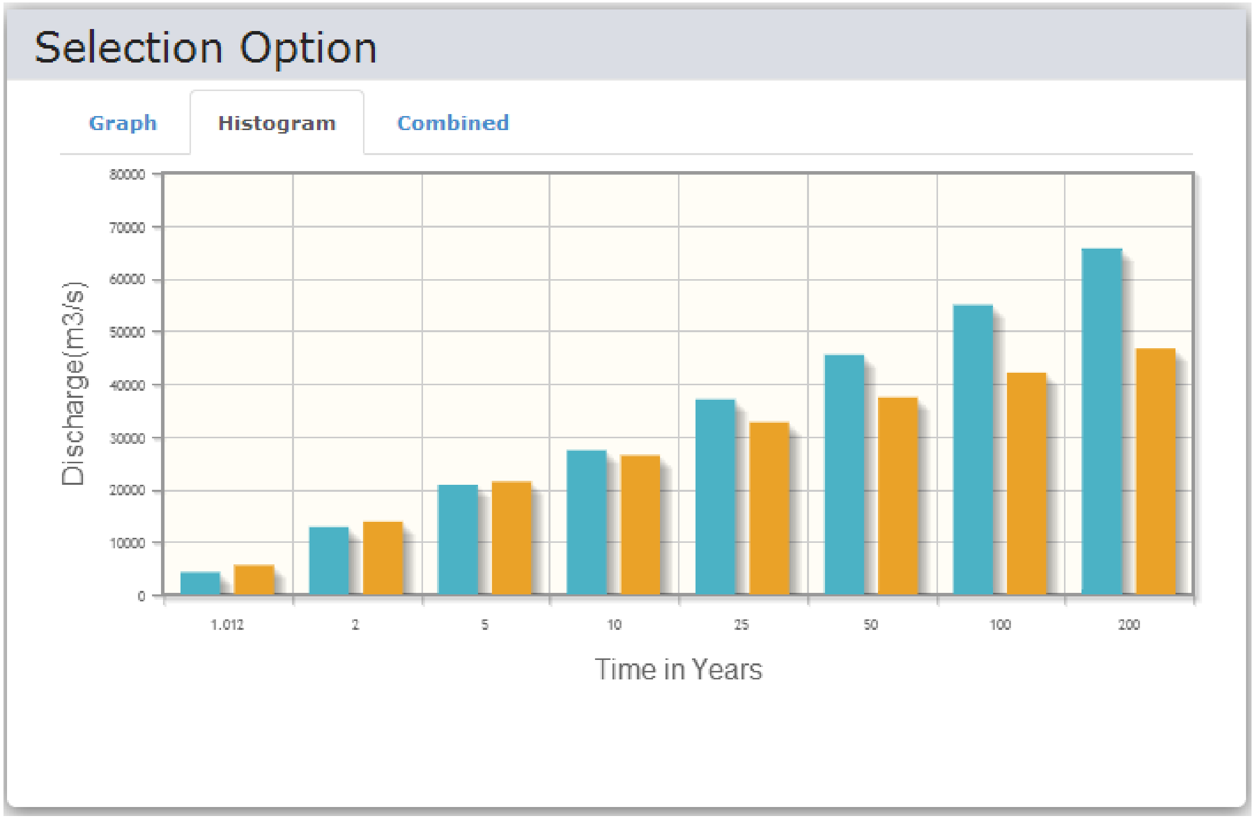



**Figure 8.6: Combined Histogram Plot for Gumbel's and Log-Pearson III FFA Methods**

In the above figure average return back discharge by both method is plotted in histogram.

## 8.2 Flood Map Generation

### 8.2.1. Phase I: RAS Geometry Creation

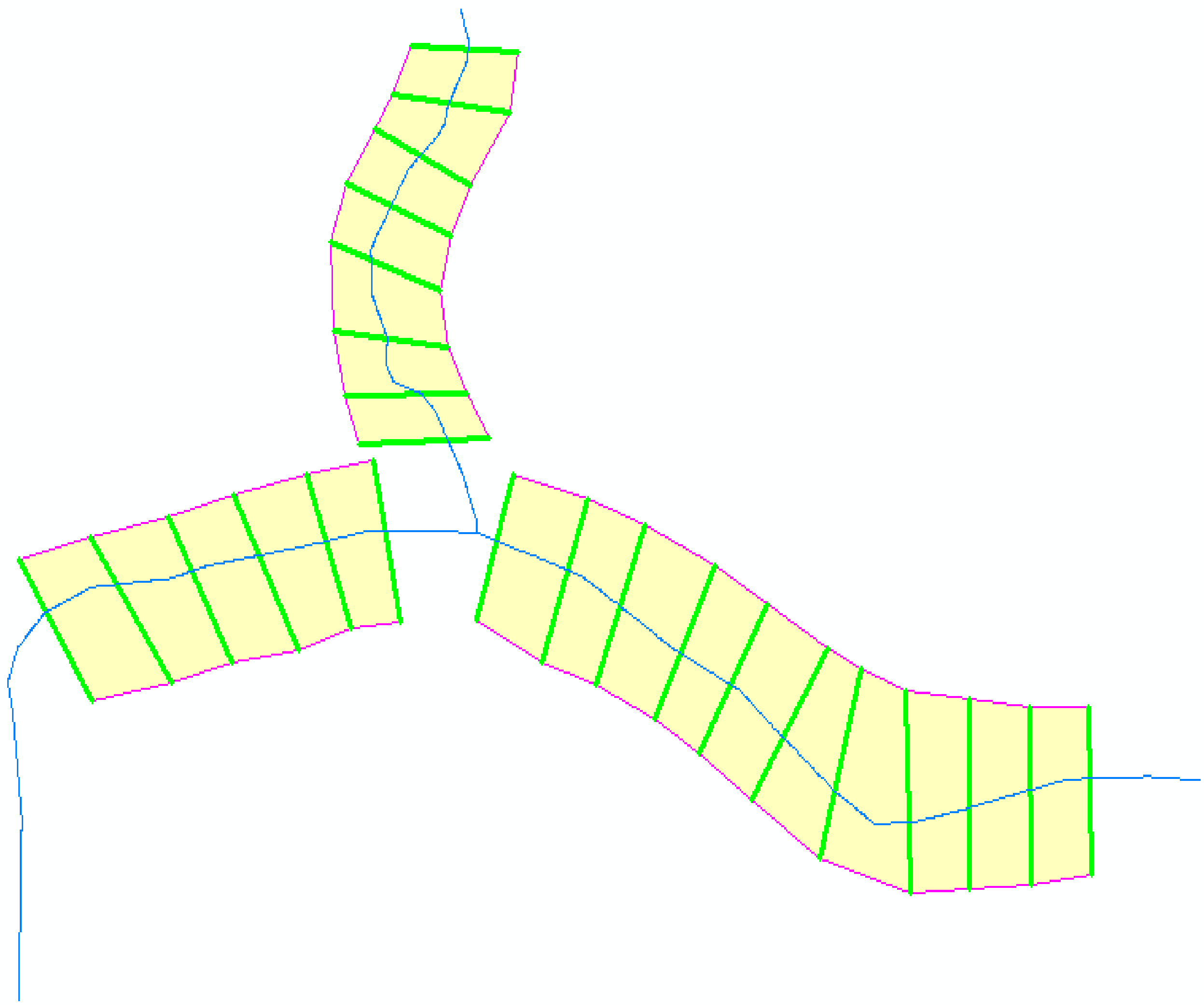


**Figure 8.7: RAS Geometry Creation**

A river Cross-Section is generated using ArcMap. The above picture is of Baxter River. There are three parts, the right one is Upper Baxter River, the middle one is Tule Creek and the left one is the lower Baxter River. Corresponding river cross-section are generated along the river path. Cross-section is including area from left bank to right bank.

### 8.2.2 Phase II: Ground Layer Setup

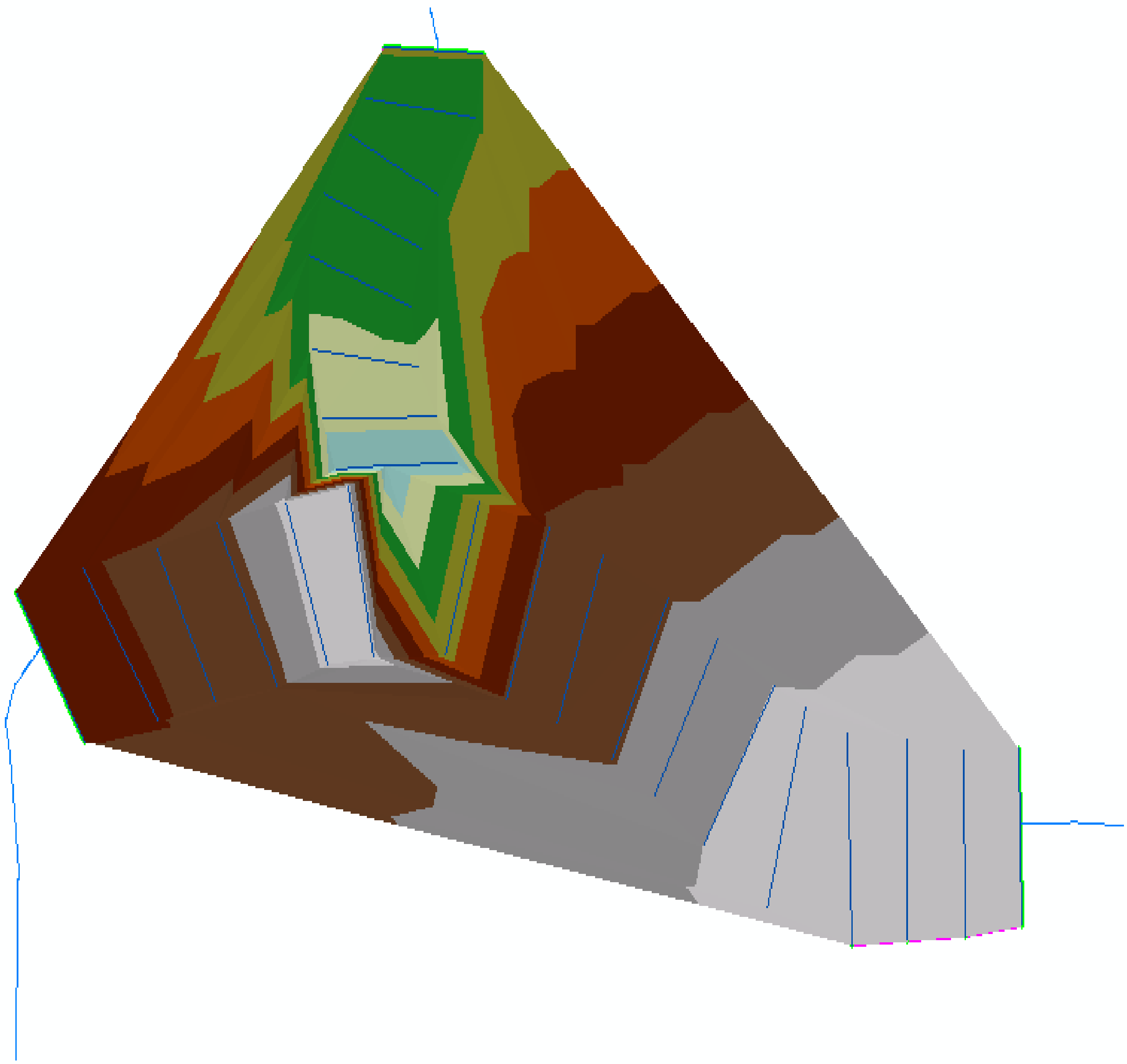


Figure 8.8: Base Layer Setup

Over the river cross-section, a base layer must be setup with geo-spatial reference in order to assign a co-ordinate system to the map. This layer is determined from the cross-sections.

### 8.2.3 Phase III: Flood Map Generation

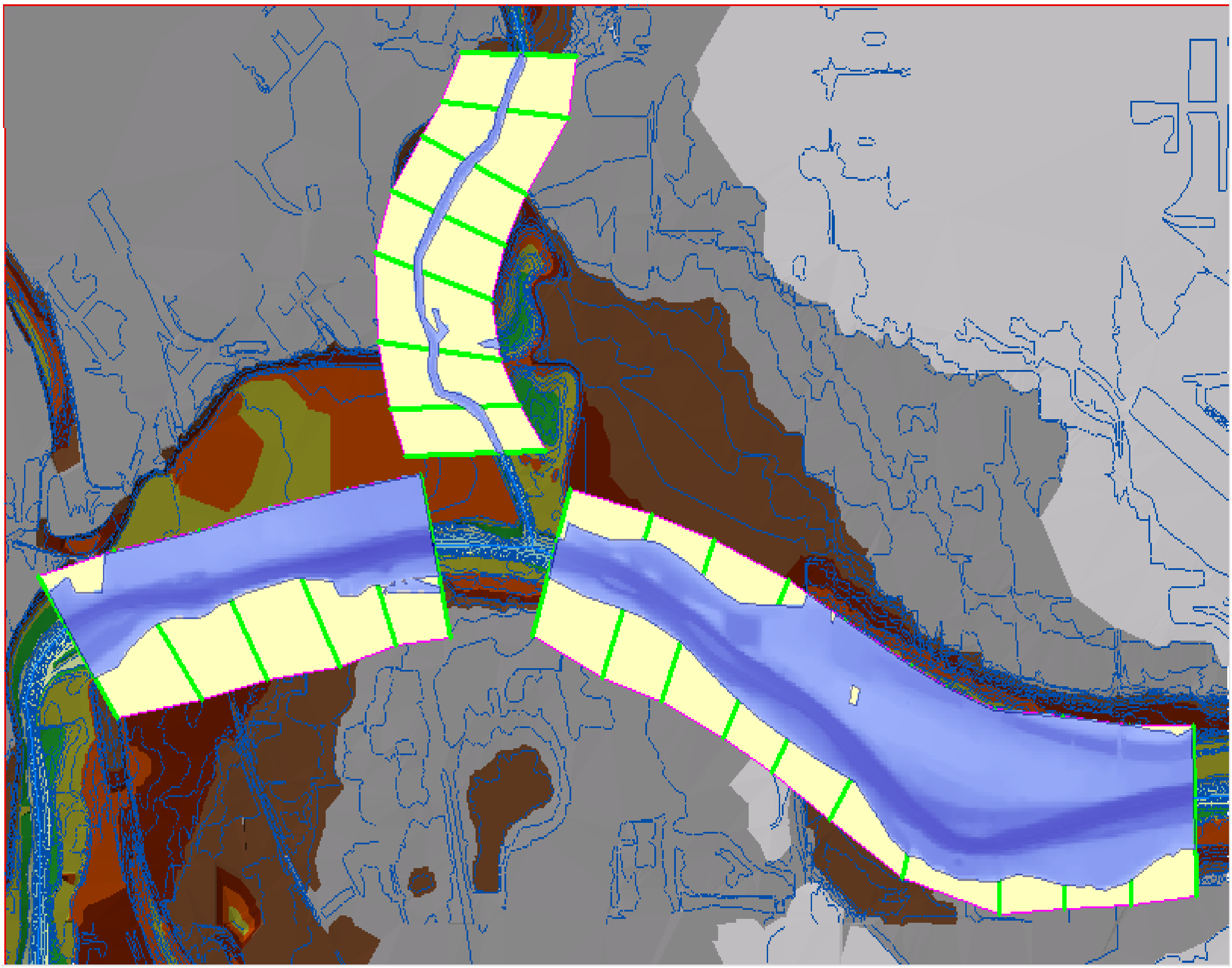


Figure 8.9: Flood Map Generation over Base Layer

The above figure shows the flood map generated over Baxter River in all parts. The upper Baxter River has a different discharge value than that of Tule Creek and lower Baxter River. The flood map helps to determine the overlap of river flow with the base Layer. As in the above figure we can see that the Tule Creek being small in size has lower value of discharge.

### 8.2.4 Phase IV: Addition of Aerial Layer

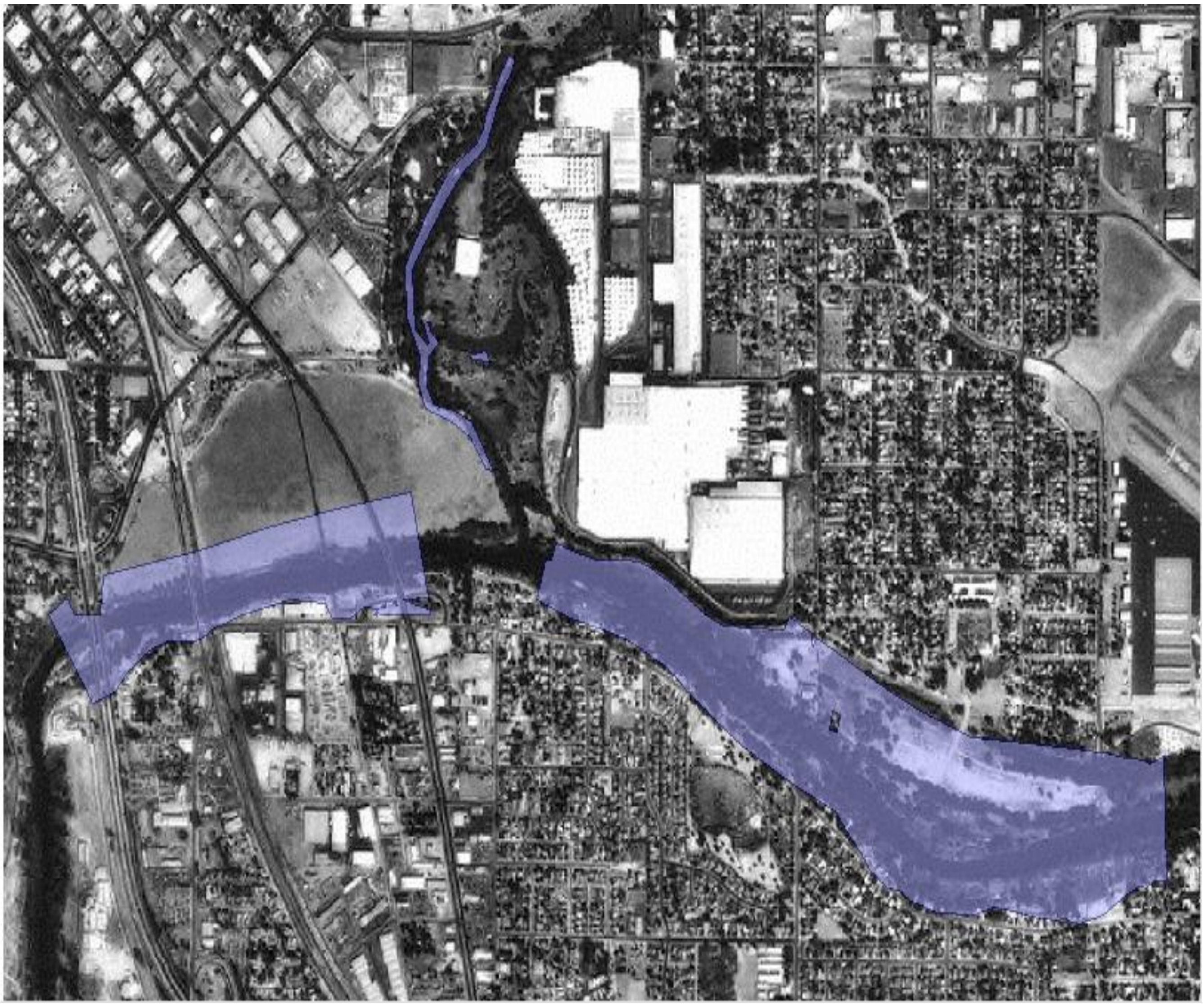
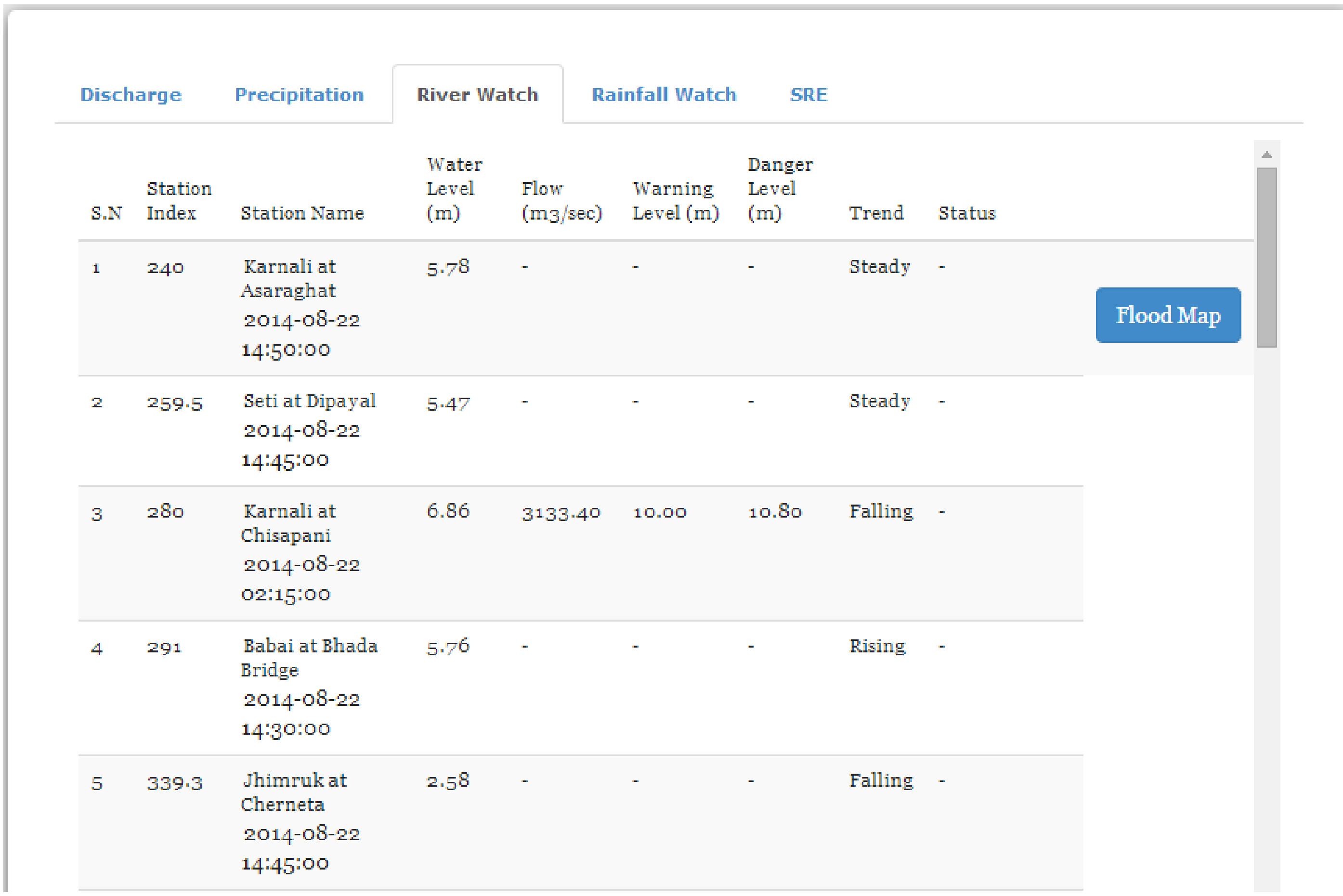


Figure 8.10: Addition of Aerial Layer over Base Layer

Corresponding aerial Layer is added over the base layer in order to visualize the overlap of flood discharge over the residential area. As shown in the above figure, upper Baxter River having greater discharge is supposed to have greater effect on the residential area  than small sized Tule Creek.

## 8.3 Discharge Value Measurement




| S.N | Station Index | Station Name | Water Level (m) | Flow (m3/sec) | Warning Level (m) | Danger Level (m) | Trend | Status |
|---|---|---|---|---|---|---|---|---|
| 1 | 240 | Karnali at Asaraghat 2014-08-22 14:50:00 | 5.78 | - | - | - | Steady | - |
| 2 | 259.5 | Seti at Dipayal 2014-08-22 14:45:00 | 5.47 | - | - | - | Steady | - |
| 3 | 280 | Karnali at Chisapani 2014-08-22 02:15:00 | 6.86 | 3133.40 | 10.00 | 10.80 | Falling | - |
| 4 | 291 | Babai at Bhada Bridge 2014-08-22 14:30:00 | 5.76 | - | - | - | Rising | - |
| 5 | 339.3 | Jhimruk at Cherneta 2014-08-22 14:45:00 | 2.58 | - | - | - | Falling | - |

**Figure 8.11: Discharge data measurement**

Discharge value are measured belonging to particular station. Station index 240 with the station name Karnali at Asaraghat is measured to have 5.78 m water level on 2014 August 22 at 14:50. The trend appearing in this station is steady. That implies that the current water level is neither falling nor rising. Station number 280 named Karnali at Chisapani at 2014 August 08 is measured to have 6.86 m water level with flow of 3133.40 $m^3$/s and the trend is falling.

## 8.4 Precipitation Measurement

Discharge | Precipitation | River Watch | Rainfall Watch | SRE

| S.N | Basin Name | Station Index | Station Name | RAINFALL IN mm 1 hour (13-14) | 3 hour (11-14) | 6 hour (08-14) | 12 hour (02-14) | 24 hour (14-14) | Status |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Karnali | 240 | Karnali at Asaraghat | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Below Warning Level |
| 2 | Karnali | 259.5 | Seti at Dipayal | 0.00 | 0.00 | 0.00 | 0.20 | 36.60 | Below Warning Level |
| 3 | Karnali | 280 | Karnali at Chisapani | N/A | 0.00 | 0.20 | 2.60 | 64.00 | Below Warning Level |
| 4 | Karnali | 402 | Dailekh | 0.00 | 0.00 | 0.60 | 0.60 | 0.60 | Below Warning Level |
| 5 | Karnali | 404 | Jajarkot | 0.00 | 0.00 | 0.00 | 0.00 | 1.80 | Below Warning Level |
| 6 | Babai | 417 | Ranijaruwa | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | Below Warning Level |

**Figure 8.12: Real Time Measurement of Rainfall in mm.**

Similar to discharge measurement, we have included the real time measurement of rainfall in mm. 3 hourly measurement of rainfall is done at particular station. For instance at station number 280 named Karnali at Chisapani is measured to have 0.0, 0.60, 2.60 and 64.00 mm rainfall throught the day at intervals of 3 hour. The status currently is estimated to be Below Warning Level.

## 8.5 Daily Rainfall Watch

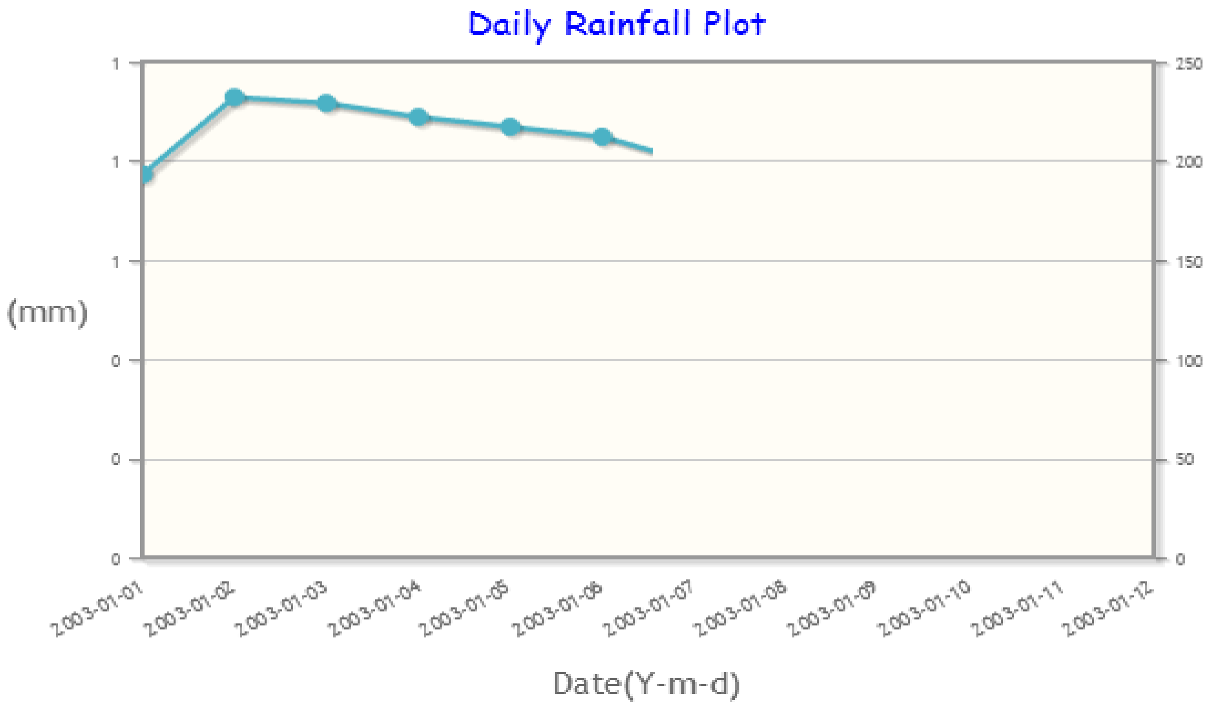



**Figure 8.13: Daily Rainfall Plot of Koshi River, Station number 681**

A daily rainfall watch is plotted to visualize the extent of rainfall at different rivers in different stations. The above plot shows the daily rainfall plot from 2003 January 1 to 2003 January 12 of station number 681 in Koshi River. The y-axis shows the rainfall value in mm and the x-axis has date axis with the format (Y-m-d).

## 8.6 Daily Discharge Watch

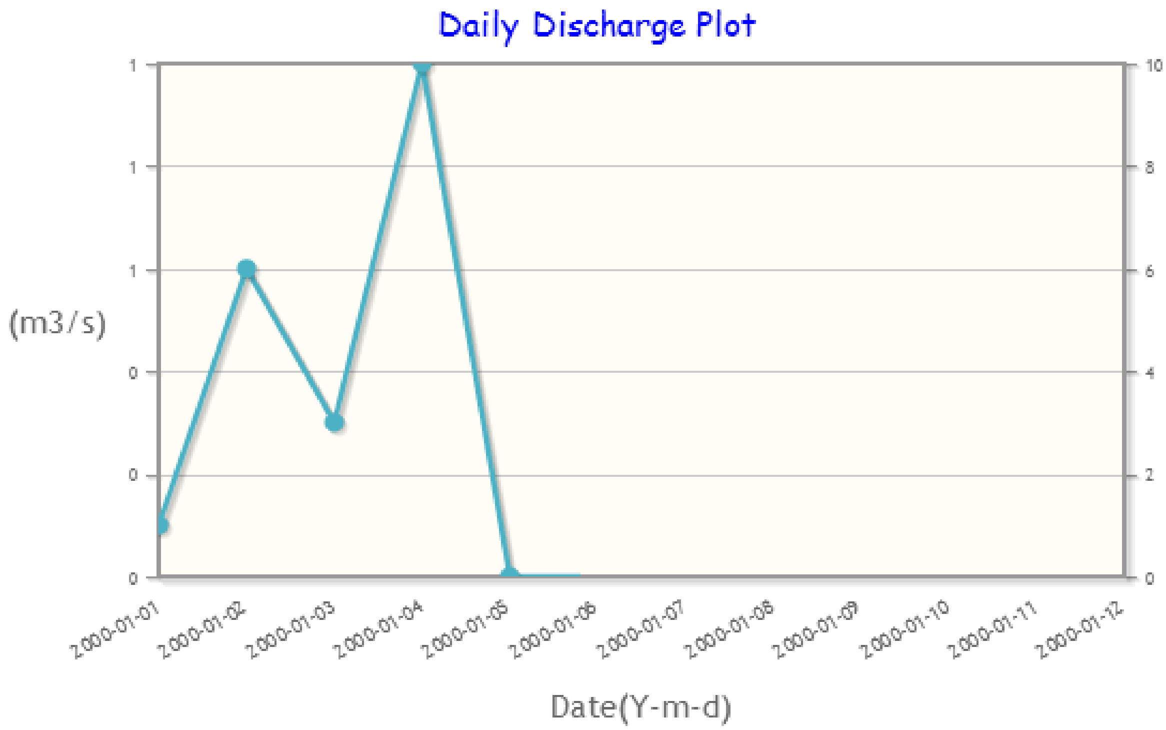



**Figure 8.14: Daily Discharge Plot of Koshi River, Station number 681**

A daily discharge watch is plotted to visualize discharge value flowing in the river measured at different stations. The above plot shows the daily discharge plot from 2000 January 1 to 2000 January 12 of station number 681 in Koshi River. The y-axis shows the discharge value in $m^3/s$ and the x-axis has date axis with the format (Y-m-d).

## 8.7 Annual Rainfall/Discharge Watch

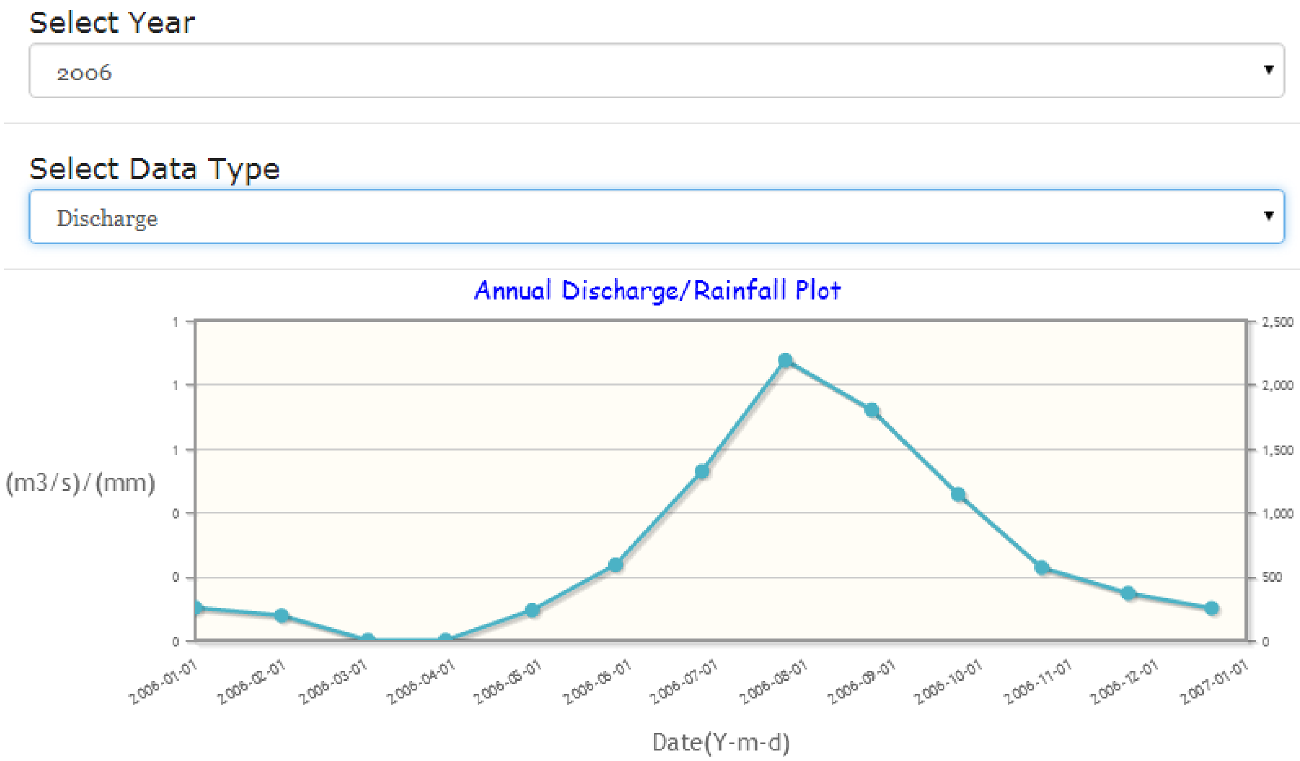



**Figure 8.15: Annual Rainfall/Discharge of Koshi River, Station number 681**

In the above plot, annual discharge has been plotted. The year of which discharge is plotted is 2006. A particular year can be selected and either discharge or rainfall data can be plotted. Y-axis label corresponds to the data being plotted. For discharge the y-axis label is $m^3/s$ and the x-axis label is Date(Y-m-d). Similarly for rainfall y-axis label is mm and the x-axis label is Date(Y-m-d).

# Chapter Nine - Tools, Platforms and Technologies Used

## 9.1 Language

Java is used as our development language. For client side scripting and visualization, Javascript and JQuery is used and PHP is used for server side scripting. Python is used to analyze the Satellite Rainfall Estimate image. Python is used for analyzing satellite rainfall image and estimating rainfall out of it.

## 9.2 Database

MY-SQL is used as database query language.

## 9.3 Visualization Tools

### 9.3.1 Animated Graphs

JqPlot is a plotting and charting plugin for the jQueryJavascriptframework.Computation and drawing of lines, axes, shadows even the grid itself is handled by pluggable "renderers". It allows custom event handlers, creation of new plot types, adding canvases to the plot.JqPlot is used for data visualization. Bar-Graph and Line-Graph are plotted using JqPlot.

### 9.3.2 Visualization in Map

Google Maps is a desktop and mobile web mapping service application and technology provided by Google, offering satellite imagery, street maps, and Street View perspectives, as well as functions such as a route planner for traveling by foot, car, bicycle (beta test), or with public transportation.

Google Map is used to show river stations and to extract corresponding location information. A particular river station is marked in Google Map and corresponding river discharge is plotted on selecting that particular station.

### 9.3.3 Visualization in Flood Map

Flood map is generated over an aerial (satellite) image to help visualize which areas have been affected. This flood map is generated using ArcObjects Java API as an extension of ArcGIS. RAS geometry is generated from ArcMap and this is fed to HecRas for steady flow analysis and finally results are transferred back to ArcMap to generate Flood Map showing River Flow of certain discharge Value.

## 9.4 UI/UX Design using Twitter Bootstrap

Twitter Bootstrap is a powerful tool by Twitter for user Interface Design. It provides various facilities for the design. We used twitter bootstrap to design the UI and enhance the User Experience.

## 9.5 Tools for Flood Map Generation

### 9.5.1 ArcMap

ArcMap is a huge software for GIS analysis. It is an extensively used GIS manipulation tool. We preferably used this software to generate RAS geometry (river cross-section) and to perform RAS mapping for flood map generation.

### 9.5.2 HecRas

This tools was used as a RAS mapper. The RAS geometry exported from ARCMAP was used to perform steady flow analysis and generate data for RAS mapping.

### 9.5.3 ArcObjects

To manipulate the GIS maps and objects, we used ArcObjects. It is an ArcGIS extension implemented in Java to programmatically manipulate GIS maps and objects.

## 9.6 Tools for Data Analysis

### 9.6.1 JSON Parser

Json is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate. It is based on a subset of the JavaScript Programming Language, Standard ECMA-262 3rd Edition - December 1999. JSON is a text format that is completely language independent but uses conventions that are familiar to programmers of the C-family of languages, including C, C++, C#, Java, JavaScript, Perl, Python, and many others. These properties make JSON an ideal data-interchange language.

JSON is built on two structures:

A collection of name/value pairs. In various languages, this is realized as an *object*, record, struct, dictionary, hash table, keyed list, or associative array.

An ordered list of values. In most languages, this is realized as an *array*, vector, list, or sequence.

## 9.7 Cross Language Connector

### 9.7.1 JxBrowser

We have used this tool as JavaScript-Java Bridge. HTML pages and Javascript events are handled across Java through JxBrowser.

## 9.8 Local Server

### 9.8.1 Xampp

Xampp is used as our local server storage of data. Xampp itself incorporates SQL and Apache Server to establish a virtual remote connection.

## 9.9 Development Platform

### 9.9.1 NetBeans

Java being used as our primary development language, we preferred Netbeans for our application development. Netbeans is an extensive IDE for Java and other programming language with high intelligence and code formatting support.

### 9.9.2 Pycharm

For data analysis, we used Python and PyCharm as its IDE. PyCharm being light and simple, it is extensively used for Python Scripting.

# Chapter Ten - Conclusion and Future Enhancements

## 10.1 Conclusion

Flood has always been one of the dangerous natural disasters in Nepal. Each year more than more than 100 people die on average. Due to lack of tools and early warning system loss of live and property is beyond expected values. Thus, our system will help in decreasing the casualties and victims of flash flood by predicting and visualizing the possible outcome of affected areas. With the help of frequency analysis, we can detect the possible discharge and precipitation values with probability of its occurrence thus; our system may also act as useful tool for the analyst of related areas (hydrology and disaster management). Flood maps are very useful tool in visualizing flooded areas; the generation of flood maps with the help of predicted discharge may be extremely useful in flood disaster analysis. With the help of SRE (satellite rainfall estimation) we can predict the possible precipitation of coming days thus; it will also help in knowing the possible discharge.

## 10.2 Recommendation:

We have made following recommendations for those who wish to do a  project in this are in the future:

1. Be clear about the objective and the path to be taken to reach that objective.
2. Be in touch with a person who has an expertise in the area.
3. Be clear about the scope of the project and plan accordingly.

## 10.3 Future Enhancements

Our application has not been a full or an applicable flash flood early warning system at this moment. The data we have right now are not consistence i.e. all the data are not of the same place so the testing and enhancement of our system can only be done with the consistence data from the same place. ICIMOD is dedicated in supplying the required data for the future works. Some of the enhancements that can be done in our project are as follow:-

1. Critical Discharge and precipitation calculation

   With the help of historical data, we can calculate possible critical discharge and precipitation values. This critical values calculation will help in damage prediction, community alarm generation etc.

2. Damage prediction

   As we have generated flood maps, these flood maps along with demographical data and geological data can be very useful in predicting damage. Damage prediction is one of the most required features of any early warning system, rescuing life and reducing property loss can be facilitated with damage prediction.

3. Community Alarm

   Another useful feature of FFEWS is community alarm. Knowing demographic distribution and possible discharge values we can guide community towards safe place where flood can’t reach. This is a required as well as challenging feature since wrong route prediction may increase the casualties and vulnerability of flood.

4. Hydrological analysis and Bridge analysis

   Frequency analysis is one of the major tools for construction of bridge and other hydrological structures but there has to be a huge modification on our software.

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