

# Flood Map Delineation of Narayani River Using HEC-RAS, HEC-GEORAS and ARC-GIS

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## Abstract

This paper is based on the one-dimensional hydrodynamic model simulation of flood map of one of the largest river basins i.e. Narayani River floodplain, located in the Central zone of Nepal. The study area covers around twenty kilometers of the flood area located at the upper stream of the bridge section in East West Highway of Narayani River. The Trishuli and the Kaligandaki are thus considered as our tributaries to calculate the catchment and for the flood model analysis. The precipitation data collected from Department of Hydrology has been used to calculate the four scenario (100, 200, 500 and 1000 years) flood analysis from Gumbell method. Contour lines were plotted in the Google Earth and the maps were extracted using ARCGIS by downloading terrain file from ASTER DEM website. The digital model is then developed through ARCGIS by feeding the Gumbell analyzed flood data using flood depth as a hydraulic characteristic factor of flood.

The hydrodynamic model for mapping were developed using the Hydrologic Engineering Center River Analysis System (HEC-RAS) in concert with HEC-GeoRAS. HEC-GeoRAS set procedures, tools, and utilities for processing Geographic Information Systems (GIS) data by using a graphical user interface on a GIS platform. Automated GIS processing procedures in HEC-GeoRAS provided a useful and expeditious method for repetitive hydraulic model development during analysis of the Narayani River Flood Plain. Reach length, stream centerline, main channel bank, flow path lines, cross drainage structures and cross sections have been determined using HEC-RAS. The resultant water depth exported from HEC-RAS simulations has been processed by HEC-GeoRAS for flood inundation delineation and hazard map generation. Finally, as per the discharge taken for four scenario (100, 200, 500 and 1000 years) different flood Map zone has been prepared and the inundation area has been identified.

## Keywords

Hydrodynamic Model, Narayani River Floodplain, Flood Map, Gumbell Method, ARCGIS, HEC-RAS, Inundation Area

## 1. Introduction

Flood is one of the most devastating natural hazards which affect the social and economic aspects of the population claiming more lives and economic loss than any other natural disasters. The tendency of the occurrence of the flood has been increasing around the globe which has become a major concern. Generally, flooding is caused by the change in the land use pattern and drastic increase in precipitation. These extreme phenomena are driven by the rapid by climate change. Nepal is also prone to the hazardous effect of flood and its effects are already seen on regular basis with varying intensity and magnitude. Three large river basins in Nepal which flow from northern Himalayas to the low land in the south even make more vulnerable to the water induced disaster.

Narayani river basin is one of the largest river basins with steep flow that has greater effect. The lower lands near the bank of Narayani River are highly exposed to flood induced disaster since this basin is accompanied by heavy rainfall resulting rise in the river level and inundating the nearby lowlands in consequent cost the life and property. Chitwan and Gaidakot are located on either side of the bank of Narayani River at around 415 m from the mean sea level. The main cause of these disasters is the extreme monsoon rainfall which occur mostly from June-September [1]. About 80% of annual rainfall occurs during monsoon season and thus, extreme floods during monsoon season occur due to this concentrated spells of heavy rainfall [2].

There are various methods that are used to, to prevent

and manage the devastation from flood. Out of different method flood forecasting is one of the most important measure [3]. It is a non-structural method use to predict the flood which helps to efferently reduce the damage caused by the flood. It should be incorporated as the integral part as a part of flood control system and should be prioritized as a tool at the national flood policy. Hazard Mapping is very important nonstructural method that help to comprehend the characteristic of disaster and hence take necessary steps to mitigate them [4]. A complete hydrological analysis would be helpful to delineate the flood hazard area for the particular geographic area at particular time for a select peak flow.

## 2. Study Area

### 2.1 Study Area

The study area is a Narayani River basin which lies in the central part of the Nepal. The coordinates of the latitude are 25.49°N to 29.28°N and longitude 85.02°E to 85.83°E. It is a transboundary river basin, which originates from the Tibetan Plateau in the North and extends up to Ganges river in the South in India. Most of the basin lies in Nepal which comprises of around 32,104 sq. within Nepal out of the total area of 46,300 sq.[5][6]. Narayani river is formed by the assimilation of seven different large river system i.e. Marsyangdi, Daraudi, Seti, Madi, KaliGandaki, Budhi Gandaki, and Trishuli. It begins form high Himalayas in the North with high flow along the steep gradient, flow through the mid hill areas and finally onto the plain Terai of Nepal. Average annual precipitation ranges from 152 mm to 5493 mm and mostly occurs in the period of June to September [6, 7].

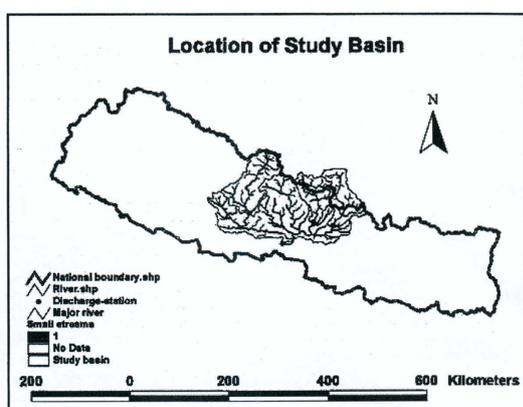


Figure 1: A Representation of the Narayani River Basin

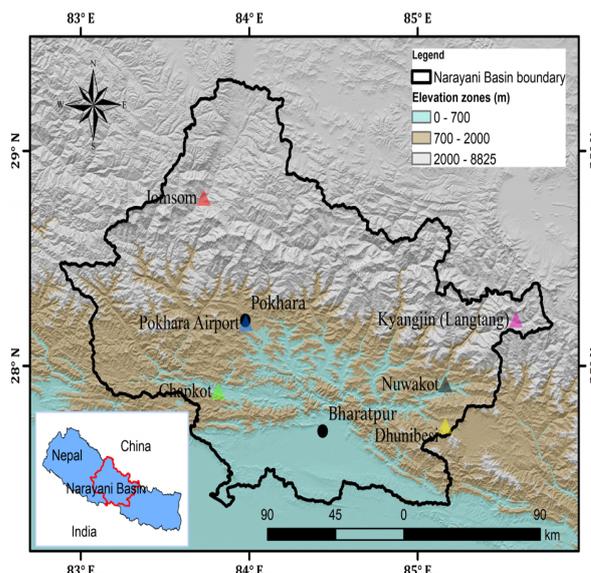


Figure 2: A Geographical Map of Narayani Basin Boundary

## 3. Objectives

The most specific objective of this study is the delineation of the flood inundation map of Narayani River basin at different flood stages for different time period. In order to achieve the objective a one-dimensional HEC-RAS model is used.

## 4. Methodology

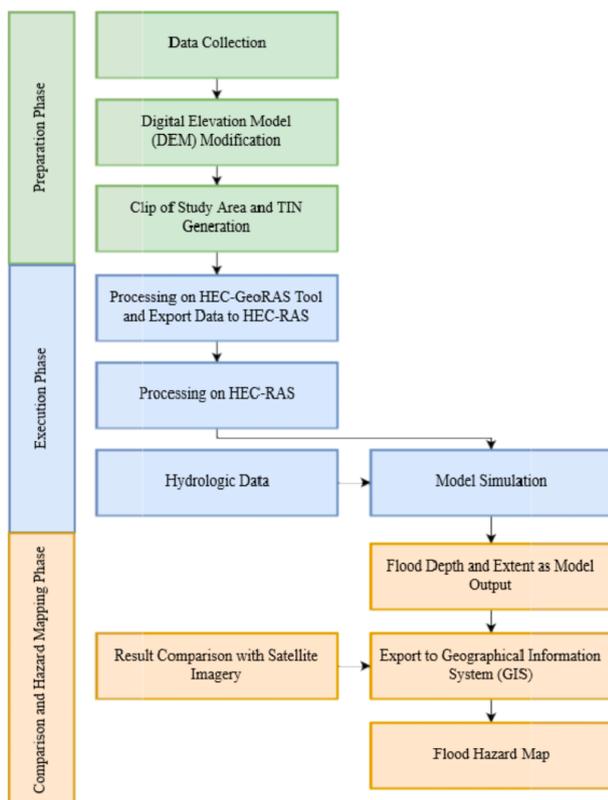
In order to achieve the objective of this research a hydrological model can be very helpful to clearly depict the reality and predict future water scenario at the basin. The selection of a model mainly depends upon the complexity, available resources and modelling objectives. Based on the process, the hydrological model can be classified into three different categories, Lumped, distributed and semi distributed models [8] and [?]. A semi distributed hydrologic model of HEC-HMS is used for the flood delineation of Narayani River Basin. It is a Hydraulic Engineering Center-Hydrologic Modelling System developed by USA Army Corps of Engineers. The model allows to predict the future water availability based on the past record of the flood. The estimation of the occurrence of the flood in the future is very important for quantitative analysis of extreme flood events. There is no such method that computes the precise value of streamflow or precipitation responsible for the flooding. Mostly there are three types of empirical and probabilistic approach which

are used for the analysis of flood. Gumbel's, Log Normal and Log Pearson III type, etc. are the methods which are based on probability theory. In this study most widely used probability distribution function formulated by Gumbel is used for the prediction of Peak flow and maximum precipitations [9]

$$X_T = X_{avg} + KS_{n-1}$$

where,

- $X_T$ =maximum rainfall or flood peak discharge
- $X_{avg}$ =average value of  $X$
- $S_{n-1}$ =Standard Deviation of sample size  $n = \sqrt{((X - X_{avg})^2 / (n - 1))}$
- $K$ =frequency factor expressed as  $K = (Y_T - Y_n) / S_n$
- $Y_T$ =reduced mean, a function of sample size  $n$
- $n$ =sample size and
- $S_n$ =reduced standard deviation, a function of sample size  $n$ .



**Figure 3:** A flow chart representation of the methodology of flood Mapping

**GIS** Geographic Information System(GIS) is a software that is used to study and analyze the

geospatial data .GIS is used for capturing, storing, querying, analyzing and displaying geographic referenced data [9] along with the HEC-HMS interface .GIS helps to prepare the inundation maps overlays which helps to illustrate more clearly the areas of flooding. Likewise a HEC-GeoRAS interface of ArcGIS is used to process the geospatial data for the use with the HEC-RAS. It helps in the preparation of the geometric data required to for the HEC-RAS and result obtained from the HEC-RAS is exported back to it for the simulation-RAS is another interface were all the hydraulic analysis is done by providing the Geometric input from GIS, manning's constant and extreme discharge. The framework of the approach with use of above tools have been provided in the figure 3.

#### 4.1 Preparation Phase

**Data Collection** A topographic dataset is the most important geospatial data for hydrological simulations in the HEC-RAS model. The SRTM Digital elevation model (DEM) with a 30 m resolution available in Geo TIFF file format is used. The DEM correction has been done by filling the sinks and pits where the water accumulation could occur. DEM in GIS, help define watershed, river network, drainage pattern, slope length, gradient, sub-basin and helped generate other information about terrain

**Modification of Digital Elevation Model (DEM)** A DEM is modified or prepared as per the requirement to depict the required topographic information and enhances the modeling of flow across topography, a controlling factor in distributed models of landform processes 30\*30 resolution DEM has been used for the study and the elevation of the DEM has been taken from the mean sea level.

#### 4.2 Execution Phase

Pre-processing in HEC-GeoRAS

The process is the HEC-GeoRAS is divided into two parts preprocessing (preRAS) and post- processing (postRAS). Only preprocessing is used in this study to achieve our objective. Preprocessing is used to import the RAS file from GIS.It contains all the geometric information necessary to perform hydraulic computations in HEC-RAS. Likewise, the elevation data, cross sectional data required for the processing are extracted from the selected Digital Terrain Model (DTM) of thee basin.DTM is available mainly in TIN

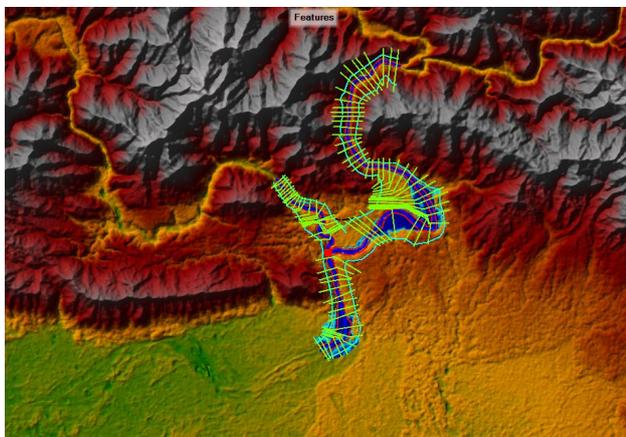
or GRID format, in this study a GRID format DTM has been used.

**River Centerline and Bank Creation** Centerline layer has been used to represent the river alignment. The lining starts from upstream and is worked its way to downstream. The deepest part of the channel has been taken for the representation of the river. Once the centerline was created, another important component is the creation of river banks. River banks are very important for the steady state simulation. During flooding, the outer land area or overbanks is separated from main channel by the riverbanks Banks helps to separate the

**Flow Path Creation** Flow path centerlines is one of the important phases, the flow path centerlines help to identify hydraulic flow path in the left overbank, main channel, and right over bank. Flow paths are created to assign the flow paths by digitizing the flow paths in the direction of flow (upstream and downstream)

**Exporting GIS Data to HEC-RAS:** In the HEC-GeoRAS interface a HEC-RAS compatible data file is created in the preprocessing stage. The input file contains the terrain elevation information extracted from the GRID. Once the input file has been created, the RAS import format file was loaded in HC-RAS.

**Processing on HEC-RAS (Model Development)** After, all the data preparation is completed, the hydrological model development is done in the HEC-Raster full hydrological model development is done in three phases, the step wise procedure has been provided in sequential order.



**Figure 4:** A DEM showing the centerlines, Bank line, flow path of the river

### PROCEDURE OF THE PROJECT IN HEC-RAS, HEC-GEORAS AND ARCGIS

- Rainfall Data was collected from Department of Hydrology and Meteorology (DHM) for the Chitwan Stations
- Gumbel Distribution was used to calculate the flood discharge using the precipitation data from Chitwan for different return periods (100 yrs,200yrs,500yrs,1000yrs)
- After that, river profile was plotted in the Google earth which was imported to ArcGIS for digitization of the profile and the HEC-RAS software having version 5.0.3 was installed and work is started in HEC-RAS environment.
- The terrain data in the GRID format was acquired of the study area basin to create the hydraulic model along with the other useful information such as aerial photographs and land use information.
- The dataset available to us is a portion of the Narayani River and its tributary, Kaligandaki and Trishuli and its small rivers combined.
- In the HEC- RAS interface a new project is run and a specific Title to the Project is given
- A Geometric File is created so that all the file contains all the geometric information that HEC-RAS will require for its computations.
- Data is imported into the RAS MAPPER but before importing data, it is important to set coordinate system in RAS Mapper. All datasets should be in same coordinate system. RAS Mapper uses an ESRI projection file to import the coordinate system.
- A .prj format file is used to create the setting up the coordinate system HEC-RAS project shapefile for the study area, and the details of the coordinate system are extracted automatically from the .prj file and populated in the “RAS Mapper Options”
- DEM is imported into the RAS Mapper, layer of map made in the GIS which shows river profile in a topographic map is added and the river profile is plotted in HEC-RAS

- All the centerlines, bank lines, flow path and cross section were digitized in the DEM provided in the RAS Mapper
- First, centerline will be created to define overall extent of the model and the river centerline is used to define the river in each network. It has Trishuli River flowing from northeast to southwest (upper right to lower left) and Kaligandaki also meeting at the junction as its tributary, Trishuli, Kaligandaki and Naryani Lower.
- At last for each reach the digitization of at least one feature is done following river centerline in the flow direction leaving some space from boundary. Also, the river center line is digitized starting from the upstream section of Trishuli River reach and is continued downstream until the intersection with the Kaligandaki river, after that digitization of lower part of the Narayani River is done.

for both the high and low chords are defined, new cross-section with the bridge opening is formed.

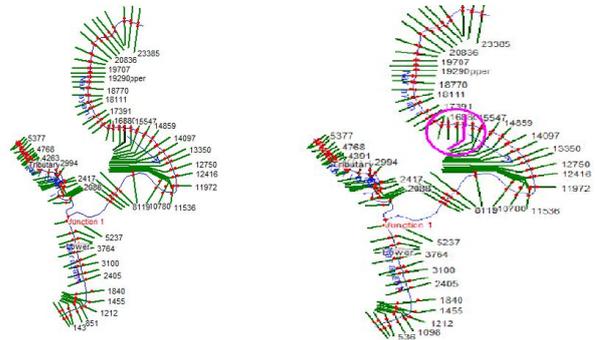


Figure 5: Digitizing of the cross section and Bridge structure locations

**Creating Bridges and Culverts** Cross-section can be added using geometry editor in HEC-RAS, bridge is between cross-sections 5195 and 5996. Generally, bridges are not captured in a DEM, which is a 2D representation of topography, hence, the elevation of the road section and the opening from which the river is flowing should be defined. First it was necessary to find out top elevation of the bridge. Next, it is required to know opening for the bridge. The road was assumed around 6 ft thick, which means the elevation of the lower chord of the bridge is 218 ft where the bridge is open.

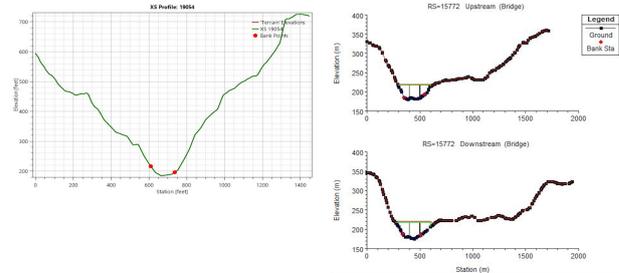


Figure 6: Bridge Culvert Data

In addition to providing the station and elevation information, as well as provide position of the bridge relative to the cross-sections. The distance field shows distance between upstream cross-section and upstream face of the bridge and the width shown represent the width of the deck/roadway. In this case, bridge was considered as 50 ft wide. Typically, the distance field was filled by measuring distance between the cross-section and approximate upstream face of the bridge in the DEM or aerial photograph. The width is usually extracted from field surveys.

Highest elevation of the bridge is represented by the high chord column whereas the bottom of the bridge deck is represented by the low chord column. If there is no any value assigned to the low chord then, deck will extend to the ground surface. Once the values

**Deck/Roadway Data Editor**

Distance	Width	Weir Coef
22.86	10.	2.6

Upstream			Downstream		
Station	high chord	low chord	Station	high chord	low chord
1 0	220		0	220	
2 200	220	218	200	220	218
3 600	220	218	600	220	218
4 700	200		700	200	
5					
6					
7					
R					

U.S Embankment SS:       D.S Embankment SS:

**Weir Data**  
 Max Submergence:       Min Weir Flow El:

**Weir Crest Shape**  
 Broad Crested  
 Ogee

Enter distance between upstream cross section and deck/roadway. (m)

Figure 7: Deck/Railway Data Editor

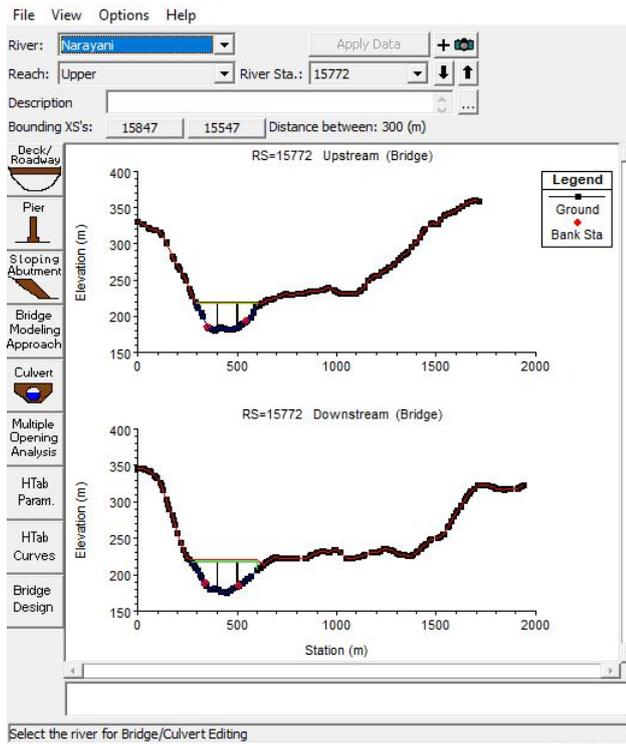


Figure 8: Representation of Bridge Location and pier

Once the opening is defined, Bridge Design tool is used to enter pier information. Here two piers of 10ft width and a spacing of 200ft is assumed.

**Assigning Manning’s n values to cross-sections**

The last step is to assign the appropriate value to the manning constant, to each of the individual cross section manning’s coefficient value 0.2 for built up area and 0.035 for forest area was taken, likewise manning’s coefficient of 0.06 for middle river region was taken.

**Entering Flow Data and Boundary Conditions**

Generally the river flows are defined at the upper most upstream point of each river/tributary and also at the junctions. Furthermore, condition arises when flow needs to be defined at more locations. Each of the flows that needs simulation in a HEC-RAS is called profile.

**Entering steady flow data** Before steady flow analysis steady flow data must be entered. Four number of profiles for analysis and comparison of steady flow data was created for 100, 200, 500 and 1000 years return period flow data which are as listed in PF1, PF2, PF3 and PF4 respectively. The extreme flood data for different return periods are used for different catchment area available. The catchment

area of river reach was calculated in ArcGIS and all river data has been shown below:

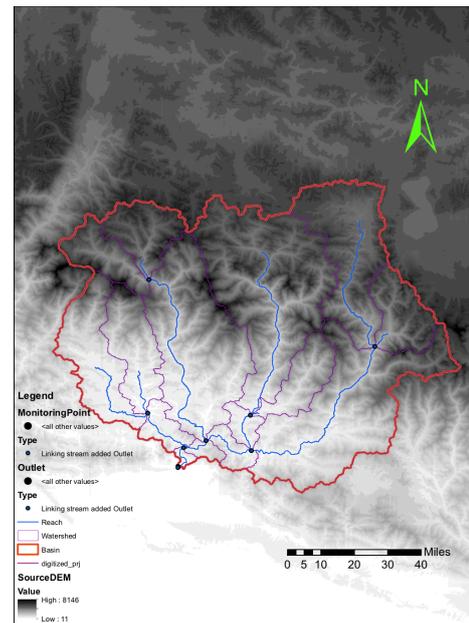


Figure 9: Representation of Catchment area of Narayani River

- Total catchment area for lower Narayani river reach, A = 31,828.612 km<sup>2</sup>
- Catchment area of kaligandaki tributary, B= 11,781.289 km<sup>2</sup>
- Catchment area of upper reach of Narayani, C = 19,820.157 km<sup>2</sup>

Four return periods i.e. PF1 (100 years), PF2 (200 years), PF3 (500 years) and PF4 (1000 years) is taken and calculated accordingly. Taking Q= 284.66 m<sup>3</sup>/s (for 100 years RT). Here Q is the value for total catchment area A. For upper reach of river, area, C = 19,820.157 km<sup>2</sup>. Hence discharge value for area C, q = 284.66 x (A/C) = 284.66 x (31,828.612/19,820.157) = 11,181.05 m<sup>3</sup>/s. The rest are also calculated in similar pattern and the data are as shown in fig. below.

River	Reach	RS	PF 1	PF 2	PF 3	PF 4
1	Kaligandaki Tributary	5227	1446.123	7184.137	2892.945	9431.401
2	Narayani Upper	23385	11311.05	12096.17	13201.31	14182.82
3	Narayani Lower	5227	17955.32	19409.84	21326.47	22775.77

Figure 10: Steady Flow Data

**Table 1:** The gumbel analysis data is as shown in table below.

Return. period(T)	Y(T)	$K=((YT-Y_n)/S_n)$	Expec.pk. Dis.(m <sup>3</sup> /s)	Latitude
2	0.367	-0.153	96.566	27.13
5	1.5	0.856	146.924	27.35
10	2.25	1.525	180.266	27.2
15	2.674	1.902	199.077	26.92
20	2.97	2.166	212.248	26.67
30	3.384	2.535	230.646	26.63
40	3.676	2.795	243.617	26.88
50	3.902	2.996	253.645	26.68
100	4.6	3.618	284.666	26.87
150	5.007	3.98	302.756	27.15
200	5.296	4.237	315.574	26.58
300	5.702	4.599	333.626	26.68

HEC-RAS is run for Steady Flow Analysis, selecting Subcritical Flow Regime with simulations run and the result is viewed on the RAS Mapper.

## 5. Results and Output

### 5.1 Exporting HEC-RAS output to HEC GEORAS

As, steady flow analysis was completed RAS data is exported to GIS file through HEC-GEO RAS plugin. The exported file which was in SDF format was converted to XML format before flood inundation mapping was done. Each time one flow was selected for analysis. [5] [?]

### 5.2 Flood Inundation Mapping

A geodatabase is created during flood inundation where default 20 map units for Rasterization Cell Size was accepted. Grid terrain file during flood inundation was used which was also converted to a DEM. The cell size of DTM grid is equal to Rasterization Cell Size. Water surface generation was done for all flow i.e. PF1, PF2, PF3 and PF4. The purpose of surface generation of water helps to create boundary polygon which defines the extent for the inundation flood mapping. This is created when the end points of the cross section cut lines are connected

This will create a surface with water surface elevation for the selected profile. The GRID that was created define a zone that will connect outer points of bounding polygon, which means the grid include area outside the possible inundation.

In the flood inundation mapping delineation was done of floodplain using raster for different flow profile. In

the series of data observed area with positive results (meaning water surface is higher than the terrain) is flood area, and area with negative results is dry. All the cells in water surface grid that result in positive values after subtraction are converted to a polygon, which is the final flood inundation polygon.

The result of inundation mapping for different flow profile showing flooded area is shown in table below:

**Table 2:** PF1 100 Years Return Period

FID	Shape	ID	Grid Code	Shape Length	Shape Area
1	Polygon	1	1	2650.34487	271301.3624
2	Polygon	2	1	112.85704	612.618861
3	Polygon	3	1	209.092483	1960.765263
4	Polygon	4	1	112.85906	612.641192
5	Polygon	5	1	112.85805	612.630027
6	Polygon	6	1	112.85805	612.630027
7	Polygon	7	1	212.395105	2119.867648
8	Polygon	8	1	112.859227	612.643016
9	Polygon	9	1	112.858261	612.632362
10	Polygon	10	1	112.858094	612.630539
11	Polygon	11	1	112.858217	612.63185
12	Polygon	12	1	444.524844	8826.483273
13	Polygon	13	1	212.395264	2119.872576
14	Polygon	14	1	169.718053	1207.825353
15	Polygon	15	1	172.151154	1039.904506
16	Polygon	16	1	447.349868	7397.889252
17	Polygon	17	1	867.820141	24712.43614
18	Polygon	18	1	169.272564	1221.733298
19	Polygon	19	1	112.858217	612.63185
20	Polygon	20	1	112.858261	612.632362
21	Polygon	21	1	72671.95181	11657546.16
				Total Area	11985580.62

**Table 3: PF2 200 Years Return Period**

FID	Shape	ID	Grid Code	Shape Length	Shape Area
1	Polygon	1	1	112.85704	612.618861
2	Polygon	2	1	209.092483	1960.765263
3	Polygon	3	1	112.85906	612.641192
4	Polygon	4	1	112.85805	612.630027
5	Polygon	5	1	211.306403	2073.003168
6	Polygon	6	1	212.395105	2119.867648
7	Polygon	7	1	112.859227	612.643016
8	Polygon	8	1	112.858261	612.632362
9	Polygon	9	1	112.858094	612.630539
10	Polygon	10	1	112.858217	612.63185
11	Polygon	11	1	444.524844	8826.483273
12	Polygon	12	1	212.395264	2119.872576
13	Polygon	13	1	169.718053	1207.825353
14	Polygon	14	1	172.151154	1039.904506
15	Polygon	15	1	447.349868	7397.889252
16	Polygon	16	1	867.820141	24712.43614
17	Polygon	17	1	112.858217	612.63185
18	Polygon	18	1	169.272564	1221.733298
19	Polygon	19	1	112.858261	612.632362
20	Polygon	20	1	74109.20035	12051802.32
				Total area	12109995.79

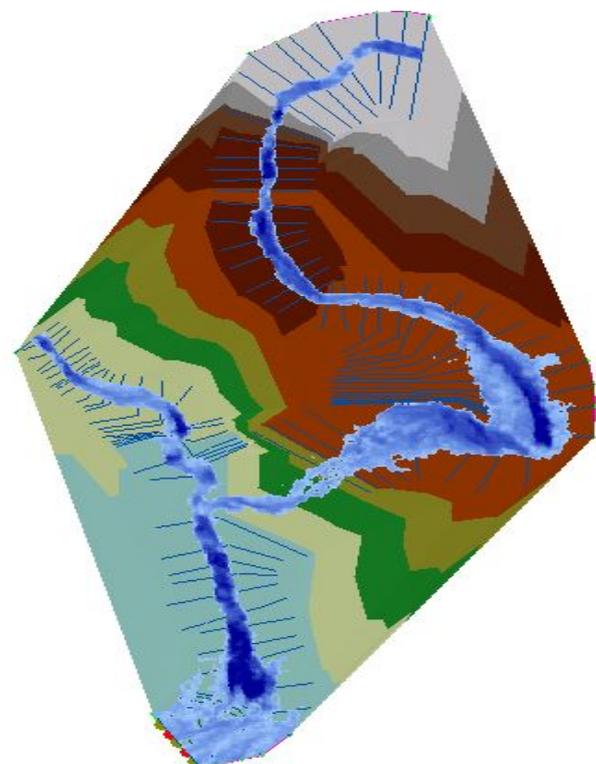
**Table 4: PF3 500 Years Return Period**

FID	Shape	ID	Grid Code	Shape Length	Shape Area
1	Polygon	1	1	112.857164	612.620173
2	Polygon	2	1	169.71808	1207.826166
3	Polygon	3	1	209.092483	1960.765263
4	Polygon	4	1	112.85906	612.641192
5	Polygon	5	1	211.306403	2073.003168
6	Polygon	6	1	212.395105	2119.867648
7	Polygon	7	1	112.859227	612.643016
8	Polygon	8	1	112.858261	612.632362
9	Polygon	9	1	112.858094	612.630539
10	Polygon	10	1	708.586125	17016.4552
11	Polygon	11	1	169.718053	1207.825353
12	Polygon	12	1	211.562923	2099.902406
13	Polygon	13	1	112.858217	612.63185
14	Polygon	14	1	112.858217	612.63185
15	Polygon	15	1	169.272564	1221.733298
16	Polygon	16	1	119.6518	894.784578
17	Polygon	17	1	112.858217	612.63185
18	Polygon	18	1	112.858217	612.63185
19	Polygon	19	1	112.858261	612.632362
20	Polygon	20	1	72213.48695	12270313.32
				Total area	12306241.81

**Table 5: PF4 1000 Years Return Period.**

FID	Shape	ID	Grid Code	Shape Length	Shape Area
1	Polygon	1	1	112.857164	612.620173
2	Polygon	2	1	169.71808	1207.82617
3	Polygon	3	1	209.092483	1960.76526
4	Polygon	4	1	112.85906	612.641192
5	Polygon	5	1	262.244271	3020.62515
6	Polygon	6	1	112.859227	612.643016
7	Polygon	7	1	112.858173	612.631338
8	Polygon	8	1	112.85805	612.630027
9	Polygon	9	1	112.858094	612.630539
10	Polygon	10	1	112.858217	612.63185
11	Polygon	11	1	708.586125	17016.4552
12	Polygon	12	1	169.718053	1207.82535
13	Polygon	13	1	211.562923	2099.90241
14	Polygon	14	1	112.858217	612.63185
15	Polygon	15	1	169.272564	1221.7333
16	Polygon	16	1	119.6518	894.784578
17	Polygon	17	1	112.858217	612.63185
18	Polygon	18	1	112.858217	612.63185
19	Polygon	19	1	72077.17514	12361558.4
				Total area	12396314.6

our cross-profile data is 10.115 m/s for PF1, 10.293 m/s for PF2, 10.505 m/s for PF3 and 10.696 m/s for PF4 at cross profile 20332 at Narayani upper reach.



**Figure 11:** Showing flood profile along with terrain map generated in HEC Geo Ras

From above tables the total flooded areas within our profile reach for 100, 200, 500 and 1000 years are respectively 11.986 km<sup>2</sup>, 12.120 km<sup>2</sup>, 12.306 km<sup>2</sup>, 12.396 km<sup>2</sup>. The maximum velocity observed within

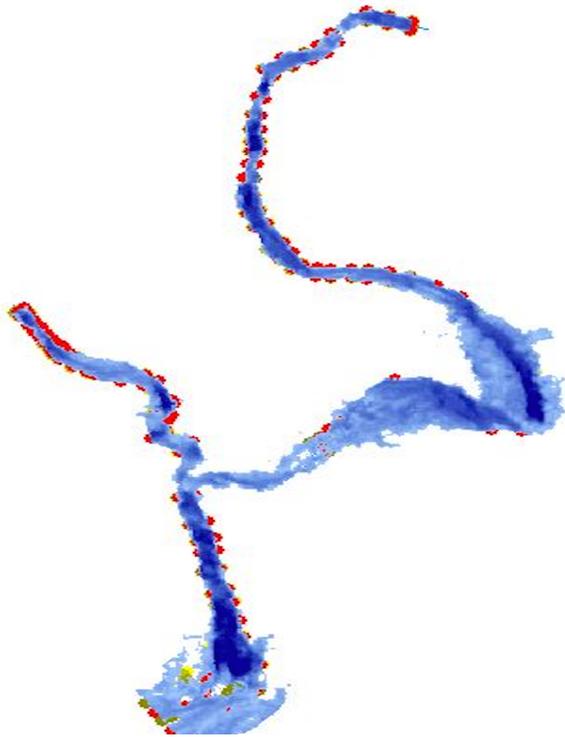


Figure 12: The two red dots show the boundary line

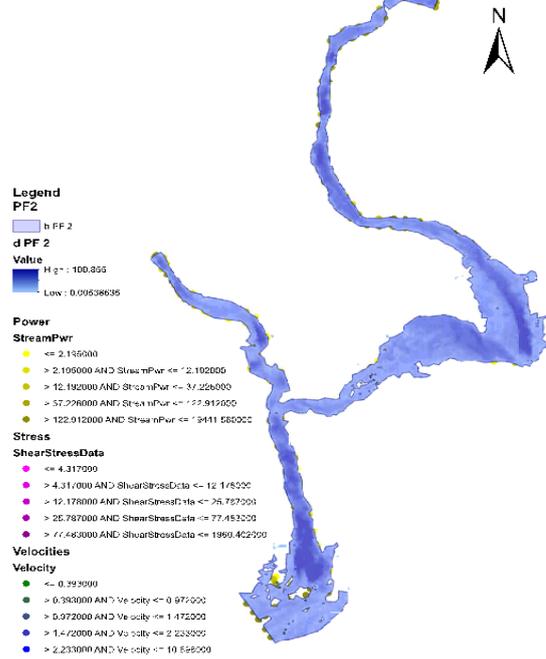


Figure 14: Naryani's Flood Modeling PF2

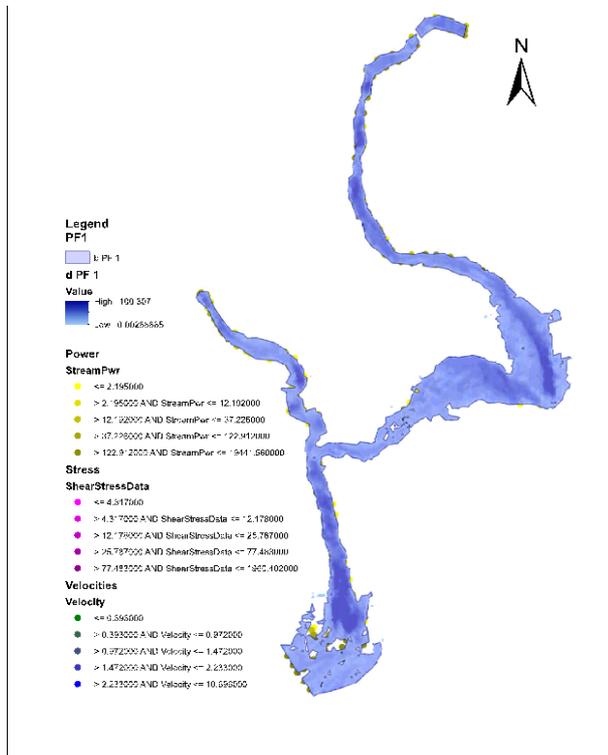


Figure 13: Naryani's Flood Modeling PF1

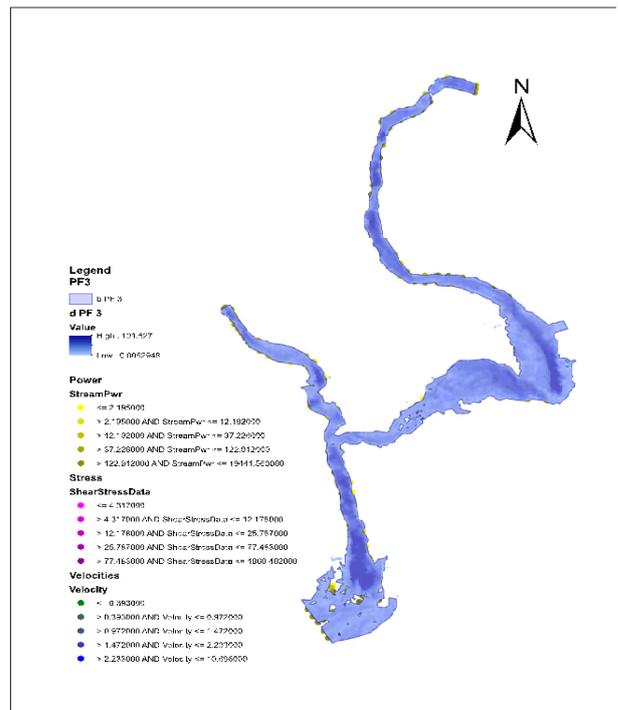


Figure 15: Naryani's Flood Modeling PF3

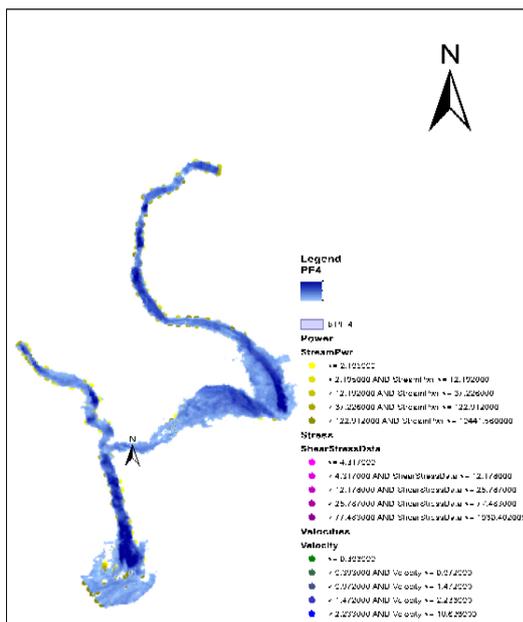


Figure 16: Naryani's Flood Modeling PF4

## 6. Conclusion and Recommendations

### 6.1 Conclusion

Flood Inundation Map delineation of Narayani River Basin for different return periods at different flood stages was been developed. The result obtained from the study will be beneficial to assess the potential flood hazard that are likely to happen in the future and take precautionary steps as well as take measures to mitigate the negative effects of flood. From the flood hazard map in association with the administrative map of the basin, the most hazardous areas were found to be lower reach of Narayani river (below 1455 ft cross profile) near built up areas and second most flood hazardous areas are few kilometers above the confluence of tributary (between 8119 to 155,47ft cross profile) in the upper Narayani river reach near the settlement areas. The use of this method to study the flood forecasting realized to be very effective for flood mapping.

### 6.2 Recommendations

The following recommendations are made

1. In areas with maximum flood level i.e. between 8119 to 15547ft cross profile in upper Narayani

river reach and below 1455 ft of cross profile in lower Narayani reach special flood protection works such as river training can be provided.

2. Two-dimensional analysis along with the use of High-Resolution DEM can be used to represent the real topography in future for better performance and to generate the flood delineation map
3. Apart from inundation depth, other important factor such as frequency of flood, duration, velocity can be considered in hydrological analysis.

## References

- [1] SR Chalise, ML Shrestha, and RP Nayaju. Rainfall as the primary indicator of water induced disasters in nepal (proc. international seminar on water induced disaster (iswid), march 1995), 191-201. *Water Induced Disaster Prevention Technical Centre (DPTC), Kathmandu, 1995.*
- [2] B Shakya. Problems due to some severe floods and other catastrophic events associated with synoptic situation in nepal. In *Polish Polar Studies: 25th International Polar Symposium, Warszawa 1998*, pages 205–213. Institute of Geophysics of the Polish Academy of Sciences. Warszawa pg, 1998.
- [3] MINATI Singh and KAILASH NATH Singh. Flood hazards: A perspective on their control, planning and management. *Planning in Integrated Rural Environment*, 1988.
- [4] Samjwal Ratna Bajracharya, Sudan Bikash Maharjan, Finu Shrestha, Wanqin Guo, Shiyin Liu, Walter Immerzeel, and Basanta Shrestha. The glaciers of the hindu kush himalayas: current status and observed changes from the 1980s to 2010. *International Journal of Water Resources Development*, 31(2):161–173, 2015.
- [5] Piyush Dahal, Nicky Shree Shrestha, Madan Lall Shrestha, Nir Y Krakauer, Jeeban Panthi, Soni M Pradhanang, Ajay Jha, and Tarendra Lakhankar. Drought risk assessment in central nepal: temporal and spatial analysis. *Natural hazards*, 80(3):1913–1932, 2016.
- [6] Deo Raj Gurung, Sudan Bikash Maharjan, Anu Bhalu Shrestha, Mandira Singh Shrestha, Sagar Ratna Bajracharya, and MSR Murthy. Climate and topographic controls on snow cover dynamics in the hindu kush himalaya. *International Journal of Climatology*, 37(10):3873–3882, 2017.
- [7] Bikas Chandra Bhattarai and Dhananjay Regmi. Impact of climate change on water resources in view of contribution of runoff components in stream flow: a case study from langtang basin, nepal. *Journal of Hydrology and Meteorology*, 9(1):74–84, 2015.

- [8] Barbara Lastoria. *Hydrological processes on the land surface: A survey of modelling approaches*. Università di Trento. Dipartimento di ingegneria civile e ambientale, 2008.
- [9] Kanhu Charan Patra. *Hydrology and water resources engineering*. Alpha Science International, 2008.