High Powered Committee for Integrated Development of the Bagmati Civilization
Kathmandu

JUNE 2022

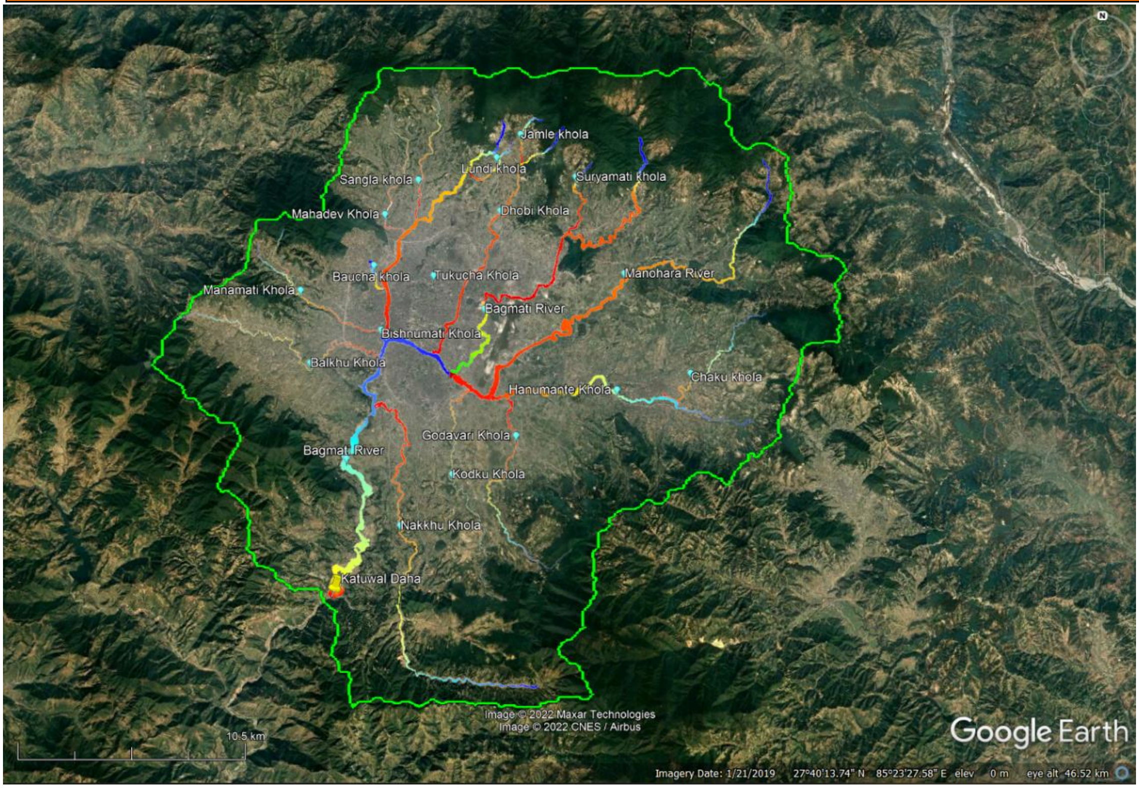
FINAL REPORT

Supplementary Volume (II) - Hydrological & Flood Modelling Report

for

Preparation of Bagmati Action Plan

RFP No.: BIP-BAP-01-077/78



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High Powered Committee for Integrated Development of the Bagmati Civilization

Kathmandu

Preparation of Bagmati Action Plan

Supplementary Volume (II) - Hydrological & Flood Modelling Report

June, 2022

This document is the Final report (Supplementary Volume (II) - Hydrological & Flood Modelling Report) of work, for the project "**Preparation of Bagmati Action Plan; RFP No.: BIP-BAP-01-077/78**" undertaken by High Powered Committee for Integrated Development of the Bagmati Civilization (HPCIDBC), Kathmandu. This document spells out the Hydrological modelling of Bagmati basin and recommended the minimum water way of the river with Bagmati basin of Kathmandu Valley.

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Project team

ABBREVIATION

amsl	:	Average mean sea level
BAP	:	Bagmati Action Plan
BRBIP	:	Bagmati River Basin Improvement Project
DEM	:	Digital Elevation Model
DHM	:	Department of Hydrology and Meteorology
HMS	:	Hydrologic Modeling System
HPCIDBC	:	High Powered Committee for Integrated Development of the Bagmati Civilization
ICIMOD	:	International Centre for Integrated Mountain Development
Km/km	:	Kilometer
m	:	Meter
mm	:	Millimeter
NSE	:	Nash and Sutcliffe Efficiency
RMSE	:	Root Mean Square Error
SCS-CN	:	Soil Conservation Service Curve Number
SCS-UH	:	Soil Conservation Unit Hydrograph
Stn	:	Station
Yrs	:	Years

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1 EXISTING SCENARIO OF STUDY AREA

1.1 General

Bagmati River is largest river system in the Kathmandu Valley comprising of 57 rivers and rivulets as its tributaries. The Bagmati River originates in Kathmandu valley, which comprises of the area of Bagmati basin in Nepal. The Bagmati basin is characterized as medium dry basin fed by spring and monsoon rainfall (WECS, 2008). The river originates where three headwater streams converge at Baghdwar at an altitude of 2690 m, where the water flows out through a gargoyle shaped like tiger's mouth situated in Shivpuri National park northeast of Kathmandu. The river is characterized with steep gradient (about 128.6 m/km) in Shivapuri range and gentle slope (about 2.7 m/km) in Kathmandu valley area. River gradient values are calculated using the integrated model of DEM data and cross section survey data of the river stretch. The hydrological studies of the Bagmati River for Bagmati Action Plan (BAP) has been carried out for its catchment and tributaries upstream of the river point at Katuwal Daha. The hydrological studies of the project focus on study of 17 tributaries with the stream order from 6 to 9. Different studies in past regarding the hydrological modelling focusing on flood discharge computations and flood mapping in the urban region of Kathmandu valley due to maximum instantaneous flood in its tributaries have been reviewed for carrying out detail hydrological studies of Bagmati river system. The administrative project location map showing the catchment area map of Bagmati river basin in Kathmandu valley is presented in Figure 1-1.

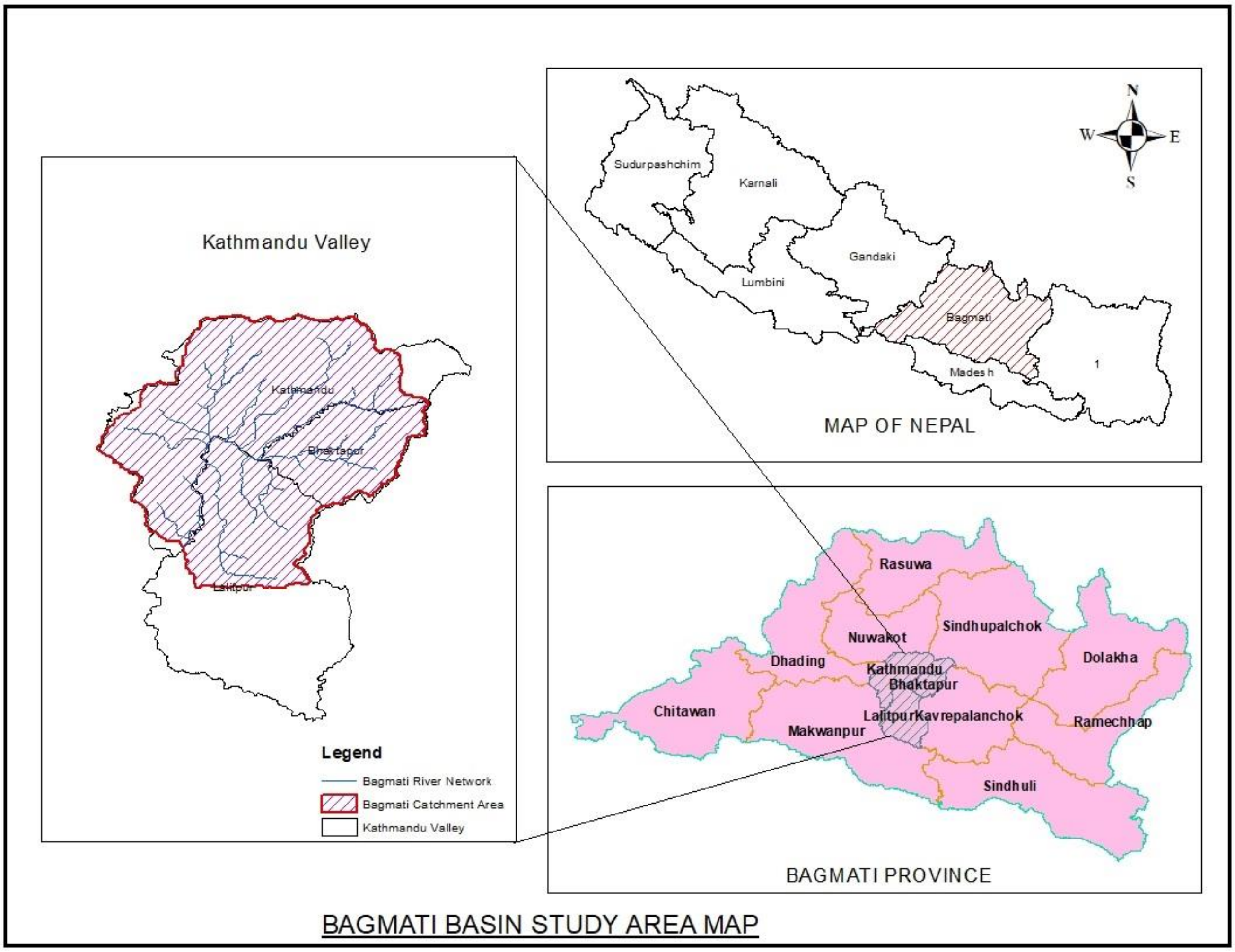

Figure 1-1: Administrative Location Map of Bagmati Catchment Area

1.2 Hydrological Data Availability

Hydrological modelling works and its accuracy depends on the available data at the study area which are used for calibration and validation processes. Hydrological data collection is carried out from various institutions involved in study of Bagmati river basin and its tributaries.

Department of Hydrology and Meteorology (DHM) which is under Ministry of Energy, Water Resources and Irrigation was sole organization responsible for establishment of hydrological stations for discharge measurement and meteorological station for precipitation, temperature, evapotranspiration, sunshine and other climatic data collection, dissemination and publication of the data. However, recently different research organizations have also been involved in collection of the hydrological data of Bagmati Basin particularly focusing in Bagmati River and its tributaries in Kathmandu valley. DHM, WECS (Water and Energy Commission Secretariat), HPCIDBC (High Powered Committee for Integrated Development of the Bagmati Civilization), ICIMOD (International Centre for Integrated Mountain Development), S4W Nepal (SmartPhones4Water), etc. are among some organization directly and indirectly involved in hydrological studies of Bagmati river basin and its tributaries.

Summary of the available hydrological data of Bagmati river basin within the study area collected from the Department of Hydrology and Meteorology (DHM) are presented in Table 1-1 and Table 1-2 respectively. Hydrological and meteorological stations in Kathmandu Valley area and its vicinity established by DHM are presented in Figure 1-2.

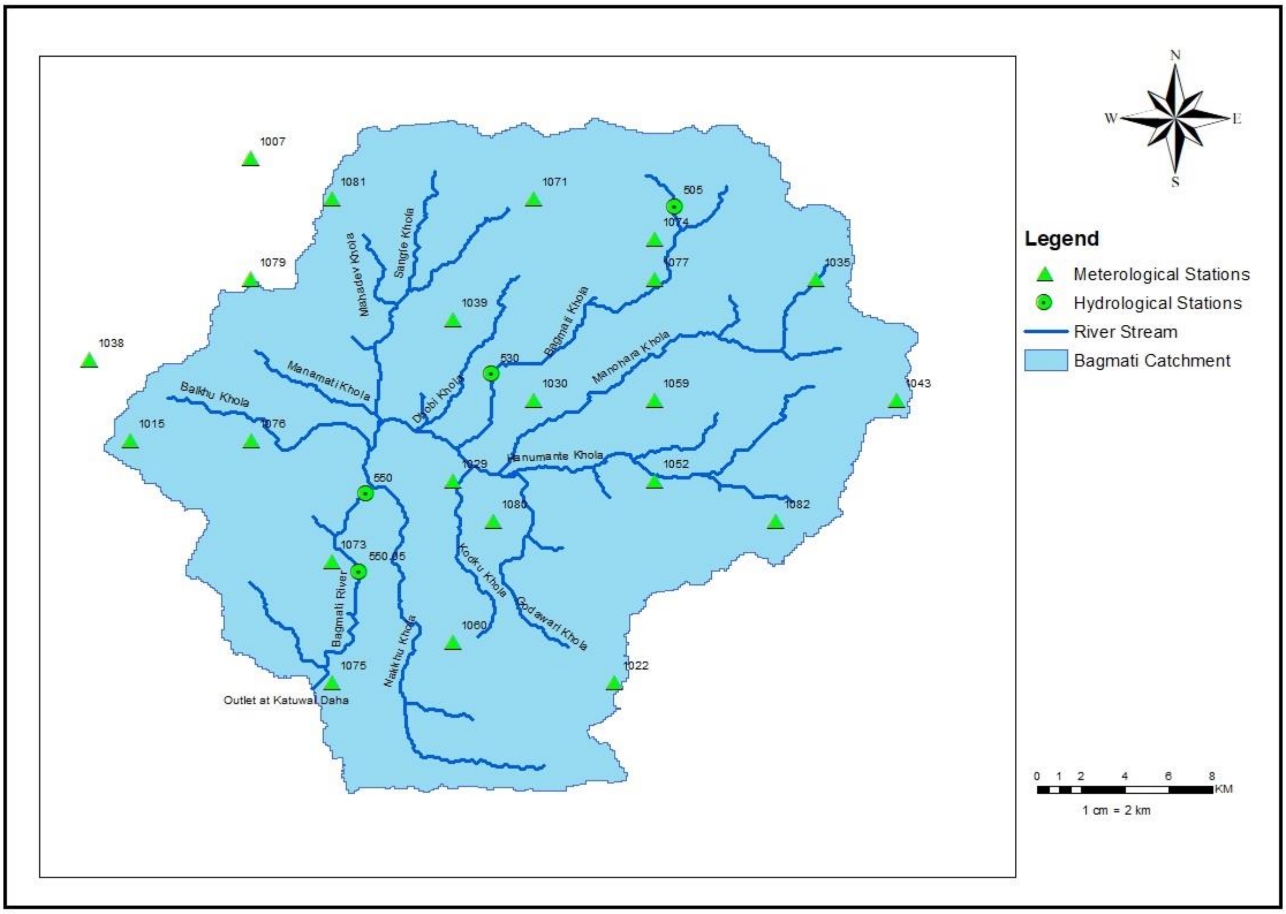

Figure 1-2: Available Hydrological and Meteorological Stations on Bagmati River Basin with its tributaries

Table 1-1: Hydrological Data Collection (Based on Data available at DHM)

Station Number	River Name	Location	Latitude /Longitude	Station Elevation, m amsl	Catchment Area (km²)	Data Availability	Data Quality
505	Bagmati	Sundarijal	27 ° 46 ‘ 49” N 85 ° 25 ‘ 36” E	1600	17	1963 to 2015	Fair
530	Bagmati	Gaurighat	27 ° 42 ‘ 35” N 85 ° 21 ‘ 10” E	1300	68	1993 to 2015	Fair
550	Bagmati	Chovar	27 ° 39 ‘ 40” N 85 ° 17 ‘ 50” E	1280	585	1963 to 1980	Good
550.05	Bagmati	Khokana	27 ° 37 ‘ 44” N 85 ° 17 ‘ 41” E	1250	658	1992 to 2015	Fair

Table 1-2: Meteorological Data Collection (Based on Data available at DHM)

Index Number	Location	District	Type of Station	Elevation, m amsl	Data Availability
1007	Kakani	Nuwakot	Agro meteorology	1007	1962 to 2020
1015	Thankot	Kathmandu	Precipitation	1630	1967 to 2020
1022	Godavari	Lalitpur	Climatology	1400	1953 to 2020
1029	Khumaltar	Lalitpur	Agro meteorology	1350	1967 to 2020
1030	Kathmandu Airport	Kathmandu	Aeronautical	1337	1968 to 2020
1035	Sankhu	Kathmandu	Precipitation	1449	1971 to 2020
1038	Dhunibesi	Dhading	Climatology	1085	1971 to 2020
1039	Panipokhari	Kathmandu	Climatology	1335	1971 to 2020
1043	Nagarkot	Bhaktapur	Climatology	2163	1971 to 2020
1052	Bhaktapur	Bhaktapur	Precipitation	1330	1971 to 2020
1059	Changunarayan	Bhaktapur	Climatology	1543	1971 to 2020
1060	Chapa Gaun	Lalitpur	Precipitation	1448	1971 to 2020
1071	Budhanilkantha	Kathmandu	Climatology	1350	1971 to 2020
1073	Khokana	Lalitpur	Climatology	1590	1971 to 2020
1074	Sundarijal	Kathmandu	Precipitation	1490	1993 to 2020
1075	Lele	Lalitpur	Precipitation	1590	1994 to 2020
1076	Naikap	Kathmandu	Precipitation	1520	1997 to 2020
1077	Sundarijal	Kathmandu	Precipitation	1360	1971 to 2020

Index Number	Location	District	Type of Station	Elevation, m amsl	Data Availability
1079	Nagarjun	Kathmandu	Precipitation	1690	1997 to 2020
1080	Tikathali	Lalitpur	Precipitation	1341	2000 to 2020
1081	Jetpurphedhi	Kathmandu	Precipitation	1320	2000 to 2020
1082	Nangkhel	Bhaktapur	Precipitation	1428	2002 to 2020

Similarly, climatic parameters which influence the hydrological characteristics such as river base flow, peak discharge, hydrograph, etc. are collected from DHM. Temperature data (daily maximum and minimum) of all the climatological stations mentioned in Table 1-2 were available at DHM and collected for hydrological modelling. For sunshine, relative humidity and wind speed; the data were collected from Kathmandu Airport station (Stn. No. 1030). Long term mean monthly evapotranspiration data were collected from CLIMWAT 2.0 software for Kathmandu valley.

1.3 Trend Analysis from available data

Based on available historical discharge and rainfall data in Bagmati Khola basin and its tributaries, the trend analysis has been carried out to understand the overall changes in the flow and rainfall pattern. For observation of discharge variation over time, the mean flow in winter period (December-February), pre-monsoon period (March-May), monsoon period (June-September), and post monsoon period (October-November) at three different DHM gauging stations have been used for trend analysis. Daily discharge data recorded in Bagmati River at DHM gauging Station No. 505 at Sundarijal, Station No. 530 at Gaurighat and Station No. 550.05 at Khokana are used to calculate mean monthly flow at different seasonal period. Overall trend analysis of river discharge is very useful to study its impacts on agriculture, hydropower, biodiversity, water quality and human health.

Based on trend analysis of average seasonal discharge; the average winter discharge in Bagmati river at Khokana and Sundarijal is decreasing whereas at Gaurighat is increasing. For average pre-monsoon discharge the trend analysis shows increasing trend at Khokana and Gaurighat whereas decreasing at Sundarijal. The trend analysis of monsoon discharge which is mostly responsible for flood events in Kathmandu Valley shows decreasing trend in Khokana and Sundarijal whereas increasing trend in Gaurighat region. Average post monsoon discharge at Khokana follows decreasing trend whereas at Gaurighat follows increasing trend and at Sundarijal follows uniform non-varying trend. Variation in the trend of river discharge at different stretches is the result of spatial variation of rainfall in the different region of Bagmati Khola basin and its catchment at the same time period. The trend analyses of the average discharge in different seasons in Bagmati Khola at different stretches in chart are presented in Figure 1-3, Figure 1-4, Figure 1-5 and Figure 1-6.

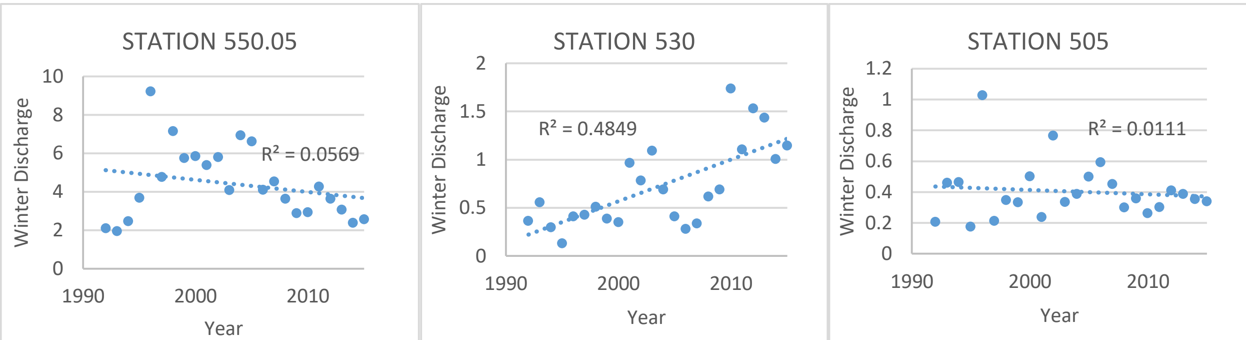

Figure 1-3: Average Winter Discharge Trend Analysis in Bagmati River at Khokana (550.05), Gaurighat (530) and Sundarijal (505)

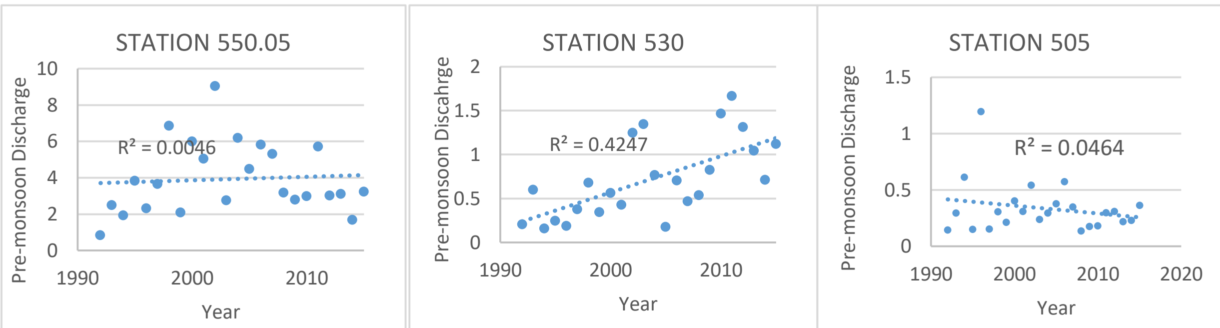

Figure 1-4: Average Pre-Monsoon Discharge Trend Analysis in Bagmati River at Khokana (550.05), Gaurighat (530) and Sundarijal (505)

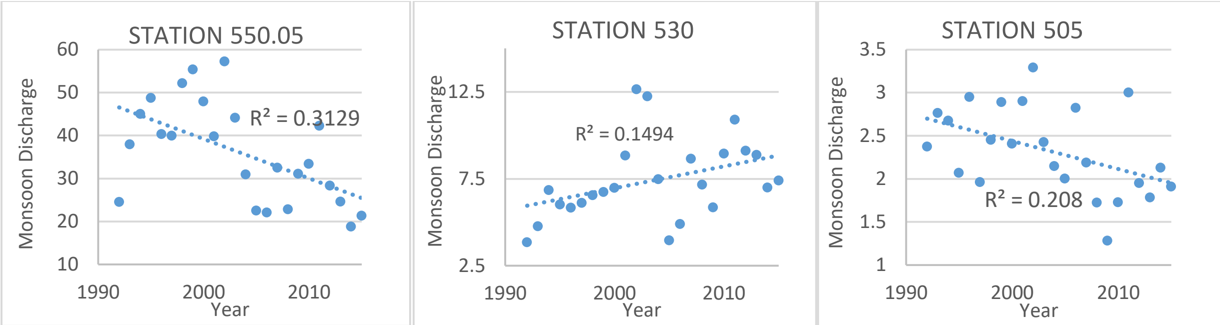

Figure 1-5: Average Monsoon Discharge Trend Analysis in Bagmati River at Khokana (550.05), Gaurighat (530) and Sundarijal (505)

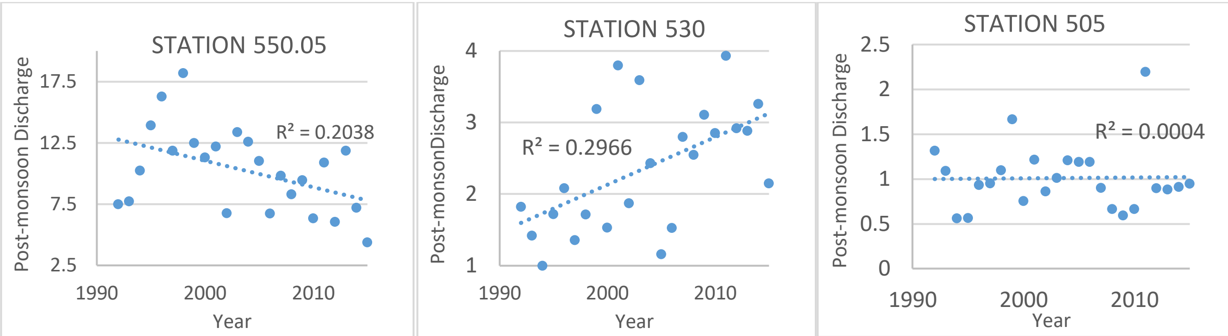

Figure 1-6: Average Post-monsoon Discharge Trend Analysis in Bagmati River at Khokana (550.05), Gaurighat (530) and Sundarijal (505)

Similarly, trend analysis has been carried out for seasonal precipitation, annual precipitation and maximum daily precipitation of Bagmati basin. For computation of daily, seasonal and annual precipitation from the year 1992 to 2015, the daily precipitation data from 15 different meteorological stations were collected and by using thiessen polygon method, daily precipitation in the catchment of Bagmati Khola is computed which is used to compute seasonal and annual precipitation in Bagmati basin. The trend analysis of the rainfall is carried out for total precipitation in four season; winter period (December-February), pre-monsoon period (March-May), monsoon period (June-September), and post monsoon period (October-November); annual precipitation and daily maximum precipitation of each year. Trend analysis shows uniform values of winter precipitation, increasing trend in pre-monsoon precipitation, decreasing trend in monsoon precipitation and slightly increasing trend in post-monsoon precipitation values. Maximum Daily Precipitation follows the decreasing trend over the years and annual precipitation in Bagmati basin also follows the decreasing trend. Diagrammatic representation of trend analysis of seasonal precipitation, annual precipitation and maximum daily precipitation are presented in Figure 1-7, Figure 1-8 and Figure 1-9.

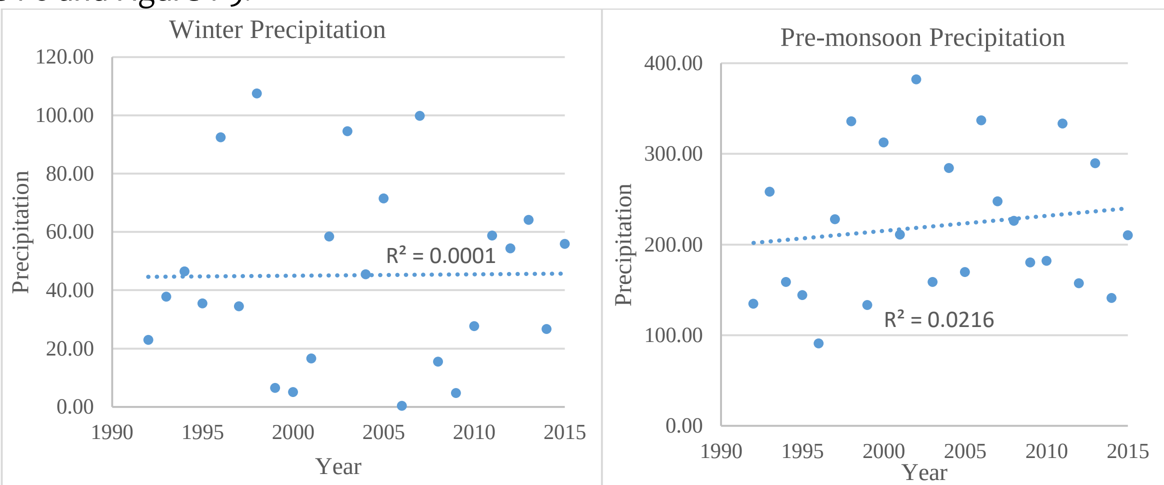

Figure 1-7: Winter and Pre-monsoon Precipitation Trend Analysis of Bagmati Basin

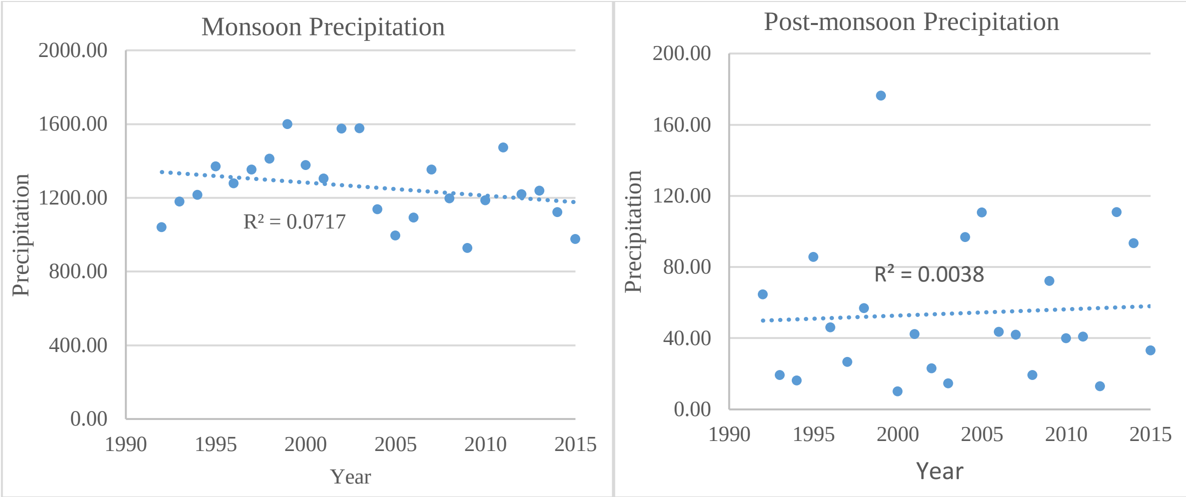

Figure 1-8: Monsoon and Post-monsoon Precipitation Trend Analysis of Bagmati Basin

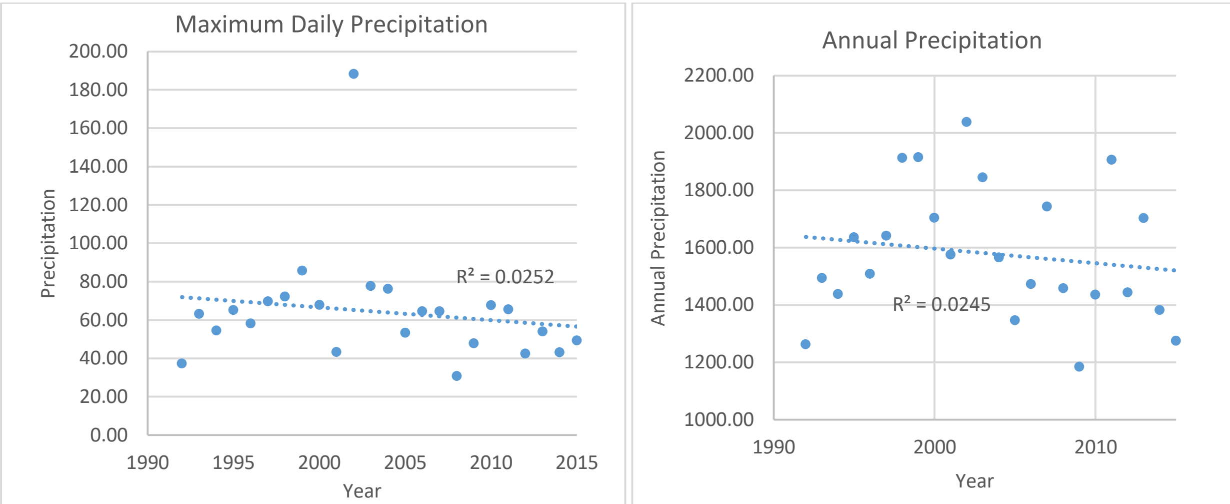

Figure 1-9: Trend Analysis of Maximum Daily Precipitation and Annual Precipitation of Bagmati Basin

Trend analysis of the hydrological and meteorological data represent the variation of the discharge and precipitation over the time period which are crucial parameters to evaluate the impacts of climate change, urbanization and other factors on the hydrology of Bagmati basin. From overall trend analysis, hydro climatological changes are observed in Bagmati basin which are due to regional, global and local effects.

2 LITERATURE REVIEW

Hydrological models are used for various purposes, including flow forecasting, flood forecasting and short and long term water management and the choice of a hydrological model depends on the purpose of its utilisation and data availability (Singh and Marcy, 2017). Criteria such as purpose of model application, type of system to be modelled, hydrological processes to be considered, degree of causality of the process, required time and space discretization and availability of hydrological and meteorological data are considered for the selection of hydrological modelling of Bagmati river basin in Kathmandu Valley. Hydrological models require the inputs such as rainfall, temperature, soil characteristics, land use land cover data, hydrogeology and other physical parameters.

Bunganaen et. al. have studied the rainfall-runoff simulation of Benanain Watershed of Timor Island using HEC-HMS model. The study determines the physical characteristics of the Benanain watershed based on curve number (CN) values, land cover, peak discharge, and peak time. The study was carried out on Benanain watershed with 29 sub watersheds covering 3181.521 km^2. HEC-HMS software has been used in the study which must be calibrated by adjusting model parameters to obtain the historical data by adjusting parameters such as initial abstraction, lag time, recession, baseflow values and curve number. The model predicated the peak discharge by simulation using SCS-CN method which was in the range of 7-15 % of results from previous studies (Bunganaen et. al.).

Sani and Merufinia have estimated the flood hydrograph with different return period in Urmia Shahar Chay Basin. For the study, GIS techniques and HEC-HMS hydrological model were used. Arc GIS was used to investigate the Sub-basin of Shahar Chay River which was used to estimate the physical characteristics of the catchment basins and the parameters used in HEC-HMS model. The study area were divided into 17 sub-basins by the software. For estimation of flood discharge at different return period, HEC-HMS software and SEC method was used. The same model was used to estimate the Curve Number (CN) characterisitics of basin by combining land use maps and the soil hydrologic groups in ARC GIS software (Sani and Meufina, 2015).

Devkota and Shakya has developed the rainfall-runoff model of Bagmati river basin for extreme storm events. For study, they used HEC HMS model with Deficit and constant for loss method, Synders user-specified Unit Hydrograph for direct runoff method, recession model for base flow method and Muskingum-Cunge for reach routing. They used the daily observed discharge from year 1992 to 2013 available at Khokana station in Bagmati Khola in calibration process and for validation, hourly rainfall was compared with hourly observed real-time discharge for the event of 2011, 2012 and 2013. The results obtained from the model were satisfactory and acceptable. The study summarizes that the satisfactory performance of the model proves its applicability in flood forecasting and early warning system design (Devkota and Shakya, 2021).

Oleyiblo and Li have studied the application of HEC-HMS model for flood forecasting in Misan and Wan'an catchments in China. The study presented the applicability, capability and suitability of flood forecasting using HEC-HMS model. The model was calibrated and verified using historical observed data where the determination coefficients and coefficient of agreement for all flood events were above 0.9 and the relative errors in peak discharges were all within the acceptable range. The study concluded HEC-HMS model as simple and powerful tool for flood forecasting (Oleyiblo and Li, 2010).

Thapa et. al. have analyzed the water balance dynamics in Kathmandu Valley Nepal using multi-model approach. The study applied three hydrological models (i.e. SWAT, HBV and BTOPMC) to analyze the water balance components and their temporal and seasonal variations in the Kathmandu Valley, Nepal. Based on the study, there was close agreement between the monthly observed and calibrated runoff at the watershed scale, and all three models captured well the flow patterns for most of the seasons. The performance indicators NS, PBIAS and R^2 had similar indicator values in three models and showed satisfactory performance for runoff simulation (Thapa et. al., 2017).

Ahbari et. al. have carried out the study for estimation of initial values of HMS model parameters for application to the basin of Bin El Ouidane (Azilal, Morocco). A comprehensive approach to estimate the initial values of the parameters of the HMS formalisms are presented in the study paper. The estimation approach uses the data of African soil grid 250 m data for parameter estimated based on soil properties, a supervised classified ETM+ satellite image for parameters needing land use characteristics and the daily discharge for parameter demanding stream flow recession analysis. The study concluded that the parameters values resulting from the estimation approach are best suited to start simulation and should be followed by a calibration process (Ahbari et. al., 2018).

Haibo et. al. have studied the application of Synthetic Unit Hydrograph on HEC-HMS Model for flood forecasting in Huan River Basin. Arc GIS software was used to extract the watershed information according to the river DEM data in the study and the net rainfall was calculated through the initial constant rate loss model. In this study, the surface runoff was calculated using the Snyder unit line model and the basis was calculated by the exponential decay model. The model was calibrated and verified using historical observed data. In overall, the study concludes the integration of unit lines according to the size of secondary flood clean rain could improve the accuracy of flood forecasting. Also, the HEC-HMS model could be effectively applied in forecasting the secondary flood in the river basin (Haibo et. al., 2018).

For flood mapping from the hydrological results obtained from the hydrological modelling, different researchers and organizations have studied and prepared inundation map of different rivers worldwide. Different tools and hydraulic modelling software are available for flood mapping of rivers such as HEC-RAS, HEC-HMS, FLOW-3D, MIKE, etc. Review of research papers as part of literature review before carrying out the detail hydraulic analysis of Bagmati Khola and its tributaries are carried out in detail for understanding the methodology and interpretation of results and outputs.

Aryal et.al have carried out flood hazard assessment in Dhobi-Khola watershed of Bagmati river basin using hydrological model. The study has assessed the flood vulnerable site of Dhobi-Kola watershed and delineates the flood prone area using hydrological HEC-HMS model and GIS application. The model was calibrated and validated in Bagmati river with discharge data of Gaurighat and rainfall data of Sundarijal station. Final model outputs were used to predict the floods of different return period using HEC-RAS model together with HEC-GeoRAS to generate food inundation maps. The study concluded that the two sites are very highly vulnerable. The study indicates that the area near Anamnagar, Thapagaun, below Bhatkekopul, behind Sukhedhara fall under High Hazard, Very High Hazard and Extremely High Hazard category (Aryal. et. al.)

Dangol and Bormudoi have prepared flood hazard mapping and vulnerability analysis of Bishnumati river which is one of major tributary of Bagmati Khola. The study describes the technical approach of probable flood vulnerability and flood hazard analysis. Bishnumati catchment was taken as area of study. One dimension model of HEC-RAS with HEC-GeoRAS interface in co-ordination with ArcGIS was applied for the analysis. Analysis shows that the flood area increases with flood intensity. Higher flood depth increases and lower flood depth decreases with increase in intensity of flood. Inundation of huge area of urban land indicates that in future human lives are more prone to flood disaster. The study concludes that such type of models are very useful and important for pre-planning of disaster and also planning of proper land use, land development and settlement planning (Dangol and Bormudoi).

Gautam and Kharbuja have studied on flood hazard mapping of Bagmati river in Kathmandu valley using geo-informatics tool. The study suggested Hydrological and hydrodynamic models coupled with Geographic Information System (GIS) as powerful tools. The study presented the flood maps which can be used to provide guidelines for development of built-up areas along the river bank and help to minimize loss of life and property due to floods (Gautam and Kharbuja, 2006).

Dasalegn and Mulu have carried out study for mapping flood inundation areas using GIS and HEC-RAS model at Fetam river, Upper Abbay Basin, Ethiopia. Flood inundation mapping is used to define the zones which are more susceptible to flood along the river when the release of a stream surpasses the bank-full stage along the river. The flooded areas on Fetam River have been represented depending on 5% incidence peak flows for different reoccurrence eras using the HEC-RAS model, GIS for spatial data handling, and HEC-GeoRAS for interfacing among HEC- RAS and GIS. These critical floods were damaging the areas around Fetam River, which is hazardous to social and economic growth due to loss of lives and destruction of properties. Built-up areas and agricultural fields are located along the river banks and are highly sus- ceptible to flooding. The study discovered that flooded areas in the upstream and middle parts of Fetam River are high as related to the downstream parts (Dasalegn and Mulu, 2021).

Pandey and Dugar have prepared flood flood hazard mapping and inundation mapping at Hanumate Basin, Bhaktapur using geographic information systems and hydraulic modelling (HEC-RAS 5.0.7). The study also presented the maximum rainfall frequency analysis for different return period for the 4 stations located in the study area. The flood hazard maps were created using hydraulic and topographic modelling, not historical flood observations, so one can more accurately visualize a wider range of flooding scenarios. The main intent of this study is to fill a critical knowledge gap regarding the extent of urban flooding for a small ungauged Hanumante stream for various return periods. The study concludes effective waterway of Hanumante river has been reduced over the years due to silting. According to Department of Water Induced Disaster Management, Hanumante needs 50 meters width to pass flood effectively. However, the recent survey data by HPCIDBC shows that Hanumante has minimum width of 8 m in some sections. The study recommended to the concerned authority to implement suitable measures to increase the carrying capacity of the river (Pandey and Dugar, 2019).

3 HYDROLOGICAL MODEL

3.1 General

The use of hydrological modelling for water resource study is being used widely for water resource management planning and decision making. For ungauged basins, the hydrological modelling is the suitable option for an estimation and prediction of hydrological components based on available data. The hydrological model can provide flood depth and extent which helps in flood hazard assessment and will give insights into various ways of dealing with hazards and disaster problems. This flood hazard analysis identifies high risk zones which helps to take mitigation measures effectively and efficiently. This study is designed to assess the flood vulnerable sites of Bagmati Khola watershed and mapping disaster prone areas using hydrological models.

3.2 Study Area

Bagmati River originates from the Shivapuri hills located at the upper part of the Kathmandu valley, surrounded by the hill of the Mahabharat range. The study covers the hydrological modelling of the Bagmati river and its tributaries with the outlet point at Katuwal Daha with catchment area between 85° 11' 19.99" E to 85° 31' 33.99 "E longitudes and 27° 32' 13.72" N to 27° 48' 56.37" N longitudes. The total catchment area of the Bagmati River at Katuwal Daha is 637.54 sq. km. with max. elevation of 2717 m amsl at Shivapuri hills and min. elevation of 1197 m amsl at Katuwal Daha outlet point. Major tributaries of the Bagmati Khola are Hanumante Khola, Godavari Khola, Manohara Khola, Dhobi Khola, Nakkhu Khola, Bishnumati Khola, Balkhu Khola and Kodku Khola with other sub tributaries. The Bagmati river flows through Middle Mountain region in Kathmandu valley, then via Siwalik range before entering into the flat region of Terai, Nepal. The Bagmati river basin in Kathmandu valley is characterized by warm and temperate climate in semi-tropics with 80 % of 1755 mm annual rainfall during monsoon (Acres International, 2004). Site photograph showing the headwater location of Bagmati Khola at Baghdwar is presented in Figure 3-1.

Figure 3-1: Headwater Location of Bagmati Khola Catchment at Baghdwar, Shivapuri Heights

3.3 Data Processing

Hydrological Model of the Bagmati basin for the study area requires the Digital Terrain Model (DTM) of the basin for producing the input files, stream network, stream characteristics, sub basin boundaries and connectivity of the sub basin using reaches and junctions. For this purpose, 30 m × 30 m resolution DEM data of the study area has been used. The hydrological models has been generated with help of ARC Map 10.2 and HEC-Geo HMS using the same DEM. Pre-processing and basin processing are carried out for preparation of the hydrological model in HEC-HMS model.

3.4 Terrain Preprocessing

For catchment delineation, generation of catchment (basin) and sub basin characteristics; terrain preprocessing is carried out with following steps:

- *Filling Sinks*
- *Flow Direction*

- *Flow Accumulation*
- *Stream Definition*

3.5 Selection of Hydrological Model

For the selection of suitable hydrological model for Bagmati river and its tributaries, different parameters considered for the study are:

- *Purpose of the application of model and study*
- *Hydrological Processes and related variables*
- *Data Availability*
- *Degree of Causality of the Process*
- *Required time and space discretization*

All the conceptual models (Lumped / Semi-distributed / Distributed) describe all hydrological processes with a number of interconnected rivers which represent physical elements in a catchment in which they are recharged by rainfall, infiltration and percolation and are emptied by evaporation, drainage, runoff, etc. Based on availability of data, input parameters and the purpose of the study; semi-distributed model has been used in Bagmati basin hydrological modelling works with main focus on preparation of rainfall-runoff model to estimate flood discharge of different return period in Bagmati River and its tributaries.

The modelling software used for hydrological modelling is Hydrologic Modeling System (HEC-HMS) which simulates the complete hydrologic processes of dendritic watershed systems. This software has been made available by U.S. Army Corps of Engineers without charge to any users. HEC-HMS is a plugin to ESRI's ArcGIS software and hence the integrated GIS tools with HEC-HMS shall allow the users to create a basin mode from Digital Elevation Model (DEM).

3.6 Detail Methodology for Hydrological Modelling

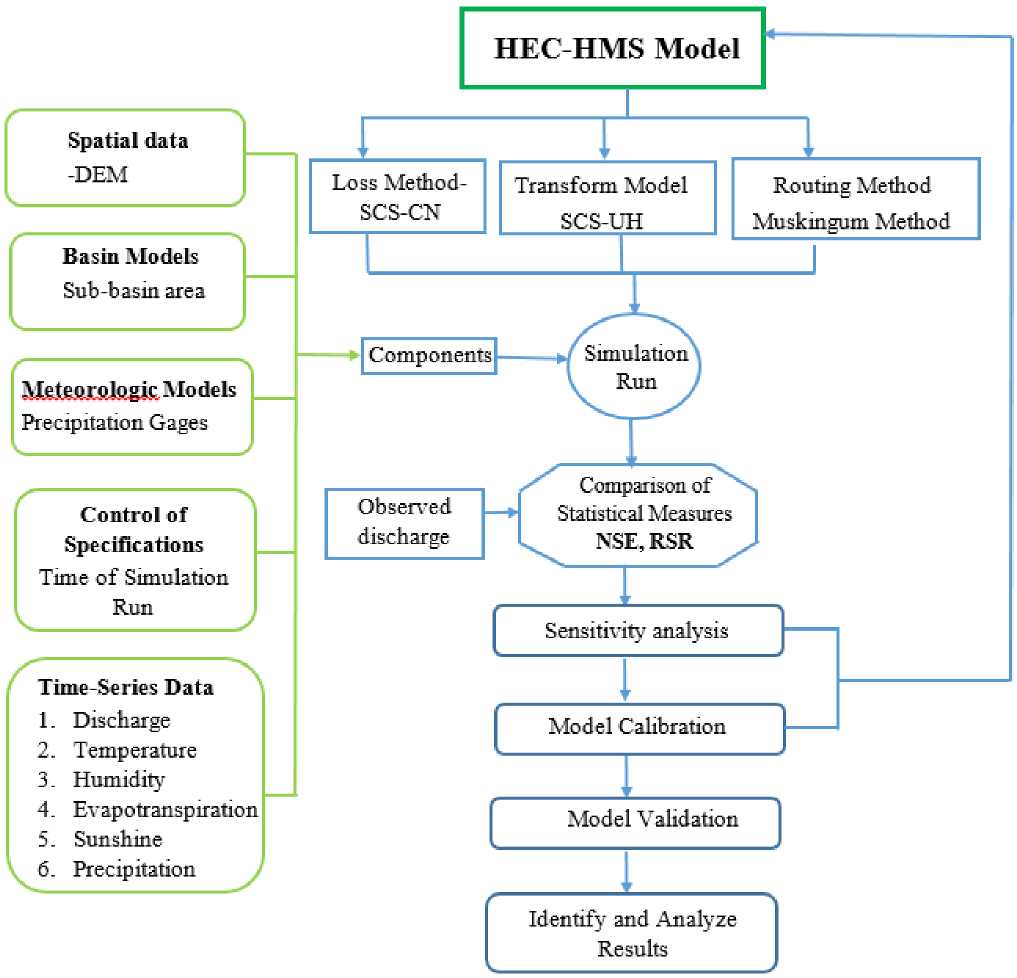

Figure 3-2: Adopted Methodology for Hydrological Modelling of Bagmati Basin

3.6.1.1 Basin and Sub-basin division (Basin Models)

The semi-distributed model of Bagmati basin has been prepared for preparation of basin model which divides the basin into number of sub-basins. For sub basin division, major tributaries of Bagmati Khola and their junctions are considered. Similarly, sub-basins are also divided based on available hydrological data stations on Bagmati basin as calibration and validation are possible in those points. Based on the sub-basin division, junctions, reaches and sink (outlet point) of the river network in Bagmati basin was prepared. In overall, the whole of the basin has been divided into 18 sub-basins. The whole of the Bagmati catchment (basin), sub-basins, junctions, reaches and sink (outlet point) prepared for hydrological model in HEC-HMS is presented in Figure 3-3.

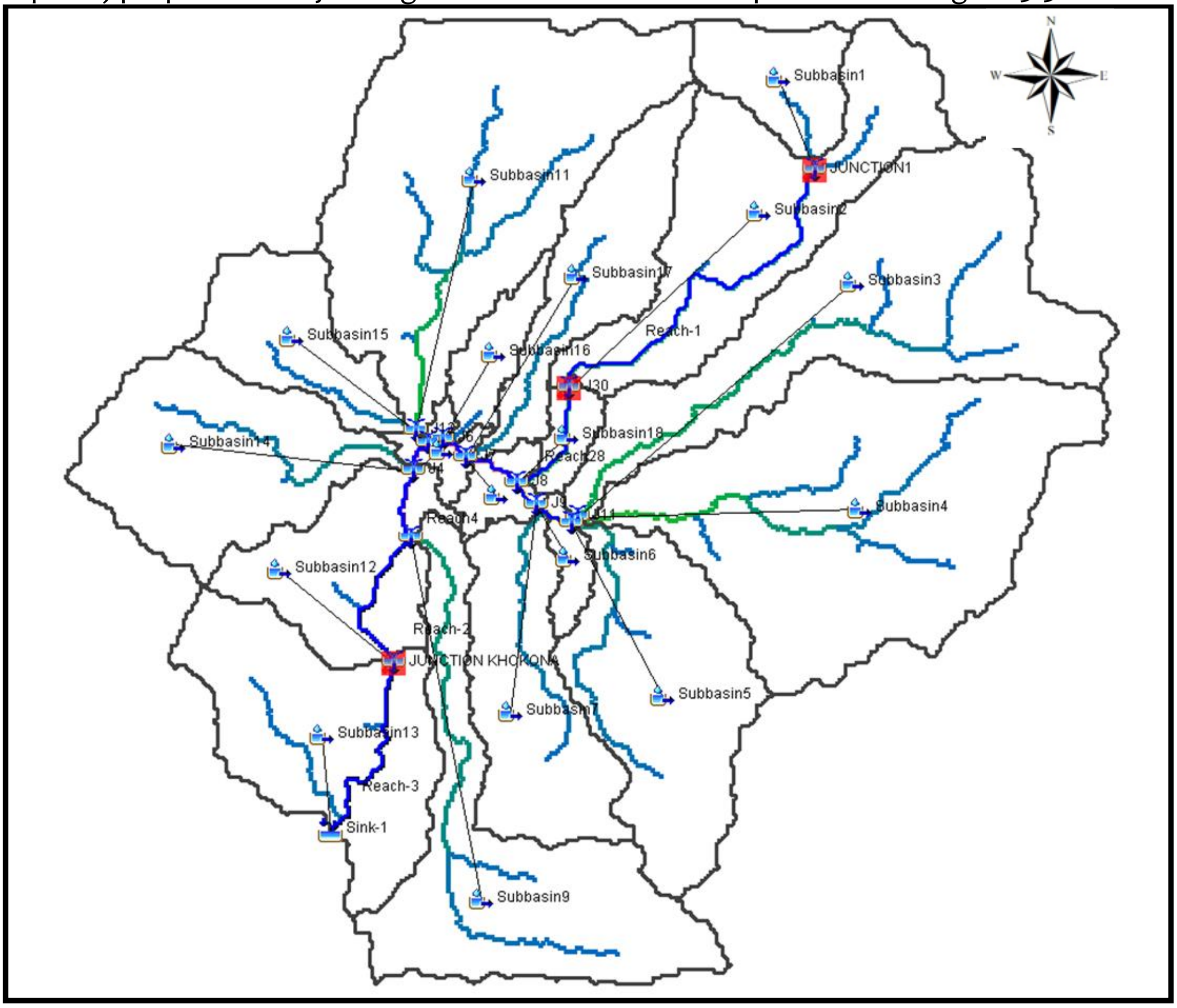

Figure 3-3: Schematic Diagram of Sub-basin, Junction and Reaches (Basin Model) of Bagmati River prepared in HEC-HMS

The details of each sub-basin with its catchment area, flow path, river and basin slope, drainage density and other characteristics based on Hydrological model of Bagmati basin are presented in Table 3-1.

Table 3-1: Sub-Basin Characteristics of Bagmati Basin

Sub-basin	Catchment Area (km^2)	Longest Flow path Length (km)	Longest Flow path Slope	Centroidal Flow path Length (km)	Centroidal Flow path Slope	Basin Slope	Basin Relief (m)	Relief Ratio	Elongation Ratio	Drainage Density (km/km^2)
Sub-basin1	14.791	6.72	0.15785	2.8	0.05223	0.3529	1061	0.15785	0.64562	0.18037
Sub-basin2	51.686	20.86	0.05411	11.52	0.00534	0.20978	1129	0.05411	0.38883	0.33363
Sub-basin3	71.24	24.8	0.04286	13.2	0.00326	0.19968	1077	0.04342	0.38399	0.37046
Sub-basin4	94.414	22.14	0.03744	11.14	0.00242	0.17056	829	0.03744	0.49517	0.30658
Sub-basin5	46.518	16.57	0.07713	10.28	0.01342	0.27508	1374	0.08292	0.46446	0.31387
Sub-basin6	4.3497	5.86	0.0099	3.01	0.00332	0.0425	58	0.0099	0.40167	0.32218
Sub-basin7	33.275	14.09	0.03258	6.92	0.00584	0.15473	713	0.0506	0.46194	0.2978
Sub-basin8	5.3946	4.1	0.00987	1.69	0.00145	0.03687	41	0.01	0.63892	0.5354
Sub-basin9	53.703	24.93	0.05022	12.52	0.01595	0.32191	1277	0.05122	0.33166	0.44877
Sub-basin10	4.3497	4.17	0.01066	1.83	0.0029	0.03849	51	0.01222	0.5639	0.6219
Sub-basin11	82.32	18.45	0.07622	9.22	0.00412	0.22723	1406	0.07622	0.55503	0.30283
Sub-basin12	28.042	9.57	0.01379	3.47	0.00289	0.23249	1198	0.12517	0.6243	0.31486
Sub-basin13	45.409	11.71	0.08986	6.81	0.03933	0.34344	1290	0.11019	0.64951	0.31132
Sub-basin14	42.242	15.49	0.07535	8.56	0.00935	0.26696	1217	0.07858	0.47353	0.26766
Sub-basin15	20.453	10.47	0.06664	6.26	0.00895	0.27462	758	0.07237	0.48719	0.32455
Sub-basin16	8.0919	8.44	0.01042	3.7	0.00466	0.03576	88	0.01042	0.38012	0.1851
Sub-basin17	26.058	16.38	0.06515	8.71	0.00356	0.14271	1089	0.06649	0.35169	0.36945
Sub-basin18	5.103	4.86	0.01091	2.46	0.00179	0.05408	58	0.01194	0.52491	0.7959

3.6.1.2 Time Series Data

As input data for rainfall-runoff model, meteorological data along with climatic parameters temperature, sunshine, wind speed, evapotranspiration data and humidity data of different time series based on availability at DHM, Nepal has been used. River discharge data available at three hydrological stations; Bagmati River at Sundarijal (Stn. No. 505), Bagmati River at Gaurighat (Stn. No. 530) and Bagmati River at Khokana station (Stn. No. 550.05) have been used in model simulation. For precipitation data, 15 different meteorological stations are considered for computation of daily precipitation of each sub basin. Out of 21 meteorological stations mentioned in Table 1-2, only 15 stations are considered as these 15 stations has data available from 1992 onwards whereas other 6 stations were established later. For estimation of daily precipitation of each sub-basin; Thiessen Polygon method was used to carry the weightage of each precipitation station rainfall data in the catchment of sub-basin. The general formula used for the precipitation analysis using Thiessen Polygon for daily rainfall as input data is:

$$\mathrm{P} = \sum_{i=0}^{n} \frac{\mathrm{P_i} A_i}{\mathrm{A}};$$

Where, P= Daily Precipitation of the sub basin

A= Total Catchment Area of the sub basin

i= number of meteorological stations influencing the sub-basin

Pi= Daily Recorded Precipitation of meteorological station

Ai= Area influences by the particular meteorological station in sub-basin

Similarly, different time series data of the average daily temperature, wind speed, average monthly evapotranspiration data has been used for hydrological modelling of the Bagmati basin. In consultation with the DHM technical resources, stations with better data quality and period of data available, the time-series for calibration and simulation of the hydrological model has been selected. For average daily temperature of each sub-basin, average of daily maximum and minimum temperature of nearby climatic station of the basin has been computed and used in model. The meteorological stations and hydrological stations used for hydrological modelling of the Bagmati Basin have been presented in Figure 1-2. The schematic diagram showing the Thiessen Polygon and sub-basin map of Bagmati Catchment for calculation of daily precipitation of each of sub-basin has been presented in Figure 3-4.

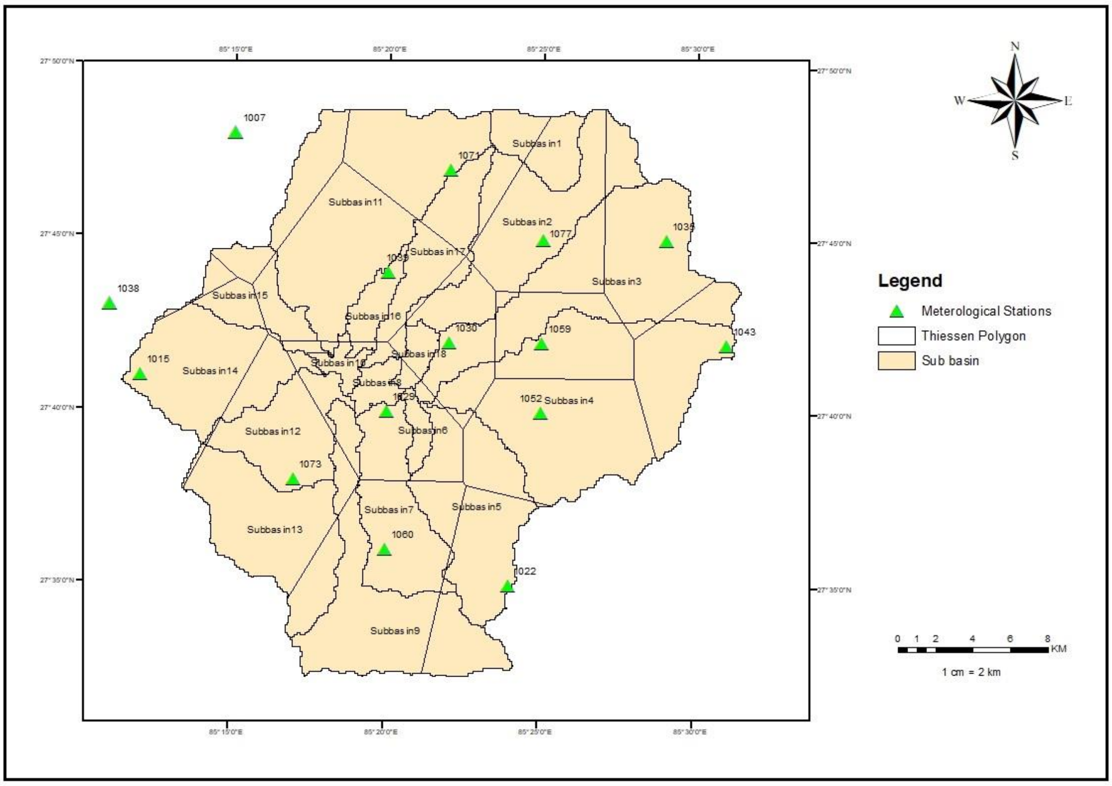

Figure 3-4: Sub Basin Thiessen Polygon for precipitation contributing stations

3.6.1.3 Methods Selection

For hydrological modelling, it is essential to select the appropriate parameters for flow routing and hydrological processes. Parameters and hydrological processes are selected for Loss Model, Transform Model and Routing Model in HEC-HMS software. Considering the catchment characteristics of the study area (i.e. Bagmati Khola basin and its tributaries); Soil Conservation Service Curve Number (SCS-CN), Soil Conservation Unit Hydrograph (SCS-UH) and Muskingum routing method are selected for Loss Model, Transform Model and Routing Model respectively. Each of sub-basin and reaches characteristics are computed using physical characteristics of the model presented in Table 3-1 along with necessary Land Cover and Soil map of the Bagmati basin in Kathmandu Valley.

3.6.1.3.1 The Loss Model

HEC-HMS Model uses various approaches for computation of runoff volume of the catchment by computing the volume of water that is intercepted, infiltrated, stored, evaporated, or transpired by subtracting it from the precipitation provided as input data for hydrological modelling. For the Loss Model, Service Curve Number (SCS-CN) method has been adopted. SCS-CN Loss Model has been selected as it considers soil type, land use and treatment, surface condition and antecedent moisture condition in single CN value. Similarly, for flood event modelling and simulation, the recommended model is SCS curve number loss model.

For initial abstraction (initial loss-Ia), the empirical relationship of Ia and S developed by SCS from many small experimental watersheds has been used which is:

$$Ia = 0.2S$$

For S.I. System, HEC-HMS Technical Reference Manual suggests estimation of maximum retention S using the following equation;

$$S = \frac{25400 - 254CN}{CN};$$

Where,

S= Maximum Retention (mm)

CN= Curve Number

The CN of sub basin has been estimated using the function of hydrologic soil group (HSG), cover type, treatment, hydrologic condition, antecedent runoff condition (ARC), and impervious area in the sub-basin. The CN is entered directly in the appropriate input form. As each of Sub-basin has several soil types and land cover, composite CN is calculated using the formula suggested by HEC-HMS Technical Reference Manual.

$$CN_{composite} = \sum_{i=0}^{n} \frac{A_i CN_i}{Ai};$$

Where,

i = an index of watersheds subdivisions of uniform land use and soil type

$CN_{composite}$ = Composite CN used for runoff volume computations

A_i = Drainage Area of sub basin i

CN_i = CN for subdivision i

For estimation of Curve Number of each Sub-basin, land use land cover map published by ICIMOD, Nepal for the year 2020 has been used. Composite CN values for urban districts, residential districts and newly graded areas are provided in Appendix A of HEC- HMS Technical Reference Manual. The Land Use Land Cover map used for estimation of composite CN for preparation of the Loss Model for Bagmati basin is presented in Figure 3-5.

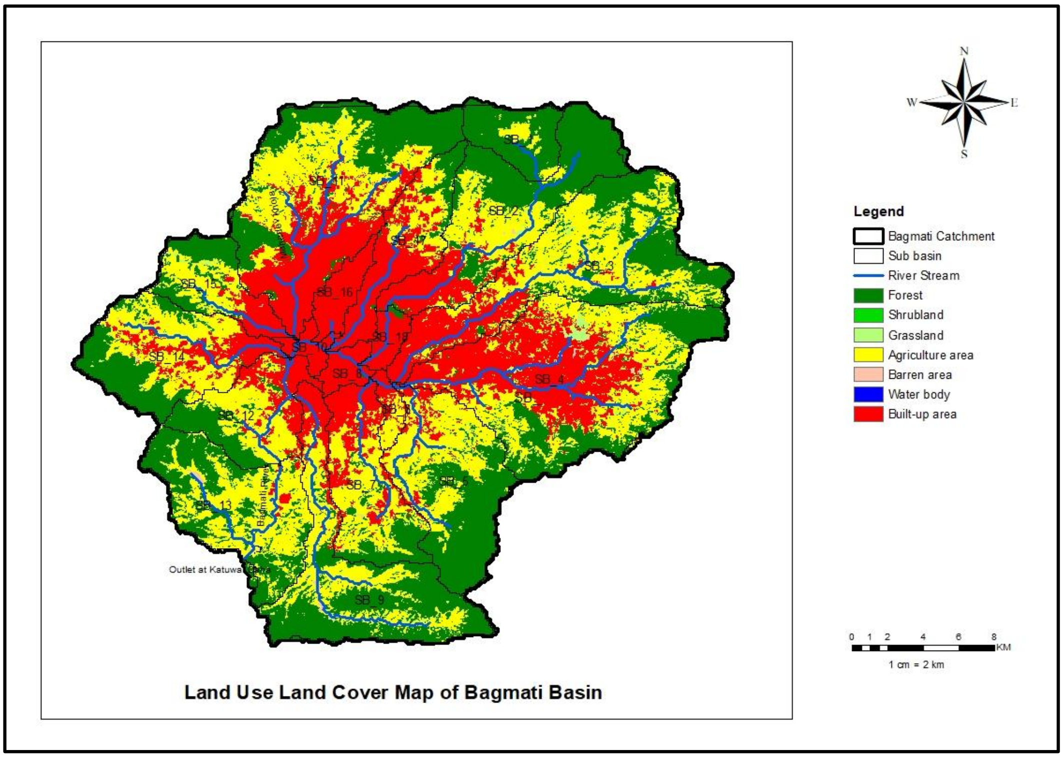

Figure 3-5: Land Use Land Cover Map of Bagmati Basin used for Computation of Composite CN Number

3.6.1.3.2 The Transform Model

The Transform model is used for actual surface runoff computations where each sub element conceptually represents infiltration, surface runoff, and subsurface processes interacting together. Among 9 different transform method, for transform model in Bagmati basin hydrological modelling, SCS Unit Hydrograph has been used which defines curvilinear unit hydrograph by first setting the percentage of unit runoff that occurs before peak flow (NRCS, 2007).

For estimation of Model parameters, following equations have been used:

$T_{lag}= 0.6T_c$

where,

T_{lag}= Unit Hydrograph Lag Time

T_c= Time of Concentration

For time of concentration, empirical Kirpich's formula which depends on basin characteristics including topography and the length of the reach has been used:

$Tc = 0.0194 \times (L^{0.77}/S^{0.385})$

Where,

T_c= Time of Concentration (hr)

L= River Reach Length (in m)

S= River Channel Slope (in m/m)

For each of sub-basin, initial parameters for simulation run data from Table 3-1 has been used in SCS Unit Hydrograph Transform model.

3.6.1.3.3 The Routing Model

The routing model in HEC-HMS account channel storage effects after the flood runoff travels through the channel reach. Storage in the reach is modelled as the sum of prism storage and wedge storage. As presented in Figure 3-6, the prism storage is the volume defined by steady flow water surface profile, while wedge storage is the additional volume under the profile of the flood wave.

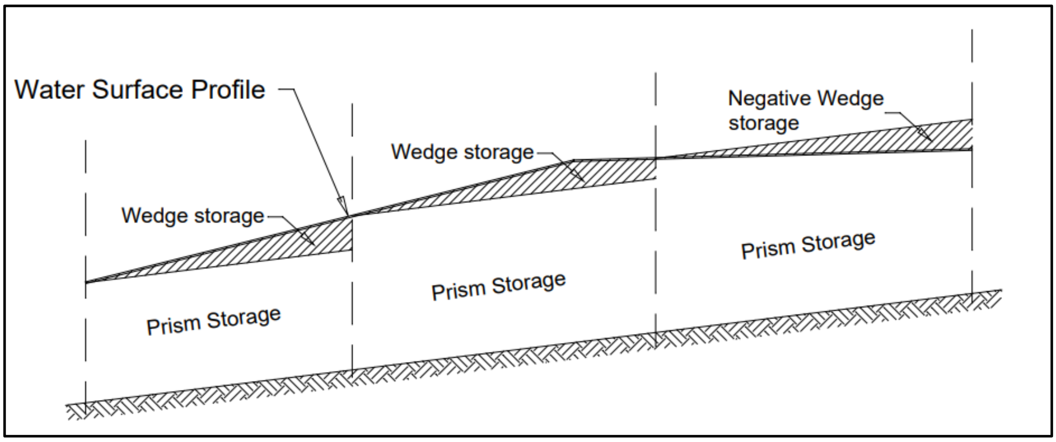

Figure 3-6: Wedge Storage (Linsley et al., 2002)

The general empirical formula used by Muskingum Routing Model consists of K and X variable which are to be fed in the HEC-HMS model for simulation. K is the travel time of the flood wave through routing reach and X is the dimensionless weight ($0 \leq X \leq 0.5$). K and X parameters are estimated using basin characteristics for initial simulation run and calibrated during the calibration processes.

3.6.1.4 Calibration and Validation

Different hydrological, meteorological and climatic parameters are used in each of hydrological model processes which has its particular specified use in estimating the runoffs. The calibration method uses the observed hydro meteorological data in systematic search for parameters which provide the best fit of the computed values to the observed runoff values. The schematic diagram of the calibration procedure adopted in HEC-HMS software is Figure 3-7.

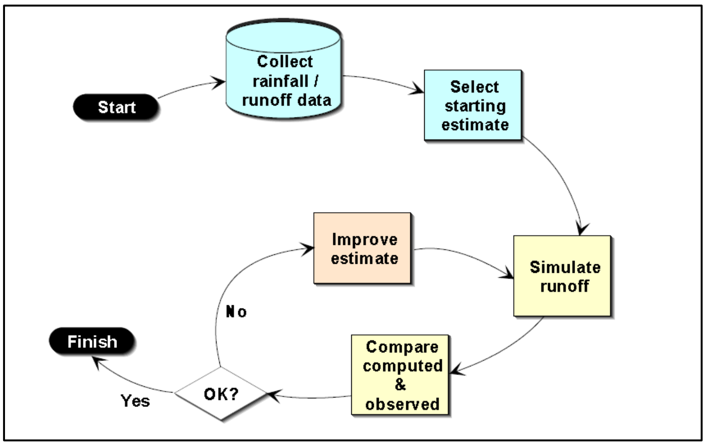

Figure 3-7: Schematic Calibration Procedure (HEC-HMS Technical Reference Manual)

For the hydrological modelling of the Bagmati River with outlet point at Katuwal Daha, the runoff observations on DHM Station No. 550.05 at Khokana, Bagmati have been used. Similarly, for rainfall precipitation data, the daily average precipitation at each sub-basin computed using Thiessen polygon method as discussed in Section 3.6.1.2 has been used. As the main goal of hydrological modelling is to compute the flood discharge at different river basin, event based calibration model has been used for hydrological modelling. The runoff time series (discharge data) and rainfall data must be from the same storm event or time series. Selected time series for calibration and validation of different events for hydrological model are presented in Table 3-2.

Table 3-2: Data Series for Hydrological Model Calibration and Validation Process

S. No.	Data-Series	Remarks
Event 1	August 9, 1993 to August 14, 1992	Calibration
Event 2	September 1, 1994 to September 10,1994	Calibration
Event 3	July 5, 1998 to July 15,1998	Calibration

S. No.	Data-Series	Remarks
Event 4	July 21, 2002 to July 28, 2002	Calibration
Event 5	August 19, 2002 to August 28, 2002	Validation
Event 6	September 4, 2007 to September 12, 2007	Validation

Generally, for the results of model calibration and validation (i.e. comparison of computed hydrograph and observed hydrograph), the software computes the index for goodness-of-fit. For the study of Bagmati basin, the following performance evaluation criteria have been selected.

3.6.1.4.1 Nash and Sutcliffe Efficiency (NSE)

NSE is a measure of efficiency that relates goodness of fit of the model to the variance of the measured data. Minimum value of NSE is -∞ (indicating worst fitness with observed data) to 1 (indicating perfect equivalent between observed and simulated data- Zou et al. 2003). Mathematical relation of NSE is:

$$NSE = 1 - \frac{\sum_{i=1}^{n}[Q_{0i} - Q_{si}]^2}{\sum_{i=1}^{n}[Q_{0i} - \overline{Q_o}]^2}$$

Where, Q_{oi} is observed discharge, Q_{si} is simulated discharge, $\bar{Q}_o$ is simulated discharge, i is each time step, and n is the number of time steps.

3.6.1.4.2 Root Mean Square Error (RMSE)

RMSE error indicates the range of best fit based on measure of differences (residuals) between simulated and observed discharge values. Mathematical relation of RMSE is:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Q_o - Q_{si})^2}{n}}$$

3.6.1.4.3 Percentage Bias (PBIAS)

PBIAS measures the average tendency differences between the observed and simulated flow (Morasi et. al. 2007). Mathematically, it expressed as:

$$PBIAS = \sum_{i=1}^{n} \frac{(Q_{oi} - Q_{si})100}{\sum_{i=1}^{n} Q_{oi}}$$

3.6.1.4.4 Coefficient of determination (R^2)

Coefficient of determination (R^2) error indicates the degree of correlation between simulated and observed discharge values. Mathematical relation of R^2 is:

$$R^2 = \frac{[\sum_{i=1}^{n}(Q_{si} - \overline{Q_s})\,(Q_{oi} - Q_o)]^2}{[\sum_{i=1}^{n}(Q_{si} - \overline{Q_s})]^2\,[\sum_{i=1}^{n}(Q_{oi} - \overline{Q_o})]^2}$$

3.6.1.5 Results of Model Calibration and Validation

For rainfall-runoff modelling in HEC-HMS, peak flood events presented in Table 3-2 are calibrated and validated. The simulated discharge from the model is compared with the observed discharge. Results of model calibration with comparison of observed discharge, simulated discharge and rainfall data are presented in Figure 3-8, Figure 3-9, Figure 3-10, Figure 3-11, Figure 3-12 and Figure 3-13.

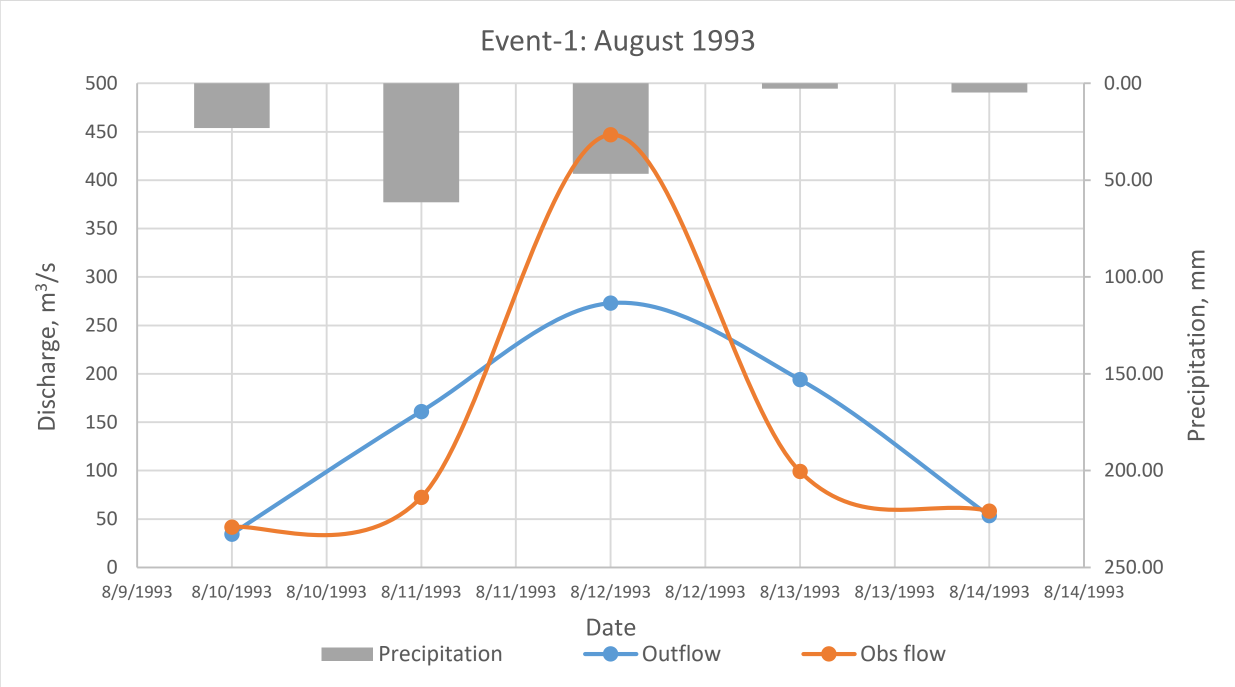

Figure 3-8: Comparison of Observed and Simulated Discharge based on Calibration Result on August 1993

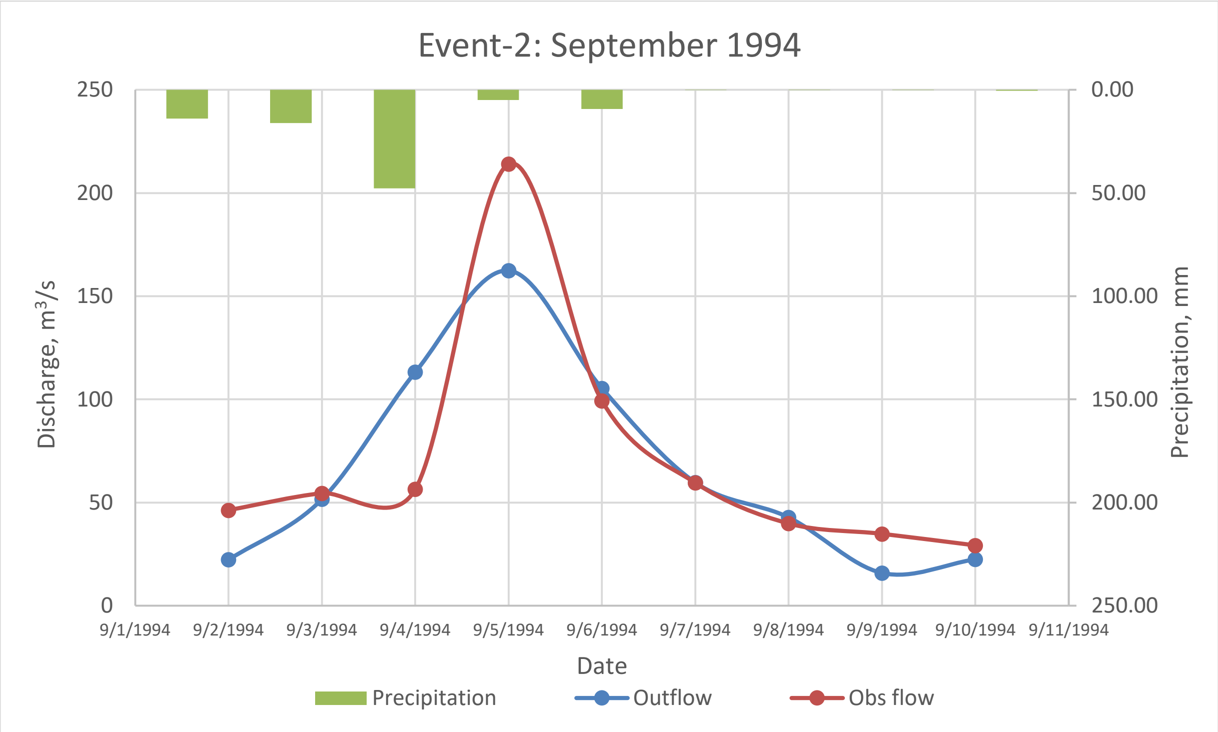

Figure 3-9: Comparison of Observed and Simulated Discharge based on Calibration Result on September 1994

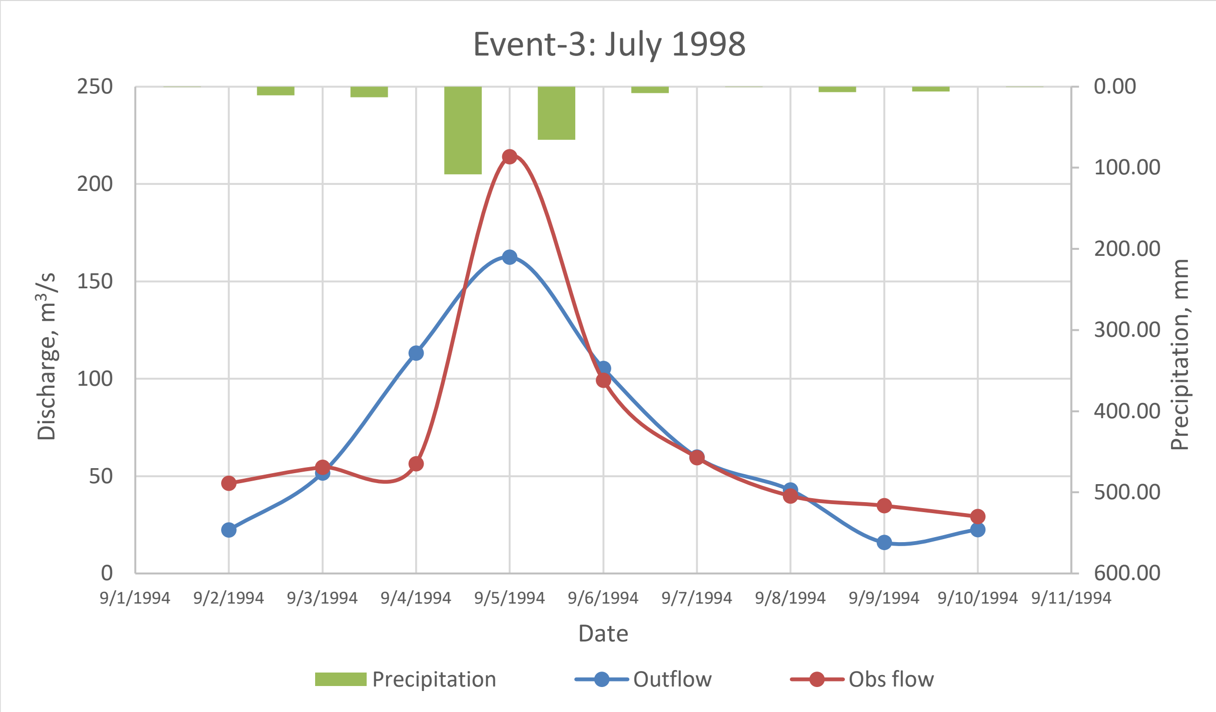

Figure 3-10: Comparison of Observed and Simulated Discharge based on Calibration Result on July 1998

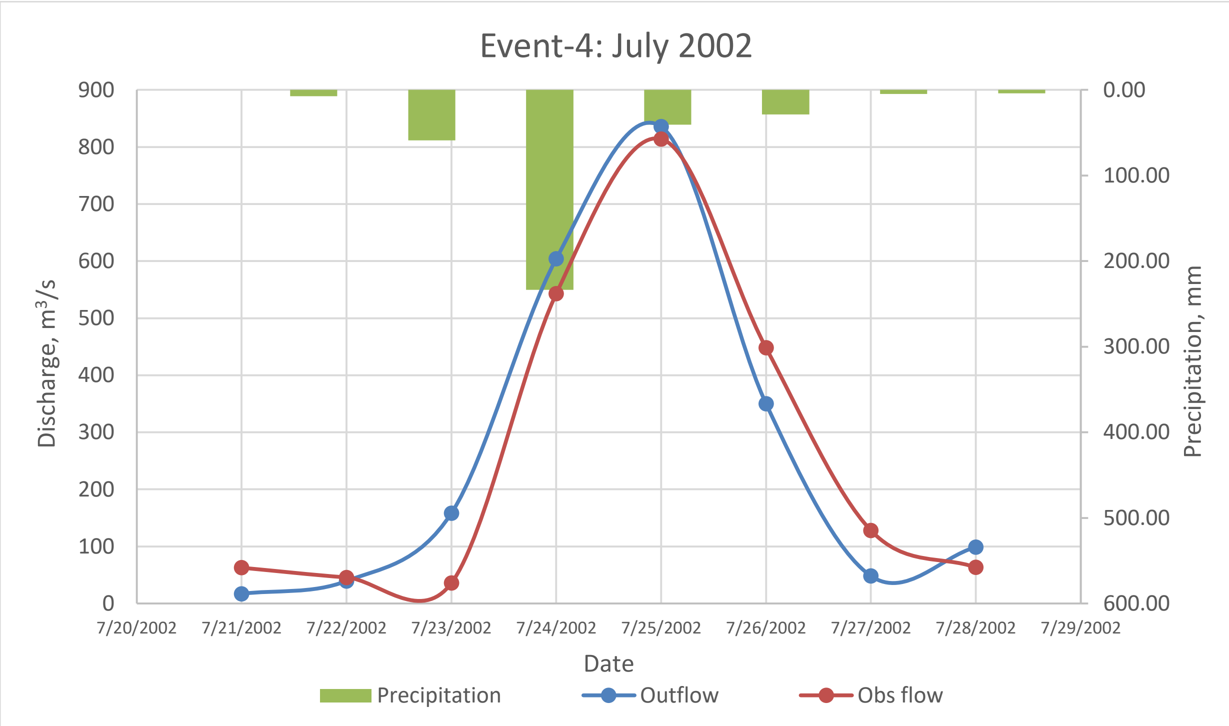

Figure 3-11: Comparison of Observed and Simulated Discharge based on Calibration Result on July 2002

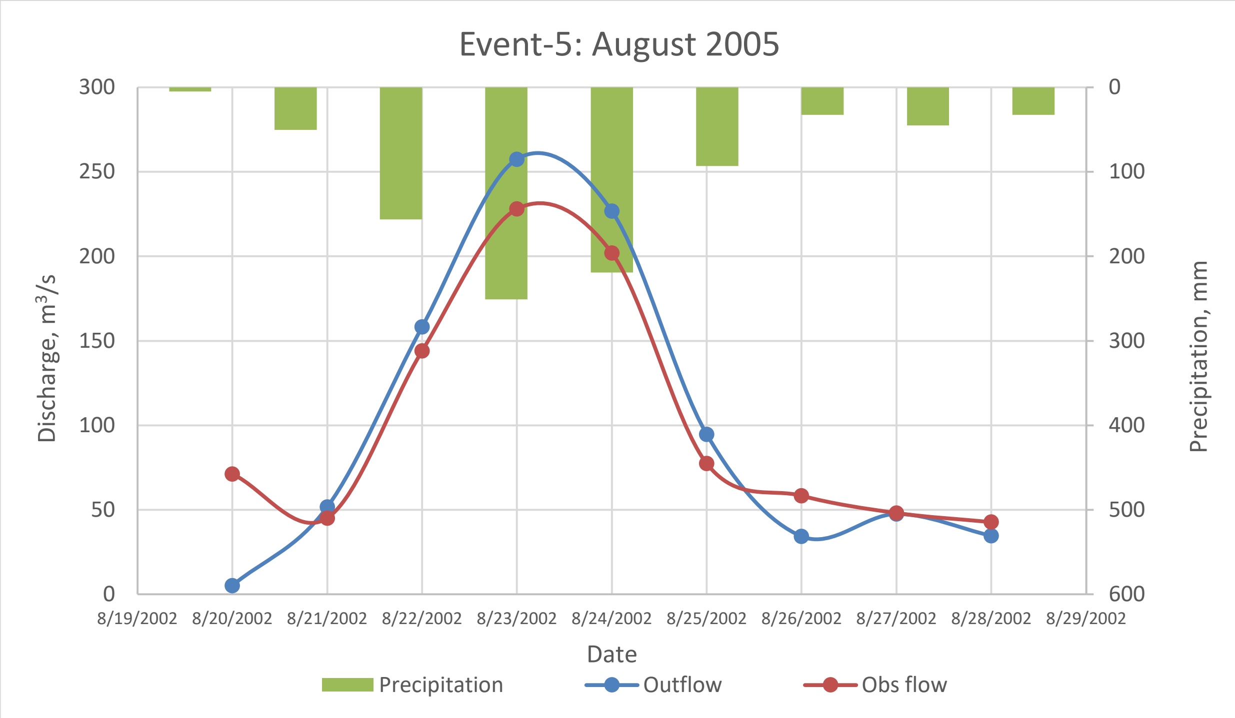

Figure 3-12: Comparison of Observed and Simulated Discharge based on Validation Result on August 2005

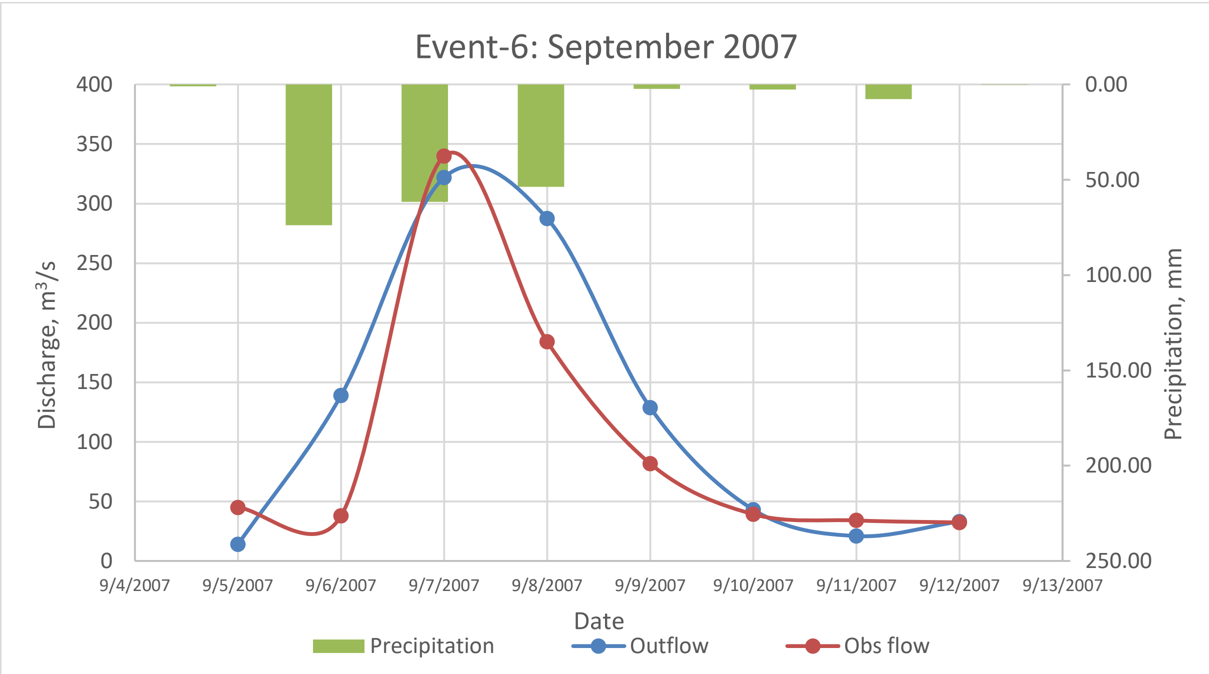

Figure 3-13: Comparison of Observed and Simulated Discharge based on Validation Result on August 2007

The performance evaluation and goodness of fit of the simulated discharge from hydrological model has been extracted from HEC-HMS model after model calibration and validation which are presented in Table 3-3.

Table 3-3: Performance Indicators for Model Calibration and Validation during different events

Events	Years	Nash Sutcliffe	Percent BIAS	R^2
1	8/9/1993 to 8/14/1993	0.603	-6.47	0.62
2	9/1/1994 to 9/10/1994	0.63	-13.43	0.68
3	7/5/1998 to 7/15/1998	0.605	34.09	0.66
4	7/21/2002 to 7/28/2002	0.937	0.53	0.94

Events	Years	Nash Sutcliffe	Percent BIAS	R^2
5	8/19/2002 to 8/28/2002	0.557	-10.92	0.81
6	9/4/2007 to 9/12/2007	0.581	9.88	0.7
Average		**0.652**		**0.74**

The results from the model calibration and validation shows that the model is well calibrated and validated as the performance indicators are in acceptable range with average value of NSE efficiency 65.2 % and R^2 74 %. The range of PBIAS is also below ± 15 % except for one event (July 1998). As the model has been calibrated and validated using daily data, Moriasi et. al. (2007) suggests the performance rating of the hydrological model as very good for R^2 greater than 65 %, NSE greater than 65 % and PBIAS less than ± 15. Hence, the hydrological model which shall be further used for computation of flood discharge at different return period is well calibrated model.

3.6.2 Flood Frequency Analysis and Extreme Maximum Rainfall Frequency Analysis

Bagmati River at three different location is gauged with gauging station with peak instantaneous flood discharge available for each year. The peak instantaneous flood discharge of three gauging station; i.e. DHM Station No. 550.05 at Khokana Bagmati river, DHM Station No. 505 at Sundarijal, Bagmati and DHM Station 530 at Gaurighat, Bagmati were collected from Department of Hydrology and Meteorology for flood frequency analysis. Three different methods have been used for flood frequency analysis. Peak maximum instantaneous flood recorded at these DHM Gauging station from period 1992-2015 which have been used for flood frequency analysis are presented in Table 3-4.

Table 3-4: Peak Instantaneous Discharge in Bagmati River recorded at different DHM Gauging Stations

Year	Peak Instantaneous Discharge (m^3/s)		
	Bagmati Khola at Sundarijal (Stn. No. 505)	Bagmati Khola at Gaurighat (Stn. No. 530)	Bagmati Khola at Khokana (Stn. No. 550.05)
1992	17.9	21.6	113
1993	7.8	52.6	938
1994	6.66	51.5	533
1995	5.61	60.5	393
1996	7.22	43.3	328
1997	7.8	66.9	493
1998	4.84	33.5	649
1999	5.82	38.2	421
2000	6.8	54.4	519
2001	5.4	66.2	275
2002	10	108	942
2003	8.6	66.9	421
2004	8	66.9	268
2005	8.2	38.2	226
2006	14.6	70.1	191
2007	16.8	51.5	424
2008	7.8	40.7	135
2009	23.6	51.5	375
2010	7.0	48.5	354
2011	29.2	73.6	480
2012	6.05	41.7	173
2013	23.9	63.6	130
2014	5.02	38.1	176
2015	4.54	54.1	364

For flood frequency analysis using abovementioned peak instantaneous flow, following methods have been used.

3.6.2.1 Gumbel Distribution Method

Gumbel's Method is one of the most widely used probability distribution functions for extreme hydrologic and meteorological studies for prediction of flood peaks and maximum rainfall. 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 flow. Gumbel defined the flood discharge for return period T as:

$Q_T = Q_{avg} + \sigma/\sigma_n*(y - y_n)$

Where, Q_T = Discharge of T-yr Return Period

Q_{avg} = Average Discharge of Discharge series

σ = Standard Deviation of Discharge series

σ_n = Standard Deviation of reduced variat

y = Reduced variate

3.6.2.2 Log-Pearson Type III Distribution

In this flood frequency analysis, the variate is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. If X is the variate of random hydrologic series, then the series of Z variate where

$Z= \log X$

are first obtained. For this Z series, for any recurrence interval T is obtained using:

$Z_t= Z_{avg} +K_z \sigma_z$

Where,

Kz is a frequency factor which is a function of recurrence time interval T and the coefficient of skew Cs.

3.6.2.3 Log-Normal Distribution

In this flood frequency analysis, the variate is first transformed into logarithmic form (base 10) and the transformed data is then analyzed. However, coefficient of skewness considered for this method is zero. The general formula for Log Normal distribution is given by:

$\ln Q_T = \ln Q + K.\ln s$

Where,

$\ln Q_T$ = Natural logarithmic value of design discharge for T-years return period in m^3/sec;

$\ln Q$ = Natural logarithmic value of mean flood in m^3/sec;

K = Frequency factor depending on the return period; and

lns = Standard deviation of natural logarithmic series of the values

Using these three flood frequency analysis, the flood discharge computed at different return period time are:

Table 3-5: Flood Frequency Analysis in Bagmati Khola at Sundarijal (DHM Station No. 505)

Return Period (Yrs)	Flood Discharge in Bagmati Khola at Sundarijal (DHM Station No. 505)		
	Gumbel's Analytical Method	Log-Pearson-Type III Distribution	Log-Normal Distribution
2	9.35	8.11	8.84
5	16.53		
10	21.28	18.28	17.72
20	25.84		
50	**31.75**	**34.86**	**26.93**
100	36.17	45.08	31.21
200	40.58	57.88	35.74
500	46.39		
1000	50.79	101.49	47.22

Table 3-6: Flood Frequency Analysis in Bagmati Khola at Gaurighat (DHM Station No. 530)

Return Period (Yrs)	Flood Discharge in Bagmati Khola at Gaurighat (DHM Station No. 530)		
	Gumbel's Analytical Method	Log-Pearson-Type III Distribution	Log-Normal Distribution
2	51.62	52.77	51.63
5	69.90		
10	82.00	77.20	78.51
20	93.60		
50	**108.62**	**93.95**	**101.06**
100	119.88	100.10	110.45
200	131.10	105.86	119.86
500	145.89		
1000	157.08	118.17	141.79

Table 3-7: Flood Frequency Analysis in Bagmati Khola at Khokana (DHM Station No. 550.05)

Return Period (Yrs)	Flood Discharge in Bagmati Khola at Khokana (DHM Station No. 550.05)		
	Gumbel's Analytical Method	Log-Pearson-Type III Distribution	Log-Normal Distribution
2	355.05	338.25	332.67
5	586.68		
10	740.05	685.63	700.95
20	887.16		
50	**1,077.58**	**1,039.65**	**1,097.98**
100	1,220.27	1,194.07	1,286.08
200	1,362.44	1,353.43	1,487.26
500	1,550.01		
1000	1,691.77	1,742.47	2,005.20

Similarly, frequency analysis has been carried out using maximum daily precipitation of each year of Bagmati Khola catchment computed using Thiessen Polygon method. The results of precipitation at different return period using frequency analysis method are presented in Table 3-8.

Table 3-8: Frequency Analysis for computation of Maximum Daily Precipitation at Different Return Period in Bagmati Basin

Return Period (Yrs)	Maximum Daily Precipitation (mm)		
	Gumbel's Analytical Method	Log-Pearson-Type III Distribution	Log-Normal Distribution
2	59.746	56.19	60.01
5	90.776		
10	111.321	95.84	93.92
20	131.029		
50	**137.280**	**149.26**	**123.00**
100	156.538	178.60	135.27
200	175.653	212.86	147.62
500	194.699		
1000	219.826	316.53	176.66

Similarly, the frequency analysis has also been carried out for computation of rainfall of different return period of each sub-basin of Bagmati river. The results of the precipitation analysis of the different sub-basin from the frequency analysis are presented in Table 3-9.

Table 3-9: Frequency Analysis of Maximum Daily Precipitation of each Sub-basin by Gumbel's Method

Sub-basin Description	Precipitation (mm)				
	5 Yrs	10 Yrs	20 Yrs	50 Yrs	100 Yrs
Sub-basin-1	93.02	112.76	131.70	**156.21**	174.58
Sub-basin-2	91.03	111.75	131.62	**157.34**	176.62
Sub-basin-3	88.34	105.77	122.48	**144.12**	160.33
Sub-basin-4	92.94	111.12	128.56	**151.13**	168.05
Sub-basin-5	107.84	129.53	150.33	**177.25**	197.43
Sub-basin-6	132.45	157.32	181.18	**212.06**	235.20
Sub-basin-7	105.07	124.40	142.94	**166.93**	184.91
Sub-basin-8	90.31	105.99	121.03	**140.50**	155.09
Sub-basin-9	115.20	138.05	159.97	**188.35**	209.61
Sub-basin-10	89.03	104.62	119.58	**138.94**	153.44
Sub-basin-11	88.19	105.25	121.62	**142.81**	158.68
Sub-basin-12	121.67	148.98	175.17	**209.08**	234.48
Sub-basin-13	123.53	152.17	179.64	**215.19**	241.83
Sub-basin-14	135.40	167.43	198.16	**237.93**	267.74
Sub-basin-15	98.41	118.30	137.37	**162.07**	180.57
Sub-basin-16	95.39	113.79	131.44	**154.29**	171.41
Sub-basin-17	87.88	105.13	121.68	**143.09**	159.14
Sub-basin-18	97.73	113.58	128.78	**148.46**	163.21

3.6.3 Results of Hydrological Modelling

Hydrological model, calibrated and validated using historical available daily rainfall and discharge data has been used for estimation of peak flood discharge and flow hydrograph during peak flood time at different river stretches (reaches) and junction of Bagmati River and its tributaries. As input, 50 years return period rainfall of each Sub-basin presented in Table 3-9 have been used in hydrological model to compute the peak flood discharge at 50 years return period. 50 years return period daily maximum precipitation has been converted into hourly rainfall data using the similar scale factor as observed during peak flood event occurred in 23rd July, 2002. The half-hourly rainfall data of the Kathmandu valley from GPM-Imerg satellite data has been used to estimate the scale factor for hourly estimation of rainfall data during peak period. The hourly distribution of flood event in 23rd July, 2002 as per GPM-Imerg satellite data has been presented in Figure 3-14.

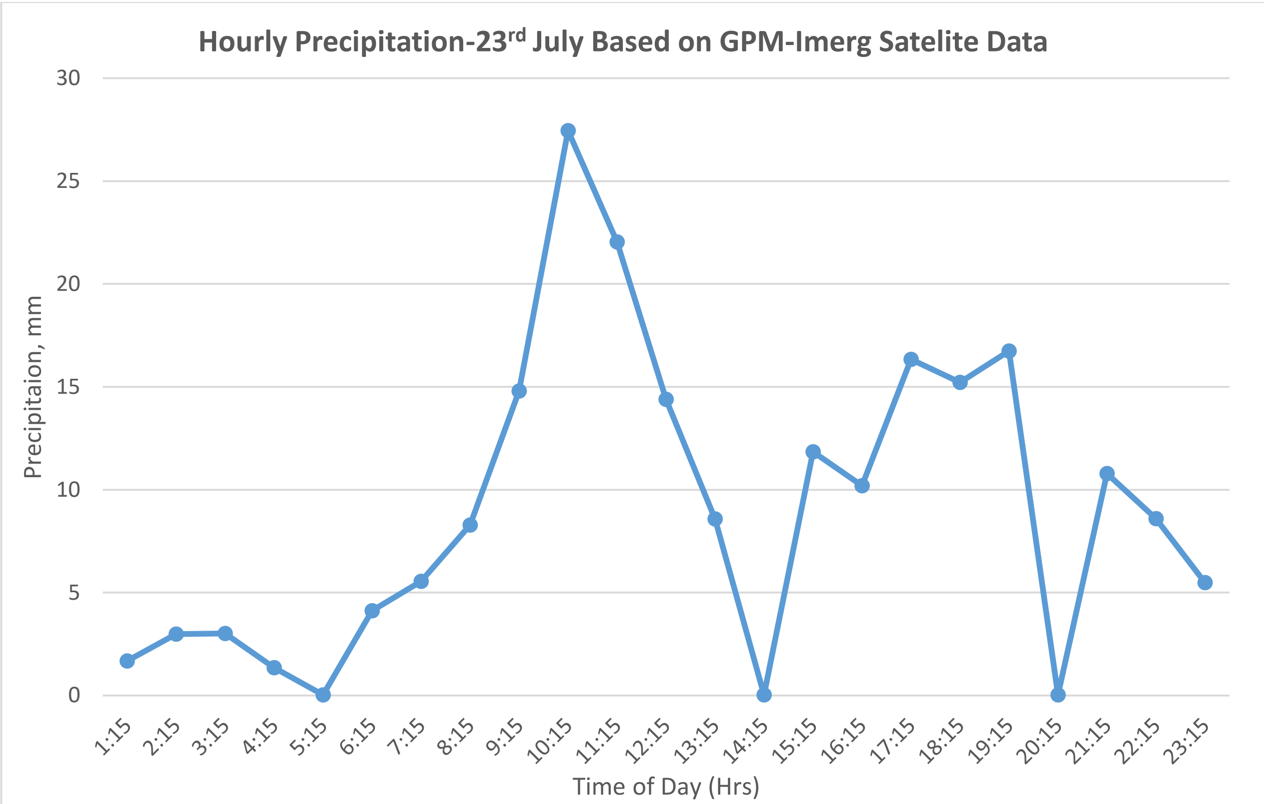

Figure 3-14: Hourly Precipitation of Kathmandu Valley Area based on GPM-Imerg Satellite Data recorded on 23rd July, 2002

Based on hydrological modelling, 50 years return period precipitation data used as input and results of hydrological modelling which are 50 years return period flood discharge at different river stretches (reaches), junction and sub-basin are presented in Table 3-10.

Table 3-10: Summary of 50 Years Return Period Flood and Precipitation at Different sub-basin, reaches and junctions in Bagmati Khola Basin in Kathmandu Valley

Description	50 Yrs Return Period Daily Maximum Precipitation (mm)	50 Yrs Return Period Peak Discharge (m^3/s)	Remarks (Description of Area)
Sub-basin4	151.3	163.7	Hanumante Khola Basin
Sub-basin3	144.12	125.9	Manohara Khola Basin
J11	-	289.1	Junction of Hanumante and Manohara Khola
Reach11	-	289.1	From Junction 11 to Junction 10 (Manohara Khola)
Sub-basin5	177.25	106.4	Godavari Basin
J10	-	394.4	Junction of Godavari and Manohara Khola
Reach10	-	394.4	From Junction 10 to Junction 9 (Manohara Khola)
Sub-basin7	166.93	97	Kodku Khola Basin
Sub-basin6	212.06	10.7	Manohara Khola basin for Reach 10
J9	-	495.4	Junction of Manohara Khola and Kodku Khola
Reach9	-	488.3	From Junction 9 to Junction 8 (Manohara Khola)

Description	50 Yrs Return Period Daily Maximum Precipitation (mm)	50 Yrs Return Period Peak Discharge (m^3/s)	Remarks (Description of Area)
Sub-basin1	156.21	30.3	Bagmati Khola Basin (Sundarijal Area, Upstream of Mulkharka)
J1	-	30.3	Junction of Bagmati Khola and Nagmati Khola (D/S of Sundarijal DHM station-Stn. No. 505)
Sub-basin2	157.34	104.5	Bagmati Khola Basin (Basin within Junction1 and Junction30)
Reach-1	-	29.7	From Junction 1 to Junction 30 (Bagmati Khola Basin)
J30	-	132.8	Bagmati Khola at Gaurighat DHM Station (Stn. No. 530)
Reach28	-	131.4	From Junction 30 to Junction 6 (Bagmati Khola)
Sub-basin18	148.46	10.5	Bagmati Khola Basin (Basin within Junction 30 to Junction 6)
J8	-	626.9	Junction of Bagmati and Manohara Khola
Reach8	-	623.4	From Junction 8 to Junction 7 (Bagmati Khola)
Sub-basin17	143.09	46.6	Dhobi Khola Basin
Sub-basin8	140.5	10.7	Bagmati Khola Basin (Basin within Junction 8 and Junction 7)
J7	-	677.2	Junction of Bagmati Khola and Dhobi Khola
Reach7	-	673.7	From Junction 7 to Junction 6 (Bagmati Khola)
Sub-basin16	154.29	16.5	Tukucha Khola Basin
J6	-	688.4	Junction of Tukucha Khola and Bagmati Khola
Reach6	-	675.3	From Junction 6 to Junction to Junction 5 (Bagmati Khola)
Sub-basin11	142.81	160.7	Bishnumati Khola Basin
Sub-basin15	162.07	45.1	Manamati Khola Basin
J12	-	205.8	Junction of Bishnumati Khola and Manamati Khola
Reach12	-	202.3	From Junction 12 to Junction 6 (Bishnumati Khola)
J5	-	867.4	Junction of Bishnumati Khola and Bagmati Khola
Reach5	-	847.4	From Junction 5 to Junction 4 (Bagmati Khola)
Sub-basin14	237.93	134.3	Balkhu Khola Basin
Sub-basin10	138.94	8.8	Bagmati Khola Basin for Reaches 5, 6 and 7 (i.e. from Junction 7 to Junction 4)
J4	-	971.5	Junction of Balkhu Khola and Bagmati Khola

Description	50 Yrs Return Period Daily Maximum Precipitation (mm)	50 Yrs Return Period Peak Discharge (m^3/s)	Remarks (Description of Area)
Reach4	-	951	From Junction 4 to Junction 3 (Bagmati Khola)
Sub-basin9	188.35	104.7	Nakhu Khola Basin
J3	-	1045.9	Junction of Bagmati Khola and Nakhu Khola
Reach-2	-	1024.6	From Junction 3 to Junction Khokana (Bagmati River)
Sub-basin12	209.08	81.9	Bagmati Khola Basin for Reach 2
JUNCTION KHOKONA	-	1097.5	Bagmati Khola basin at Khokana DHM Station (Stn. No. 550.05)
Reach-3	-	1071.9	From Junction Khokana to Sink-1
Sub-basin13	215.19	141	Bagmati Khola Basin for Reach3
Sink-1	-	1200.4	Outlet Point of Bagmati Khola at Katuwal Daha

4 MINIMUM WIDTH REQUIRED FOR NATURAL WATERWAY OF RIVERS

For wide streams or rivers, wetted perimeter P, approximately equals to the width of the river. With same assumption for Bagmati River and its major tributaries, according to Lacey, for alluvial rivers, the flow regime width is computed using formula: Regime Width (W) = $4.75\sqrt{Q}$, where Q denotes the maximum discharge passing through the river section.
Based on Lacey's formula, the minimum waterway width required for passage of 50 years return period peak discharge of each sub-basin river of Bagmati Khola and its tributaries are presented in Table 4-1.

Table 4-1: Required Width of Waterway during 50 years return period flood in Bagmati river & its tributaries at different river stretches

S.N.	River	River Stream	Sub-basins	50 yrs Return Period Precipitation (mm)	50 yrs Return Period flood discharge (m^3/s)	Required waterway for the river (m)
1	Bagmati Khola	Baghdwar to Nagmati Junction	Sub-basin 1	156.21	30.30	26.15
		Nagmati Junction to Suryamati Khola Junction	Sub-basin 2	157.34	90.28	45.13
		Suryamati Khola Junction to Manohara Khola Junction	Sub-basin 2 & 18		132.80	54.74
		Manohara Khola Junction to Dhobi Khola Junction	Sub-basin 8	140.50	626.90	118.93
		Dhobi Khola Junction to Tukucha Junction	Sub-basin 10	138.94	677.20	123.61
		Tukucha Junction to Bishnumati Khola Junction			688.40	124.63
		Bishnumati Khola Junction to Balkhu Khola Junction			867.40	139.90
		Balkhu Khola Junction to Nakhu Khola Junction	Sub-basin 12	209.08	971.50	148.05
		Nakhu Khola Junction to Katuwal Daha	Sub-basin 12 & 13		1097.50	157.36
2	Bishnumati Khola	Origin to Lundi Khola Junction	Sub-basin 11	142.81	16.05	19.03
		Lundi Khola Junction to Sangla Khola Junction			49.31	33.36

S.N.	River	River Stream	Sub-basins	50 yrs Return Period Precipitation (mm)	50 yrs Return Period flood discharge (m^3/s)	Required waterway for the river (m)
		Sangla Khola Junction to Mahadev Khola Junction			86.28	44.12
		Mahadev Khola Junction to Baucha Khola Juntction			144.46	57.09
		Baucha Khola Junction to Manamati Khola Junction			160.70	60.21
		Manamati Khola Junction to Bagmati Khola Junction	Sub-basin 10	138.94	205.80	68.14
3	Manohara Khola	Origin to Salambu Devi Temple area	Sub-basin 3	144.12	58.68	36.39
		Salambu Devi Temple area to Hanumante Khola Junction			125.90	53.30
		Hanumante Khola Junction to Kodku Khola Junction	Sub-basin 6	212.06	394.40	94.33
		Kodku Khola Junction to Bagmati Khola	Sub-basin 8	140.50	495.40	105.72
4	Hanumante Khola	Origin to Chaku Khola	Sub-basin 4	151.13	38.49	29.47
		Origin to Godavari Khola Junction			163.70	60.77
		Godavari Khola Junction to Manohara Khola Junction	Sub-basin 5	177.25	289.10	80.76
5	Dhobi Khola	Origin to Jamla Khola Junction	Sub-basin 17	143.09	6.26	11.89
		Jamla Khola Junction to Bagmati Khola			46.60	32.43
6	Suryamati Khola	Origin to Bagmati Khola	Sub-basin 2	157.34	30.10	26.06
7	Nakhu Khola	Origin to Bagmati Khola Junction	Sub-basin 9	188.35	104.70	48.60
7 8	Balkhu Khola	Origin to Balambu area	Sub-basin 14	237.93	91.57	45.45

S.N.	River	River Stream	Sub-basins	50 yrs Return Period Precipitation (mm)	50 yrs Return Period flood discharge (m^3/s)	Required waterway for the river (m)
		Origin to Bagmati Khola			134.30	55.05
9	Sangla Khola	Origin to Bishnumati Khola	Sub-basin 11	142.81	39.43	29.83
10	Mahadev Khola	Origin to Bishnumati Khola Junction			44.70	31.76
11	Chakhu Khola	Origin to Hanumante Khola	Sub-basin 4	151.13	48.38	33.04
12	Manamati Khola	Origin to Bishnumati Khola	Sub-basin 15	162.07	45.10	31.90
13	Baucha Khola	Origin to Bishnumati Khola	Sub-basin 11	142.81	19.07	20.74
14	Lundi Khola	Origin to Bishnumati Khola			5.68	11.32
15	Jamle Khola	Origin to Dhobi Khola	Sub-basin 17	143.09	3.22	8.52
16	Tukucha	Origin to Bagmati Khola	Sub-basin 16	154.29	16.50	19.29
17	Kodku Khola	Origin to Manohara Khola	Sub-basin 7	166.93	97.00	46.78
18	Godavari Khola	Origin to Hanumante Khola	Sub-basin 5	177.25	106.40	49.00

However, Bagmati River and its tributaries in most of urban zone and in few stretches of peri-urban zone consists of road corridor, built-up areas with different infrastructures within the required waterway width as presented in Table 4-1. Hence, it is recommended to provide river training structures as well as carry out land acquisition in possible site for provision of sufficient cross sectional area to allow 50 years return period flow in the river system. It is also recommended to refer to the model based flood inundation map presented in Figure 5-4 for understanding the extent of vulnerable areas during 50 years return period flood in Bagmati river system.

5 MODEL BASED FLOOD MAPPING OF BAGMATI RIVER AND ITS TRIBUTARIES

5.1 General

Kathmandu valley generally has monsoon season starting from June and ending in September mostly. During latter stages of the summer monsoon, the surface runoff increases predominantly as the land is usually saturated. Due to increased urbanization, river encroachment in most of Bagmati river tributaries and changes in land use and land cover pattern over the years; the threat and risk of the urban flooding has increased in Kathmandu Valley area. Various flood events occurred on past indicates the nature of the flood and its hazards are of big threat to the land, settlement and infrastructure facilities in Kathmandu valley mostly near the riverbanks. Hydrodynamic modelling of the Bagmati River and its tributaries considering the extreme flood events to find out the flood inundation map for 50 years return period flood discharge shall recommend the necessary right of way for relevant flood events in Kathmandu valley. Assessment of flood hazard map are concentrated to study the impacts of flood events on infrastructures such as bridges, road and buildings; land use-settlement area, agricultural area, barren area within the river buffer area.

For flood risk assessment, flood discharge of different return period computed from hydrological modelling and analysis has been used for flood simulation on the Bagmati river basin.

5.2 Methodology

For delineation of flood inundation map, 50 years return period flood at Bagmati River and its tributaries are considered. HEC-RAS computer software is used to compute the water surface profile during the flood events and preparation of the flood inundation map of Bagmati River and its tributaries. The boundary that shall be affected by the flood is based on 2 dimensional hydraulic simulation (i.e. unsteady flow analysis) carried out with the flood discharge obtained from hydrological analysis and topography of the river and river banks prepared using DEM and cross section survey data. DEM data of resolution size 2.5 m × 2.5 m is found insufficient to delineate river line in urban area and hence DEM has been further processed using cross section survey data to redefine the DEM raster file for preparation of flood inundation map.

The cross-section survey carried out in Bagmati River and its tributaries for preparation of flood inundation map based on flood modelling are presented in Google earth image in Figure 5-1.

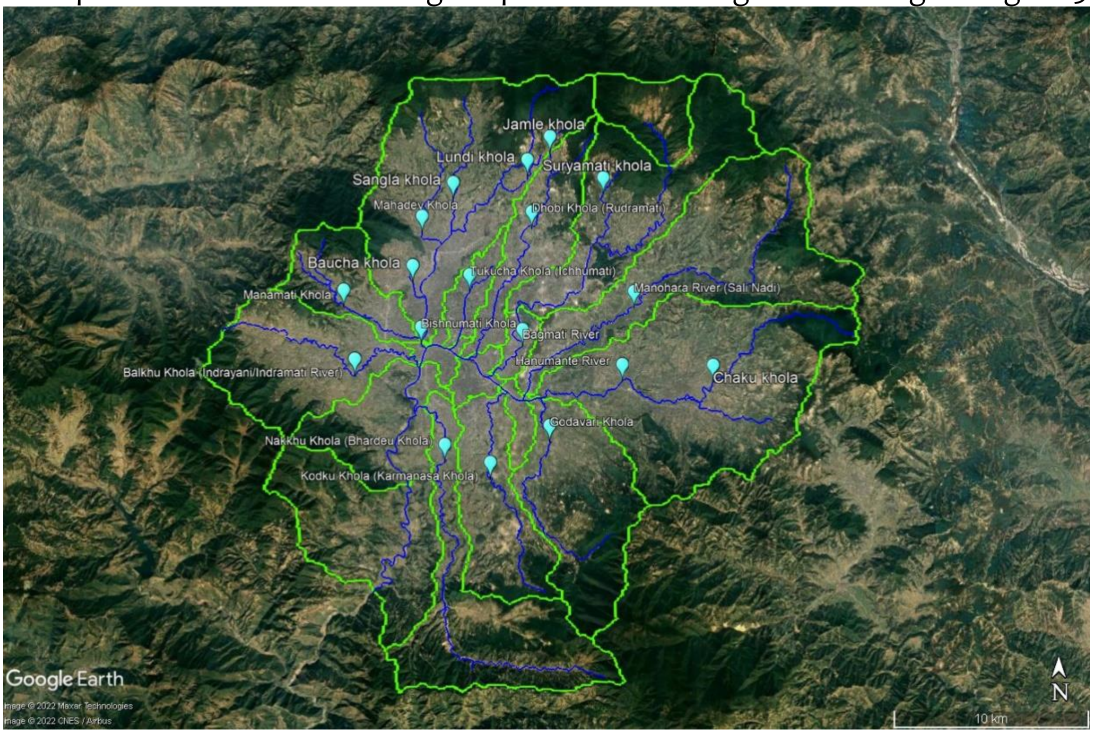

Figure 5-1: Cross Section Survey Lines carried out in Bagmati river and its tributaries for flood modelling

Along with the water surface profile; flow depth and flow velocity at the river and river banks are also presented in Google earth images. Right of the way for the Bagmati River and its tributaries shall be prepared based on the flood inundation map on these rivers.

Output of the hydraulic simulations can be transferred to GIS and Google earth to generate flood layer for different scenarios. The inundation maps provide crucial information regarding the vulnerability of the areas and necessary right of way from river for development of infrastructure and other facilities. Potential risk of the flood hazards to the households and other facilities located in the river banks and surroundings can also be evaluated from flood inundation mapping.

Digital Terrain Model (DTM) data of the Bagmati basin of 2.5 m × 2.5 m resolution data has been used in RAS Mapper for flood modelling. Similarly, cross-section survey carried out in Bagmati River and its major tributaries has been used for transferring the ground point data to the DEM in ARCGIS. The peak flood discharge at different return period has been computed using frequency analysis and hydrological modelling process in HEC-HMS software.

Detail assessment of river banks, its flood plain and river main stretch have been done during the cross section survey to have the baseline information for section of Manning's roughness coefficient (n) for flood modelling. The manning's n values adopted for flood modelling in HEC-RAS is presented in Table 5-1.

Table 5-1: Manning's Value for River bank Environmental Conditions (Chow, 1959)

S. No.	Land Use Type	Manning's Coefficient
1	Forest	0.15
2	Shrub land	0.05
3	Grassland	0.04
4	Agricultural Area	0.05
5	Barren Land	0.03
6	Water Bodies (River)	0.035
7	Built Up Area	0.15

Land Use Land Cover Map of Kathmandu valley has been used for providing the manning's roughness value for different land types; i.e. river channel, flood plains and river banks based on Table 5-1. The land use land cover map of Nepal published by ICIMOD, 2020 presented in Figure 3-5 has been used in RAS Mapper to define the Manning's n values for the flow area in hydraulic simulation.

HEC-RAS (Hydrological Engineer Center- River Analysis System) computed software has been used with its RAS- Mapper feature for modelling of flood in the river which is well tested hydraulic simulation software.

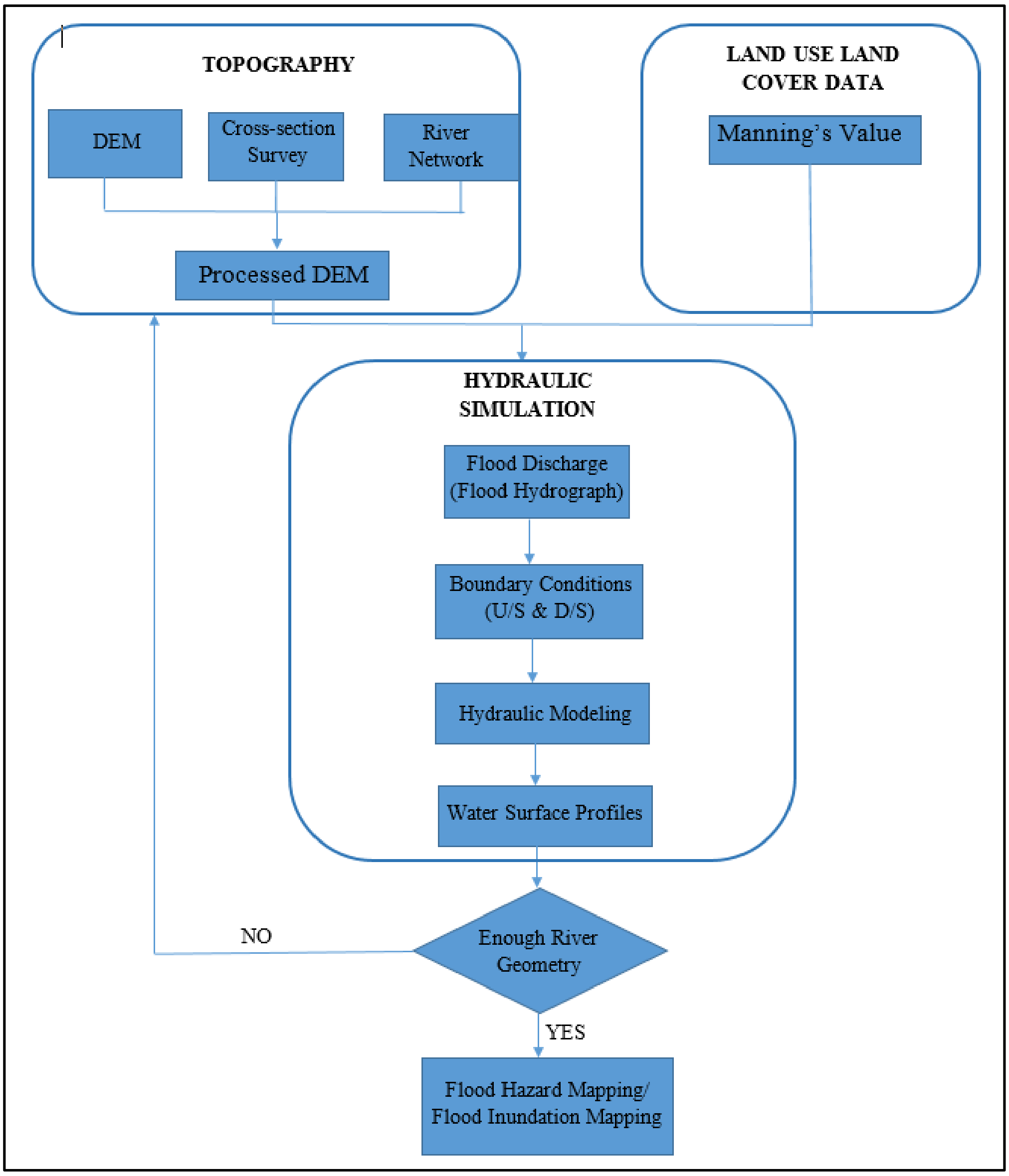

Figure 5-2: Methodology for Flood Risk Assessment

5.3 Flood Hydrograph

Flood discharge computed at different return periods by using flood frequency analysis, empirical approaches recommended by various organizations and hydrological modelling in HEC-HMS are compared. Based on the output of hydrological model as presented in Table 3-10, flood discharge and hydrograph for 50 years return period has been used for preparation of flood inundation mapping. Hourly variation of discharge for 24 hours obtained from the hydrological modelling has been used for flood modelling in HEC-RAS.

5.4 Boundary Conditions

From HEC-HMS model and flood frequency analysis at different Sub-basin and their junctions, flood discharge and hydrograph for different return periods have been computed. Following downstream and upstream boundary conditions have been used for hydraulic simulation and flood mapping in Bagmati River and its tributaries:

- *Flow Hydrograph for Upstream boundary condition*
- *Normal Flow Depth and River Bed Slope as Downstream boundary condition*

5.5 Preparation of Flood Hazard Map

The extent of flood hazard in Bagmati River within the Kathmandu valley for various return period shows that the total hazard area increases as the return period increase. The flood inundation map of Bagmati River and its tributaries is obtained by using hydrological model of Bagmati basin, field survey data, GIS and HEC-RAS model for 50 years return period. The flood water width which is obtained from HEC-RAS is shown in the figure and tables below.

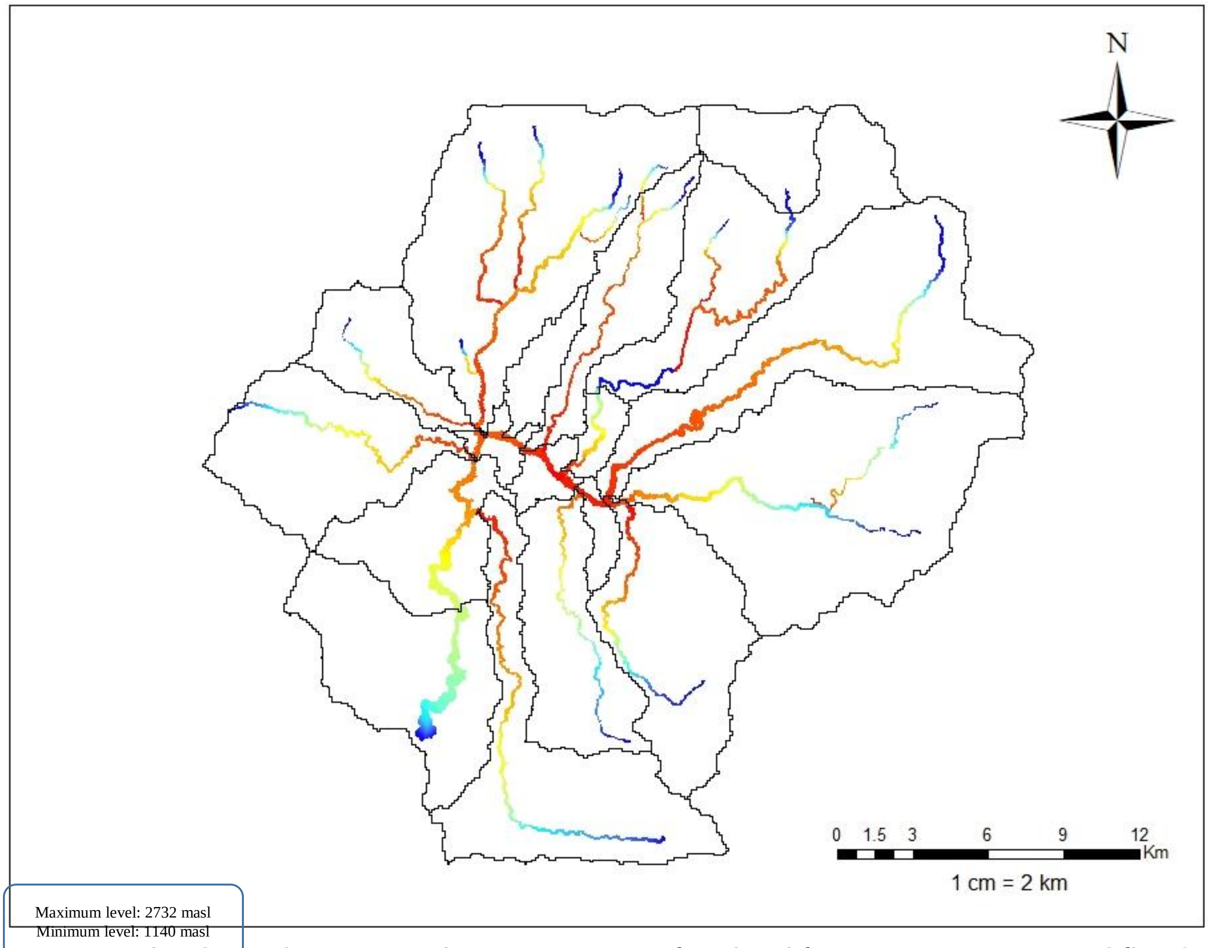

Figure 5-3: Flood Inundation Map showing water surface level for 50 yrs. return period flood in Bagmati Basin

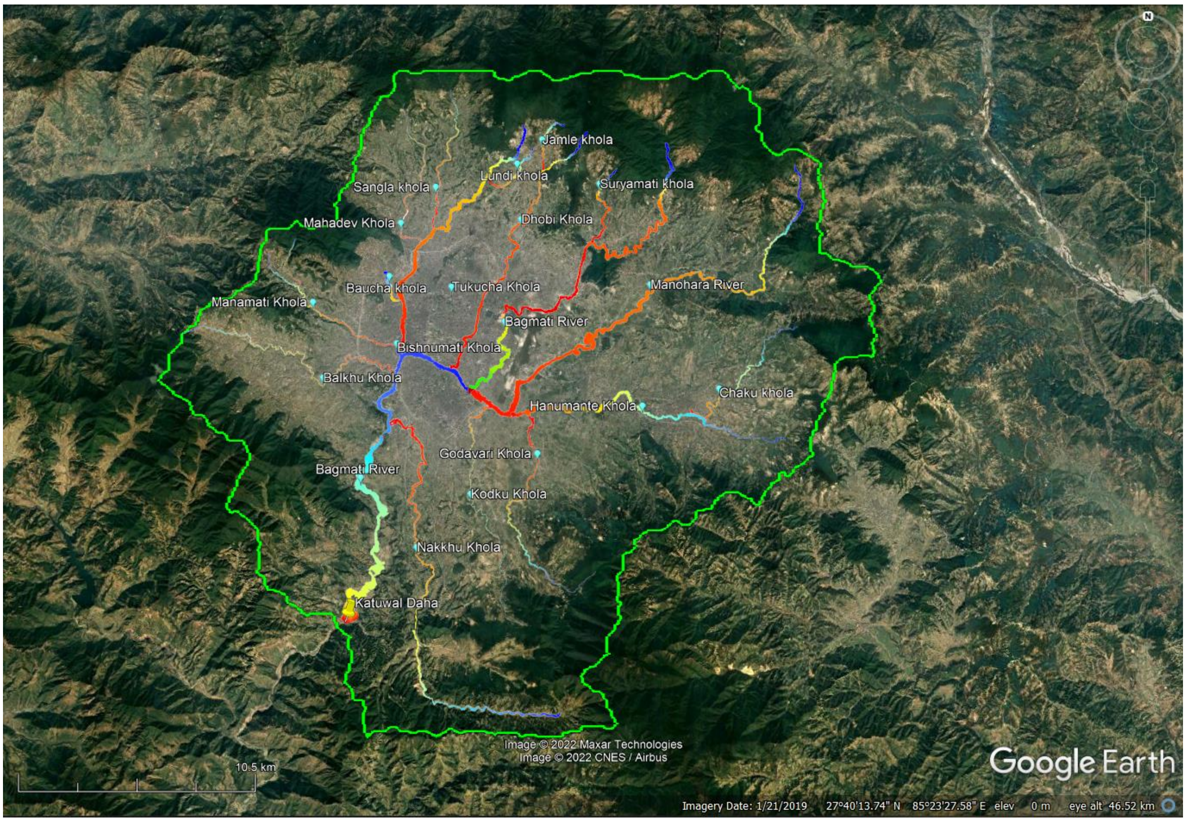

Figure 5-4: Flood Inundation Map during 50 years return period flood in Bagmati river & its tributaries in Google Earth

The main purpose of hydrological model is to estimate the flood discharge equivalent to 50 years return period in Bagmati River and its tributaries and prepare the flood inundation map of the Bagmati river system in Kathmandu Valley upstream of Katuwal daha area. The model based flood map prepared using the 2D HEC-RAS tool also provides the detail idea about the different vulnerable areas in Bagmati river system during 50 years return period flood. The model based flood map shall also be used readily in times of emergency to warn the population in advance to lessen the damages and hazard due to flood. Based on validated hydrological model and flood inundation map of 50 years return period flood, the Bagmati River at Gokarneswor and Guheswori area are medium flood risk area. Bagmati River downstream of Shankhamul near UN park area is also found to be inundated during the flood event. River corridor of Dhobi Khola in most of the stretches (Dhumbarahi area, Gyaneswor area and Anamnagar area) with low river depth are found more vulnerable during the flood events. Uneven banks and river training works in rivers are also observed due to landscape restriction and corridor road mostly in Dhobi Khola stretches which ultimately result the built up area in low flood plain more vulnerable to flood. Bishnumati Khola road corridor and built-up areas near Gongabu and Teku area are high vulnerable site based on model based flood inundation map of Bishnumati Khola. Manohara Khola upstream of jadibuti area with very low depth river cross section is found more vulnerable. As the Manohara Khola is highly meandered in many places; it is recommended to provide river training works in such stretches to minimize the river bank erosion during flood event and provide the stable bank and river for passage of flood discharge. Hanumante Khola is found to be very narrow downstream of Chardobata bridge at Thimi and are vulnerable during flash flood event. The settlement area near Hanumante Khola in Thimi and Radhe Radhe area are found more vulnerable. River stretches with narrow section in between wider sections are more vulnerable to the flood risk as they result in increase in water depth and cause large flood inundation area mostly in upstream stretches. Similarly, construction of infrastructures such as bridges, culverts, etc. on river with the traffic operation area (deck level) below high flood level are observed in few bridges and culverts which affect the bridge structures as well as the built-up area on its bank. During flooding, blockage of the sewer lines and drain pipes due to backwater effect and less discharge capacity also increases the vulnerability of many areas. Hence, proper design of the sewer and drainage pipes and its outlet with sufficient discharge capacity are recommended to lessen the hazard due to high flood on these structures and nearby settlement zone. The details of extent of flood inundation map in the surveyed cross section for 50 years return period flood discharge based on flood mapping in HEC-RAS are presented in tables below.

Table 5-2: Model based flood inundation extent during 50 years return period flood in Bagmati River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	21.5	27°45'55.64"N	85°25'26.93"E	10.6	10.9	Forest area (U/S of Sundarijal hydropower)
2	27.6	27°45'49.68"N	85°25'26.12"E	16.1	11.5	
3	26.6	27°45'42.28"N	85°25'21.62"E	12.6	14	U/S of Sundarijal water Treatment Plant area
4	37.5	27°45'36.25"N	85°25'17.01"E	16.6	20.9	Sundarijal water Treatment Plant area
5	35.9	27°45'28.11"N	85°25'14.34"E	17.2	18.7	D/S of Sundarijal water Treatment Plant area
6	47.1	27°45'21.59"N	85°25'14.88"E	21.1	26	Sundarijal area
7	47.9	27°45'15.57"N	85°25'17.59"E	20.7	27.2	Sundarijal area
8	66	27°45'5.91"N	85°25'21.41"E	28.4	37.6	Sundarijal area
9	66.8	27°44'56.67"N	85°25'23.16"E	24.3	42.5	Sundarijal area
10	58.2	27°44'56.40"N	85°25'14.49"E	42.3	15.9	Sundarijal area
11	77.8	27°44'51.95"N	85°25'9.68"E	38.3	39.5	Sundarijal area
12	38.2	27°44'46.29"N	85°25'0.47"E	20.7	17.5	Bhadrabas water tank area
13	79.4	27°44'40.87"N	85°24'58.64"E	22.7	56.7	Bhadrabas water tank area
14	47	27°44'36.06"N	85°24'55.89"E	21	26	D/S of Bhadrabas water tank area
15	62.7	27°44'27.40"N	85°24'43.73"E	47.7	15	D/S of Syalmati Khola
16	82.6	27°44'17.16"N	85°24'43.99"E	16	66.6	D/S of Syalmati Khola
17	85.1	27°44'12.14"N	85°24'35.95"E	35.5	49.6	Gokarneshwor Area
18	97	27°44'13.50"N	85°24'22.09"E	78.8	18.2	Gokarneshwor Area
19	73.9	27°44'5.26"N	85°24'14.07"E	56	17.9	Gokarneshwor Area
20	137	27°44'10.14"N	85°24'0.61"E	112.6	24.4	Gokarneshwor Area
21	114	27°44'0.22"N	85°23'47.23"E	44	70	Near Uttar Bahini Temple
22	98.3	27°44'5.71"N	85°23'47.19"E	35.3	63	Near Uttar Bahini Temple
23	44	27°44'6.55"N	85°23'48.79"E	25	19	Near Uttar Bahini Temple
24	97.8	27°44'11.66"N	85°23'46.38"E	45.9	51.9	D/S of Uttar Bahini Temple
25	74	27°44'18.79"N	85°23'43.69"E	53.8	20.2	Narayantole area
26	50.3	27°44'16.61"N	85°23'30.82"E	36.6	13.7	Narayantole area
27	50.7	27°44'21.54"N	85°23'18.72"E	19.7	31	Near Gokarneshwor Mahadev Temple

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
28	39.8	27°44'20.83"N	85°23'16.24"E	22	17.8	Near Gokarneshwor Mahadev Temple
29	34.3	27°44'15.48"N	85°23'11.61"E	15.3	19	Makalbari Area
30	62.3	27°44'9.65"N	85°23'10.48"E	28	34.3	Makalbari Area
31	55.6	27°43'46.84"N	85°23'3.45"E	26.3	29.3	Makalbari Area
32	56	27°43'40.97"N	85°23'2.77"E	20.6	35.4	Jorpati Area
33	72.9	27°43'31.89"N	85°23'0.14"E	39.6	33.3	Jorpati Area
34	70.9	27°43'17.52"N	85°22'56.78"E	19	51.9	Jorpati Area
35	77.9	27°43'10.53"N	85°22'56.69"E	33.9	44	Jorpati Area
36	73.1	27°43'5.68"N	85°22'54.01"E	38.4	34.7	Jorpati Area
37	67.7	27°42'59.33"N	85°22'44.61"E	50.7	17	Jorpati Area
38	74.1	27°43'0.76"N	85°22'32.82"E	39.8	34.3	Jorpati Area
39	67.9	27°42'58.41"N	85°22'29.28"E	45.3	22.6	Jorpati Area
40	100	27°42'45.12"N	85°22'21.79"E	70.2	29.8	Gothatar fun park area
41	93.6	27°42'42.91"N	85°22'22.10"E	35.5	58.1	D/S of Gothatar fun park area
42	94.8	27°42'41.52"N	85°22'17.89"E	59.5	35.3	Nayabasti area
43	82.8	27°42'38.83"N	85°22'8.03"E	52.1	30.7	Nayabasti area
44	52.3	27°42'39.73"N	85°22'1.49"E	23.2	29.1	Nayabasti area
45	62.8	27°42'41.60"N	85°21'55.42"E	37.9	24.9	Airport Area
46	75.2	27°42'41.35"N	85°21'52.58"E	34.8	40.4	Airport Area
47	69.8	27°42'40.57"N	85°21'46.69"E	24.2	45.6	Bouddha Area
48	70	27°42'44.88"N	85°21'36.39"E	44.4	25.6	Bouddha Area
49	56.7	27°42'37.18"N	85°21'24.74"E	34.1	22.6	Kumarigal Area
50	55.9	27°42'34.16"N	85°21'19.56"E	32.2	23.7	Kumarigal Area
51	74	27°42'38.05"N	85°21'16.71"E	37.9	36.1	Kumarigal Area
52	58	27°42'41.86"N	85°21'14.11"E	34.4	23.6	Kumarigal Area
53	68.9	27°42'46.10"N	85°20'58.35"E	39.1	29.8	Gaurighat Area
54	62.3	27°42'44.61"N	85°20'57.89"E	38.5	23.8	Gaurighat Area
55	30.7	27°42'38.09"N	85°20'57.19"E	17.2	13.5	Near Pashuptinath Temple

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
56	52.6	27°42'30.17"N	85°20'54.44"E	32.4	20.2	Gaushala Area
57	59.6	27°42'20.43"N	85°20'57.42"E	29.9	29.7	Gaushala Area
58	48.5	27°42'13.14"N	85°20'59.61"E	25.7	22.8	Tilganga Area
59	52.2	27°42'11.75"N	85°21'0.00"E	25.7	26.5	Tilganga Area
60	56.8	27°42'8.48"N	85°20'59.45"E	27.1	29.7	D/S of Tilganga Area
61	88.2	27°41'58.36"N	85°20'51.32"E	55.6	32.6	Sinamangal Area
62	67.2	27°41'54.57"N	85°20'47.46"E	44.7	22.5	Sinamangal Area
63	90	27°41'44.34"N	85°20'55.14"E	52.6	37.4	Jagritinagar Area
64	54.2	27°41'37.01"N	85°21'6.78"E	19.9	34.3	Near Aviation Museum
65	59.5	27°41'32.84"N	85°21'4.70"E	1.5	58	Jagritinagar Area
66	74.7	27°41'29.48"N	85°20'58.16"E	42.5	32.2	Jagritinagar Area
67	91.9	27°41'26.08"N	85°20'52.92"E	57.7	34.2	Jagritinagar Area
68	69.4	27°41'22.74"N	85°20'53.60"E	40.6	28.8	Gairigaon Area
69	77.7	27°41'16.67"N	85°20'48.38"E	53.1	24.6	Gairigaon Area
70	153	27°41'12.07"N	85°20'39.71"E	87	66	Tinkune Area
71	157	27°41'9.69"N	85°20'36.97"E	104.6	52.4	Subidhanagar Area
72	79.4	27°40'57.87"N	85°20'21.01"E	37.2	42.2	Subidhanagar Area
73	78.4	27°40'47.71"N	85°20'12.02"E	50.6	27.8	Chhitijnagar Area
74	138	27°40'44.12"N	85°20'3.26"E	48	90	Near Manohara and Bagmati Junction
75	136	27°40'43.41"N	85°19'57.71"E	45.8	90.2	D/S Manohara and Bagmati Junction
76	114	27°40'49.49"N	85°19'48.79"E	64.7	49.3	Near Sankhamul Patuk
77	116	27°41'4.28"N	85°19'41.10"E	66.8	49.2	U/S of UN Park
78	166	27°41'8.32"N	85°19'38.03"E	120.4	45.6	Near UN Park
79	149	27°41'11.76"N	85°19'27.30"E	101.6	47.4	Jwagal Area
80	129	27°41'13.65"N	85°19'14.69"E	40.9	88.1	Thapathali Area
81	110	27°41'19.77"N	85°19'2.16"E	40.9	69.1	Thapathali Area
82	115	27°41'22.40"N	85°18'59.14"E	47.9	67.1	Kupondole Area
83	125	27°41'25.79"N	85°18'54.30"E	76.8	48.2	Kupondole Area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
84	138	27°41'30.44"N	85°18'41.17"E	71.3	66.7	U/S of Bainsighat Area
85	138	27°41'35.56"N	85°18'23.94"E	102.4	35.6	Gusingal Area
86	95	27°41'34.19"N	85°18'17.84"E	60.2	34.8	Gusingal Area
87	110	27°41'30.23"N	85°18'8.91"E	53	57	Rajtirtha Area
88	93.9	27°41'7.47"N	85°18'0.16"E	31.1	62.8	Balkhu Area
90	104	27°40'37.97"N	85°17'52.55"E	41.5	62.5	Shantibasti Area
91	105	27°40'29.77"N	85°17'39.73"E	47.1	57.9	Near TU Cricket Ground
92	105	27°40'23.01"N	85°17'31.26"E	66.6	38.4	Bagmati Khola
94	115	27°40'6.45"N	85°17'50.08"E	46	69	Near Baghdol area
95	108	27°39'59.09"N	85°17'51.27"E	11.8	96.2	Near Baghdol area
96	92.1	27°39'52.49"N	85°17'46.93"E	64.6	27.5	Near Chobhar Area
97	97.1	27°39'47.06"N	85°17'47.38"E	73.1	24	Near Chobhar Area
98	99	27°39'38.92"N	85°17'47.71"E	46.3	52.7	Bagmati Khola
100	97.4	27°39'28.81"N	85°17'36.99"E	50.9	46.5	Near Jal Binayak temple
101	92.6	27°39'22.23"N	85°17'36.54"E	39.5	53.1	Near Bhaisepati Area
102	97.3	27°39'11.35"N	85°17'23.60"E	40.9	56.4	Bagmati Khola
103	161	27°38'57.81"N	85°17'12.73"E	110.9	50.1	Near Khokana Area
104	154	27°38'44.91"N	85°17'14.90"E	113.4	40.6	Near Khokana Area
105	106	27°38'39.66"N	85°17'9.83"E	24	82	Near Sikal mandir
106	107	27°38'40.38"N	85°16'56.44"E	58.3	48.7	Near Chalnakhel area
107	100	27°38'27.33"N	85°17'1.80"E	45.5	54.5	Near Chalnakhel area
108	146	27°38'10.53"N	85°17'19.95"E	88.6	57.4	Near Tappal Area
109	122	27°38'2.39"N	85°17'34.60"E	29.2	92.8	Tappal Area
110	141	27°37'46.49"N	85°17'35.42"E	102	39	Bagmati Khola
111	104	27°37'34.66"N	85°17'35.91"E	63.4	40.6	Bagmati Khola
112	105	27°37'22.05"N	85°17'35.08"E	81.2	23.8	Near Bagmati Organic Farn (Bungmati Area)
113	111	27°37'8.34"N	85°17'30.19"E	89.1	21.9	Near Bungmati Area
114	118	27°36'57.04"N	85°17'32.12"E	88.8	29.2	Near Bungmati Area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
115	68.8	27°36'38.10"N	85°17'27.78"E	51.6	17.2	D/S of Pharping Hydropower Station
116	193	27°36'19.50"N	85°17'39.01"E	87	106	Bagmati Khola
117	142	27°35'58.50"N	85°17'29.29"E	52.3	89.7	Near karyabinayak Area
118	152	27°35'52.19"N	85°17'15.03"E	120.8	31.2	Near karyabinayak Area
119	158	27°35'35.70"N	85°17'6.50"E	73.4	84.6	Near karyabinayak Area
120	120	27°35'38.24"N	85°17'2.08"E	70.6	49.4	Near karyabinayak Area
121	72.4	27°35'42.93"N	85°16'47.62"E	30.4	42	Bagmati Khola
122	136	27°35'21.41"N	85°16'46.98"E	36.2	99.8	Near Mokubeashi
123	147	27°35'7.09"N	85°16'50.09"E	112.8	34.2	Near Katuwal daha
124	157	27°34'58.92"N	85°16'44.03"E	34	123	Near Katuwal daha

Table 5-3: Model based flood inundation extent during 50 years return period flood in Suryamati River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	64.3	27°44'23.88"N	85°23'22.67"E	25.4	38.9	Junction with bagmati Khola
2	31	27°44'26.06"N	85°23'22.37"E	19.5	11.5	Suryamati Khola
3	27.1	27°44'30.38"N	85°23'24.52"E	13.9	13.2	Suryamati Khola
4	37.9	27°44'31.28"N	85°23'26.91"E	29.5	8.4	Suryamati Khola
5	20.3	27°44'31.58"N	85°23'30.45"E	14.6	5.7	Suryamati Khola
6	36.9	27°44'32.29"N	85°23'33.21"E	21.9	15	Suryamati Khola
7	27.6	27°44'34.63"N	85°23'35.57"E	18.04	9.56	Suryamati Khola
8	25.9	27°44'37.37"N	85°23'36.25"E	10.9	15	Suryamati Khola
9	17.5	27°44'41.13"N	85°23'38.49"E	14.28	3.22	Suryamati Khola
10	26.5	27°44'43.30"N	85°23'40.59"E	23.21	3.29	Suryamati Khola
11	26	27°44'46.54"N	85°23'43.79"E	12.2	13.8	Suryamati Khola
12	17.3	27°44'50.12"N	85°23'41.01"E	12.57	4.73	Suryamati Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
13	26.6	27°44'54.14"N	85°23'38.09"E	18.5	8.1	Suryamati Khola
14	28.6	27°44'57.24"N	85°23'37.39"E	22.31	6.29	Suryamati Khola
15	24.9	27°45'0.01"N	85°23'39.52"E	16.7	8.2	Suryamati Khola
16	20	27°45'2.10"N	85°23'42.20"E	10.27	9.73	Suryamati Khola
17	17.8	27°45'7.16"N	85°23'43.91"E	10.24	7.56	Suryamati Khola
18	14	27°45'9.90"N	85°23'45.48"E	7.62	6.38	Suryamati Khola
19	42.3	27°45'11.80"N	85°23'50.08"E	8.7	33.6	Suryamati Khola
20	46.7	27°45'14.05"N	85°23'50.60"E	6.5	40.2	Suryamati Khola
21	28.8	27°45'16.07"N	85°23'48.08"E	8.2	20.6	Suryamati Khola
31	23.7	27°45'35.60"N	85°23'30.60"E	15.27	8.43	Suryamati Khola
32	21.5	27°45'37.25"N	85°23'31.61"E	12.28	9.22	Suryamati Khola
33	17.6	27°45'40.36"N	85°23'32.71"E	5.1	12.5	Suryamati Khola
34	18.4	27°45'42.69"N	85°23'32.86"E	12.63	5.77	Suryamati Khola
36	18.5	27°45'45.54"N	85°23'36.24"E	7.9	10.6	Suryamati Khola
37	11.4	27°45'47.68"N	85°23'36.09"E	3.8	7.6	Suryamati Khola
38	25	27°45'50.90"N	85°23'37.68"E	7.8	17.2	Suryamati Khola
39	13.6	27°45'51.19"N	85°23'40.65"E	7.64	5.96	Suryamati Khola
40	13.2	27°45'52.66"N	85°23'43.04"E	4.02	9.18	Suryamati Khola
41	16.4	27°45'54.76"N	85°23'44.80"E	10.43	5.97	Suryamati Khola
42	18.3	27°45'55.90"N	85°23'45.44"E	10.79	7.51	Suryamati Khola
43	12.8	27°45'57.48"N	85°23'44.60"E	9.68	3.12	Suryamati Khola
44	13.5	27°45'59.95"N	85°23'46.84"E	7.15	6.35	Suryamati Khola
45	8.11	27°46'2.63"N	85°23'49.73"E	5.11	3	Suryamati Khola

Table 5-4: Model based flood inundation extent during 50 years return period flood in Balkhu River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	41.6	27°40'58.41"N	85°17'55.93"E	9.6	32	Near Balkhu Chowk
2	32.8	27°41'6.33"N	85°17'52.26"E	8.1	24.7	Near Balkhu Chowk
3	113	27°41'8.95"N	85°17'51.32"E	63	50	Near Balkhu Chowk
4	30	27°41'10.47"N	85°17'46.89"E	9.8	20.2	Delight Dental care
6	26.4	27°41'14.83"N	85°17'39.19"E	12	14.4	Kamal English Boarding School
7	29.9	27°41'14.97"N	85°17'33.71"E	11.1	18.8	Aadar Trade Mall
8	31.5	27°41'20.04"N	85°17'27.89"E	14.9	16.6	Mindol Ling Balkhu Gumba
10	30	27°41'18.66"N	85°17'21.13"E	21.82	8.18	Advance College of Engineering and Management
12	33.5	27°41'22.91"N	85°17'11.05"E	17	16.5	National Business Trade Centre
13	36.6	27°41'28.78"N	85°17'4.05"E	14.5	22.1	Bhatbhateni Supermarket
14	34.7	27°41'23.63"N	85°17'2.73"E	19.5	15.2	Himalayan Java Kalanki
15	29.6	27°41'26.11"N	85°16'54.40"E	13.9	15.7	Land revenue office kalankai
16	26.6	27°41'30.68"N	85°16'38.33"E	11.4	15.2	Sahid Basu Smriti marg
17	32.5	27°41'20.26"N	85°16'37.73"E	23.69	8.81	Balkhu Khola
18	25	27°41'8.96"N	85°16'25.98"E	12.7	12.3	Balkhu Khola
20	26.2	27°41'4.69"N	85°16'20.79"E	15.2	11	Balkhu Khola
21	19.2	27°41'1.90"N	85°16'15.30"E	7.2	12	Bhiradil kaike sakura park
22	33.4	27°40'57.39"N	85°16'13.65"E	14.6	18.8	Prithvi narayan shah bridge
23	29.9	27°40'53.11"N	85°16'6.55"E	14.4	15.5	Balkhu Khola
24	29.3	27°40'50.66"N	85°16'2.85"E	15.5	13.8	Balkhu Khola
25	39.4	27°40'43.95"N	85°15'56.61"E	20.2	19.2	Kutumba basti
26	38.8	27°40'47.41"N	85°15'51.01"E	19.1	19.7	Kutumba basti
27	28.8	27°40'54.71"N	85°15'44.48"E	15.4	13.4	Balkhu Khola
28	29.2	27°40'56.04"N	85°15'40.07"E	17	12.2	Bishnu Devi temple
29	36.6	27°40'56.00"N	85°15'37.46"E	14.4	22.2	Balkhu Khola
30	30.4	27°41'3.03"N	85°15'40.84"E	18.5	11.9	Bishnu Devi village
31	28.8	27°41'10.86"N	85°15'36.73"E	15.9	12.9	Balkhu pul

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
32	29	27°41'15.46"N	85°15'26.13"E	16.3	12.7	Spiradi Treading Pvt.Ltd.
33	41.2	27°41'18.25"N	85°15'20.24"E	26.6	14.6	Balkumari Bridge
34	36.8	27°41'21.99"N	85°15'20.36"E	24.9	11.9	Balkhu Khola
35	36.3	27°41'28.70"N	85°15'25.10"E	17.8	18.5	Balkhu Khola
36	36.6	27°41'30.92"N	85°15'24.03"E	20.8	15.8	Balkhu Khola
37	35.8	27°41'31.07"N	85°15'18.64"E	17.4	18.4	Balkhu Khola
38	46.2	27°41'34.72"N	85°15'13.72"E	17.6	28.6	Balkhu Khola
39	46.6	27°41'31.72"N	85°15'11.06"E	28.6	18	Balkhu Khola
40	41.9	27°41'33.73"N	85°15'1.94"E	19.6	22.3	Balkhu Khola
41	25.6	27°41'29.96"N	85°14'54.69"E	14.2	11.4	Balkhu Khola
42	34.5	27°41'36.54"N	85°14'47.61"E	21.8	12.7	Bhimsen temple
43	26.9	27°41'39.56"N	85°14'45.98"E	12.2	14.7	Binayak multipurpose printers pvt.ltd
44	20.8	27°41'39.73"N	85°14'40.59"E	13.89	6.91	Nepal Hilltop industries
45	27.2	27°41'36.93"N	85°14'38.52"E	18.55	8.65	Dahachowk bridge
46	27	27°41'40.91"N	85°14'37.17"E	13.5	13.5	Balambu
47	31.3	27°41'40.78"N	85°14'33.62"E	14.1	17.2	Balambu
48	32.2	27°41'42.41"N	85°14'30.16"E	20.2	12	Balambu
49	29.5	27°41'44.22"N	85°14'24.69"E	8.3	21.2	Dahachowk
50	35.1	27°41'35.21"N	85°14'16.97"E	17.5	17.6	Mahadevsthan
51	31.6	27°41'39.94"N	85°14'11.98"E	13.1	18.5	Dahachowk
52	35.7	27°41'43.75"N	85°14'4.95"E	11.2	24.5	Dahachowk
53	30.7	27°41'41.89"N	85°14'2.56"E	7.2	23.5	Dahachowk
54	30.6	27°41'40.55"N	85°14'0.61"E	20.6	10	Dahachowk
55	29.4	27°41'45.50"N	85°13'54.31"E	12.4	17	Dahachowk
56	27.2	27°41'49.72"N	85°13'53.15"E	12.5	14.7	Dahachowk
57	28.9	27°41'55.35"N	85°13'51.78"E	20.34	8.56	Thankot
58	24	27°41'58.72"N	85°13'47.20"E	13.7	10.3	Thankot
59	24	27°41'57.20"N	85°13'45.03"E	10.7	13.3	Thankot

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
60	22.4	27°41'57.56"N	85°13'36.12"E	11.4	11	Thankot
61	21.2	27°42'0.25"N	85°13'31.03"E	10.7	10.5	Thankot
62	20.7	27°42'0.34"N	85°13'27.80"E	10	10.7	Thankot
63	33.7	27°41'59.31"N	85°13'21.15"E	14.5	19.2	Thankot
64	26	27°42'0.23"N	85°13'13.91"E	16.8	9.2	Thankot
65	30.7	27°42'4.87"N	85°13'1.75"E	12.5	18.2	Thankot
66	27.8	27°42'5.48"N	85°12'54.63"E	14.3	13.5	Thankot

Table 5-5: Model based flood inundation extent during 50 years return period flood in Godavari River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	118	27°40'8.37"N	85°21'39.14"E	67.4	50.6	At junction with hanumante Khola
2	62.9	27°40'3.77"N	85°21'41.95"E	33.7	29.2	Balkot height
4	126	27°39'58.64"N	85°21'46.37"E	62.6	63.4	Balkot height
6	58	27°39'50.75"N	85°21'47.73"E	44.5	13.5	Balkot chowk
7	85.8	27°39'47.39"N	85°21'44.96"E	36.2	49.6	Balkot chowk
8	77.9	27°39'42.33"N	85°21'40.73"E	25	52.9	Balkot chowk
9	79.8	27°39'38.16"N	85°21'39.75"E	26.4	53.4	Balkot chowk
10	63.2	27°39'33.26"N	85°21'41.26"E	23.2	40	Tikathali
11	73	27°39'27.45"N	85°21'42.62"E	25.6	47.4	Tikathali
12	75.9	27°39'21.87"N	85°21'42.66"E	18.6	57.3	Tikathali
13	51.3	27°39'19.53"N	85°21'48.85"E	18	33.3	Tikathali
14	32.5	27°39'15.66"N	85°21'53.41"E	21.8	10.7	Changathali
15	27.9	27°39'9.77"N	85°21'56.59"E	9.58	18.32	Changathali
16	97.5	27°39'1.30"N	85°21'53.04"E	18.3	79.2	Changathali
17	35.9	27°38'58.92"N	85°21'57.91"E	16	19.9	Siddipur
18	67.8	27°38'55.07"N	85°21'56.66"E	32.9	34.9	Siddipur

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
19	42.5	27°38'49.95"N	85°21'53.95"E	18.7	23.8	Siddipur
20	61.5	27°38'42.84"N	85°21'52.53"E	23.6	37.9	Siddipur
21	51.5	27°38'35.48"N	85°21'50.82"E	35.6	15.9	Siddipur
22	58.6	27°38'33.08"N	85°21'42.91"E	27.3	31.3	Siddipur
23	38.6	27°38'28.34"N	85°21'39.84"E	9.62	28.98	Bisandol
24	52.4	27°38'24.43"N	85°21'39.21"E	26.6	25.8	Bisandol
25	39.4	27°38'17.38"N	85°21'40.28"E	22.8	16.6	Bisandol
26	49.3	27°38'9.05"N	85°21'38.44"E	29.3	20	Bisandol
27	40.4	27°38'2.23"N	85°21'33.79"E	27	13.4	Godavari Khola
28	34.9	27°38'1.98"N	85°21'29.61"E	19.5	15.4	Godavari Khola
29	52.8	27°37'58.81"N	85°21'23.21"E	37.6	15.2	Godavari Khola
30	53.2	27°37'59.75"N	85°21'16.38"E	31	22.2	Godavari Khola
31	41.2	27°37'55.67"N	85°21'12.06"E	17	24.2	Godavari Khola
32	53.8	27°37'49.55"N	85°21'6.54"E	30	23.8	Thaiba
33	57	27°37'45.16"N	85°21'10.52"E	25.9	31.1	Thaiba
34	36.9	27°37'40.67"N	85°21'10.59"E	23.1	13.8	Thaiba
35	33.4	27°37'34.08"N	85°21'12.74"E	19.6	13.8	Thaiba
36	40.5	27°37'29.92"N	85°21'9.73"E	21.3	19.2	Thaiba
37	32.7	27°37'26.36"N	85°21'12.90"E	14	18.7	Godavari Khola
38	48	27°37'22.78"N	85°21'15.56"E	21.5	26.5	Godavari Khola
39	35.7	27°37'18.88"N	85°21'22.79"E	20.7	15	Godavari Khola
40	33.6	27°37'16.56"N	85°21'25.53"E	16.7	16.9	Godavari Khola
41	55.7	27°37'11.46"N	85°21'30.38"E	32.8	22.9	Godavari Khola
42	38.8	27°37'8.02"N	85°21'29.97"E	24	14.8	Godavari Khola
43	47.3	27°37'4.96"N	85°21'26.81"E	27	20.3	Godavari Khola

Table 5-6: Model based flood inundation extent during 50 years return period flood in Mahadev River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	82.4	27°44'20.32"N	85°18'35.81"E	45.9	36.5	Junction with Bishnumati Khola
2	26.8	27°44'22.18"N	85°18'34.68"E	17.43	9.37	Mahadev Khola
3	35.5	27°44'26.28"N	85°18'25.69"E	24	11.5	Mahadev Khola
4	44.2	27°44'26.35"N	85°18'20.37"E	28.3	15.9	Mahadev Khola
5	44.3	27°44'27.42"N	85°18'10.77"E	27.9	16.4	Mahadev Khola
6	37.4	27°44'31.55"N	85°17'59.61"E	20.2	17.2	Mahadev Khola
7	30.6	27°44'39.03"N	85°18'0.58"E	15.9	14.7	Mahadev Khola
8	40.4	27°44'46.98"N	85°18'0.95"E	18.5	21.9	Nepaltar
9	47.6	27°44'52.11"N	85°18'2.74"E	17.8	29.8	Nepaltar
10	46.1	27°45'0.29"N	85°18'6.47"E	21.5	24.6	Paiyatar
11	45.6	27°45'4.29"N	85°18'10.03"E	14.2	31.4	Paiyatar
12	45	27°45'8.92"N	85°18'10.41"E	29.2	15.8	Paiyatar
13	38.9	27°45'11.64"N	85°18'9.45"E	17.2	21.7	Paiyatar
14	25.3	27°45'13.57"N	85°18'8.24"E	11.8	13.5	Paiyatar
15	35.3	27°45'17.98"N	85°18'5.19"E	25.1	10.2	Takeswor
16	27.9	27°45'27.10"N	85°18'6.37"E	11.7	16.2	Takeswor
17	30.7	27°45'31.63"N	85°18'12.90"E	15.7	15	Dharmasthali
18	31.3	27°45'32.05"N	85°18'18.01"E	15.9	15.4	Dharmasthali
19	33	27°45'36.02"N	85°18'21.93"E	20.6	12.4	Dharmasthali
20	38.4	27°45'40.45"N	85°18'26.00"E	22	16.4	Dharmasthali
21	34.8	27°45'46.50"N	85°18'30.73"E	18.8	16	Dharmasthali
22	28.6	27°45'49.41"N	85°18'32.31"E	23.44	5.16	Phutung
23	27.3	27°45'55.76"N	85°18'31.93"E	10.2	17.1	Phutung
24	39.9	27°45'59.65"N	85°18'30.87"E	23.9	16	Phutung
25	34.8	27°46'1.67"N	85°18'30.34"E	14.6	20.2	Phutung
26	29	27°46'6.50"N	85°18'32.43"E	13.8	15.2	Phutung
27	29.6	27°46'11.32"N	85°18'33.85"E	19.4	10.2	Phutung
28	25.7	27°46'16.45"N	85°18'36.95"E	13.9	11.8	Phutung

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
29	28.4	27°46'19.15"N	85°18'38.57"E	15.5	12.9	Chimber pokhari
30	32.6	27°46'22.11"N	85°18'37.67"E	17.7	14.9	Chimber pokhari
31	21.6	27°46'29.33"N	85°18'34.56"E	11.99	9.61	Chimber pokhari
32	18.6	27°46'38.83"N	85°18'36.84"E	8.76	9.84	Chimber pokhari
33	14.3	27°46'43.60"N	85°18'36.64"E	7.84	6.46	Chimber pokhari
35	14.5	27°46'46.70"N	85°18'36.34"E	6.01	8.49	Chimber pokhari
36	12.7	27°46'51.35"N	85°18'27.07"E	5.19	7.51	Chimber pokhari
37	18.2	27°46'52.24"N	85°18'22.40"E	11.71	6.49	Tarakeswar
38	16	27°46'56.17"N	85°18'19.29"E	7.62	8.38	Tarakeswar
39	14.9	27°46'58.92"N	85°18'13.24"E	5.67	9.23	Tarakeswar
40	12.3	27°47'4.44"N	85°18'8.84"E	7.12	5.18	Tarakeswar
41	10.8	27°47'11.36"N	85°18'6.40"E	5.27	5.53	Tarakeswar
42	11	27°47'14.37"N	85°18'6.66"E	6.5	4.5	Tarakeswar
43	7.65	27°47'21.10"N	85°18'7.44"E	2.93	4.72	Tarakeswar
43	8.21	27°47'28.97"N	85°18'4.84"E	2.32	5.89	Tarakeswar
43	7.39	27°47'31.95"N	85°18'2.14"E	3.77	3.62	Tarakeswar
43	6.11	27°47'36.08"N	85°18'1.36"E	2.58	3.53	Tarakeswar
43	6.87	27°47'40.64"N	85°17'59.55"E	2.01	4.86	Tarakeswar

Table 5-7: Model based flood inundation extent during 50 years return period flood in Sangla River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	77.2	27°44'41.28"N	85°18'54.97"E	43.3	33.9	Junction with Bishnumati Khola
2	88.4	27°44'45.70"N	85°18'54.57"E	44.1	44.3	Manamaiju
3	58.8	27°44'49.84"N	85°18'54.07"E	19.5	39.3	Manamaiju
4	73.4	27°44'52.77"N	85°18'54.18"E	34.4	39	Manamaiju
5	62.3	27°45'1.66"N	85°18'58.69"E	26.3	36	Manamaiju

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
7	65	27°45'8.42"N	85°18'57.98"E	41	24	Manamaiju
8	41	27°45'13.88"N	85°18'59.50"E	16.4	24.6	Manamaiju
9	52.5	27°45'23.02"N	85°19'0.70"E	43.74	8.76	Srijana nagar
10	77.2	27°45'23.62"N	85°18'59.27"E	63.9	13.3	Srijana nagar
11	23.6	27°45'28.23"N	85°18'57.71"E	16.73	6.87	Srijana nagar
12	25.3	27°45'33.05"N	85°18'57.84"E	14.7	10.6	Srijana nagar
13	29.2	27°45'36.87"N	85°18'58.52"E	14.2	15	Srijana nagar
15	26	27°45'42.86"N	85°19'1.73"E	15	11	Sangla Khola
16	32.6	27°45'47.59"N	85°19'4.38"E	22.93	9.67	Sangla Khola
17	28.7	27°45'48.95"N	85°19'4.69"E	16.7	12	Sangla Khola
18	28	27°45'53.02"N	85°19'3.43"E	10.6	17.4	Sangla Khola
19	19.8	27°46'0.08"N	85°19'1.24"E	10.08	9.72	Sangla Khola
20	25.4	27°46'4.26"N	85°19'0.82"E	15.95	9.45	Sangla Khola
21	26.7	27°46'7.75"N	85°18'59.73"E	8.1	18.6	Sangla Khola
22	38.6	27°46'10.47"N	85°18'56.96"E	23.1	15.5	Sangla Khola
23	45.9	27°46'14.84"N	85°18'58.19"E	39.96	5.94	Sangla Khola
24	52.6	27°46'17.56"N	85°19'4.20"E	16.4	36.2	Sangla Khola
26	52.7	27°46'23.65"N	85°19'9.17"E	43.49	9.21	Chimber pokhari
27	35	27°46'24.77"N	85°19'14.16"E	8.2	26.8	Chimber pokhari
28	46.6	27°46'26.52"N	85°19'22.08"E	6.7	39.9	Chimber pokhari
29	51.5	27°46'30.69"N	85°19'20.25"E	13.3	38.2	Chimber pokhari
30	61.3	27°46'35.10"N	85°19'17.80"E	28.2	33.1	Chimber pokhari
31	30.3	27°46'35.10"N	85°19'17.80"E	17.3	13	Chimber pokhari
32	74.6	27°46'39.35"N	85°19'13.93"E	41.4	33.2	Chimber pokhari
34	33.6	27°46'45.55"N	85°19'15.15"E	21.3	12.3	Sangla Khola
36	36.9	27°46'51.94"N	85°19'15.09"E	8.2	28.7	Sangla Khola
37	29.5	27°46'55.68"N	85°19'19.14"E	3.5	26	Sangla Khola
38	21.4	27°47'11.70"N	85°19'32.75"E	9.1	12.3	Sangla Khola
40	27.9	27°47'14.57"N	85°19'28.36"E	16.2	11.7	Sangla Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
41	24.6	27°47'19.19"N	85°19'28.49"E	10.7	13.9	Sangla Khola
42	19.2	27°47'24.54"N	85°19'28.13"E	9.71	9.49	Sangla Khola
43	20	27°47'28.19"N	85°19'26.25"E	9.5	10.5	Sangla Khola
44	22.5	27°47'32.91"N	85°19'29.17"E	19.06	3.44	Sangla Khola
45	10.8	27°47'37.63"N	85°19'31.06"E	4.23	6.57	Sangla Khola
46	8.4	27°47'42.96"N	85°19'30.20"E	1.3	7.1	Sangla Khola
47	19.6	27°47'45.31"N	85°19'29.13"E	4.2	15.4	Sangla Khola
48	10.9	27°47'49.50"N	85°19'27.56"E	7.2	3.7	Sangla Khola
49	16	27°47'51.31"N	85°19'24.81"E	6.71	9.29	Sangla Khola
50	17.3	27°47'53.36"N	85°19'24.21"E	7.3	10	Sangla Khola
51	21.8	27°47'56.71"N	85°19'21.78"E	8.1	13.7	Sangla Khola
52	38.7	27°48'0.29"N	85°19'19.22"E	19.8	18.9	Sangla Khola
53	10.8	27°48'3.99"N	85°19'18.35"E	6.29	4.51	Sangla Khola
54	7.37	27°48'7.97"N	85°19'18.48"E	3.94	3.43	Sangla Khola
55	23.2	27°48'12.11"N	85°19'17.89"E	16.53	6.67	Sangla Khola

Table 5-8: Model based flood inundation extent during 50 years return period flood in Bishnumati River at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	101	27°41'30.65"N	85°18'6.60"E	56	45	Junction with Bagmati Khola
2	96.7	27°41'32.97"N	85°18'2.85"E	70.7	26	Teku
3	88.5	27°41'42.28"N	85°18'0.84"E	34.1	54.4	Junction with Manamati Khola
4	130	27°41'49.27"N	85°18'6.07"E	86	44	Tankeshwor
5	109	27°41'54.59"N	85°18'9.00"E	54	55	Tankeshwor
6	78.6	27°42'2.05"N	85°18'9.84"E	47.6	31	Tankeshwor
7	109	27°42'8.21"N	85°18'7.97"E	67	42	Tankeshwor
8	119	27°42'16.30"N	85°18'6.80"E	64	55	Naradevi

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
9	108	27°42'26.30"N	85°18'8.41"E	68	40	Naradevi
10	100	27°42'33.02"N	85°18'9.77"E	56.6	43.4	Dallu
11	120	27°42'35.65"N	85°18'9.48"E	84.5	35.5	Dallu
12	124	27°42'41.28"N	85°18'8.61"E	75.8	48.2	Dallu
13	93.8	27°42'49.85"N	85°18'7.44"E	60.3	33.5	Dallu
14	96.5	27°42'54.24"N	85°18'5.96"E	47	49.5	Dallu
15	168	27°42'57.02"N	85°18'3.46"E	95.2	72.8	Khusibun
16	93.8	27°43'6.06"N	85°17'57.53"E	48.6	45.2	Khusibun
17	86	27°43'11.61"N	85°17'58.36"E	61.4	24.6	Khusibun
18	91.4	27°43'19.75"N	85°18'2.62"E	65	26.4	Bishnumati Khola
19	94.4	27°43'33.35"N	85°18'20.35"E	54.9	39.5	Bishnumati Khola
20	125	27°43'49.47"N	85°18'24.77"E	91.3	33.7	Bishnumati Khola
21	109	27°44'1.19"N	85°18'24.70"E	80.1	28.9	Bishnumati Khola
24	95.7	27°44'20.16"N	85°18'36.72"E	61.7	34	Bishnumati Khola
25	68	27°44'26.12"N	85°18'44.68"E	42.4	25.6	Bishnumati Khola
26	107	27°44'33.52"N	85°18'52.70"E	71.2	35.8	Bishnumati Khola
27	77.6	27°44'40.52"N	85°18'55.87"E	37.9	39.7	Bishnumati Khola
28	43.1	27°44'40.96"N	85°19'0.07"E	27.4	15.7	Bishnumati Khola
29	94.4	27°44'41.69"N	85°19'12.26"E	65.9	28.5	Bishnumati Khola
30	109	27°44'40.18"N	85°19'15.07"E	76.3	32.7	Bishnumati Khola
31	66.1	27°44'48.33"N	85°19'18.35"E	44.8	21.3	Bishnumati Khola
33	75	27°44'56.56"N	85°19'22.55"E	43.4	31.6	Gongabu
34	80	27°45'1.69"N	85°19'22.06"E	53.3	26.7	Gongabu
35	69.3	27°45'4.88"N	85°19'22.33"E	52.4	16.9	Gongabu
36	76.3	27°45'12.49"N	85°19'30.46"E	-9.5	85.8	Grande Hospital
37	77.1	27°45'11.36"N	85°19'35.36"E	37.1	40	Grande Hospital
38	90.9	27°45'23.36"N	85°19'40.29"E	75	15.9	Bishnumati Khola
39	101	27°45'24.48"N	85°19'42.29"E	67.8	33.2	Bishnumati Khola
40	141	27°45'23.12"N	85°19'49.87"E	69	72	Bishnumati Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
41	145	27°45'25.69"N	85°20'1.61"E	86.9	58.1	Chyasundol
42	118	27°45'33.17"N	85°20'3.07"E	84.4	33.6	Chyasundol
43	131	27°45'41.58"N	85°20'12.21"E	50.1	80.9	Chyasundol
44	70	27°45'52.30"N	85°20'17.82"E	27	43	Bishnumati Khola
45	113	27°45'59.28"N	85°20'25.71"E	60.2	52.8	Bishnumati Khola
46	85	27°46'14.18"N	85°20'28.89"E	40.8	44.2	Bishnumati Khola
47	43	27°46'21.14"N	85°20'41.00"E	27.5	15.5	Bishnumati Khola
48	38.4	27°46'23.68"N	85°20'44.84"E	17.3	21.1	Bishnumati Khola
49	41	27°46'26.86"N	85°20'46.04"E	13.4	27.6	Bishnumati Khola
50	48	27°46'25.12"N	85°20'57.57"E	12.6	35.4	Thapa gaun
51	28.1	27°46'27.72"N	85°21'5.71"E	6.6	21.5	Thapa gaun
52	26	27°46'31.08"N	85°21'10.39"E	6.4	19.6	Thapa gaun
53	20.1	27°46'37.38"N	85°21'15.28"E	11.3	8.8	Thapa gaun
54	23	27°46'43.66"N	85°21'14.27"E	10.8	12.2	Dulal gaun
55	18.5	27°46'47.58"N	85°21'16.88"E	11	7.5	Dulal gaun
56	16.3	27°46'55.18"N	85°21'21.56"E	9.5	6.8	Dulal gaun
57	13	27°46'59.82"N	85°21'23.50"E	6.79	6.21	Dulal gaun
58	13.6	27°47'9.71"N	85°21'26.52"E	8.1	5.5	Dulal gaun

Table 5-9: Model based flood inundation extent during 50 years return period flood in Dhobi Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	91.6	27°41'13.48"N	85°19'28.54"E	54.3	37.3	Junction with bagmati Khola
2	98.5	27°41'15.76"N	85°19'29.90"E	71	27.5	Thapathali
3	83.6	27°41'19.28"N	85°19'41.17"E	44	39.6	Buddhanagar
4	56.4	27°41'23.66"N	85°19'41.71"E	27.1	29.3	Buddhanagar
5	54.9	27°41'27.45"N	85°19'42.03"E	37.3	17.6	Rudramati marg

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
6	71.7	27°41'33.39"N	85°19'44.60"E	50.6	21.1	Rudramati marg
7	105	27°41'39.63"N	85°19'47.56"E	78.3	26.7	Rudramati marg
8	64.2	27°41'44.43"N	85°19'47.53"E	45.9	18.3	Anamnagar
9	53.2	27°41'52.81"N	85°19'52.26"E	35.9	17.3	Anamnagar
10	92.4	27°41'59.31"N	85°19'52.05"E	79.9	12.5	Anamnagar
11	48.5	27°42'11.27"N	85°20'9.89"E	21.9	26.6	Seto pul
12	42.9	27°42'28.01"N	85°20'12.50"E	21.3	21.6	Rato pul
13	56.5	27°42'41.60"N	85°20'14.49"E	28.1	28.4	Kalo pul
14	64.6	27°42'44.15"N	85°20'15.89"E	28.1	36.5	Dhobi Khola
15	93.5	27°42'54.82"N	85°20'19.02"E	42.4	51.1	Bhatkeko pul
16	61.5	27°43'4.90"N	85°20'22.35"E	24.8	36.7	Dhobi Khola
17	66	27°43'8.21"N	85°20'27.09"E	31.2	34.8	Dhobi Khola
18	109	27°43'11.89"N	85°20'31.37"E	51.6	57.4	Dhobi Khola
19	69.8	27°43'18.71"N	85°20'39.84"E	37.3	32.5	Dhobi Khola
20	90.5	27°43'18.85"N	85°20'42.68"E	22.8	67.7	Dhobi Khola
21	75.8	27°43'21.29"N	85°20'44.99"E	31.2	44.6	Dhobi Khola
22	56.8	27°43'28.60"N	85°20'44.99"E	17.6	39.2	Kumaristhan
23	53.1	27°43'37.79"N	85°20'56.40"E	37.4	15.7	Kumaristhan
24	70.7	27°43'43.74"N	85°21'0.20"E	27.5	43.2	Dhobi Khola
25	33.6	27°43'52.37"N	85°20'58.12"E	15.1	18.5	Dhobi Khola
26	58.6	27°43'59.99"N	85°21'6.06"E	19.7	38.9	Dhobi Khola
27	59.6	27°44'11.38"N	85°21'13.00"E	18.6	41	Dhobi Khola
28	59.3	27°44'18.77"N	85°21'16.24"E	19.8	39.5	Barphedi
29	48.6	27°44'24.07"N	85°21'8.03"E	34.3	14.3	Dhobi Khola
30	66	27°44'28.41"N	85°21'2.52"E	56.19	9.81	Dhobi Khola
31	72.8	27°44'37.70"N	85°21'5.94"E	32.2	40.6	Dhobi Khola
33	69.7	27°44'49.50"N	85°21'22.55"E	34.7	35	Dhobi Khola
34	73.9	27°44'54.13"N	85°21'31.22"E	47.3	26.6	Dhobi Khola
35	84	27°45'6.11"N	85°21'33.51"E	36.5	47.5	Dhobi Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
36	91.6	27°45'53.56"N	85°21'51.38"E	80.4	11.2	Dhobi Khola
37	87.6	27°45'12.66"N	85°21'38.32"E	50.4	37.2	Dhobi Khola
38	75.5	27°45'22.22"N	85°21'40.63"E	39.9	35.6	Dhobi Khola
39	29.2	27°45'28.21"N	85°21'49.31"E	16.4	12.8	Dhobi Khola
40	17.4	27°45'39.34"N	85°21'51.27"E	8.9	8.5	Budhanilkantha
41	14.7	27°45'47.69"N	85°21'53.02"E	6.7	8	Budhanilkantha
42	15.5	27°45'58.27"N	85°21'51.90"E	6.16	9.34	Budhanilkantha
43	15.2	27°46'3.04"N	85°21'52.11"E	6.9	8.3	Budhanilkantha
44	13.9	27°46'8.82"N	85°21'54.69"E	7.7	6.2	Budhanilkantha
45	29	27°46'12.59"N	85°21'59.32"E	19.2	9.8	Dhobi Khola
46	20.9	27°46'14.97"N	85°22'8.48"E	12.7	8.2	Dhobi Khola
47	23.9	27°46'21.94"N	85°22'13.70"E	16	7.9	Dhobi Khola
48	31.7	27°46'24.19"N	85°22'17.93"E	25.9	5.8	Dhobi Khola
49	21.9	27°46'27.55"N	85°22'25.12"E	13.8	8.1	Dhobi Khola
50	12.3	27°46'29.25"N	85°22'36.30"E	9.1	3.2	Dhobi Khola

Table 5-10: Model based flood inundation extent during 50 years return period flood in Lundi Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	103	27°45'58.27"N	85°20'25.63"E	56.2	46.8	Junction with bishnumati Khola
2	69.5	27°45'56.53"N	85°20'27.62"E	34.8	34.7	Lundi Khola
3	62.2	27°45'53.77"N	85°20'27.37"E	10.9	51.3	Lundi Khola
4	62.4	27°45'52.43"N	85°20'30.72"E	47.9	14.5	Lundi Khola
5	57.7	27°45'49.79"N	85°20'31.64"E	24.7	33	Lundi Khola
6	45.3	27°45'48.70"N	85°20'35.38"E	26.4	18.9	Lundi Khola
7	46.3	27°45'46.26"N	85°20'39.57"E	11.9	34.4	Lundi Khola
8	47.3	27°45'45.92"N	85°20'45.13"E	38.75	8.55	Lundi Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
9	28.2	27°45'46.44"N	85°20'50.46"E	20.8	7.4	Lundi Khola
10	61.5	27°45'47.84"N	85°20'52.51"E	41.6	19.9	Lundi Khola
11	59.7	27°45'51.77"N	85°20'58.70"E	32.2	27.5	Lundi Khola
12	47.6	27°45'53.49"N	85°21'1.95"E	18.7	28.9	Lundi Khola
13	26.7	27°45'58.57"N	85°21'4.37"E	22.15	4.55	Golfutar
14	35	27°46'0.98"N	85°21'8.98"E	31.2	3.8	Golfutar
15	19.3	27°46'3.27"N	85°21'11.84"E	9.99	9.31	Golfutar
16	12.4	27°46'4.59"N	85°21'14.09"E	3.13	9.27	Golfutar
17	21.3	27°46'9.37"N	85°21'13.56"E	18.48	2.82	Golfutar
18	18.7	27°46'11.14"N	85°21'18.38"E	10.31	8.39	Golfutar
19	18.9	27°46'15.80"N	85°21'19.70"E	6.9	12	Golfutar
20	56.6	27°46'18.69"N	85°21'18.90"E	20	36.6	Golfutar
21	34.7	27°46'22.38"N	85°21'19.46"E	23.5	11.2	Golfutar
23	32.3	27°46'26.52"N	85°21'23.15"E	24.66	7.64	Golfutar
27	35.1	27°46'29.48"N	85°21'33.98"E	16.8	18.3	Golfutar
30	23.3	27°46'37.08"N	85°21'36.23"E	11.5	11.8	Golfutar

Table 5-11: Model based flood inundation extent during 50 years return period flood in Jamla Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
		Northing	Easting	(meters)	(meters)	
1	94	27°46'12.22"N	85°21'58.71"E	43.2	50.8	Junction with dhobi Khola
2	43.4	27°46'13.19"N	85°21'57.30"E	33.81	9.59	Jamle Khola
3	28.4	27°46'15.53"N	85°21'58.09"E	20.4	8	Jamle Khola
4	33.8	85°21'58.09"E	85°21'57.99"E	12.9	20.9	Jamle Khola
5	25	27°46'19.46"N	85°21'58.32"E	2.7	22.3	Jamle Khola
6	49.6	27°46'21.86"N	85°21'58.81"E	2.6	47	Jamle Khola
7	19.5	27°46'22.09"N	85°21'56.50"E	15.37	4.13	Jamle Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
8	13.9	27°46'24.90"N	85°21'56.50"E	10.7	3.2	Jamle Khola
9	13	27°46'27.16"N	85°21'56.59"E	7.9	5.1	Jamle Khola
10	9.97	27°46'28.97"N	85°21'56.71"E	7.19	2.78	Jamle Khola
11	17.4	27°46'31.99"N	85°21'57.31"E	11.82	5.58	Jamle Khola
12	16.6	27°46'33.08"N	85°21'56.42"E	9.98	6.62	Jamle Khola
13	22	27°46'35.61"N	85°21'55.70"E	16.77	5.23	Jamle Khola
14	33.2	27°46'37.17"N	85°21'56.21"E	16	17.2	Jamle Khola
15	25.9	27°46'37.96"N	85°21'57.12"E	5.4	20.5	Jamle Khola
16	14.7	27°46'39.20"N	85°21'57.19"E	6.09	8.61	Jamle Khola
17	20	27°46'41.69"N	85°21'56.82"E	15.37	4.63	Jamle Khola
18	25.7	27°46'43.73"N	85°21'56.92"E	14	11.7	Jamle Khola
19	14	27°46'45.45"N	85°21'55.51"E	6	8	Jamle Khola
20	14.2	27°46'46.61"N	85°21'55.22"E	9.87	4.33	Jamle Khola
21	17.2	27°46'48.10"N	85°21'55.24"E	5.8	11.4	Jamle Khola
22	23	27°46'49.71"N	85°21'56.08"E	12.9	10.1	Jamle Khola
23	16	27°46'50.87"N	85°21'55.57"E	12.63	3.37	Jamle Khola
24	18.9	27°46'52.80"N	85°21'56.40"E	8.5	10.4	Jamle Khola
25	11.4	27°46'54.36"N	85°21'56.29"E	5.76	5.64	Jamle Khola
26	11.9	27°46'55.94"N	85°21'56.77"E	7.47	4.43	Jamle Khola
27	20	27°46'57.78"N	85°21'57.05"E	10.75	9.25	Jamle Khola
28	22.2	27°46'59.12"N	85°21'58.01"E	19.04	3.16	Jamle Khola
29	23	27°47'1.76"N	85°21'59.11"E	9	14	Jamle Khola
30	17	27°47'2.68"N	85°21'59.10"E	8.72	8.28	Jamle Khola
31	16.7	27°47'4.51"N	85°21'58.96"E	11.4	5.3	Jamle Khola
32	18.8	27°47'5.47"N	85°22'0.88"E	7.2	11.6	Jamle Khola
33	20.2	27°47'9.33"N	85°22'3.59"E	11.63	8.57	Jamle Khola
34	17.9	27°47'11.99"N	85°22'4.71"E	5.9	12	Jamle Khola
35	18	27°47'14.56"N	85°22'7.26"E	11.29	6.71	Jamle Khola
36	22.6	27°47'16.77"N	85°22'8.95"E	10.3	12.3	Jamle Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
37	15	27°47'21.19"N	85°22'13.19"E	7.77	7.23	Jamle Khola
39	12.5	27°47'22.58"N	85°22'16.94"E	2.5	10	Jamle Khola
40	10.6	27°47'23.96"N	85°22'18.98"E	5.5	5.1	Jamle Khola

Table 5-12: Model based flood inundation extent during 50 years return period flood in Kodku Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
1	76.7	27°40'18.21"N	85°20'36.69"E	27.7	49	Junction with bagmati Khola
2	88.7	27°40'14.80"N	85°20'33.40"E	38.7	50	Balkumari area
3	64.5	27°40'16.85"N	85°20'30.03"E	13.8	50.7	Balkumari area
4	85.3	27°40'11.23"N	85°20'21.71"E	5.3	80	Balkumari area
5	64.7	27°40'2.29"N	85°20'18.92"E	51	13.7	Balkumari area
6	81.1	27°40'1.10"N	85°20'13.11"E	42.7	38.4	Balkumari area
7	60.1	27°40'0.48"N	85°20'6.38"E	29.3	30.8	Balkumari area
8	16.5	27°39'57.42"N	85°20'1.48"E	11.74	4.76	Balkumari area
10	153	27°39'51.09"N	85°20'4.11"E	90.8	62.2	Gwarko area
11	193	27°39'46.56"N	85°20'2.37"E	94.2	98.8	Gwarko area
12	128	27°39'45.07"N	85°20'6.83"E	45.2	82.8	Gwarko area
13	98.4	27°39'42.64"N	85°20'6.89"E	44.8	53.6	Gwarko area
14	161	27°39'35.91"N	85°20'8.30"E	104	57	Gwarko area
15	100	27°39'30.99"N	85°20'8.54"E	43.6	56.4	Gwarko area
16	54.2	27°39'27.44"N	85°20'10.05"E	34.3	19.9	Gwarko area
17	85.9	27°39'20.59"N	85°20'8.30"E	78.9	7	Little angles school
18	141	27°39'17.04"N	85°20'7.29"E	75.4	65.6	Little angles school
19	75.9	27°39'11.69"N	85°20'6.04"E	15.9	60	Little angles school
22	37.4	27°38'58.11"N	85°20'12.57"E	18.1	19.3	Little angles school
23	53.5	27°38'51.81"N	85°20'9.43"E	36.1	17.4	Little angles school

Section No.	Model Based Floodway Width	Coordinates of River Centerline		Floodway in Left bank from river centerline	Floodway in Right bank from river centerline	Remarks
	(meters)	Northing	Easting	(meters)	(meters)	
24	111	27°38'48.88"N	85°20'8.79"E	82.1	28.9	Hattiban area
25	105	27°38'39.51"N	85°20'4.70"E	27.6	77.4	Hattiban area
26	60	27°38'32.24"N	85°20'4.44"E	17	43	Dhapakhel area
27	91	27°38'28.49"N	85°20'6.14"E	24.5	66.5	Dhapakhel area
28	63.9	27°38'23.85"N	85°20'6.49"E	14.9	49	Dhapakhel area
29	62.7	27°38'18.51"N	85°20'7.18"E	29.2	33.5	Dhapakhel area
30	69.3	27°38'14.69"N	85°20'9.95"E	56.5	12.8	Dhapakhel area
31	84	27°38'12.88"N	85°20'6.43"E	46.5	37.5	Dhapakhel area
32	53.2	27°38'8.66"N	85°20'5.18"E	30.3	22.9	Dhapakhel area
33	66.5	27°38'8.28"N	85°20'3.03"E	32.6	33.9	Dhapakhel area
34	70.9	27°38'2.88"N	85°20'1.34"E	28.3	42.6	Dhapakhel area
35	63.4	27°38'0.00"N	85°20'6.66"E	36	27.4	Dhapakhel area
36	41.6	27°37'56.36"N	85°20'10.26"E	34.73	6.87	Dhapakhel area
37	33.8	27°37'53.60"N	85°20'8.66"E	9.2	24.6	Dhapakhel area
38	45.8	27°37'49.71"N	85°20'13.54"E	38.85	6.95	Dhapakhel area
40	70.3	27°37'44.88"N	85°20'19.81"E	53.1	17.2	Thaiba area
41	59.3	27°37'44.34"N	85°20'25.20"E	34.8	24.5	Thaiba area
42	70.8	27°37'41.15"N	85°20'25.78"E	53	17.8	Thaiba area
43	84.4	27°37'39.41"N	85°20'31.97"E	74.69	9.71	Thaiba area
44	60.5	27°37'33.93"N	85°20'34.89"E	50.1	10.4	Jharuwarashi area
45	64.8	27°37'29.69"N	85°20'33.53"E	16.8	48	Jharuwarashi area
46	38	27°37'19.50"N	85°20'32.86"E	8.4	29.6	Jharuwarashi area
47	15.5	27°37'13.57"N	85°20'40.28"E	8.71	6.79	Jharuwarashi area
48	18.2	27°37'8.23"N	85°20'52.62"E	6.3	11.9	Jharuwarashi area
49	23.7	27°37'4.23"N	85°20'55.23"E	11.1	12.6	Jharuwarashi area
50	16	27°36'59.67"N	85°20'56.01"E	7.04	8.96	Jharuwarashi area
51	22	27°36'53.28"N	85°20'59.35"E	6.9	15.1	Jharuwarashi area
52	30.6	27°36'46.06"N	85°21'4.73"E	23.06	7.54	Jharuwarashi area
53	28.5	27°36'33.08"N	85°21'2.81"E	18.1	10.4	Jharuwarashi area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
54	36	27°36'25.07"N	85°20'58.52"E	18.3	17.7	Jharuwarashi area
55	31.5	27°36'18.81"N	85°21'1.24"E	14.3	17.2	Jharuwarashi area
56	29	27°36'13.88"N	85°21'4.93"E	18.5	10.5	Badhikhel area
57	25.3	27°36'11.41"N	85°21'4.54"E	10.9	14.4	Badhikhel area
58	14.4	27°36'4.93"N	85°21'9.72"E	5.47	8.93	Badhikhel area
59	13.6	27°35'58.75"N	85°21'6.19"E	6.26	7.34	Badhikhel area
60	16.4	27°35'52.71"N	85°21'0.45"E	6	10.4	Badhikhel area
61	17.1	27°35'44.53"N	85°21'1.24"E	11.82	5.28	Badhikhel area
62	16.9	27°35'40.44"N	85°21'0.35"E	11.9	5	Badhikhel area
63	10.9	27°35'35.33"N	85°20'59.45"E	5.6	5.3	Badhikhel area
64	9.5	27°35'25.88"N	85°21'3.08"E	5.12	4.38	Badhikhel area
65	9.22	27°35'22.64"N	85°21'6.06"E	7.99	1.23	Badhikhel area
66	8.74	27°35'13.79"N	85°21'8.41"E	3.64	5.1	Badhikhel area
67	10.2	27°35'8.90"N	85°21'10.35"E	5.63	4.57	Badhikhel area
68	11.5	27°35'5.85"N	85°21'18.42"E	5.8	5.7	Badhikhel area
69	12.2	27°35'4.36"N	85°21'25.97"E	5.93	6.27	Badhikhel area
70	9.63	27°35'2.55"N	85°21'30.96"E	6.66	2.97	Badhikhel area
71	12.2	27°35'1.08"N	85°21'39.79"E	8.2	4	Badhikhel area

Table 5-13: Model based flood inundation extent during 50 years return period flood in Manamati Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
1	92	27°41'43.14"N	85°18'0.65"E	44.1	47.9	Junction with bishnumati Khola
2	31.4	27°41'46.29"N	85°17'54.96"E	13.4	18	Tankeshwor area
3	69.3	27°41'47.02"N	85°17'51.78"E	40.1	29.2	Tankeshwor area
4	51.6	27°41'47.40"N	85°17'46.23"E	29.6	22	Tankeshwor area
6	68.2	27°41'46.72"N	85°17'31.88"E	46	22.2	Tankeshwor area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
9	55.2	27°41'50.74"N	85°17'19.37"E	23.1	32.1	Kalimati area
10	49.9	27°41'51.46"N	85°17'13.21"E	33	16.9	Kalimati area
11	45.6	27°41'53.63"N	85°17'9.62"E	34.2	11.4	Kalimati area
12	46.3	27°41'57.21"N	85°17'2.35"E	15	31.3	Kalimati area
13	45	27°41'58.72"N	85°16'57.69"E	26.1	18.9	Kalimati area
14	42.5	27°41'58.41"N	85°16'52.92"E	29	13.5	Syuchatar area
15	38.1	27°42'0.58"N	85°16'46.63"E	18.8	19.3	Syuchatar area
16	32.3	27°42'5.66"N	85°16'42.87"E	27.72	4.58	Syuchatar area
17	37.7	27°42'11.44"N	85°16'38.74"E	30.49	7.21	Syuchatar area
18	36.3	27°42'17.36"N	85°16'29.59"E	27.79	8.51	Syuchatar area
19	41.4	27°42'20.06"N	85°16'27.43"E	13.4	28	Syuchatar area
20	34.8	27°42'17.99"N	85°16'25.39"E	28.12	6.68	Syuchatar area
21	35.8	27°42'18.71"N	85°16'20.46"E	22.9	12.9	Syuchatar area
22	35.9	27°42'23.40"N	85°16'6.08"E	12.2	23.7	Syuchatar area
23	46.5	27°42'23.40"N	85°16'6.08"E	17.2	29.3	Syuchatar area
25	47.7	27°42'27.16"N	85°15'59.06"E	22.4	25.3	Syuchatar area
28	30.5	27°42'29.09"N	85°15'51.24"E	25.13	5.37	Manamati Khola
29	31.3	27°42'32.87"N	85°15'46.44"E	26.49	4.81	Manamati Khola
30	30	27°42'36.47"N	85°15'40.87"E	18	12	Manamati Khola
31	22.4	27°42'42.32"N	85°15'37.14"E	10.7	11.7	Manamati Khola
32	19.5	27°42'44.26"N	85°15'31.31"E	13.92	5.58	Manamati Khola
33	24.3	27°42'42.91"N	85°15'25.41"E	19.06	5.24	Manamati Khola
34	25.6	27°42'46.21"N	85°15'20.75"E	20.46	5.14	Manamati Khola
36	18	27°42'49.84"N	85°15'19.18"E	13	5	Ramkot area
37	13.5	27°42'56.17"N	85°15'22.89"E	4.5	9	Ramkot area
38	15.9	27°43'0.71"N	85°15'19.11"E	7.19	8.71	Ramkot area
39	14.2	27°43'4.30"N	85°15'12.28"E	6.91	7.29	Ramkot area
40	14.9	27°43'12.89"N	85°15'10.36"E	7.71	7.19	Ramkot area
41	12.4	27°43'16.89"N	85°15'13.37"E	7.24	5.16	Ramkot area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
42	15.1	27°43'18.96"N	85°15'11.64"E	10.85	4.25	Ramkot area
43	15.3	27°43'20.64"N	85°15'8.15"E	8.73	6.57	Ramkot area
44	12	27°43'22.44"N	85°15'2.62"E	8.11	3.89	Ramkot area
45	10	27°43'28.88"N	85°14'56.60"E	4.76	5.24	Ramkot area
46	9.62	27°43'30.42"N	85°14'52.72"E	5.84	3.78	Ramkot area
47	9.61	27°43'33.10"N	85°14'47.89"E	5.51	4.1	Ramkot area
48	9.24	27°43'39.80"N	85°14'45.28"E	3.94	5.3	Tersa gaun
49	8.92	27°43'46.21"N	85°14'46.25"E	4.27	4.65	Tersa gaun
50	8.1	27°43'54.95"N	85°14'52.04"E	5	3.1	Tersa gaun

Table 5-14: Model based flood inundation extent during 50 years return period flood in Manohara Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
1	93.4	27°40'43.09"N	85°20'1.20"E	51.8	41.6	Junction with bagmati Khola
2	81.6	27°40'38.30"N	85°20'8.86"E	49	32.6	Chyasal area
3	75.5	27°40'33.66"N	85°20'15.05"E	22.8	52.7	Chyasal area
4	74.2	27°40'30.39"N	85°20'21.80"E	44.9	29.3	Chyasal area
5	90.5	27°40'21.94"N	85°20'31.52"E	35.2	55.3	Balkumari area
6	85	27°40'19.70"N	85°20'36.43"E	44.2	40.8	Balkumari area
7	76.3	27°40'6.89"N	85°20'53.83"E	34.8	41.5	Balkumari area
8	83.7	27°40'4.84"N	85°21'5.73"E	49	34.7	Junction with hanumante Khola
9	66.4	27°40'6.22"N	85°21'8.13"E	35.5	30.9	Manohara Khola
10	47.2	27°40'11.40"N	85°21'8.57"E	26.9	20.3	Manohara Khola
11	53.2	27°40'26.45"N	85°21'17.92"E	29.5	23.7	Jadibuti area
12	52	27°40'31.64"N	85°21'19.61"E	32.1	19.9	Jadibuti area
13	47	27°40'37.15"N	85°21'19.63"E	22.1	24.9	Jadibuti area
14	44.5	27°40'53.70"N	85°21'23.89"E	17.9	26.6	Pepsi cola area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
15	106	27°40'56.51"N	85°21'40.37"E	41.5	64.5	Pepsi cola area
16	88.8	27°41'0.71"N	85°21'43.62"E	45.3	43.5	Pepsi cola area
17	77.6	27°41'10.89"N	85°21'53.50"E	46.2	31.4	Pepsi cola area
18	51.3	27°41'21.37"N	85°22'10.33"E	25	26.3	Purano sinamangal
19	65.2	27°41'26.31"N	85°22'17.79"E	46.9	18.3	Purano sinamangal
21	85.6	27°41'36.64"N	85°22'42.79"E	51.3	34.3	Gothatar area
22	82.4	27°41'40.15"N	85°22'52.13"E	47.9	34.5	Gothatar area
23	74	27°41'37.60"N	85°22'56.36"E	38.2	35.8	Gothatar area
25	90.4	27°41'43.67"N	85°23'9.58"E	34.1	56.3	Gothatar area
26	118	27°41'44.41"N	85°23'19.16"E	24.6	93.4	Gothatar area
27	90.5	27°41'55.60"N	85°23'24.44"E	43	47.5	Gothatar area
30	68.2	27°42'12.61"N	85°23'32.78"E	44.7	23.5	Mulpani area
31	70.2	27°42'9.06"N	85°23'40.25"E	27.5	42.7	Mulpani area
32	109	27°42'12.98"N	85°23'48.90"E	57.3	51.7	Mulpani area
33	93.2	27°42'17.45"N	85°23'56.39"E	42.3	50.9	Mulpani area
34	113	27°42'22.55"N	85°24'1.87"E	56	57	Mulpani area
35	75	27°42'24.03"N	85°24'9.84"E	35.4	39.6	Mulpani area
37	103	27°42'29.28"N	85°24'19.97"E	59.4	43.6	Mulpani area
38	107	27°42'36.03"N	85°24'23.93"E	53.8	53.2	Mulpani area
39	75.2	27°42'41.68"N	85°24'34.86"E	44.7	30.5	Manohara Khola
40	72.8	27°42'43.23"N	85°24'42.34"E	31.1	41.7	Manohara Khola
41	86.9	27°42'50.56"N	85°24'39.66"E	46.2	40.7	Manohara Khola
42	104	27°42'51.92"N	85°24'42.86"E	61	43	Manohara Khola
43	173	27°42'58.91"N	85°24'49.39"E	84.4	88.6	Manohara Khola
44	188	27°43'10.14"N	85°24'55.51"E	61	127	Manohara Khola
45	134	27°43'9.39"N	85°25'1.39"E	59.4	74.6	Manohara Khola
46	139	27°43'16.61"N	85°25'6.49"E	69.1	69.9	Manohara Khola
47	141	27°43'17.07"N	85°25'15.23"E	104	37	Manohara Khola
48	117	27°43'21.27"N	85°25'21.88"E	55.5	61.5	Manohara Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
49	129	27°43'24.87"N	85°25'23.98"E	56.6	72.4	Manohara Khola
50	148	27°43'26.67"N	85°25'27.96"E	67.3	80.7	Manohara Khola
51	142	27°43'27.54"N	85°25'32.53"E	63.5	78.5	Manohara Khola
52	99	27°43'30.71"N	85°25'42.50"E	38.7	60.3	Manohara Khola
53	121	27°43'33.04"N	85°25'51.44"E	49.7	71.3	Manohara Khola
54	106	27°43'34.80"N	85°25'54.16"E	46	60	Manohara Khola
55	52.6	27°43'38.20"N	85°26'0.22"E	39.6	13	Manohara Khola
56	47	27°43'38.84"N	85°26'2.06"E	26.6	20.4	Manohara Khola
57	73.2	27°43'37.42"N	85°26'8.54"E	13.9	59.3	Manohara Khola
58	40.6	27°43'41.26"N	85°26'15.56"E	31.5	9.1	Manohara Khola
59	58.7	27°43'41.11"N	85°26'21.15"E	46.8	11.9	Manohara Khola
60	79.6	27°43'38.63"N	85°26'24.84"E	38.3	41.3	Manohara Khola
61	76.2	27°43'34.54"N	85°26'24.34"E	33.7	42.5	Manohara Khola
62	86.6	27°43'31.11"N	85°26'26.92"E	39.2	47.4	Manohara Khola
63	85.5	27°43'29.62"N	85°26'29.25"E	34.6	50.9	Salambutar area
64	98.3	27°43'32.92"N	85°26'39.45"E	57.9	40.4	Salambutar area
65	97.3	27°43'33.35"N	85°26'43.32"E	45.3	52	Salambutar area
66	87.5	27°43'30.43"N	85°26'45.66"E	48.6	38.9	Salambutar area
67	81	27°43'26.66"N	85°26'49.33"E	40	41	Salambutar area
68	60	27°43'26.16"N	85°26'51.18"E	31.9	28.1	Salambutar area
69	74.8	27°43'23.62"N	85°26'55.68"E	39.8	35	Salambutar area
70	108	27°43'17.50"N	85°27'2.78"E	8	100	Salambutar area
71	128	27°43'17.28"N	85°27'8.95"E	55.9	72.1	Salambutar area
72	134	27°43'18.15"N	85°27'13.15"E	69.4	64.6	Salambutar area
73	127	27°43'13.32"N	85°27'18.70"E	22	105	Salambutar area
74	140	27°43'12.02"N	85°27'21.68"E	23	117	Salambutar area
75	120	27°43'11.34"N	85°27'27.87"E	38.3	81.7	Salambutar area
76	89.2	27°43'14.03"N	85°27'29.60"E	43.6	45.6	Salambutar area
77	62.5	27°43'14.65"N	85°27'35.05"E	45.6	16.9	Salambutar area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
78	72.5	27°43'8.43"N	85°27'42.51"E	17.8	54.7	Salambutar area
79	60.9	27°43'10.28"N	85°27'49.88"E	31.6	29.3	Salambutar area
80	76.7	27°43'11.54"N	85°27'54.91"E	26.9	49.8	Salambutar area
81	67.3	27°43'13.72"N	85°27'59.75"E	39.3	28	Salambutar area
82	80.2	27°43'15.29"N	85°28'3.42"E	45.2	35	Salambutar area
83	97	27°43'14.51"N	85°28'8.88"E	42.4	54.6	Sankhu area
84	76.5	27°43'18.26"N	85°28'11.21"E	32.8	43.7	Sankhu area
85	71.3	27°43'22.61"N	85°28'10.37"E	28.7	42.6	Sankhu area
86	69.3	27°43'26.63"N	85°28'11.73"E	23.4	45.9	Sankhu area
87	64	27°43'31.37"N	85°28'9.10"E	30.5	33.5	Sankhu area
88	56.2	27°43'36.51"N	85°28'3.90"E	29	27.2	Sankhu area
89	40	27°43'40.31"N	85°28'9.64"E	20.8	19.2	Sankhu area
90	36.9	27°43'45.91"N	85°28'10.21"E	10.8	26.1	Manohara Khola
91	36.9	27°43'47.46"N	85°28'9.42"E	12.9	24	Manohara Khola
92	33.3	27°43'55.23"N	85°28'10.23"E	5.5	27.8	Manohara Khola
94	15.3	27°44'15.40"N	85°28'13.62"E	6.51	8.79	Manohara Khola
95	21.3	27°44'24.49"N	85°28'22.28"E	10	11.3	Manohara Khola
96	16.5	27°44'32.70"N	85°28'31.49"E	8.4	8.1	Manohara Khola
97	18.6	27°44'39.57"N	85°28'41.66"E	12.5	6.1	Manohara Khola
98	17.3	27°44'41.19"N	85°28'47.36"E	8.01	9.29	Manohara Khola
99	12.9	27°44'49.75"N	85°28'51.50"E	6.26	6.64	Manohara Khola
100	13.6	27°44'59.61"N	85°28'57.03"E	7.22	6.38	Manohara Khola
101	13	27°45'3.69"N	85°29'4.22"E	7.56	5.44	Manohara Khola
103	8.8	27°45'27.83"N	85°29'16.01"E	4.84	3.96	Manohara Khola
105	8.11	27°45'45.55"N	85°29'9.21"E	3.23	4.88	Manohara Khola
106	6.85	27°45'55.52"N	85°29'11.17"E	3.69	3.16	Manohara Khola
107	8.19	27°46'5.48"N	85°29'12.83"E	4.4	3.79	Manohara Khola
108	9.11	27°46'15.05"N	85°29'5.52"E	4.01	5.1	Manohara Khola

Table 5-15: Model based flood inundation extent during 50 years return period flood in Hanumante Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
1	162	27°40'4.84"N	85°21'9.80"E	65.7	96.3	Junction with Manohara Khola
2	98.55	27°40'7.66"N	85°21'30.05"E	50.85	47.7	Lokanthali area
3	127.05	27°40'9.09"N	85°21'39.05"E	64.65	62.4	Balkot area
4	113.55	27°40'11.18"N	85°21'49.30"E	63.3	50.25	Balkot area
5	131.7	27°40'14.68"N	85°21'49.82"E	70.35	61.35	Balkot area
6	88.35	27°40'18.87"N	85°21'49.37"E	61.8	26.55	Balkot area
7	83.85	27°40'22.52"N	85°21'53.14"E	44.4	39.45	Balkot area
8	61.2	27°40'21.56"N	85°21'55.47"E	29.25	31.95	Balkot area
9	72.75	27°40'17.89"N	85°21'58.90"E	25.8	46.95	Balkot area
10	73.8	27°40'15.27"N	85°22'4.68"E	33.45	40.35	Balkot area
11	85.5	27°40'16.64"N	85°22'13.97"E	38.7	46.8	Balkot area
12	81.9	27°40'16.47"N	85°22'20.46"E	43.65	38.25	Balkot area
13	106.8	27°40'17.02"N	85°22'39.00"E	53.85	52.95	Rose village
14	71.55	27°40'15.34"N	85°22'52.78"E	41.1	30.45	Hanumante Khola
15	96.3	27°40'19.81"N	85°22'58.71"E	32.85	63.45	Hanumante Khola
16	61.95	27°40'17.44"N	85°23'4.31"E	36.15	25.8	Hanumante Khola
17	76.95	27°40'15.56"N	85°23'9.58"E	37.2	39.75	Near madhyapur hospital
18	86.25	27°40'13.64"N	85°23'17.90"E	27.6	58.65	Near madhyapur hospital
19	81	27°40'16.38"N	85°23'39.55"E	40.5	40.5	Sallaghari area
20	76.2	27°40'22.97"N	85°23'47.27"E	48.15	28.05	Sallaghari area
21	83.1	27°40'23.21"N	85°23'53.62"E	47.55	35.55	Sallaghari area
22	78	27°40'27.85"N	85°24'0.57"E	40.2	37.8	Sallaghari area
23	87.3	27°40'35.68"N	85°24'7.68"E	44.55	42.75	Sallaghari area
24	88.2	27°40'38.13"N	85°24'25.02"E	45.6	42.6	Sallaghari area
25	71.25	27°40'28.45"N	85°24'28.18"E	30.3	40.95	Sallaghari area
26	56.1	27°40'22.88"N	85°24'33.89"E	26.7	29.4	Sallaghari area
27	46.8	27°40'22.21"N	85°24'34.71"E	13.35	33.45	Sallaghari area
28	30.6	27°40'19.30"N	85°24'42.82"E	9.9	20.7	Sallaghari area

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
29	37.35	27°40'13.95"N	85°24'48.23"E	15.75	21.6	Sallaghari area
30	63.6	27°40'10.52"N	85°24'57.49"E	40.65	22.95	Sallaghari area
31	80.25	27°40'6.89"N	85°25'4.38"E	26.55	53.7	Ghatte tol
32	46.35	27°40'3.33"N	85°25'12.13"E	23.85	22.5	Ghatte tol
33	47.85	27°40'3.49"N	85°25'20.98"E	17.25	30.6	Gapali area
34	58.5	27°40'5.12"N	85°25'29.27"E	19.8	38.7	Gapali area
35	61.8	27°40'4.51"N	85°25'38.27"E	33.6	28.2	Gapali area
36	61.8	27°40'7.52"N	85°25'50.15"E	34.05	27.75	Kwacha tol
37	68.4	27°40'7.50"N	85°25'55.48"E	23.7	44.7	Kwacha tol
38	63	27°40'9.06"N	85°26'2.76"E	38.25	24.75	Kwacha tol
39	47.55	27°40'8.78"N	85°26'4.92"E	23.55	24	Junction with chakku Khola
40	54.9	27°40'7.36"N	85°26'5.58"E	28.95	25.95	Jagati area
41	43.35	27°40'9.05"N	85°26'13.05"E	23.85	19.5	Jagati area
42	30.3	27°40'7.26"N	85°26'20.73"E	13.2	17.1	Jagati area
43	43.5	27°40'1.70"N	85°26'31.34"E	21	22.5	Hanumante Khola
44	35.1	27°39'54.18"N	85°26'31.21"E	19.8	15.3	Hanumante Khola
45	44.85	27°39'52.83"N	85°26'39.17"E	10.65	34.2	Hanumante Khola
46	32.7	27°39'50.85"N	85°26'47.54"E	14.7	18	Hanumante Khola
47	27.6	27°39'48.80"N	85°26'53.89"E	12.15	15.45	Hanumante Khola
48	24.3	27°39'49.24"N	85°27'2.10"E	12.36	11.94	Hanumante Khola
49	27.3	27°39'48.68"N	85°27'11.29"E	16.35	10.95	Hanumante Khola
50	32.7	27°39'44.66"N	85°27'15.78"E	15.3	17.4	Hanumante Khola
51	29.4	27°39'41.34"N	85°27'22.74"E	14.1	15.3	Hanumante Khola
52	25.2	27°39'35.90"N	85°27'30.12"E	17.55	7.65	Hanumante Khola
53	15.75	27°39'35.37"N	85°27'37.56"E	7.65	8.1	Hanumante Khola
55	16.05	27°39'35.72"N	85°27'55.06"E	5.265	10.785	Hanumante Khola
56	15.45	27°39'36.09"N	85°28'8.17"E	5.7	9.75	Hanumante Khola
57	13.725	27°39'29.95"N	85°28'18.86"E	7.725	6	Hanumante Khola
58	14.085	27°39'30.57"N	85°28'28.98"E	5.52	8.565	Hanumante Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
59	14.25	27°39'31.86"N	85°28'31.84"E	6.45	7.8	Hanumante Khola

Table 5-16: Model based flood inundation extent during 50 years return period flood in Nakkhu Khola at different surveyed Cross section

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
1	186	27°39'47.88"N	85°17'49.63"E	88.5	97.5	Junction with bagmati Khola
3	103.05	27°39'53.91"N	85°18'5.21"E	49.05	54	Nakkhu area
4	44.25	27°39'44.55"N	85°18'20.24"E	9.9	34.35	Nakkhu area
5	59.85	27°39'40.51"N	85°18'27.96"E	28.5	31.35	Nakkhu area
6	91.95	27°39'34.22"N	85°18'27.41"E	25.65	66.3	Nakkhu area
7	75.9	27°39'27.16"N	85°18'37.82"E	72.06	3.84	Nakkhu area
8	79.05	27°39'18.73"N	85°18'43.13"E	22.5	56.55	Kusunti area
9	50.4	27°39'10.55"N	85°18'44.44"E	17.85	32.55	Kusunti area
10	63.9	27°39'2.78"N	85°18'44.74"E	13.05	50.85	Nakhudole
11	76.35	27°39'0.66"N	85°18'45.98"E	40.05	36.3	Nakhudole
12	52.95	27°38'52.23"N	85°18'48.07"E	29.4	23.55	Nakhudole
13	61.05	27°38'45.18"N	85°18'40.27"E	28.65	32.4	Nakhudole
14	85.5	27°38'29.99"N	85°18'43.52"E	30.15	55.35	Nakhudole
15	63.45	27°38'21.99"N	85°18'39.49"E	26.55	36.9	Nakhudole
16	64.8	27°38'14.04"N	85°18'30.81"E	18.3	46.5	Nakhudole
17	52.2	27°38'9.87"N	85°18'30.75"E	10.35	41.85	Nakhudole
18	66.6	27°38'2.05"N	85°18'26.17"E	25.35	41.25	Nakhudole
19	62.1	27°37'54.77"N	85°18'26.38"E	40.35	21.75	Shorakhutte
20	64.95	27°37'53.47"N	85°18'34.31"E	43.5	21.45	Shorakhutte
21	73.05	27°37'48.51"N	85°18'37.13"E	55.65	17.4	Shorakhutte
22	64.95	27°37'42.49"N	85°18'37.81"E	34.95	30	Shorakhutte
23	72.45	27°37'37.06"N	85°18'43.38"E	23.4	49.05	Shorakhutte

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
24	51.75	27°37'32.98"N	85°18'41.65"E	19.95	31.8	Shorakhutte
25	57	27°37'24.21"N	85°18'34.37"E	21.75	35.25	Dhaichhap area
26	45.75	27°37'19.33"N	85°18'34.69"E	13.05	32.7	Dhaichhap area
27	52.8	27°37'13.68"N	85°18'36.73"E	21	31.8	Dhaichhap area
28	74.55	27°37'8.73"N	85°18'38.08"E	61.185	13.365	Dhaichhap area
29	60	27°37'2.94"N	85°18'37.38"E	29.4	30.6	Dhaichhap area
30	53.1	27°36'57.54"N	85°18'39.90"E	27.3	25.8	Dhaichhap area
31	56.4	27°36'53.58"N	85°18'37.63"E	17.7	38.7	Dhaichhap area
32	49.2	27°36'49.43"N	85°18'38.54"E	19.65	29.55	Dhaichhap area
33	67.05	27°36'43.96"N	85°18'44.25"E	34.05	33	Dhaichhap area
34	52.35	27°36'41.34"N	85°18'42.76"E	25.8	26.55	Dhaichhap area
35	52.35	27°36'35.19"N	85°18'42.59"E	33.6	18.75	Champpi area
36	75.75	27°36'29.79"N	85°18'50.58"E	57.75	18	Champpi area
37	51	27°36'25.22"N	85°19'0.92"E	30	21	Champpi area
38	95.4	27°36'22.36"N	85°19'5.49"E	58.65	36.75	Champpi area
43	69.15	27°35'48.02"N	85°18'59.10"E	46.05	23.1	Champpi area
44	64.8	27°35'40.32"N	85°18'53.86"E	28.8	36	Champpi area
45	44.4	27°35'36.24"N	85°18'51.95"E	24	20.4	Champpi area
46	74.4	27°35'27.02"N	85°18'50.08"E	58.2	16.2	Champpi area
47	49.8	27°35'19.27"N	85°18'41.55"E	15.6	34.2	Tikabhairab temple
48	39	27°35'4.38"N	85°18'43.16"E	30	9	Tikabhairab temple
49	38.25	27°34'40.21"N	85°18'42.47"E	13.95	24.3	Shikharpa area
50	44.25	27°34'31.44"N	85°18'45.86"E	29.25	15	Shikharpa area
51	31.5	27°34'17.45"N	85°18'42.94"E	13.5	18	Shikharpa area
52	38.85	27°34'5.96"N	85°18'47.67"E	21.9	16.95	Nakkhu Khola
53	53.4	27°33'50.58"N	85°18'49.72"E	22.35	31.05	Nakkhu Khola
54	37.95	27°33'40.38"N	85°18'50.84"E	12.45	25.5	Nakkhu Khola
55	36	27°33'27.92"N	85°18'59.11"E	18	18	Nakkhu Khola
56	28.95	27°33'18.59"N	85°18'58.22"E	10.2	18.75	Nakkhu Khola

Section No.	Model Based Floodway Width (meters)	Coordinates of River Centerline		Floodway in Left bank from river centerline (meters)	Floodway in Right bank from river centerline (meters)	Remarks
		Northing	Easting			
57	32.25	27°33'11.64"N	85°19'11.48"E	8.85	23.4	Nakkhu Khola
58	23.7	27°33'9.23"N	85°19'19.21"E	15.915	7.785	Nakkhu Khola
59	23.55	27°33'6.36"N	85°19'33.94"E	14.07	9.48	Nakkhu Khola
60	22.5	27°33'2.75"N	85°19'53.02"E	14.625	7.875	Nakkhu Khola
61	20.4	27°33'3.10"N	85°20'7.48"E	12.36	8.04	Nakkhu Khola
62	21.9	27°33'2.27"N	85°20'23.96"E	12.645	9.255	Nakkhu Khola
63	55.95	27°32'59.46"N	85°20'34.81"E	37.8	18.15	Nakkhu Khola
64	15.45	27°32'55.23"N	85°20'55.62"E	7.8	7.65	Nakkhu Khola

6 CONCLUSIONS AND RECOMMENDATIONS

- Hydrological modelling of Bagmati River and its tributaries is used for estimation of basin, sub-basin and river physical characteristics. Using these physical characteristics of the catchment and sub-basin, the initial values of the parameters for different hydrological processes in HEC-HMS such as SCN Curve Number, time of concentration, lag time, Muskingum constants K and X. etc. are computed. Peak flood discharge and maximum daily precipitation for 50 years return period at different river basin, junctions and reaches are estimated using hydrological modelling in HEC-HMS followed by calibration and validation of different hydrological parameters.
- Based on the results from hydrological modelling, required waterway width required for Bagmati River and its tributaries are estimated based on the Lacey's formula as well as model based flood inundation map. As Bagmati River and its tributaries have varying width and depth (cross-section) within small stretches, the results obtained from the model based flood map for waterway width are more precise, accurate and site specific. Model based flood map are prepared using redefined DEM of 2.5 m × 2.5 m resolution, physical infrastructures such as bridges and cross-section data of river along with recent available Land Use Land Cover Map of Kathmandu Valley.
- Based on hydrological modelling, field survey and site visit, most of the Bagmati River system in Kathmandu valley are not sufficient in width and depth for safe passage of 50 years return period flood which is used in preparation of flood inundation map. Hence, provision of river training structures, retaining wall and flood embankments are provided in some stretches which are found effective for flood mitigation in those areas. Hence, it is recommended to carry out river training works to avoid the possible impacts of flood to the adjacent lands.
- Melamchi Water Supply Project (MWSP) which diverts the flow of 170 MLD of fresh water to Kathmandu Valley from Melamchi River in Sindhupalchowk district and additional 170 MLD from Yangri and Larke rivers shall have minimum impact during flood events in Kathmandu Valley. The equivalent river discharge contributing from water supply project and treatment plant is about 3.94 m^3/s which is very less than computed flood discharge at different points in Bagmati River and shall have no impact during the peak flood event considered for flood inundation mapping. Computed 50 years return period flood discharge using flood frequency analysis at Khokana and Gaurighat DHM gauging station are 1,077.58 m^3/s and 108.62 m^3/s respectively which are on very high range in comparison to discharge from Melamchi Water Supply Project (MWSP).
- For flood and related damages which may occur due to dam break of Dhap Dam and Nagmati Dam constructed upstream catchment of Bagmati River, the detail impacts and flood assessment due to respective dam breach shall need to be referred in respective study report. Based on the dam-break simulation in FSR report, the flood map produced and water depths calculated; it is considered there is no likely impact to on any settlements downstream in the very unlike event that the Dhap Dam should fail. However for Nagmati Dam, based on modelling carried out by Entura in reference to the extent of feasibility model, it is likely that the impact of dam break flood will extend much further downstream than modelled in the relevant report. Dam Break and Consequence report recommends that for the purposes of preparing accurate maps, the model should represent the floodplain in two-dimensions and the river channel and hydraulic structures should be modelled in one-dimension.
- River encroachment and narrowing down of waterway should not be permitted to lessen the damages due to flood hazards.

- It is recommended to increase the number of hydrological gauging stations in different stretches of Bagmati River and its tributaries for daily discharge measurement and instantaneous flood discharge measurement. As Kathmandu valley is highly populated urban city, it is recommended to adopt citizen science based rainfall and hydrological station monitoring system in Bagmati River and its tributaries.
- Development of flood early warning system based on citizen science based model is recommended to reduce the hazards due to flood in downstream reaches.
- Provision of water retaining structures such as dam in upper catchment region of different rivers of Kathmandu valley as recommended in Main Action Plan Report also play significant role in regulating the flood discharge and dry season discharge in the Bagmati river system. Hence, it is recommended to study in detail the development of such infrastructure works in the Bagmati river system for flood control as well as preserving the ecosystem of Bagmati river system.
- It is recommended to use the high resolution satellite image for preparation of DEM and study of historical flood events during hydrological modelling and flood map preparation of urban areas like Kathmandu Valley which will reduce the effort for editing of river corridor and provide better information and results for risk analysis of flood related hazards.

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ANNEX-I: SITE PHOTOGRAPHS

River Training Works- Stone Masonry Wall in Kodku Khola (Karmanasa)

Wide section at u/s of Bagmati Khola near Gaurighat

Narrow section at d/s Bagmati Khola at Gaurighat area

Bagmati Khola viewing D/S at Sundarighat area

Bagmati Khola viewing U/S at Sankhamul Park

Dhobi Khola and corridor road near seto pul area

Low depth zone of Dhobi Khola viewing D/S at Double Arch Bridge near Bijulibazaar

Low depth zone of Dhobi Khola viewing U/S near Bijulibazaar

Hanumante Khola Viewing D/S at Naya Thimi

Hanumante Khola Viewing U/S at Chardobato Area

Manohara Khola near Pepsicola Bridge viewing D/S

Manohara Khola near Pepsicola Bridge viewing U/S

ANNEX-II: COMMENT MATRIX

i. *For the computation of waterway along the Bagmati River and its tributaries, 50 years return period flood seems to consider. In this context, it is advised to explain the basis for the selection of 50 years' period flood. Also it is well understood that higher return period has not been considered due to resettlement, rehabilitation issues and huge investment requirement for the compensation. However, reasons of not considering lower value of return period like 5 years, 10 years, 20 years and 30 years etc. to be elaborated.*

Response: Generally for urban areas, considering the existing model of settlement plan and from economic point of view as well as long term vision; waterway width with 50 years return period will be effective for regulatory purpose. From Consultant's point of view; the major consideration of 50 years return period for waterway computation is Terms of Reference (ToR) provided by the Client (Refer TOR Activity 2: Point iii)

ii. *Q_0 has been written as simulated discharge which must be observed discharge & needs to be corrected accordingly*

Response: Q_0 is the average of observed discharge and shall be corrected accordingly in the report.

iii. *Flood frequency analysis seems to be carried out using Gumbel distribution, LP-III distribution and Log normal distribution methods. Result from which distribution has been used for the computation of water way and how design flood has been selected from the result obtained from these three methods. Selection criteria of designed flood needs to be explained.*
Also to be explained the reason of neglecting other distribution methods like Normal distribution, PT-III and Log-Gumbel distribution.

Response: Flood Frequency Analysis was carried out to find the flood discharge at different return period at particular DHM station; however the scope of work was to calculate the flood discharge at Bagmati Khola and its tributaries at different stretches and river junctions for which the long term river discharge recorded at the these stations have been used for hydrological modelling in HEC-HMS and later the same hydrological model have been used for flood modelling and flood discharge obtained from hydrological modelling has been used for computation of waterway width at different junction and river stretches which was found more relevant and accurate.

iv. *Frequency Analysis for computation of Maximum Daily Precipitation at Different Return Period in Bagmati River has been carried out using Gumbel, LP – III and Log Normal methods and presented in table 3.8. Out of these three methods which has been considered for the design purpose. This needs to be elaborated.*

Response: Frequency Analysis for maximum daily precipitation using Gumbel's method has been used for flood modelling in HEC-HMS hydrological model. For this 50 years return period maximum daily precipitation at each sub-basin has been used. Table 3-9 and Section 3.6.3 of the main report elaborates the use of the precipitation data for the modelling and design purpose.

v. *Reason out the use of Gumbel's method for the computation of maximum daily precipitation (table-3.9) of different return period.*

Response: Among various methods, Gumbel's method values are found on the average range in most of the DHM stations and more scientific for the design purpose.

vi. *It is observed that Lacy's equation has been used for the computation of waterway however other alternatives are not considered in the context of bank protected rivers. Instead of Natural River course along the alluvial deposit most of the rivers in Kathmandu valley are artificially bank protected due to which natural and alluvial rivers cross sections have been converted in to trapezoidal or rectangular. In coming days too, bank protection work will continue for the protection of houses/temples/heritages etc located along the river bank. Keeping in view of this aspect, maximum flood of given return period has to pass safely assuming certain geometrical section like trapezoidal. Possibility of this aspect, if can reduce the reduce the water way needs to be discussed.*

Response: For the waterway width computation, initially required river width was calculated according to the flood inundation map of 50 yrs return period from HEC-RAS modelling; however considering the requirement from the Client for identification of river encroachment land; standard width requirement was suggested in different stretches. Hence, considering the available methodologies for river width and studying the nature of Bagmati river and its tributaries, with discussion with stakeholders and HPCIDBC Lacy's formula has been used. In case of provision of river training work in critical areas; required river width can be reduced however, it shouldn't cause the backwater effect during instantaneous flood scenario. Hence, for identification of river natural regime width Lacy's equation has been used.

vii. *All the hydrological & meteorological data and models used for the analysis to be submitted to the client in soft/hard copy.*

Response: Most of the data and model files are provided already. In case any files are yet to be submitted in soft/hard copies they will be provided along with the GIS and Hydrological model data