# Hydrological modeling of Lower Basin of Tapi River using HEC-HMS for flood assessment and planning in Surat city

Thesis submitted in

Partial Fulfilment for

The Award of the Degree of

**Master of Urban and Regional Planning**

by


Rafaliya Maulik Mansukhbhai

Second Semester, MURP II - 2020 - 21


Primary Guide: Mr. Pradeep Rajput

Secondary Guide: Dr. Deepa Gavali

सत्यं शिवं सुन्दरम्


Master of Urban and Regional Planning (M.U.R.P.) Programme

Department of Architecture

Faculty of Technology and Engineering

The Maharaja Sayajirao University of Baroda

D. N. Hall, Pratap Gunj, Vadodara, Gujarat, India


JUNE 2021

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CERTIFICATE

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The contents presented in this Thesis represent my original work and it has not been submitted for the award of any other Degree or Diploma anywhere else.

**Rafaliya Maulik Mansukhbhai**

This Thesis is submitted in partial fulfilment of the requirements for the

Degree of Master of Urban and Regional Planning

at the Department of Architecture

Faculty of Technology and Engineering

The Maharaja Sayajirao University, Vadodara, Gujarat, India

The present work has been carried out under our supervision and

Guidance and it meets the standard for awarding the above stated degree.

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Mr. Pradeep Rajput

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Dr. Deepa Gavali

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*"Have a goal in life. When water is everywhere, it is a flood, but if it is in between banks, it is a river. It is nice to have a goal, so your life force gets channelized!"*

*– Sri Sri Ravi Shankar*

# ABSTRACT

This paper describes a study carried out of hydrological modelling in Lower sub basin of Tapi River (India) for flood inundation. Flood is natural disaster which is occurring in almost every part of the country. Total of 21 years (2000-2020) hydrological data has been given as an input to the model study. Lumped continuous hydrological model is developed for the study area using HEC-HMS 4.7.1. In order to run HEC-HMS model for assessment of flood at Surat outlet of Tapi river basin the input such as Rainfall, soil map and land use/land cover map required are extracted from soil. Input files were prepared using HEC-GeoHMS and later imported to HEC-HMS along with the meteorological and hydrological data to calculate run-off at the watershed outlet. Analysis was carried out in HEC-HMS to determine peak stream flow and occurrence time. In this study to account for loss, SCS Curve Number method is being used. For better runoff estimation SCS unit hydrograph method for the study area is chosen for the final simulation. To estimate the reference evapotranspiration, FAO Penman-Monteith method is being used. From the stimulated $Q_{peak}$(discharge) and observed $Q_{peak}$ the flood model can be derived in HEC-HMS. Satellite image of area near Tapi region is selected and with the help of software we could analyse the flood prone areas. Parameters like population Density, resources availability; Elevation of geographical area, etc. database were collected using GIS. Software like ArcGIS was used to get the data of flood. From the data obtained using HEC-HMS and GIS the area of Surat is divided into High risk and Low risk zones. This study it will be helpful in identification of low lying & flood prone areas in Surat city and also useful in Surat urban planning near Tapi River. Finally study concludes that HEC-HMS model can be used with reasonable approximations on Tapi River.

# Acknowledgments

First and foremost, I would like to thank my thesis Guides Mr. Pradeep Kumar Rajput (Town and Country Planner), Dr. Deepa Gavali (Ecologist) for providing a clear vision and framework for the project. Their constant encouragement and practical inputs have helped us to deal with the complexities.

I express our deep gratitude to all the respected Faculty members of 'Master in Urban and Regional Planning', under whose guidance, valuable suggestions and enthusiastic approach we are able to present this study.

Special thanks to Dr. Bhawana Vasudeva the Head of the Department of Architecture, M.S. University of Baroda for his involvement in this program.

It would not have been possible without support from various Govt. Agencies like Central Water Commission (CWC), India Water Resources Information System (IWRIS) & Surat Municipal Corporation (SMC) that provided the required secondary data regarding various facts and fundamentals.

I would also like to thank each and every people who participated & supported me for this study.

Last but not the least I thank God & my Parents who made it possible.

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# Chapter 1: Introduction

## 1.1 Review of Project Preliminary

Rainfall- runoff correlation is a complex phenomenon to represent in the mathematical form. Rainfall runoff process involves in many parameters either it may be physical features of the catchment or climatological parameter. In the real world system rainfall runoff process is influenced by each and every physical characteristics of catchment and to generalize all physical characteristics of the catchment is really a difficult task. Consider the infiltration phenomenon which has direct influence on the runoff process but when observe the infiltration at different sites in the catchment it comes out to be wide range of infiltration rates. In case of lumped hydrological model representation of such a wide range of values is difficult because parameter values are to be averaged for the particular catchment in case of lumped model. Climatological parameters are also having great influence on the runoff process. Consider the evapotranspiration process it is influenced by the temperature, wind speed, vapor pressure and other parameters. Getting proper data for all these parameters is itself is the difficult task. Even if omitted the single parameters can lead to the imprecise estimation of any process.

Today's advance computing techniques have overcome the most of the real world complexity. It is possible to represent even a complex phenomenon in fairly better way. Using the gridded distributed models it is possible to represent the catchment in more realistic way. Watershed management is really an important subject which is helpful in future planning of Hydro projects and natural resources management. HEC-HMS tool is used to predict the runoff process in Tapi basin at the different gauging stations.

Hydrological Model is a simplified representation of natural system. Model is necessary for efficient planning and management. It provides information that can help us to

- Be proactive and control a situation at the time of floods
- Estimate the increase in the volume.
- Regulate floodplain activities

– Operate or evaluate existing hydraulic-structures

During floods, it becomes very important to find out how much part of that run-off was contributed by rainfall and how much is due to the release from the dam. Rainfall-runoff simulation is also a vital knowledge to have while fixing reservoir capacity. For a water harvesting planner, the most difficult task is therefore to select the appropriate "design" rainfall according to which the ratio of catchment to cultivated area will be determined.

## 1.2 General

During the 2006 Surat floods, the region experienced very heavy rainfall resulting in floods. At such times it becomes very important to find out how much part of that enormous flood run-off was contributed by rainfall and how much was due to the release from Ukai. Rainfall-runoff simulation is also a vital knowledge to have while fixing reservoir capacity. For a water harvesting planner, the most difficult task is therefore to select the appropriate "design" rainfall according to which the ratio of catchment to cultivated area will be determined. Design rainfall is defined as the total amount of rain during the cropping season at which or above which the catchment area will provide sufficient runoff to satisfy the crop water requirements. If the actual rainfall in the cropping season is below the design rainfall, there will be moisture stress in the plants; if the actual rainfall exceeds the design rainfall, there will be surplus runoff which may result in damage to the structures. To be able to determine these factors we must be in a position to find out the amount of runoff generated in a catchment owing to the rainfall. Other flow conditions of the stream can be directly measured, but runoff is one major factor which cannot be directly found. Hence, we have chosen this extremely important topic of Rainfall- Runoff simulation for our project work. The software chosen for this purpose is HEC-HMS. HEC-HMS is a product of the Hydrologic Engineering Center within the U.S. Army Corps of Engineers. The program was developed beginning in 1992 as a replacement for HEC-1 which has long been considered a standard for hydrologic simulation. The program is a generalized modelling system capable of representing many different watersheds. A model of the watershed is constructed by separating the water cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. This software was recently procured by the Computational Hydraulics Lab of the Water Resources Engineering, Civil Engineering Department, SVNIT, Surat. Hence, it is easily accessible and available for use in this project. Thus, it is selected for the purpose of our study.

## 1.3 Aim, Scope of Study & Objectives

**Research Question**

- Is the major zones of Surat city are safe against flood inundation after 2006?
- Are Developed Structural elements enough to tackle flood more than past years?

**Aim**

- To Provide efficient flood preventive planning for Surat City with the help of HEC-HMS Hydrological Modeling.

**Scope of Study**

- To study and explore the working and functions of HEC-HMS v4.7.1 which is quite useful in Hydrologic Modeling
- To develop the Hydrologic Model for the lower Tapi Basin, from downstream of Ukai to the sea, covering a net area of about 1672 $km^2$
- To determine the contribution of rainfall in the floods that occurred in Surat in 2006

**Objectives**

- Studying and simulating rainfall runoff process.
- Learning the basic concepts of modeling software
- Preparation of draft model Using different hydrologic elements available
- Computing and modeling run off
- Efficient Planning according to outcomes.

# Chapter 2: Review of Literature

## 2.1 Background

Preliminary literature review on Rainfall-Runoff modelling using various software has been carried out. Basic fundamental understanding of simulation of rainfall-runoff process studied through various literatures. Amongst various codes available for Rainfall-runoff modelling, HEC- HMS has been chosen, as it was recently procured in Computational Hydraulic Laboratory of water Resources Section. Learning functioning of aforementioned software has been explored through example of Waller Creek in Austin, Texas. Upon studying of previous research work carried out on HMS, the software was found to be suitable to carry out the rainfall-runoff simulation with a satisfactory degree of accuracy. To better understand the working and inputting of data, some hypothetical data was taken and the models prepared in HEC-HMS. The resulting hydrographs were interpreted and their results were discussed.

## 2.2 Theissen Polygon Method

This method takes its name after A.M. Theissen who suggested it first in 1911. It attempts to make allowance for irregularities in gauge location by weighing the record of each gauge in proportion to area which is closer to that gauge than to any other gauge .These areas for a given network of gauge stations are determined as described below.

i) Straight lines are then drawn joining the adjacent rain gage location to form triangles.

ii) ii) Perpendicular bisectors are now drawn to each side of all the triangles . These bisectors define a set of polygon contains only points that are closer to the gauge at its centre than to any other gauge.

iii) iii) The polygonal areas around each rain gauges station within the basin boundary are then measured.

iv) iv) The average depth of rainfall P is computes as…

$$P=\frac{A_1P_1+A_2P_2+A_3P_3+\cdots+A_nP_n}{A_1+A_2+A_3+\cdots+A_n}$$

Where P1, P2 …. Are the rainfall recorded at rain gage stations with A1, A2 …..as the polygonal areas around them.

## 2.3 SCS CURVE NUMBER METHOD

The runoff curve number is an empirical parameter used in hydrology for predicting direct runoff or infiltration from rainfall excess. The runoff curve number was developed from an empirical analysis of runoff from small catchments and hill slope plots monitored by the soil conservation service. It is widely used and efficient method for determining the approximate amount of direct runoff from a rainfall event in a particular area.

The runoff curve number is based on the area's hydrologic soil group , land use , treatment and hydrologic condition . The basic assumption of the scs curve number method is that for a single storm the ratio of the actual soil retention after runoff begins to potential maximum retention is equal to the ratio if direct runoff to available rainfall. By study from many small experimental watersheds. An empirical relation was developed:

$$I_a = 0.2S$$

On this basis

$$P_e = \frac{(P-0.2S)^2}{P+0.8S}$$

Where $I_a$=Initial abstraction

$P_e$= rainfall excess

$F_a$=continuing abstraction

P= total precipitation

The curve number and S are related by

$$S = \frac{1000}{CN} - 10$$

Plotting the data for P and Perform many watersheds, the SCS found standard curves. To standardize these curves a dimensionless curve number CN is defined such that 0< CN<100. For impervious and water surface CN= 100 for natural surfaces CN<100.

**Limitations of Application:** Several characteristics of the proposed equation that limited the types of problems for which it should be used. The equation does not contain any expression for time. It is for estimating runoff from single storms. In practice, the amount of daily rainfalls is often used: total runoff from storms of great duration is calculated as the sum of daily increments. For a continuous storm, one with no breaks in the rainfall, equation 2.3 can be used to calculate the accumulated runoff. For a discontinuous storm, which has intervals of no rain, there is some recovery of infiltration rates during the intervals. When the rainless periods are over an hour, a new, higher CN is usually selected on the basis of the change in antecedent moisture. The initial abstraction term Ia consists of interception, initial infiltration, surface storage, and other factors. The relationship between Ia and S was determined on the basis of data from both large and small watersheds. Further refinement of Ia is possible, but was not recommended because under typical field conditions very little is known of the magnitudes of interception, infiltration and surface storage.

## 2.4 SCS UNIT HYDROGRAPH METHOD

Since peak flow and time of peak flow are two of the most important parameters characterizing a unit hydrograph, the Snyder method employs factors defining these parameters, which are then used in the synthesis of the unit graph (Snyder, 1938).

- The parameters are Cp, the peak flow factor, and Ct, the lag factor.
- The basic assumption in this method is that basins which have similar physiographic characteristics are located in the same area will have similar values of Ct and Cp.
- Therefore, for un-gaged basins, it is preferred that the basin be near or similar to gaged basins for which these coefficients can be determined.

Snyder collected rainfall and runoff data from gaged watersheds, derived the UH as described earlier, parameterized these UH, and related the parameters to measurable watershed characteristics. For the UH lag, he proposed:

$$t_p = 5.5 t_r$$

$$t_p = \text{CC1}(LL_c)^{0.3}$$

Where Ct= basin coefficient; L = length of the main stream from the outlet to the divide; Lc= length along the main stream from the outlet to a point nearest the watershed centroid; and C = a conversion constant (0.75 for SI ) The parameter Ct of and Cp of are best found via calibration, as they are not physically-based parameters. Bedient and Huber (1992) report that Ct typically ranges from 1.8 to 2.2, although it has been found to vary from 0.4 in mountainous 6 areas to 8.0 along the Gulf of Mexico. They reported that Cp ranges from 0.4 to 0.8, where larger values of Cpare associated with smaller values of Ct.

## 2.5 ABOUT HEC-HMS

The Hydrologic Modelling System (HEC-HMS) is designed to simulate the precipitation- runoff processes of dendritic drainage basins. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff. Hydrographs produced by the program are used directly or in conjunction with other software for studies of water availability, reservoir planning, urban drainage, flow forecasting, future urbanization impact, reservoir spillway design of damage, floodplain regulation and system operation. The program is a generalized modeling system capable of representing many different watersheds. A model of the watershed is constructed by separating the water cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgement. HEC-HMS is a product of the Hydrologic Engineering Center within the U.S. Army Corps of Engineers. The program was developed beginning in 1992 as a replacement for HEC-1 which has long been considered a standard for hydrologic simulation. The new HEC-HMS provides almost all of the same simulation capabilities, but has modernized them with advances in numerical analysis that take advantage of the significantly faster desktop computers available today. It also includes a number of features that were not included in HEC-1, such as continuous simulation and grid cell surface hydrology. It also provides a graphical user interface to make it easier to use the software. The program is now widely used and accepted for many official purposes, such as floodway determinations for the Federal Emergency Management Agency in the United States.

### 2.5.1 SCOPE OF HEC-HMS

Hydrologic engineers are called upon to provide information for activities for a variety of water resource studies:  Planning and designing new hydraulic-conveyance and water-control facilities.  Operating and/or evaluating existing hydraulic-conveyance and water-control facilities.  Preparing for and responding to floods.  Regulating floodplain activities.

### 2.5.2 ADVANTAGES

HEC-HMS has merits, notably its support by the US Army Corps of Engineers, the future enhancements in progress, and its acceptance by many government agencies and private firms. It is in the public domain and peer-reviewed and available to download free of charge from HEC's web site. Various private companies are registered as official "vendors" and offer consulting support and add on software. Some also distribute the software in countries that are not permitted to access US Army web sites. However, the direct download from HEC includes extensive documentation, and scientists and engineers versed in hydraulic analysis should have little difficulty applying.

## 2.6 HEC-HMS INTERFACE

The HEC-HMS interface consists of a menu bar, tool bar, and four panes. These panes are referred to as the Watershed Explorer, the Component Editor, the Message Log and the Desktop.

**Watershed Explorer** - The Watershed Explorer was developed to provide quick access to all components in an HEC-HMS project. For example, the user can easily navigate from a basin model to a precipitation gage and then to a meteorological model without using menu options or opening additional windows. The Watershed Explorer is divided into three parts: Components, Compute, and Results. The hierarchal structure of model components, such as basin models, meteorological models, etc., is available from the “Components” tab of the Watershed Explorer. The Watershed Explorer organizes model components into individual folders. When a component is selected, the Watershed Explorer expands to show sub-components. For example, when a basin model is selected the Watershed Explorer will expand to show all hydrologic elements in the basin model. The plus/minus sign beside model components and sub-components can be used to expand/collapse the Watershed Explorer. All project simulation runs, optimization trials, and analyses are accessed from the “Compute” tab of the Watershed Explorer. Model results are available from the “Results” tab of Watershed Explorer. Results from different simulations can be compared in the same graph or table.

**Component Editor** - When a component or sub-component in the Watershed Explorer is active (simply use the mouse and click on the component name in the Watershed Explorer), a specific Component Editor will open. All data that can be specified in the model component is entered in the Component Editor. Any required data will be indicated with a red asterisk. For example, parameter data for the SCS curve number method is entered in the Component Editor for a sub- basin element.

**Message Log** - Notes, warnings, and errors are shown in the Message Log. These messages are useful for identifying why a simulation run failed or why a requested action, like opening a project, was not completed.

**Desktop** - The Desktop holds a variety of windows including summary tables, time-series tables, graphs, global editors, and the basin model map. Results are not confined to the desktop area. A program settings option will allow results to be displayed outside the desktop area. The basin model map is confined to the Desktop. The basin model map is used to develop a basin model. Elements (sub-basin, river reach, reservoir, etc.) are added from the toolbar and connected to represent the physical drainage network of the study area. Background maps can be imported to help visualize the watershed.

## 2.7 HMS MODEL COMPONENTS

HMS has four main model components (you can see these by selecting components on the menu bar): basin model, meteorological model, control specifications and input data (time series, paired data and gridded data). The Basin Model, for instance, contains information relevant to the physical attributes of the model, such as basin areas, river reach connectivity, or reservoir data. Likewise, the Meteorological Model holds rainfall data. The Control Specifications section contains information pertinent to the timing of the model such as when a storm occurred and what type of time interval you want to use in the model, etc. Finally, the input data component stores parameters or boundary conditions for basin and meteorological models. HEC-HMS model components are used to simulate the hydrologic response in a watershed.

**Basin Model Components** - The basin model represents the physical watershed. The user develops a basin model by adding and connecting hydrologic elements. Hydrologic elements use mathematical models to describe physical processes in the watershed. Following are the different hydrologic elements:-

- Sub-basin– Used for rainfall-runoff computation on a watershed.
- Reach – Used to convey (route) stream flow downstream in the basin model.
- Reservoir – Used to model the detention and attenuation of a hydrograph caused by a reservoir or detention pond.
- Junction – Used to combine flows from upstream reaches and sub-basins.
- Diversion – Used to model abstraction of flow from the main channel.
- Source – Used to introduce flow into the basin model (from a stream crossing the boundary of the modelled region). Source has no inflow.
- Sink – Used to represent the outlet of the physical watershed. Sink has no outflow.

**Meteorological Model Component** - The meteorological model calculates the precipitation input required by a sub-basin element. The meteorological model can utilize both point and gridded precipitation and has the capability to model frozen and liquid precipitation along with evapo-transpiration. The newly added snowmelt method uses a temperature index algorithm to calculate the accumulation and melt of the snow pack. The evapo-transpiration methods include the monthly average method and the new Priestly Taylor and gridded Priestly Taylor methods. An evapo-transpiration method is only required when simulating the continuous or long term hydrologic response in a watershed.

**Control Specifications Component** - The control specifications set the time span of a simulation run. Information in the control specifications includes a starting date and time, ending date and time, and computation time step.

**Input Data Components** - Time-series data, paired data, and gridded data are often required as parameter or boundary conditions in basin and meteorologic models.

## 2.8 CAPABILITIES

The program has an extensive array of capabilities for conducting hydrologic simulation. Many of the most common methods in hydrologic engineering are included in such a way that they are easy to use. The program does the difficult work and leaves the user free to concentrate on how best to represent the watershed environment.

1. Watershed Physical Description - The physical representation of a watershed is accomplished with a basin model. Hydrologic elements are connected in a dendritic network to simulate runoff processes. Available elements are: sub-basin, reach, junction, reservoir, diversion, source, and sink. Computation proceeds from upstream elements in a downstream direction.

An assortment of different methods is available to simulate infiltration losses. Options for event modelling include initial constant, SCS curve number, gridded SCS curve number, exponential, Green-Ampt and Smith Parlange. The one-layer deficit constant method can be used for simple continuous modelling. The five-layer soil moisture accounting method can be used for continuous modelling of complex infiltration and evapo-transpiration environments. Gridded methods are available for both the deficit constant and soil moisture accounting methods.

Seven methods are included for transforming excess precipitation into surface runoff. Unit hydrograph methods include the Clark, Snyder, and SCS techniques. User-specified unit hydrograph or s-graph ordinates can also be used. The modified Clark method, ModClark, is a linear quasi-distributed unit hydrograph method that can be used with gridded meteorologic data. An implementation of the kinematic wave method with multiple planes and channels is also included.

Five methods are included for representing baseflow contributions to sub-basin outflow. The recession method gives an exponentially decreasing baseflow from a single event or multiple sequential events. The constant monthly method can work well for continuous simulation. The linear reservoir method conserves mass by routing infiltrated precipitation to the channel. The nonlinear Boussinesq method provides a response similar to the recession method but the parameters can be estimated from measurable qualities of the watershed.

A total of six hydrologic routing methods are included for simulating flow in open channels. Routing with no attenuation can be modeled with the lag method. The traditional `Muskingum method is included along with the straddle stagger method for simple approximations of attenuation. The modified Puls method can be used to model a reach as a series of cascading, level pools with a user-specified storage-discharge relationship. Channels with trapezoidal, rectangular, triangular, or circular cross sections can be modeled with the kinematic wave or Muskingum-Cunge methods. Channels with overbank areas can be modeled with the Muskingum-Cunge method and an 8-point cross section. Additionally, channel losses can also be included in the routing. The constant loss method can be added to any routing method while the percolation method can be used only with the modified Puls or Muskingum-Cunge methods.

Water impoundments can also be represented. Lakes are usually described by a user-entered storage-discharge relationship. Reservoirs can be simulated by describing the physical spillway and outlet structures. Pumps can also be included as necessary to simulate interior flood area. Control of the pumps can be linked to water depth in the collection pond and, optionally, the stage in the main channel.

2. Meteorology Description - Meteorologic data analysis is performed by the meteorologic model and includes precipitation, evapo-transpiration, and snowmelt. Six different historical and synthetic precipitation methods are

included. Three evapo-transpiration methods are included at this time. Currently, only two snowmelt methods are available.

Four different methods for analyzing historical precipitation are included. The user-specified hyetograph method is for precipitation data analyzed outside the program. The gage weights method uses an unlimited number of recording and non-recording gages. The Thiessen technique is one possibility for determining the weights. The inverse distance method addresses dynamic data problems. An unlimited number of recording and non-recording gages can be used to automatically proceed when missing data is encountered. The gridded precipitation method uses radar rainfall data.

Four different methods for producing synthetic precipitation are included. The frequency storm method uses statistical data to produce balanced storms with a specific exceedance probability.

Potential evapo-transpiration can be computed using monthly average values. There is also an implementation of the Priestley-Taylor method that includes a crop coefficient. A gridded version of the Priestley-Taylor method is also available where the required parameters of temperature and solar radiation are specified on a gridded basis.

Snowmelt can be included for tracking the accumulation and melt of a snowpack. A temperature index method is used that dynamically computes the melt rate based on current atmospheric conditions and past conditions in the snowpack; this improves the representation of the "ripening" process. The concept of cold content is incorporated to account for the ability of a cold snowpack to freeze liquid water entering the pack from rainfall. A subbasin can be represented with elevation bands or grid cells.

3. Hydrologic Simulation - The time span of a simulation is controlled by control specifications. Control specifications include a starting date and time, ending date and time, and a time interval.

A simulation run is created by combining a basin model, meteorologic model, and control specifications. Run options include a precipitation or flow ratio, capability to save all basin state information at a point in time, and ability to begin a simulation run from previously saved state information.

Simulation results can be viewed from the basin map. Global and element summary tables include information on peak flow and total volume. A time-series table and graph are available for elements. Results from multiple elements and multiple simulation runs can also be viewed. All graphs and tables can be printed.

4. Parameter Estimation - Most parameters for methods included in subbasin and reach elements can be estimated automatically using optimization trials. Observed discharge must be available for at least one element before optimization can begin. Parameters at any element upstream of the observed flow location can be estimated. Seven different objective functions are available to estimate the goodness-of-fit between the computed results and observed discharge. Two different search methods can be used to minimize the objective function. Constraints can be imposed to restrict the parameter space of the search method.
5. Analyzing Simulations - Analysis tools are designed to work with simulation runs to provide additional information or processing. Currently, the only tool is the depth-area analysis tool. It works with simulation runs that have a meteorologic model using the frequency storm method. Given a selection of elements, the tool automatically adjusts the storm area and generates peak flows represented by the correct storm areas.
6. GIS Connection - The power and speed of the program make it possible to represent watersheds with hundreds of hydrologic elements. Traditionally, these elements would be identified by inspecting a topographic map and manually identifying drainage boundaries. While this method is effective, it is prohibitively time consuming when the watershed will be represented with many elements. A geographic information system (GIS) can use elevation data and geometric algorithms to perform the same task much more quickly. A GIS companion product has been developed to aid in the creation of basin models for such projects. It is called the Geospatial Hydrologic Modeling Extension (HEC-GeoHMS) and can be used to create basin and meteorologic models for use with the program.

## 2.8 LIMITATIONS OF HEC-HMS

Every simulation system has limitations due to the choices made in the design and development of the software. The limitations that arise in this program are due to two aspects of the design: simplified model formulation, and simplified flow representation. Simplifying the model formulation allows the program to complete simulations very quickly while producing accurate and precise results. Simplifying the flow representation aids in keeping the compute process efficient and reduces duplication of capability in the HEC software suite.

**1. Model Formulation -** All of the mathematical models included in the program are deterministic. This means that the boundary conditions, initial conditions, and parameters of the models are assumed to be exactly known. This guarantees that every time a simulation is computed it will yield exactly the same results as all previous times it was computed. Deterministic models are sometimes compared to stochastic models where the same boundary conditions, initial conditions, and parameters are represented with probabilistic distributions. Plans are underway to develop a stochastic capability through the addition of a Monte Carlo analysis tool. All of the mathematical models included in the program use constant parameter values, that is, they are assumed to be time stationary. During long periods of time it is possible for parameters describing a watershed to change as the result of human or other processes at work in the watershed. These parameter trends cannot be included in a simulation at this time. There is a limited capability to break a long simulation into smaller segments and manually change parameters between segments. Plans are underway to develop a variable parameter capability, through an as yet undetermined means. All of the mathematical models included in the program are uncoupled. The program first computes evapo-transpiration and then computes infiltration. In the physical world, the amount of evapo-transpiration depends on the amount of soil water. The amount of infiltration also depends on the amount of soil water. However, evapo-transpiration removes water from the soil at the same time infiltration adds water to the soil. To solve the problem properly the evapo- transpiration and infiltration processes should be simulated simultaneously with the mathematical equations for both processes numerically linked. This program does not currently include such coupling of the process models. Errors due to the use of uncoupled models are minimized as much as possible by using a small time interval for calculations. While preparations have been made to support the inclusion of coupled plant-surface-soil models, none have been added at this time.

**2. Flow Representation** -The design of the basin model only allows for dendritic stream networks. The best way to visualize a dendritic network is to imagine a tree. The main tree trunk, branches, and twigs correspond to the Main River, tributaries, and headwater streams in a watershed. The key idea is that a stream does not separate into two streams. The basin model allows each hydrologic element to have only one downstream connection so it is not possible to split the outflow from an element into two different downstream elements. The diversion element provides a limited capability to remove some of the flow from a stream and divert it to a different location downstream in the network. Likewise, a reservoir element may have an auxiliary outlet. However, in general, branching or looping stream networks cannot be simulated with the program and will require a separate hydraulic model which can represent such networks. The design of the process for computing a simulation does not allow for backwater in the stream network. The compute process begins at headwater sub-basins and proceeds down through the network. Each element is computed for the entire simulation time window before proceeding to the next element. There is no iteration or looping between elements. Therefore, it is not possible for an upstream element to have knowledge of downstream flow conditions, which is the essence of backwater effects. There is a limited capability to represent backwater if it is fully contained within a reach element. However, in general, the presence of backwater within the stream network will require a separate hydraulic model.

# Chapter 3: Research Approach & Analysis of The Study

## 3.1 Background

Tapi River is a river of Central India. Tapati, Tapti, Tapee, Taapi are the various names used to denote Tapti River. Also known as the daughter of Sun God, its basin extends over an area of 65, 145 km sq. - a whooping area which totals to

2% of the total area of India. In India, Tapti River originates at Multani of Betul District (M.P.). The Basin of Tapti River lays in three Indian States, namely, Gujarat, Madhya Pradesh and Maharashtra. For the present study only part of the Tapi basin is being considered.

## 3.2 Study Area

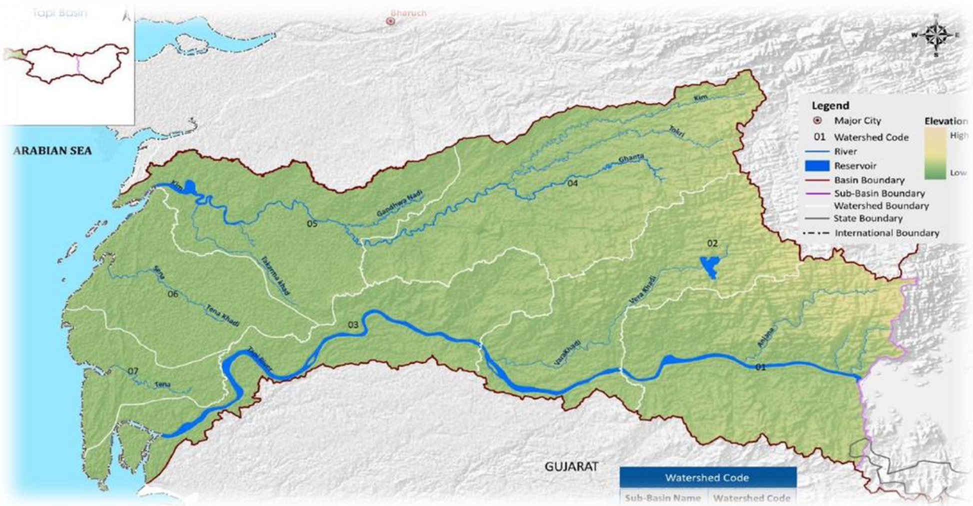



*Figure 1 Selected Study area of Lower Tapi Basin for the study*

Tapti River with its ancient original name Tapi River is a river in central India in Gujarat passing through Surat and Songarh. The river rises in the Eastern Satpura range of southern Madhya Pradesh and flows westward, draining Madhya Pradesh's Nimar region, Maharastra's Kandesh, and east Vidarbha and South Gujarat before entering into the Gulf of Cambay, Arabian Sea

- The Tapi river basin includes an area of **65145 Km$^2$**
- The basin lies in the states of
  - Maharastra – **50504 Km$^2$**
  - Madhya Pradesh - **9804 Km$^2$**
  - Gujarat - **3837 Km$^2$**
- Study area is confined to the lower Tapi basin located downstream of Ukai dam.
- This area has been measured during the course of study to be approximately **1672 Km$^2$**

## 3.3 Data Collection

### 3.3.1 Precipitation Data

In the downstream of Ukai there are 11 different rain gauge stations located at different Talukas. Daily raingauge measurements are done every day at 8 in the morning. This comes under the supervision of the State Water Data Centre, Gandhinagar. The precipitation data included the details of the rain gauge station, i.e. its name, location (latitude and longitude),Taluka at which it is located. Since 2006 was very important year considering the flood therefore the data of 2006 were collected. Details of the data are as shown in Table 3.1.

### 3.3.2 Topographic Data

#### 3.3.2.1 Catchment Area

The measurement and identification of the catchment of Tapi in the study area concern can be demarcated by identifying the point of maximum elevation in the surrounding area of Tapi downstream of Ukai. This was done with the help of Google Earth Pro.5.1. The elevation of all point could be clearly identified and the line of demarcation can be drawn beyond which the elevation was clearly decreasing thus the total catchment which would drain water to the Tapi River is plotted on the map and then its area is measured with the help of area measuring tools of Google Earth Pro. As the Latitude and Longitude of the rain gauge station is known to pin point accuracy from the data collected from State Water Data Centre, Gandhinagar, this point can be clearly demarked and identified with accuracy within the catchment. This is clearly shown in Figure 3.2.

#### 3.3.2.2 River Cross Section

The measurement of the various cross sections of the Tapi River at appropriate distances is carried out and the records are clearly maintained by the Surat Municipal Corporation, Surat. This data was collected from the SMC office in Surat and given in the AutoCAD usable format. It proved to be of great value in calculating the bottom width and the side slopes of the river at points of interest. A sample of this data is shown below in figure 3.3.

### 3.3.3 SOIL CLASSIFICATION

A map clearly showing the different soil conditions in the region of interest was procured from National Bureau of Soil survey & Land Use Planning (INDIAN COUNCIL OF AGRICULTURAL RESEARCH), NAGPUR

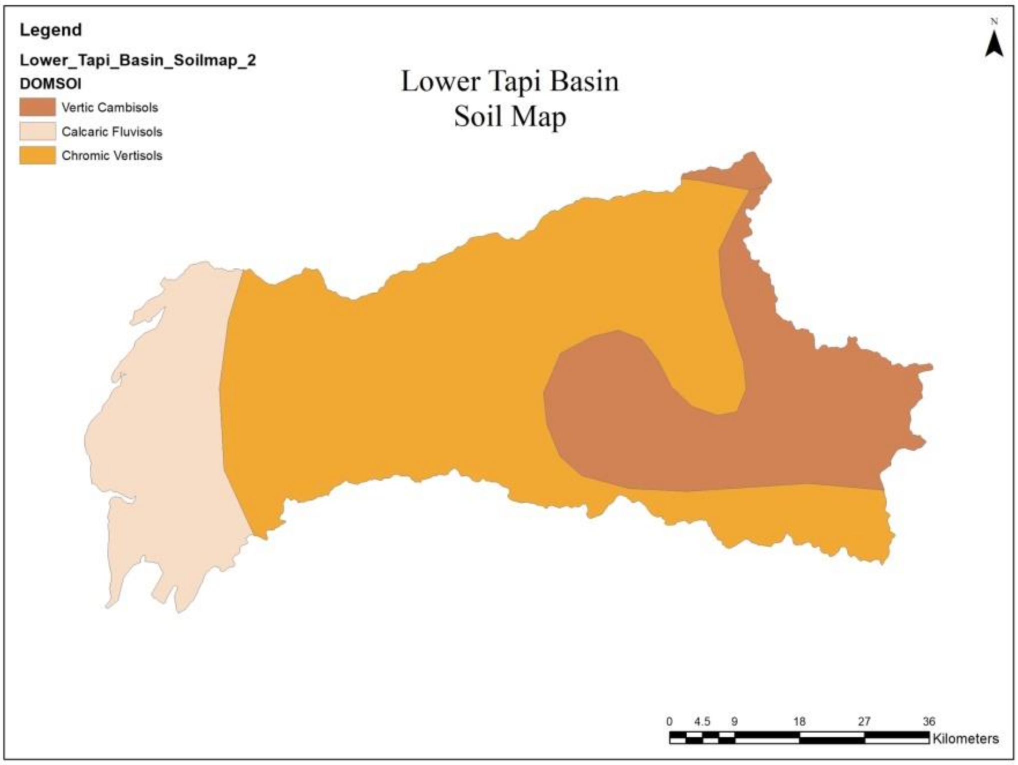



*Figure 2 Soil Map of Lower Tapi Basin*

### 3.3.4 Land use & Land cover

Land Cover is defined as observed physical features on the Earth's surface. When an economic function is added to it, it becomes Land Use.

Tapi river is perennial river because of that too much urbanization have been done from past 20 years and due to which Land use change has, potentially, a very strong effect on floods as humans have heavily modified natural landscapes. Large areas have been deforested or drained, thus either increasing or decreasing antecedent soil moisture and triggering erosion.

Large patches of Scrub lands are prominently visible in the lower part of the basin. Some gullied lands along the river are also observed in the basin

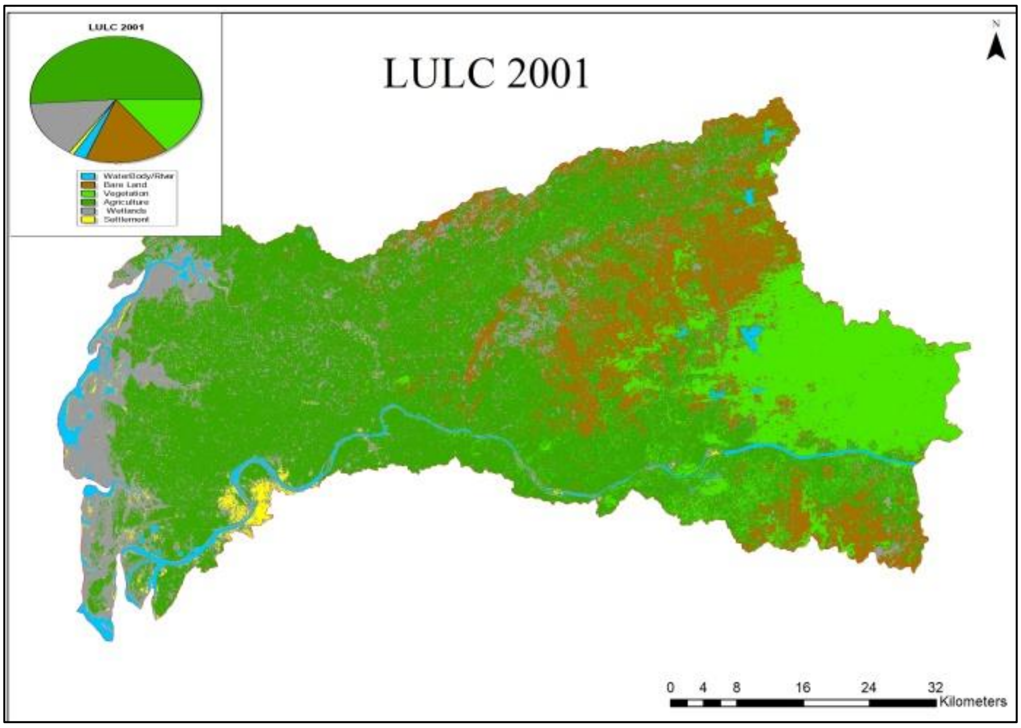



*Figure 3 Land use and Land cover Map of Lower Tapi Basin 2001*

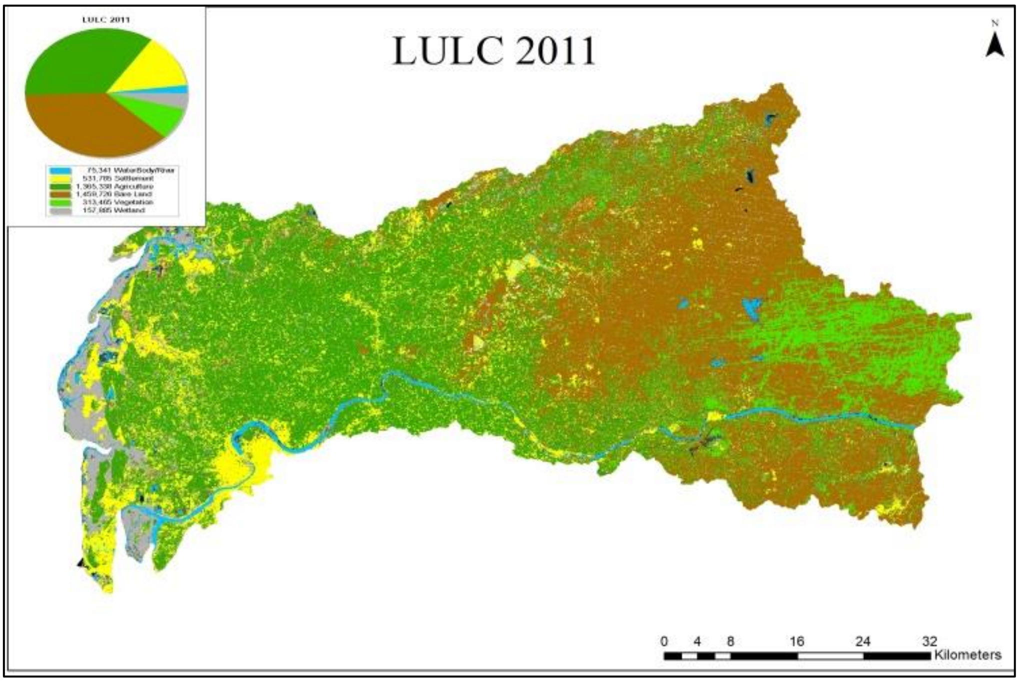



*Figure 4 Land use and Land cover Map of Lower Tapi Basin 2011*

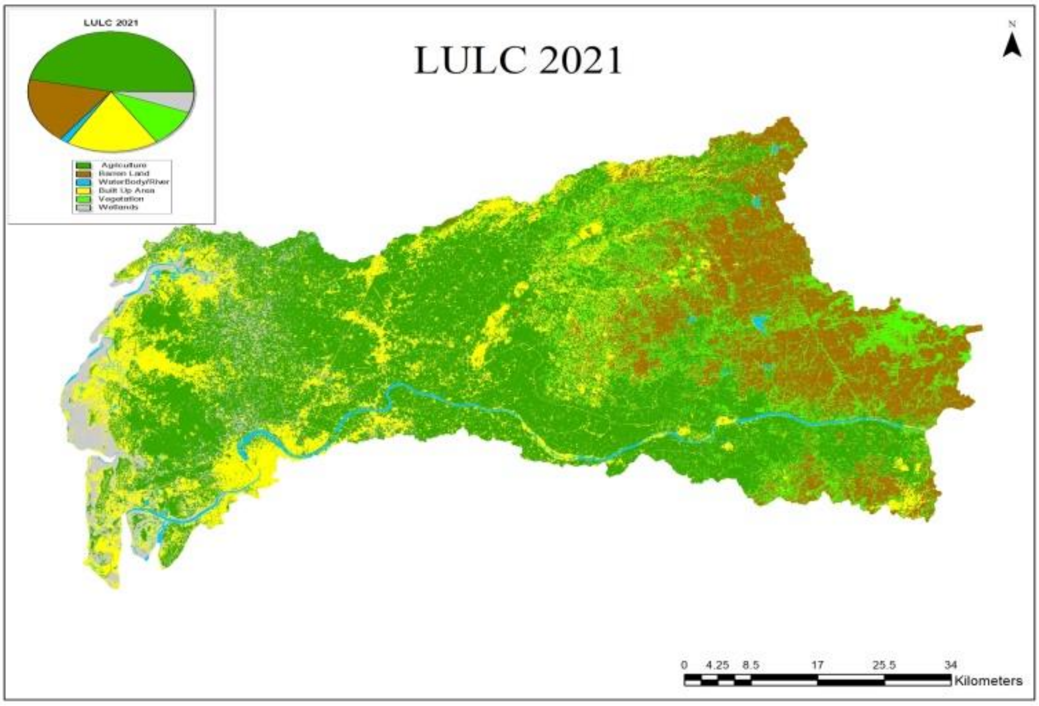
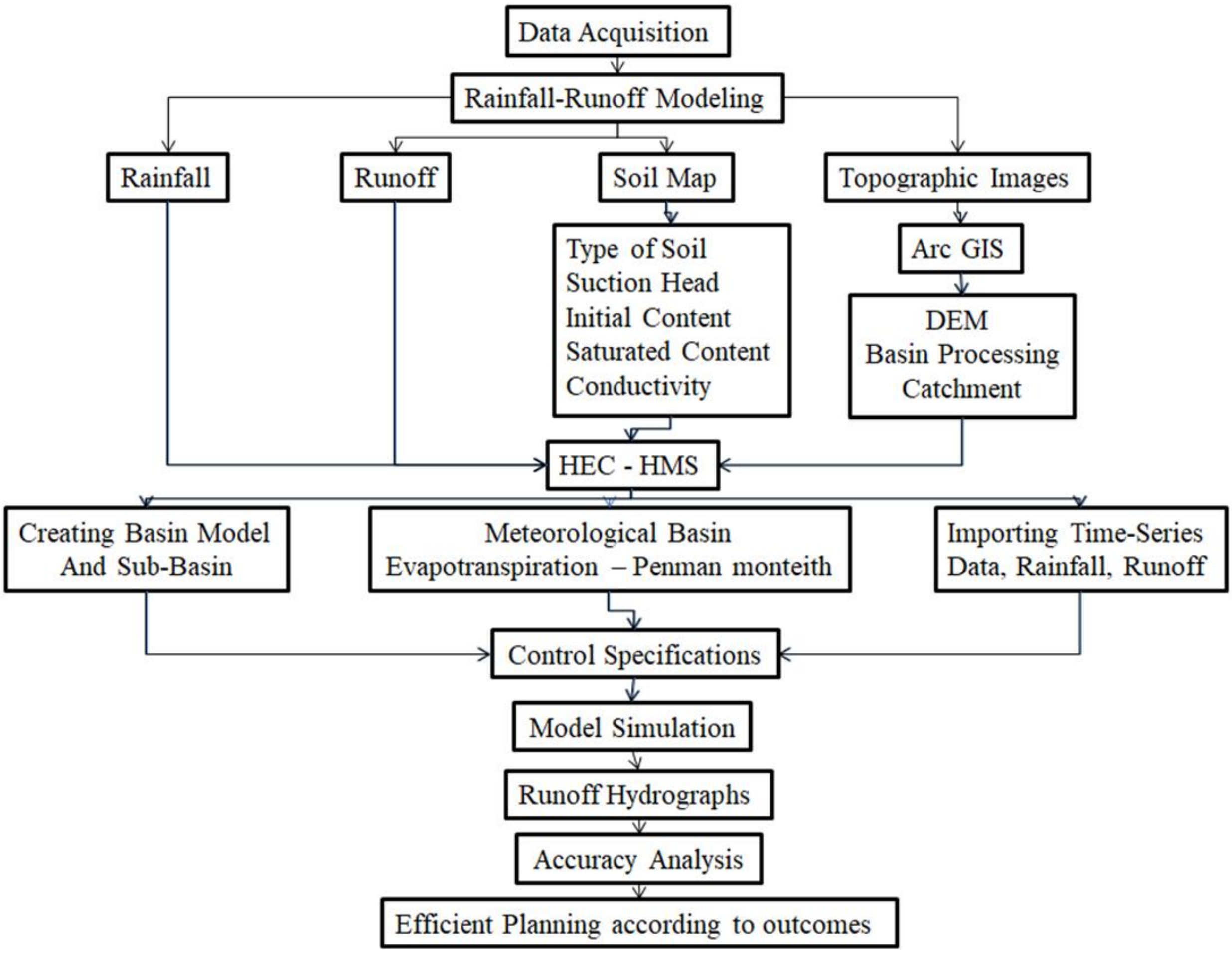



*Figure 5 Land use and Land cover Map of Lower Tapi Basin 2021*

## 3.4 Methodology




## 3.5 Computation of Average Rainfall

Rainfall at a daily time scale is the single most important parameter in hydrological computer simulation models and researchers are often faced with the problem of which interpolation technique to use when determining the spatial distribution of daily rainfall from rain-gauge positions. The arithmetic-mean method is the simplest method of determining areal average rainfall. However, this method is satisfactory only if the gages are uniformly distributed over the area and the individual gage measurements do not vary greatly about the mean. However, in this case the gages are not uniformly distributed over the catchment. In such a case, some gages are considered more representative of the area concerned than others and the relative weights may be assigned to the gages in computing the areal average. Due to these limiting conditions, the Theissen polygon method is best suited for finding out the average rainfall of the catchment concerned. This method assumes that at any point in the watershed the rainfall is the same as that at the nearest gage. So the depth recorded at a given gage is applied out to a distance halfway to the next station in any direction. The rainfall at all the 11 rain gauge stations is measured on a daily basis and is known accurately. The Theissen Network for the given condition is constructed by joining all the rain gauge stations to form a triangular network. Straight lines are drawn joining the adjacent rain gage location to form triangles. Perpendicular bisectors are now drawn to each side of all the triangles. These bisectors define a set of polygon that contains only points that are closer to the gauge at its center than to any other gauge. This will demarcate the entire area of the basin into regions which will contain only one rain gage stations. That area is the weighted area for the particular rain gage station. The areal average precipitation for the watershed is given by

Similarly, the average rainfall for all the days are calculated and inputted to find the average for all the days. The resulting hyetograph is as shown below in Figure 4.2:-

## 3.6 Division of Basin into Sub-Basins

The catchment area of the Tapi River is demarcated by joining all the points of highest elevation along the Tapi basin. Care has to be taken to see that beyond those points the elevation should decrease and no points of higher elevation should be located beyond that point. This is done with the help of Google Earth Pro v5.1. The basin demarcated is as shown in the Figure 4.3. Since there are no major tributaries available on the downstream of Ukai, it becomes extremely difficult to divide the area into the various sub-basins. However, considering the smaller tributaries available in the region and the soil characteristics of the different zones, a classification as given in figure 4.4 has been suggested. This is not accurate but under the limiting conditions of the region, this can be assumed to be accurate. The detailed areas of the various sub-basins are as soon as follows in Table 4.2:-

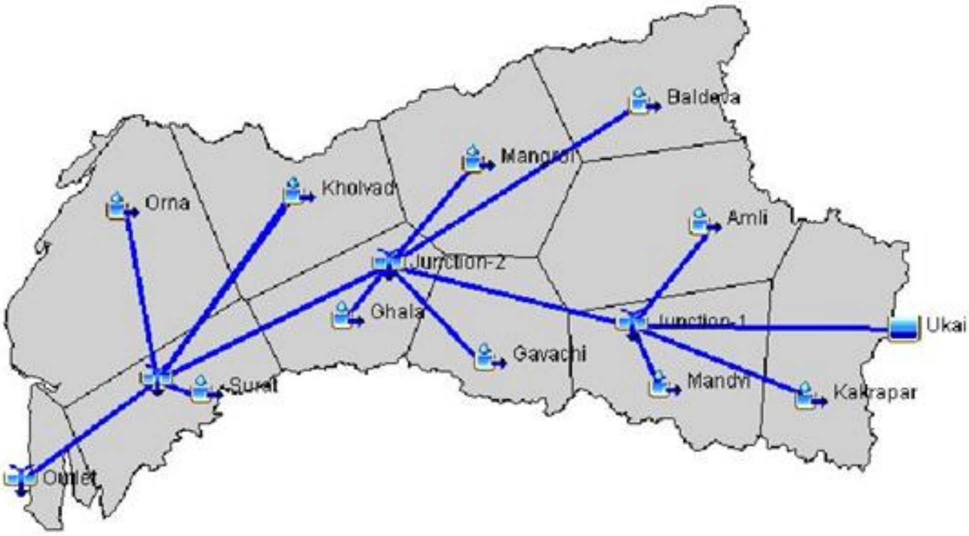



*Figure 6 Division of Basin into Sub-Basins*

## 3.7 Preparation of Stream Network

The catchment of Tapi in the study area concerned is demarcated by identifying the point of maximum elevation in the surrounding area of Tapi downstream of Ukai.

This is done with the help of Google Earth Pro.

The line of demarcation is drawn beyond which the elevation is clearly decreasing.

Thus the total catchment which would drain water to the Tapi River is plotted on the map.

Its area is measured with the help of area measuring tools of Google Earth Pro and is found to be approximately 1672 Km2

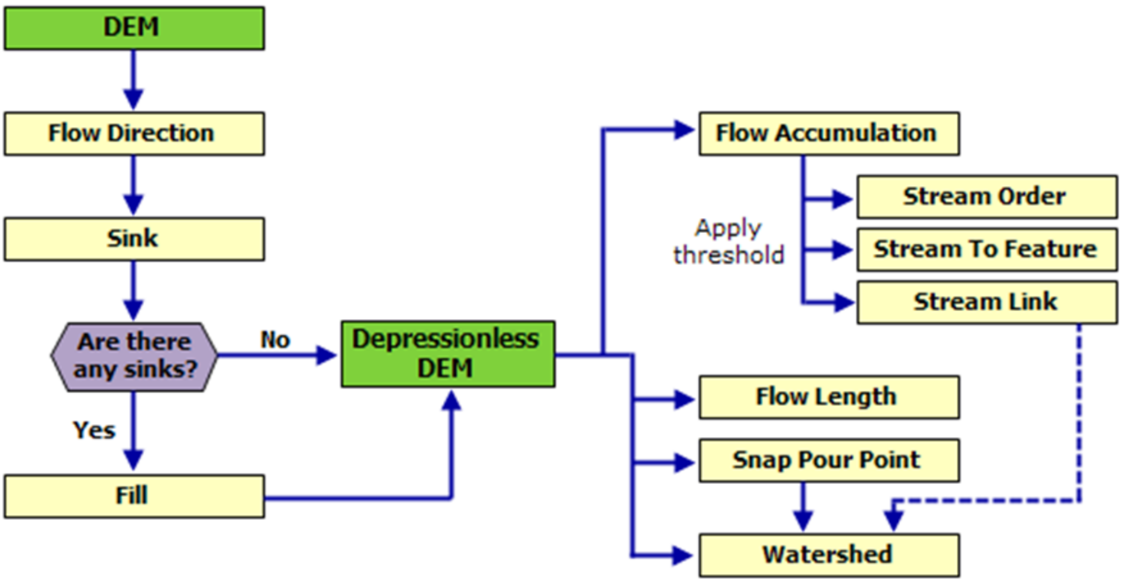



*Figure 7 Steps followed for Preparation of Stream Network*

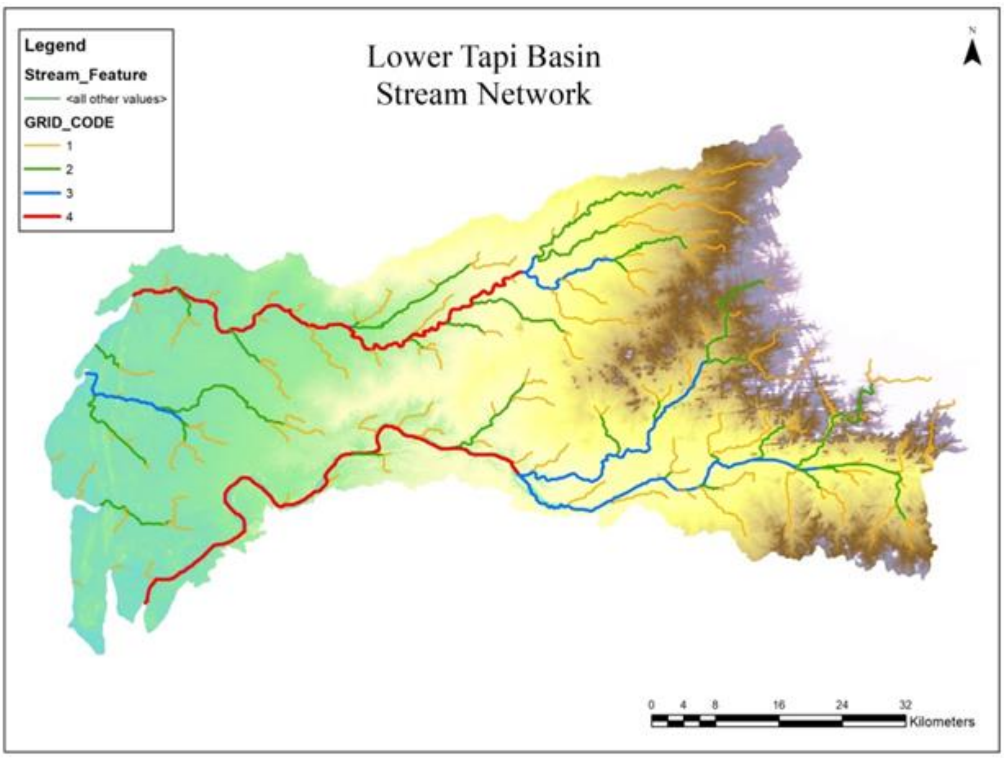



*Figure 8 Stream Network of Lower Tapi Basin prepared in ArcGIS*

## 3.8 RAINFALL-RUNOFF SIMULATION

The rainfall runoff processes of the dendritic catchment systems were simulated by using the hydrological modelling system of the HEC-HMS software. After considering the pre-processing in the HEC-GeoHMS, the model was imported to the HEC-HMS software as a basin file. Figure 8 shows the basin model file. HEC-HMS input data are important to run the rainfall-runoff modelling.

The calculated parameters, such as loss parameters (curve number, initial abstraction and percentage of imperviousness), transform parameters (lag time) and routing parameters (k and x), were added to the sub-basins and the reaches either manually or automatically from the GIS attribute tables. The precipitation, temperature, evaporation and discharge gauge data were added as time series using the time series data manager, while the elevation-area table was added as paired data.

Three files were created for rainfall data input in the meteorological folder, corresponding to the twenty hydrological year intervals 2000–2001 to 2020–2021. For the control run, daily rainfall was started on 1 June at 00:00 and ended on 30 October at 00:00. The selected time interval for the hydrograph was of one day for the corresponding hydrological years.

# Chapter 4: Results & Discussion

## 4.1 Background

After all information and inputs fed into the HEC-HMS model, simulation is being carried out. Twenty years data is used for the model simulation and fifteen years data is used for the model validation. Hydrographs are as shown in Figures,

## 4.2 Hydrographs & Global Summary

The model was run for one year of daily rainfall data for validation purposes. The runoff was simulated by using the hydrological year interval 2015–2016 in the validation model. The model calibration parameters were applied to the validation model. The simulated and observed hydrograph and regression scatter plot for the outlet section for the validation period of the years 2015 and 2016 is presented.

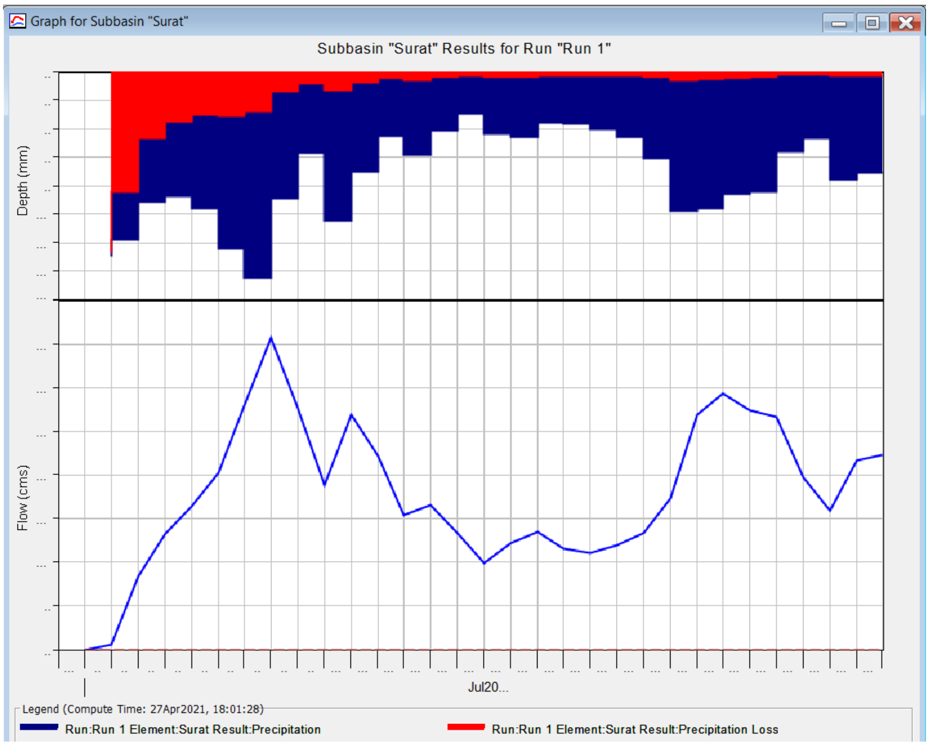



*Figure 9 the resulting hydrograph at Sub-basin Surat*

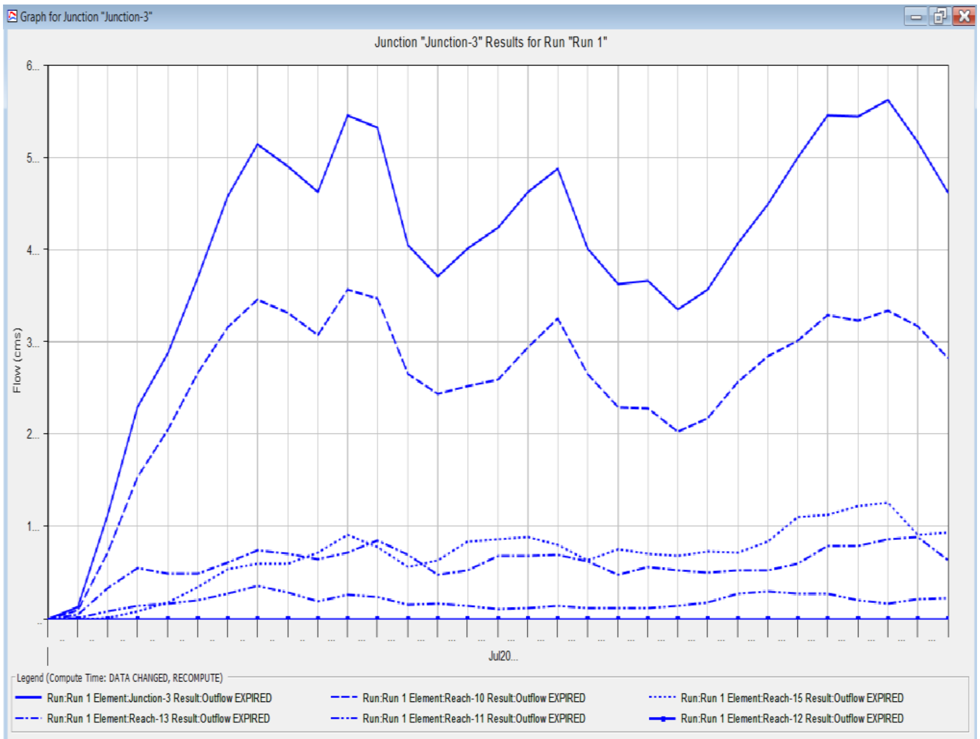



Figure 10 the resulting hydrograph at Junction 3

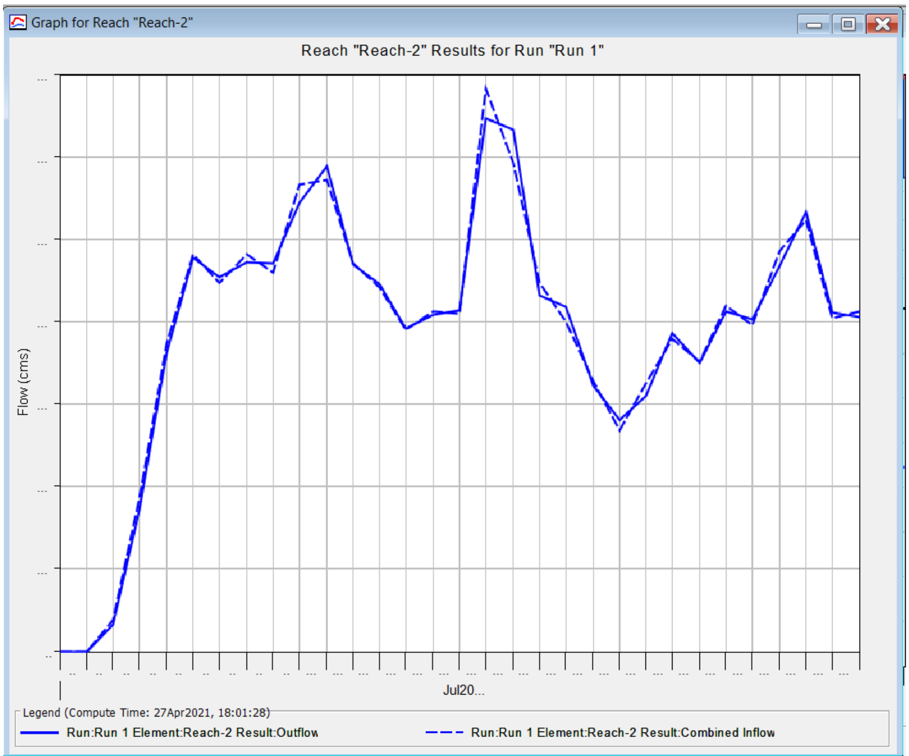



Figure 11 the resulting hydrograph of Reach 2

Show Elements: All Eleme... Volume Units: MM 1000 M3 Sorting: Hydrolo...

| Hydrologic Element | Drainage Area (KM2) | Peak Discharge (M3/S) | Time of Peak | Volume (MM) |
|---|---|---|---|---|
| Surat | 282 | 35.7 | 08Jul2016, 00:00 | 166.33 |
| Baldeva | 314 | 56.3 | 17Jul2016, 00:00 | 270.66 |
| Ukai | 0.0 | 0.0 | 01Jul2016, 00:00 | n/a |
| Kakrapar | 381 | 68.3 | 17Jul2016, 00:00 | 270.66 |
| Amli | 460 | 47.9 | 08Jul2016, 00:00 | 145.00 |
| Reach-4 | 460 | 47.5 | 08Jul2016, 00:00 | 144.75 |
| Reach-2 | 381 | 64.6 | 17Jul2016, 00:00 | 270.05 |
| Mandvi | 363 | 90.0 | 28Jul2016, 00:00 | 429.04 |
| Reach-3 | 363 | 89.2 | 28Jul2016, 00:00 | 428.58 |
| Reach-1 | 0.0 | 0.0 | 01Jul2016, 00:00 | n/a |
| Junction-1 | 1204 | 181.6 | 11Jul2016, 00:00 | 269.97 |
| Reach-8 | 1204 | 180.1 | 11Jul2016, 00:00 | 269.17 |
| Mangrol | 405 | 50.0 | 08Jul2016, 00:00 | 163.28 |
| Reach-6 | 405 | 49.8 | 08Jul2016, 00:00 | 162.88 |
| Reach-5 | 314 | 53.3 | 18Jul2016, 00:00 | 269.78 |
| Gavachi | 280 | 69.5 | 29Jul2016, 00:00 | 433.12 |
| Reach-7 | 280 | 68.5 | 30Jul2016, 00:00 | 432.11 |
| Ghala | 267 | 49.9 | 18Jul2016, 00:00 | 293.19 |
| Reach-9 | 267 | 48.9 | 18Jul2016, 00:00 | 292.93 |
| Junction-2 | 2470 | 364.7 | 11Jul2016, 00:00 | 272.86 |
| Reach-10 | 2470 | 357.0 | 11Jul2016, 00:00 | 271.95 |
| Kholvad | 357 | 88.6 | 29Jul2016, 00:00 | 433.12 |
| Orna | 564 | 126.3 | 28Jul2016, 00:00 | 313.83 |
| Reach-15 | 564 | 126.2 | 29Jul2016, 00:00 | 312.57 |
| Reach-13 | 357 | 88.0 | 30Jul2016, 00:00 | 431.76 |
| Reach-11 | 282 | 35.7 | 08Jul2016, 00:00 | 166.13 |
| Reach-12 | 0.0 | 0.0 | 01Jul2016, 00:00 | n/a |
| Junction-3 | 3673 | 561.7 | 29Jul2016, 00:00 | 285.60 |
| Reach-14 | 3673 | 557.8 | 29Jul2016, 00:00 | 284.88 |
| Outlet | 3673 | 557.8 | 29Jul2016, 00:00 | 284.88 |

*Figure 12 Global Summary*

In analysing a flood event, the most important aspect of the hydrograph is the peak flow, because the peak flow corresponds to the maximum downstream flooding. In contrast, peaks that are significantly less than the maximum may correspond to increased water levels, but not necessarily a flood event. The results of the hydrological model in this study showed a reasonable fit between the model and observations after optimization; the hydrograph shape and timing of peaks matched well, although the model tended to overestimate the runoff before optimization, in the majority of events, the hydrograph shape was accurately reproduced in the model output.

*Table 1 Continuous Twenty years computed results in HEC HMS 4.7.1*

| Year | Average Rainfall (mm) | Annual Maximum Discharge (cumec) |
|---|---|---|
| 2000 | 742.28 | 3435 |
| 2001 | 1286.93 | 4076 |
| 2002 | 1103.05 | 9000 |
| 2003 | 1797.9 | 7564 |
| 2004 | 1628.93 | 5909 |
| 2005 | 1593.31 | 4458 |

| | | |
|---|---|---|
| 2006 | 1510.77 | 14430 |
| 2007 | 1577.91 | 11827 |
| 2008 | 1184.89 | 3406 |
| 2009 | 1139.31 | 3942 |
| 2010 | 1346.27 | 4876 |
| 2011 | 1144.9 | 4404 |
| 2012 | 813.26 | 10481 |
| 2013 | 1778.7 | 9027 |
| 2014 | 906.58 | 10946 |
| 2015 | 864.76 | 7553 |
| 2016 | 1059.28 | 8117 |
| 2017 | 1278.68 | 5735 |
| 2018 | 1219.5 | 9463 |
| 2019 | 2049.02 | 4180 |
| 2020 | 1954.41 | 6267 |

## 4.3 Calibration & Predicting Runoff

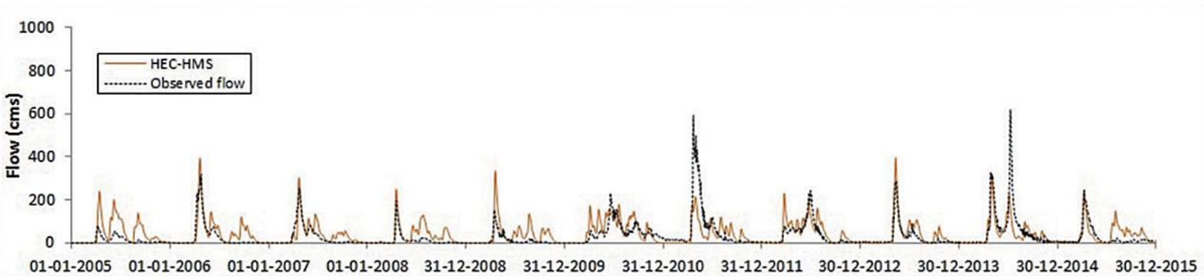



*Figure 13 Simulated and observed flows using HEC-HMS model for the calibration period (2005–2015)*

The model is calibrated by using the daily rainfall data from the hydrological year intervals 2005–2006 to 2014–2015. Manual calibration was applied to estimate the values of the different parameters. The optimal values of the Muskingum Model parameters (K, X) were obtained by comparing the observed and simulated flows, while the parameters of the Loss Model and the Transform Model were calculated

The model used in our research is useful in predicting runoff volumes and flooding in the area of interest. Figure shows that the peaks of the estimated discharges for the hydrological years from 2005 to 2015 occurred between August and October, which is considered to be the time in which severe flooding takes place in the area. Moreover, it can be noted that during the August to October period, runoff depth and volume increased, and therefore, special attention should be dedicated to dam outlet management during this period in the coming years. The simulation results of runoff discharge peaks are slightly different compared with the observed data.

### 4.4 Preparation of Flood Hazard Map

After combining the DEM with river bank levels, a flood risk map for various water-level scenarios at 0.5 m intervals was prepared.

The sample flood mapping potential areas for the all zones have been demarcated. The possible areas under each water level height are depicted with different colours in the flood hazard map.

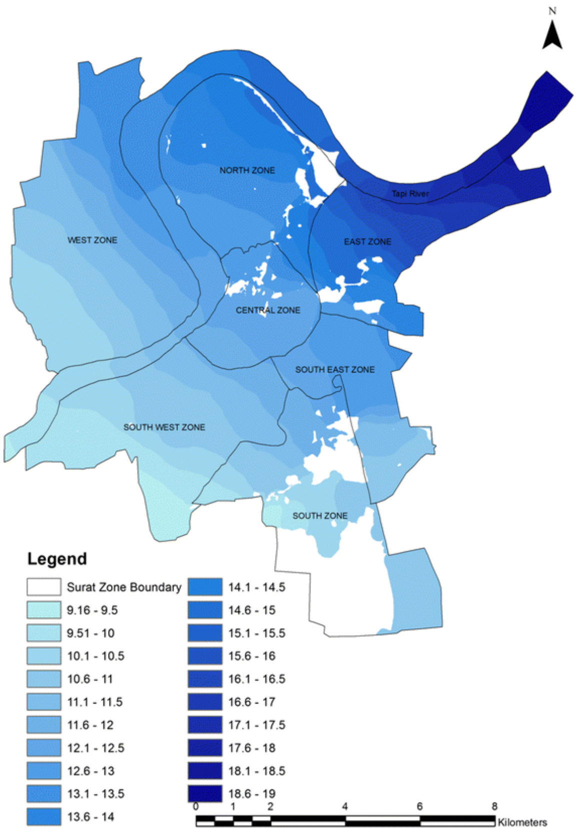



*Figure 14 Water Elevation Map of Surat City*

- Depending on elevation of area, population density, and past flood records of flood in Surat. Total study area is divided in three categories Lower risk area, moderately risk area and highly risk area of city.
- From this map it clearly suggested that lower elevation, highly populated areas near river are widely affected due to flood

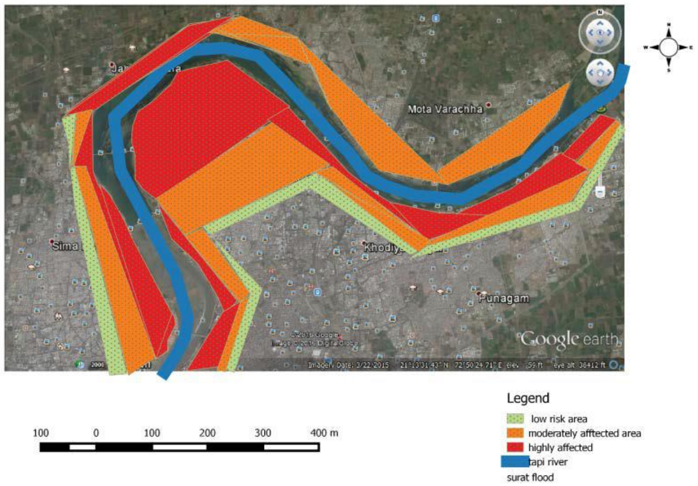



*Figure 15 Flood Hazard Map of Surat City*

*Table 2 Major Flood Event at Surat City*

| Flood Event | Discharge (Lac Cusecs) | Water Level at Nehru Bridge | Period/Danger Level at Nehru Bridge 9.5 |
|---|---|---|---|
| 2002 | 3.25 | 8.2 | September |
| 2006 | 9.09 | 12.40 | August |

*Table 3 Estimated Flood levels at River Sections*

| ID | River Section | Normal Water Level | Water Levels at Discharge (Including Bank Height) | | | |
|---|---|---|---|---|---|---|
| | | | F.D.E 2.5 | F.D.E 3.2 | F.D.E 5 | F.D.E 7 |
| 1 | NH 48 Bridge | 6.00 | 8.50 | 9.20 | 11.00 | 13.00 |
| 2 | Railway Bridge | 6.00 | 8.50 | 9.20 | 11.00 | 13.00 |
| 3 | Kosad Bridge | 7.00 | 9.50 | 10.20 | 12.00 | 14.00 |
| 4 | Wier | 4.00 | 6.50 | 7.20 | 9.00 | 11.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 5 | Nehru Bridge | 4.00 | 6.50 | 7.20 | 9.00 | 11.00 |
| 6 | Low Level | 3.00 | 5.50 | 6.20 | 8.00 | 10.00 |
| 7 | Sardar Bridge | 3.00 | 5.50 | 6.20 | 8.00 | 10.00 |
| 8 | ONGC Bridge | 4.00 | 6.50 | 7.20 | 9.00 | 11.00 |
| 9 | Hazira Point | 5.00 | 7.50 | 8.20 | 10.00 | 12.00 |
| *F.D.E.= Flood Discharge Elevation | | | | | | |

Examples of water levels of the 2006 flood were compared with Nehru Bridge. It was found that Nehru Bridge has a bank level of 4.1 m; therefore there will be about 3–4 m water over the right-bank area. Hence, the major parts of the Adajan area will be submerged. The Rander area will also be submerged by 1–2 m depth of water, as was experienced during the August 2006 flood.

This shows the accuracy of our hydrological and GIS model for flood mapping.

## 4.5 ESTIMATION OF FLOOD ARRIVAL TIME

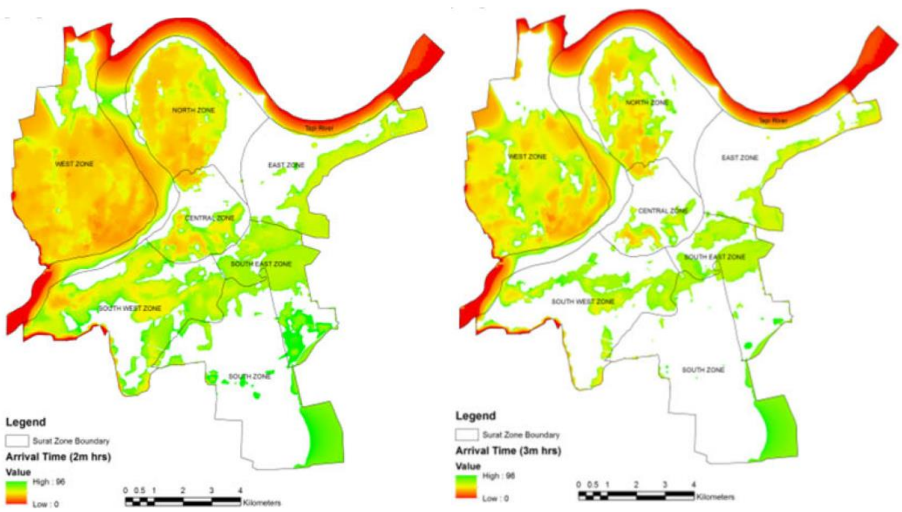



*Figure 16 Flood arrival time in hours, during depth of a 2 m & 3 m*

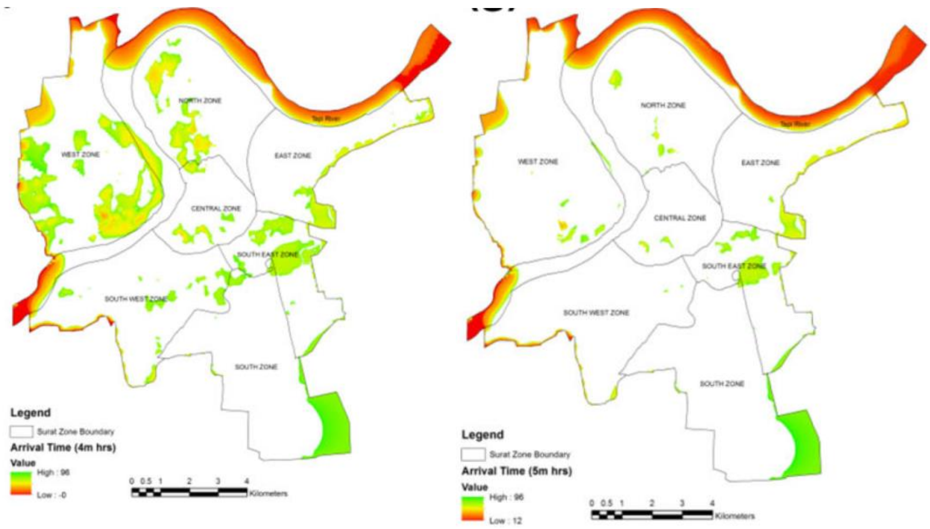



*Figure 17 Flood arrival time in hours, during depth of a 4 m & 5 m*

The water takes 10–12 h to make the city flooded. If the same discharge was released from the Ukai Dam in future considering the same stages, then the simulated result shows the Surat city will be under inundation for approximately 24.22, 2.08, 0.19, 0.26, 0.0, 3.71 and 0.0 km2 areas of west, central, north, east, south, southwest and southeast zones, respectively, for the corresponding release of 14,430 m3 s-1 from Ukai Dam. The simulated results show that the west zone has the maximum chance to get flooded in such a future flood event due to uncompleted bank protection work at d/s of Sardar Bridge, whereas the north zone is safe.

## 4.6 Provisions of Earthen Embankments & Storm Water Management

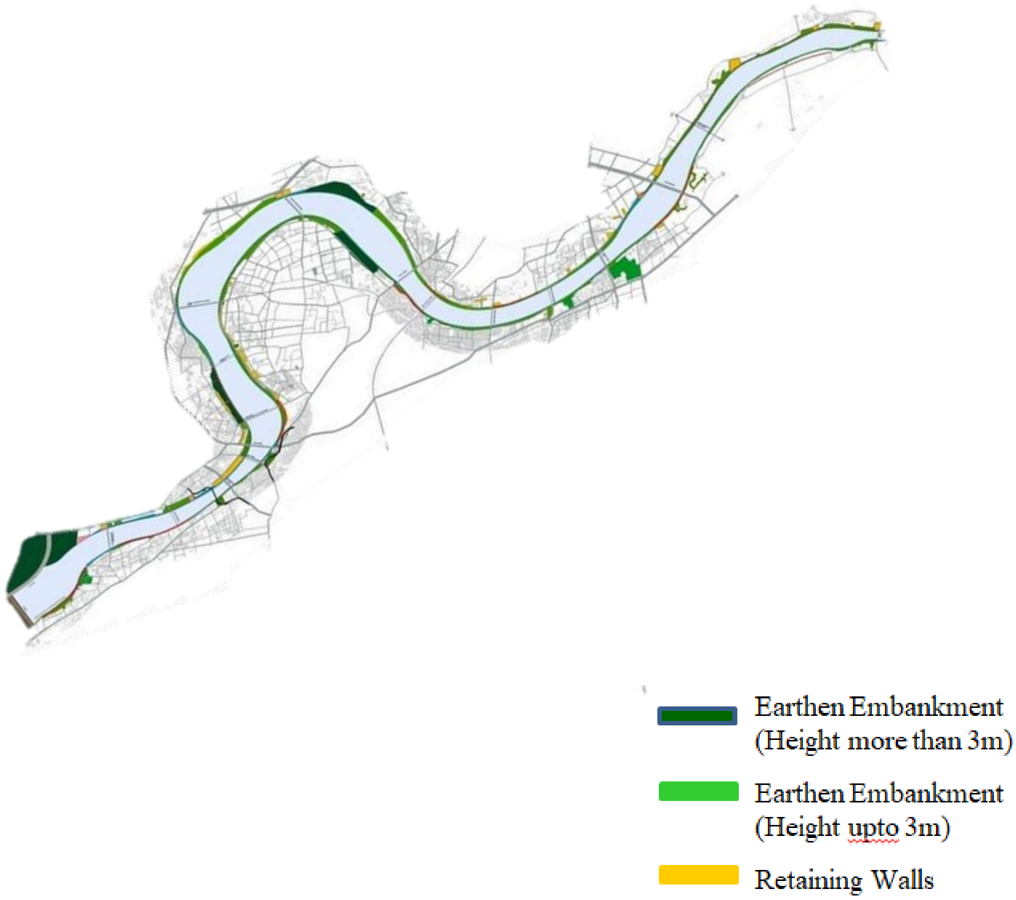



*Figure 18 Provisions of Earthen Embankments & Storm Water Management*

- Conclusions on finding of these studies presented in below in form of recommendations are made for protection from possible flooding of Surat city, other urban development's along banks and the Hazira industrial area. Proposed embankments and retaining walls suggested shown below Fig. to minimize Tapi River flood impacts for Surat City.

**Storm water Management.**

- Storm water harvesting along both the sides of roads with the help of suitable, simple structures, would not only control storm water hazards in cities, but will enhance ground water availability 8 to 10 times compared to natural process of rainfall infiltration.

- The urban flooding will get worse, much worse, and the only solution is de-construction and establishing green infrastructure are the major strategy for mitigating urban flooding.

### 4.7 Provisions of Policies & Plans

- Construction of Embankments and Retaining walls-Restoration and strengthening of existing flood protection earthen embankment on the bank of river Tapi has been constructed for prevention from flood.
- Flood inundation map-Using Remote sensing and GIS flood Inundation maps for different water levels are prepared it helps in disaster managers during flood.
- Early warning system-The early warning flood system is installed in the catchment area of Tapi basin and Surat city This system help in efficient way to monitor flow throughout the basin. This help in monitoring high inflow events. Early warning system installed – telemetry system - at 23 points in Tapi catchment area is considered the main reason for there being no floods after 2006 in Surat.
- Disaster management plan-The disaster management plans can be prepared in advance and use modern technology for relief operations. The flood cell becomes active during monsoon season. The releases from Ukai dam, Ukai Reservoir level and inflow to the reservoir is not only monitored but inform people in vulnerable areas for flooding. Apart from public awareness programme, health measures, proper medical facility for affected areas, spreading of pesticides, fogging and several other measures are adopted after Flooding. Also inform people about various shelters, Hospitals used during flood time for protection of peoples.

# Chapter 5: Conclusion & Recommendation

The study has explored the applicability of the new HEC-HMS version 4.7.1 for flood inundation analysis at Lower Tapi Basin. It is an applicable tool for decision makers to explore in advance the possibility of flood velocity, depth, arrival time, recession and duration at as specific location in floodplain. Through the simulated results, the decision makers will take the appropriate decision in precise time to reduce the death toll and property losses.

- The salient research finding is summarized herewith from the hydrological modelling:
  - West zone is the low-laying area in Surat city; the discharge versus submergences curve for west zone is steep, and it has high chances to inundate in a future flood events.
  - The study shows that the west margin of the River Tapi is the most hazardous one; it has bigger flood extent, deeper flood depths and longer flood duration. In flooded areas, the water has a velocity lower than 0.50 m s-1.
  - The area of interest does not have an available discharge station other than the one located near the Ghala. Discharge stations could provide real observed discharge data that can be used to validate the modeling results. Therefore, the provision of an downstream discharge station is vital.
  - Presently, at 14,429.68 m3/s, major zones of Surat city are safe against flood inundation. If water rises and accelerates gradually, then the same inundation conditions will be followed as in 2006. It shows that present levees are not enough to fully protect the Surat city against 25,770 m3/s release from Ukai. It is a prime requirement to develop the advance flood forecasting and warning system for Surat city along with structural measures.
  - The development of serious water policy and planning strategies in accordance with the results obtained from this study could reduce the probability of floods and may help in the management and control of the dam outlet.

– During modeling using HEC-HMS, it was noticed that the main parameters which affect runoff quantities were the curve number and then initial abstraction. However, lag time and percentage of impervious area were less affected by the runoff result.

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