ONE DIMENSIONAL HYDRODYNAMIC FLOOD MODELING FOR AMBICA RIVER, SOUTH GUJARAT

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Abstract: Navsari is a developing, thinly populated city located on the bank oh river Ambica. The frequent flooding in Navsari city has become a recurrent phenomenon of last decade. The city has faced frequent flooding since long back. Major flood event occurred in year 1981, 1984, 1994, 1997, 2001, 2003, 2004, 2006, 2013 and 2014. At present, the carrying capacity of the river is approximately about 2.5 lakh cusecs (7071 cumecs). The flooding problem in the Navsari city has been perennial each time causing a reversal of gains on economic and social development. This paper presents a model developed to determine water level along the Ambica river from Ichhapur to 11 km Dhamdachha village using the HEC-RAS hydrodynamic model and past flood events of the year 1984, 1994 and 2004. The study reach consists of 359 cross-sections. The model was calibrated and verified for steady flow conditions. It provides water levels and inundation areas along the river for different discharges. The study compares the result obtained from the model with the help of observed flood level taken during past flood events. Based on the above study, it is strongly recommended to construct a retaining wall or either raised the height of the existing wall at a particular cross-section.

Keywords: Ambica River, Flood, HEC-RAS, Hydrodynamic modelling.

1. Introduction

Flood are among the most devastating natural hazard in the world, claiming more lives and causing more property damage than any other natural phenomena. When the depth of flow during flood event exceeds the height of the main channel, the flow expends in to the relatively flat floodplains. Flood are of many types including flash flood, river flood, coastal flood, urban flood and flooding due to the opening or breaking of dam or reservoir. Now a day excessive human interference has caused flooding in many places that previously was not flood. So that in addition to excessive rainfall, snowfall and tsunami, some human activities increases the risk of flooding such as the construction in the floodplain area of the river that reduce the natural capacity of the river. So the management of floodplains will be very important.

Floods impact on both individuals and communities, and have social, economic, and environmental consequences. In monetary terms, the extent of damages caused by floods is dependent on the location, extent, depth and duration of flooding, and the velocities of flows in the flooded areas, and the vulnerability and value of the natural and constructed environments they affect. Flood protection can be achieved through various structural measures such as dykes, diversion channels, reservoirs, floodway, improving channel conveyance capacity and non-structural measures such as flood forecasting and warning, mass evacuation, watershed management, insurance and etc. (Honghai *et al*. 2011). One dimensional (1D) river flow modelling and computation of flood inundation became easier after the rapid advancement in computer technology. Hydraulic modelling is performed in order to predict important information from a flood event including the extent inundation and water surface elevation at specific locations. Metha *et al.* (2014) studied the different cross-sections using HEC-RAS to check the adequacy of flood carrying capacity of Tapi River basin using past flood data. The HEC-RAS gives the easy prediction of possible effects of flood in Surat city and surrounding area. The discharge for given basin was varied according to last previous discharge data available during floods or storms in the Tapi River using HEC-RAS with manning's constant as 0.022. Timbadiya *et al*. (2014) studied the one-dimensional hydrodynamic models proposed for prediction of water level and inundation extent are computationally quite efficient; these models suffer from limitation when applied to flood plain. Nandala (2009) has been studied the flood water levels along the 79 km long Kalu River in Sri Lanka were simulated using the 1D HEC-RAS hydrodynamic model to reduce flood damages. Alaghmand *et al.* (2009) studied the River flood modelling is a tool for assessment, evaluation and prediction of river flood risk in various scenarios. River flood risk modelling consists of four main components: hydrological modelling, hydraulic modelling, river flood visualization and river flood risk mapping. Timbadiya *et al.* (2011) has predicted flood for Lower Tapi River in India using HEC-RAS for 1998 and 2003 years. The calibrated model, in terms of channel roughness, has been used to simulate the flood for 2006 year in the river. The performance of the calibrated HEC-RAS based model has been accessed by capturing the flood peaks of observed and simulated floods; and computation of root mean squared error (RMSE) for the inter-mediated gauging stations on the lower Tapi River. Vijay et al. (2007) describes a hydrodynamic model called River cad that provides the flood levels and land availability at various cross-sections in order to assess the limitation and evaluate the possibilities for riverbed development. Numerical models are important tool for understanding flood events, flood hazard assessment and flood management planning. Salimi *et al.* (2008) have integrated the HEC-RAS simulation model and geographic information system (GIS) to get the areal extent and depth of flooding. Roushan *et al.* (2013) simulated hydraulic behavior of the Bashar River using HEC-RAS and GIS. The purpose of this study was to combination the HEC-RAS hydraulic model and Arc View GIS software using HEC-GeoRAS extension for simulating the hydraulic parameters of Basher River. The results of this study indicate that the HEC-RAS model can provide the appropriate numerical values for investigating the hydraulic characteristics of flow in rivers and used for flood hazard mapping with more accuracy and low cost. Pramanik *et al.* (2009) developed a 1D model of the Brahmani River in India using field-surveyed and DEM-extracted data and the MIKE 11 hydrodynamic module.

This paper presents a model developed for the Ambica river from Ichhapur to Dhamdachha village using a public domain software to predict flood levels along the river. The possibility to get the affected community or society directly involved the flood warning and disaster mitigation process can be very successful (Fakhruddin *et al.* 2005).

2. Objective of Study:

The objective of the study is to implement a one dimensional hydrodynamic model for the lower part of Ambica river reach between Ichhapur to Dhamdachha village using HEC-RAS (5.0.3) modelling software.

3. Study Area and Data Collection

3.1 *Study Area*

Navsari is a developing, thinly populated city located on the bank of River Ambica. Ambica River is one of the important westward flowing rivers. It originates from Saputara Hill near village Kotambi of Surgana taluka in the Nasik district of Maharashtra, having a length of 136 km, and falls into the Arabian Sea. Majority of higher order tributaries namely Kapri, Wallan, Kaveri and Kharera join the Ambica River. The Ambica basin located with the geographical coordinates 20° 31' and 20° 57' of North latitude and 72° 48' and 73° 52' of East longitude. The total catchment area of Ambica basin is 2715 km^2, out of which 102 km^2 and 2613 km^2 lie in the Maharashtra and Gujarat respectively. There are three hydrological stations within the basin. Over 90% of the total rainfall arrives during the south west monsoon (i.e. June–September) season in the basin, and the flow is negligible in the remainder of the year. Flood occurs at study region due to excess rainfall and many big hazardous situation are occurred so this area to be chosen for flood analysis.

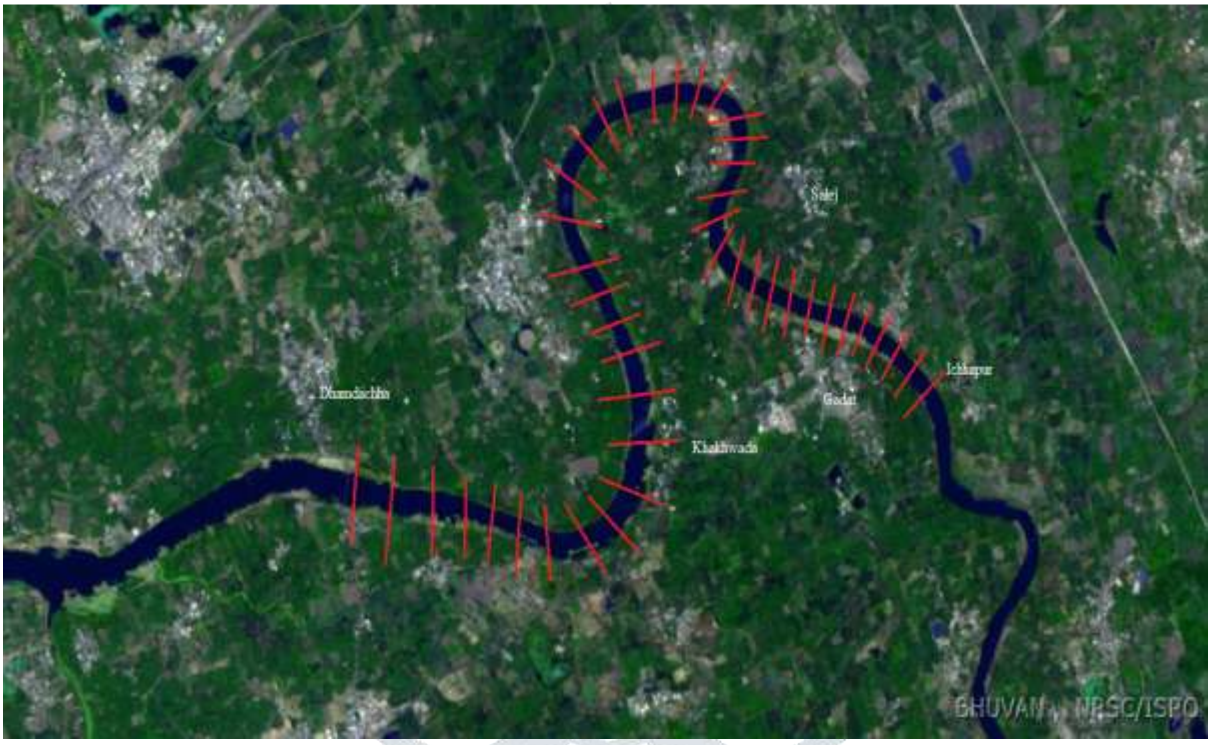

Figure 1: Study Reach with Cross-Sectional Details

Figure 1 shows the study reach with 359 cross-sectional details. Following are the details of study area: Length of river reach is 11 km (11000 m), Red line indicates cross-section in river reach and average interval between cross-sections to cross-section is 30 meters.

3.2 *Data Collection*

The Navsari Drainage department provided the topographic data of the study reach in the form of contour and Cross-sections at locations in the study reach in the Auto CAD (.dwg file) format. The cross-section data at 30 m intervals exceeding over a length of 11000 m has been provided. Data includes the station and elevation coordinates, reach length and channel width at the section. The State Water Data Centre (SWDC) Gandhinagar, Government of Gujarat provided past flood peak discharge data.

4. Overview of HEC-RAS Software

HEC-RAS (5.0.3) is open source soft tool which designed in 1995, the United States Army Corps of Engineers Hydrologic Engineering Center's River Analysis System (HEC-RAS) is "software that allows you to perform one-dimensional steady and unsteady flow river hydraulics calculations, sediment transport-mobile bed modelling, and water temperature analysis." In a HEC-RAS steady state simulation, water surface profiles are computed from one cross-section to the next by solving the standard step method to solve the energy equation. The energy equation is intended to calculate water surface profiles for steady gradually varied flow. The energy equation is shown in Equation 1 for two adjacent cross-sections CS_1 and CS_2.

$$Z_2 + Y_2 + \frac{a_2 V_2^2}{2g} = Z_1 + Y_1 + \frac{a_1 V_1^2}{2g} + h_e \qquad Eq^n.\ 1$$

Where Z_1 and Z_2 are elevations of the main channel inverts, Y_1 and Y_2 are depths of water at adjacent cross-sections, V_1 and V_2 are average velocities (total discharge/ total flow area), α_1 and α_2 are velocity weighting coefficients, g is the gravitational acceleration and h_e is energy head loss. The energy head loss term is defined in Equation 2.

$$h_e = L\,\overline{S_f} + C\left|\frac{a_2V_2^2}{2g} - \frac{a_1V_1^2}{2g}\right| \qquad \text{Eq}^n.\ 2$$

Where L is discharge weighted reach length, $\overline{S_f}$ is representative friction slope between cross-sections, and C is an expansion or contraction loss coefficient. The representative distance weighted reach length are defined in Equation 3.

$$L = \frac{L_{lob}\overline{Q}_{lob} + L_{ch}\overline{Q}_{ch} + L_{rob}\overline{Q}_{rob}}{\overline{Q}_{lob} + \overline{Q}_{ch} + \overline{Q}_{rob}} \qquad \text{Eq}^n.\ 3$$

Where L_{lob}, L_{ch} and L_{rob} are cross-section reach lengths for flow in the left over-bank, main channel, and right over-bank, respectively, and $\overline{Q}_{lob}$, $\overline{Q}_{ch}$ and $\overline{Q}_{rob}$ are arithmetic average of the flows between sections for the left over-bank, main channel, and right over-bank, respectively. Limitations in the HEC-RAS steady flow simulation include the assumptions that the flow is steady, the flow is gradually varied, the flow is one-dimensional, and the river channels have small slopes.

For situations when the flow may be rapidly varied, the momentum equation is used to solve the water surface profiles. These situations include hydraulics of bridges, river confluences, and mixed flow regimes such as hydraulic jumps. The momentum equation used in HEC-RAS is shown in Equation 4.

$$\frac{Q_2\beta_2}{gA_2} + A_2\overline{Y}_2 + \left(\frac{A_1+A_2}{2}\right)LS_O - \left(\frac{A_1+A_2}{2}\right)L\overline{S}_f = \frac{Q_1\beta_1}{gA_1} + A_1\overline{Y}_1 \qquad \text{Eq}^n.\ 4$$

Where β is momentum coefficient that accounts for a varying velocity distribution in irregular channels, Y_1 and Y_2 are depths measured from the water surface to the centroid of the cross-sectional area at CS_1 and CS_2, Q_1 and Q_2 are discharge at locations CS_1 and CS_2, A_1 and A_2 are wetted area of the cross-section at locations CS_1 and CS_2, L is distance between sections CS_1 and CS_2 along the channel, S_o is slope of the channel based on mean bed elevations, and $\overline{S_f}$ is slope of the energy grade line.

4.1 *HEC-RAS Input Parameter*

4.1.1 Geometric Data

The geometric data consists how the river reach establishing by various cross-sections connected (River System Schematic). The geometric data in the form of a series of cross-sections, reach length and left and right bank station, a friction parameter in the form of Manning's n values and contraction/expansion coefficient across each cross-section. The Navsari Drainage department provided geometric data of present study reach as contour map in Auto CAD (.dwg file) format.

4.1.2 Cross sectional Data

Boundary geometry for analysis of flow in river reach is specified in terms of ground surface profiles (cross-sections) and the measure distance between them (reach length). Cross-sections should be perpendicular to the flow lines and extend across the entire flood plain. Cross-sections are requires at locations where changes occur in discharge, slope, shape or roughness. Each cross-section is identified by a Reach and River station label. The cross-section is described by entering the station and elevations from left to right, with respect to moving in the downstream direction.

4.1.3 Steady flow Data

Steady flow data including flow rates, flow change locations, and boundary conditions. Steady flow data consists of the number of profiles are three and the flow data inputted PF 1 as 11000 $m^3\ s^{-1}$, PF 2 as 6500 m3 s^{-1} and PF 3 as 5000 $m^3\ s^{-1}$. The upstream boundary condition and downstream boundary condition should be known water surface elevation, critical depth, Normal Depth, or Rating Curve. Required model parameters for HEC-RAS include for a steady state sub-critical simulation, the boundary condition is a normal depth.

4.1.4 Flood Conveyance performance

For evaluation of flood performance, past flood data collected from the SWDC, Gandhinagar were used. Major flood events took place in the year 1981, 1984, 1994, 1997, 2001, 2003, 2004, 2006, 2013 and 2014. The summery of the floods is given in the Table 1.

Table 1 PAST FLOOD EVENT

Sr. No.	Year	Cusecs In Lakhs	Cumec (m^3/s)
1	1979	0.586	1660
2	1981	0.523	1480
3	1984	3.88	11000
4	1994	2.29	6500
5	1997	1.13	3200
6	2004	1.76	5000
7	2006	0.971	2750

5. Methodology

Following are the steps required for steady flow simulation in HEC-RAS:

- Create a schematic project of Ambica River system.
- Import geometric data of cross sections extracted from Auto CAD file.
- Entering the river and reach information, the right and the left banks of the cross sections, distance of the main channel and the left and the right bank from the downstream section, Manning's roughness coefficient in the main channel and the left and the right banks are "0.030". (Roughness coefficient was obtained using the table of Chow roughness coefficients according to bed material of river reach).
- River network geo-referenced using HEC-GeoRAS and GIS.
- After adding all data and geo-referencing the river network we get Geometric cross-sections (Fig. 2) in HEC-RAS which is same as that collected from Navsari Drainage Department.
- Once the geometric data is entered, the necessary steady flow data for different flood peak discharge can be entered subsequently. Steady flow data consists of the number of profiles are 3 and the flow data inputted PF 1 as 11000 $m^3 s^{-1}$, PF 2 as 6500 m3 s^{-1} and PF 3 as 5000 $m^3 s^{-1}$.

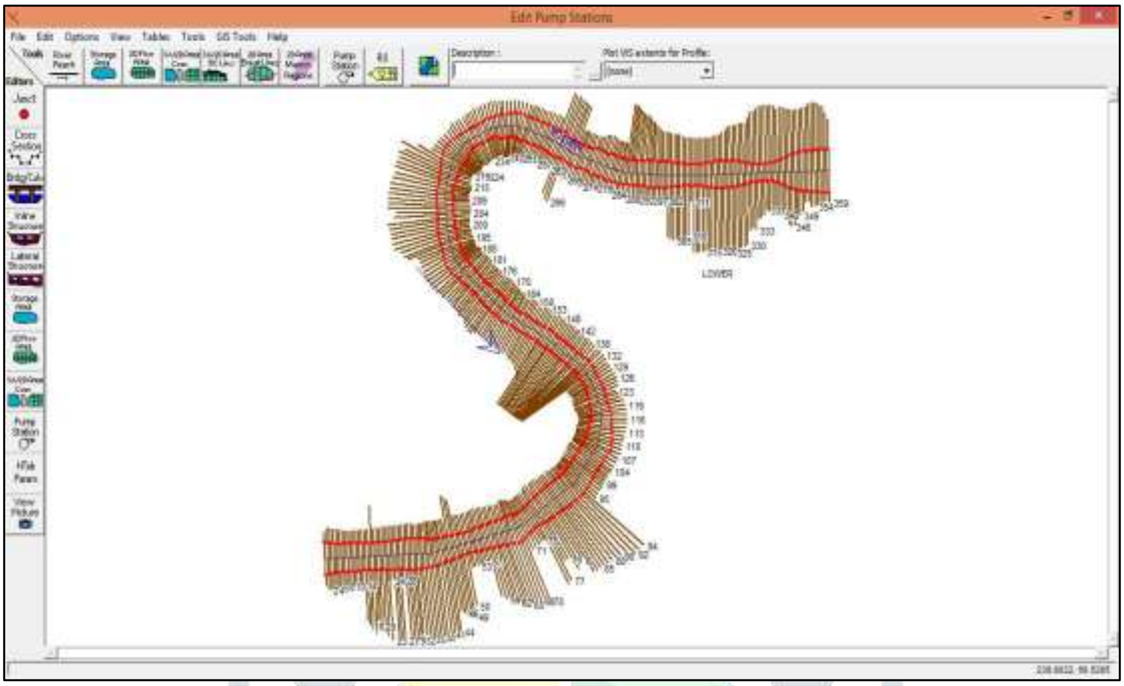

Figure 2: Georeferenced River Network

- Determine the boundary conditions in steady flow window (There are four boundary conditions such as rating curve, normal depth, critical depth and water surface level. Here, downstream boundary condition of normal depth 0.00418 (river bed slope) is considered).
- Finally, after entering all of the data, open run windows and the simulation was carried out and the water surface profiles were extracted.

Results and Discussions

The hydrodynamic flood modelling for the Ambica River in present study was performed using the HEC-RAS version 5.0.3 for one dimensional steady flow analysis. After collecting all data of study reach, input all data for designing of river reach section in uniform flow and the model was run for one dimensional steady flow water surface profile computations for river Ambica. The energy equation, using the standard step method, solved the steady flow, while Manning's equation and contraction and expansion coefficients determined head losses. The study of behavior of river cross-sections under various flood discharge are carried out. The integrative water surface profile in two and three dimensional views intensifies that there is an irregularity in the flow behavior of the river as can be clearly seen in Fig. 3 and Fig. 4. Conversely, anywhere the channel width has been narrow, the width of flood area has reduced in the same proportion and also the depth of flood levels has increased. Shown in Figure 3 is an example of water surface profile plot with three water surfaces, each representing a different instance in time during the simulation.

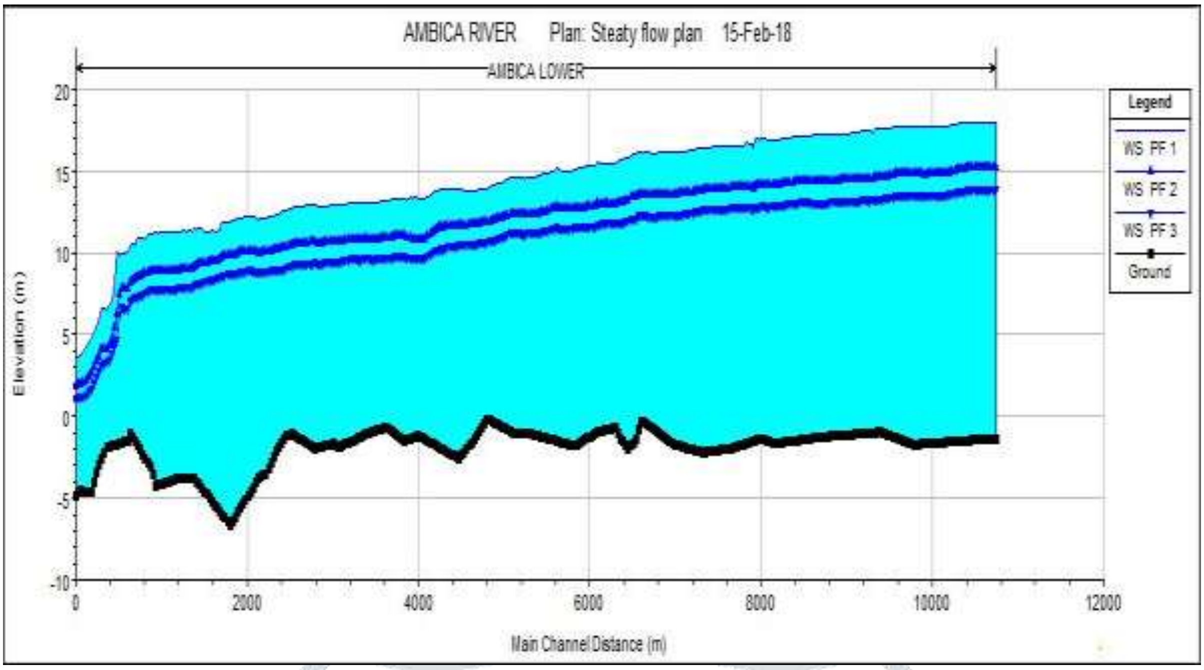

Figure 3: Profile Plot of Ambica River

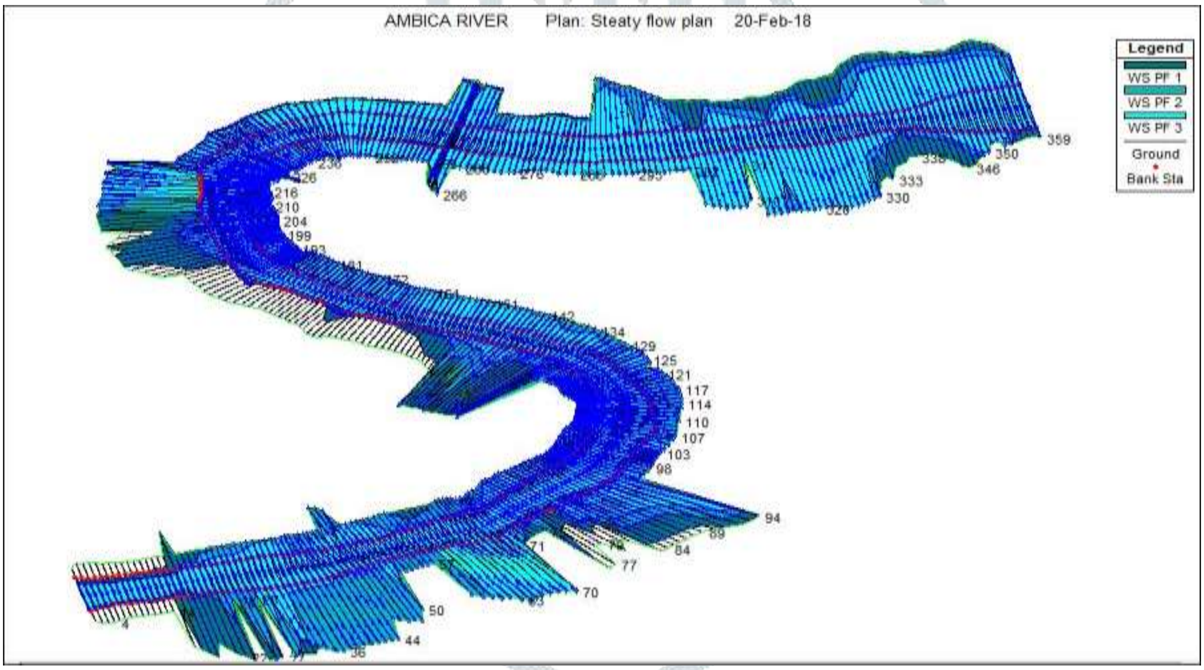

Figure 4: 3D Profile Plot of Ambica River

The flow in the channel as, 11000 cumec, 6500 cumec and 5000 cumec has been considered for uniform flow analysis. When these values are given as input at all the 359 cross-sections the simulation results were shown the flood level in cross section as Fig. 5 to Fig.14.

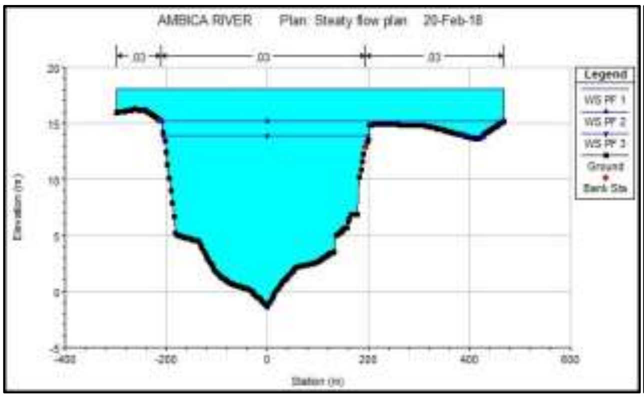

Figure 5: Water Surface Profile at cross section 359

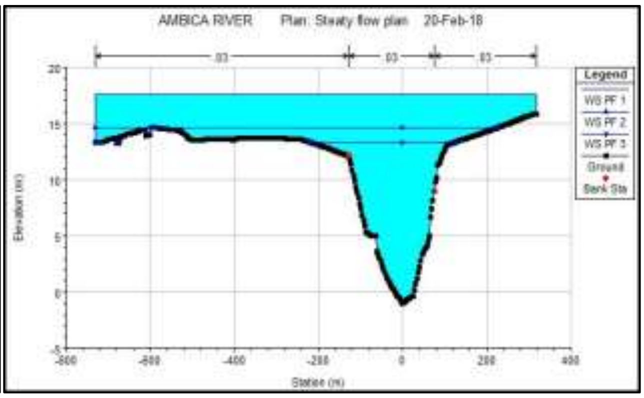

Figure 6: Water Surface Profile at cross section 315

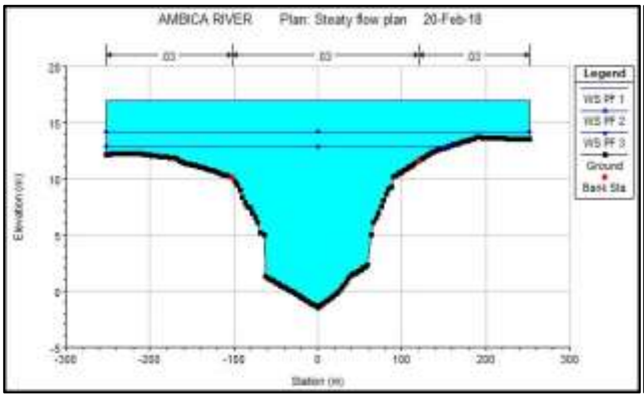

Figure 7: Water Surface Profile at cross section 270

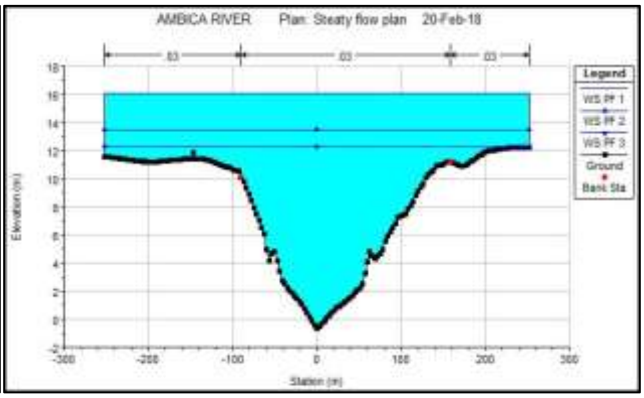

Figure 8: Water Surface Profile at cross section 225

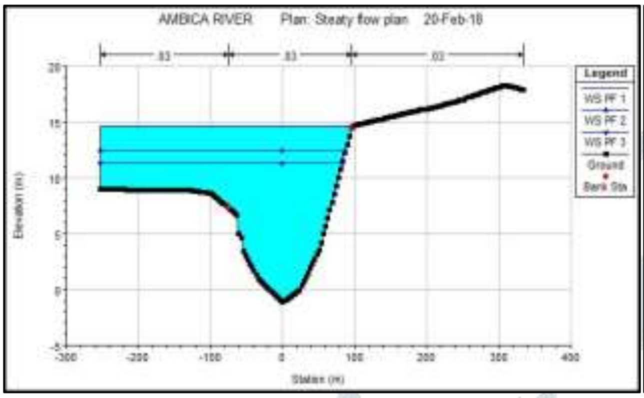

Figure 9: Water Surface Profile at cross section 180

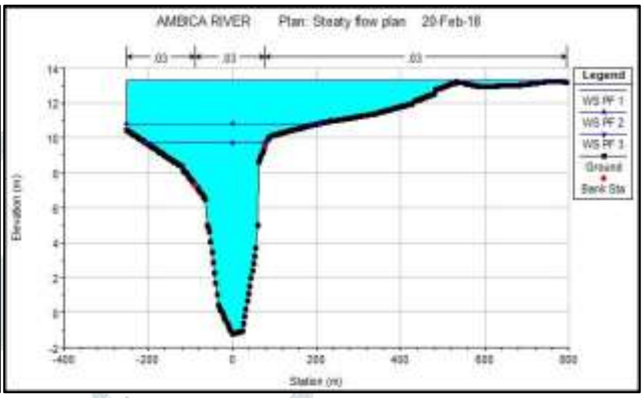

Figure 10: Water Surface Profile at cross section 135

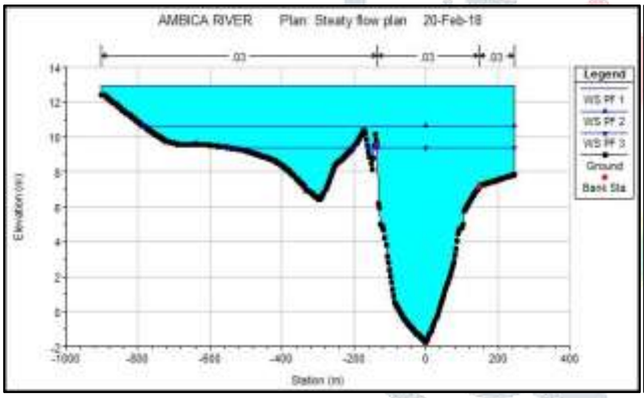

Figure 11: Water Surface Profile at cross section 90

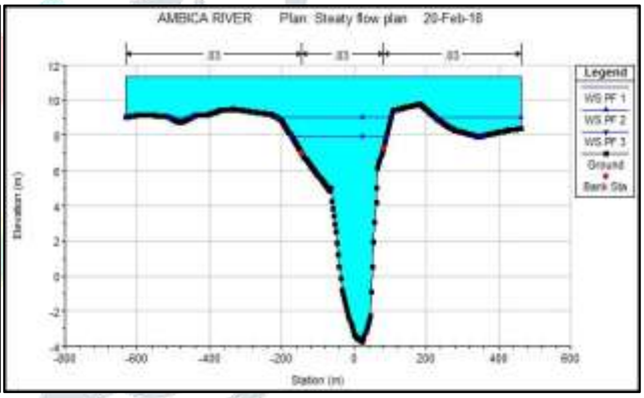

Figure 12: Water Surface Profile at cross section 45

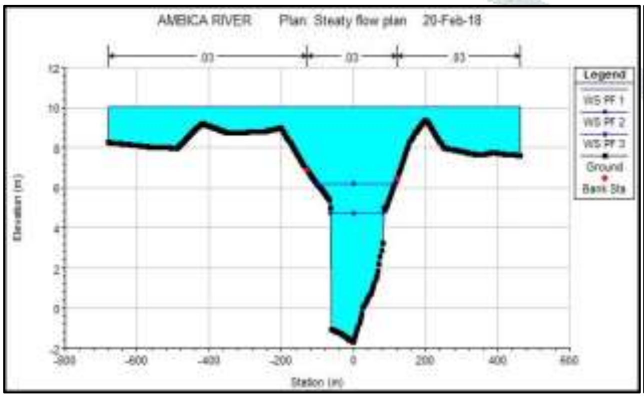

Figure 13: Water Surface Profile at cross section 17

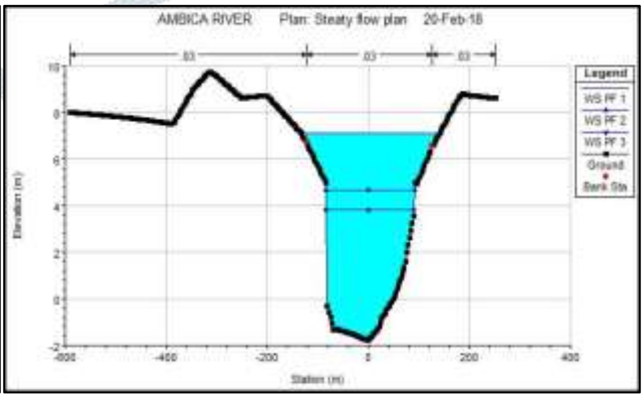

Figure 14: Water Surface Profile at cross section 15

Conclusion

The model developed can be used to predict water levels along the river reach from Ichhapur to Dhamdachha village foe different water flows in the river. Flood study of year 1984, 1994 and 2004 has been done to assess inundation of the area. By considering the past flood events, it is strong recommend to improve the carrying capacity of Ambica River which will help to minimize the flood in surrounding of Navsari city. Result from the scenarios investigations indicate that dykes breaching was the major causes of the flood events. At the breached dykes, the water level was above the river embankment. Based on the above study and analysis, it is recommended that the sections which overtops over the existing embankment or retaining wall need to be raised.

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