# Feasible Structural and Non- Structural Measures to Minimize Effect of Flood in Lower Tapi Basin

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*Abstract:* Floods have always been a major problem to the human race, as many settlements have grown up around rivers. The fastest growing city of India, Surat, is settled on the bank of river Tapi. Varekhadi, a group of 26 mini watersheds lead water into river Tapi and the flow takes a small time period to reach near Surat city. Due to which, the city gets flooded once in a 4 to 5 years and losses large amount of property and lives. Present work describes the flood potential of Varekhadi watershed group by application of Soil and Water Assessment Tool (SWAT) model, using Remote Sensing (RS) and Geographical Information System (GIS). In order to minimize the effect of flood, in and around Surat city, feasible structural and non-structural measures are suggested.

Key-Words: - Flood, Tapi, Varekhadi, SWAT, LTB, CWC, GIS, Ukai dam

# **1** Introduction

### 1.1 General:

Floods are probably the most recurring, widespread, disastrous and frequent hazard of the world. India is one of the worst flood-affected countries, being second in the world after Bangladesh and accounts for 1/5<sup>th</sup> of global death count due to floods. About 40 million hectares or nearly 1/8<sup>th</sup> of India's geographical area is flood-prone. Tapi is the second largest westward draining inter-state river after mighty Narmada. The Tapi has its source at 'Multai' in Betul district of Madhya Pradesh. The river has a total length of 724 km, out of which, 282 km is in the Madhya Pradesh, 228 km is in the Maharashtra and the last lap of the 214 km is in Gujarat and ultimately meets the Arabian Sea in the Gulf of Cambay, which is approximately 19.2 km west of Surat [3]. It covers approximately 51504 km<sup>2</sup> (79%) in Maharashtra, 9804 km<sup>2</sup> (15%) in Madhya Pradesh and 3837  $\text{km}^2$  (6%) in the Gujarat state as shown in Figure.1.

Tapi river receives several tributaries on its both the banks. There are 14 major tributaries, 4 on the right bank and 10 on the left bank, having a length more than 50 km. Catchment areas of main tributaries are shown in Figure.2 through bar chart. Ukai dam is the largest structure constructed across river Tapi, as a multi-purpose reservoir project to serve purpose of irrigation, hydro-power generation and other facilities, shown in Figure.3. The Ukai reservoir, at its full reservoir level of 105.15 m (345 ft), has a live storage capacity of 7369 Mm<sup>3</sup> with water spread of about 600 km<sup>2</sup> and maximum length of about 112 km. The reservoir is expected to attain Maximum Water Level (MWL) of 106.99 m (351ft) while passing the Probable Maximum Flood (PMT) of 59747  $m^3/s$  (21.16 lakh cusecs) [4]. For the purpose of flood protection and moderation, a reservoir operation schedule is prepared by Central Water Commission (CWC), New Delhi, for the monsoon period.

The overall behavior of Ukai dam in last 34 years during the flood in river Tapi, is shown in Figure.4. Flood occurs once in five years, the massive flood years are shown in Figure.5. Ukai reservoir provides protection against heavy floods to an area of 827 km<sup>2</sup> on the downstream (D/S) [5]. Later, by constructing the flood embankments on both the banks of the river Tapi, between Kathor and Surat, it provides protection to an additional area of 230 km<sup>2</sup>. Thus, the Ukai reservoir and the flood embankment, together provide protection to 1057 km<sup>2</sup> of land area, saving approximately 2 million inhabitants residing in greater Surat region around river banks. Flood embankments are designed for uniform river discharge of 24069 m<sup>3</sup>/s (8.5 lakh cusecs). The Safe carrying capacity of river at Surat is estimated to be 11326 m<sup>3</sup>/s (4.0 lakh cusecs) [4].



Fig.1 Drainage Area Distribution



Fig.2 Catchments of Tributaries



Fig.3 Ukai Dam



Fig.4 Behaviour of Ukai Dam



Fig.5 Disasters Flood Years



Fig.6 Inflow/Out Flow Responsible for Flood Event, 1998



Fig.7 H.F.L. in Dam, 2006



Fig.8 Daily Inflow/Outflow, 2006



Fig.9 Operation of Ukai Dam, 2006



Fig.10 Water Spill from the Dam, Flood 2006.



Fig.11 Photograph, 2006 Flood



Fig.12. River Tapi, Tributaries and Division of Tapi Basin

## **1.2 Flood History of LTB:**

Ukai dam was constructed in 1973, with main purpose to fulfill the irrigation requirement of the area and as a partial fulfillment, to reduce effect of flood. After the construction of the dam, major floods had occurred in the river Tapi, in year 1998 and 2006. Flood of year 1998, had created a disaster and mass demolition of human lives and properties.

In that flood event, due to heavy rainfall in state Madhya Pradesh and Maharastra, city Surat was under water for 5 days. Inflow at Ukai dam was more than 11156.7 m<sup>3</sup>/s  $(3.94 \times 10^5 \text{ cusecs})$ , while the outflow from dam was only 25.48 m<sup>3</sup>/s (900 cusecs), for 10 hours on 14/09/1998. The inflowoutflow graph is shown in Figure.6. The inflow was reduced below 36.24 m<sup>3</sup>/s (1.28  $\times$  10<sup>3</sup> cusecs) after 11 to 12 hours, on 14/09/1998. The inflow was then continuously increased up to  $28571.34 \text{ m}^3/\text{s}$  (10.09)  $\times 10^5$  cusecs) and accordingly water was discharged to 19793.23 m<sup>3</sup>/s (6.99  $\times$  10<sup>5</sup> cusecs) during 36 hours. On 19/09/98, the inflow from upstream was then reduced to about 5096.97 m<sup>3</sup>/s ( $1.8 \times 10^5$ ) cusecs) and water released from the dam was kept constant, at rate of 5606.66 m<sup>3</sup>/s ( $1.98 \times 10^5$  cusecs) [5, 7]. Rander, Jahangirpura, Kosad, Amroli and 60% area of Surat city were severally affected in the flood of 1998. The flood level, more than 1 m, was noticed at most of the places like, katargam, Amroli, Umra, Magdalla etc.

The flood of 2006 caused even greater damage and also affected the states like Gujarat, falling in semi-arid and arid agro-climatic region. It is estimated that a single flood event during 7-14 august, 2006 in Surat and Hazira twin-city, resulted 300 people being killed and property damag worth Rs 20000 Crores. The human life was paralyzed for almost 2-weeks and health problems were reported from several localities in the city municipal limits. Record of water stored during 5 days of August, 2006 is shown in Figure.7 through bar chart. As indicated in graph, the water level rise continuously from 102.108 m (335 ft.) to 105.344 (345.62 ft.) as maximum after 4 days. The reservoir was having large catchment area and due to constant inflow, the large volume of water accumulated in it. The graph shown in Figure.8 indicates that on 7<sup>th</sup> of August, compare to inflow, water released from dam was very less, almost half. The dam operation during 10 days of August 2006, combining inflow, outflow and reservoir level, is shown by hydrograph in Figure.9. The inflow in the dam was continuously fluctuating for first 20 hours from 05/08/2006 and then suddenly rose up to 16423  $\text{m}^3/\text{s}$  (5.8  $\times$  10<sup>5</sup> cusecs), whereas the outflow from the dam was below 5663 m<sup>3</sup>/s (2  $\times$  10<sup>5</sup> cusecs) for that period. Next 36 hours from 06/08/2006 afternoon were very critical and during that period, the inflow touched to 33980 m<sup>3</sup>/s ( $12 \times 10^5$  cusecs), maximum in the recent flood history and to manage the situation, water released from the dam was about  $25768 \text{ m}^3/\text{s}$  $(9.1 \times 10^5 \text{ cusecs})$  for 24 hours (Figure.10). The inflow then down to 12742.42 m<sup>3</sup>/s (4.5  $\times$  10<sup>5</sup> cusecs) and out flow was maintained almost same.

Effect of 2006 flood, in the fastest growing city of India, is shown through picture in Figure.11.

#### **1.3 Issues of Lower Tapi Basin**

The river basin, between Ukai dam and Arabian sea, is known as LTB and is facing following problems.

- 1. The discharge carrying capacity of Tapi river at Surat city is reducing. [6, 8]
- 2. Non completion of flood embankments on both sides of river Tapi, U/S of Surat city. [4, 5, 7]
- 3. Extensive encroachment on river flood plains, in and around Surat city. [4, 5, 7]
- 4. Extensive siltation in river channel, in and around Surat city. [4, 5, 7]
- Afflux created due to the construction of Singanpure weir, just upstream of Surat city. [5, 7]
- 6. Inadequate rain gauge and river gauge networking for LTB, in terms of flood forecasting.
- 7. Uncertain discharge, leads by Varekhadi mini watersheds, in lack of gauge network.
- 8. Heavy siltation at Mouth of river and back water flooding due to Arabian Sea tide.
- 9. Dam operation policy.[4]
- 10. Lack of advanced flood forecasting system.

## **1.4 Preventive measure by Structural & Non**structural measure.

#### **1.4.1 Structural Measure:**

Flood management is often done to prove peak flow formation and to reduce the extreme discharge. The following conventional structural measures are considered, depending upon the flood peak and degree of defence provided.

- 1. Flood control dams and retention dikes, to protect urban property and productive agriculture lands.
- 2. Flood control gates, to prevent the back-up of high flood waters.
- 3. Widening and deepening of river bed, tributaries and natural drains.
- 4. Diversion channels and retention ponds, to divert floods to pre-designed wetland areas, where habitation and agricultural activities are avoided.
- 5. Mobile deflectors, for protection of rural infrastructures.
- 6. Reservoir storage or flood-basins, as water retention for dry season irrigation.

In this research work about hydrological modelling project for lower Tapi basin, we have evaluated the feasibility for each structural measure and suitable alternative recommendations are suggested based on hydrological models.

#### **1.4.2 Non-structural Measures**

The experiences from several river basins around globe [10], it is suggested that the structural measures alone are not sufficient to provide guaranteed flood proofing. Non-structural measures are essential along with structural measures, to achieve entire efficiency, effectiveness and economy of development. The following nonstructural measures can be considered in the flood management.

- 1. The introduction of advanced hydro-dynamic simulation techniques for early warning and flood forecasts.
- 2. An improved system of collection and dissemination of water level information and reinforcement of hydro-meteorological network, to improve the flood forecasting information.
- 3. Use of satellite flood imagery, differential Global Positioning System (GPS), topographic mapping and spatial database for possible analysis of flood prone-areas and sufficient accuracy for inundation forecasting.
- 4. Regional approach to the planning and design support and further institutional strengthening by setting up independent river basin authorities.
- 5. Capacity building of current staff in irrigation, water resources and municipal authorities.
- 6. The formation of state disaster management plan and flood policy for each urban centre for flood relief, local preparedness and actions in flood mitigation.
- 7. Relocation of buildings, from the flood plain areas, as per the extreme value analysis.

The non-structural methods for mitigation of flood hazards are very cost effective compared to structural ones (dams and dikes) [10]. Japan has developed an advance flood warning system, which allows the smooth evacuation of residents and to promote an awareness of flood prevention. Therefore, the non-structural measures are adopted in mitigation of flood disaster. A good way to prevent/reduce damages occurred from flood is, to develop a Flood Forecasting and Warning System (FFWS) in the affected area. All in all, integrating structural and non structural measures can be a very power full tool, to minimize effect of flood in and around Surat city.

# 2 Study Area

River Tapi, originates in Madhya Pradesh and passing through Maharastra. It meets to Arabian Sea in Gujarat state, near Surat city. Length of the river is 724 km and it is divided in three different basins, known as Upper, Middle and Lower Tapi Basin. Details of river, tributaries and location of Surat city is shown in Figure.12 and 13. Varekhadi watersheds shown in Figure.14 are a part of the LTB basin, covering about 1500 km<sup>2</sup>. The study area is bounded by north latitudes  $21^{\circ}$  00" to  $21^{\circ}$  30" and east longitudes 73° 15" to 73° 45".(Survey Of India, SOI, 1974). The study area occurs immediately in D/S of the Ukai reservoir, which is the main reservoir on the Tapi river and extends up to the Ghala village, located further 40 km downstream from the Kakarapar weir. The distance between the Kakarapar weir and Ukai dam is 25 km. Hence, the total study area is 65 km, extended from Ukai dam to Ghala village. There are total 26 mini watersheds in the study area. The topography in LTB, comprises of narrow valley and gently sloping ground [3]. The LTB receives an average annual rainfall of 1376 mm, (State Water Data Center, SWDC, Government of Gujarat) [4] and these heavy downpours result into devastating floods and water loggings in D/S. The major watershed, between Surat city and Ukai dam, is a group of Varekhadi mini watersheds. This watershed leads the surplus discharge in Tapi river at LTB. It is very uncertain because of the ungauged Varekhadi watershed, which leads the problem to the dam authority for taking the decision of excessive water discharge from the Ukai dam. The Surat city lies at a bend of the river Tapi, where its course swerves suddenly from the south-east to south-west. From the right bank of the river, the ground rises slightly towards the north, but the height above mean sea level is 13 m. The topography is controlled by the river, which is flat in general and the general slope is from northeast to south-west.



Fig.13 Location Map of Surat City with it's 7 Zone.



Fig.14 Location Map of Study Area.

## 3) Methodology

To estimate the discharge from the watersheds, procedure [1] followed is discussed as under:

### 3.1 Delineation of watershed

Step1: Automatic delineation of mini-watershed (Figure.15) with the input of Digital Elevation Model (Shuttle Radar Topography Mission, SRTM data is used), digitized drainage network, and area of interest in the grid (mask) format.

Step2: The system default threshold value for delineating the drainage tributaries is adjusted.

Step3: To identify the outlet pour point on the drainage.

### 3.2 Overlaying of Landuse and soil map

Step4: Landuse map in shape file/grid format has to be provided (Figure.16).

Step5: File containing re-codified landuse classes, as per SWAT model requirement, are provided.

Step6: The soil map is given in shapefile/grid format.

Step7: Soil classes are re-codified and file containing re-codified soil classes is provided.

Step8: Landuse and soil map are overlaid with mini watershed.

Hydrological response unit: (Figure.16)

Step9: Hydrological response units for the study area are also delineated by the system.

Weather input: (Figure.17)

The different inputs are given in the weather input file (wgn file)

Step10: Identification of path to the rainfall station file (dbf/text format).

Step11: Identification of path to the temperature station file (dbf/text format).

Step12: The model itself then simulates weather station file, using values provided, as well as default values, based on look up table available with the model for the region.

Step13: The model then simulates solar radiation file.

Step14: The model then simulates wind station file.

Step15: Identification of path to the relative humidity station file (dbf/text format).

Write input file: (Figure.18)

Step17: In this step, the model itself, extracts the required inputs from the provided files and generate the different input parameter as per its requirement.

Model - Simulation: (Figure.19)

Step18: After writing all required input files, the final stage is to run the simulation model.

Step19: The output file format is identified as daily, monthly or annual runoff along with the period of years.

At the end, SWAT model was run (Figure.20) and as an output of the work, daily, monthly and yearly runoff of the Varekhadi mini watersheds is obtained.



Fig.15 Delineation of Watersheds



Fig.16 Overlaying of Landuse and Soil map



Fig.17 Weather Input



Fig.18 Write Input file



Fig.19 Model – Simulation



Fig.20 Run SWAT

## **4 Result Analysis**

Varekhadi watershed is falling between two rainfall and runoff recording stations i.e. Ghala and Mandvi. In order to study the behavior of Varekhadi watershed, discharge leaded by it was calculated by SWAT model in three flood events viz. 1998, 2004 and 2006. It is important to note that, in the flood event of year 1998, the calculated peak discharge leaded by Varekhadi watershed was 586.9 m<sup>3</sup>/s and in the flood event of year 2004, it was 1909.08  $m^3/s$ . However, the results of flood event 2006 are discussed in the present work. As Varekhadi watershed is comprises of 26 mini watersheds, for computing peak discharge, it is split in to 12 groups i.e. G-1 to G- 12. Each group contains different watershed and discharge from them is shown in Figure.21-25. Highlights of this exercise are discussed as under.

1) The Varekhadi watershed and its 26 mini watersheds, discharges water in a very fluctuate range. Minimum 251  $m^3/s$  to maximum 1909.08  $m^3/s$  of peak discharges were recorded in the year of 2004. The hydrograph shows that 586.9  $m^3/s$ , 1909  $m^3/s$  and 502  $m^3/s$  of water was discharged in to the river Tapi in the year 1998, 2004 and 2006 respectively.

2) Ghala is a river gauging and recording station, which is about 30 to 35 km in upstream side from Surat city, so that the data available from this station are taken in to account for flood forecasting. The water flow from river Tapi, takes about 1.5 hr. to 2 hr. to enter near the Surat city. Water discharged from Varekhadi to river Tapi with magnitude of 1909 m<sup>3</sup>/s and 1207 m<sup>3</sup>/s, resulted in rise of 1.5 to 2.0 m in water surface.

3) The peak discharges calculated for year 2006, for different groups, i.e. G1 to G-12, is given in Table-1.

4) Peak discharges calculated from year 1998 to 2006, is shown through graph in Figure.26.



Fig. 21 Location Map of G-1 and Discharge Graphs of WS 1,2,3,5,6,7 and 8











Fig. 22 Discharge Graphs of WS 10, 12, 14,15, 17,18,22 and 24











Fig. 23 Location Map of G-2,3,4,5 and Discharge Graphs of WS 4,9,11 and 13



Fig. 24 Location Map of G-6,7,8,9 and Discharge Graphs of WS 16,19,20 and 21



Fig. 25 Location Map of G-10,11,12 and Discharge Graphs of WS 23,25 and 26





Fig. 26 Daily Peak Discharge from 1998 to 2006

Groups		Discharge
of	Varekhadi	measured
Watersh	Watersheds	in m <sup>3</sup> /s
eds		(2006)
G-1	WS-1	179.58
	WS-2	43.01
	WS-3	43.01
	WS-5	5.52
	WS-6	29.40
	WS-7	6.89
	WS-8	2.45
	WS-10	2.54
	WS-12	71.21
	WS-14	53.46
	WS-15	6.13
	WS-17	2.89
	WS-18	3.36
	WS-22	6.16
	WS-24	5.36
G-2	WS-4 (2,3,4)	88.82

Table 1 Peak Discharge of G1 to G12, 2006

G-3	WS-9 (6,7,9)	14.80
G-4	WS-11(5-11)	19.15
G-5	WS-13(1-4,13)	382.32
G-6	WS-16(5-12)	89.42
G-7	WS-19(5-12, 16-19)	96.56
G-8	WS-20(5-12, 15-20)	102.78
G-9	WS-21(1-4,13,14,21)	431.05
G-10	WS-23(1-4,13,14,21-23)	432.68
G-11	WS-25(1-23,25)	499.15
G-12	WS-26 (1-26)	502.12

## 5) Preventative Measures

In order to minimize the effect of flood in the region, some structural and non structural preventive measures are suggested as under.

### **5.1 Structural Measure**

In attempt to reduce the discharge from Varekhadi mini watersheds, water harvesting structures like Check dams, Under sluice way, etc. can be planned by identifying the suitable sites. Geo-visualization concept [2] is helpful to locate the ideal site for water harvesting structure. The site, without taking field visit, can be visualized and decision can be made for locating an appropriate water harvesting structure. These structures directly check the excessive water coming from the watersheds.

There is some water storage structures already exist in the Varekhadi watershed. Under sluice is constructed at Amli and Gordha villages, while water reservoirs 1, 2 and 3 are also existed in the watershed. After identifying suitable locations by application of GIS, proposed reservoir in several mini-watersheds like 1, 5, 7, 8, 9, 10, 14, 17, 18, 22, 23 and 24 are suggested and shown in Figure 27. Ukai left bank canal is exists in LTB and it is passing through mini watershed no. 7, 8, 9, 10, 17 and 18. As shown in Figure.27, certain storage reservoirs are proposed and can be filled by providing canal escape on appropriate location in Ukai left bank to reduce water level at the dam. Kakrapar right bank canal is also passing through Varekhadi watershed via watershed no. 15, 23 and 24. Planning can be done, for storage reservoir, in watershed no. 23 and 24 by providing canal escape in the similar way as Ukai canal. The existing storage reservoirs in Varekhadi watershed can store 138754949.74 m<sup>3</sup>, while if the proposed storage reservoirs are constructed, can store 270792265.76 m<sup>3</sup>. Hence, large amount of water can be saved over there, which ultimately reduce the peak of the river. Estimated water storage capacity of proposed structures is given in graph, as shown in Figure 28.



Fig. 27 Proposed Water Storage Structures at Varekhadi Watersheds



Fig. 28 Estimated Storage Capacity of Proposed Structures at Varekhadi Watersheds

#### **5.2 Non structural Measure**

#### 5.2.1 Existing Flood Forecasting System

Flood damages can be minimized by issuing dependable warning of incoming flood timely to the revenue and engineering authorities. Such warnings are helpful to authorities for timely evacuation of movable property, human life, cattle etc. to the considerable extent. Flood forecasting, thus plays a vital role to reduce flood damages and in proper regulation of reservoirs. In India, the CWC is engaged in the work of flood forecasting and flood warning in different river basins. The Tapi division CWC, Surat has entrusted in the flood forecasting work, for three interstate river basins viz. Narmada, Tapi and Damanganga.

The Tapi division has established a network of 18 rainfall stations, 9 discharge Stations and 7 gauged stations. with wireless equipped facility, for communication collecting and transmitting the hydrological data to the flood control room at Surat. In the Upper Tapi Basin, gauge and discharge data are recorded at 2 stations namely Dedtalai and Burhanpur, while in Middle Tapi Basin, record stations are at Darpuri, Savkheda, Malkheda, Morne, Gidhade and Sarangkheda. The methodology adopted is as per the CWC manual on flood forecasting for both the level and inflow forecasts. Graphical technique is mainly used for most of the sites. For this, various co-relation diagrams, depicting the effect of basin parameters have been prepared and tested for accuracy. These curves are updated every year. Flood level forecasts and inflow forecasts are issued as per the criteria fixed by state government in consultation of CWC.

There are some deficiencies [6] in the current forecasting systems, viz. forecasting is based on river gauging and there is no weightage of rainfall measurement. Secondly, for water release, they follow form system, indicating Normal, High or Emergency warning and it is based on present indication available at base station viz. Gidhade, with the assumption that there is a not appreciable rain in the intermediate catchment during the period of forecast. Third one, the information sending to the collector officers, may have less knowledge about hydrology of the basin.

It is marked that there is no raingauge station between Gidhade and Ukai [7]. A flood forecast by CWC is very uncertain and there is remarkable difference in the forecasted and actual inflow received at Ukai. Gidhade is at a distance of 175 km from the Ukai in the upstream and catchment area between Gidhade and Ukai dam, which drains in to Ukai reservoir, is 7475 km<sup>2</sup> [7]. This is the area from where, no rainfall or runoff information is available at the Ukai till the water reaches Ukai dam. Flood forecasted by CWC and flood volume received at Ukai is shown through bar chart in Figure.29. In the event of 1998, the difference between flood forecasted and received at Ukai dam was 156 Mm<sup>3</sup> [7].





Fig.29 Flood forecasted and Received Ukai Dam, 1998

# 5.2.2 Recommended Advanced Flood Forecasting System

The existing CWC flood forecasting system seems inadequate for current period because the agency is having limited information in terms of rainfall record, not enough inflow data and absence of recent techniques useful for river monitoring and forecasting system as modern technology is developed day by day. However, rapid population growth in the region, intensification of agriculture, climate change, changes in landuse and river morphology and rapid technology development, it is essential to upgrade the conventional forecasting system. Using latest technology the informative and effective warning system should be installed. Improvement in flood forecasting operations requires continuous efforts in many fields including river monitoring network. For that, the automatic rain gauge stations should be established, which records hourly data accurately and transmitted it to the data centre. Hourly data gives precise results than the daily data and it is proved by comparing the actual and estimated inflow at Ukai during the flood of 1998. Development of advanced forecasting techniques, communication network and assessment of forecasts can be done by data collection, transmission and processing. To improve the river monitoring network, data collection and transmission system and the hydro-meteorological network is in the process of being rehabilitated and upgraded to provide more timely and accurate data.

To establish new flood forecasting system we require 1) Adequate rainfall and runoff record, river gauging and discharge measurement stations at several locations. 2) Proper method, for finding out safe carrying capacity of river at various sections along the river. 3) DEM of the Surat city [6, 9] to find the probable submerge area. Keeping all these aspects in mind, the recommended procedures for flood forecasting has been prepared and cited in the Figure.30.



Fig. 30 Advance flood Forecasting system

The safe carrying capacity of the Tapi river is significantly reduced due to encroachment in flood plain area, silting in the river bed, and afflux created by Singanpur weir constructed on the river very close to Surat city. With the help of the software developed in Microsoft Excel, it is assessed that the river at Surat can now carry only up to 5663 m<sup>3</sup>/s (2 L) [6, 9] without causing significant damages. The dem generated for Surat city at 0.5 m contour interval, gives idea about the reduced level of each zone and the flood hazard map shows the possible submergence area when water level rise to 7.5 m [8] at hope bridge.

Inflow at Surat can be calculated by following equation for better prediction,

$$Q = Q_1 + Q_2 + Q_3 + Q_4 + Q_5$$

#### Where,

- Q<sub>1</sub>= Discharge released from Ukai dam
- Q<sub>2</sub>= Discharge from tributaries
- Q<sub>3</sub>=Discharge lead by Varekhadi watershed
- $Q_4$  = Runoff by heavy precipitation on Surat city
- Q<sub>5</sub>=Back water flooding from Arabian Sea (Tide effect)

Hence, Q<sub>1</sub>, the discharge released from Ukai dam is directly depends on the inflow from upstream. In existing system, this inflow is estimated based on hydro-meteorological data of base station Gidhade and available condition of intermediate catchment between Gidhade and Ukai. Instead of it, Q<sub>1</sub> Should be estimated exactly by establishing automatic raingauge station at suitable location viz. in Upper Tapi Basin at Dedtalai and Burhanpur, in Middle Tapi Basin at Darpuri, Savkheda, Malkheda, Morne, Gidhade and Sarangkheda. It is remarkable that the catchment area between Gidhade and Ukai is very large and there is not a single raingauge station which is connected through Satellite. Q2, the discharge lead by several tributaries D/S to the Ukai and Upstream to Kakrapar weir should be calculated by either developing hydrological network or by preparing SWAT model.  $Q_3$  is the discharge from Varekhadi and its group of mini watershed. As described earlier, using SWAT model, it should be predicted. Q4, the runoff lead by heavy rain fall on the entire Surat city. It is comparatively low with respect to other inflow and should be taken in to account by establishing temporary raingauge stations. Q<sub>5</sub> the backwater flow from the Arabian sea (Tidal effect), experienced by Surat during last flood event of 2006. In order to determine it, Tidal flood modeling can be developed. Routing of the river is essential to get additive discharge due to the rainfall of the intervening catchment between two forecasting stations. It can be done by Muskingum method for correction of the inflow to the downstream station. It is insisted that the correction of inflow should be done at Kakrapar Weir, Mandvi, Ghala and Kathor to achive higher accuracy. By viewing all this and using Thessian polygon method we can say that the existing raingauge stations are inadequate. The no. of rain gauge stations required can be computed and new automatic rain gauge /river gauge station should be established. Proposed locations of rain/river gauge stations for LTB are shown in the Figure.30.

In the existing system, river is gauged at kakrapar weir, Mandavi, Ghala, Kathor Singanpur weir and at Hope bridge. It is suggested to establish more rain gauge stations at Amlidam, Godadha dam, Godsamba village and at Luharpur. All these stations should be interlinked with each other through satellite as cited in the Figure.30. Thus, by networking of whole Tapi basin through satellite, in assistantship of computer, hydrologically rich information can be available on hand.

Above information alongwith the two way system should be used for operation of Ukai Dam. As mentioned in Figure.30, the flood cell at Gandhinagar and the dam authority at Ukai shall remain interlinked. For that, initially, hightech network of personal computers with appropriate software, analog-to-digital converters, pressure or liquid-level sensors should be established at each recording stations as well as at decision taking offices. The interlinked computers in this system shall convert the raw data into desired forms, store data for later use and communicate with other computers in network. Such custom designed computer system will make the officers free from filling different forms like N, H and E indicating normal, high alert and emergency situation based on the graph, indicating threshold value. It describes the emergency warning start and more importantly at the same time, the decision makers will well aware with the latest update. The available information from the different rain gauge, discharge and river gauge stations can be collected through Satellite and should be analyzed properly by experts of the hydrology or by special cell like flood cell at Gandhinagar and forecasted directly to the dam authority at Surat. From available information at D/S of Ukai dam, the dam authority will take decision about the quantum of discharge to be released, keeping the river carrying capacity of river Tapi near Surat, in mind. Under the circumstances, when the water level may cross the danger level of 106.98m (351 ft), the Ukai dam authority will send the information to flood cell at Gandhinagar about the occurrence of flood and its extremities. The flood cell at Gandhinagar will convey the information to collector of Surat, disaster management body of the state and central government for the evacuation/rescue. In the evacuation route, the top priority will be given to the low lying area for shifting people to safer places. To prepare evacuation route, readily available digital elevation model [9] showing reduced level of entire Surat city, shall be used.

Surat has been frequently hit by big floods and suffered from flood disasters. Hydrological information and forecasting, as one important nonstructural measure, plays an important role in flood control and disaster relief and therefore, the advance flood forecasting system should be established by removing deficiency of such system.

## 6) Conclusion:

- Timely validation of the SWAT model is essential to predict the flow at Ghala station.
- Sufficient and reliable data are much needed to achieve higher degree of accuracy, which can be achieved by establishing new automatic recorded river gauge station.
- To survive the Surat city from flood, advanced flood forecasting/warning system should be established as early as possible. All the existing and proposed river gauging stations should be connected through satellite and after proper analysis of data, available information should be transferred to the Ukai dam authority. Considering D/S carrying capacity of the channel, authority will take decision to release discharge.
- Learning lessons from the past flood events. Modifications are necessary in the rule curve for the operation of Ukai dam.
- Comparison between peak discharge from Varekhadi and the flood in the river Tapi with respect to time indicates the interesting results. Graph, as shown in Figure.31, indicates that the discharge from Varekhadi is quite low at the time of flood occurred in the river Tapi, but possibility may be that, there is a large amount of water will release from Ukai reservoir and at the same time excessive inflow from Varekhadi reach near Surat city, simultaneously. Such undesirable condition must be taken into consideration and cannot be ignored to save the city Surat against flood.



Fig.31 Comparison of Discharge

- Possibility of history floods in Surat, if quite high runoff from Varekhadi and discharge from Ukai, meet at same time.
- Varekhadi and its mini watersheds having large catchment area, lead excessive amount of water into the river Tapi. Random prediction of the inflow may create a serious condition. To avoid such venerability, river gauging and discharging stations must be established.

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