

Flood Water Surface Profile in Tapi River- Surat

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Abstract. Surat is a highly developed, thickly populated cosmopolitan character city with full of various activities going on day and night. Any natural calamity which causes loss of lives to property and infrastructure along with effects on industrial processes going on has serious impact on economy of the state. Therefore, it becomes highly necessary that flood events are studied and analyzed properly in order to propose adequate flood control and protection measures in time to come. Many research organizations like Central Water Commission (CWC), Gujarat Engineering Research Institute (GERI), Central Water Power and Research Station (CWPRS), are already involved in study of flood phenomena of Tapi River. It appears to be of vital importance to initiate studies as an extension in lights of finding of such studies, using modern computer, model and software technology. In this research paper in detail, morphological processes in Tapi River Basin studied. It is also studied presently available mathematical models by proving them for Tapi flood data and to develop an “Optimization Process” to minimize the flood impacts. It is further attempted to validate the model with studies on physical model development with studies on physical model developed/constructed by any Govt. or Semi Govt. organization like CWC, GERI, and CWPRS etc. Subsequent to construction of Ukai dam large urban developments have taken place along Tapi river banks. With the moderation of flood at Ukai reservoir, no major floods were experienced at Surat and Hazira till 1994. During 1994, 1998 and 2006 floods of the order of 14870 m³/s (5.25 lakh cfs), 19820 m³/s (7.00cfs) and 28315 m³/s (9.10lakh cfs) were experienced. Large portion of Surat area was inundated along with large scale flooding at Bhata, Bharatpur, Surat, and surrounding areas. There were heavy damages of industrial and urban properties costing 21000 Crores. This paper presents CHARIMA mathematical model for prediction of water levels in Tapi Creek under influence of flood and tide. This mathematical model is capable of handling unsteady floods in river channel network validated for September 1998 flood situation and then applied for predictions with 28315 m³/s (10 lakh cfs flood discharge). On the basis of the results this study the necessary measures to be taken for flood forecast and flood protection schemes to minimi Tapi river flood impacts on Surat, Gujarat, India, have been suggested.

Keywords: Charima, Peak flood, Flood forecast, Flood protection.

Introduction

River Tapi is the 2nd largest river of Gujarat State. It originates from Mulati, of Betul district of Madhya Pradesh; which includes 323 Km. from Maharashtra and 189 Km. from Gujarat. Tapi is known for occurrence of large floods due to influence of depressions originating from bay of Bengal traveling East to West causing rainfall, first in the upper catchments and then in lower catchments resulting of flood along its course. Ukai Dam (Tapi River valley 2nd Stage) is the largest multipurpose project, next to Narmada Project, undertaken by GOG. It was completed in 1973. The Dam is located at village Ukai, Taluka Songadh of District Surat at distance of 90Kms. From Surat city it caters multiple purposes like Irrigation, Power generation, Water supply to industries and households, fisheries etc.

Surat, popularly known as Diamond city, is probably the richest city of Gujarat with a vastly developed Diamond and Cotton industries. It is an industrial hub where significant portion of Gujarat's total economic activities, is centered with an inflation of industrial and economic activities. It has grown at very fast rate in last few decades. With highly increasing population ratio. Surat is on a path of becoming metropolitan city with cosmopolitan culture. Presently spreaded over 334.23 Km² areas. Surat had a population of 2877241 in 2001. Surat has been blessed with flow of river Tapi which fulfills most of its water requirements. It flows through city and meets Arabian Sea at about 16 Km. from Surat. Big water resources projects like Ukai Dam, Kakrapar weir are near the Surat, five main and several minor creeks pass through the Surat and meet river Mindhola in south of it. Surat has been blessed by the flow of Tapi however it has also suffered a lot because of floods in Tapi since historic time. There have been several events, known to us since late 19th century; which

has done great damage to this city. The most unforgettable and severe event was the flood of 2006. Overtopping of Tapi River embankments resulted in great damages in different areas like Fulpada, Chhapra-Bhata, Amroli-Uttran, Jahangirpura-Rander, Katargam, Ved-Dabholi, Rander-Adajan etc. covering major important areas of main city including outskirts. In addition to overtopping, back water effect of tide influenced the flood water level and added to the severity of the disaster.

This flood caused damages on flood embankment and retaining wall at many places. It also resulted in losses of municipal properties like roads, equipments, material, street lights, infrastructures, furniture-assets, records in addition to buildings. The flood also resulted in total losses of 21000 Crores in the year 2006. This flood event of 2006 signified concern on flood protection and control as such frequent event causes extensive damage to public property, infrastructure, agriculture, trade, industries, wages etc. along with loss to private properties and business establishments in general. Keeping in view the serious concern of flood protection and control it feels the research in that direction is of vital importance.

Tapi River: The River Tapi is the second largest west-flowing river of India. The Tapi River merges at Mulati in Betul District of Madhya Pradesh. The river has a total length of 720 km out of which 208 km lies in the Madhya Pradesh, 323 km in the Maharashtra and 189 km in Gujarat as shown in Fig. 1 and 2. It ultimately meets the Arabian Sea approximately 19.2 km west of Surat in Gujarat.



Fig. 1. Tapi basin

Ukai dam

Ukai is the largest multipurpose Project undertaken by the State and is next to Narmada Project, so far as benefits are concerned. Ukai forms the terminal reservoir harnessing nearly half the water of the Tapi. Development of Tapi River Valley 2nd stage Ukai reservoir project in the year 1972.

Surat City

Basic Data Area of City: 334.23 Sq.km. total population: 28, 77,241(census 2001), total 7 nos. zone average Rainfall: 1894 mm, major rivers: Tapi, major dams: Ukai, Kakrapar, major flood disaster started from the year 1994 heavy loss of human, property, industries etc. in Surat city.

Topography

- River Tapi flows through the city and meets the Arabian Sea at about 16 km from Surat.
- Surat is 90 km in downstream of Ukai Dam over river Tapi.
- Five main and several minor creeks pass through the city and meet river Mindhola in south of Surat.

Choosing of Model, Mathematical Model

The choice of any prediction or simulation technique mostly depends on desired. Accuracy and extent and quality of data available for representing the topography and boundary conditions. In the present

Distribution Of Catchment (Sq.Km.)

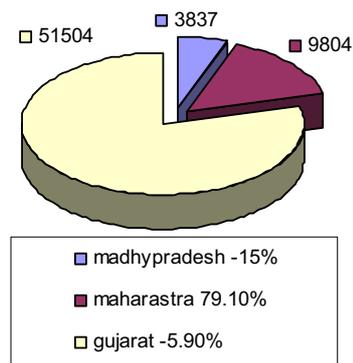


Fig. 2. Distribution of Tapi basin study, there is necessity of flow simulation with tidal wave and flood wave in Tapi creek network system. This situation demands a mathematical model capable of simulating gradually varied unsteady flow in the channel network, comprising river junctions, bifurcations, looped channel, islands and also a weir as an internal boundary. At present three-one-dimensional models suitable for such studies:

1. NETWORK model of National Weather Services, USA, Developed by D.L. Fared (1985).
2. NECHA (Networks of Channel) Model Developed at CWPRS (1987).
3. CHARIMA Model of Iowa Institute of Hydraulic Research (I IHR), University of Iowa.

Developed by Prof. F. M. Holly 1985.

The latest version of CHARIMA model (April 1994) is available at CWPRS. The first and second models deal with only water flow in channel network. However, CHARIMA deals with unsteady water sediment flows in channel network. Keeping present requirements in view the CHARIMA model was adopted for these studies.

Mathematical Model—CHARIMA—An optimal solution For Tapi River flood water level prediction.

CHARIMA' 1-Dimensional mathematical model was developed at Iowa Institute of Hydraulic Research (IIHR) in 1998 to study the braided river channel network of

Susitna River (Alaska). This model is 1-D mathematical model for numerical simulation of unsteady water and sediment movement in multiply connected network of mobile bed channels. This model is capable of handling unsteady water and sediment flows in multiply connected channels highly non uniform sediment and grain sorting and armoring process. The model can simulate processes such as; sediment sorting, bed armoring, flow dependent friction factor and alternate drying and flooding of perched channels. The flow over the weir can also be handled.

Continuity and Momentum equations are the Governing Equations for water flow. Model uses widely applied Pressiman 4 point weighted implicit finite difference scheme. For solution of

governing equations terms in the equation are discretised in x-t plane and system of linearised simultaneous difference between equations is obtained i.e. Coefficient matrix is a banded matrix. CHARIMA model uses Double sweep algorithm. The entire network of channel is schematized into links (Channel) and Nodes (junctions or any bifurcation points or end or beginning of channels) so that each link has one node at each end and each node has at least one link (Channel) starting from it or ending at it. In each link, there are grid points where the cross sectional data given. The nodes could be of internal and boundary nodes.

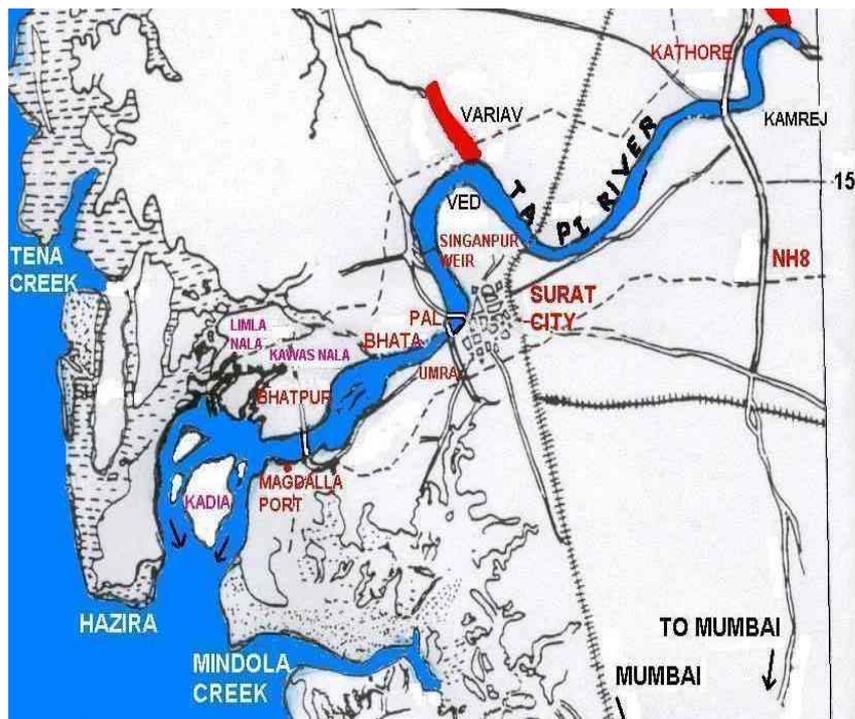


Fig. 3. Schematic diagram of Tapi River

Model Assumptions and Limitations.

St. Venant Hypothesis for water flow is assumed (i.e. uniform velocity and horizontal. Distribution, applicability of steady state resistance law for unsteady flow and small bed slopes).

- (a) Channel network pattern assumed (i.e. total no. of channels, and their inter-connections) must remain same during a particular simulation.

- (b) Cross sections are assumed to rise or fall without changing its shape.
- (c) Effects of bends cannot be accounted in present formulation
- (d) Continuous lateral flows not considered However, in additions due to rainfall could be represented by channel joining at regular interval.
- (e) Other restrictions / assumptions associated with sediment routing processes (i.e. those required for sorting, armoring sediment discharge, friction prediction etc).

Model equation

Model uses St. Venant equations for water flow, equations for sediment continuity and provides alternatives sediment discharge and friction factor predictions. Generally for governing equations for channel geometry, hydraulic sorting and armoring of bed surface are given below separately. Governing equations are water continuity equation, momentum equation, sediment discharge predictor, friction factor prediction sediment continuity equation, channel geometry equation, hydraulic sorting of bed material, armoring of bed surface.

Water Continuity Equation:

$$\frac{\partial A}{\partial t} + \frac{\partial Q}{\partial x} = 0 \dots\dots\dots \text{eq (i)}$$

Momentum Equation:

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} (\alpha Q^2) + g A \frac{\partial y}{\partial x} + g A Q \frac{Q}{K^2} \dots\dots\dots \text{eq.(ii)}$$

Sediment Discharge Predictor:

$$F1 (Q_s, D_{50}, Q, A, d, S_f, ACF) = 0 \dots\dots\dots \text{eq. (iii)}$$

Friction Factor Predictor:

$$F2 (A, A, d_{50}, S_f, D, ACF) = 0 \dots\dots\dots \text{eq. (IV)}$$

Sediment Continuity Equation:

$$(1-P) B \frac{dz}{dt} + \frac{dQ_s}{dx} = 0 \dots\dots\dots \text{eq. (v)}$$

Channel Geometry Equation:

$$A = A (d, x) \quad B = B (d, x) \dots\dots\dots \text{eq. (vi)}$$

Hydraulic Sorting of Bed Material:

$$D_{50}^{(n)} \implies D_{50}^{(n+1)} \dots\dots\dots \text{eq. (vii)}$$

Armoring or Bed Surface:

$$ACF^N = ACF^{N+1} \dots \dots \dots \text{eq. (vii)}$$

Where,

Q – Water Discharge	B – Water Surface Width
A – Cross Sectional Area	d – Flow Depth
Y – Water Surface Elevation	k - Conveyance
z – Bed Elevation	D₅₀ – Medium Size of Bed Material
Sf – Energy Slope	k – Distance along Channel
α – Momentum Correction Factor	t – Time
g – Gravitational Acceleration	P – Porosity of Bed Material

Model solution procedure/schemes

In general model follows Preissmann Implicit Scheme for discretising the water flow and sediment continuity equation. The solution procedure include water routing with forward and backward sweeps in each branch, formulation of node matrix solution of sediment continuity equation and then grain sorting and armoring. The analytical simultaneous solutions of all equations used in this are not possible due to following reasons: (a) Inherent non-linear (b) Tabular nature of equation for channel geometry (i.e. equations 6 and 7). (c) Adhoc procedure (as against mathematical relationships) for equations for bed material sorting and armoring of bed surface (equation 8 and 9). (d) Necessity to solve equation of sediment continuity (5) for each size friction followed by reconstitution of total change in bed elevation. Therefore, solution of these equation decoupled solution approach is adopted as described below: The solution proceeds in three stages.

STAGE 1 Equations for sediments discharge (equation 3), friction factor (equation 4), channel geometry (equation 6 and 7), and districted equations of water flow are solved in a hydraulic sweep. During this sweep bed elevation (z), median diameter (D50) of sediment and armoring factor (AFC) are kept constant as if bed is frozen temporarily. Thus during this sweep at grid point I water flow (QI),

water level(y) and sediment transport capacity Qs (I, j) for each size fraction j of bed material are computed.

STAGE 2 During this stage discretised equation of sediment continuity is solved in downstream sweep to yield new bed levels at grid point i.e. the sediment discharge Q_{sn+1} computed in stage1 is treated constant assuming that it is unaffected by evolution process (bed level change), armoring and grain sorting (change in D50).

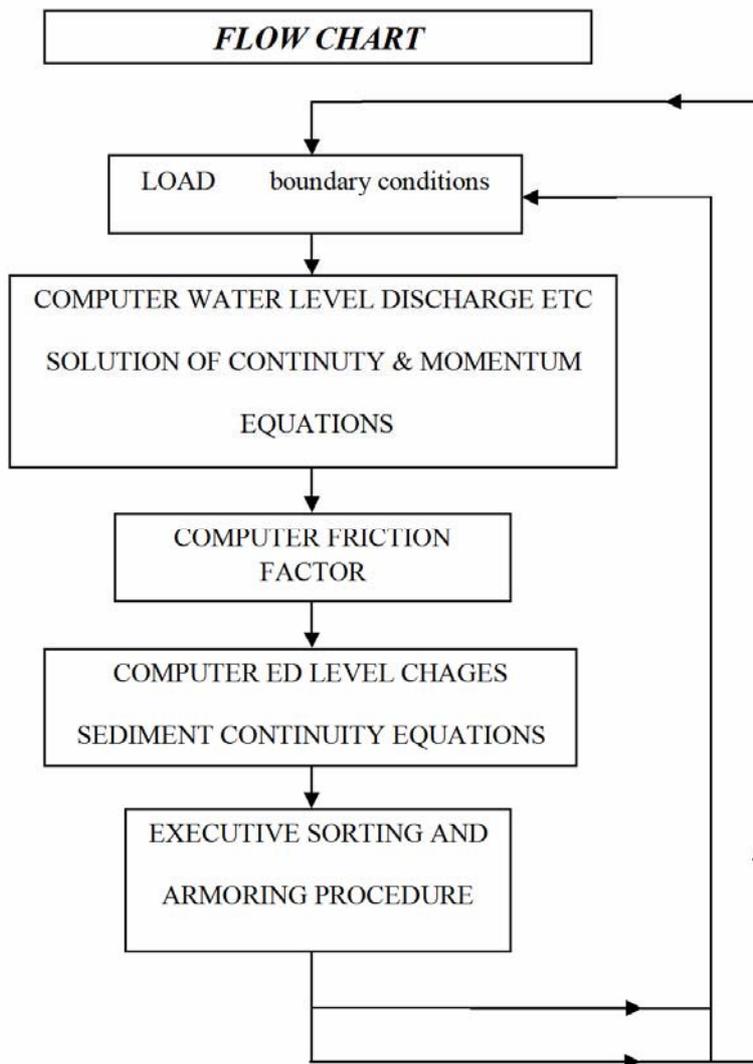
STAGE 3 In this stage accounting procedure is executed using aggradations or degradation computed in stage 2 (i.e. sorting) bed material to compute new D50 and computation of ACF_{n+1-n} (armoring factors).The above procedure is called uncoupled as it assumes, these processes (in above stages) occur sequentially not concurrently in a given time steps. This violation simultaneously of all mechanisms involved becomes necessary due to practical difficulties associated with the lack of closed form representation of armoring and sorting processes. Such decoupled approach models are based on assumption the Changes in any one variable during a time steps is small enough that its effects on other variable during the time step can be ignored. Required sequence of operations is as follows (and all shown in flow chart below):

- *1. Load boundary conditions (water and sediments inflow and down steams water levels)
- *2. Using latest z , $D50$, ACF compute water depth, flow are friction slope, water surface width and water and sediment discharge at all grid points (through simultaneous solutions of equations 1, 2, 3, 4, 5, 6, 7)
- *3. Using estimated sediment discharge (Q_s) and water surface width (B)

computed in *3 a new estimate of bed surface elevation obtained by solution of equation (5) i.e. sediment continuity.

- *4 using changes in bed elevation in *3 new estimates of armoring factor and medium dam are computed using equations (3) and (9). Steps *2 to *4 are repeated till successive estimates of bed elevations (Z^{n+1}) no longer changes.

FLOW CHART FOR CHARIMA MODEL PROGRAMING



Supplementary relations used in

The model uses following supplementary relations for simulating different processes:

1. Total sediment load prediction: for this purpose following sediments transport formula have been coded in CHARIMA:

(a) TLTM formula by Karim and Kennedy

(b) England and Hanson formula.

(c) Modified Ackers & white formula

(d) Power law predictor

2. Dune height predication:

(a) Yalin's relation

(b) Allen's relation

Input Data Requirements: Model needs following input data

1. Topographic Data i.e. channel cross sections, layout and connectivity, configuration of weirs
2. Hydrologic Data i.e. inflow hydrographs for upstream and downstream boundary condition, bed roughness.
3. Sediment data i.e. size, properties, distributions, sediment inflow hydrographs by class
4. Calibration and verification data i.e. discharge hydrographs, sediment transport rates by size class, observed changes in bed levels and composition

Solution of Water Flow Equations

- Formulation of set of linearised difference equations for each link.
- Carrying out forward and backward sweep in each channel and storing the coefficients
- Formulation of node matrix
- Solution of node matrix to obtained the water levels at each node
- Computing the water level and discharged at each grid point in each channel using the coefficients stored and water levels at nodes.

During these computations the numerical parameter such as distance step (Δx), time step (Δt), time weighting coefficient (θ),

CHARIMA

3. Hydraulic sorting of bed material.

4. Changes in bed material composition

5. Armoring of bed surface/armoring factor (friction of bed surface covered by non-moving armoring particles).

6. Effect of bed forms on armoring

7. Effect of armoring on sediment discharge and mixed layer thickness.

Most of these procedure and relation are similar to these used for IALLUVIAL MODEL developed at IIHR.

and space weighting coefficient (ψ) are involved. In the present studies Δx was variable depending upon grid point spacing. Time step Δt was adopted as 10 minutes. Value of θ and ψ were 0.55 or 0.50 respectively. The θ value of 0.55 was adequate to avoid the damping of flood or tidal.

Comprehensive Research studies

Prediction of flood levels due to provision of flood levels for the discharge of 28315 m³/s (10 lakhs cfs) in river Tapi.

1. Rise in flood levels due to provision of flood embankments from Nehru Bridge to Hazira or Magdalla bridge-Surat.

2. Preliminary studies on Ukai reservoir operation considering floods of the year 1968, 1998 and 2006 and probable maximum flood.

3. Possible measures for protection of urban and industrial area between Surat to Hazira.

Tapi River Flood Overview – Surat

Surat is usually affected by two types of floods: Tapi River flood and Khadi flood. Tapi River flood occurs due to heavy inflow of rainfall in Tapi basin while Khadi flood occurs due to heavy rainfall in city and tidal effect of the sea. Data collection and analysis listed here in Table 1, 2, 3 and fig.4 to 16.

Table 1. Details of Major Flood Received in River Tapi after Ukai Dam Construction

Year	Date-Month	Maximum Water Level In Feet	Maximum Flood Released in Lakhs Cusecs
1975	28-Sept.	345.10	2.99
1981	4-Oct.	345.24	0.51
1989	8-Sept	345.93	0.44
1994	23-Sept.	345.24	5.08
1998	17-Sept.	346.00	7.00
2006	9-Aug.	346.07	9.10 Max. value (1972- 2007)

CHART SHOWING OPERATION OF UKAI RESERVOIR DURING 8 / 2006

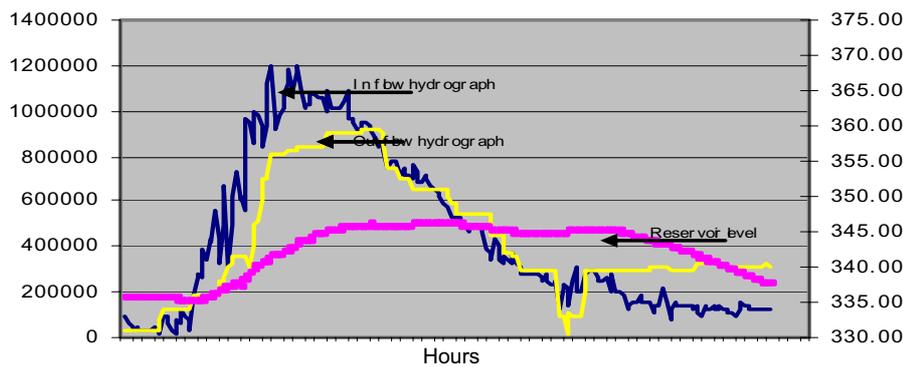


Fig. 4. Chart Showing Operation of UKAI

Figures 5, 6, 7, 8, 9, 10, 11, 12 and 13 Shows details of water levels for different flood quantities along with important

locations of Surat city during Tapi River reach respectively.

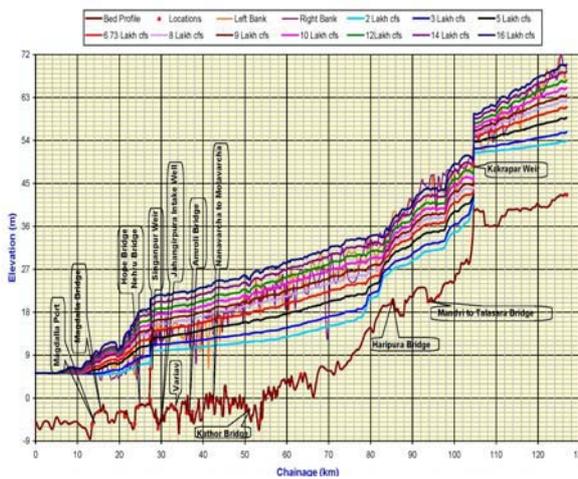


Fig. 5. Water Surface Profiles of Tapi River for Different Discharges during tide at HWL with Existing Condition

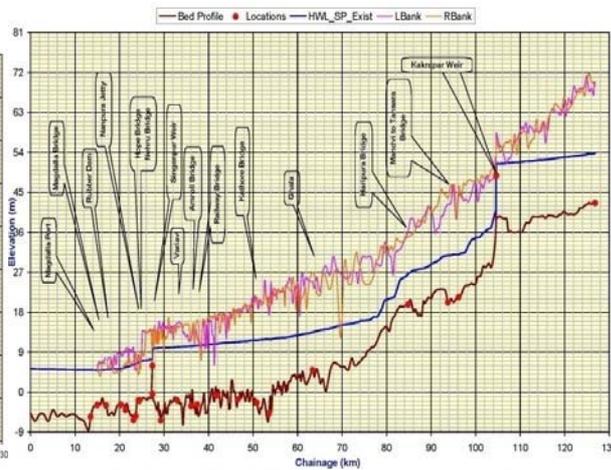


Fig. 6. Water Surface Profile of Tapi River for Discharge 2 Lakh cfs during Spring Tide at HWL

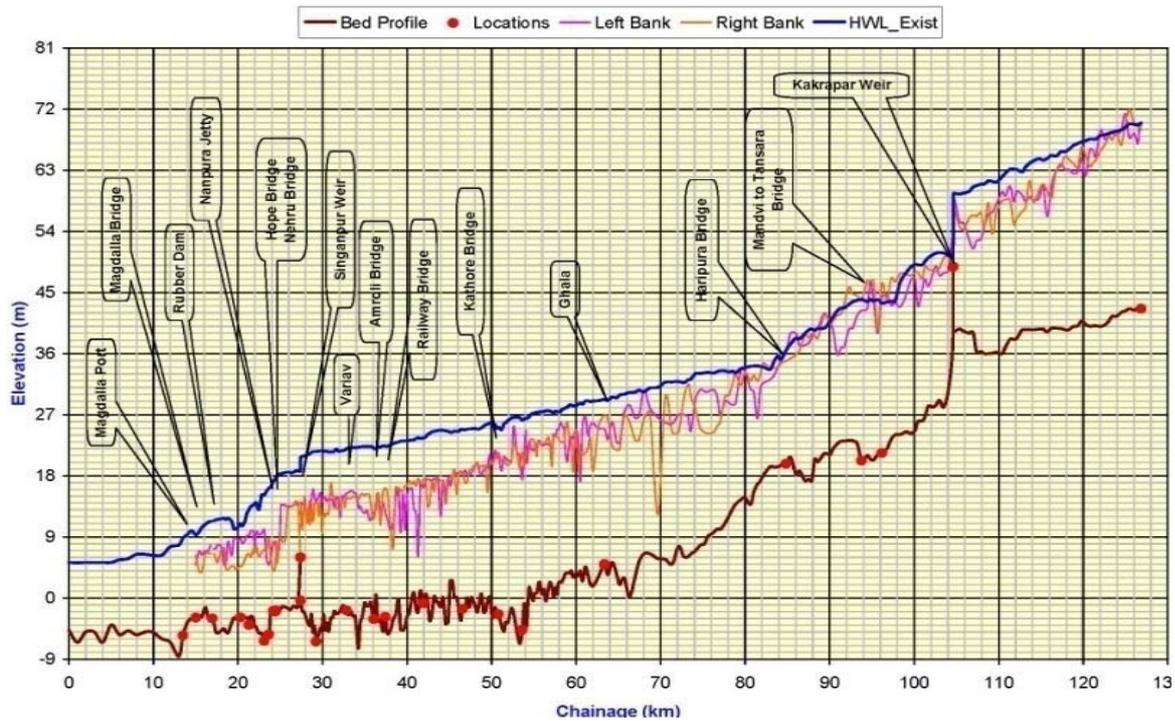


Fig. 13. Water Surface Profiles of Tapi River for Discharge 16 Lakh Cumecs during Tide at HWL

Table 2. Flood Water Levels along Tapi River for Different Flood Condition

Condition No.	Maximum Upstream Flood Discharge (m ³ /s)	Water Levels at Various Locations (m)						
		Magdalla Bridge	Umra/Bhata	Nehru Bridge	Singanpur Weir	Variay	Amroli Bridge	Kathor Bridge
I	19057 (6.73 Lakh cfs)	6.80 (6.75)	8.62 (8.55)	11.36 (11.40)	13.56 (13.90)	14.99 (14.23)	15.58 (14.77)	18.77 (18.29)
	22650 (8.0 Lakh cfs)	7.13	9.51	11.95	14.29	16.01	16.79	20.24
II	25482 (9.0 Lakh cfs)	7.39	9.92	12.41	14.78	16.72	17.55	21.00
	28315 (10 Lakh cfs)	7.86	10.63	12.90	15.24	17.34	18.17	21.55
III	28315 (10 Lakh cfs)	7.92	10.66	12.93	15.24	17.43	18.29	21.76
IV	(A) 28315 (10 Lakh cfs)	8.26	10.76	14.60	16.21	18.02	18.69	21.88
V	(B) 19057 (9.73 Lakh cfs)	7.08	8.82	12.00	14.07	15.16	15.75	18.90

Table 3. Comparison of Flood Levels Predicted by CWPRS AND CDO

Tapi Flood Discharge	Prediction by	Predicted Water at Various Locations (m)						
		Magdalla Bridge	Umra/Bhata	Nehru Bridge	Singanpur Weir	Variay	Amroli Bridge	Kathor Bridge
1998 Flood	CDO	7.80 (Reported at port)	8.80	11.50	12.81	14.31	14.87	18.40
19057 m3/s (7 lakh cfs)	CWPRS	6.80 (at Bridge)	8.62	11.36	13.56	14.99	15.58	18.77
	Observed level In September 1998	6.80 (at Bridge)	8.55	11.40	13.90	14.23	14.77	18.29
28315 m3/s (10 lakh cfs)	CDO	9.88 (at Bridge)	-	13.95	15.57	17.05	17.61	21.29
	With Sept. 1998 tide	7.86 (at Bridge)	10.63	12.90	15.24	17.34	18.17	21.55
	With highest Spring tide	7.92 (at Bridge)	10.66	12.93	15.24	17.43	18.29	21.76

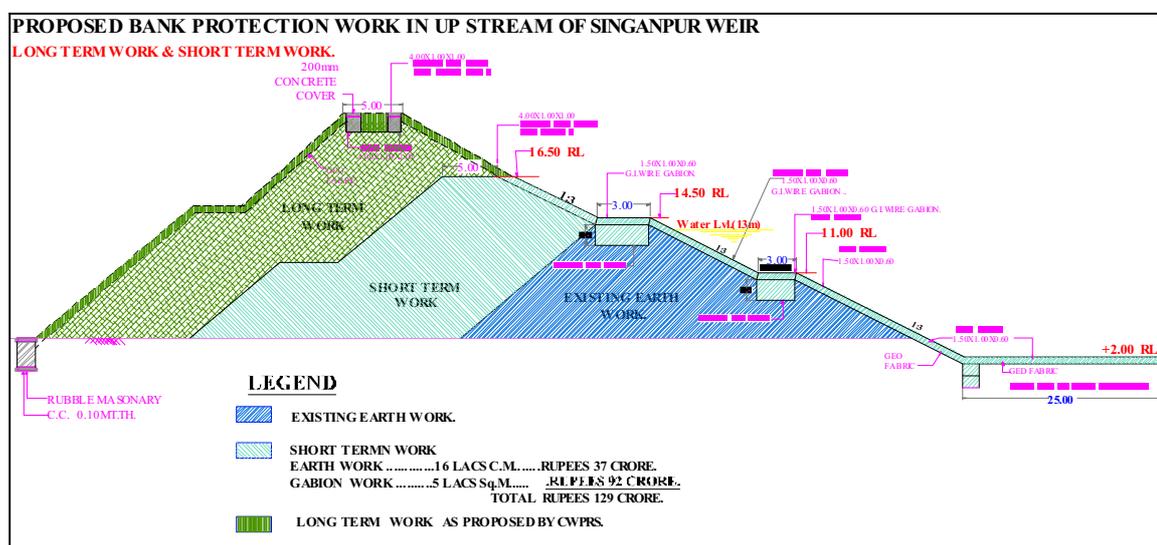


Fig. 14. Flood Protection Works for Short term and Long term basis KOTAR NO. 7&9

Results

These studies were taken up with the help of Charima mathematical model capable of handling unsteady flow in river channel network comprising junctions, bifurcations and loops. The total river reach of about 66 km from the mouth at Hazira to about 15 km upstream of Kathor Bridge was simulated along with existing flood embankments from Surat to Kathor. The Teena creek from the mouth to its junction with Tapi River near Bhata village was also reproduced in the model. The tidal water level at outer Hazira was used as d/s boundary condition and flood hydrograph at Kakrapar was used to provide u/s

boundary condition. First the model was validated for the September 1998 flood by giving appropriate boundary conditions. The predicted flood water surface profile during period of passage of peak flood in close agreement with the observed levels of 6.8m at Magdalla bridge, 8.55m at Umra, 11.4 m at Nehru bridge, 13.9 m at Singanpur and 18.29 m at Kathor. The predicted flood level near ONGC is also in good agreement with the observed flood levels. Further model runs were taken with the neap tide (same tidal conditions as that during flood of different years) and spring tide with HFL of 5.0 m as d/s boundary along with the flood of 28315 m3/s(10lakh

cfs) from upstream. The research studies with neap tide indicated the flood levels in order of 7.86 m at Magdalla (Hazira), 10.63 m at Umra (Bhata village), 12.90 m at Nehru Bridge, and 15.24 m at Singanpur and 21.55 m at Kathor Bridge. The studies with Spring tide indicate nearly same water levels upstream of Magdalla Bridge. There was marginal rise of about 0.06m at Magdalla Bridge. Further downstream, rise in flood level was more with spring tide. Flood levels of 6.05 m and 5.65 m were predicted at KRIBHCO and L and T jetty respectively. Further studies were taken up with flood embankment on both banks in the reach from Nehru Bridge to Hazira. These research studies indicate overall rise in flood levels all along river Tapi. Flood levels of 8.0 m at KRIBHCO, 9.55m at Magdalla, 11.28 m at Umra, 14.85m at Nehru Bridge, 16.37 m at Singanpur, 18.15 m at Variav and 21.88 m at Kathor were predicted with these flood embankments under the condition of spring tide and 28315 m³/s flood discharge. According to sedimentation report for Ukai reservoir done by GERI, Vadodara by using integrated bathymetric system and Surfer software (2003) contours and 3-D representation were prepared. This report already stated that silt index of 5.686 ham/100 sq.km./year against designed value 1.49 ham/100 sq.km./year is higher side. The annual loss in gross capacity is 0.42 % and hence reservoir is classified as "significant category" as per IS 12182-87.

Conclusion

Based on the analysis of results of these studies it was concluded that the flood levels with 28315 m³/s (10lakh cfs) flood discharge are likely to be of the order of 10.60m near Bhata and industrial area around ONGC i.e. nearby about 2.0 m above 1998 flood levels. These flood levels will further rise to a level of 11.30 m after provision of flood embankments. Ukai reservoir operation policy in view of 1998, 2006 flooding as well as PMF of 72490 m³/s (25.6 lakh cfs) at Ukai have

been considered essential. The need of evolving emergency operation policy during flood emphasized. The improvement of Ukai reservoir operation has been recommended as immediate measure for flood control. In order to assess possibility of improving reservoir by using reservoir volume between FRL (345 ft i.e. 105.16 m) MWL (351 ft i.e. 106.98 m) preliminary studies carried out. By using this 1.0 m height above FRL the maximum outflow from Ukai could be restricted to 8495 m³/s (3lakh cfs) which could be passed without flooding in Surat and Hazira during at Ukai(similar to 1998). Also, flood similar to 1968 (15lakh cfs) could be dealt effectively by restricting Ukai outflow below 11327 m³/s (4 lakh cfs) by keeping appropriate reservoir levels and by raising MWL by about 1.5 m. Flood protection works should not be constructed in flood plain area because that type of preventive measures further increase in afflux and flood water level. The important immediate measures are completion of ongoing flood protection works, effective operation of Ukai reservoir, review of Ukai reservoir operation policy and detailed studies on reservoir operation, development of a CHARIMA mathematical model for entire Tapi basin river channel network. Upgradation/expansion of hydrological data, acquisition networks and improvement of local drainage systems passing through Surat city. If Ukai reservoir policy cannot be modified then long term measures like diversion of part of Tapi river floods into Sena, Kim and Mindhola creek on north needs to be examined. If diversion is not found feasible, then partial flood embankments from Nehru Bridge to Magdalla Bridge only have been recommended last alternative. The project authority is advised to take suitable measures as per IS 12182-87 and IS 6518-1992 for the performance of the Ukai reservoir.

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