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Development of Tapi River Flood Water Surface Profileby Using Arima 1-D Model

KEYWORDS: ARIMA, Flood water surface profile, Armoring, Flood frequency,Location

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ABSTRACT *The Indian sub-continent in general, and the western peninsula in particular, experienced heavy floods during 8th to 11th August 2006 that cause great damage to personal and property. 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 flood 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. 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 Indian Rupees 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 revised Ukai dam reservoir operation for flood protection & control, it feels the research in that direction for minimization of Tapi river flood impacts –Surat (Gujarat) is of vital importance. Tapi River flood water surface profile predicted while passing through Surat city by using ARIMA 1-D mathematical model at different conditions of flood frequency at various locations.*

INTRODUCTION

In the case of multipurpose reservoir operation, the goals are more complex than the single purpose reservoir operation and often involve various problems such as insufficient inflows and larger demands. In order to achieve the best possible performance of such a reservoir system, a model should be formulated as close to reality as possible. In this process, the model is expected to solve problems having nonlinearities in their domain. For example, a typical hydropower production function is complex, with nonlinear relationships in objectives and constraints. So, the linear programming methods cannot be used. The dynamic programming approach faces the additional problem of the curse of dimensionality, whereas the nonlinear programming methods have the limitationof flow rate of convergence, requiring large amount of computational storage and time compared with other methods (Yeh 1985). In spite of development of many conventional techniques for optimization, each of these techniques has its own limitations. To overcome those limitations, recently met heuristic techniques are being used for optimization. By using these techniques, the given problem can be represented more realistically. Tapi river flood water surface profile prepared by using ARIMA-1D mathematical model in this research study.

ARIMA - 1D MATHEMATICAL MODEL

One dimensional (1-D) mathematical model Auto Regression Integrated Mathematical Analysis (ARIMA) prepared to determine Tapi river flood water surface profile under different flood frequency i.e. outflow ranging from 2 lacs Cusec to 8 lacs Cusec. 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 discritised in x-t plane and system of linearised simultaneous difference between equations is obtained i.e. Coefficient matrix is a banded matrix. ARIMA 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. Each link there are grid points where the cross sectional data given. The nodes could of internal and boundary nodes.

INPUT DATA REQUIREMENTS

1. Topographic data i.e. Channel Cross Sections, layout & connectivity, Configuration of weirs
2. Hydrologic Data i.e. Inflow hydrographs for upstream & downstream boundary condition, bed roughness.
3. Sediment Data i.e. Size, Properties, Distributions, Sediment inflow hydrographs by class
4. Calibration & 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.

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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).

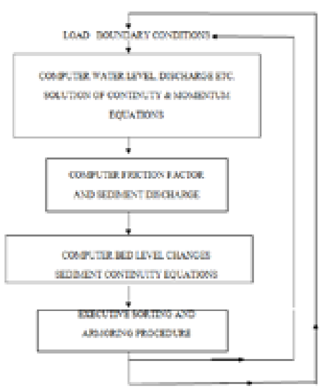
- Channel network pattern assumed (i.e. total no. of channels, and their inter-connections) must remain same during a particular simulation.
- Cross sections are assumed to rise or fall without changing its shape.
- Continuous lateral flows not considered However, in additions due to rainfall could be represented by channel joining at regular interval.
- Other restrictions associated with sediment routing processes (i.e. those required for sorting, armoring sediment discharge, friction prediction etc).

MODEL EQUATIONS

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 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 surfaceused from 32 equations.

METHODOLOGY

Methodology adopted shown here in form of flow chart programming.



ANALYSIS

Results of analysis shown in Graph.1 which indicates water surface profile of Tapiriver 5669 m^3/sec (2 lac Cusecs), 8503 m^3/sec (3 lac Cusecs), 4172 m^3/sec (5 lac Cusecs), 19076 m^3/sec (6.73 lac Cusecs) and 22676 m^3/sec (8 lac Cusecs) along with left and right bank levels at different locations at Surat. Table .1 shows predicted velocities and water levels along TapiRiver for different discharges.

Simulation of September 1998 Flood

The mathematical model run for this simulation was taken under condition i.e. with September 1998 flood hydrograph as upstream boundary and predicted tidal levels at Outer Hazira as downstream boundary. Table. 1 gives the water levels and velocities along the above river reach for different discharges along with river bed and bank levels. Fig.1 shows the water level profiles for different discharges along with the river bed profile. The observed high flood levels on 17.09.1998 at various locations along Tapi reach between Magdalla Bridge Kathor Bridge are superimposed on the water surface profile predicated from mathematical model for comparison the predicted water surface profile

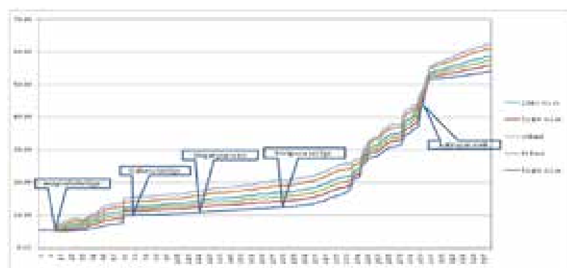


Fig.1 Tapi River Water Surface Profile for Different Flood Scenario – Surat

Table.1 Predicted Water Levels along Tapi River for different dischargesat Spring tide

Sl No	C/S No.	Ch km	Thwg m	Bride	Lt Bank	Rt Bank	2 Lac		3 lac		5 lac		6.73 lac		8 lac		Remark
							WL m	Vel m/s	WL m	Vel m/s	WL m	Vel m/s	WL m	Vel m/s	WL m	Vel m/s	
1	1	0.00	-4.75				5.26	1.60	5.26	-0.51	5.26	-0.39	5.26	-0.26	5.26	-0.09	
2	2	1.00	-6.50				5.24	1.60	5.24	-0.63	5.25	-0.46	BRA5	-0.28	5.25	-0.02	
3	3	2.00	-5.00				5.23	1.59	5.24	-0.48	5.24	-0.33	5.26	-0.16	5.23	0.07	
4	4	2.99	-5.00				5.22	1.59	5.23	-0.42	5.24	-0.24	5.25	-0.07	5.23	0.18	
5	5	3.99	-6.50				5.22	1.59	5.23	-0.42	5.24	-0.18	5.25	0.02	5.23	0.29	
6	6	5.01	-3.96				5.18	1.58	5.20	-0.50	5.22	-0.13	5.24	0.17	5.18	0.57	
7	7	6.01	-5.43				5.14	1.57	5.19	-0.44	5.22	-0.03	5.24	0.31	5.21	0.73	
8	8	7.00	-4.82				5.11	1.56	5.17	-0.39	5.21	0.10	5.25	0.50	5.18	1.00	

show good agreement with the observed high flood levels especially at the location Magdalla Bridge, Nehru Bridge and Kathor bridge where gauges are installed. In general there is good agreement between predicated and ob-

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served flood levels over the entire reach. Comparison of predicted and observed flood levels predicated on East of Magdalla – Icchapur are about 8.50 m which is close to the observed levels of 7.90 m at GAIL and 8.50 m at Hazira branch canal (estimated from flood level mark on bridge parapets shown in Photo 24) velocities predicted in deferent reaches of Tapi rivers are 1.5 m/s to 2.5 m/s in the reach downstream of Magdalla bridge. 1.5 m/s to 3.0 m/s in the reach form Umra to Kathor. These velocities are quite realistic and reasonable. Mathematical model was thus very well validated for flooding situation of 1998. The predicted water levels in the reach upstream of Singanpur weir were higher than the observed levels by 0.5 m to 0.9 m. The model run with reduced peak discharge also indicated that the observed water levels in this reach correspond to discharge of 1840 m^3/s (6.5 lac cfs). It may be mentioned here that the discharges at Kakrapar are given as upstream boundary 15 km upstream of Kathor Bridge. In reality there could be some reduction in peak discharge due to routing from Kakrapar to Kathor. This explains the difference in observed and predicted flood levels. The difference could be attributed to the lack of exact widths of cross sections at higher elevations and the difference in actual and simulated discharge

Flood level Predictions for 28315 m^3/s (without flood embankment d/s of Nehru Bridge)

With tidal conditions at Outer Hazira during1998 flood (neap tide) and extension of flood hydrograph up to 28315 m^3/s (10 lac cfs)i.e., the mathematical model was run as explained. Predicted water surface profile for 22650 m^3/s (8 lac cfs) and 28315 m^3/s (10 lac cfs) are presented. The predicted water levels along Tapi River were 7.86 m at Magdalla bridge 10.63 m at Umra, 12.93 m at Nehru bridge, 15.23 m at Singanpur weir and 21.55 m at Kathor bridge.

Another model run with 28315 m^3/s peak flood discharge from upstream boundary and highest spring tide (with 5.3 m HWL) at downstream boundary was taken. The water surface profile during peak flood discharge. It could be seen that the flood levels upstream of MagdallaBridge nearly remain same under both conditions indicating no effect of tide in this reach. On the downstream of Magdalla bridge the water levels rise by about 0.9 m at KRIBHCO jetty and by about 1.5 m at L & T. In comparison to flood levels of 1998(condition I) the rise in flood levels will be 1.12 m at Magdalla bridge, 2.0 m at Umra, 1.5 m at Nehru bridge, 1.7 m at Singanpur weir and about 3.0 m at Kathor bridge. Rise in flood levels around ONGC will be about 2.0 m above 1998 flood levels.

Flood Level Predictions for 28315 M^3/S with Flood Embankments from Nehru Bridge to Haziraand Nehru Bridge to Magdalla Bridge.

Analysis of results of these studies is presented and the comparison of predicted flood levels with the flood levels predicted for other conditions is shown in Table 4.3 and 4.4. These results show that the construction of flood embankments on both the banks in the reach Nehru Bridge to Hazira will result in rise in flood levels along TapiRiver especially in the reach Hazira to Singanpur. The comparison of predicted water levels without and with flood embankments indicated that the fleed levels at Magdalla bridge will go up from 7.92 m to 9.55 m, at Bhata/Umra from 10.66 m to 11.28 m at Nehru bridge from 12.93 m to 14.85 m and at Singanpur weir from 15.24 m to 16.43 m. the rise in flood levels in the reach upstream of Singanpur weir between Variav and Kathor will be between 0.7 m to 0.1 m this comparatives marginal. Thus, the Surat city and surrounding urban developments between Singanpur weirs to Magdalla Bridge will be subject to high rise in flood levels of about 1.20 m to 1.6 m. In the reach them Magdalla bridge to L&T the flood levels with flood embankments will vary from 9.55 m to about 8.0 m under worst condition. Thus, the flood levels will further rise by 1.6 to 2.9 m in this reach after construction of flood embankments. In comparison to 1998 flood levels the rise in flood levels in the reach from Hazira to Bhata will be between 2 to 2.5 m if the flood embankments are provided and flood discharge of 28.315 $m^{3/s}$ (10 lac cfs) arrives at the time of highest spring tide. Even with partial flood embankment from Nehru Bridge to Magdalla bridge flood levels will be 8.26 m at Magdalla. 10.70 m at Umra, 14.60 m at Nehru bridge, 16.21 m at Singanpur weir, 18.02 m at Variav and 18.69 m at Amroli. Thus, there is substantial rise in flood level even with these flood embankments in the reach Magdalla to Singanpur. However, at downstream of Magdalla the flood levels reduce in comparison to those under condition i.e. embankment up to Hazira. The water level near L & T or Limla/Kawas outfall will be around 7.3 m with the partial embankment. For the discharge of 6.73 lac cfs the rise in flood level with flood level with flood embankment will be about 0.5 to 0.6 m between Nehru Bridge and Singanpur weir. Thus, if at all necessary the flood embankment from Nehru Bridge to Magdalla bridge could be provided to give protection up to a flood discharge of 6.73 lac cfs since the rise in flood levels for this discharge is moderate as compared to flood discharge of 28315 $m^{3/s}$ (10 lac cfs).

Keeping in view the average ground levels of 4.5 m to 6 m along right bank in the reach between Bhata to Hazira with the flood levels of 11.28 at Bhata and about 8.0 m at L&T Hazira the height of flood embankment will be 5 to 7 m considering 1.5 m of free board. Construction and maintenance of such high flood embankments for the length of about 18 kms will be a huge task and costly affair apart from possibility of rise in flood levels all along the river reach up to Singanpur.

Table.2 shows flood water levels along Tapi River for different flood condition, Table.3 comparison of calculated flood levels with observed flood level, CWPRS and CDO, Table.4 shows Ukai reservoir operation trials with August 1998 flood inflow hydrograph.

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

Maximum Upstream Flood Discharge (m3/s)	Water Levels at Various Locations (m)						
	Magdalla Bridge	Umra/ Bhata	Nehru Bridge	Singanpur Weir	Varivay	Amroli Bridge	Kathor Bridge
19057 (6.73 Lac 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 Lac cfs)	7.13	9.51	11.95	14.29	16.01	16.79	20.24
(7 Lac cfs)	6.80	8.57	11.41	13.91	14.27	14.80	18.32
25482 (9.0 Lac cfs)	7.39	9.92	12.41	14.78	16.72	17.55	21.00
28315 (10 Lac cfs)	7.86	10.63	12.90	15.24	17.34	18.17	21.55
28315 (10 Lac cfs)	7.92	10.66	12.93	15.24	17.43	18.29	21.76

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(A) 28315 (10 Lac cfs)	8.26	10.76	14.60	16.21	18.02	18.69	21.88

Table.3Comparisons of Calculated Flood Levels with Observed Flood Level, CWPRS and CDO

Tapi Flood Discharge	Prediction by	Predicted Water at Various Locations (m)						
		Magdalla Bridge	Umra/ Bhata	Nehru Bridge	Singanpur Weir	Varivay	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 lac 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
	Calculated	6.80 (at Bridge)	8.57	11.41	13.91	14.27	14.80	18.32
28315 m3/s (10 lac 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
	Calculated	7.94 (at Bridge)	10.68	12.95	15.24	17.45	18.32	21.78

Table.4Ukai Reservoir Operation Trials with August 1998 Flood Inflow Hydrograph

Time (Hours)	Ukai Inflow (Cu.m/s.)	Ukai Outflow (Cu.m/s)	Ukai Reservoir Level(m) with				
			1998 Outflows		Outflows restricted to		
			Ob-served	Com-puted	3 lakh cfs	3.5 lakh cfs	4 lakh cfs
1	7890	826	104.17	104.17	104.17	104.17	104.17
2	6901	3313	104.21	104.20	104.20	104.20	104.20
3	7574	3313	104.24	104.22	104.22	104.22	104.22
4	11297	6199	104.30	104.24	104.24	104.24	104.24
5	12331	6199	104.35	104.27	104.27	104.27	104.27

RESULTS

The water levels predicted along Tapi river for different discharges from 5669 m^3/sec (2 Lac cfs) to 45351 m^3/sec (16 lac cfs) under existing conditions (with Singanpure and Kakrapar weir and existing embankment on bath banks on u/s and d/s of Singanpur weir) for the reach from Tapi river mouth at Hazira to the Ukai Dam are enclosed. The bank top levels are also shown along the reach. It may be mentioned that the results enclosed are with the d/s boundary condition as spring tide with HWL of 5.26 m (GTS). All the levels mentioned are with reference to GTS. The chainages given in table and in Graphs are from the d/s boundary of mathematical model located at 27.4 km d/s of Singanpure weir.

In general it could be seen that the flood water starts spilling on right bank d/s of Nehru Bridge at dischange of 8503 m^3/sec (3 Lac cfs) in the reach between Singanpure weir to Kathor Bridge the water levels will be above existing bank levels beyond 19841 m^3/sec (7 Lac cfs). In the reach from Kathore Bridge to Kakrapar weir the flood up to discharge of 28345 m^3/sec (10 Lac cfs) will be mostly contain with the high banks with some spillage with locally low bank top levels. In general on u/s of Kakrapar weir also the water levels will be higher than the river bank levels for the discharge beyond 34013. 60 m^3/sec (12 Lac cfs.)

Concluding Remarks

1. The September 1998 maximum flood levels around Hazira Industrial Area and Surat city were about 7.5 m at ONGC, 7.0 m at KRIBHCO colony and 7.9 m at GAIL complex. Along Tapi river the flood levels were 6.8 m at Magdalla bridge, 7.9 m at Bhatpur, 8.55 m at Umra, 11.4 m at Nehru bridge, 13.9 m at Singanpur, 14.23 m at Variav and 18.29 m at Kathor.

2. The main reasons for flooding in Surat and surrounding Urban area and Hazira Industrial Area in 1998 were as given below :

- The reservoir operation during September 1998 flood indicated that the incoming flood discharge flood discharges of about 29820 m^3/s (1053000 cfs). The high flood of 19057 m^3/s (6.73 lac cfs) was released on downstream as the reservoir level was at FRL. in 1994 the discharge of 13815 m^3/s (4.87 lac cfs) also flooded the entire area. The maximum outflow could have been restricted to 8495 m^3/s (3 lac cfs) as shown in reservoir operation studies. The storage space between FRL and MWL was not utilized for flood moderation.
- Absence of any protection wall along low level right bank (with levels of 6.5 m to 4.5 m) between Bhata and Magdalla bridge from where flood water spilled all along the right bank.

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- Incomplete protection works / embankment / sluice regulators along right bank between Nehru bridge to Kathor which allowed entry of flood water which ultimately found its way towards urban and industrial areas near Bhatpur and Hazira on west along right bank
- Raising height of flood embankments in the reach upstream of Singanpur weir was delayed.
- Rise in flood levels due to encroachments along Tapi River by private construction.
- Low natural ground levels (4.0 m to 4.5 m) as well 1 as low finished ground levels (5.5 m to 6.0 m) in the industrial area and high level embankment for roads, canals and railways creating obstruction to the flow of flood water. In particular the railway embankment on north of ONGC and KRIBHCO colonies obstructed flow of flood water to Tena creek.
- Inadequate waterways of many bridges on natural drains between Bhata and Icchapur and also bridges on Tena River. There is no adequate data to show that silting of river bed contributed to the increased flood levels. The mathematical model developed for Tapi river reach from mouth to about 15 km upstream of Kathor bridge (total 66 km reach) is capable of handling unsteady flows in looped river channel network with tide and flood hydrograph as boundary conditions. The predicted water surface profile for the peak discharge of 19057 m3/s (6.7 lac cfs) in September 1998 closely follow the observed high flood levels at various locations along Tapi river reach between Magdalla bridge to Kathor bridge. The mathematical model was thus adequately validated for 1998 flood.Predicated water levels versus time curve at bridge also shows good Predicted velocities for 1998 Hood vary between 1.5 m/s lo 2.5 m/s in the reach downstream of Magdalla aim between 2.0 m/s to 3.0 in the upstream reach up to Kathor. The How remained unidirectional towards sea.

3. Model studies with Hood hydrograph with peak discharge of 28315iru/s (10 lac cfs) as upstream boundary condition and Spring tide (with HWL of 5.3 in) or Neap tide (with HWL of 2.0 in) as downstream boundary condition indicate that on upstream of Magdalla bridge the water levels remain more or less unchanged irrespective of tidal condition. The maximum flood levels under these conditions will be 10.66 m at Umra / hata. 12.93 m at Nehru bridge 15.24 m at Singanpur weir 17.43 m at Variav18.29 m at Amroli and 21.76 m at Kathor. At Magdalla bridge. The water levels will be 7.86 m and 7392 m and 7.92 m for neap tide and spring tide condition respectively.

4. With flood discharge of 28315 m3/s (10 lac cfs) the expected rise in water levels above September 1998 flood levels will be about 1.12 m at Magdalla bridge, 2.0 m at Umra, 1.5 m at Nehru bridge, 1.7 m at Singanpur weir, 2.4 m at Variav and about 3.0 m at Kathor bridge. The flood levels around ONGC will be about 10.6 m i.e. about 2.0 m above 1998 flood levels.

5. For the flood discharge of 28315 m3/s (10 lac cfs) the predicted flood levels vary between 10.66 m at hata, 7.92 m at Magdalla bridge, 6.0 m at KRIBHCO jetty to about 5.65 m at L & T jetty. The natural right bank levels in this reach vary from 6.4 m. This lead to heavy flooding under this situation. Therefore, either the Ukai outflow need to be restricted to 8500 to 9910 m3/s or there is necessity of flood protection works along right bank at least in the reach right from Nehru bridge to Magdalla bridge and further downstream up to KRIBHCO/ L & T jetty. Provision of protection works along right bank from Nehru bridge to Magdalla bridge has been made in the proposal of Surat Irrigation Circle.

6. Mathematical model studies for floods discharge of 28315 m3/s with flood embankments on both banks in the reach from Nehru bridge to river mouth at Hazira (condition IV in Table VIII) predicted flood levels of 8.0 m at KRIBHCO jetty, 9.55 m at Magdalla bridge. 11.28 m at Umra / hata. 14.85 m at Nehru bridge, 16.37 m at Singapur weir, 18.18 m at Variav, 18.81 m at Amroli bridge and 21.88 m at Kathor bridge. There will be Substantial rise of about 1.2 m to 1.6 m in flood levels in the reach from Singanpur weir to Magdalla bridge over the flood levels predicted without flood embankments as seen from comparison of flood levels.

7. With partial flood embankments between Nehru bridge to Magdalla bridge and flood discharge of 28315 m3/s the flood reduce to 8.26 m at Magdalla bridge 10.76 m at Umra. 14.02 m at Nehru bridge 16.27 m at Siganpur weir However, in the reach downstream of Magdalla bridge flood levels near L & T / KRIBHCO jetty will be about 7.50m

8. With partial flood embankment from Nehru to Magdalla bridge and flood discharge of 19057 m3/s (6.73 lac cfs) however. The rise in flood levels above 1998 HFLs will be relatively low (less than 0.60 m) as seen from comparison of predicted flood level under condition I and V (B) of the table VIII.

9. The preliminary reservoir operation studies conclude following ;

- The floods similar to 1998 flood could be moderated effectively by restricting outflow of about 8500 to 9910 m3/s (3 to 3.5 lac cfs) and with initial reservoir level of 102.11 m (...5 ft) to 104.17 m (341.75 ft) respectively. The reservoir level close to FRL could have been maintained with these restricted outflows.
- The floods upto 28315 m3/s (10 lac cfs) could be managed by restricting outflow to 9910 m3/s (3.5 lac cfs) with maximum reservoir level close to FRL.
- If the present MWL is not allowed to be exceeded then during flood similar to that of 1968 the Ukai outflow Level of 100.58 m (330 ft). This high release will cause flooding similar to that in 1998 in the downstream, reaches.
- In view of the high flood levels experienced during the recent of 1994 and 1998 as well as predicted high flood levels for the discharge of 28315 m3/s (10 lac cfs) and the result of preliminary operational studies there is need to take review of Ukai flood reservoir operation. Along with general operational policy on seasonal basis an emergency policy to deal the floods above 28315 m3/s (10 lac cfs) need to be evolved. The existing rainfall and gauging network Tapi basin upstream of Ukai need to be modernized / updated and expanded if Necessary so as to get adequate to be 72490 m3/s (25.6 lac cfs). In view of all these factors detailed reservoir operation studies including power generation and irrigation aspect are required to be carried out to evolve an effective seasonal as well emergency operational policies to minimize flooding of urban and industrial area around Surat city by keeping Ukai outflows preferably between 8500 m3/s to 9910 m3/s (3.0 to 3.5 lac cfs)
- There is need to develop a mathematical model for

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predicting time dependent flows (discharges and water levels) in river channel network of entire Tapi basin upstream of Ukai reservoir to get adequate and timely information of flood discharge approaching Ukai reservoir. The data acquired by hydrological network will provide necessary input data for this model. This mathematical model could also be used to make quick trials on Ukai reservoir operation to decide appropriate outflow as function of time deal with incoming flood. This mathematical model of Tapi basin network will also be useful to study rise in flood levels in the upstream reaches.

RECOMMENDATIONS

Propose embankments and retaining walls suggested for Surat shown below Fig.2.

Fig. 2 Embankments and Retaining Walls

- Improve communication links for the transmission of basic data and providing related warning information about natural hazards. The development and use of radar/GPS/GIS etc. for forecasting and measuring rainfall events gives better results. The increased number of telemetric rainfall stations for the rapid collection and processing of precipitation data and thus the forecasting of floods.
- Ukai reservoir created silting at an average annual rate of 5% actual rate of sedimentation greater than designed rate of sedimentation. Therefore, the reservoir capacities for moderating floods are decreasing rather fast. Even the live storage of several dams has been encroached by the reservoir sedimentation. Cleaning of siltation (16 lacs m^3 quantity) from such river, removal of unauthorized slums/residential buildings/commercial buildings and cleaning of drains should be first priority. 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.
- Construction for widening of canal to divert 2 lacs cusec flood should consider first priority.
- Keeping in view that, for any release from Ukai dam, actual Tapi river water carrying capacity is 1.6 to 4 lacs cusecs while passing through Surat city. Also, probability for occurrence peak flood at Surat is every eight years frequency. Behavioral training and actions against this type of flood disaster should consider for Surat city people and surrounding nearby industrialists.
- ARIMA mathematical model help to forecast Tapi River water surface profile for different flood scenario at various locations at Surat city.
- At meandering of Tapi River, diverting of Tapi River in to nearby Kim and Seem creek consider for most of flood diversion to save Surat city and nearby areas. Desk study required for diversion of Tapi river flood water to the north side Tena, Sena, Kim and Mindhola creek.
- Authority must finalize Tapi river boundary and bank levels. Providing vegetative fencing of hub, shrub & trees at 500 feet interval to the constructed river flood embankments.
- All floods can be moderated up to 8.40 lac cusecs. Not to provide any embankment in d/s of Nehru bridge on right side of Tapi river because (it increases afflux) this area is flood plain area of Tapi river.
- Flood Protection works along right bank of Tapi may be taken up from Nehru bridge to Magdalla bridge on top priority, and then in the reach from Nehru bridge to Kathor bridge may be completed at the earliest.

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