FRAMEWORK DEVELOPMENT OF HYDROMETEOROLOGICAL OBSERVATIONAL NETWORK AND FLOOD HAZARD MITIGATION MODELING SYSTEMS

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ABSTRACT *An appropriate real-time hydrometeorological observational network is designed and established for developing a full-scale hazard mitigation modeling system in respect of floods covering 24 rivers with an objective to develop an enhanced technical capacity to deal with the floods in future using all available technologies and modeling tools. The framework includes set of hydrological and hydrodynamic models, storm surge inundation assessment along with suitable Geographical Information System (GIS) interfacing for facilitating the quantification and spatial description of the impact of flooding (in terms of river and surge inundation) with a sufficient lead-time so as to plan for effective relief routing plans/rehabilitation strategies. Performance evaluation of the hazard mitigation modeling systems for the past flood events is presented in this study.*

Key words Flood; hazard mitigation; modeling; storm surge; observational network.

INTRODUCTION

The coastline of the state of Andhra Pradesh along the east coast of India is one of the most vulnerable zones for floods associated with heavy rainfall in river catchments and in coastal areas due to cyclones. Andhra Pradesh Hazard Mitigation and Emergency Recovery Project (APHM&ECRP) was taken up to restore the public infrastructure damaged during the cyclone of November, 1996, and also to build-up hazard management capacity through a number of key activities listed below:

- Monitoring and prediction of disasters associated with cyclones and floods through development of computer models;
- Preparation of appropriate hazard maps of flooding, storm surge inundation and cyclone wind induced damage etc. involving various spatial and non-spatial themes involving Geographical Information System (GIS) framework;
- Installation of meteorological equipment (meteorological, tide/surge gauging measurements, river and rain gauges, high wind speed recorders, digital cyclone warning dissemination systems; establishment of optimal number of rainfall and run-off measuring satellite based telemetry stations in the state covering 24

major and minor river systems, to provide hourly data as an input to the models for effective monitoring of evolving scenarios;

- Establishment of computer network and satellite based communication facilities; establish mandal level computer network for operating Hazard Management Information System (HMIS) etc. required for real-time operations.

Under this initiative, specific topographic and thematic data sets such as contour, slopes, land use/land cover, drainage and surface water bodies, canal network, dykes, soil, settlements, demography, and socio-economic data etc. are being utilized for interpretation and to generate visual impact of disasters at a desirable geographical scale using GIS. Further, for setting up of flood forecasting system for 24 major rivers of the state, detailed river cross section surveys were conducted to generate digitized information of various river cross sections. Apart from developing a system of effective impact minimization due to natural disasters, especially cyclones and floods, it is strongly believed that it is possible to enhance sustainable development of the coastal zone leading to the reduction of vulnerability through evolving an appropriate Integrated Coastal Zone Management (ICZM) Plan. The overall objective of the ICZM is to envisage optimum utilization of coastal resources, minimization of impacts due to natural disasters and improvements in equitable quality of life levels while ensuring environment protection and biodiversity conservation by utilizing the outputs of hazard mitigation models of cyclones and floods. The essential part of the ICZM is to ensure a balance between damage reduction measures and optimum use of coastal resources and the basis for this is the risk assessment analysis (physical/social/economical point of view). Thus, within the ICZM, the hazards are constraints on two counts, firstly as they cannot be avoided, and secondly committed investments are to be made towards mitigation works so as to sustain the expected levels of coastal zone outputs.

STUDY AREA

The study area covers three major river systems – Godavari, Krishna and Pennar and 21 minor river systems viz., Vamsadhara, Nagavali, Gostani, Mehadrigedda, Sarada, Varaha, Thandava, Pampa, Yelleru, Gunderu, Ramileru, Thammileru, Errakalava, Nallamada, Vogeru, Maneru, Gundlakamma, Paleru, Romperu, Swarnamukhi, and Kandaleru of Andhra Pradesh (Fig. 1).

The study area covers the entire coast of Andhra Pradesh, 12 nautical miles on the sea side and 20 km on the land side and the complete deltas of the Pennar, Krishna and Godavari. The coastal region can be characterised as a generally low lying coastal plain consisting of unconsolidated sediments of fluvial material like sand, silt and gravel and fluvi-marine materials like mud, clayey soils and coastal sands of recent origin. Towards the interior underlying the recent deposits are meta-sediments and granites which outcrop occasionally in the form of small hills. The coast has a number of geomorphological features of which the deltas are the most prominent. There is a well-developed command area of one million ha in the deltas of the Krishna, Godavari and Pennar. In addition to the large rivers, there are

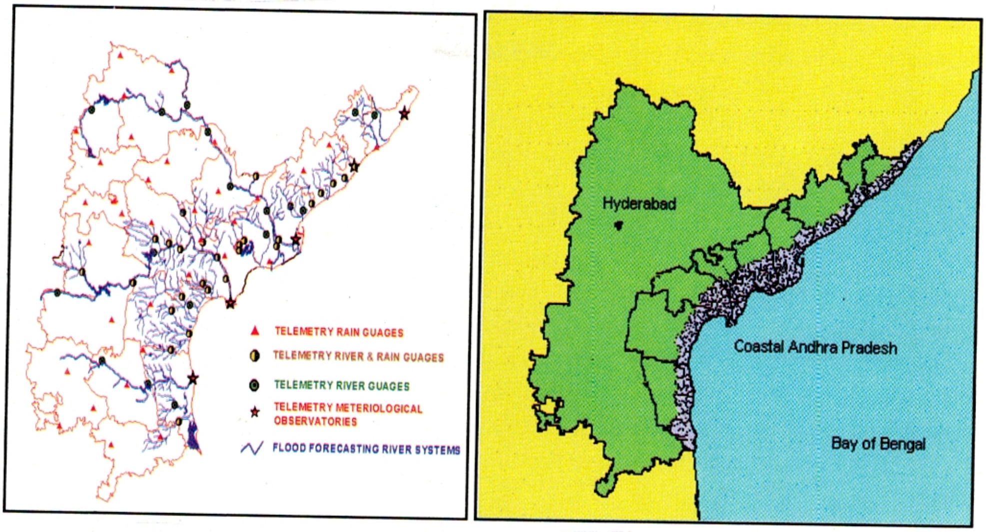

Fig. 1 Study area and observational telemetry network.

several creeks and important lakes such as Pulicat in the south and Kolleru in between the two large deltas, which also drain into the Bay of Bengal. Based on physiography, land use, and climate, the entire coast can be divided into three more or less distinct sub-areas viz., North coast, Deltas and South coast. These sub-areas coincide with three different agro-climatic zones:

- North coast: Annual rainfall (mainly during Southwest Monsoon) averages between 1000 and 1100 mm.
- Delta coast: Annual rainfall (mainly during Southwest Monsoon) averages between 800 and 1000 mm.
- South coast: Annual rainfall (mainly during Southwest Monsoon, but a larger proportion than other districts during Northeast Monsoon) averages between 700 and 1100 mm.

The north coast comprising Vishakapatnam, Vizianagaram, Srikakulam and the northern part of East Godavari Districts consists of hills immediately bordering the sea. The prevailing longshore coastal drift towards the north usually closes the estuaries with mouth bars, effectively blocking the way to sea. Coastal dunes are relatively high and also occur in the old hills on the sides of the estuaries. Vishakapatnam is the main industrial and urban centre along the north coast that has a number of petrochemical industries. Other industries include fertilisers, iron and steel, engineering, shrimp and prawn culture, shipping and cement. The deltas of the Godavari and Krishna Rivers together form the second subdivision of the study area i.e., the Delta Coast. The area lies within the southern part of East Godavari, West Godavari, Krishna and Guntur Districts (as far as the 20 km zone is concerned). The Godavari Delta is the second largest delta in India. It has a coastline of 150 km and a slope of 0.0004. For the Krishna River the estimated slope is 0.0002 and it has a coastline of 125 km. Both rivers receive their sediments from a variety of geological formations, the most important being the Deccan Traps of Late Cretaceous-

Palaeocene age which occupy 55% and 48% of the drainage basins of the Godavari and Krishna rivers, respectively. The distribution pattern of sand, silt and clay in the Krishna and Godavari Deltas indicate that flood waters from the rivers inundated the nearby floodplains, natural levees and swales and the deposited sediments are characterised by relatively high fractions of silt and clay. In both deltas river channels, spits, beach, dune and channel bars are characterised by over 90% sand. The coastlines of the deltas comprise of a number of clearly defined coastal types viz., tidal flats and mangroves, lagoons, bays, spits, beaches, and dunes. Three spits are growing in southwest direction in the Krishna Delta. The Krishna Delta beach is wide with gentle slope and is devoid of any significant profile features. Godavari Delta beach on either side of the river mouth has arcuate bends with steep slopes indicating active deposition to the north of the delta. In the deltas irrigated agriculture is the dominant land use. Paddy fields are lined with coconut and Borassus palms. Other forms of land use include coconut/banana plantations, sugar cane and aquaculture. Major cities are Rajamundry in East Godavari District and Vijayawada in Krishna District. The south coast consists of a gently sloping coastal plain with a significant beach/dune complex near the coast. A belt of coastal alluvium soils of 30-40 km wide is found all along the south coast of the Krishna Delta. Many rivers flow to the sea, such as the Swarnamukhi, Penner, Palleru, Musi and Gundalamma rivers. Of these, only the Penner has formed a significant delta. Also a number of lagoons are present, of which Pulicat Lake is the most significant feature. Irrigation is mostly limited to tank and groundwater irrigation. Rainfed agriculture includes cotton, peas and groundnut. Dunes are planted with cashew, Eucalyptus and Casuarina. Parts of the dunes are excavated (sand mining) up to the groundwater level, after which paddy is planted. Nellore is an industrial centre with power and shipping related sectors.

SATELLITE TELEMETRY BASED HYDROMETEOROLOGICAL OBSERVATIONAL NETWORK AND FLOOD HAZARD MITIGATION MODELING SYSTEM

The telemetry network of rain gauges, river gauges and coastal gauges are depicted in Fig. 1. Remote field gauging stations are being established throughout Andhra Pradesh for data collection. These stations are essential to determine the real-time flood characteristics of a river system. The sites of the gauging stations have been determined by an assessment of the hydraulic and hydrological requirements so as to accurately represent the parameters in the various numerical models. Three types of stations are installed as listed below:

- River water level gauges (number of water level gauges 44)
- Rain gauges (number of rain gauges 55)
- Meteorological instruments (high wind speed, tide/gauge, rainfall, temperature, at 5 locations

Each of these stations will comprise of gauging equipment (rain and water level instrumentation), Data Collection Unit (DCU) (with analogue, digital and counter input cards), INSAT transmitter (data communications interface) and solar array comprising of regulator, charger and maintenance free batteries for 45 days backup. The Monitoring Centre is commissioned within the Planning Department premises designated as DMU in the Government of Andhra Pradesh Secretariat, Hyderabad. It is receiving data from all remote field-gauging stations as mentioned above through satellite communications equipment with the host telemetry and communications hub. To ensure reliable and secure operation, a dual receiving system working in 'master and hot standby' configuration (for redundancy) is procured. The 'hot standby' Monitoring Centre will be a true replica of the 'master' Monitoring Centre. It will comprise of the following except the printers:

- Dual computers; Real time clock;
- Two GUIs (VDUs); Colour graphics printers; Alarm/Event logging printer;
- LAN; Dual telemetry front end; Full software to support real-time operation, logging, retrieval and transfer;
- Satellite communications base station; Voice and fax facilities; UPS etc.

The main components of the earth station will include antenna, LNB (includes the feed, LNA and down converter), synthesized down converter, digital receiver / burst demodulator, PC data processor software modules, and, power supply through UPS with surge and other protections.

Figures 2 and 3 show the hourly observations of river flow and rainfall received at Hyderabad in real-time from the remotely located telemetry stations of Perur and Gollalamoda for typical cases of Godavari river water level rising gradually during Monsoon-2004 and intense rainfall recorded at Gollalamoda(Krishna River Mouth at Bay of Bengal coast) over a 24-hour period during December 15-16, 2003. The observational network set-up for hazard monitoring and generating real-time inputs for hazard mitigation models of floods and cyclones constitutes a technologically advanced system set-up first time in India successfully.

The framework of the system consists of Flood Watch, UP Model, MIKE 11 and GIS based Decision Support System (DSS) modules as shown in Fig. 4. The systems to be installed offer a number of advantages that include full integration of hydrometric data and hydrological and hydraulic modeling, enabling much greater

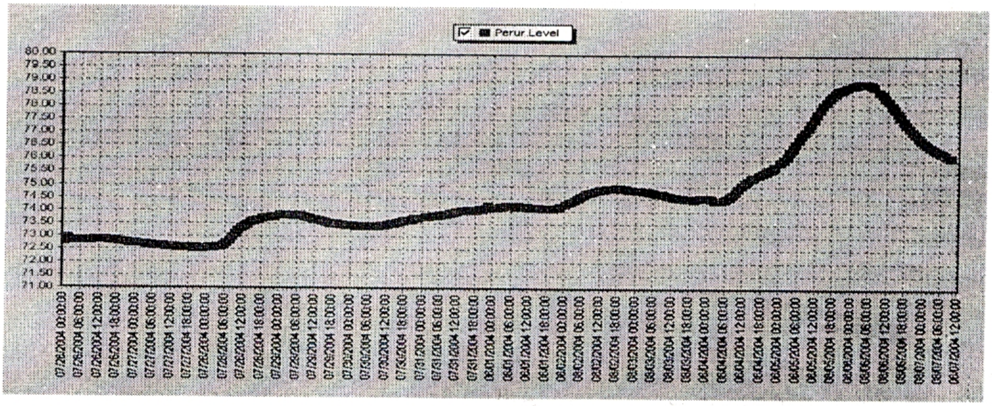

Fig. 2 Hourly river flow measurements on Godavari River at Perur during August 2004.

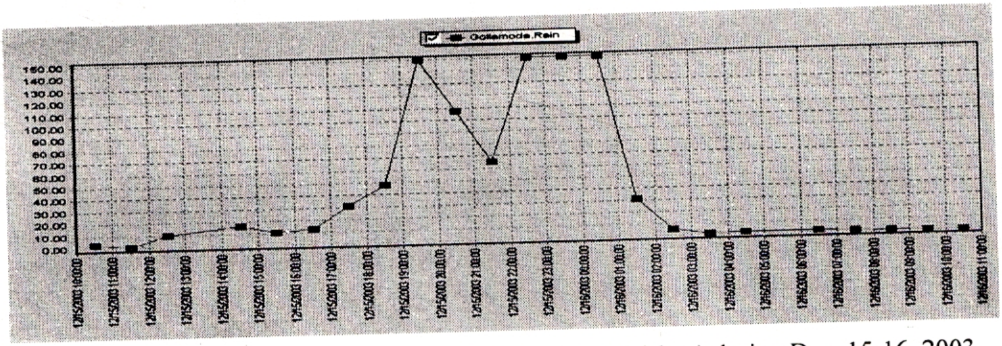

Fig. 3 Hourly rainfall measurements at Gollalamoda (Krishna) during Dec. 15-16, 2003.

lead-times to be provided, and a seamless interface with dissemination using modern means of communication. Forecasts for the major rivers will allow alerts to be issued 72 hours in advance of flooding, with increasing accuracy of prediction as the lead-time shortens. Forecasting model shall use latest telemetered data during real-time operations.

The UP (rainfall-runoff hydrological) Model will use the data from telemetry stations, together with other observations from the IMD/state rainfall networks, satellite derived rainfall for catchments with in the state/outside state and rainfall forecast from atmospheric model for whole of the 24 river catchments. MIKE 11 (hydrodynamic model) will use fluvial flow forecast inputs from the UP model and the latest predictions of tide and storm surge sea boundary. During calculation of the hydraulic results/forecasts, the MIKE 11 FF Model will update the calculated real time values with the latest river flow/water levels received from the field gauge stations through the telemetry system. The structure of the forecasting data flow is shown in the Fig. 4. The physical river cross-section data and longitudinal profile of river banks from river mouth to the starting point of hydraulic model domain for flood routing was used to set-up MIKE 11 (Hydrodynamic), UP (Upscaled Physical hydrological) and GIS interfaces.

Flood Watch

MIKE Flood Watch (FW) is a management system for real-time flood forecasting and warning. It is a decision support system combining an advanced time series data base with the MIKE 11 hydrodynamic modeling and real-time forecasting system, MIKE 11 Flood Forecasting (FF) together with GIS (DHI, 2000a, b, c). FW comprises a number of elements:

- FW Graphical User Interface (GUI), a customised ArcView project which provides a live display of station measurements and forecasts.
- MIKE 11 hydrodynamic modeling system with additional FF module used to produce the forecasts
- FW database, for the storage of real time data
- Suite of modular tools performing a range of tasks, from data transfer and processing to forecast plotting and bulletin production.

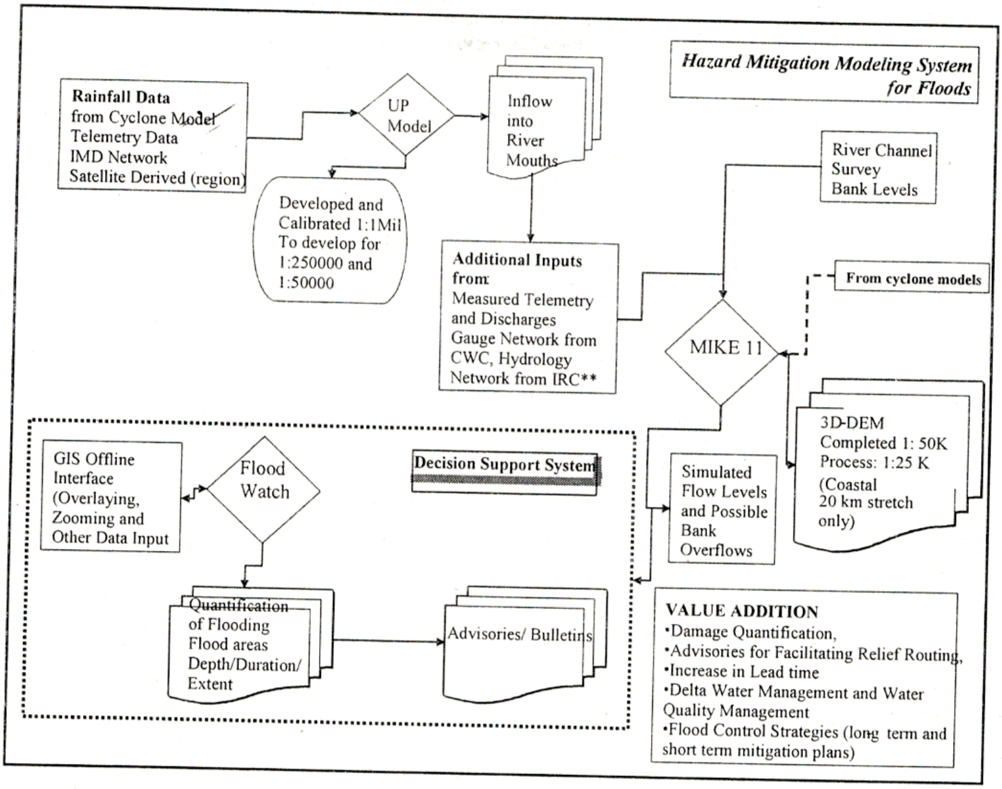

Fig. 4 The structure of flood hazard mitigation system.

The integration of a flood forecasting system in a GIS environment provides a very powerful tool for real-time flood forecasting and flood warning. A schematic outline of the FW System is shown in Fig. 5. The telemetry data from river, rain and coastal gauges is automatically imported to Flood Watch. It processes the input data such as interpolation, consistency, gap filling and Q/H calculation before using the data in the models.

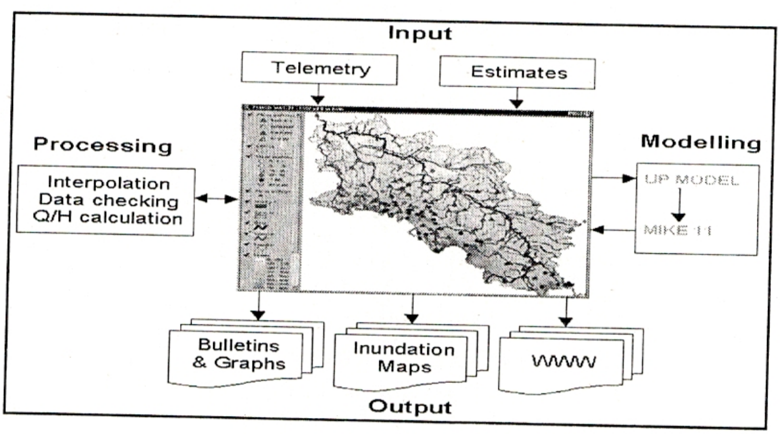

Fig. 5 An outline of Flood Watch System.

Once the system is started, it will automatically extract the required data from the FW database to UP and MIKE 11 modules to execute, generate and transfer the MIKE 11 simulated forecasts to the FW database for display, preparation of custom made warnings and further dissemination. In addition, the spatial flood information and forecasts of water levels and discharges can be produced.

Upscaled Physical Model

The Upscaled Physical (UP) model was developed by the Water Resources Systems Research Laboratory, Newcastle, UK. It is a semi-distributed model consisting of two components, one representing the rainfall-runoff generation mechanism and another to transport the runoff from the hill slopes and through the channel system to the catchment outlet. The flow routing in the model is performed using a transfer function and St.Venant equations. The function is derived from a Digital Elevation Model (DEM). UP basin model has physical characteristics that reflect the variations in elevation, vegetation, and soils across the basin. The model could be successfully applied to modeling the water budget and hydrological processes (Kilby et al., 1999) from catchment scale to continental scale. The model results were used as upstream boundary conditions (discharge) of the MIKE 11 Model. The catchments of all the rivers that were modeled are shown in Fig. 6.

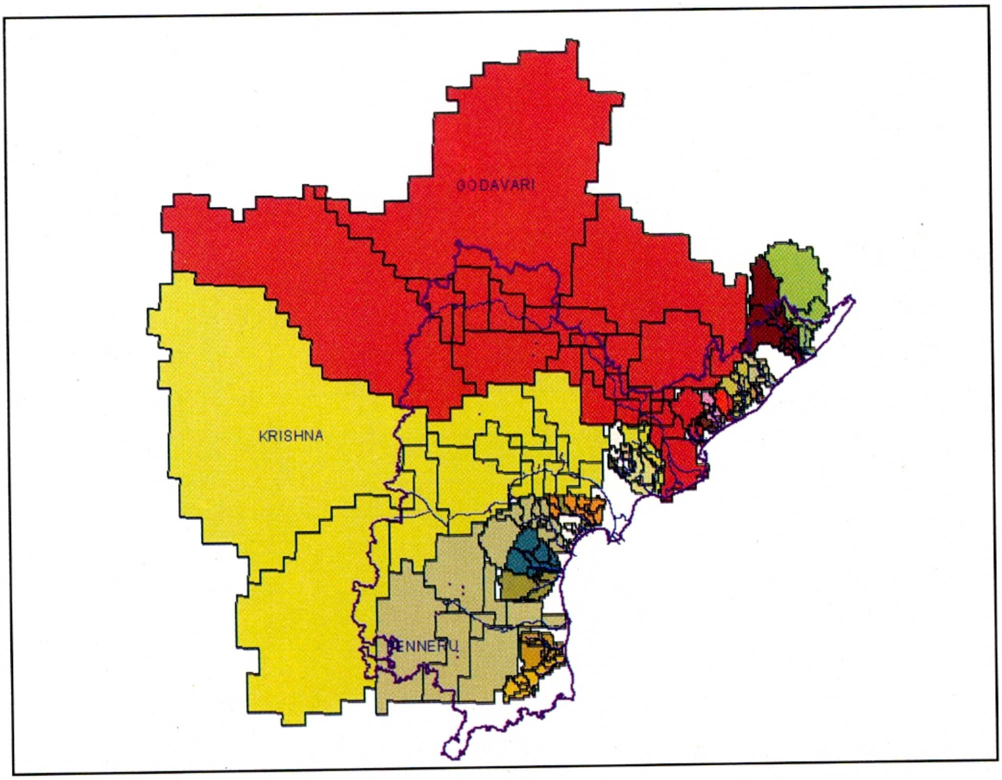

Fig. 6 Various UP catchments.

MIKE 11

The MIKE 11 software is adopted in this framework for hydrodynamic modeling purposes. This software includes modules allowing many hydraulic structures to be included in the river flow simulations, such as include bridges, weirs, culverts and user defined structures. In this study, the upstream boundary of the model for all the river systems is set as flow (discharge), and downstream as water level corresponding to tidal conditions in the Bay of Bengal. The river channel survey data in conjunction with SOI sheets were used to assist in recognizing areas where flood plains need to be included in the model. Initial parameter values for bed friction were assigned to each river cross-section and flood plains. FF module in MIKE 11 performs the calculations required to predict the variation in water levels and discharges in river systems as a result of catchment rainfall and runoff and inflow/outflow through the model boundaries. The measured and simulated water levels and discharges are compared and analyzed in the observed period and the simulations corrected to minimize the discrepancy between the observations and model simulations.

Numerical Experimentation and Results

Pennar River model extends from Somasila to Bay of Bengal with the total modeled length of around 117 km. One CWC station exists at Nellore within the hydraulic model reach. Calibration was done for Pennar River for three flood events (1988, 1991, 2001) and the results of 2001 event are presented in Figs. 7 to 9.

UP Model Results

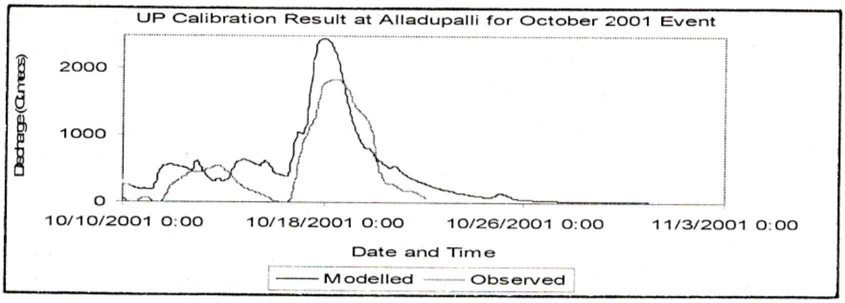

Fig. 7 Comparison of modeled and observed inflows at Alladupalli.

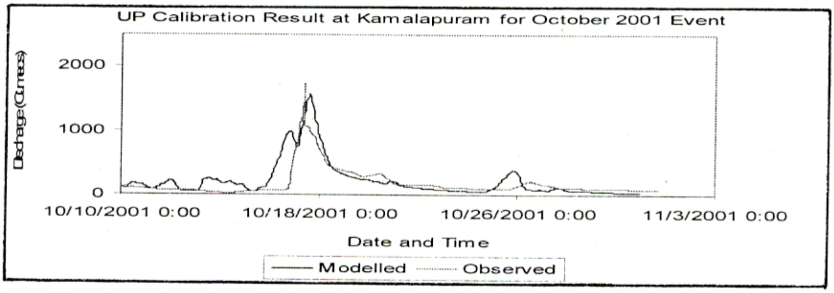

Fig. 8 Comparison of modeled and observed inflows at Kamalapuram.

Table 1 gives the comparison of observed and simulated peak discharges obtained from UP model for events on major tributaries of River Krishna.

Table 1 Observed and simulated peak discharges for major tributaries of River Krishna.

Catchment (gauge)	Event	Observed Flow (m^3/s)	Simulated Flow (m^3/s)	Difference (%)
Tungabhadra (Mantralayam)	Aug 1991	3,471	3,811	8.9
	Nov 1992	12,132	10,653	-13.9
Munneru (Keesara)	July 1989	6,780	6,667	-1.7
	Sept 1991	3,420	3,490	2.0
Upper Krishna (Agraharam)	Sept 1989	8,891	9,899	10.2
	July 1994	15,400	14,930	-3.1
Halia (Halia)	July 1989	939	926	-1.4
	Sept 1991	2,567	2,677	4.1
Paleru (Paleru Bridge)	Sept 1988	1,086	1,192	8.9
	July 1989	1,780	1,567	-13.6
Musi (Dameracherla)	July 1989	6,575	6,695	1.8
	Sept 1991	2,000	1,875	-6.7

MIKE 11 Results

The modeled and observed results of flood forecasting model showing discharge and water level are shown in Fig. 9.

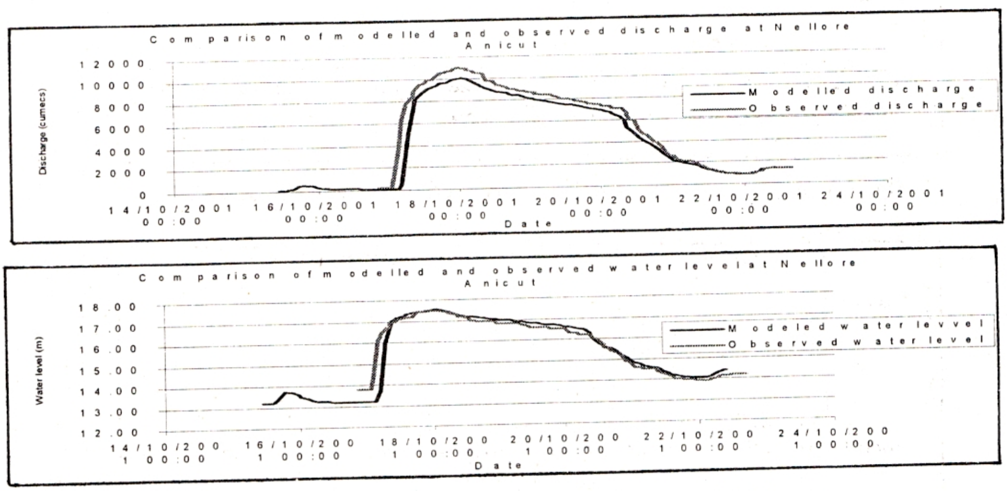

Fig. 9 Discharge and water level comparisons for 2001 event.

The inundation map for the 2001 event showing inundation values in cm is shown in Fig. 10 with full spatial description of depth and extent of inundation in the neighbouring flood plains along with the superimposed administrative boundaries of villages, mandals and districts. The DSS system developed would allow total flexibility to overlay other topographic layers (viz. road network) and linkage to attribute data (demography, income, cyclone shelters, hospitals and schools) for facilitating the effective relief, relocation and rehabilitation planning with the identification of targeted communities to provide the support on priority.

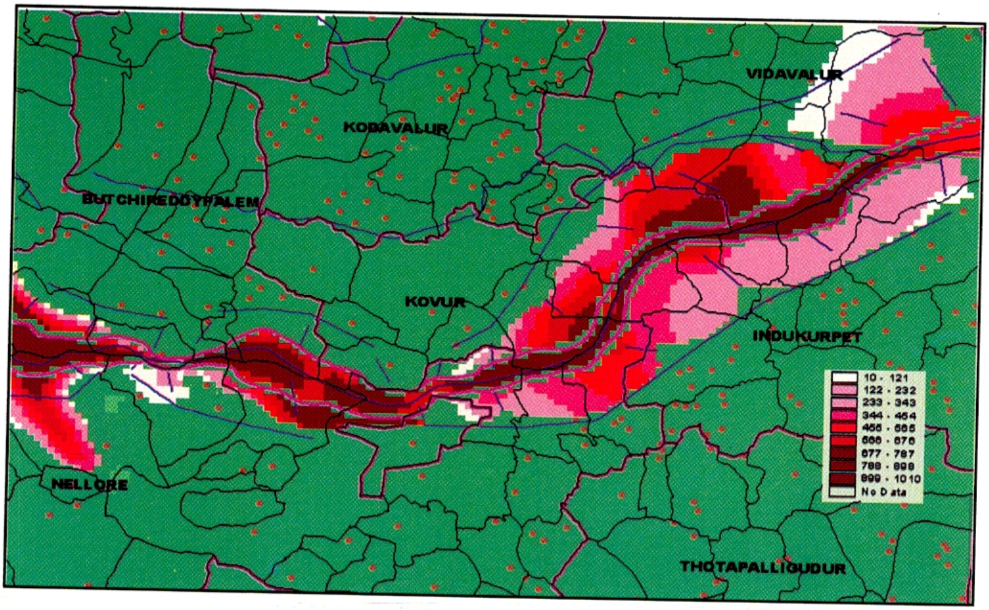

Fig. 10 Inundation map of 2001 event.

CONCLUSIONS

The framework development of hazard mitigation modeling systems in respect of floods covering 24 river systems and cyclones covering 9 coastal districts of Andhra Pradesh is presented in this study along with selected preliminary results of their performance evaluation for the past cases. The fully customized system of modeling and GIS based DSS tools have shown that the hazard maps on dynamical basis are possible to generate within the limitations of model design and spatial data resolution. The framework thus generated can be expanded depending upon the requirements in future. It is to be noted that the representativeness of the quantitative hazard maps would depend heavily on the appropriateness of the prescribed attribute data of the respective fields (crops, houses and infrastructure).

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