Transactions on Ecology and the Environment vol 50, © 2001 WIT Press, www.witpress.com, ISSN 1743-3541

Flood forecasting in Andhra Pradesh, India

M.D. Stewart[1], D.J.J. Buzzacott[1], K.J. Riddell[2], T.M. van Kalken[3] & C.G. Kilsby[4]

[1]*Babtie International, Hyderabad, Andhra Pradesh, India*
[2]*Babtie Group Limited, Croydon, UK*
[3]*DHI Water and Environment, Shrewsbury, UK*
[4]*WRSRL, Department of Civil Engineering, Newcastle University*

Abstract

This paper describes the development of the Andhra Pradesh river flood forecasting system. The system provides state-wide flood forecasting using state-of-the-art technology, including real-time data collection from field stations, rainfall-runoff and river hydraulic models, and a GIS-based Graphical User Interface allowing visualisation of model results, and automated warning preparation and dissemination. The system dramatically improves the technology available to assist flood forecasting in Andhra Pradesh and provides the state with one of the most advanced and largest flood forecasting systems of its type in the world.

1 Introduction

Andhra Pradesh is the fifth largest state in India and is approximately the size of the UK. It is located on the eastern side of the Indian Peninsula (Figure 1), and has over 950 km of coastline traversed by 24 significant rivers that include the Rivers Godavari and Krishna, two of the largest rivers in India. All of these rivers are prone to flooding during the bi-annual monsoons. A large proportion of the population of Andhra Pradesh lives in flood prone regions and much of the wealth of the state is generated by agriculture within the delta regions of the major rivers. At present, a flood warning system exists for only two of the rivers of the state, providing 24 hour flood warnings at a limited number of locations.

In order to extend the coverage of the warning system and to improve the technology used in flood forecasting the Government of Andhra Pradesh commissioned a project in September 1999 to develop a new flood warning system for the State. The project was part of wider World Bank funded schemes that were looking at other hazard mitigation measures including the development of cyclone storm surge, wind and rainfall models.

This paper describes the new river flood forecasting system for Andhra Pradesh. The system provides a fully integrated Decision Support System that includes real-time data collection from field stations, rainfall-runoff and river hydraulic models, the incorporation of model predictions and other data within a GIS environment, and a Graphical User Interface to allow automated warning preparation and dissemination. The system dramatically improves the technology available to assist flood forecasting in Andhra Pradesh and provides the state with one of the most advanced and largest flood forecasting systems in the world.

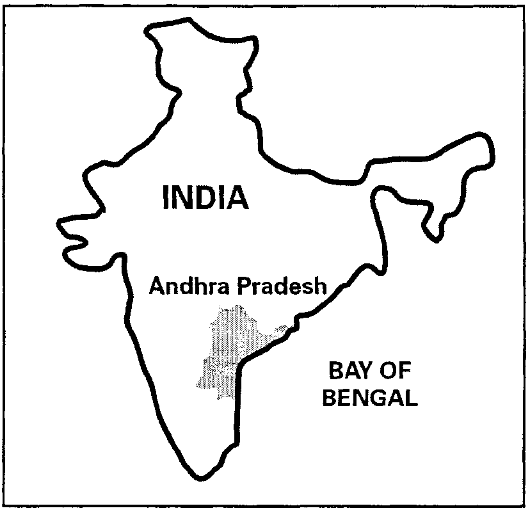

Figure 1: Location Map of Andhra Pradesh

2 Flood forecasting in Andhra Pradesh

At present flood forecasting in Andhra Pradesh is provided by the Indian Central Water Commission (CWC). Forecasts are only provided for the Godavari and Krishna Rivers, for 24 hours in advance and for a limited number of locations. Furthermore, forecasts for each river are given by separate offices using different forecasting methodologies. For the other 22 flood affected rivers in Andhra Pradesh there is currently no flood forecasting and there is flow gauging on only six of these rivers.

A new system was required that considered all of the rivers affected by flooding within the State, which utilised inputs from real-time river and rainfall gauges, and which was incorporated within a Decision Support System linked to a GIS database. With the project being funded by the state government and considering rivers within Andhra Pradesh alone, an extension to the CWC system was not possible. Hence, a new flood warning system was developed to be managed by a Disaster Management Unit within the Government of Andhra Pradesh. This provided the added benefit of centralising all warning preparation and dissemination at a single management centre.

A number of factors affected the development of the flood forecasting system,

- The short time scale of the project. The project had to be implemented within two years, including the commissioning of a number of field gauging stations.
- The system had to improve on the current flood warning capabilities of the State
- A large number of rivers (24) had to be incorporated into the system. Many of the rivers themselves were of a large scale, with some flood flows in excess of 50,000 m^3s^{-1}.
- The system had to incorporate predictions of cyclone-storm surge inundation, provided by a separate suite of numerical models.
- The presence of the Indian INSAT satellites, the development of a state optical fibre network and GIS data base opened the possibilities of utilising state-of-the-art methods of data transfer, data presentation, and warning dissemination.
- Issues relating to warning dissemination within a developing country, including the centralised nature of the decision-making process during hazards, the size of populations vulnerable to hazards, and the variation in education standards, languages and dialects of the public. Sensitivity had to be used to maintain understandable communications between users of state-of-the-art technology in a management centre and a public who often had limited understanding and access to technology.

3 The extent of the forecasting system

The proposed system was required to provide flood forecasting for the medium and major rivers within the coastal districts of Andhra Pradesh, covering 24 rivers. The extent of the main river channels is shown in Figure 2 and the scale of each of the river systems is outlined in Table 1.

The two largest rivers flowing through the State, the Godavari and Krishna, have the greatest flood hazard, in terms of high flows and the number of people potentially affected by flooding. Both rivers originate outside of Andhra Pradesh,

but have a number of tributaries entering the main river within the State. The flow time from the western state boundary of the two rivers to the coast is of the order of 3-4 days, providing a good forecast lead-in time from gauged flows at these points. River models driven by gauged flows at the state boundary, updated in real-time with flows from gauges within the state and on major tributaries, as well as with runoff predictions from measured and forecast rainfall, have the potential to provide successful long-term 48–72 hour flood forecasts. Many of the rivers in Andhra Pradesh are affected by major dam projects. Flooding on the Krishna is substantially controlled by two major dams lying mid- way between the state boundary and the coast. Forecasts of reservoir level and real-time dam discharge measurements are required to provide accurate flood forecasts to the coastal regions.

Table 1: Major rivers in Andhra Pradesh

River	Total Catchment Area (m^2)	River Length within AP (km)	Maximum Recorded Discharge (m^3s^{-1})
Godavari	314,000	772	>100,000 (1986)
Krishna	252,000	612	33,800 (1998)
Pennar	50,000	595	51,275 (1946)

The other 22 rivers within the state vary between steeper rivers in the north adjacent to the Eastern Ghats hill range, and more low gradient rivers to the south of the Godavari River. Heavy rainfall can result in flash floods in the northern rivers. Consistently reliable flash flood forecasting is beyond the immediate scope of the project as the raingauge network density and the quality of available rainfall forecasts are unlikely to provide the required data for flash flood forecasts. However, these rivers are also prone to flooding due to prolonged but low intensity rainfall. For many of these river systems the developments within the project will provide flow gauging and flood studies on the rivers for the first time.

In addition to being at threat from river flooding, the coastal region of Andhra Pradesh is also one of the most cyclone prone regions in India, with cyclones capable of producing extensive flooding due to storm surges and heavy rainfall. Major cyclones crossed the Andhra Pradesh coast in 1990 and 1996 resulting in thousands of deaths and estimated costs of over one billion US dollars in each event. As well as considering flooding due to monsoonal rainfall the proposed flood warning system had to incorporate outputs from storm surge inundation, and cyclone induced rainfall prediction models. The river flood forecasting system processes all the results to prepare predictions of combined cyclone and river flood inundation.

The effect of cyclones is the most acute if the cyclone makes landfall on one of the major deltas of the Godavari and Krishna. These low-lying areas are irrigated and heavily populated, and are prone to extensive flooding due to storm surge and heavy rainfall. The flood forecasting system also incorporates a representation of the delta regions, and their canal and drainage networks.

Transactions on Ecology and the Environment vol 50, © 2001 WIT Press, www.witpress.com, ISSN 1743-3541

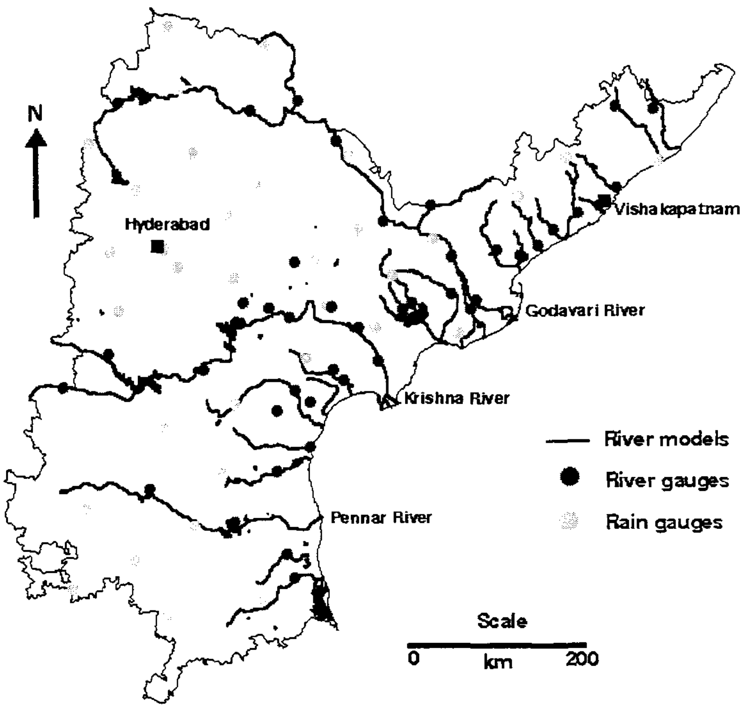

Figure 2: Extent of river modelling and locations of real-time river flow and rain gauges.

4 The Andhra Pradesh River Flood Forecasting System

The structure of the proposed flood warning system is given in Figure 3.

4.1 Data inputs

Real-time inputs to the system include measured and predicted rainfall, measured river water levels, predicted tidal surges, and dam releases.

The project is establishing a network of 94 river and raingauges across Andhra Pradesh (Figure 2), linked to a modelling centre by satellite communications systems using the Indian INSAT system. INSAT only allows one-way communications, but its use is currently free to Indian Government users. Where possible gauges were proposed at already existing sites to ensure security and to assist in gauge calibration. However, during the project new gauge sites are being established on 16 rivers. The number of gauges was selected as a careful balance between cost and the requirements of the rainfall-runoff and river models. There is scope for additional rainfall

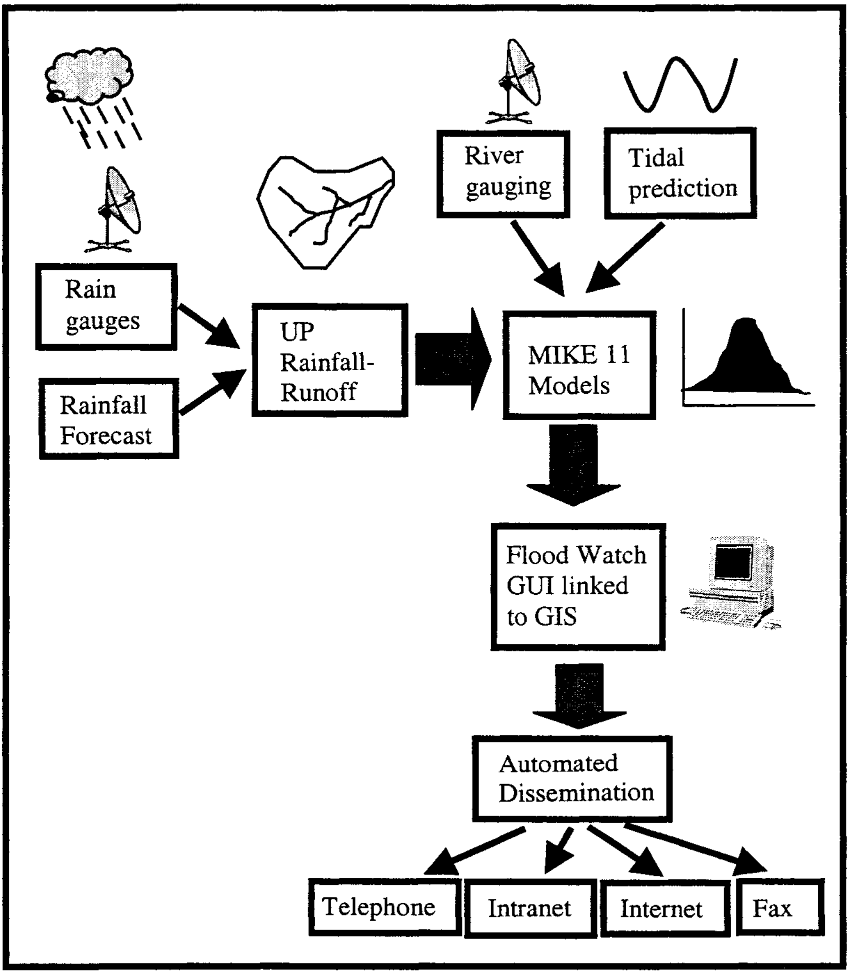

Figure 3: Structure of the Andhra Pradesh Flood Forecasting System

measurements to be used in real-time operation should the need arise and facilities are being developed to allow existing offline stations to radio or email readings to the modelling centre.

Daily quantitative precipitation forecasts (QPF's) are issued by the Indian Meteorological Department (IMD) for major river catchments. These provide 24 hour banded predictions of rainfall, and are generated on a sub-catchment scale. This information will be supplemented by forecasts generated by a rainfall model developed in a companion study. This model will operate on a 1.5° grid covering the whole of Andhra Pradesh and neighbouring states.

Cyclone-induced surge levels are provided by a model of the Bay of Bengal which has been developed in a separate study, based on cyclone track predictions issued by the IMD. These surge levels are incorporated into the river models as downstream boundary conditions.

All the models will operate in a coordinated but time delayed manner to ensure that the most recent data is available for flood forecasting runs.

4.2 Rainfall-runoff modelling

The rainfall measurements and predictions are used by rainfall-runoff models of each of the river basins to generate boundary condition inflows for the river hydraulic models. The Upscaled Parameter (UP) model, developed by the Water Resource Systems Research Laboratory (WRSRL) at the University of Newcastle-upon-Tyne, was selected for the rainfall-runoff modelling component. The UP methodology combines the flexibility of a distributed model, with the operational speed of a lumped model [1]. Initial calibrations are undertaken on representative catchments using a detailed SHETRAN distributed modelling approach. In Andhra Pradesh grid scales of 2 km were used on catchments of the scale of 1400 km^2. The parameters developed using SHETRAN are then scaled [2] to be used within simpler, larger-scale (20km x 20 km and 10km x 10km) UP elements that together comprise the catchments to be modelled in the real-time system. The UP elements essentially operate as lumped models, providing the fast run times required for the real-time system. The entire catchment modelling system will run within a few minutes.

4.3 River flood modelling

The engines of the flood forecasting system are Danish Hydraulics Institute (DHI) MIKE11 river models [3] developed for each of the 24 principal rivers. The models are driven by gauged inflows at the boundaries of the rivers, supplemented by predicted inflows generated by the rainfall-runoff models.

The MIKE11 suite of programs is robust and user-friendly, ideal for the development of a large flood warning system. MIKE11 has been tested in thousands of modelling applications worldwide and has been used successfully in the Bangladesh Flood Warning system for the last 3 years. The suite also contains integrated software that allows model operation within a flood forecasting system including units permitting automatic model operation [4], linkage to incoming telemetered data, linkage to rainfall-runoff models, and the automatic generation of flood maps in a GIS system [5]. For most of the State flood mapping is only possible on a coarse DEM, based on 1:50,000 scale mapping. In this region inundation maps can be indicative only. However, for a 20km strip close to the coast more detailed flood mapping is possible using specifically prepared maps with 0.5 m contours.

The MIKE11 system also allows real-time updating of the predicted flows using the gauged river flows recorded by the new gauge stations sited within the river models. This updating corrects model predictions so that they are consistent with the available measured flow data.

In total the system will incorporate over 3000 km of river models.

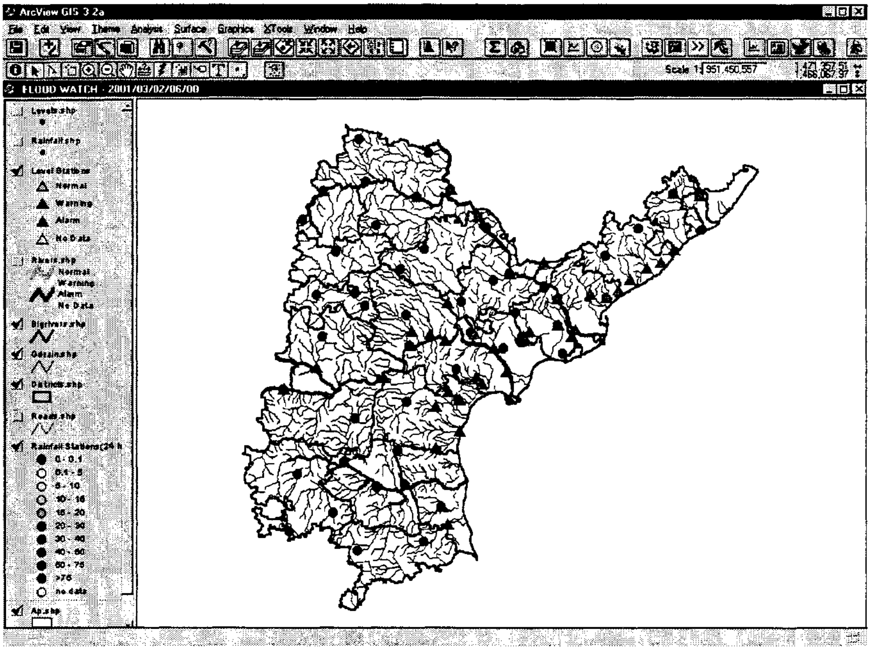

Figure 4: The FloodWatch GUI

4.4 Graphical User Interface

With the modelling of multiple rivers it is vital that the model results are made available to the user in a format where they can be readily interpreted, interrogated and acted upon. These functions are performed by the DHI FloodWatch software [6], the Graphical User Interface, which also drives the flood forecasting system. FloodWatch is developed within the ESRI ArcView GIS package with project specific customisations. However, it retains the full utility of the GIS software. This powerful tool not only provides the user with a means of viewing model results and field data, it also controls the operation of the models in real-time and automatically generates customised warning messages that can be printed, telephoned, emailed or disseminated on the Internet/Intranet. Figure 4 indicates the main screen view for the Andhra Pradesh FloodWatch system.

Set within a GIS environment, the system allows the user to access any other available data sets, permitting detailed GIS manipulations, e.g. the determination of population of predicted flood affected areas, or the indication of flooded transport links. This allows customised information to be provided to the users to assist them in their response to the predicted hazard.

4.5 Dissemination Media

The extra information provided by the flood forecasting system is only of use if it can be successfully passed on to the end user in an understandable form.

Warning dissemination to government agencies is through multiple pathways, and at two levels of information provision. Basic warning messages are sent to a list of recipients providing information on the size, extent and timing of the flooding. These messages are sent through a combination of telephone messages, faxes and emails. Where possible the messages will have a high degree of visual content (e.g. maps of inundated mandals/districts), as well as having lists of future water levels at forecast points. These messages will be supplemented by data stored on the state-wide Intranet, accessible to all government offices down to the local level. This database will be able to store more detailed information and graphical outputs generated using the state GIS database. Although the format of the main warning messages are currently being decided during the project period, the nature of the Intranet content can be continually developed by local operators for the needs of the user agencies.

Information will be passed to the public through a cascade system within the government agencies and through direct contact through the media, using local languages where applicable. Local responses to the hazard will be linked into already well-developed District Action Plans.

5 Implementation and future possibilities

The Andhra Pradesh flood forecasting system is a very ambitious project in terms of the extent of the area covered by the river models and in terms of the information that can be disseminated to user groups. Much of the information provided by the system will be new to the users, but it its important that the system is able to be used operationally from the outset. Fortunately, Andhra Pradesh has existing already in place systems to deal with flood warning, and though there is some inertia toward institutional change, this is balanced by a desire within the state to use new technologies. At the outset the new system will tap into the available knowledge. Warnings will reference current hazard action plans and will provide forecasts for the locations listed in the existing CWC system. However, warnings will also be provided at new locations to introduce users to new information within an understandable framework.

In due course, the system will provide more information to those involved in hazard response, to policy makers and to the public. It is clear that the full potential of the system will only be available once the system has bedded in, and users have had time to become practiced in its live operation. The current project is installing gauging for the first time in over 15 rivers and the models of these rivers will require further calibration as field data becomes available. The use of the Intranet and the ability of the system to provide water level forecasts at many more locations than are currently possible will enable groups at lower levels (e.g. local district, village) to consider their own response to forecasts and to determine their own specific warning thresholds. Much of the future development of the system will depend on how far the user groups wish to take the new technology.

References

[1] Kilsby, C.G., Ewen, J., Sloan, W.T., Burton,A., Fallows, C.S. and O'Connell, P.E. The UP modelling system for large-scale hydrology: simulation of the Arkansas-Red River basin. *Hydrology and Earth Systems Sciences*, **3(1)**, pp. 137-149, 1999.

[2] Ewen, J., Sloan, W.T., Kilsby, C.G., O'Connell, P.E. UP modelling system for large scale hydrology: deriving large-scale physically-based parameters for the Arkansas-Red River basin. *Hydrology and Earth Systems Sciences*, **3(1)**, pp. 125-136, 1999.

[3] Havnø, K, Madsen, M.N. and J. Dørge, J. MIKE11 - A Generalized River Modelling Package. *In Computer Models of Watershed Hydrology*, ed.V.J.Singh, Water Resources Publications, Colorado, USA, 1995.

[4] Rungø,.M, Refsgaard, J.C. and K. Havnø, K. The updating procedure in the MIKE11 modelling system for real-time forecasting. *Proceedings of the International symposium on Hydrological applications of Weather Radar*, Salford, UK, August 1989.

[5] Kjelds, J.T., van Kalken, T.M. and Syme, W.J. Integrating MIKE11 Flood Dynamics and ArcView GIS for Flood Defence and Floodplain Management. *RIVERTECH '96*, Chicago, September 22-26, 1996.

[6] Ammentorp, H.C., Jørgensen, G and van Kalken, T.M FloodWatch – A GIS based Decision Support System. *HYDROINFORMATICS '98*, Copenhagen, August 24-26, 1998.