FLOOD MODELLING IN BANGLADESH

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SYNOPSIS

A general mathematical modelling system for real-time flood forecasting and flood control planning is described. The system comprises a lumped conceptual rainfall-runoff model, a hydrodynamic model for river routing, reservoir and flood plain simulation, an updating procedure for real-time operation and a comprehensive data management system. The system is being used for real-time flood forecasting as well as for flood control modelling studies in a large number of projects. The present paper describes the model application for the Surface Water Simulation Modelling Programme in Bangladesh, where the system is beeing established for the entire country with a coarse discretization and for the South East Region of Bangladesh with a fine model discretization. The objectives of the modelling application in Bangladesh are to enable predictions of the effects of alternative river regulation structures in terms of changes in water levels, inundations, siltation and salinity.

1.0 INTRODUCTION

Occurrence of floods is a natural phenomenon all over the World. With the increase in population and human activity in the flood plains, flood damages represent an increasing hazard in many countries in spite of increasing investments in flood control measures. Consequently, it is of utmost importance to utilize the most efficient methods in flood forecasting, in assessment of reservoir operation schemes, and in evaluation of the effects of various flood control measures.

The recent years' progress within hydrology and river hydraulics has now made it feasible to perform flood forecasting and flood control planning by means of comprehensive mathematical models. The paper presents the NAM-S11 mathematical modelling system and its application to a flood control modelling project in Bangladesh.

2.0 THE MODELLING SYSTEM, NAM-S11

The NAM-S11 has been applied in a number of projects for flood control modelling and real-time forecasting. The NAM-S11 participated successfully in the WMO project on simulated real-time intercomparison of hydrological models (WMO, 1988). The NAM-S11 consists of the following four elements:

2.1 The Rainfall-Runoff Model, NAM

The NAM Model is a generally applicable soil moisture accounting model of the lumped, conceptual type. It has been successfully applied for rainfall-runoff prediction in more than 10 countries throughout the World. The NAM model was originally developed at the Technical University of Denmark (Nielsen and Hansen, 1973). In order to enable simulation of the shallow groundwater table in a flat alluvial plain as Bangladesh the groundwater part of the model has been modified slightly in its present version. The structure of the model is illustrated in Fig. 1.

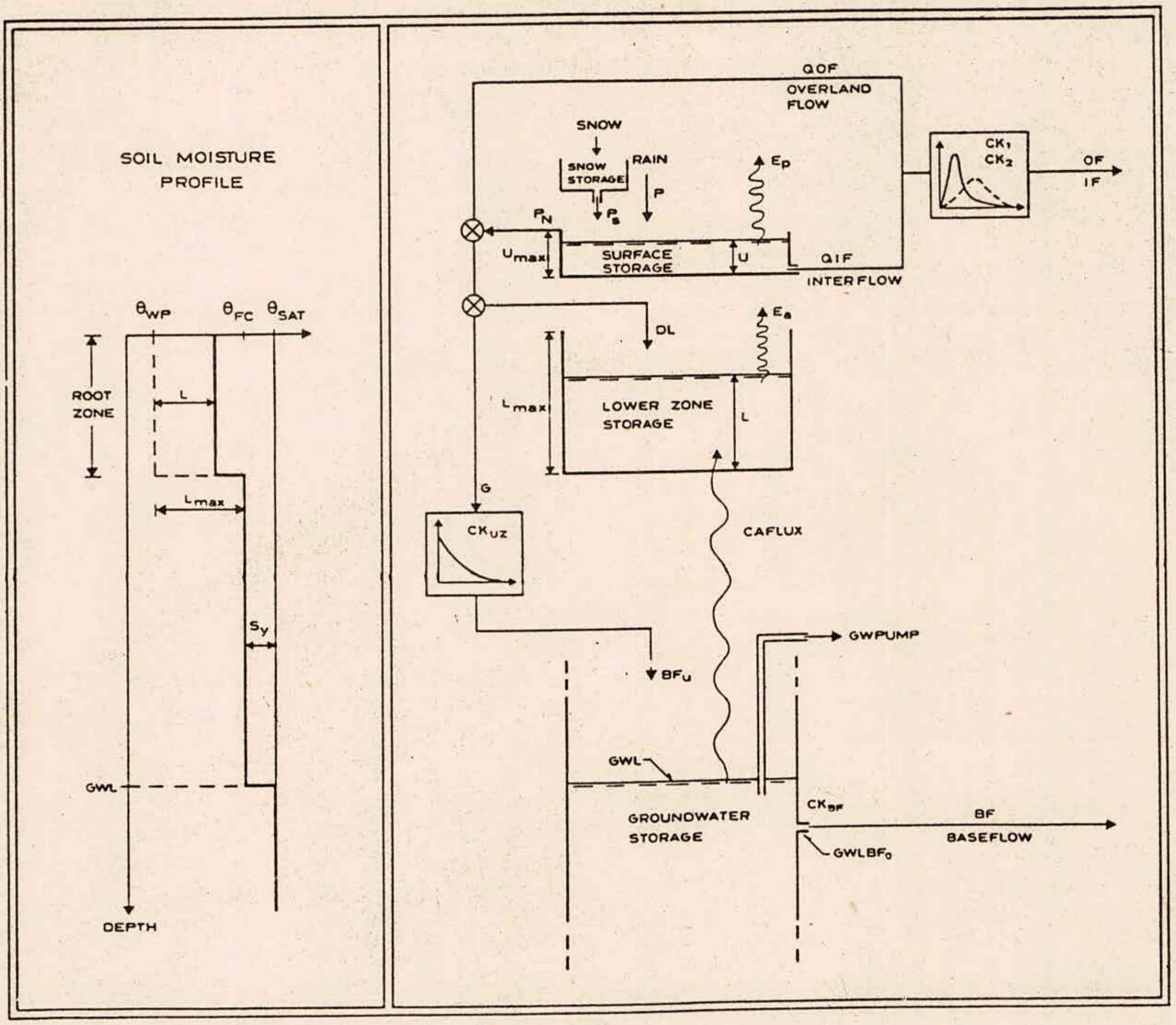

Fig. 1 Structure of the NAM Rainfall-Runoff Model.

2.2 The Hydrodynamic River Model, System 11

System 11 is a general mathematical modelling system for the simulation of flows and water levels in rivers, reservoirs, estuaries and canal systems.

In its most advanced form, System 11 is based upon numerical solution of the general one-dimensional 'Saint Venant' equations (conservation of mass and momentum)

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = q$$

$$\frac{\partial}{\partial x}\left(\alpha \frac{Q^2}{A}\right) + \frac{\partial Q}{\partial t} + gA\frac{\partial \xi}{\partial x} + \frac{gQ|Q|}{M^2 A R_*^{\frac{4}{3}}} = gAI_0$$

Kinematic wave (last two terms)

Diffusive wave (last three terms)

Dynamic wave (all terms)

where

A	- flow area (m^2)
M	- Manning's roughness coefficient ($m^{1/3}s^{-1}$)
g	- acceleration of gravity (ms^{-2})
ξ	- water depth (m)
Q	- discharge (m^3s^{-1})
R_*	- resistance radius (m)
α	- momentum distribution coefficient
I_0	- slope of river bed
x	- horizontal coordinate (m).
q	- lateral inflow

The equations are solved as time-centered, implicit difference equations in a grid, the prints of which can be set as required. For details regarding the numerical scheme, references are made to Abbott (1979) and Cunge et. al. (1980), while the model is described more thoroughly in DHI (1984).

System 11 has the options of using the diffusive or the kinematic wave approximation if the fully dynamic wave description is not required. System 11 allows for description of (pseudo) two-dimensional flows over wide flood plains.

A crucial feature in unsteady flow modelling in a delta area like Bangladesh is the storage on the flood plains. About 20 per cent of Bangladesh undergoes regular flooding increasing to more than 40 per cent during high flood events. Flooding is caused by a combination of spilling from the large rivers and water logging due to inadequate drainage conditions. Two different types of model schematizations are used depending on whether it is predominantly a spilling or a drainage area as illustrated in Fig. 2.

In spilling areas natural levees are formed along the rivers by sedimentation due to abrupt reduction in flow velocity of the spilling water, while these levees are not present in the drainage areas.

A special flood cell technique has been used to model the spilling areas as illustrated in Fig. 3.

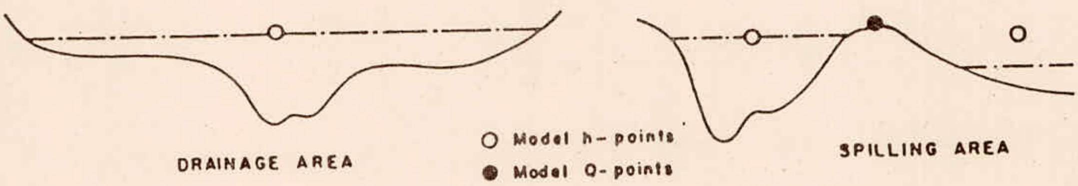

Fig. 2 The principal difference between drainage and spilling areas.

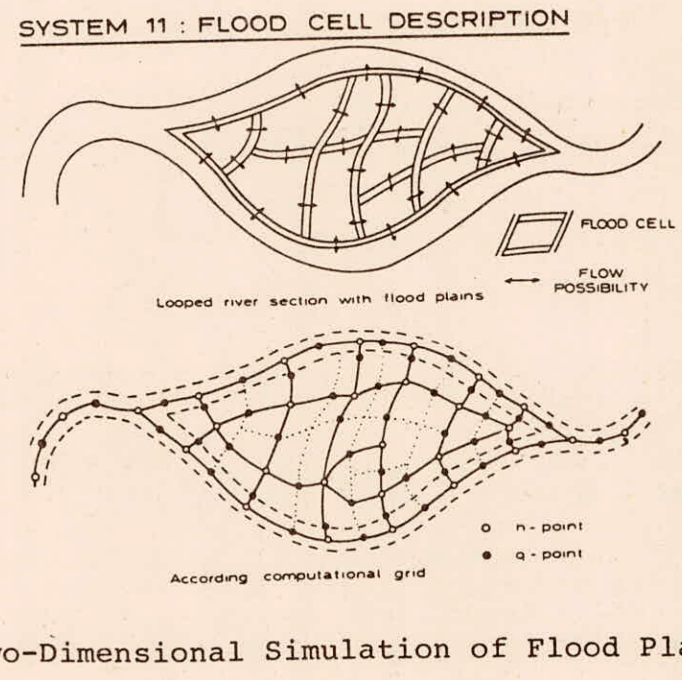

Fig. 3 Pseudo Two-Dimensional Simulation of Flood Plains.

2.3 The Updating Procedure for Real-Time Forecasting

A classical problem in real-time operation of hydrological models is that the simulated runoff generally deviates from the measured at the time of forecast. In order to obtain optimal benefit of the real-time runoff measurements in the forecasts, some sort of updating of the hydrological model is required before the forecast is made.

The updating procedure applied in the NAM-S11 is a fully computerized procedure based on a so-called 'error prediction' simulating the deviations between measured and simulated runoff through a linear autoregressive model. The simulated deviation ('error') is used to adjust the streamflows simulated by NAM prior to the routing by System 11. Thus, in situations with an initial discrepancy between simulated and recorded flows the deviations can be reduced (almost removed) by the updating procedure, hence obtaining a more accurate forecast from the more realistic initial conditions. Such a two-stage updating approach has also been successfully applied by e.g. Jamieson et al. (1971), Lundberg (1982) and Szöllözi-Nagy et al. (1983).

2.4 The Data Management Programmes

A comprehensive data management package is an integral element of the NAM/S11 modelling system. In a real-time forecast situation, a fast, flexible and reliable data manipulation capability is an absolute requirement, without which even the most advanced simulation model is of no use. The data management package consists of a number of programs for data entering, data checking, and data processing. A special, interactive menu-driven user interface makes the data management system very easy, quick and safe to use.

3.0 REAL-TIME FLOOD FORECASTING, INDIA

The application of the model for real-time flood forecasting in the Damodar catchment is described in Refsgaard et al. (1985) and Refsgaard and Ghanekar (1986).

4.0 FLOOD CONTROL PLANNING, BANGLADESH

The NAM-S11 model has been transferred to the Master Plan Organization under the Ministry of Irrigation, Water Development and Flood Control, Government of Bangladesh, for use as a general planning tool in connection with studies related to irrigation and flood control. The project, denoted the Surface Water Simulation Modelling Programme, is being financed by the UNDP and assisted by the World Bank. During this project, which started in 1986, the NAM-S11 is being established for the entire Bangladesh with a coarse model discretization and for the South East Region of Bangladesh with a fine model discretization. The objectives are to enable predictions of the effects of alternative river regulation structures in terms of changes in water levels, inundations, siltation and salinity.

Some of the specific modelling problems encountered under the Bangladesh hydrological conditions are described in the following (MPO, 1988).

4.1 Calibration of the NAM Rainfall-Runoff Model

For calibration of the rainfall-runoff model, a major problem is to identify suitable headwater basins applicable for calibration. The entire river and canal system in Bangladesh is interconnected in a network with complicated flow conditions, so that almost all identifiable sub-catchments flowwise are interconnected to neighbouring catchments, between which the water exchange is not known. The best way of calibration has thus been by matching simulated and recorded groundwater tables. An example is illustrated in Fig. 4 while the measured rainfall and simulated runoff is shown in Fig. 5 for the same area.

4.2 Flood Plain Resistance in the System 11 Hydrodynamic Model

During the 1986 monsoon it was observed that the flow through culverts in road and railway embankments was less than envisaged at the start of the project, and it was concluded that water level differences in flood plains mainly result from the flow resistance by the deepwater rice vegetation and only to a minor extent from road and railway obstructions.

Originally, it was envisaged that the Manning flow resistance coefficients on flood plains would be only 2-3 times larger than those applied to the rivers and khals. For a further analysis of this resistance consider the concept that the deepwater rice stems are neatly arranged in rows perpendicular to the flow direction as shown in Fig. 6.

The flow contraction during the passage of each row will lead to an energy head loss described by

$$\Delta H = \xi \frac{u^2}{2g}$$

where ξ is a head loss coefficient, u the flow velocity between the rice stems and g the acceleration due to gravity.

Assuming an average diameter D for the stems and a spacing at distances d the average flow velocity between the rows of rice stems can be described as

$$\bar{u} = \frac{d-D}{d} u$$

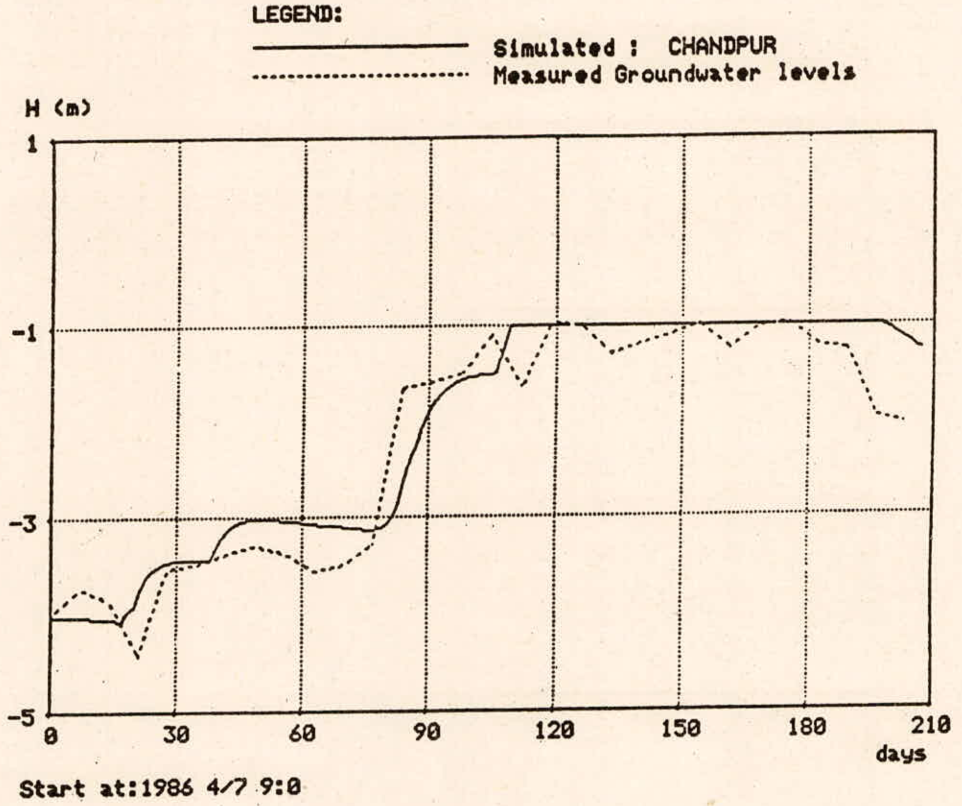

Fig. 4 Groundwater level variation, computed and measured at Chandpur.

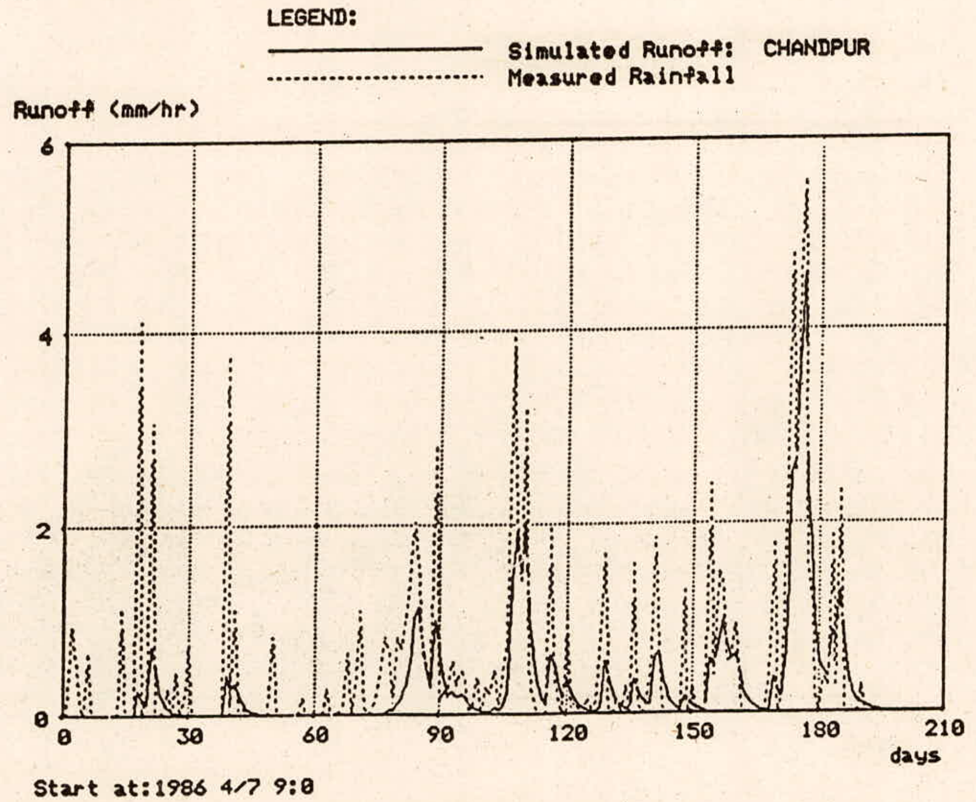

Fig. 5 Measured rainfall and simulated runoff at Chandpur.

Defining, furthermore, a ratio δ between diameter and distance, given as $\delta = D/d$ the head loss can be formulated

$$\Delta H = \xi \left[\frac{1}{1-\delta}\right]^2 \bar{u}^2$$

This head loss can be introduced in the Manning equation, which gives, under the assumption that also the rows are placed at distances d apart

$$\bar{u} = \frac{1}{n} h^{2/3} \left[\frac{\Delta H}{d}\right]^{1/2}$$

where h is the water depth.

In deepwater rice fields a common value for the stem density is 250 per m^2 and the stem diameter is typically 1 cm. For a head loss coefficient $\xi = 1.0$ the following values of Manning's n are found for various flood depths:

h (m)	n ($s/m^{1/3}$)	M ($m^{1/3}/s$)
1.0	1.06	0.94
2.0	1.68	0.60
3.0	2.20	0.45

These values are 40 to 100 times higher than the Manning coefficient typically found in channels.

Although it is extremely difficult to obtain reliable data on flood plain discharges, float observations through the culverts throughout the Southeast Region proved indicative of the conveyance of the flood plain. Based on a series of calibration runs it was concluded that the combination of a flood plain threshold depth of 0.25 m and a relative resistance coefficient of 100 yielded quite realistic results in the submodels located in Meghna flood plain.

4.3 Model Setup for the South-East Region

The model schematization for the South-East Region is shown in Fig. 7. The SE-Region is, like all other areas in Bangladesh, hydraulically very complex due to a dense channel network with altering flow direction during the monsoon, tidal influence, and extensive flooding as a result of both local rainfall and spilling from the main rivers. The total area of about 9000 km^2 was divided in 26 sub-catchments for the NAM rainfall-runoff modelling. For the System 11 modelling 1145 computational grid points were used.

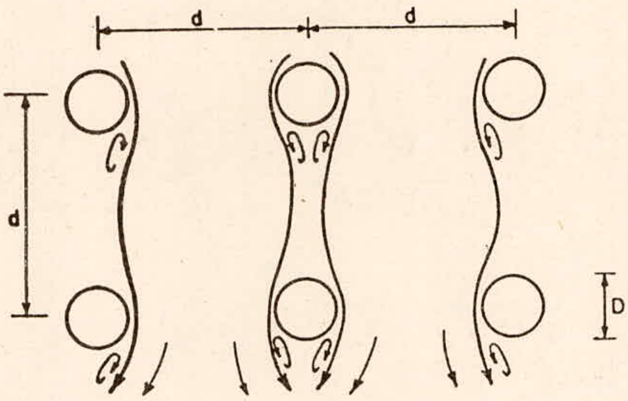

Fig. 6 Concept of a paddy field with stems placed in rows and lines.

Examples of comparisons of measured and computed water levels and discharges for the Dakatia River are shown in Fig. 8 and 9, respectively. The hydrograph simulation is noticed to be not as accurate as is often possible in headwater catchments with simpler flow regimes, and there are obviously still scopes for improvements. However, considering the uncertainty in data input, including very uncertain bench mark levels, the results have been concluded as satisfactory at this stage of the modelling project.

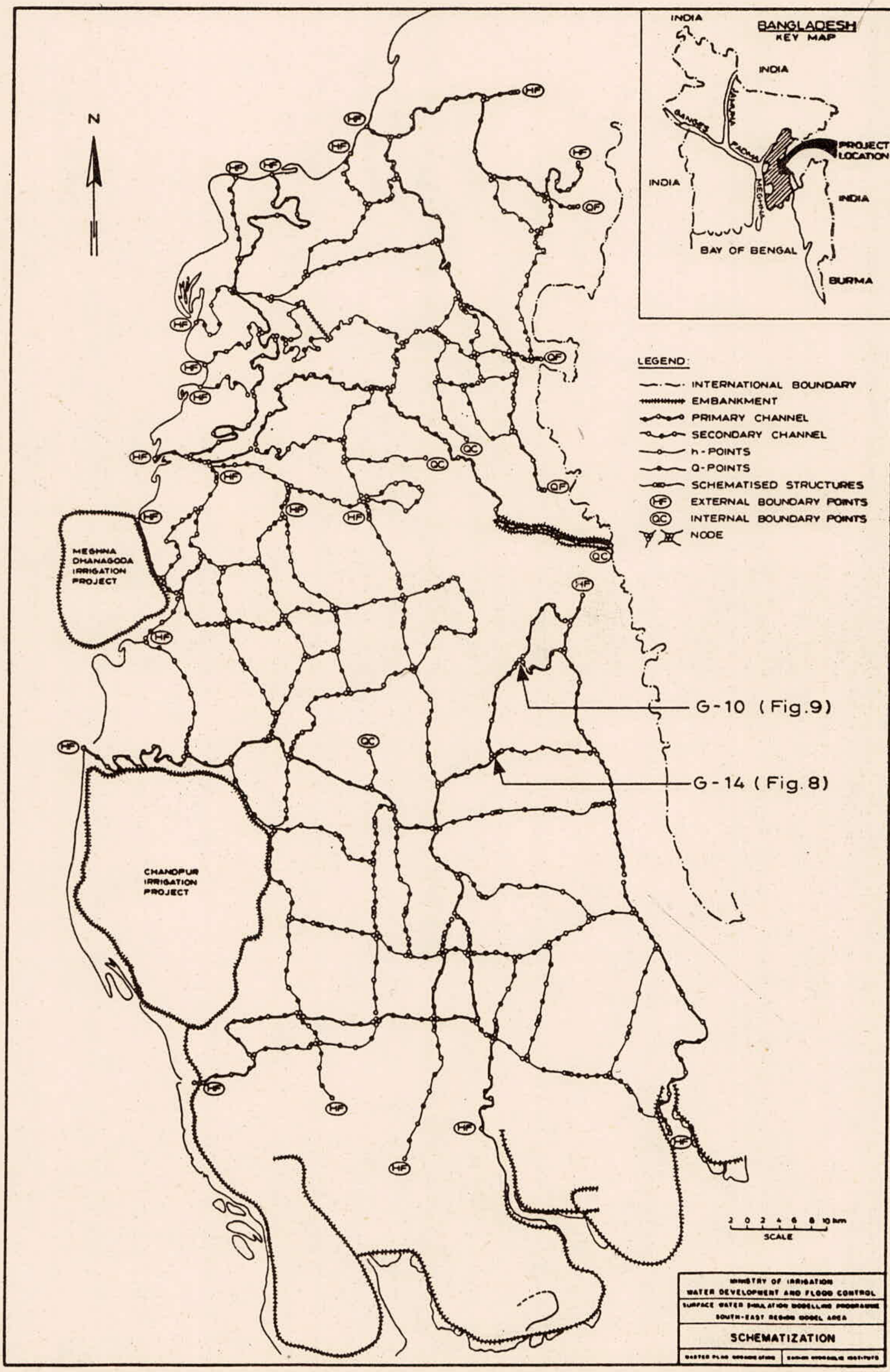

Fig. 7 Model schematization for the South East Region.

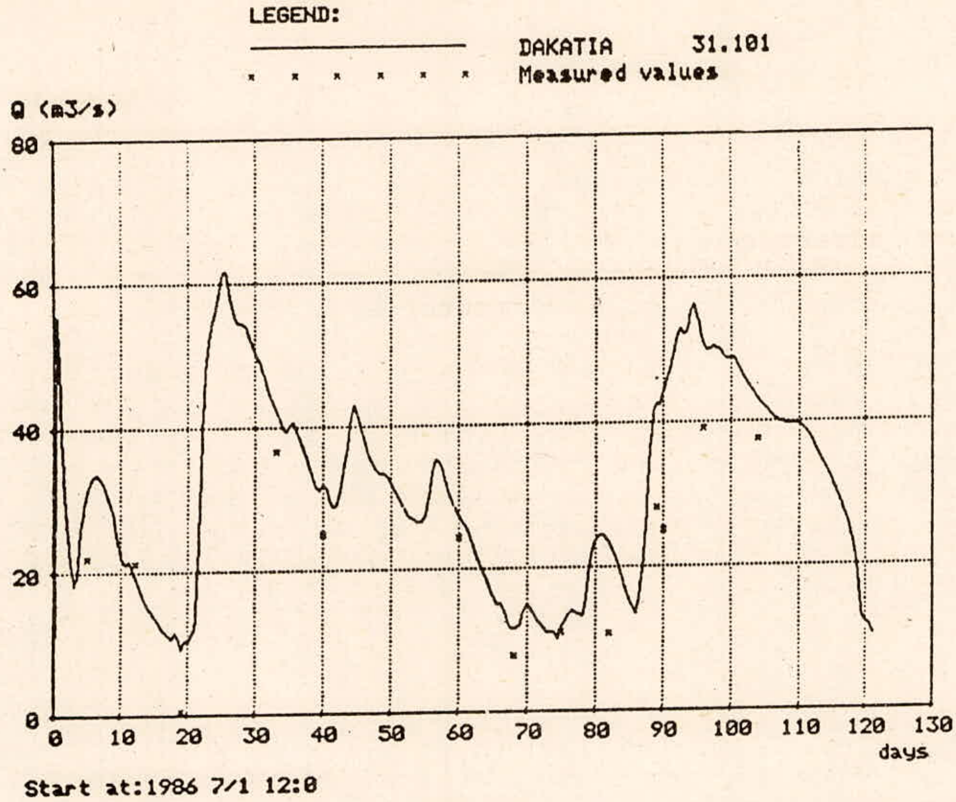

Fig. 8 Comparison of measured and computed discharges at Dakatia Rivers, Laksham, G-14.

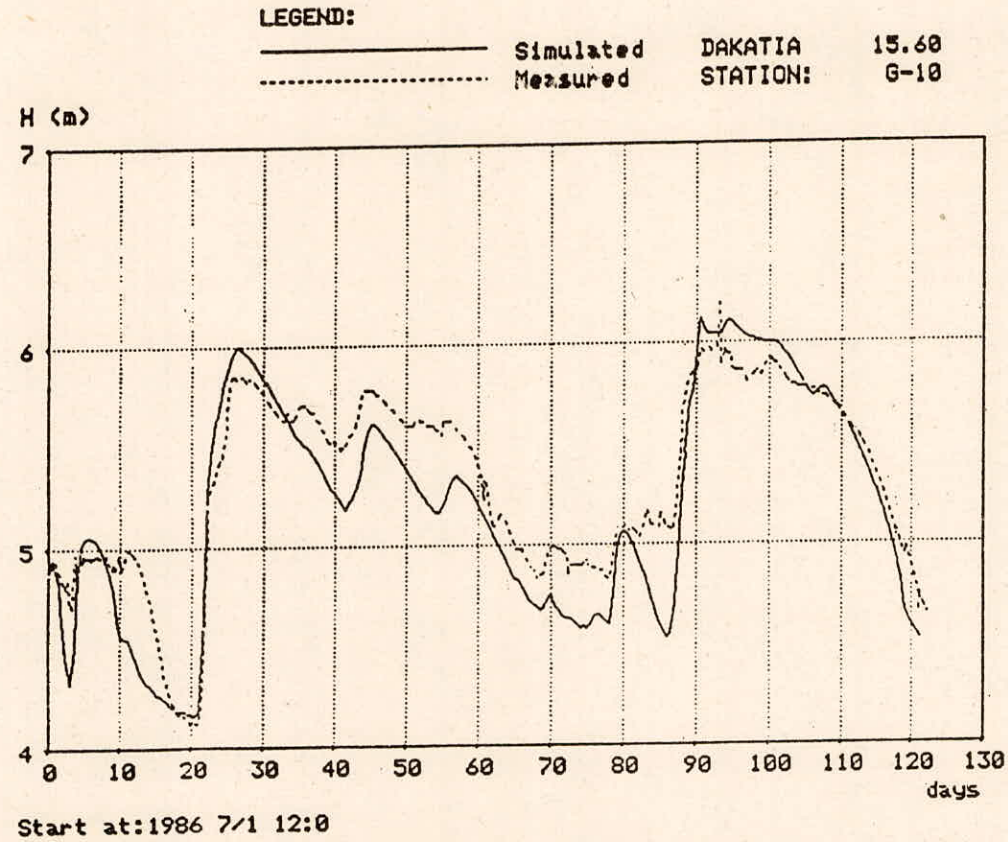

Fig. 9 Comparison of measured and computed water levels at Dakatia, G-10.

4.0 CONCLUSIONS

Floods are major hazards that should be tackled with the most efficient techniques available. The mathematical modelling system, NAM-S11, for real-time forecasting and flood control planning, is an advanced and very powerful tool The model has been applied to large and very complex catchments and flow regimes and has been transferred to several computer systems.

Generally, the best practical use of such modelling systems are often obtained if it is applied on a routine basis by the institution responsible for the water management in the actual country. In order to develop the necessary local expertise and experience a model transfer for this purpose has to be combined with a comprehensive training programme running over a couple of years, involving several local professionals, and covering the first examples of practical model application.

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