BANGLADESH FLOOD MANAGEMENT MODEL: TOWARDS A SPATIAL DECISION SUPPORT SYSTEM

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Abstract: In Bangladesh, floods and flood management are a part and parcel of life. For centuries, farmers have been managing and controlling the passage of flood waters for irrigation of rice and other crops. Major floods, however, can be devastating to human life, agriculture, industry, and infrastructure. Total flood prevention is unrealistic and unwise, but flood preparedness and embankment schemes are viable options. Schemes that reduce flood damage, optimise rural production, and improve living standards are necessary for Bangladesh's development.

Calibrated computational flood models provide reliable data on flood hydraulics and are useful tools for studying flood management problems. Geographically combining flood model data with agriculture, fisheries, and socioeconomic data opens new avenues for flood management. The Flood Management Model (FMM) interfaces a geographic information system (GIS) with computational flood models as the first step towards a spatial decision support system (SDSS). This paper presents a brief background to floods and flood modelling in Bangladesh, FMM GIS interface design, and initial developments.

1. INTRODUCTION

Severe floods have caused widespread damage to human life, crops, roads, railways, cities, and towns in Bangladesh. The 1987 and 1988 floods were two of the most severe floods in its history. The Government of Bangladesh, in cooperation with several bilateral and international agencies, has undertaken a major study, called the Flood Action Plan (FAP), mainly to identify and prepare structural and non-structural flood control and water management plans for the country.

In order to study and predict the hydraulic behaviour of the complex river systems of Bangladesh, mathematical modelling tools are being used. The mathematical models are based on one dimensional (1-D) hydraulic modelling of flows in rivers and channels and a quasi 2-D modelling of floodplain flows. The MIKE11 modelling system developed by the Danish Hydraulic Institute (DHI 1992) was selected as the standard system.

Hydraulic modelling tools have proved to be most useful in assisting the planning, design, and operation of flood control options and, hence, are being used as a basis for decision support tools to manage river hydraulic problems.

However, their limitation in terms of spatial display and analysis becomes more apparent when there is greater need for a spatial decision support system (SDSS) for floodplain management. Due to the flat topography and very complex river network of Bangladesh, SDSS tools will be vital for future planning. The present study aims to orient flood modelling activities towards the development of an integrated SDSS. The first step is the development of the Flood Management Model (FMM) which fully integrates the MIKE11 modelling system with the geographic information system, ARC/INFO.

2. FLOOD MODELLING IN BANGLADESH

Flood control and management of floodplains pose a continuing challenge to policy-makers and agencies. Computer-based modelling techniques have successfully improved management skills in the industrial sector, owing to the abundance of mathematical models. Large-scale (basin wide) hydraulic problems cannot be solved by a direct procedure or by physical modelling. However, the hydraulic behaviour of any complex system can be simulated by using a computational-mathematical model.

Background

The complex network of Bangladesh's rivers drains an area of about two million square kilometres, out of which only eight per cent lies within its territorial boundaries (Figure 1). This physical setting severely limits the degree of control and management that can be applied to the water inflow, both in the monsoon season and during the dry period.

Owing to its geographical location, Bangladesh is exposed to a wide range of extreme natural phenomena; it is located on a fragile portion of land in the world's largest delta, which is

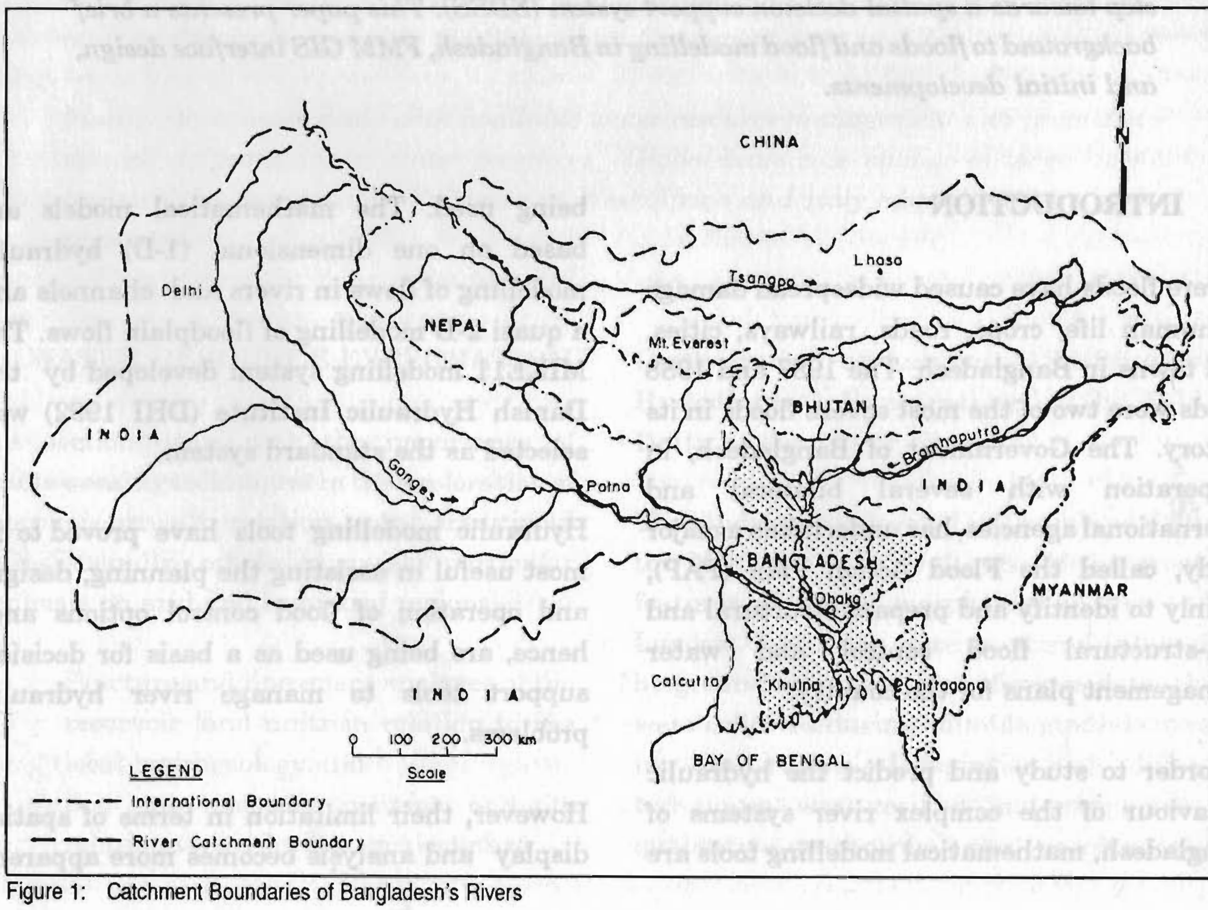


Figure 1: Catchment Boundaries of Bangladesh's Rivers

comprised of three of the world's most unstable rivers. The rivers flowing into Bangladesh drain some of the wettest catchment areas on earth, with average yearly rainfall as high as 11m. In addition, Bangladesh is one of the most fertile and densely populated regions in the world. Life in Bangladesh is pervasively influenced by the rivers.

The rivers also cause damage to a vast area during massive floods. Approximately 40 per cent of the country is subject to regular flooding, causing death as well as extensive damage. Apart from river floods, Bangladesh suffers severely from storm surges generated in the Bay of Bengal. The surge waves are induced by tropical cyclones and can reach heights of seven metres as they approach the coast. The consequences are often disastrous, including massive loss of human lives in the coastal regions.

The need for water control varies within the country. In rural areas, floods can have beneficial impacts when not too extreme, and the rural population has, over the centuries, developed mechanisms to cope with floods. In many such regions, floods have beneficial impacts, e.g., on rice and jute crops as well as on inland fisheries which require abundant water supply. Under these circumstances, control, rather than elimination, of floods is required.

Flood Action Plan (FAP) and Flood Management

The 1987 and 1988 floods focussed attention on the need to develop a long-term strategy to cope with complex flood impacts. The extent and complex nature of these floods underlined the fact that total elimination of flooding is neither feasible nor desirable from an agro-ecological perspective. However, the protection of people's lives and their places of habitation, including commercial and industrial centres, is absolutely essential. To meet these objectives, the Government prepared a National Flood Protection Programme and, with the assistance of UNDP specialists, carried out a Flood Policy Study (GOB and WB 1992).

FAP focussed on the identification, planning, and possible construction of technically, economically, environmentally, and socially acceptable projects. FAP followed a stage-wise approach so that regional and supporting studies could provide inputs for the planning and design of the main components of this and subsequent Action Plans. The feasibility of embankments on both sides of the major rivers, river training, channel improvement, and protective infrastructure for major towns and key installations were also considered. Improvement of flood forecasting and warning systems, study of watershed management, coastal afforestation, and sustainable development of agriculture and fisheries were other issues taken into account by FAP.

Flood Simulation Models

The Brahmaputra, Ganges, and Meghna form the backbone of the water system in Bangladesh, and, along with lesser rivers and '*khals*', they form a complex drainage pattern. The mathematical, computer-based model represents this complex drainage pattern through equations and data. The model can simulate the passage of floods through the rivers. They may then be altered to test the effect of design proposals, e.g., embankments and barrages. Such a powerful tool is vital for flood control and drainage planning in Bangladesh.

The Surface Water Modelling Programme (SWMP) was formulated because of the widespread recognition that the effective control and utilisation of water resources in Bangladesh is vital for economic and social development. In this respect, mathematical models of the complex river system are indispensable tools for an integrated approach to planning and design.

The main modelling tool used in Bangladesh at present is the MIKE11 package developed by the Danish Hydraulic Institute. MIKE11 is a professional engineering software platform for the simulation of flows, water quality, and sediment transport in estuaries, rivers, irrigation systems, channels, and other water bodies. It is a dynamic, user-friendly, one-dimensional modelling tool for detailed design, management, and operation of both simple and complex river and channel systems. Due to its flexibility and speed, MIKE11 provides a complete and effective design environment for engineering, water resources, water quality management, and planning applications. It owes its power to advanced programming techniques and mathematical model formulations that have been tested, developed, and proven in a number of applications since the 1960s.

The modelling strategy has been used to develop detailed regional models of the six separate regions of Bangladesh (Figure 2). The General Model (GM) covers the main rivers of almost the entire country and can thus provide hydraulic linkages among the regional models. It serves as a planning and design tool for large-scale flood control, drainage, and irrigation projects (WRPO 1992).

The regional models provide a finer resolution of the regional river and drainage network than the GM. They are used as planning and design tools, within the particular region, to describe the effects of embankments along minor rivers, polders, regulators, pump stations, dredging, etc; they may also be the basis for accurate flood forecasting on a regional scale, and, finally, they may provide boundary conditions for sub-regional models required for detailed analysis of specific projects.

3. GIS INTERFACE - STEP ONE TOWARDS A SPATIAL DECISION SUPPORT SYSTEM (SDSS)

The first stage in developing a Spatial Decision Support System (SDSS) consists of interfacing existing flood management practices with a spatial or geographic information system (GIS). The development of a flood management model (FMM) is included in the first stage.

After a three-month inception phase, FMM development started in March 1993 and is due for completion in September 1993. From October 1993 to October 1994, the FMM will be rigorously applied on national, regional, and sub-regional scales.

Building up local expertise and technology transfer are key project issues. Two Bengali professionals are working under the guidance of two expatriates. The FMM will be applied also by a group of local and expatriate engineers.

ARC/INFO (workstation) was selected as the GIS for interfacing with MIKE11. This decision has thus far proved to be sound, especially for prototyping methodologies. However, a less expensive and more portable platform (PC-based) is being investigated for field installation. Such a platform is unlikely to facilitate all FMM functions but would incorporate those necessary for on-site operation. The combination of ARC/INFO at workstations in a central office, with PC-based platforms in the field, is a possible long-term solution.

The FMM GIS interface is based on a modular design. The major modules are as follows.

System Process control, file management, and initialisation.

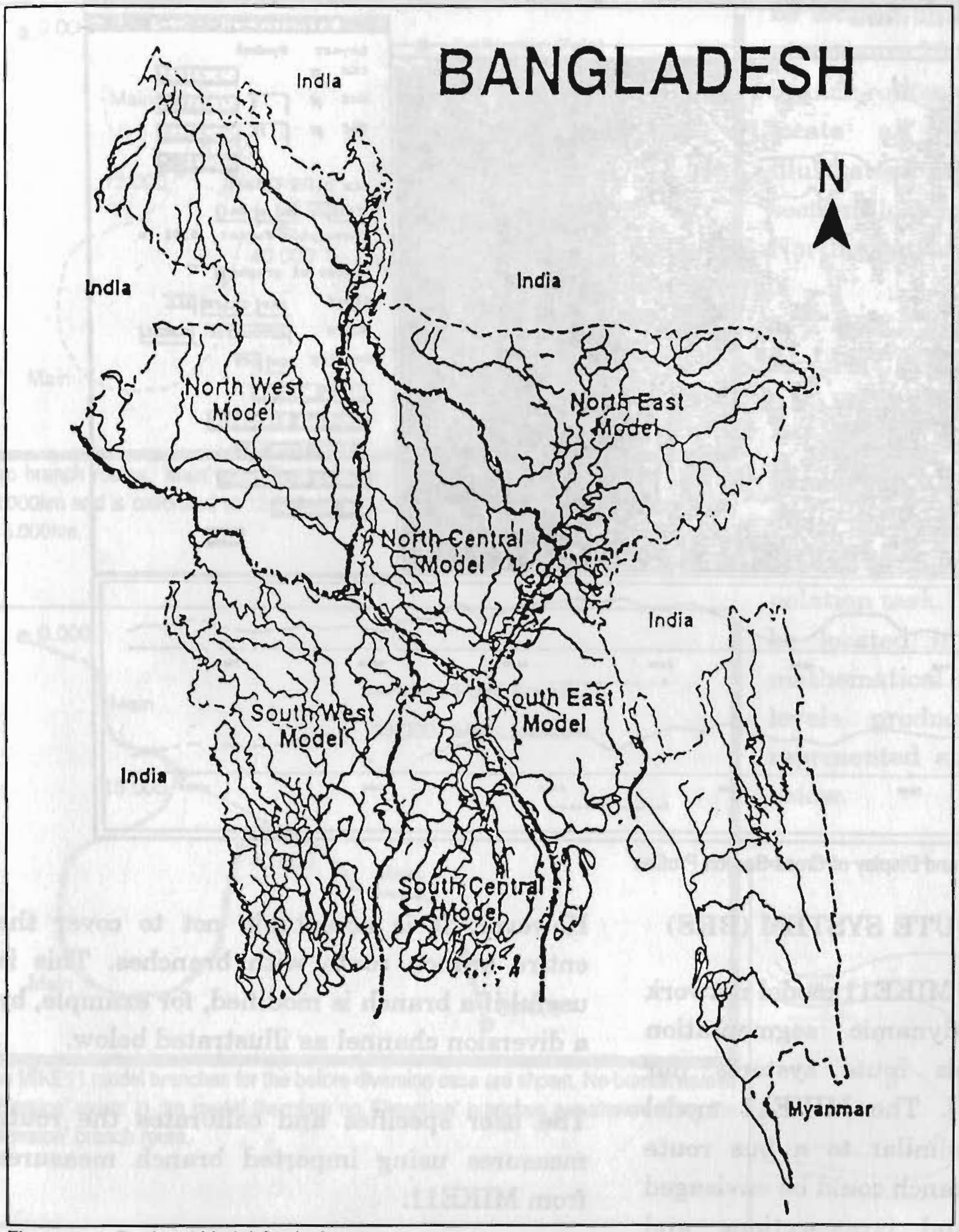


Figure 2: Regional Model Study Areas

Database Import of MIKE11 data into relational database. The database format facilitates easy data retrieval, comparison, and management.

Edit FMM coverage editors. Main coverage consists of the bench route system, storage cells, cross-section profile lines, water surface coverage for generating 3-D surfaces, catchment boundaries, and rain gauges.

Topographic Data Generates cross-section profiles and surface area elevation (AE) curves from a DTM and exports to a MIKE11 cross-section database. Profiles and AE curves can be interactively selected, displayed, and exported (Figure 3).

Surface Generation 3-D surface generation of water levels, water depths, flood duration, and water and ground levels combined, at instances in time or as a statistical measure (e.g., maximum; monthly average).

Analysis and Display Data viewing and impact assessment analysis. The viewing environment displays: flood inundation, depth and duration maps, water level and cross-section profiles, water level and discharge time-series, and 3-D views.

Impact assessments are aided by comparing MIKE11 simulations, using time-series graphs, and by mapping water level differences. Mapping agriculture and fisheries' flood damage estimates based on water level changes and flood duration will be prototyped.

Two important FMM developments, the branch route system and generating a 3-D water surface from the MIKE11 model output, are discussed below.

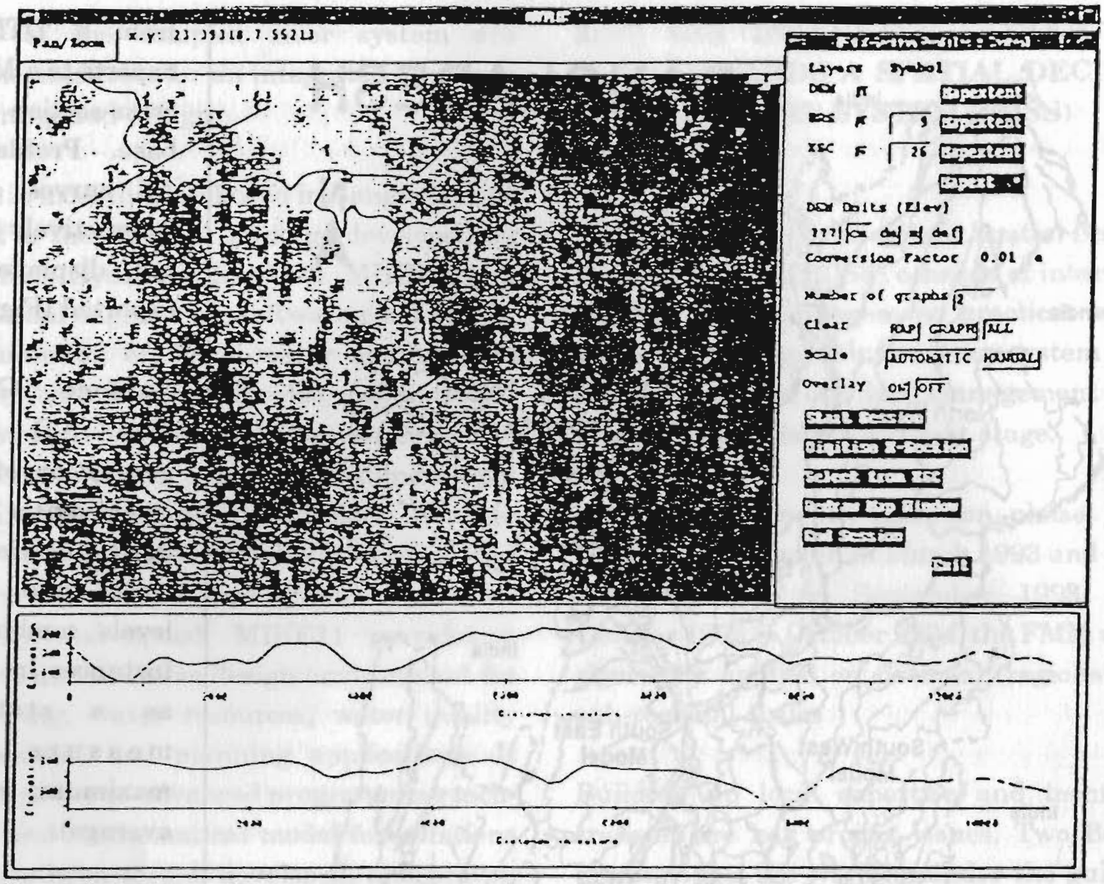


Figure 3: Extraction and Display of Cross-Section Profiles

4. BRANCH ROUTE SYSTEM (BRS)

GIS representation of MIKE11 model network uses ARC/INFO's dynamic segmentation facility which models route systems (for example, bus routes). The MIKE11 model network concept is similar to a bus route system. A network branch could be envisaged as a bus route and cross-sections and structures as bus stops.

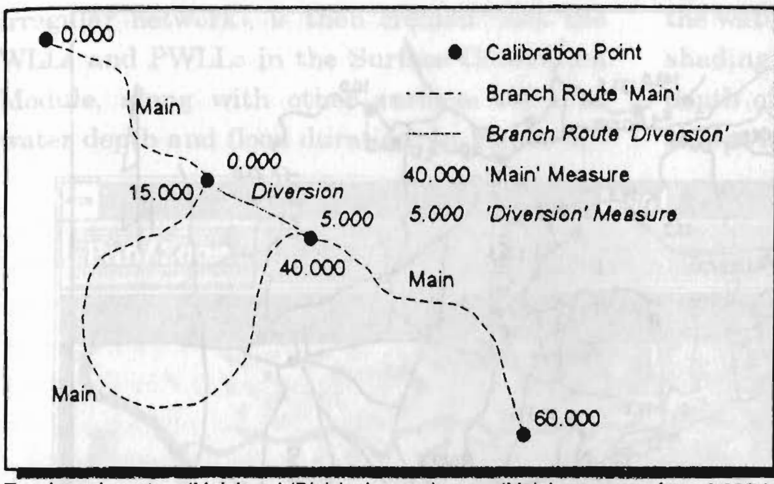
The branch route system (BRS) is a single route system, representing all MIKE11 models for a study area. Its branch routes locate the models' branches using a measuring system. For example, a branch route named 'MAIN' is measured starting from 0.000 and ending at 60.000km. A MIKE 11 model branch, 'MAIN', from 0.000 to 35.000km, will be located along branch route 'MAIN' according to its measurements.

Branches from a model must not overlap or extend outside the branch route end measures. However, it is acceptable not to cover the entire branch route with branches. This is useful if a branch is modified, for example, by a diversion channel as illustrated below.

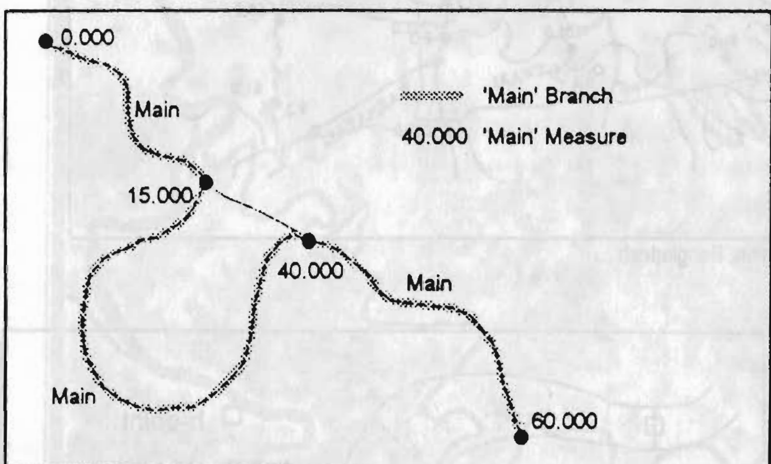
The user specifies and calibrates the route measures using imported branch measures from MIKE11.

Initially the end measures of a route are specified and intermediate measures are linearly interpolated. Usually linear interpolation is inaccurate and calibration of the measures is needed. Useful calibration points are branch route junctions (nodes). The branch routes' measures at the node are specified and the routes are remeasured (calibrated). A linear interpolation is used between calibration points.

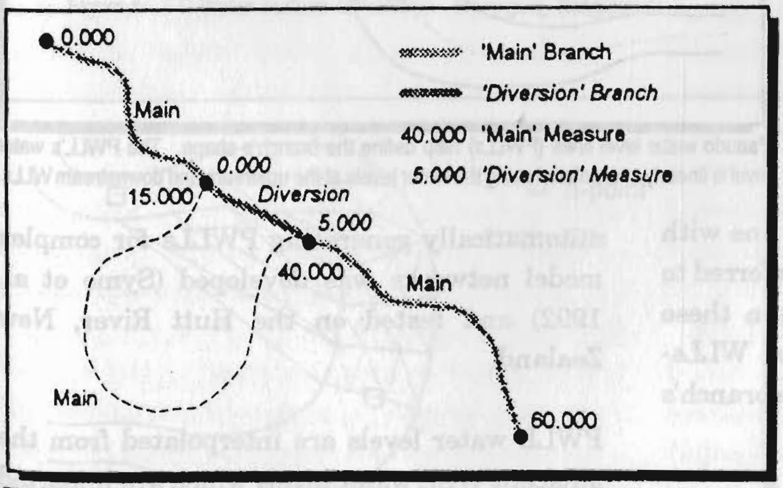
Branch route measures control the location of features such as cross-sections and structures. For example, a structure at 'MAIN' 20.000 will



Two branch routes, 'Main' and 'Division', are shown. 'Main' measures from 0.000 to 60.000km and is calibrated at 15.000 and 40.000km. 'Diversion' measures from 0.000 to 5.000km.



The MIKE11 model branches for the before diversion case are shown. No branch named 'Diversion' exists in the model therefore no 'Diversion' branches are shown along the 'Diversion' branch route.

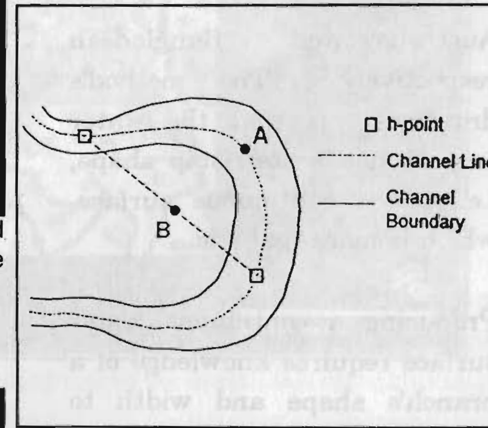


The MIKE11 model branches for the after diversion case are shown. The branches on 'Main' are 0.000 to 15.000km and 40.000 to 60.000km. As the branch 15.000 to 40.000km is not in the model, this section of branch route 'Main' is ignored.

be located on branch route 'MAIN' at measure 20.000. Re-measuring of branch routes will automatically re-locate all features. Figure 4 illustrates branch routes and cross-section locations for part of the North Central Region.

5. CREATING WATER SURFACES FROM A 1-D NETWORK MODEL

Creating a 3-D water surface from a 1-D network model, such as MIKE11, is not a simple interpolation task. The water levels can be located in 3-D space, but a mathematical interpolation between levels produces a poor, badly represented surface as illustrated below.



Water levels are calculated at two h-points around a meander. The water level location halfway between them (Point A) is best estimated by measuring along a "centreline" (channel line), but without any knowledge of the meander shape (channel boundary) the best estimate, which is a poor one, would be at Pont B.

The simplest approach assumes that each h-point represents a level pool. A polygon is digitised for each h-point and assigned a water level. Syme and McColm (1990) and FAP19 (1993) have applied this method successfully in

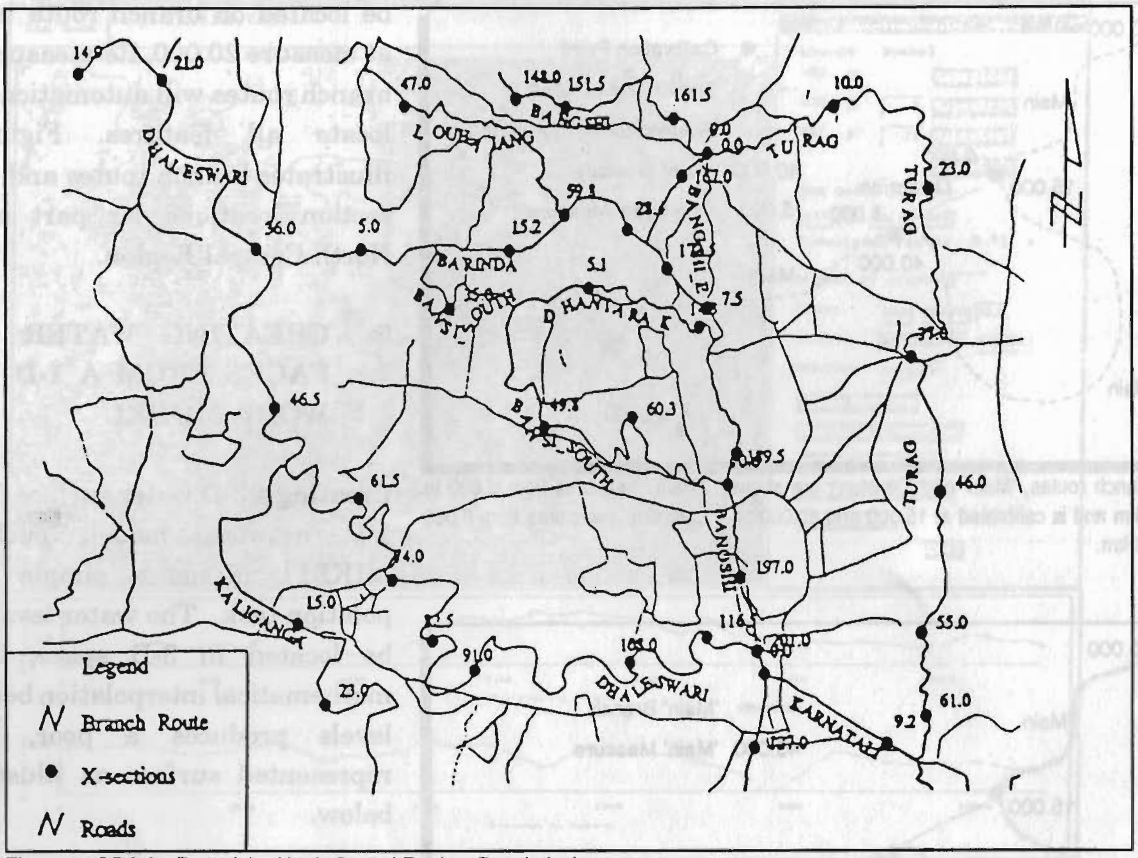
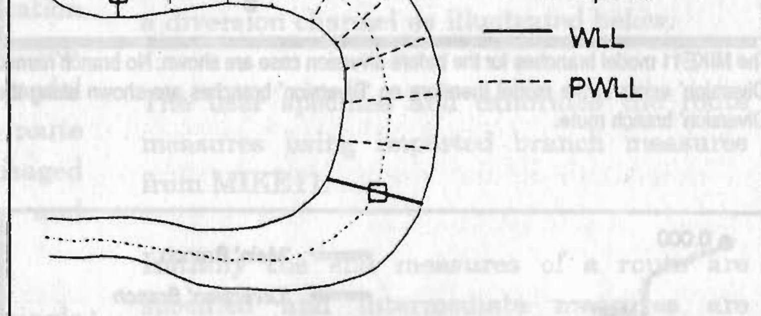


Figure 4: BRS for Part of the North Central Region, Bangladesh

Australia and Bangladesh respectively. The method's drawback is that the water surface has a stair-step shape, i.e., not a continuous surface, which is more realistic.



Pseudo water level lines (PWLLs) help define the branch's shape. The PWLL's water level is linearly interpolated using the water levels at the upstream and downstream WLLs.

Producing a continuous water surface requires knowledge of a branch's shape and width to create a water surface. Applying the 1-D assumption that the water level is horizontal across a cross-section, each h-point (water level calculation point) is assigned a line with a horizontal water level. This line is referred to as a water level line (WLL). Between these lines, intermediate lines (pseudo WLLs-PWLLs) are created to help define the branch's shape.

Using ARC/INFO edit and dynamic segmentation functions, a robust methodology for automatically generating PWLLs for complex model networks was developed (Syme et al. 1992) and tested on the Hutt River, New Zealand.

PWLL water levels are interpolated from the adjacent WLL water levels which are imported from a MIKE11 simulation. A 3-D continuous water surface, modelled as a TIN (triangular irregular network), is then created from the WLLs and PWLLs in the Surface Generation Module, along with other surfaces such as water depth and flood duration. In Figure 5, the water depth is shaded grey (the lighter the shading the shallower the depth). The water depth of the Manikgunj area, Bangladesh, is shown in the figure.

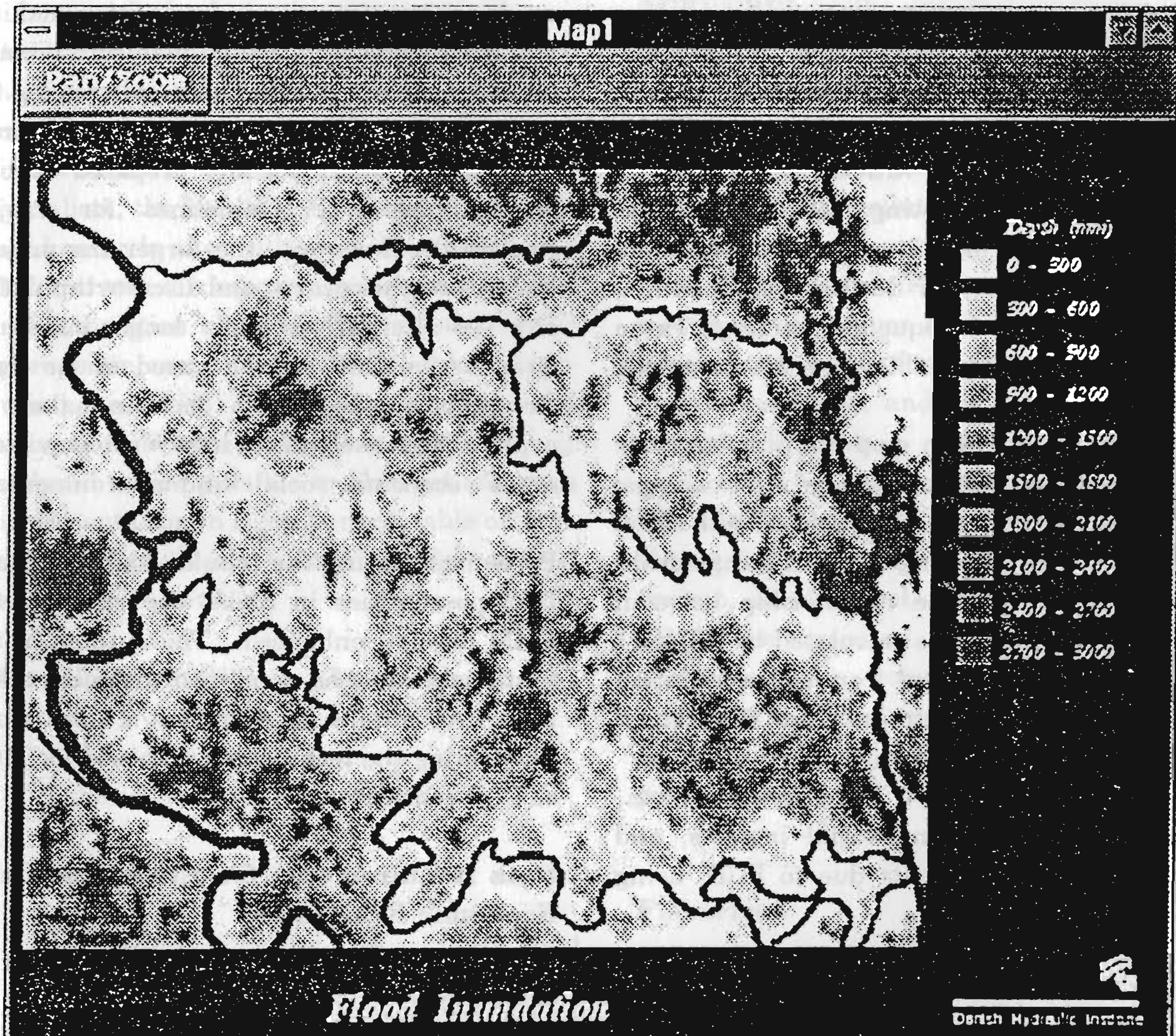
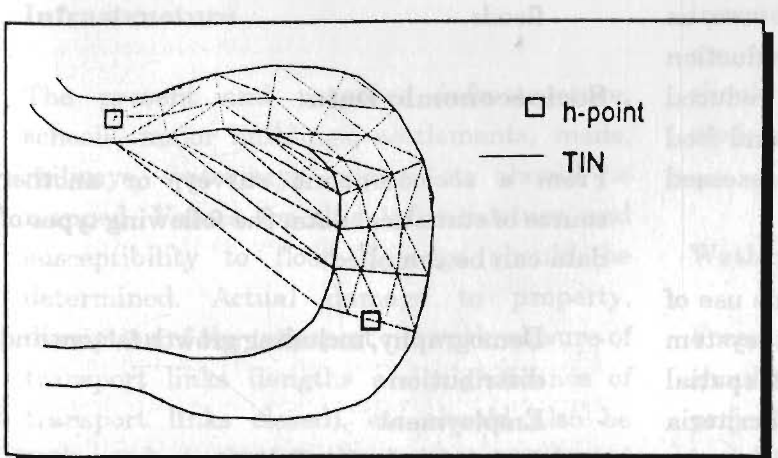


Figure 5: 3-D Water Surface Generation - Manikgunj, Bangladesh



A TIN is created from the WILLs and PWLLs to give a continuous 3-D water surface based on MIKE11 water levels.

6. APPLICATION OF FLOOD PLAIN MAPPING FROM MIKE11-GIS

The guidelines for project appraisal, drawn up by the Flood Action Plan (FAP), require, amongst other considerations, that environmental and social impacts of schemes are considered within the framework of a Multi-criteria Assessment

(MCA). The floodplain mapping output by MIKE11 GIS provides valuable information in digital and GIS formats which can be used to carry out such studies, followed by an MCA.

The first phase of carrying out an economic assessment, an Environmental Impact Assessment (EIA), and social impact assessment, combined with the outline design and cost of implementing Flood Control and Drainage (FCD) measures, would involve the use of GIS outputs for flooded area duration, depth, extent, and frequency mapping. These have a number of possible uses, which include

- combination with crop planting/land use data to assess flood damage relationships;
- combination and comparison with flood phase soil mapping (used in Bangladesh) to determine the relationship between flood depths/areas calculated by MIKE11 and those obtained from soil association maps, taking into account the return period of the flood; and
- assessment of indirect costs, environmental and social impacts, and incremental benefits due to FCD, using GIS.

These are important areas of interest since many FAP studies have used the incremental benefits, obtained by changing the distribution of the flood phase areas by FCD measures, as a way of estimating the damage reduction caused by flooding. Benefits from reduced flood damage to property, livestock and food stores, transport, and fisheries are assessed independently.

The second phase of demonstrating the use of the FMM, spatial decision support system (SDSS) would be the integration of spatial outputs from MIKE11 GIS into a Multi-criteria Assessment-oriented DSS. Typically, the problem for any given proposed scheme, or regional floodplain management system, is to allocate investment resources to a project or collection of projects (measure) in an acceptable way. Ordinary economic analysis is used to determine criteria for decision-making, but the FAP is required to take into account multiple criteria, which means comparing the separable estimated impacts of a set of discrete alternatives in a specially prepared tabular format (see FAP Guidelines for Project Appraisal). However, the larger the project, the greater the options, and discrete tabulation of a few alternatives is no longer viable. A quantitative DSS can be used under these circumstances to enable decision-makers to explore the consequences in several important areas - economic, social, and environmental.

By demonstrating the tabular and integrated DSS possibilities in MCA, the value of the FMM can be enhanced. The outputs of the first phase could be combined with data taken from FAP studies to carry out a pilot study illustrating the techniques proposed for MCA of FCD schemes.

Data Requirements for EIA, Social, and Economic Evaluation

Flood Data

- Preparation of flood depth, area, and duration maps for a series of critical floods.

Socioeconomic Data

From a socioeconomic survey, or another source of statistical data, the following types of data can be compiled.

- Demography, including growth factors and distribution
- Employment
- Social status (landholdings, etc)
- Education

These data will be mapped as relevant GIS themes.

Environmental Impact Assessment

The environmentally significant impacts and their possible scope should be identified and surveys carried out to establish the 'without-project scenario'. In consultation with subject specialists, the probable kinds of impacts that could occur in the 'with-project scenario' (and alternatives), during construction and over the project duration, should be determined. Where appropriate maps of the 'with and without-project scenarios' should be prepared for evaluation. The maps should be quantitatively analysed where possible to abstract statistics for presentation in a comparison table of 'with and without-project scenarios', for several project alternatives.

The following sectors may be considered:

- fisheries (capture, culture);
- ecology;
- pollution, surface water, groundwater; and
- forestry, fuelwood.

Infrastructure

The present and proposed infrastructure, schools, major buildings, settlements, roads, railways, waterways, power, etc should be mapped. Values for this infrastructure and susceptibility to flood damage should be determined. Actual damage to property, disruption of the transport network, closure of transport links (lengths and significance of transport links closed), etc should also be estimated, both for the 'with-project' and 'without-project' scenarios.

Agriculture and Livestock

GIS maps showing the Water Master Planning (MPO)/SRDI soil association maps (soil association and flood phase) should be prepared, as well as cropping pattern maps (with and without-project). Unit inputs and outputs to cropping patterns, including factors such as labour, pollution impacts on surface and groundwater, costs and returns, yields, etc should be assessed. They can be used in GIS modelling techniques to estimate impacts by location and district for the 'with' and 'without-project' scenarios, and as inputs to decision support and MCA.

The present population and animal holdings should be surveyed. Values as sources of protein, labour, fuel, energy, and fertiliser, should be assessed. Food, fodder, grazing, and labour (i.e., computation of unit inputs and outputs) requirements should be noted. Animal holdings should be mapped on to project areas.

Fisheries

Fisheries, by location and type (capture, culture), should be estimated using surveys where appropriate, including impacts on fish breeding. Inputs and outputs, existing capital investment, jobs, food and cash income sources, etc, should be assessed. These resources should be mapped for assessment, using GIS modelling.

Wetlands, Habitats, Forestry

Forest tracts, wetlands, and other habitats should be mapped for the 'with'- and 'without-project' scenarios. The value of these resources, social forestry as energy, construction materials, etc should be assessed.

Mapping Sources

Soil association maps are in digital form in FAP 19. Other data may be collected from project reports and studies but may need to be digitised into map form, or linked to spatial mapping units (*mauzas*). It will not be possible to carry out surveys. Remotely-sensed data could be used.

7. CONCLUSIONS

A Flood Management Model, primarily based on an interface between the MIKE11 river modelling software and the ARC/INFO GIS, has been developed as a management tool for Bangladesh's rivers and floodplains. The interface will be used to analyse and display MIKE11 flood data in combination with spatial data on agriculture, fisheries, and socioeconomics.

The MIKE11 GIS interface has already been used to produce flood maps for subsequent impact analysis.

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