Regional Cooperation for

Flood Disaster Mitigation

in the Hindu Kush-Himalayan Region
Technical Papers

Kathmandu, Nepal, March 2003

ICIMOD Partnership Platforms 3/03 (Supp.)

Supplement

about the organisations

ICIMOD

The **International Centre for Integrated Mountain Development** (ICIMOD) is an independent 'Mountain Learning and Knowledge Centre' serving the eight countries of the Hindu Kush-Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan – and the global mountain community. Founded in 1983, ICIMOD is based in Kathmandu, Nepal, and brings together a partnership of regional member countries, partner institutions, and donors with a commitment for development action to secure the future of the Hindu Kush-Himalayas. The primary objective of the Centre is to promote the development of economically and environmentally sound mountain ecosystems and to improve the living standards of mountain populations.

WMO

The **World Meteorological Organization** (WMO) is the specialised agency of the United Nations system responsible for monitoring and forecasting the state of the world's atmosphere, climate and water resources. In the field of freshwater, its stated aim is "to apply hydrology to meet the needs for sustainable development and use of water and related resources; to the mitigation of water-related disasters; to ensure effective environmental management at national and international levels."

The Organization has its origins in the 1860s and operates on the basis of cooperative action by the National Meteorological and Hydrological Services of its Member countries and territories, which numbered 186 in June 2003.

While WMO's principal contacts are with the National Meteorological and Hydrological Services of countries, its collaborative work embraces joint projects with many other intergovernmental and non-governmental organisations and regional bodies. It receives support from a wide range of donor institutions and countries. This also involves participation in many high-level intergovernmental meetings and programmes. Whether at the local level or intergovernmental level, WMO's aim is to help countries develop the knowledge base that they need to manage their water resources and combat the threats of flood and drought.

USDS/REOSA

The **Department of State's Regional Environment Office for South Asia** supports transboundary cooperation in dealing with environmental, other scientific and health challenges among the countries of South Asia. Water issues are a major focus of its efforts. The office is based in the U.S. Embassy in Kathmandu.

USAID/OFDA

The **United States Agency for International Development's (USAID) office of U.S. Foreign Disaster Assistance (USAID/OFDA)** is responsible for providing international disaster assistance and coordinating the U.S. government (USG) response to declared disasters in foreign countries. USAID/OFDA's Mission is to minimize and where possible, prevent loss of life, human suffering, and damage to economic assets in disaster affected countries. The sub-regional office of USAID/OFDA is based in Kathmandu.

REGIONAL COOPERATION FOR
Flood Disaster Mitigation
IN THE HINDU KUSH-HIMALAYAN REGION
Technical Papers

Report of the 2nd High Level Consultative Meeting on
Establishment of a Regional Flood Information System
Kathmandu, Nepal, 10-13 March 2003

Editor
Mandira Shrestha

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Foreword*

The mountains of the Hindu Kush-Himalayas (HKH) are some of the largest storehouses of freshwater in the lower latitudes in the world and the source of many mighty rivers including the Indus, Ganges, Brahmaputra, Meghna, and Mekong. These rivers provide water for drinking and food production, and contain the potential for generating the hydropower that could improve livelihoods and support economic development throughout the region. Equally, these same rivers, untamed and uncontrolled, yearly cause such extensive floods as to threaten the lives of millions of people downstream and cause untold damage to property.

Too often, the people in the path of these floods have no warning, and in many cases it is the poorest of the poor, those with the least resources for recovery, who are exposed most. Controlling these floods is a daunting, and perhaps impossible, task – but much can be done to reduce the damage they cause by providing sufficient warning of the impending disaster for threatened populations to protect their property or move to safer areas. By their nature, floods are a regional issue. Most of the rivers that rise in the HKH region flow through more than one country. The countries of the region are drawn together through common river basins, and must come together to link upstream events with downstream consequences, and downstream policies with upstream consequences. To forecast floods with any degree of accuracy, timely and reliable hydrometeorological information is needed from the whole of each river basin, thus information must be exchanged across national borders, and all countries need a sufficient and compatible capacity in data collection, transmission, and flood forecasting.

The International Centre for Integrated Development (ICIMOD) has been concerned with issues of water management and disaster prevention in the HKH region for some twenty years, and has supported regional efforts to increase scientific and technical collaboration on water issues – from watershed management and micro-water harvesting to regional data sharing through the HKH-FRIEND project supported by UNESCO. At the global level, the World Meteorological Organization (WMO) has been promoting regional cooperation in hydrometeorological observation for a number of years through its World Hydrological Cycle Observation System (WHYCOS), which is increasingly being used as a framework for collaboration and development of resources.

In 2001, ICIMOD joined with WMO, with the support of ICIMOD's regional member countries, to initiate a project designed to address flood data and information exchange in the HKH region and its downstream plains areas, in particular the establishment of a regional flood information system. ICIMOD and WMO are ideally situated to help forge the active partnership between countries in the region that will be pivotal in the project's success, as all the HKH countries are members of both organisations.

* Foreword to the main volume

The project has been substantially supported by the U.S. Department of State Regional Environment Office for South Asia (USDS/REOSA) and the U.S. Agency for International Development Office of Foreign Disaster Assistance (USAID/OFDA), with further support from the Department of Hydrology and Meteorology of His Majesty's Government of Nepal and a small contribution from the Danish International Development Agency (DANIDA). The overarching goal of the project is to reduce the flood vulnerability of the HKH region and minimise the loss of lives and property, focusing in the first instance on the Ganges-Brahmaputra-Meghna and Indus river basins. The two major challenges are collection of the necessary high quality hydrometeorological data in all parts of the major river basins, including in remote areas with limited infrastructure, and facilitating a system for exchange of this data in real-time between the countries through which each river runs which builds on the bilateral arrangements already established in some cases.

The project has proceeded through a series of meetings: a 1st High Level Consultative Meeting held in May 2001, during which a framework was developed for a regional flood information system based on the proven concept of the WHYCOS, now called HKH-HYCOS; a Consultative Panel Meeting held in May 2002, at which a concept note was drafted and short, medium, and long term action plans outlined; and the 2nd High Level Consultative Meeting held in March 2003 which is the subject of this report. HKH-HYCOS has been formalised as a joint project of WMO and ICIMOD, as facilitating organisations between the regional member countries, through a Memorandum of Understanding between the two organisations.

This publication summarises the development of the project to date and provides a detailed report of the 2nd High Level Consultative Meeting held in March 2003, including summaries of the technical papers, and an outline of future plans. The full text of the technical papers is being published in a supplementary volume*. The meeting provided a valuable opportunity for high-level government representatives, directors of national hydrological and meteorological services, technical experts from the region and from the United States United States Geological Survey (USGS) and National Oceanic and Atmospheric Administration (NOAA), and representatives of international organisations, to share information and discuss organisational and technical approaches to flood forecasting and mitigation of flood-related damage. The participants discussed the draft project document and agreed on the action plan for the next stage. In the ongoing process, national consultations are now being held to identify the specific needs and priorities of each country for the establishment of the regional flood information system.

The people of the region have learned to seek in the Himalayas both spiritual solace and the means to improve the livelihoods of the people, both upstream and downstream. We hope that the optimism and cooperative spirit displayed at the meeting will imbue the commitment to follow through in each country and that we will be successful in establishing a regional flood information system, building on bilateral arrangements, that will provide the basis for ensuring physical security, saving lives, and reducing economic loss, while safeguarding the environment. ICIMOD is proud to be a part of this valuable initiative, and hopes that this publication will help to stimulate interest in and support for the project.

Dr. J. Gabriel Campbell
Director General
ICIMOD

* This volume

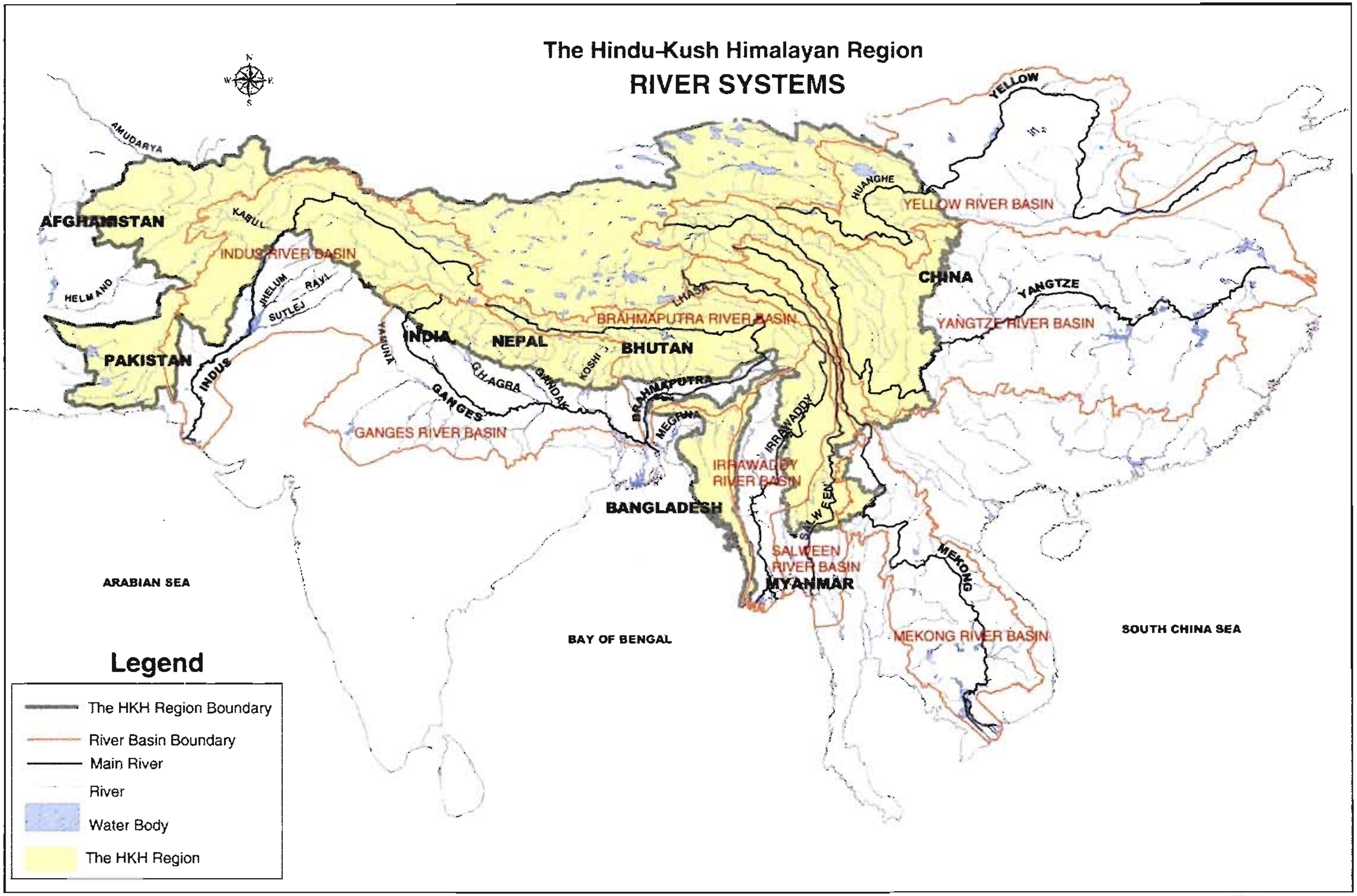
Note: The papers in this volume have undergone language editing, and in some cases been abbreviated, after submission by the authors.

Acronyms and Abbreviations

ADM	A Distributed Model
APHMECRP	Andhra Pradesh Hazard Mitigation and Emergency Cyclone Recovery Project
ATOVS	Advanced Tirros Operational Vertical Sounder
BUP	Bangladesh Unnayan Parishad
BWDB	Bangladesh Water Development Board
CBO	community based organisation
CBS	Commission for Basic Systems (WMO)
CEGIS	Centre for Environmental and Geographic Information Services (Bangladesh)
CGMS	Coordination Group for Meteorological Satellites (WMO)
CMA	China Meteorological Administration
cumecs	unit of flow, cubic metres per second
cusecs	unit of flow cubic feet per second (0.28317 cumecs)
CWC	Central Water Commission (India)
DAB	digital audio broadcasting
DANIDA	Danish Agency for Development Assistance
DCP	data collection platform
DCS	data collection system
DCW	Digital Chart of the World (US National Imagery and Mapping Agency)
DDRGS	digital direct readout ground station
DEM	digital elevation model
DHI	Danish Hydraulic Institute
DHM	Department of Hydrology and Meteorology (Nepal)
DSP	digital signal processor
DVB	digital video broadcasting
DVC	Damodar Valley Corporation
ELOS	extended line-of-sight radio
ESRI	Environmental Systems Research Institute
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAP	flood action plan
FCD	flood control and drainage
FDMA	frequency division multiple access

FF	flood forecasting
FFWC	Flood Forecasting and Warning Centre (Bangladesh)
FFWS	flood forecasting and warning system
FMO	Flood Meteorological Office (India)
ftp	file transfer protocol
GBM	Ganges-Brahmaputra-Meghna
GBMHTS	GBM Hydrometeorological Telecommunications System
GBMHTSIP	GBMHTS Implementation Plan
GDAS	global data assimilation system
GIS	geographical information system
GLOF	glacial lake outburst flood
GOES	Geostationary Operational Environmental Satellite (NOAA)
GTS	Global Telecommunication System (WMO)
GUI	graphical user interface
HF	high frequency
HIS	Hydrometeorological Information System (DHM)
http	hyper text transfer protocol
IMD	India Meteorological Department
IP	internet protocol
IPCC	Intergovernmental Panel on Climate Change
IWM	Institute of Water Modelling (Bangladesh)
LGO	local government organisation
mha	million hectares
MTC	mid-tropospheric cyclone
NCAR	National Center for Atmospheric Research (US)
NCEP	National Centers for Environmental Prediction (US)
NCMRWF	National Center for Medium Range Weather Forecasting (India)
NESDIS	National Environmental Satellite, Data, and Information Service (NOAA)
NEXRAD	next generation radar
nfs	network file system
NGO	non-government organisation
NOAA	National Oceanic and Atmospheric Administration (US)
NPOESS	National Polar-orbiting Operational Environmental Satellite System
NRCS	Natural Resources Conservation Service (US Dept. of Agric.)
NWIS	National Water Information System (US)
NWS	National Weather Service (US)
OECD	Organisation for Economic Cooperation and Development
PRA	participatory rapid appraisal
PSU/NCAR	Pennsylvania State University / National Center for Atmospheric Research
PTT	platform terminal transmitters
QFP	quantitative precipitation forecasting

RDBMS	relational database management system
RTH	Regional Telecom Hub (New Delhi) (GTS)
SCAN	Soil Climate Analysis Network (NRCS)
SDE	spatial database engine (ESRI)
SHEF	Standard Hydrometeorological Exchange Format
SMS	short message service
SSB	single side band (radio)
SSI	spectral statistical interpolation
SSM/I	Special Sensor Microwave Imager
SST	sea surface temperature
TCP	transmission control protocol
TDMA	time division multiple access
TPWC	total precipitable water content
TRMM	Tropical Rainfall Measuring Mission
UNDP	United Nations Development Programme
USGS	US Geological Survey
UTC	Co-ordinated Universal Time
US	United States (of America)
VSAT	very small aperture terminal
WAPDA	Water and Power Development Authority (Pakistan)
WARPO	Water Resources Planning Organization (Bangladesh)
WL	water level
WMO	World Meteorological Organization



Source: USGS, DCW and ESRI Data & Map 2001.

PP 3/03 Supplementary Volume
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Contents

Data and Information Management for Integrated Hydrological and Meteorological Networks

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Abstract
Hydrological and meteorological data are widely used in the development of water resources projects (such as hydropower, irrigation, water supply, navigation, and flood control) as well as for agricultural planning and infrastructure development. Moreover, forecasts are essential to the day-to-day operations of civil aviation, the safety of mountaineering expeditions, and the mitigation of natural disasters such as floods and landslides. These applications require that the data are not only reliable but that they are available in a user-friendly format that implies effective management of data and information. The implementation of data and information management cycles consists of first assessing the data and information requirements of the users and then delivering the information to them in a useable format. The latter implies the acquisition of data and information, transfer of data, quality control, the building and maintenance of databases, the retrieval and analysis of data, the dissemination of data and information, and the evaluation of data and information application. This paper describes in brief how these different steps can be implemented for the effective management of data and information in integrated hydrological and meteorological networks.

Introduction

Water is one of the most important natural resources and is one of global concern. Any change in its availability, quality, or quantity impacts living beings all over the world. The dynamics of water on a global scale can be monitored through the hydrological cycle, which contains complementary hydrological and meteorological information – a thorough knowledge of both of which is required for proper water management. Water management is the interaction of human beings with the natural water cycle; thus effective water management can only be achieved by taking an integrated approach. Integration at the national level needs to balance the country's requirements, that is the demands for and uses of water, on the one hand, with its scientific and technical capability for physical water management on the other. Technical capability implies the combined use of hydrological and meteorological information systems. Different approaches are possible, and while some countries choose to maintain separate hydrological and meteorological institutions others choose to combine these two disciplines under one roof, as in the case of Nepal's Department of Hydrology and Meteorology (DHM).

Hydrological and meteorological data are the basis for the development of water resource projects, infrastructure development, and agricultural planning. For example, hydrological data such as river flow forecasts are essential for the management of flood plains, for the operation of reservoirs and for the mitigation of flood disasters. Meteorological forecasts are essential for civil aviation, for agricultural planning, and for the safety of mountaineering expeditions, among others. An integrated network of hydrological and meteorological stations provides the essential primary data; once collected this data needs to be properly stored, archived, processed, analysed, and made available to the end users in easily digestible formats by an effective data management process.

An effective data and information management process consists of the following (Figure 1):

1. assessment of data and information requirements,
2. acquisition of data and information,
3. transfer of data,
4. quality control,
5. construction and maintenance of databases,
6. data retrieval and analysis,
7. dissemination and application of data and information,
8. evaluation of information application, and
9. re-assessment of data requirements.

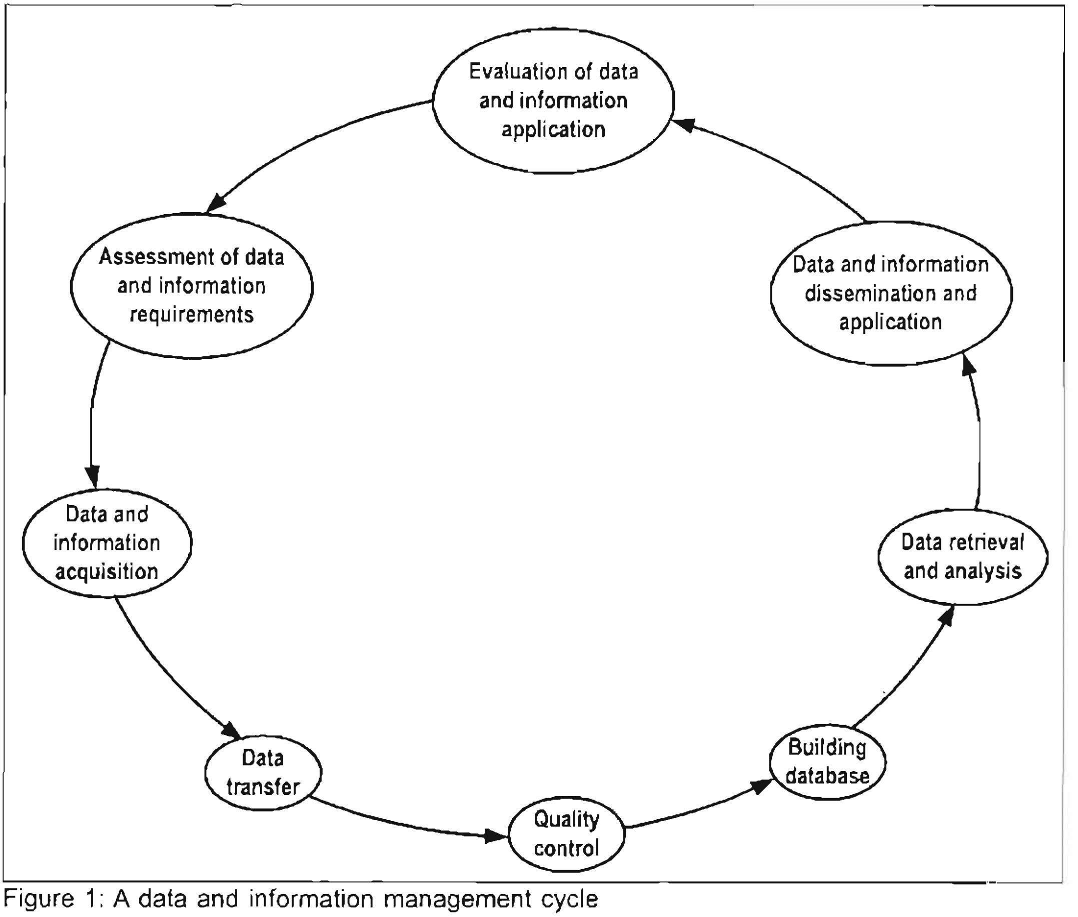

Figure 1: A data and information management cycle

Assessing Data and Information Requirements

River stage (water level), discharge, and sediment data are required for hydropower, water supply, and irrigation projects. The data requirements for flood forecasting depend on the type of forecasting required and the forecasting models used. Either water level or river flow can be forecast; however, water level forecasting is relatively easier than flow forecasting. Water level forecasting makes use of water level time series data from upstream stations and tributaries, together with rainfall data to establish gauge-to-gauge correlations; this, combined with calculations of time of travel, allows forecasts to be made of the water level at downstream stations.

Flow forecasts are usually produced by models. The simplest method of forecasting flow is to use an equation for the stage-discharge relationship after the river stages (water levels of different sections) have been forecast. There are three types of modelling paradigms in hydrology, namely, physically-based distributed models, lumped conceptual models, and empirical models.

The physically-based distributed models and lumped conceptual models use data for the catchment characteristics, which include information on the river section, initial soil moisture content of the upper and lower zone of soil, river stages, discharges, rainfall, temperature, and evapotranspiration among others. Empirical models need only rainfall and runoff/water level time series data.

All of these models have in common that they use rainfall data as a model input; hence, rainfall forecasting is intimately linked with flood forecasting. Rainfall forecasting is a complex process that includes the tracking and forecasting of frontal systems, disturbances, waves, cyclones, and storms. It is also part of the more general weather forecasting that uses observations of wind speed and direction, atmospheric pressure, cloud cover, and visibility.

Data Acquisition

Hydrological and meteorological data are collected using land-based observation systems; meteorological data are also collected from space-based observation systems such as satellites and radar. Since flood forecasting models use both hydrological and meteorological data, an integrated network of hydrological and meteorological stations is needed to record regular observations.

River stage (water level) data are collected by constructing simple staff gauges or using water level recorders. Data loggers can be used to acquire data in electronic form. Automatic weather stations equipped with data loggers provide meteorological data in electronic form.

Historical data and other information about the stations can also be obtained from periodic publications. The data on catchment characteristics, such as catchment area, length of hillslopes, and main channels, can be obtained from maps.

Exchange and Transfer of Data and Information

The conventional methods of transferring observational data from recording stations to forecasting centres were wireless sets, telephone, fax, mail, and meetings (face-to-face).

With the development of the Internet and the World Wide Web (www), data and information can be exchanged through electronic networks. Internet tools include e-mail, mailing lists, newsgroups, and chat rooms; www-based information sharing tools include file servers (based on file transfer protocol (ftp) and network file system (nfs)), document servers (based on hypertext transfer protocol (http)), newsgroups (to share e-mails), and bulletin boards. Other technologies include tele or video conferencing tools such as Net Meeting, CU-SeeMe, and MBone based systems.

Internet based tools provide the opportunity for the real-time data transfer needed for real-time forecasting; whereas historical data can be transferred to the forecasting centre by slower means. Historical data are needed to calibrate forecasting models.

Data Quality Control

The quality of rainfall data depends on the instrument used, its installation, its site characteristics, and its operation by a trained observer. Common errors include, incorrect readings, misplaced decimal points, copying errors, arithmetic errors, correct readings entered on wrong days, and systematic errors such as leaky gauges. The quality of river flow data depends on the quality of field data collection and proper establishment of stage-discharge relationships.

Technicians **assure data quality** using various methods including screening, graphical plotting, double-mass analysis, comparison with nearest-neighbour stations, and regional mapping and correlation analysis.

Data screening can be achieved in one of two ways. The first method uses maximum and minimum limits to identify outliers that do not fall within given maximum and minimum limits; the second identifies outliers that don't fall within the range of 'mean ± n * standard deviation', where n = 1, 2, 3. Simple graphical plots can also help to identify any abnormalities in time series data. Double mass analysis is performed using one 'test station' and a number of 'base stations'. The cumulative value of the mean of the base stations is plotted on the X-axis and cumulative value of the test station is plotted on the Y-axis. The plot is useful for checking the consistency of the data. Correlation analysis and the plot of the relation curve can be employed to compare data with neighbouring stations. Cross-correlation function plots of rainfall and water level time series also provide valuable information about the time lag, which is important for estimating the forecast lead time.

Continuity of data flow is achieved by filling in any missing time series data using various methods such as arithmetic averaging, the normal ratio method, the inverse distance method, and the relation curve method.

The arithmetic mean method estimates missing data from a particular station by calculating the arithmetic mean of the data from selected neighbouring stations for the same period. The formula used is

$$P_x = \left(\frac{1}{M}\right)\sum_{i=1}^{M} P_i$$

where, P_i is the data for the neighbouring station i for the duration of missing data at station x, and M is the number of selected neighbouring stations.

The formula used in the normal ratio method is

$$P_x = \left(\frac{N_x}{M}\right)\sum_{i=1}^{m} P_i N_i$$

where, P_i = the data of the neighbouring station i for the duration of missing data at station x, N_i is the normal value of the data from station i for the duration of missing data at station x, and M is the number of selected neighbouring stations.

In the inverse distance method, a weight value is assigned to the data from selected neighbouring stations. The weight value is inversely proportional to the distance between the station with missing data and the selected station. The formula used is:

$$P_x = \sum_{i=1}^{m} P_i W_i \Big/ \sum_{i=1}^{m} W_i$$

where, $W_i = 1/D_i^2$ and D_i is the distance from the missing data station to the selected station i.

The relation curve method is a statistical method for filling in missing data in which the missing data is correlated with the same data from a selected station or various combinations of selected stations. The equation for the relation curve that provides the best fit, as indicated by the highest value of r^2, is used to generate values for the missing data.

Construction and Maintenance of Databases

Observational data and other information about the catchment can be stored in a database. There are many database programmes and decision support systems for flood forecasting, including the **WINHYDRO** program that DHM has used written in Visual Basic for the purpose of storing, analysing, and publishing hydrological data (Figure 2). WINHYDRO is essentially a hydrological database program and has very limited data analysis facilities. Recently, DHM has developed another program, the **Hydrometeorological Information System** (HIS), to store, analyse, and publish both hydrological and meteorological data (Figure 3). The HIS program is an application for data management, time series analysis, spatial analysis, and production of hydrological and meteorological atlases. It uses the Environmental Systems Research Institute's (ESRI) geodatabase concept, together with the ORACLE program as the relational database management system (RDBMS), which can store both the time series and spatial data. ESRI's Spatial Database Engine (SDE) plays the role of middleware between the data repository and the front-end application that has been developed in Visual Basic. ESRI's desktop products (ArcView 8.1 and ArcInfo 8.1) have been heavily customised with ArcObjects programming to develop the interface for the spatial data. Other ArcGIS extensions such as 3D Analyst, Spatial Analyst, and Geostatistical Analyst have also been used in HIS. STATISTICA, another software package, has been used for a variety of statistical analyses (for details see Kumar et al. 2002).

The HIS consists of four major modules: the System Administration, Master Data Definition, Time Series, and Spatial modules. The System Administration module is used to define different levels of access rights to users and thus assures data integrity and security. The Master Data Definition module allows the user to define master data and

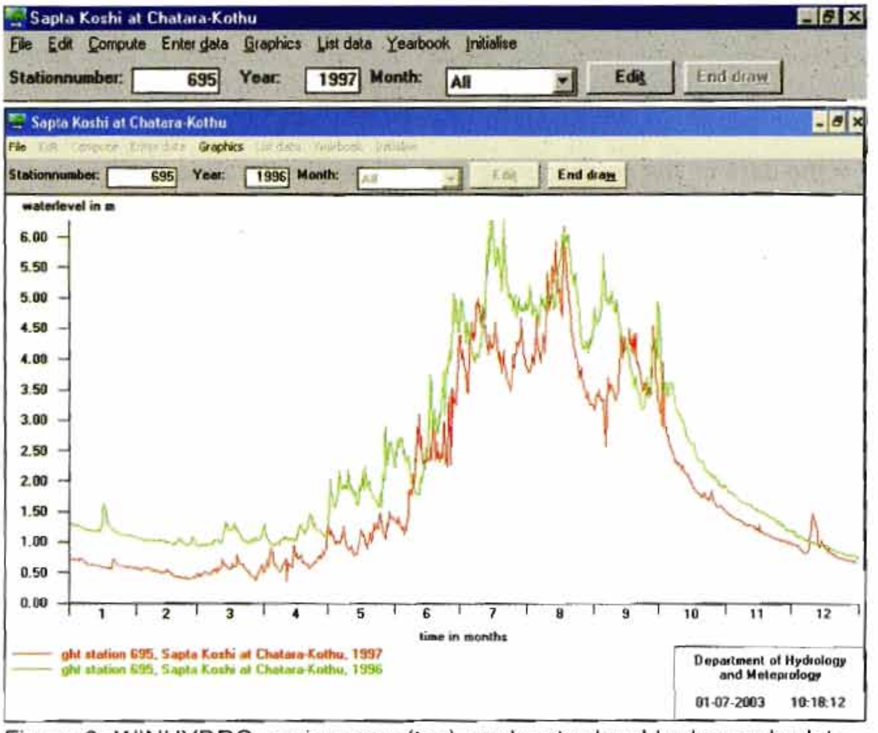

Figure 2: WINHYDRO, main menu (top), and water level hydrograph plot (bottom)

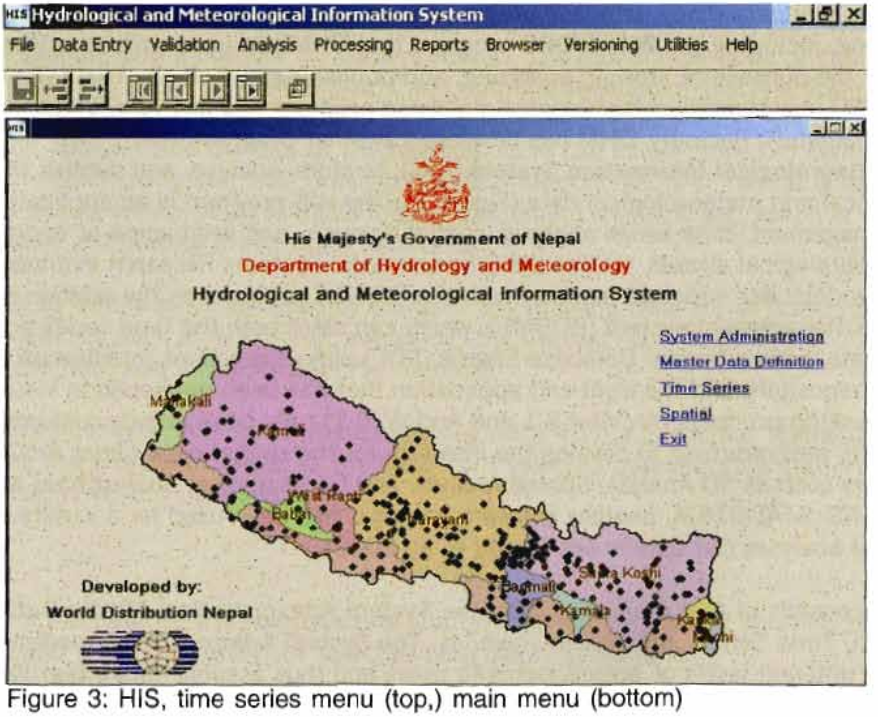

Figure 3: HIS, time series menu (top,) main menu (bottom)

their management. The Time Series module consists of a variety of tools for time series data processing and analysis. It has a menu-driven system for data entry, validation, data processing, analysis, and data browsing. The Spatial module is used to capture, analyse, and visualise hydrological and meteorological phenomena with simulated geography. It provides the tools for basin analysis as well as drainage analysis. Tools are also available to delineate watershed boundaries, to calculate slope, aspect, basin lag, and peak flow using various methods. Similarly, isohyete, isotherms, and isobars can also be generated and the average basin precipitation can be calculated.

Recently, DHM has adopted a conceptual rainfall-runoff model, ADM (A Distributed Model), for flood forecasting and the simulation of rainfall-runoff processes (Figure 4). ADM is effectively a combination of the ARNO model (Todini 1996) and the XINANJIANG model (Zhao et al.1980). ADM has two distinct parts: the first calculates the soil-level water balance and expresses the balance between the moisture content of the soil and the incoming precipitation; the second calculates the transfer to the basin outlet by estimating the outgoing quantities (evapotranspiration, surface runoff, interflow, and baseflow). The runoff is then subjected to a transfer operation which represents the transfer to the network channels along the hillslopes, and transfer to the basin outlet along the channel network. The model is characterised by 11 parameters, 7 of which identify the water balance component at soil level and 4 of which identify

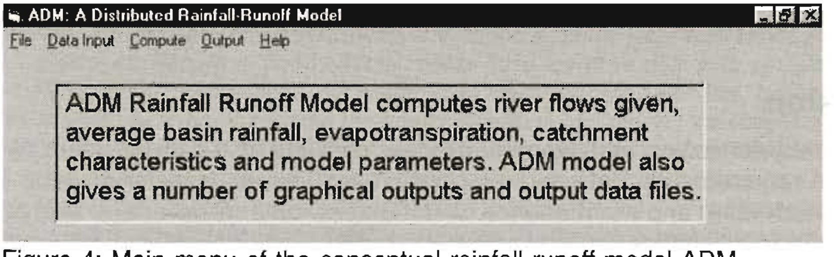

Figure 4: Main menu of the conceptual rainfall-runoff model ADM

the transfer component to the basin outlet. The water balance component consists of two parts representing the upper and lower zones of the soil respectively.
One program commonly used as a decision support system for real-time flood forecasting is **MIKE Flood Watch** (see Paudyal G.N., this volume). This program combines an advanced time series database with the MIKE 11 hydrodynamic modelling and real-time forecasting system (MIKE 11 FF), and works in the ArcView geographical information system (GIS) environment. MIKE Flood Watch is applied operationally at flood forecasting centres throughout the world – it consists of three modules: a database management module, a map-oriented data editing and presentation module, and a module for model preparation, simulation, and post-processing of results.

The MIKE Flood Watch management module is used to establish and georeference the real-time stations in ArcView GIS display. Having established the database, a data conversion module links the data blocks within MIKE 11 FF, the ArcView GIS environment, and the database. Results can be imported into the MIKE 11 GIS flood-mapping module and overlaid with depth/area inundation maps for further analysis.

The ArcView GIS display of the different stations enables the user to select stations for data editing and presentation directly from the GIS map. By direct access to MIKE 11 FF, results can be visualised in combination with other stations and maps. The simulation module includes tools to set up and execute MIKE 11 FF. A bulletin-editor is used to formulate and prepare flood warnings and other flood information for dissemination, for example on the Internet.

Data and Information Dissemination

The analysed data and information are disseminated to the public and users in various forms such as the following.

1. **Bulletins and graphs:** Daily weather forecasts are issued by television and radio transmissions throughout the country.
2. **Reports:** Other information is disseminated in the form of publications and reports, such as the Hydrological Records of Nepal, Precipitation Records of Nepal, Climatological Records of Nepal, and others.
3. **Maps**: Inundation maps, flood hazard maps, hydrological atlases, and meteorological atlases are published and made available.
4. **Internet:** www based dynamic interactive documents can be used for publishing data and information.
5. **Diskettes and CD-ROMs:** Data can also be obtained for research, insurance claims, and other purposes in electronic form on diskettes and CDs from DHM for a nominal fee.

Conclusion

The data and information management process consists of the assessment of data and information requirements, data and information acquisition, transfer of data, quality control, construction and maintenance of databases, data retrieval and analysis, data and information dissemination and application, and evaluation of the data and information application process. This paper has discussed each of these steps and described how they are carried out for hydrological and meteorological data at the Department of Hydrology and Meteorology of Nepal.

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Flood Management and Local Adaptation Strategies

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Abstract

The countries of the Hindu Kush-Himalayan (HKH) region are affected annually by floods of varying extent and intensity in terms of height and duration. Flood management encompasses three broad categories of measures: measures to moderate the flooding, measures to moderate the damage caused by the flooding, and measures to provide relief and succour to the people affected by the flooding and to secure their eventual rehabilitation. The ability to effectively forecast a flood with adequate lead time and to effectively disseminate the information to all concerned so that resources and people can be adequately mobilised for the tasks involved, can go a long way to mitigating the hazards of even severe floods. If a comprehensive flood management strategy is in place, the mobilisation can be implemented swiftly and in a coordinated fashion.

Local adaptation to floods consists of adjustments and responses at the local level aimed at minimising adverse consequences. People in flood affected areas have learnt to deal with certain aspects of flooding by making certain preparations – for example, by adjusting crop calendars; by keeping certain commodities in store; by arranging for the temporary migration of children, the elderly, and the sick; by arranging for supplies of safe drinking water; and by procurement of commonly needed medicines. Knowledge at the local level, acquired through centuries of experience, can be put to proper use if the local people have the capacity to do so. Whereas each individual alone may not have much capacity, a community approach can mobilise considerable resources. Furthermore, assistance from government and non-government organisations in terms of supplying information and providing certain critical inputs at the appropriate times would go a long way towards strengthening the ability of local people to respond more effectively to flood hazards. Nevertheless, when flooding affects extensive areas, is of long duration, and/or causes large-scale losses and damage, the local response, while still essential, needs to be augmented by major external assistance from the government and/or from other organisations.

Introduction

The causes of floods vary in nature and type depending on the geographical realities of a country as well as on the location of its flood-prone areas. These causes may be grouped into three broad categories. The first set are causes that are national in origin and nature – high intensity rainfall and cloudburst within the country, erosion of river banks, and rural infrastructure like roads and embankments impeding water flows. These are common causes of floods, regardless of a country's location along a river system (upper or lower riparian) or its topography (whether flat or mountainous). In mountainous areas, floods can also be caused by glacial lake outbursts, landslides, and debris dams. These floodwaters travel downwards and cause floods downstream. In coastal areas, floods are often caused by storm surges.

The second set of causes relates to the regional perspective. For example, a lower riparian country is subject to run-off from upper catchment areas after heavy rainfall and snowmelt in upland areas, and must bear excessive silt loads in its rivers carried by upstream floodwaters.

The third set of causes relates to oceanic activities such as El-Niño, La-Niña, and sea level rise. While La-Niña causes intensification of precipitation, sea level rise prevents water from flowing into the sea so that water stays inland for longer inundating extensive areas. The 1998 Bangladesh flood, which lasted an average of 65 days, is a good example of sea level rise impeding water flows to the Bay of Bengal.

When developing flood management strategies, it is important to understand the various causes of flooding and design local, national, and regional strategies appropriate to the different causes. Thus, while national capacity building – from central to local levels – is crucial for managing any flood, regional cooperation assumes pre-eminence as far as floods with regional causes are concerned. While it may not be possible with the present state of knowledge to address issues related to oceanic activities, it may nevertheless still be possible to mitigate some of the hazards by developing strategies and measures as appropriate for addressing the consequences of any longer duration flood.

The Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report estimates a projected global warming of 1.4 - 5.8°C and concomitant sea level rise of 9 - 88 cm, by 2100. Such changes would imply an increase in flood risks in terms of both frequency and duration in temperate and tropical Asia. These areas include the Hindu Kush-Himalayan (HKH) region in general, and the Ganges-Brahmaputra-Meghna (GBM) in particular. The Eastern Himalayan countries of Bangladesh, India, Nepal, and Bhutan are likely to be particularly affected. Thus, while the HKH regional countries have periodically suffered major loss and damage due to flooding, it would appear that they may face yet more hazardous and frequent flooding than heretofore.

Flood Management Measures

Both structural and non-structural measures are necessary for flood management. Structural measures include embankments, drainage channels, and reservoirs. Non-structural measures include flood forecasting and warning, flood-plain management measures such as flood-plain zoning and flood proofing (including disaster preparedness and response planning), public health measures, during and post-flood relief measures, and flood insurance. These measures can be broadly grouped into three categories: measures to moderate floods; measures to moderate the damage caused by flooding; and measures to provide relief and succour to the people affected during a flood and for their rehabilitation afterwards.

Generally speaking, floods have local (suffering, damage, loss), national (management concerns, resource implications), and regional (geographical inter-connections, regional causes of floods) perspectives; effective flood management implies that appropriate measures are needed at each of these levels.

Strategies and Resources for Flood Management

The efforts and resources that are needed to effectively manage a flood depend on the flood's intensity, extent, and duration on the one hand, and on the capacity of the various actors (government and non-government organisations and communities) to take the necessary actions on the other. In order for these various players to be able to mobilise resources and people effectively for the tasks, it is necessary that all concerned be given an adequate lead time by providing them with a flood forecast. If a national flood management strategy is in place, responsibilities have been properly identified, and a co-ordination mechanism has been established prior to the incident, then the mobilisation of resources and people can take place in a more effective manner.

In general, countries that are affected by floods on a regular basis have developed flood management strategies, which provide the basic framework for actions to be taken when flooding occurs. These frameworks can and should be improved as new information and analyses become available. However, ultimately, it is a country's capacity to respond that lies at the centre of most problems. Capacity building calls for trained people, necessary equipment, and financial resources. In areas where flooding is a normal occurrence, the affected people themselves can usually manage the consequences to a large extent. Unfortunately they still sustain losses and damage, which apart from causing an immediate setback, also adversely impacts their future economic prospects. When the capacity of local people to manage floods is strengthened, the immediate setback is reduced and the future economic prospects may not be so severely impacted. If strategic support is also available from relevant government and non-government organisations, so much the better.

When flooding causes major destruction to property, crops, infrastructure, and people's health (Ahmad 2000) the resources that can be mobilised locally are often insufficient. In fact, local resources are typically extremely limited, but in spite of this, governments do not make anticipatory budgetary allocations. In these situations, an effective flood forecasting system that provides a reasonable lead time for the mobilisation process to be initiated in advance, can help considerably to mitigate the consequences of devastating floods. Sufficient lead time for mobilisation beforehand can be much more effective in moderating the effects than efforts after the event. Such forecasting requires real-time data and information and the ability to plan well in advance of an approaching disaster. Given adequate lead time, governments can take steps to mobilise additional financial resources, including a budgetary re-allocation on an emergency basis, to respond to the catastrophe in a meaningful way. Adequate lead time will also enable local communities and other actors to organise the best possible collective responses.

Flood Information and Flood Management

An effective flood-forecasting model requires relevant real-time data and information from within and across regional countries. Up-to-date data and information on the various aspects of floods are needed. These include, among others, the causes of flooding, their nature and impact, the circumstances of those affected, the local resource base, the potential community responses in place, and the support institutions available and their activities. The availability of flood information and its dissemination within and across countries is thus a crucially important element in managing floods. It is important that a national flood information system be properly developed in each country. The capacity, both in human capability and technological terms, of gathering, processing, and disseminating information is the basic pre-condition for a country to have an effective flood information system.

A regional flood information system that can be used to exchange information between and among regional countries can mutually reinforce the respective national systems. For such a system to be effective, regional countries need to be able to exchange both available experiences and analytical results, and real-time information – and the mechanisms for such an exchange needs to be developed, expanded, or strengthened (as appropriate), and properly implemented.

Local Adaptation and Responses

Since floods are a regular occurrence throughout the HKH region, over time the people of these flood-prone areas have developed their own responses and their own ways of mitigating flood impacts. In some instances individuals can act alone, but in others a collective community response is needed. For example, people have learnt to prepare for higher water levels where the only means of transport is by water by keeping boats in reserve for this purpose. Another example is that they try to store adequate cattle feed to last them over the period of a flood. In spite of these and other responses that they routinely mount during a flood they nevertheless suffer losses and damage, which reduces their future economic prospects. The poorest segments of a flood-affected community usually suffer the greatest setbacks.

The responses that local people undertake can be grouped into three categories: before a flood, during a flood, and after a flood. The results of recent surveys of these activities in the flood-prone areas of Bangladesh, India, and Nepal are reported below.

Bangladesh

The Bangladesh case study was conducted in two flood-prone areas in the districts of Jamalpur and Chapai Nawabganj using participatory rapid appraisal (PRA) techniques (BUP 2003). The adaptation/coping activities undertaken by the flood affected people are summarised below. These practices are adopted generally throughout the country, but there are some local variations in areas not covered by the study.

Before a flood

- Local people try to gauge the severity of forthcoming floods based both on their previous experience of the quantity of rainfall and run-off and on any forecasts available to them. They eagerly await flood information from a flood forecasting and warning system. None of the areas included in this study had any access to nearby flood information centres from which flood information could be secured. People listen to radio and television for information about the rainfall in upper catchment areas. They also watch the behaviour of insects, domestic animals, and snakes, all of which show marked changes prior to the onset of floods. They often discuss these matters among themselves in order to try to understand the likely nature and severity of a forthcoming flood, and the ideas formulated are disseminated to community members.
- Local people try to store food as well as seeds and other agricultural inputs such as fodder for feeding cattle.
- They undertake the repair of embankments as needed; this is usually a joint undertaking by the people concerned and at times can include the support of appropriate government agencies.
- They procure or repair country-boats for possible use.

- Some people build platforms inside their houses on which to sleep and store belongings temporarily as long as floodwaters are moderate.
- Those who have the financial resources procure essential medical supplies to deal with water and vector-borne diseases – these include fuel for boiling and chlorine tablets for purifying water.

During a flood

- During a flood, the affected people move to higher ground and to safer places such as embankments, roadsides, and school buildings, or to unaffected areas to live temporarily with relatives. When they have to move they take their food stocks and other valuables with them, as far as possible.
- People help one another by providing shelter or lending money and/or food to those who are particularly affected.
- The community undertakes the repair of embankments and the clearing of congested channels to allow floodwaters to flow faster.
- Concerned government agencies, non-government organisations (NGOs), and community-based organisations (CBOs), provide some assistance, especially to those most affected.

After a flood

- After a flood, the affected people need money to buy food and agricultural supplies such as seeds, fertiliser, and pesticides, especially if their crops have been destroyed or are severely damaged and if they do not have previously saved supplies. They also need money and materials for repairing their damaged buildings.
- People often need to borrow money and are at the mercy of local moneylenders who charge high interest rates. They may also need to pre-sell their crops at low prices to people who can afford to buy them and/or sell their cattle or ornaments to buy food and agricultural inputs. Those who are forced to take such steps are at a distinct disadvantage both economically and socially compared to those who manage to secure access to credit and inputs on softer terms.
- The local people sometimes also help each other by lending supplies of seeds, fertiliser, and/or pesticides.
- When people suffer losses too large for them to be able to recover, they are often left with no choice but to migrate to urban centres where they often become squatters, itinerant vendors, or rickshaw pullers.
- It has been suggested that banks can help by giving credit, that government and non-government organisations can help in the distribution of inputs, and that both can play important roles in helping people to recover more quickly from flood damage. A main obstacle remains that rural people, particularly the poor, cannot easily access bank loans.

India

In India, case studies were conducted in six villages in the states of Bihar, Assam, and West Bengal using participatory research appraisal techniques (IRMED 2003). The results are summarised below. Care should be taken in generalising these results since it is not clear whether or to what extent they apply to flood prone areas elsewhere in India.

Before a flood

- People use previously gathered knowledge and information about precipitation patterns and run-off to generate their own forecast of the possibility of a flood and its likely severity. They also listen to radio announcements and bulletins. In Bihar, there are flood forecasting/warning centres that provide relevant information to the population. In Assam, people do not have access to so much information. In West Bengal, the population is more concerned about the possibility of cyclone storms, for which warning is usually provided in advance.
- People from the vulnerable locations harvest crops as early as possible and store them in waterproof bags or containers on raised platforms. They store dry fuel for cooking during the flood, and cattle fodder for feeding cattle, which are commonly moved to sheds on higher ground.
- Some people set aside money and other necessary items (including certain medicines) before a flood sets in.
- With a view to saving assets and avoiding re-location, some people construct raised bamboo platforms inside their homesteads where they store goods, sleep, and cook once floodwaters are at floor level. Others construct houses on high ground to ensure staying above normal flood levels.
- In West Bengal, the coping strategies mainly centre around cyclone preparedness. Here the availability of advance cyclone warnings allows people to store food and other supplies well in advance before they move out to safer and higher ground.

During a flood

- During a flood, communities stand together helping one another, putting aside intra-community differences and disputes. It is not uncommon for higher income families to offer food and cooking fuel to lower income and distressed families in the area.
- Cattle are moved to uplands and roadsides.
- The Water Board supplies chlorine for treating drinking water.
- NGOs and local Panchayats work together to help the people, providing food and clothing during flood/cyclone emergencies. NGOs also make boats available to transport people and materials.
- In the absence of boats, some people use bamboo and banana stems as makeshift rafts for transportation.

After a flood

- Rehabilitation needs after a flood depend on the losses and damage suffered. Renovation of damaged embankments and other infrastructure is the responsibility of the relevant government departments. However, the people surveyed expressed an interest in being involved in the process of planning for construction and rehabilitation of embankments and other infrastructure.
- People themselves mobilise resources to repair their homes and other assets. NGOs, community-based organisations (CBOs), and government organisations usually provide some assistance. However the assistance received is typically less than what is minimally needed to restore the properties to their pre-flood condition.

Nepal

The case study conducted in Nepal used participatory rapid appraisal techniques in flood-prone areas in Rautahat and Saptari districts (JVS 2003). The findings are summarised below.

Before a flood

- Measures taken by people before a flood generally include the storing of plastic sheets, tents, rubber tubes, and empty drums.
- Some people move their food stocks to higher ground, while others prefer to adopt a 'wait and see' strategy.

During a flood

- During a flood, those affected commonly move temporarily to higher ground and safer locations such as uplands, public buildings, and school compounds. Sometimes they take shelter with neighbours and they usually move their cattle to higher ground.
- They use the plastic sheets and tents if these have been procured beforehand and are available. If not, they depend on assistance from others, particularly government and non-government relief providers.
- Sometimes, when the lower part of a house is submerged, the household members continue to live in the upper part.

After a flood

- As a flood subsides, rehabilitation needs become crucial. The affected people, particularly the poorer ones, are usually unable to rehabilitate themselves in a meaningful way.
- Severely flood affected poor people sometimes receive support from the richer members of the community, in addition to any rehabilitation assistance from government and non-government agencies. As flood-displaced people return to their homes they need both food and clothing for their immediate needs as well as money and materials for house repairs. As floodwaters recede, water- and vector-borne diseases commonly break out and some assistance to combat this is provided by relevant public and non-government organisations.

Conclusions

On the whole, the immediate setback for a household depends on the severity of the flood and the ability of the particular household to respond. Poorer people obviously suffer the most. The future prospects of all flood-affected people are hampered – the extent to which they are affected varies, however, depending on the loss/damage sustained and their capacity to respond.

In the case of a deluge, the severely affected people become suddenly destitute. They can do very little by themselves for their survival during the flood or rehabilitation afterwards. Assistance from the government and other organisations becomes absolutely crucial although individual and community responses, to the extent possible, remain important. When rehabilitation in the locality is found to be impossible, people migrate to other areas or urban centres where they face harsh living conditions and uncertain futures.

Improving peoples' access to knowledge, information, resources, and employment opportunities can help them to mount a better response to flooding. Such access would not only help to limit their immediate setbacks but also to minimise the impact on their future prospects.

A system that can provide relief and rehabilitation assistance in an organised manner can go a long way to help reduce the suffering of flood affected victims. Unfortunately, however, coordination among the various agencies involved is usually rather weak. It is therefore necessary to improve coordination and to ensure clearly defined mandates for the various agencies so that effective relief and rehabilitation assistance can be provided as and when needed most.

It would be immensely helpful for local capacity building if people from different flood-prone locations (within a country and between different countries) could be encouraged to exchange experiences and share their coping strategies.

It is also crucial that flood forecast information is available, and disseminated to the local people and others concerned with adequate lead time so that the process of mobilisation and programming of actions can be initiated in advance and implemented properly.

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Development of the Flood Forecasting and Warning System in Bangladesh

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Abstract
Bangladesh has one of the largest and flattest river deltas in the world. Three major rivers, the Ganges, the Brahmaputra, and the Meghna, pass through Bangladesh, but 93% of their total catchment area of about 1.7 million sq.km. rivers lies outside the country in India, China, Nepal, and Bhutan. Bangladesh has an average annual rainfall of about 2,300 mm, with a range of 1,500 to 5,000 mm. It also has a unique coast line with a conical shape that causes the sea level to be higher during the monsoon months. As a result of the unique topography, river system, and rainfall pattern, floods occur in Bangladesh almost every year and devastating floods once every 5 to 10 years. Bangladesh has taken many structural and non-structural measures in order to manage floods. One of the main non-structural measures is its flood forecasting and warning system, which has undergone continuous improvement since the 1970s. What started as a very rudimentary system of food forecasting has now developed into a system which uses the most advanced real-time flood forecasting tools including the Mike'00 Hydrodynamic Model, which uses interactive GIS and can show flood inundation with a digital elevation map. This paper discusses the development of the flood forecasting and warning system in Bangladesh from its inception in the 1970s through to the latest and most advanced systems now in use.

Introduction

Bangladesh contains one of the largest deltas in the world with three major river systems, the Ganges, the Brahmaputra, and the Meghna, flowing through the country. The total catchment area of these three rivers is 1.7 million sq. km but nearly 93% of this lies beyond Bangladesh in Bhutan, China, India, and Nepal (Figure 1). The combined maximum flow of the two major rivers, the Ganges and the Brahmaputra, is about 120,000 cumecs and their estimated combined annual sediment flow is about 1.8 billion tonnes. Almost all of Bangladesh's land area was formed through siltation of these river systems. As a result, the land is very flat and prone to flooding every year. At times when there is excessive rainfall simultaneously in all three catchments, the flood situation becomes critical and can be devastating. At least 10 major flood events have occurred in Bangladesh during the last half century, and of these, four were devastating. The incidence of flooding has increased over the last two decades with an accompanying increase in flood damage compared to earlier floods. Since the early 1960s Bangladesh has implemented a good number of small, medium, and large flood control and drainage (FCD) projects and these now cover about 30% of the land area. Even so, these structural measures still cannot restrict flooding. Experience over the years has shown that complete flood control in a country like Bangladesh is neither possible nor feasible. Realising this, Bangladesh started developing a flood forecasting and warning system (FFWS) as a major non-structural measure for flood management.

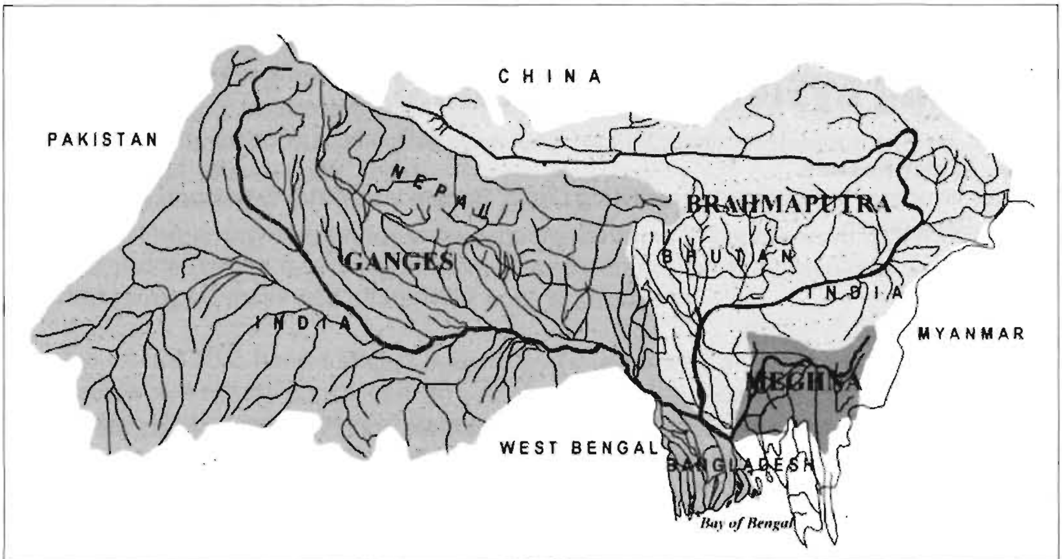

Figure 1: The Ganges, the Brahmaputra and the Meghna River Basins (Source: IWM & BWDB)

Types of Flood

Floods are generally classified according to their cause. In Bangladesh, four types of floods are common: river floods, rain-fed floods, flash floods, and tidal floods and floods due to storm surges (Figure 2).

River Floods

River floods are the most common type of flood in Bangladesh and occur in all three of the major river catchments in the country. When excessive rainfall occurs in the river catchments outside Bangladesh the river course cannot hold the flow within its banks and the water spills out onto the neighbouring flood plains. Overflow of the river banks is a very common phenomenon in Bangladesh. When the water level rises simultaneously in all three river catchments, the flooding can become devastating. In normal years about 30% of the land area is inundated, rising to about 50 to 70% in the case of devastating floods. The areas susceptible to river floods are shown in Figure 3. The flood in 1998 was the most devastating flood of the last century; it affected about 70% of the land area and lasted for 60 days, the longest time ever recorded. The major floods of the last 50 years are summarised in Table 1.

Table 1: Statistics of major floods since 1953

Year	Affected Area	
	sq.km	%
1954	36,800	25
1955	50,500	34
1974	52,600	36
1987	57,300	39
1988	89,970	61
1998	100,250	68

Flash Floods

Flash floods are characterised by a rapid rise and fall in the water level of a river. This type of flooding can occur in the flood plains, along the river course in hilly regions, and in foothill areas. Flash flooding occurs in all the transboundary rivers in the northern and the northeastern part of Bangladesh and in many rivers of the southeastern part of the country. The catchments of the transboundary rivers in the northern and the northeastern parts lie in India and flash flooding occurs as a result of excessive short-term rainfall in the Indian part of the catchments.

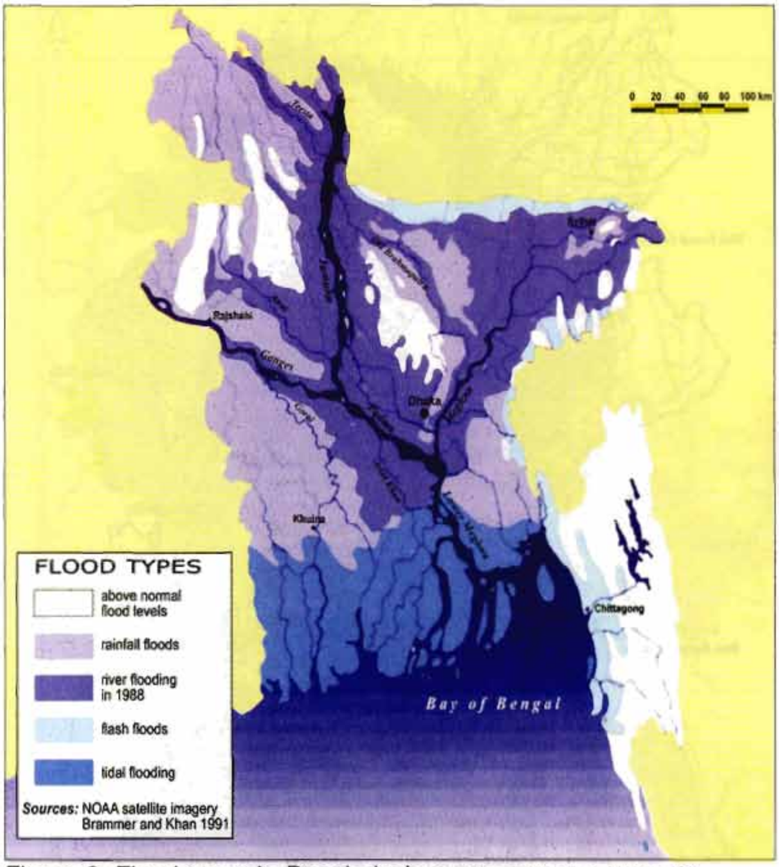

Figure 2: Flood types in Bangladesh (Source: BWDB & WARPO)

Rain-fed Floods

Rain-fed floods are most common in those parts of the country where the land elevation is relatively low and drainage is restricted. Occurrence of this kind of flood is increasing because the hydrological regime in the flood plains is changing as a result of unplanned construction of infrastructure like roads, bridges, culverts, embankments, and irrigation canals. Another important factor contributing to this phenomenon is the continuous reduction in flow in rivers and drainage channels which is leading to increased sedimentation and a concomitant rise in the bed levels. This situation can become critical when there is unprecedented rainfall inside or outside the country. One such unprecedented event occurred In September 2000 in the southwestern part of the country. There were heavy transboundary inflows resulting from extreme climatic events that occurred in some parts of Bihar and West Bengal, India. The overland flows entered Bangladesh following the natural topography, but runoff into the sea was obstructed by major changes that had taken place in the hydrological regime due to both natural and human interventions. Floodwaters, which are normally evacuated within days, stagnated for 2-8 weeks in some parts of the region. The natural topography and human interventions in the region are shown in Figure 4.

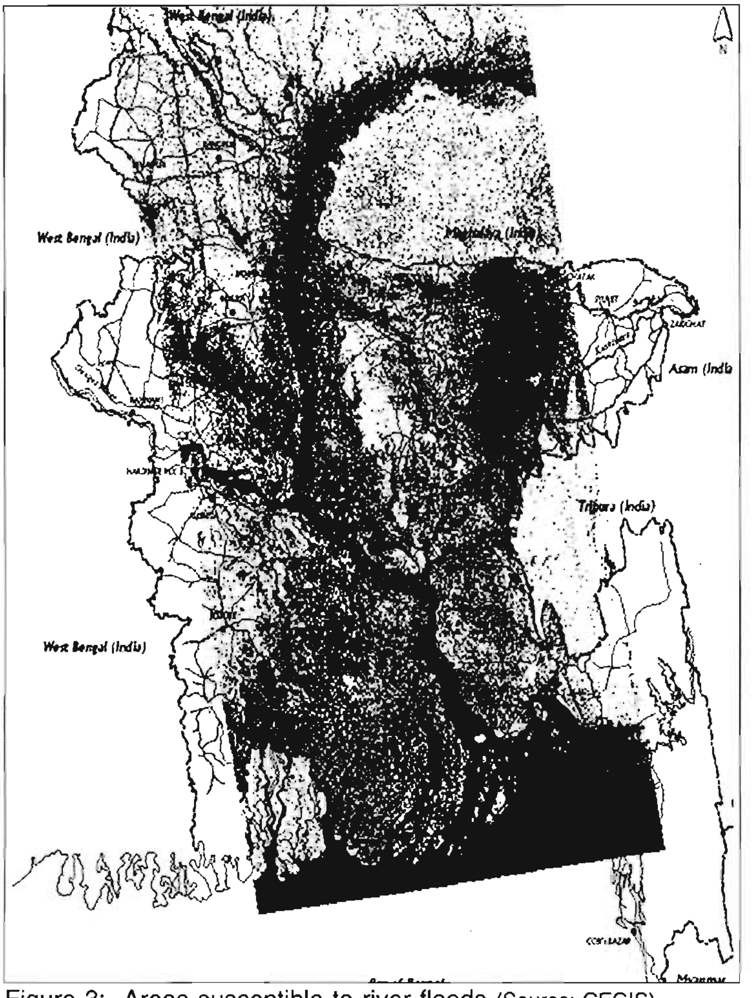

Figure 3: Areas susceptible to river floods (Source: CEGIS)

Tidal Floods

Tidal floods and floods due to storm surges occur in the tidal flood plains along the coastal areas of the country. The land elevation in the coastal areas is around 1-2 m in most parts, and the sea level rises by about 1m during the monsoon months, i.e. from June to mid-September. As a result, when the spring tide occurs during the monsoon, most of the tidal plains are susceptible to flooding. The situation is worse when storm surges occur at the same time as tropical cyclones. The loss of life which resulted from the storm surges and tropical cyclones of 1970 and 1991 exceeded a few hundred thousands. In order to prevent tidal flooding and provide protection against cyclonic surges, Bangladesh has started building polders all along the tidal estuary in the coastal areas of the country. In spite of this, newly accreted lands in the estuary and along the coast are still subject to tidal flooding. The storm surges that accompany severe cyclones still pose the threat of breaching the coastal polders endangering the lives of those in the high-risk zones.

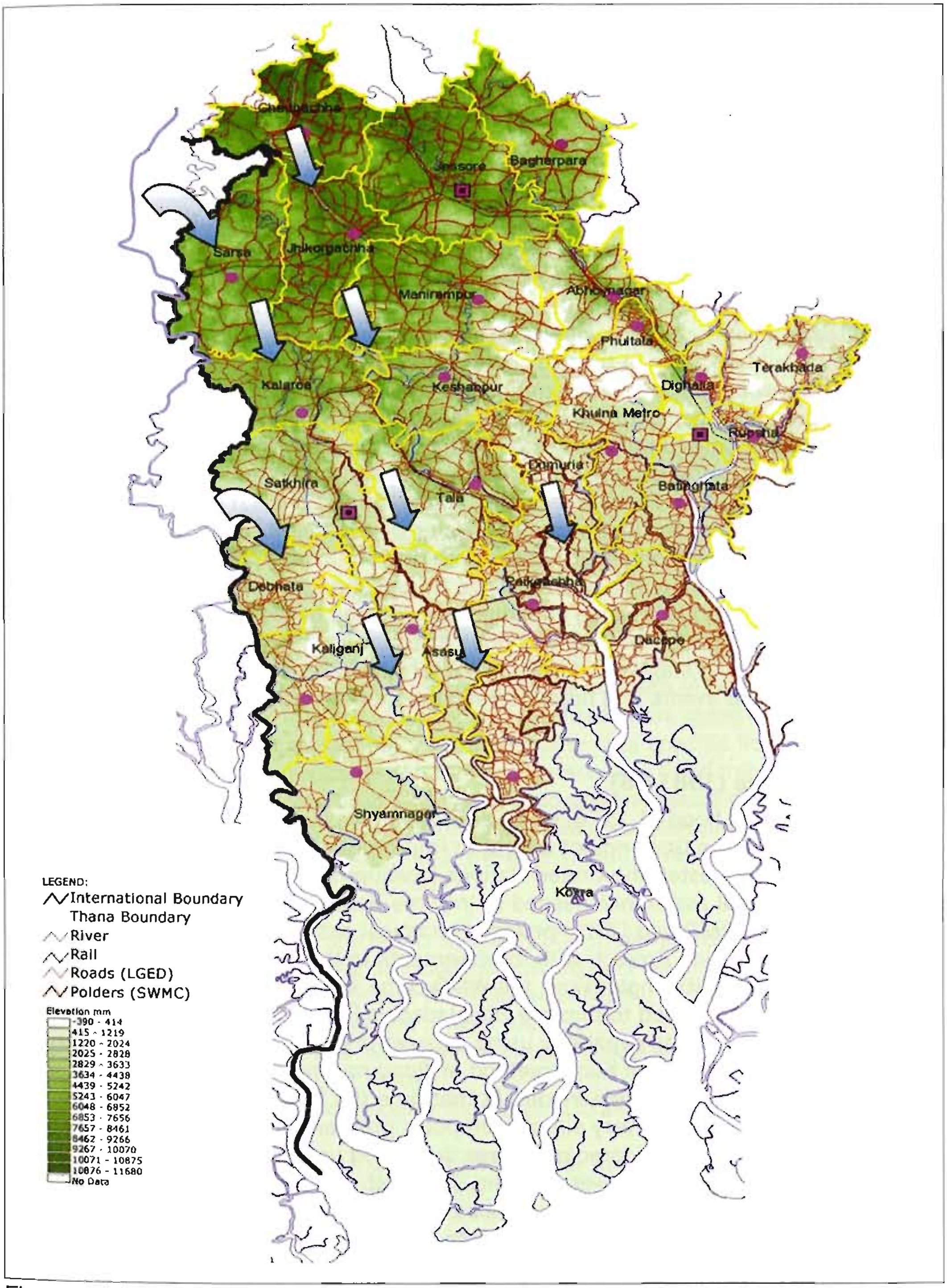

Figure 4: Natural topography and human intervention (Source: IWM & BWDB)

Development of the Flood Forecasting and Warning System

The FFWS in Bangladesh is in a state of continuous development. There have been four distinct stages of development during the past thirty years: an Initial Stage from 1972-80; a Second Stage from 1981-88; a Third Stage from 1989-99, and a Fourth Stage from 2000 up to the present.

The Initial Stage (1972-80)

During the 1960s, policy planners for water resources development and management considered that structural measures such as embankments and regulators were the most effective means of controlling flooding and did not consider any non-structural means of flood management. At the end of the 1960s and the beginning of the 1970s, policy planners realised that complete flood control is neither possible nor feasible and that whatever benefits could be gained by any flood control measures that were undertaken would take a long time to accrue. They also realised that if any major flood occurred, they would not be able to mitigate the suffering of the people. This realisation prompted policy makers to look for alternative flood management measures and eventually to come to the conclusion that a flood forecasting and warning system might be the most suitable non-structural alternative to mitigate flood losses and damage. The Bangladesh Flood Forecasting and Warning Centre (FFWC) was established in 1972 under the Bangladesh Water Development Board (BWDB). It started very humbly with only four flood monitoring stations: Bahdurabad and Serajganj on the Brahmaputra, and Hardinge Bridge and Gualnando on the Ganges. Initially the FFWC tried to develop an indigenous method based on past water level records to compute the travel time and flood attenuation. The main responsibility of the FFWC in the initial stage was to compile information on floods and publish annual reports on the flood events and flood damage that had occurred in different parts of the country.

The Second Stage (1981-88)

After the disastrous flood of 1974, which subsequently caused one of the worst famines on record, the Government sought to improve its flood forecasting services. The government requested the United Nations Development Programme (UNDP) to provide the technical assistance needed to improve flood forecasting and warning services. In 1977, WMO and UNDP provided technical assistance to the Hydrological Survey and Investigation Project, with improvements to the FFWS included as a small component. Realising its importance, the WMO came separately in 1981 to provide the technical assistance needed to improve Bangladesh's FFWS. WMO experts tried to develop a flood forecasting capability using a gauge-to-gauge statistical correlation method and the Muskinghum-Kunje method of flood routing. Initial tests did not succeed in developing a suitable model. At that time the first generation of desktop computers appeared. Using very simple computer programming, a straightforward, indigenous method for flood forecasting was developed using data from 10 water level stations, mainly on the major river systems. This first programme used only gauge-to-gauge correlation and the travel time of flood waves between the selected stations. This method enabled the peak water level and time to peak to be forecasted. During the disastrous floods of 1987 and 1988, this method was used to forecast the water level at the 10 selected stations.

The Third Stage (1989-99)

After the two consecutive devastating floods of 1987 and 1988, the government realised that non-structural measures like flood forecasting and warning systems can play a vital role in reducing flood damage and protecting human lives. Bangladesh's development partners took the issue of flood management seriously and they were determined to find non-structural means to mitigate flood damage. As a result of initiatives by the Organisation for Economic Cooperation and Development (OECD) countries, a flood action plan (FAP) was formulated. The United Nations Development Programme (UNDP) and the World Meteorological Organization (WMO) then commissioned the Danish Hydraulics Institute (DHI) to develop a flood forecasting (FF) model for Bangladesh. The DHI was already engaged in developing national and regional level surface water simulation models for the whole of Bangladesh. DHI customised the national and regional models to develop an FF model based on the NAM (rainfall-run-off) and System-II (hydrodynamic) models. A System II Model was developed on the basis of St. Venant's continuity and conservation of mass equations. During 1989-91, DHI developed the first deterministic FF Models and in 1991 flood forecasting was started for 16 water level stations. The lead times of forecast were 24 and 48 hours. The model performance was evaluated and the forecasts achieved a confidence level of greater than 90%. The FF model was further developed under the Expansion of Flood Forecasting and Warning Project (FAP 10) in 1995-99 and the number of forecasting stations was expanded to 30.

The Fourth Stage (2000 onwards)

Many lessons were learnt from the experience of the 1998 flood. People living in vulnerable communities wanted to receive flood information with adequate lead-time and they wanted the information to be made available to them in terms they could understand. They wanted to know when their homesteads were going to be inundated and for how long, in other words they were demanding area-specific flood forecasting. Moreover, many different groups were interested in receiving flood information. Many of these demands related to improved formulation and dissemination of flood information. As the credibility of the FF program grows, so does people's demands for information. With these demands in mind, the government is now trying to harvest the fruits of science for the benefit of society.

Work on the fourth stage was started in January 2000 under a project titled 'Consolidation and Strengthening of Flood Forecasting and Warning Services'; assisted by the Danish Agency for Development Assistance (DANIDA), and will continue until December 2004. The objectives of the project are:

- to improve the accuracy and lead time for flood forecasting;
- to upgrade the flood forecast model;
- to expand the real-time flood monitoring stations to all flood prone areas of the country;
- to improve the dissemination of flood information to vulnerable communities;
- to build up a sustainable institution; and
- to ensure transfer of technology.

All these activities have been started. The accuracy of forecasts has significantly improved, but so far it hasn't been possible to increase the lead time because of the lack of continuous access to upstream data on a real-time basis. Whatever data was available has been used to improve the boundary estimation of the model and thus improve the accuracy of forecasts. The FF model has been upgraded. It now includes the MIKE ZERO version, uses a Windows platform, and has many additional features like a geographic information system (GIS), flood inundation mapping (Figures 5, 6) geo-referencing of real-time data acquisition, forecasting points, and rainfall mapping (Figure 7), among others. The FF network has been extended to all flood prone areas of the country and now has 50 forecast points and an additional 30 monitoring points. Although flash floods continue to plague many parts of the country, it has not been possible to develop a reliable forecasting system for this kind of flood everywhere. However, work is continuing to improve the warning system for water levels on a real-time basis using modern technology.

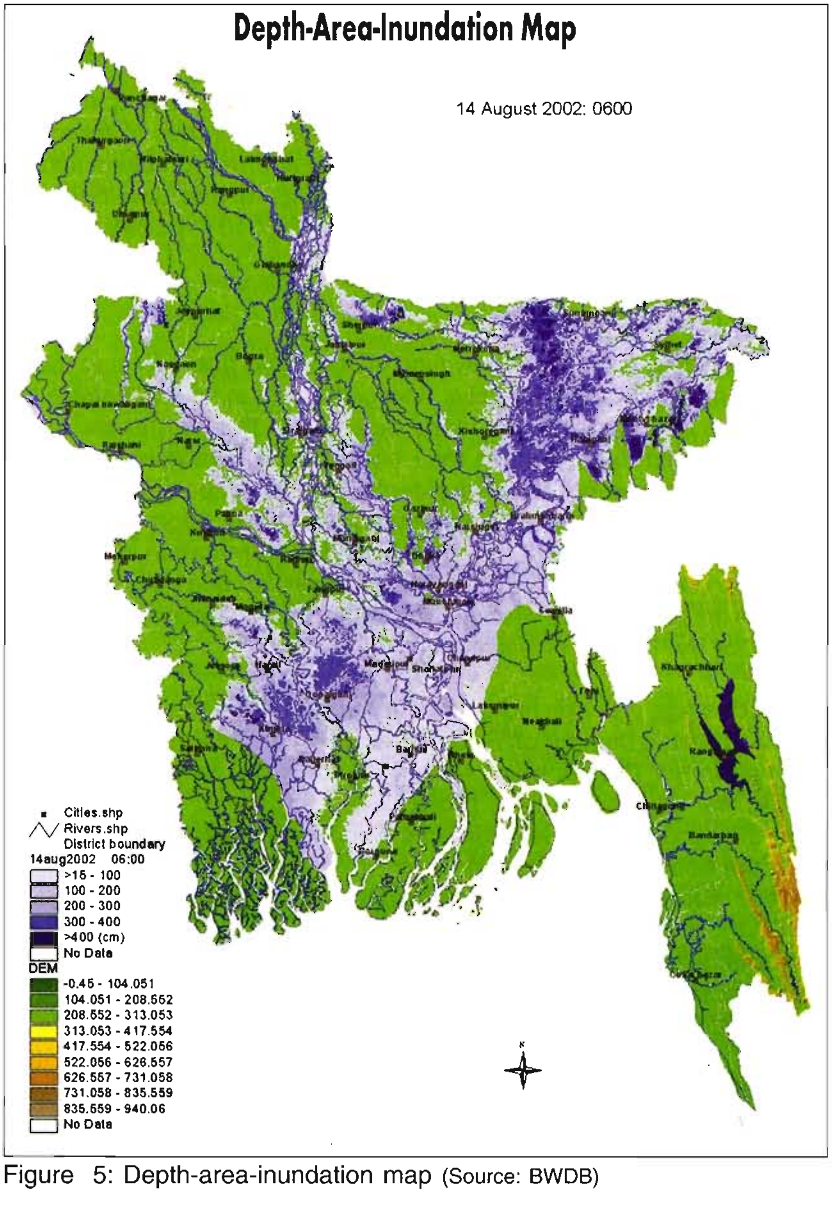

Figure 5: Depth-area-inundation map (Source: BWDB)

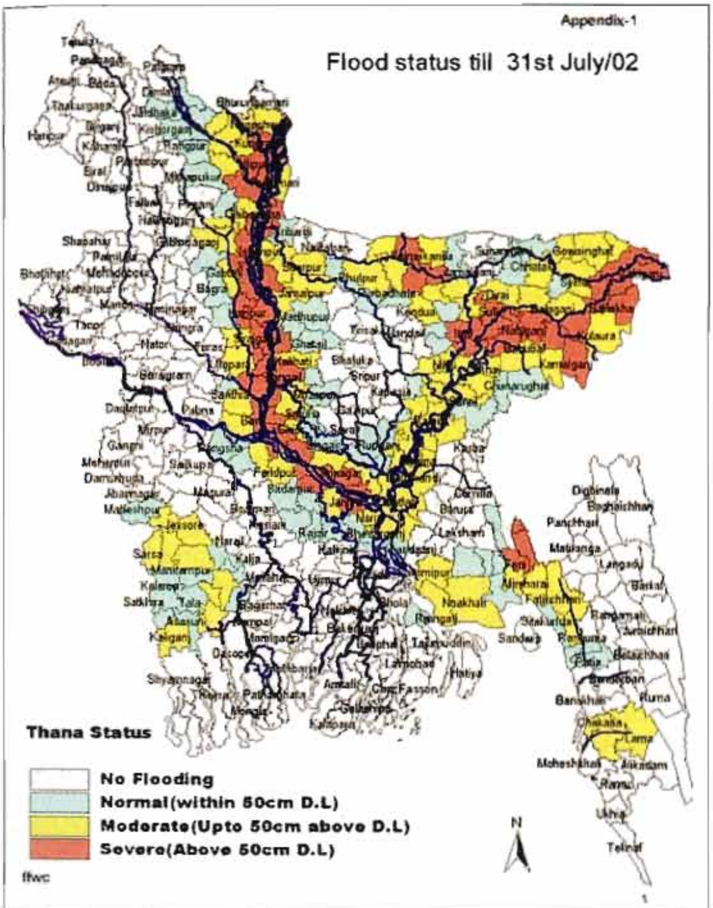

Figure 6: Daily flood status map (Source: BWDB)

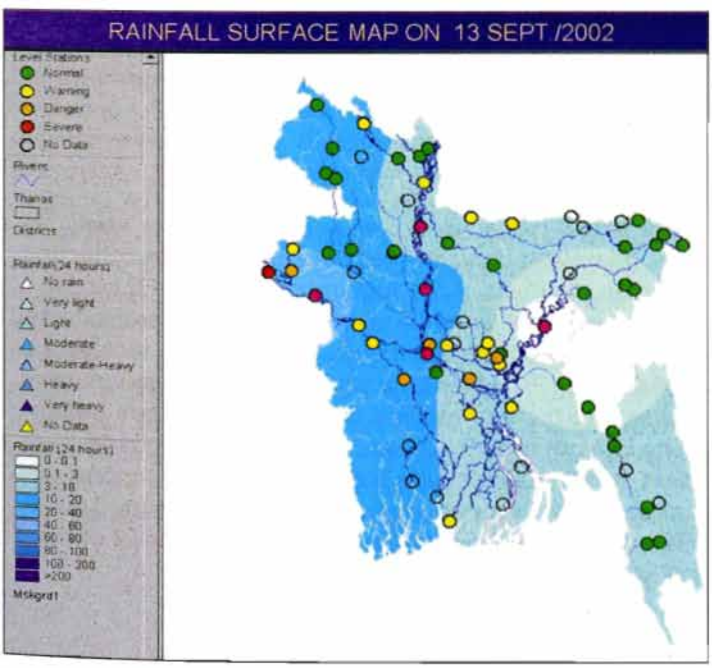

Figure 7: Daily rainfall distribution map (Source: BWDB)

Evaluation of the Flood Forecasting and Warning Services

Flood forecasting period

Flood forecasting and warning activities are mainly conducted during the monsoon months of June through September. In the beginning, there were no strict guidelines or rules governing the activities of the FFWS. Currently, these activities are conducted as per directives laid down in the government's 'Standing Orders on Disaster Management, 1994'. Both the field offices and the FFWC itself are closely involved in all the activities related to FFWS. The FFWC remains open every day during this period and 24 hours a day during extreme flood events.

Flood Forecasting Methods

Over the past two decades, Bangladesh has markedly improved its FFWS and now uses very sophisticated FF models. Maintenance of the models requires much care and attention, especially since the model was developed to cover almost the entire river system of the country. The model inputs include water level, discharge, river cross section, topography, soil information, and vegetation. The rivers of Bangladesh are morphologically very active and dynamic and many morphological features change continuously. Moreover, with the continuous developments in the flood plains, topographical features are also prone to change. If these changes are not incorporated in the models at regular intervals, the performance of the model will deteriorate. Model performance has been continuously evaluated since 1991. The absolute mean error of the forecast was relatively high during the early stages in 1991 and 1992, went down in 1995, '96, and '97, and again increased after the 1998 flood. This later increase suggests that changes occur every year in a dynamic process and that if the model is not updated regularly the results will be compromised.

Boundary Estimations

Boundary estimates for the model are very important since most of the major flows come from transboundary rivers. The quality of forecasts depends in part on the accuracy of the boundary estimates. The quality of boundary estimates depends on the flow range; they have been improved recently with some limited data from upstream.

Data Transmission from the Field

The Hydrology Organisation of the BWDB has an extensive network of water level, rainfall, flow, sediment, and water quality stations all over the country. Data collection from the field has been established on the basis of the requirements of the FF model; real-time operation of this model requires that water level and rainfall data are collected regularly. The FFWC starts its daily activities from 6 a.m. when it begins by receiving daily water level gauge readers' data from 70 water level stations. Gauge readers send the 6 a.m. water level data together with the four records of the previous day's 3-hour data. Rainfall records for the 24 hours ending at 9 a.m. are also collected from 46 stations. Most of the data are sent by SSB (single side band) wireless sets; more recently mobile phones are also being used. A pilot telemetry network covering 16 stations was established in 1996 and is used mainly to monitor the water level of the major rivers at border stations (Figure 8).

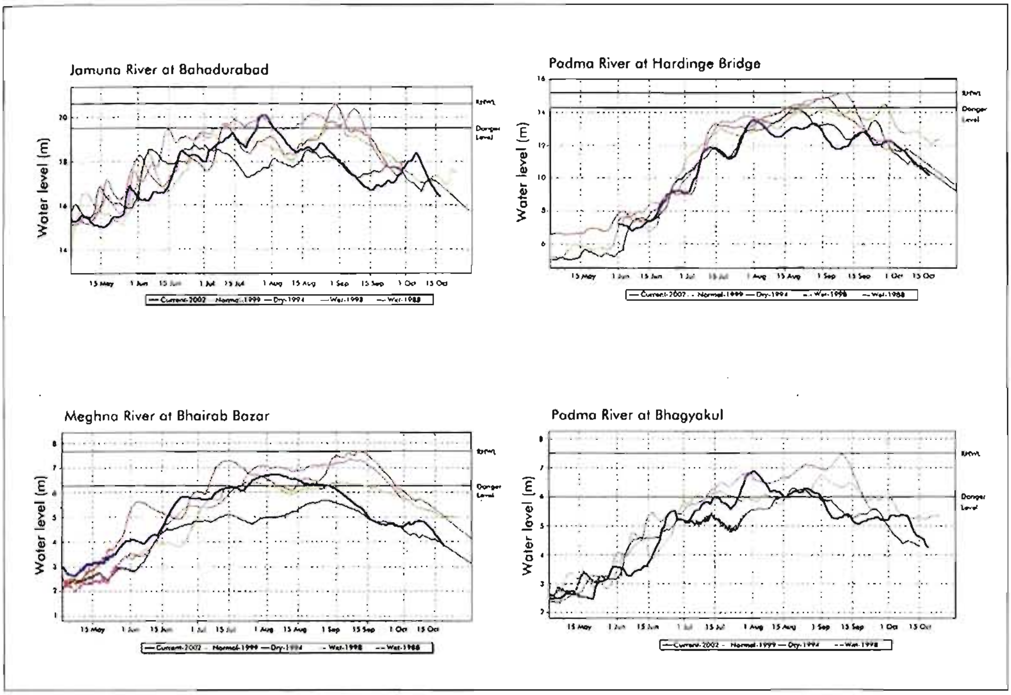

Figure 8: Water level hydrograph for major stations

Flood Forecast and Warning Dissemination

Over the past 20-30 years, Bangladesh has recognised that an early warning system can save lives and property by helping the mobilisation of an advance disaster preparedness programme – as amply demonstrated during the floods of 1987, 1988, and 1998. FFWC disseminates flood information daily using different media including the Internet, fax, and telephone. The FFWC flood information dissemination has certain limitations, however. Whereas timely information is provided to different government departments, agencies, disaster managers, NGOs, and the news media, the poorest and most vulnerable are sometimes missed. A recent study by the Centre to assess the response to its information by people living in flood prone areas showed that the most vulnerable communities often have no effective means of receiving timely information. In spite of the fact that the technological level of flood forecasting in Bangladesh, as in many countries, has reached a high degree of sophistication, the dissemination of this information to the vulnerable communities is still wanting. This aspect of flood information dissemination needs serious attention and here local government organisations (LGOs) and community-based organisations (CBOs) can play an important role. Bangladesh has had a successful experience with its cyclone preparedness programme where these organisations were involved. At present, pilot studies are being conducted to discover the best way for disseminating flood information in a timely fashion to vulnerable communities.

Conclusion

In order to maximise the benefits of timely flood forecasting information, the requirements of the different users needs to be examined carefully and met judiciously. Moreover, it will always be important to remain vigilant in providing accurate and timely forecasts for a country like Bangladesh, which is a lower riparian country with three major river systems and drains huge run-off from large catchments. The extent to which close cooperation can be developed among the co-riparian countries will also determine the extent to which the lead-time and accuracy of flood forecasting can be improved. Timely dissemination of flood information to the vulnerable communities is vital to the success of the flood forecasting and warning system of any country. It is also important to keep pace with technological innovations, which requires continuous updating of the technical capacity.

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Integrated Hydrometeorological Network Design and Operation for Flood Forecasting

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Abstract
In this paper, the information requirements for flood forecasting are analysed and the key technical features of an operational information network are outlined. A case study of the Jiangxi provincial river basin forecasting system in China is given. Suggestions for enhancing the backbone of the regional information network in the HKH region are discussed.

The Meteorological and Hydrological Information Needed for Flood Forecasting

Operational flood forecasting needs both historical and real-time information. The type of information needed includes topographical and geographical data of the basin, hydrological data, and weather data.

Topographical and geographical data are used to divide a river into drainage basins. After the basins are so divided, the hydrological parameters must be defined. These include basin area, soil moisture parameters, and routing parameters. If snow accumulation and ablation calculations are to be included, parameters for those are needed as well.

The information needed for quantitative precipitation forecasting includes synoptic data, rain gauge data, doppler radar data, satellite data, and climate data.

The data that is the quantitative output of precipitation forecasting products, real-time meteorological data, and hydrological data are the basic inputs to any flood forecasting system. If there is a reservoir in the drainage basin, then reservoir inflow and release data should also be considered.

It is important to note that the flood forecasting function relies entirely upon automated data as opposed to manual observations. Data should be collected in a local database and screened for quality before being input to the flood-forecasting model.

Criteria for the Identification of a Meteorological and Hydrological Network

Operational flood forecasting involves four stages: 1) meteorological and hydrological observation; 2) data collection and exchange; 3) data processing and flood forecasting; and 4) making flood warnings available to the public and the government. The information network is the key to each of these stages and is also the technical basis for regional cooperation in flood forecasting.

Such an information network should meet the requirements of:

- timely routine collection of observed data;
- automatic dissemination of scheduled products, both real-time and non real-time; and
- ad-hoc non-routine applications like requests for non-routine data and products.

The network should be:

- reliable;
- cost effective and affordable;
- technologically sustainable and appropriate to local expertise;
- modular and scalable; and
- flexible – able to adjust to changing requirements.

One example of such an information network is the World Weather Watch communication network, known as the Global Telecommunication System (GTS). GTS is one of the most successful projects of the World Meteorological Organization (WMO). As a result of decades of efforts by its members, the current GTS collects routinely observed data effectively and automatically disseminates scheduled products. There is a complete set of procedures for the operation of the GTS, which contributes to its reliability.

GTS has remained vital by adapting to changing requirements and available technology. Over the years, leased lines were gradually replaced by managed data communication network services; the data rate increased from 50 baud and 75 baud, to 64 and 128kbps; the dominant protocol changed from asynchronous, to X.25, frame relay and transmission control protocol/internet protocol (TCP/IP). In the beginning, only character data were exchanged, binary data exchange was supported in the 1980s, and now almost any type of data can be exchanged using a transparent file format. In addition to message switching, high frequency (HF) radio broadcasting, low speed satellite broadcasting, and high-speed satellite broadcasting were also implemented. As more categories of data, including hydrological data are exchanged on GTS, it is evolving into a more general-purpose WMO information network.

While the GTS is a real-time meteorological information network that runs continuously 24 hours a day and all the year round, few hydrological data are collected and disseminated in real time at present, and the accessibility to recent hydrological data is generally inadequate for regional flood forecasting purposes. GTS offers a reasonable choice as a communication backbone for information exchange for a regional hydrometeorological network.

Internet (email) technology can be used to collect site observation data and feed it into the GTS. The WMO Commission for Basic Systems (CBS) recently adopted a set of guidelines on practices for collecting observation bulletins via email. Other choices for data collection include the data collection platform (DCP) used by meteorological satellites, and the short message service (SMS) provided by commercial mobile phone networks.

Data broadcasting technology, especially satellite, can be used for the dissemination of data and warnings. Satellite-based digital video broadcasting (DVB) and digital audio broadcasting (DAB) data-communication techniques are highly cost-effective solutions that can be used to improve the implementation of meteorological and hydrological data-distribution systems. In areas where commercial mobile communication service is available, mobile phones and pagers are also cost-effective means for delivering warnings. Webpages operated by flood forecasting centres are very effective information portals, both for the public and for agencies involved in flood forecasting.

Data Flow and Operation of an Integrated Hydrometeorological Network

The operation of a river basin's flood-forecasting network depends on close coordination between its hydrological and meteorological services. A typical data flow is shown in Figure 1.

A flood forecasting system should be operated in a quasi-interactive fashion through a graphical user interface (GUI) which allows the forecaster to run, evaluate, and modulate the operation at each forecasting point.

To facilitate the seamless exchange of information, it is necessary to have standards in place for data format and identification; these can include, for example, data representation code forms and data file naming convention, all of which must be agreed upon by all participating stations and centres.

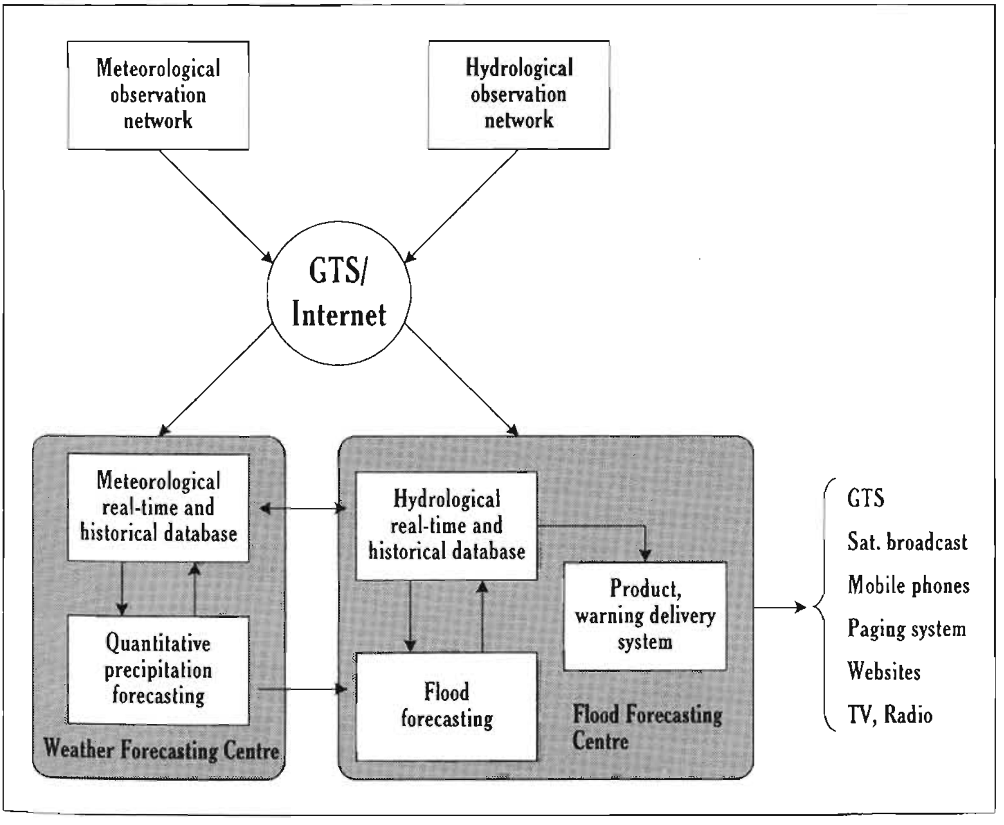

Figure 1: Data flow in an integrated hydrometeorological network

Case Study: The Provincial Basin Forecasting System of Jiangxi, China

Jiangxi province, located on the middle-lower reaches of the Yangtze River, is a region with several major rivers and frequent flooding. The provincial basin forecasting system project of Jiangxi was initiated in 1999, and by the end of 2000 one provincial basin forecasting centre and 12 city-level sub-basin forecasting centres had been established.

The basin forecasting centres receive real-time weather data from the national information network of the China Meteorological Administration (CMA) (which is based on VSAT (very small aperture terminal satellite) communication technology) and real-time hydrological data from the local hydrological services. Each centre maintains databases for real-time data and local historical data.

The data format and the data file naming convention for aerial observed precipitation data and for data from forecasting products were centrally defined. A basin-wide data exchange procedure was implemented and monitored by the provincial forecasting centre (Figures 2, 3).

River basin precipitation forecasting products are disseminated in the following ways:

- web servers run by forecasting centres;
- terminal access by selected important users;
- TV broadcasting and telephone information inquiry; and
- flood warning paging systems that cover the whole basin.

Suggestions for Enhancing Cross-boundary Information Exchange in the Hindu Kush-Himalayan (HKH) Region

As of January 2002, the GTS circuits used by the Regional Meteorological Telecommunication Network in Regional Association II (RAII) in the HKH region are of low to medium data rate (see Table).

Circuit between		Data rate
RTH New Delhi	RTH Beijing	9600bps
RTH New Delhi	NMC Dhaka	2400bps
RTH New Delhi	NMC Kathmandu	50baud
RTH New Delhi	NMC Yangon	50baud
RTH New Delhi	NMC Karachi	50baud

The exchange of meteorological and hydrological data among members in this region could be considerably improved by upgrading the 2400 bps and 50 baud circuits to at least 9600 bps (which is the basic requirement for supporting TCP/IP protocol over the circuit). The Beijing – New Delhi circuit is due to be upgraded to TCP/IP soon, and arrangements for increased data exchange, especially of numerical weather prediction model products, should be pursued.

Conclusion

An operational information network is the key to effective collaboration among countries for flood forecasting and warning in the HKH region. With improvement in circuit capacity and communication protocol, the current GTS can serve as a backbone for cross boundary meteorological and hydrological data exchange in the region. The Internet, satellite-based data broadcasting, mobile phones, and paging systems are all

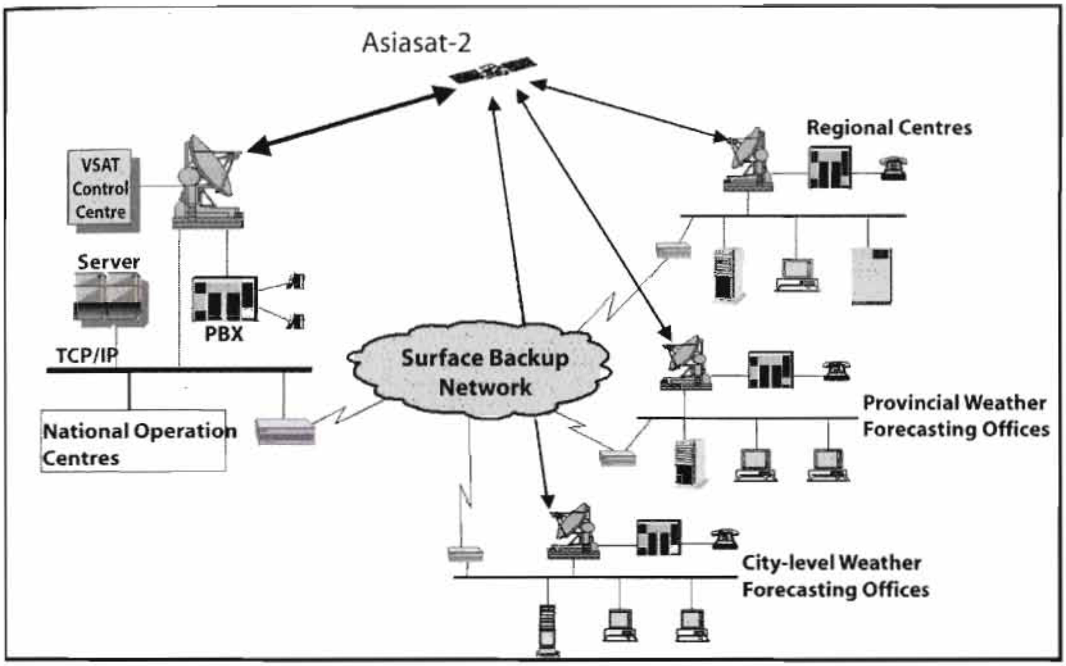

Figure 2: The China Meteorological Administration VSAT two-way information network

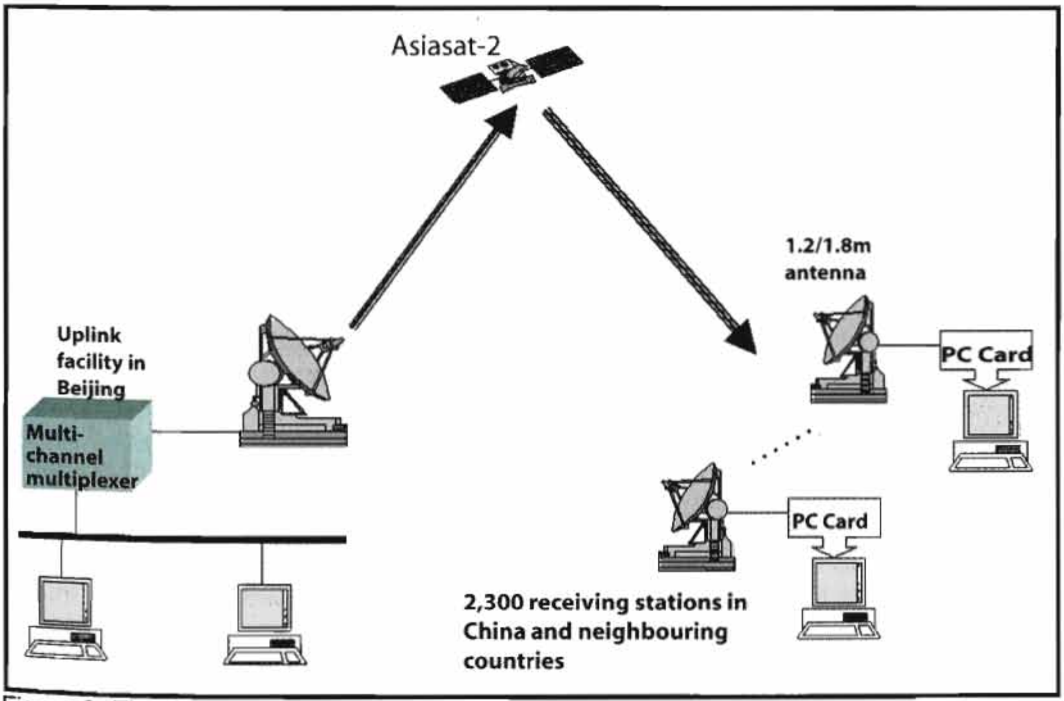

Figure 3: The China Meteorological Administration VSAT data broadcasting system

cost effective choices that can be used to disseminate forecasting and warning information. Operational management and coordination measures, such as those implemented by the World Weather Watch, should also be considered to improve real-time information exchange.

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Flood Management in Integrated River Basin Development

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Abstract
Integrated river basin development aims at the optimum use of basin water resources to best meet all of the water needs of the basin. It is a tool that can be used to address issues related to both the positive and negative aspects of floods and droughts in a basin. Effective flood management needs to consider the whole basin as a hydrological unit as well as to consider what is the most appropriate approach for the sustainable development of water resources. It also requires careful consideration of any methods that can be used to conserve floodwater for use in the dry season while reducing flood losses. Experience has shown that a judicious mix of both structural and non-structural measures can increase any benefits that would accrue from structural measures alone. While work will continue on measures for physical flood protection such as dams, reservoirs, flood embankments, and anti-erosion structures; it will be necessary to augment these with non-structural measures like flood-forecasting and flood plain zoning in order to minimise losses.

This paper deals with flood management in the development of river basins. Various aspects of flooding and its management by both structural and non-structural measures are discussed, together with the experience gained in adopting these measures in India during the last five decades and case studies.

Integrated River Basin Development

A river basin is the most appropriate hydrological unit around which to focus management and planning of water resources. Within a river basin, comprehensive account can be taken of all the supplies of water: precipitation, interbasin transfers, and surface and ground water storage (and their variation and demands including spatial, temporal, and sectional variations). Social, environmental, legal, policy, and other objectives and constraints have to be taken into account, in addition to economic objectives and technical and physical constraints. Integrated river basin development aims at the optimum utilisation of basin water resources to best meet all of the water needs of the basin. At the same time it should also minimise the negative impacts of natural occurrences such as floods and droughts and in so doing, create a suitable balance between water supply and demand in the river basin. In order to do this properly both the supply to the basin (water resources) and the demands from it (including irrigation, power, domestic and industrial water requirements, and minimum flow requirements for navigational, ecological, and religious purposes), need to be assessed. In assessing the demands for water, it is also necessary not only to take into account the increase that will result from the growth in population but also the increase that usually accompanies the shift from traditional rural to modern urban life.

The United Nations Water Conference held in Mar-del Plata, Argentina, in 1977 recommended the formulation of a master plan for countries and river basins to provide a long-term perspective for planning, including resource conservation. The International Conference on Managing Water Resources for Large Cities and Towns, held in Beijing, China, from 18-21 March 1996, also recommended that the river basin be taken as the basic unit for water resources management.

As a result of the variation in time and space for the demand and supply of water, in India a lot of water goes to waste during the rainy season that could be utilised during the dry season. The excessive and unregulated supply of water during the monsoon creates havoc and wastes water. Equally, during the dry period so little water is available that even the most essential demands for drinking water can hardly be met. The hope is that a proper river basin development plan will preserve the monsoon flow and release it during the dry period in a regulated way. In this way flood management is an important component of river basin development.

Flood Problems

Floods continue to plague many parts of the world causing phenomenal losses. About 86% of the total world land area is occupied by the river basins of large and small rivers. Historical records of water stages and floods are not available for all of this land area; however, the recording of flood discharge data started in around 1500 AD and a large flood of about 1400 cumecs was recorded for the Danube in 1501. Very large floods exceeding 50,000 cumecs have been recorded in the Amazon (Brazil); Lena (USSR); Yenisey (USSR); Brahmaputra, Ganges, Godavari, and Narmada (India); Ganges (Bangladesh); Yangtze-Kiang (China); Mekong (Cambodia); Mississippi (USA); and Irrawaddy (Myanmar). Some important historic floods are listed in Table 1.

Table 1: Some important historic floods

Country	River (gauge station)	Date	Flood discharge (cumecs)	Drainage area (sq.km)
Australia	Budekin (Clare)	17.02.1968	27,043	
Bangladesh	Brahmaputra (Jamuna) Ganges (Hardinge bridge)	01.08.1955 not available	93,500 70,790	530,000 1,073,070
Brazil	Amazon (Obidos)	22.05.1944	227,000	4,688,000
Myanmar	Irrawaddy	1877	62,700	360,000
China	Yangtze-Kiang	Not available	84,950	Not available
Egypt	Nile (Aswan)	Not available	13,500	3,000,000
Ghana	Volta (Senchi)	1963	14,272	394,095
India	Godavari (Dowleswaram) Brahmaputra (Pandu) Narmada	17.09.1959 Not available Sept. 1970	88,350 73,620 70,790	314,684 934,990 98,420
Cambodia (Khmer)	Mekong (Kratie)	1939	75,700	646,000
Madagascar	Mangoky (Banian)	09.01.1956	14,800	Not available
USA	Mississippi (Columbus) Ohio (Cairo)	27.02.1937 04.02.1937	70,792 55,218	2,387,950 528,300
USSR	Lena (Kusur) Yenisey (Igarka) Volga (Volgograd) Amur (Kombomolsk)	11.06.1944 03.06.1937 29.05.1926 1876	194,000 132,000 51,900 50,000	2,430,000 2,440,000 1,350,000 1,700,000
Zambia	Zambezi (Kariba)	05.03.1958	16,990	633,040

Flooding Problems in Selected Countries

In China, the occurrence of annual rainfall over a relatively short period of time, and the fact that the population and property are concentrated in flood prone areas, contribute to the occurrence of flood disasters. Floods in Hong Kong are particularly severe as they result from of a critical combination of two factors: heavy rainfall and an abnormal rise in sea level as a result of storm surges during typhoons. Although the urbanised metropolitan areas are relatively free from flooding, significant flood problems are being experienced in the low-lying areas of the rural districts in the New Territories. As a result of recent developments in those areas, natural flood plain storage has been reduced and as a result flooding is becoming more frequent and severe.

In Japan, the rapid urbanisation of river basins has reduced the water retaining and retarding capacities of the land, increased the volume of flood flows, reduced the time of flood concentration, and increased the danger of flood disasters. These facts are compounded with the reality that about 50% of the population and 70% of the nation's assets are located in flood prone areas that occupy only 10% of the total land area. The flood potential in Japan now ranks amongst the highest for any industrialised country.

Flood damage in the Lao People's Democratic Republic is caused primarily by the overflowing of the Mekong River, which brings heavy floods, and secondarily by the overtopping of its tributaries. The frequent flooding of the Vientiane Plain and the southern region caused by the overflow of the Mekong River and its tributaries routinely inflicts significant damage on important cultivated areas. Flash floods occur in many small steep catchments in the northern and southern regions of the country. The city of Vientiane and its surrounding area can be flooded for periods of about two weeks. The cost of the damage to this urban, and the surrounding rural, areas can amount to tens of millions of dollars.

Kuala Lumpur, the capital of Malaysia, has routinely suffered flooding caused by overflow from the Klang River (and its tributaries) since the city was first founded. The rapid urbanisation of the city itself and the bowl shaped topography of the adjacent area are mostly to blame for this frequent flooding.

In the Philippines, the annual damage resulting from flooding is enormous in both social and economic terms. The flood situation is aggravated by the uncontrolled development taking place on flood plains, the exploitation of basin watersheds, the sedimentation of waterways, and the reduction in wetland storage areas owing to rapid urbanisation. Despite improvements in flood protection measures, flood problems continue to grow and associated flood damage persists; these are mainly the result of partially implemented schemes and still insufficient protection measures.

The Republic of Korea has frequently suffered flooding in some of its major cities. As a result, many lives are lost, large populations are displaced, and property damage amounting to millions of dollars is suffered annually. The insufficient capacity of pumping stations, insufficient secondary drainage facilities, and rapid urbanisation of previously rural areas are all partly to blame.

Floods constitute a severe hazard to the people of Thailand and impede economic growth in flood affected areas. On average, Bangkok suffers significant flood damage once every five years; overland flow and local drainage problems, often prolonged by high water levels in the Chao Pharaya river, commonly cause this flooding. Rural areas in Thailand also routinely suffer considerable flooding.

Vietnam experiences many flood catastrophes throughout the country. The magnitude of flooding in urban and rural areas is such that it poses a significant problem, especially in areas where existing levee systems have failed.

In India, any area that has at any time been subjected to flooding is henceforth designated a flood prone area, unless measures have been taken to effectively protect it. The Rashtriya Barh Ayog (National Commission on Floods 1980) designated 40 mha to be natural flood prone areas in the country. Of these, about 32 mha can be provided with a reasonable degree of protection. Data from1953 to 2000 show that annually a mean area of 7.56 mha has been affected by floods, with a range from 1.46 mha (1965) to 17.5mha (1978). On average, floods affected about 33 million people between 1953 and 2000, and in future many more may be affected as a result of population growth in affected areas. Many cities, including Delhi and some state capitals, are among the places that have been affected by floods in the past (IRS 2001).

Causes of Flood

The major causes of floods are:

- inadequate capacity of a river to contain high flows within its banks;
- river bank erosion and silting of river beds;
- landslides leading to obstruction of flow and changes in the river courses;
- simultaneous flooding in a main river and its tributaries so that high flood flows occur in all rivers at the same time;
- retardation of flows due to tidal and backwater effects resulting in the stagnation of floodwater;
- poor natural drainage in flood prone areas;
- cyclones and associated heavy rainstorms/cloudbursts; and
- snowmelt and glacial lake outbursts.

Floods: Some Typical Phenomena

Flash Floods

Flash floods are characterised by a very fast rise and fall of flows of small volume and high discharge, which can cause great damage because of their suddenness. They occur in hilly regions and sloping lands where heavy rainfall and thunderstorms or cloudbursts are common. Severe flash floods in Arunachal Pradesh and Himachal Pradesh in India during the year 2000 are discussed below as examples. Large reservoirs downstream of flash flood prone areas can usually absorb the resultant flood wave, impeding the progression of the flood (IRS 2001).

Flash Flooding in the Siang River in Arunachal Pradesh – June 2000
In Arunachal Pradesh the Siang river (also known as the Tsang-Pho in Tibet and Brahmaputra in Assam) experienced flash flooding on the 11th and 12th of June 2000.

There was no heavy rainfall or cloudburst preceding the flood. All of a sudden floodwaters entered the Gelling area from its source: the Tsang-Pho river. The water level rose rapidly; with a rise of 3.2 m in one hour and total rise of 5.3 m in nine hours, but receded quickly thereafter. This flash flood inundated vast areas in four districts on both sides of the river including the Passighat Township causing considerable losses. The flood was caused by a breaching of a natural dam caused by landslides within the Tibetan Plateau area of the upstream catchments.

Flash flooding in the Sutlej river in Himachal Pradesh – August 2000
A flash flood was experienced in Himachal Pradesh in the night of 31 July to 1 August 2000. The discharge in the Sutlej river at the Rampur site rose sharply from 1,527 cumecs (54,000 cusecs) to 5,092 cumecs (180,000 cusecs) between 03:00 hrs and 05:30 hrs. Discharge at Suni downstream of the above site rose from 1,827 cumecs (64,600 cusecs) to 6,082 cumecs (215,000 cusecs) in 2 hours, but the water level receded very quickly thereafter. This flash flood caused widespread damage to life and property in the Kinnour district, where it washed away almost all the bridges and their surrounding villages. Rampur, another town downstream, also suffered heavy damage. Further downstream, this flood, which had a huge discharge but small total volume, was absorbed by the Bhakra reservoir; the reservoir level increased only marginally. A lake outburst or the failure of a landslide blockade in the upstream catchments in the Tibetan plateau area of China is suspected to be the cause.

Littoral Drift in River Estuaries

The flood problems of deltaic regions are attributed to various causes including the flatter slopes of drains and backflow due to tides. Littoral drift of sand, in the form of sand dune formations, and the consequent choking of river outfalls into the seas, is a specific problem in deltaic regions. The Biccavole and Tulabhaga drains in the Godavari Eastern delta, and the Panchnadi, Lower Kowsika, Vasaltippa, and Kunavaram drains in Godavari Central delta in India are some of the problem reaches. Straight cuts into the sea with to make the slopes steeper or outfall reaches shorter are sometimes considered effective measures to address this problem.

Snowmelt/Glacial Lake Outbursts/Natural Landslide Dam Failure

Snowmelt is a gradual process and does not usually result in major flooding. Glacier melt is usually slower than snowmelt and is not capable of causing severe flooding. But some glaciers hold large quantities of bound water in impound lakes, which may be suddenly released when ice jams melt resulting in a glacial lake outburst flood (GLOF). The rivers originating in the Himalayas are also fed by snowmelt from glaciers. In 1929, an outburst of the Chong Khundam glacier (Karakoram) caused a flood peak of over 22,000 cumecs at Attock. A glacial lake outburst is suspected to be the cause of the Sutlej river flash flood in 2000. Similar effects can occur when a natural dam, caused, for example, by a landslide, breaches.

Cyclones and Storm Surges in Coastal Areas

Floods in coastal areas can be caused by rainstorms, which are generally associated with low-pressure systems like well-marked lows, depressions, or tropical cyclones. During the past 109 years (1891–2000) over 1000 tropical cyclones and depressions originating in the Bay of Bengal and the Arabian Sea moved across the Indian subcontinent. Passage of such storms in quick succession over a river basin invariably leads to severe flooding. The soil is generally fully saturated after the passage of the first storm, which means that the rainfall from any subsequent storm will most probably lead to flooding. In India, coastal areas of Andhra Pradesh, Orissa, Tamilnadu, and West Bengal generally experience cyclones and extensive flooding as a result. The flood in the coastal belt of Orissa in October 1999 that resulted from a super cyclone combined with heavy rainfall is an example of one of the worst cases.

Cloudbursts

Sudden unexpected heavy rains resulting from particular climatic conditions, known as cloudbursts, can also cause flooding. During the year 2000, the coastal districts of Andhra Pradesh in India experienced floods of this type. A cyclonic circulation during monsoon conditions can also cause cloudbursts that lead to flooding. In July 1981 this type of situation developed over East Rajasthan (a traditionally a dry area) and many stations around Jaipur recorded more rain in three days than is usually experienced in the entire year. Annual rainfall in East Rajasthan varies from 550 mm to 700 mm. During the cloudburst the daily rainfall was 250-590 mm (2-day rainfall of 430-800 mm and 3-day rainfall of 450-900 mm) and this excessive precipitation led to flooding.

Human Activities

Human activities, whether inadvertent or intentional, can also sometimes lead to flooding. Sudden breaches in dams or reservoirs can cause devastating floods. There are many examples of dams in diverse places around the world that have failed for a variety of reasons. These failures include the following.

- The Puentes Dam in Spain (69m high, 291m long, masonry gravity): constructed in 1791, failed in 1802 due to internal erosion, leading to the abandonment of the project.
- The Gallians Dam in the USA (29m high, 210m long, masonry gravity): constructed in 1910 failed in 1957 due to submersion.
- The Banqiao dam in China (24.5m high, 2.02 km long, earthfill), constructed in 1956, failed in 1975 due to insufficient capacity of spillway and submersion.
- The Machhu-II dam in India (24.7m high, 3.9 km long earthfill/concrete gravity) constructed in 1972, failed in 1979 due to overtopping and pressure of silt. The failure caused severe damage to the town of Morbi downstream.

With the construction of dams, the chances of flooding in the downstream reaches are reduced to a great extent. This creates a false sense of security and people tend to occupy more and more of the flood plains thereby reducing the actual carrying capacity of the river. As a result, even small releases from the reservoirs sometimes create flood situations in the downstream flood plains. Reservoirs like the Damodar and Ukai in India, where there has been large-scale encroachment of the flood plains downstream, are prime examples. When embankments protect flood plains, a false sense of security also prevails and the fact that a flood beyond the design frequency can overtop the embankment is often overlooked. Some examples of such cases are cited below.

The drainage capacity of the Lower Damodar river has deteriorated considerably since the construction of the Damodar Valley Corporation (DVC) reservoir. Measures for relieving the surface drainage congestion in the lower basin could not be taken up simultaneously with the upland storage. The moderation of the flood peak encouraged further encroachment into the channel waterway downstream, and this tendency could not be controlled. The cumulative result of these factors has been that although the outflow has been reduced to <25% of the inflow, flooding still occurs in the lower basin. The problem becomes more acute, when release from the reservoirs occurs simultaneously with uncontrolled runoff from the catchment.

The Ukai dam is the terminal dam on the river Tapi, harnessing a catchment area of about 62,000 sq. km up to the dam site. The Ukai dam was designed to reduce the peaks of incoming floods and has a large storage space reserved for flood control, thereby providing considerable relief to the downstream areas. Over the years, however, the downstream reach of the Ukai dam (near the city of Surat) experienced flooding whenever there was excessive release of water from Ukai dam. The flooding was due to a number of developments including considerable reduction in the safe carrying capacity of the river channel, extensive encroachment of flood plains around the city of Surat, silting of the river channel, and the effect of tides. When the dam was constructed in the seventies, a design discharge of 24,045 cumecs (850,000 cusecs) was considered safe for the river Tapi in the Surat city area. As a result of subsequent developments and human activities in the areas downstream of the dam, especially around Surat itself, the safe discharge capacity was reduced to about 11,315 cumecs (400,000 cusecs). During the last 5-6 years, the Ukai reservoir has twice experienced high inflows as a result of flood conditions in the upstream reaches. The dam authorities were forced to release more than19,802 cumecs (700,000 cusecs). The result was extensive inundation of low-lying areas in and around the city of Surat. State government authorities are proposing various measures to solve the problem, one of which includes a proposal for real-time automatic data transmission and inflow/ flood forecasts.

Positive and Negative Effects of Floods

Since time immemorial, floods have been responsible for the loss of human life, cattle and other farm animals, crops, and valuable property all over the world. Floods also adversely affect communication systems like roads, railways, and telecommunications; it is generally agreed that floods have caused untold misery to humankind. While there are several negative effects of floods, there are a few positive effects also. One positive effect is that floods can deposit silt, which acts as a fertiliser and eventually increases crop production after the flood recedes. In some cases, however, floods deposit coarse sand, which is harmful to production. Another advantage is that floodwaters recharge the aquifers on riverbanks. This water can be drawn after the floods and used for irrigation and drinking water. In Delhi, this component is used to maintain a significant portion of the domestic water supply.

Flood Control Vs. Flood Management

In the middle of the 20th century, flood problems drew attention in South Asia. In India, the earlier approach had been to control flooding by structural measures, specifically by the construction of flood embankments and anti-erosion structures for the protection of riverbanks. Flood cushions were also provided in some reservoirs. However, it was soon realised that even though flooding could be reduced using these measures, it would never be possible to totally control floods. It was also recognised that it would not be possible to provide permanent protection to all flood prone areas for all magnitudes of floods. Providing protection would involve factors as diverse as the topographic limitations of the region as well as financial investment – and would entail prohibitively high cost of construction and maintenance.

Experience also showed that the loss of life and property could be reduced considerably by using non-structural measures such as reliable advance warning about incoming floods, flood proofing, and flood plain zoning. People can move to safer places in an organised manner as soon as advance flood warnings are received, and moving them to safer places can save valuable property and cattle. Hence, the practical approach that is now widely adopted in flood management, and which can provide a reasonable degree of protection against flooding at a reasonable economic cost, is a combination of both structural and non-structural measures.

Flood Management Strategy

Flood Management activities can be broadly classified in four major categories.

- Modifying the floods in order to keep the flood waters away from developed and populated areas by decreasing runoff, increasing channel capacity, or containing, diverting, or storing flood waters
- Modifying susceptibility to flood damage by keeping people and developed areas out of flood hazard areas or by insuring that such developed areas are flood-proof
- Modifying the loss burden by reducing the financial and social impact of flooding by providing post flood assistance and insurance
- Bearing the losses

All these measures for flood management can be classified as either structural or non-structural measures. Measures taken up under 'modifying the flood' are mostly physical measures and are termed 'structural measures', while those under the other three headings are mainly 'non- structural measures'.

Structural Measures

Flood management in the form of physical measures to prevent the floodwaters from inflicting damage usually involves one of the following.

- Dams and reservoirs
- Embankment and flood walls
- River bank protection and anti-erosion structures.
- Natural detention basins
- Channel improvement
- Drainage improvement
- Diversion of flood waters
- Catchment area treatment/afforestation

Non-Structural Measures

Non-structural measures strive to keep people away from floodwaters. One must always bear in mind; however, the stark reality that flood plains belong to the river and that floods, commonly perceived only as a curse, can be turned into a blessing in disguise if properly prepared for. Flood plains can be used judiciously and shared with developed areas by vacating and permitting use of the land by the river whenever the situation calls for it. This approach allows the flood plains to be utilised and reduces the disaster dimension, while retaining its beneficial effects.

Non-structural measures are very cost effective and can be readily implemented. In recognition of the fact that it may not be possible to halt human encroachment in flood plains areas, the main thrust is now on non-structural flood management measures. Non-structural measures can be grouped broadly as follows.

- Flood forecasting and advance warning
- Flood plain zoning
- Flood proofing
- Disaster preparedness and response planning
- Disaster relief
- Flood fighting
- Flood insurance

Flood Forecasting and Advance Warning

Flood forecasting and advance warning is gaining the greatest attention of planners as the approach of choice when considering non-structural measures to modify the susceptibility to flood damage, and is gaining acceptance with the public as well. Flood forecasting forewarns the resident population when the river is going to use its flood plain, to what extent, and for how long. In 1959, the Government of India laid the foundation for a strategy of laying more emphasis on non-structural measures by establishing a nationwide flood forecasting and warning system under the Central Water Commission (CWC). The network now consists of more than 500 hydrometeorological data observation sites (with wireless facilities) and 159 flood forecasting stations (134 for river stage forecasting and 25 for inflow reservoir forecasting). The stations operated by the CWC are located mainly on major interstate rivers. The state governments of the individual states often supplement these with their own efforts by providing reliable advance information/warning about impending floods. Advance warning helps in preventing the loss of human lives and moveable property and in reducing human misery to a considerable extent. With advance warning, people, cattle, and valuable moveable property can be removed to safe places upland of the areas that will be inundated.

Dissemination of Flood Warnings

Advance flood warning, by disseminating flood-forecast information, is the most common non-structural measure of flood management. The important considerations for advance flood warning include

- accuracy of the flood forecast;
- timeliness of the advance warning; and
- proper dissemination of the advance flood warning.

The importance of the first two are well known and are undertaken during the formulation of the flood forecast. Equally important, however, is dissemination to the right user since it is the public that is the end user of these warnings. Flood warnings are disseminated by telephone, wireless network, police wireless, flood telegrams, fax, and special messenger. Advance flood warnings are generally disseminated to the following.

Flood control rooms – State governments usually have control rooms in the capital as well as at the administrative headquarters. Advance flood warnings are passed on to these control rooms and it is their responsibility to inform all concerned to take necessary action.

Civil authorities/revenue authorities – These authorities are generally in charge of announcing warnings through loudspeakers in the areas that are likely to be affected. They are also generally in charge of disaster preparedness for the area and for transporting people and chattels to safer places. In the event of flooding, these authorities are also responsible for providing relief measures such as boats, drinking water, food packets, fodder for cattle, and medicines.

Engineering authorities – Advance flood warnings are provided to the engineers in charge of structures such as dams, reservoirs, flood embankments, anti-erosion works, railways, roads, and bridges in areas likely to be affected in order to enable them to take precautionary measures for the safety of the structures.

Important and strategic establishments – Oil refineries, power stations, coalmines, factories, and other industrial units located in the areas likely to be affected are also issued flood warnings.

Press, radio and television – Flood warnings are also sent to the press, and to radio and television stations, so that they can publish/announce appropriate warnings to the public. In India, during the flood season, the stations of All India Radio and local television channels reserve a particular time slot every evening and/or morning for flood news including advance flood warnings. The general public is aware of this and they know that they can get reliable information in time.

Flood signals – In areas prone to frequent flooding, a system of light signals can be used to indicate impending danger. For example, a yellow signal can indicate a minor warning such as may be needed when a flood occurs within the river, whereas a red signal can indicate a more serious threat such as when a large area is likely to be inundated. Such a system is in practice in the Damodar basin in India.

Village administration, schools and hospitals – In the case of particular villages, advance flood warnings are sent not only to the central flood control rooms and civil authorities, but also directly to the gram panchayat (village administration), schools, hospitals, and dispensaries among others.

Indian Experience over Five Decades

After the disastrous flood experienced in 1954, a national programme of flood management was launched in India. During the last five decades, different approaches to flood management, both structural and non-structural, have been adopted in different parts of the country. Various methods of flood protection, both long-term and short-term, have also been adopted depending on the nature of the problems and local conditions. Between 1954 and 2000, 33,630 km of new embankments and 37,900 km of drainage channels have been constructed, 2,337 town protection works completed, and 4,713 villages elevated above flood levels. Barring occasional breaches in embankments, these works have given satisfactory protection to an area of about 15.81 mha. Apart from these works, reservoirs with specific flood cushions have been constructed on the Damodar basin to provide protection to areas downstream. Storage structures constructed on the Mahanadi (at Hirakud), Sutlej (at Bhakra), Brahmani (at Rengali), and Tapi (at Ukai) rivers, and a number of major and medium reservoirs, have helped greatly in reducing the intensity of flooding in downstream areas. The flood-forecasting network, which was started in 1959, has also played a significant role in reducing loss of life and moveable property and in alerting authorities to take appropriate advance action. Flood forecasting networks cover most of the flood prone areas in the country. Advance flood warnings (6 to 48 hours before the event) help civil authorities take appropriate preventive measures, which include moving the population, and asking engineering authorities to take measures for the safety of structures including dams and embankments. The major reservoirs in the country are given inflow forecasts. These inflow forecasts are used to determine the reservoir outflow and have helped in moderating floods and reducing flood damage downstream.

Some important examples of the experience in India over the last five decades are discussed below.

Flood Moderation by Dams and Reservoirs

The Damodar Valley Reservoirs

The most important example of flood moderation by dams and reservoirs in the country is that of the Damodar valley, where a chain of reservoirs was constructed with the main objective of flood management. The CWC has inflow forecasting stations on all the dams in the valley. Inflow forecasting, based on gauge and discharge data upstream and rainfall data in the catchment, is used to provide 24hr advance warning to the reservoir authorities. Inflow-outflow figures from the Maithon, Panchet, and other reservoirs during the past years show that tangible flood moderation has been achieved.

The monsoon of 2000 provides a good example. During this period, the Damodar valley reservoirs helped to moderate floods and saved numerous lives and considerable property from possible disaster. West Bengal faced a very grim flood situation in the districts of Birbhum, Murshidabad, Nadia, and 24 Parganas (North) as a result of unprecedented heavy rainfall both in quantity and intensity. A vast reservoir was erected that reached from the high bank of the Ganga-Padma to the right bank of the Bhagirathi along a stretch of 25 to 50 km covering the whole of Murshidabad and Nadia districts and about 40 % of Birbhum, Burdhwan, and 24 Parganas (North) districts. The average annual rainfall in the districts of Birbhum, Burdwan, Murshidabad and Nadia is around 1300 mm; between the 18th and 23rd September 2000, total rainfall values of between 333 mm and 1629 mm were recorded in different parts of the Ajoy Basin, Massanjore Dam catchment, Tilpara Barrage catchment, and Damodar basin areas. The inflow into the Maithon and Panchet Reservoirs started rising on the 19th of September. By the 21st, the inflow at Maithon had increased to 5,092 cumecs (180,000 cusecs) and at Panchet to 4,045 cumecs (143,000 cusecs) necessitating the outflows to be increased to 1,980 cumecs (70,000 cusecs) and 849 cumecs (30,000 cusecs), respectively. By this time, the Maithon reservoir had used 50% of its flood cushion, and Panchet 22%. The reservoir levels rose sharply necessitating the encroachment of even higher levels in these reservoirs. For three hours, the Maithan reservoir used up to 80% of its flood cushion. As the inflows started decreasing, the release was kept at 1,980 cumecs (70,000 cusecs) from Maithan reservoir and 1,414 cumecs (50,000 cusecs) from Panchet. On the 22nd, however, the inflows again started increasing. The Maithan reservoir had to use 100% of its flood cushion for three hours, and the Panchet reservoir 58%. The inflow to the Maithan reservoir reached a peak of 7,581 cumecs (268,000 cusecs) necessitating the release of 4,950 cumecs (175,000 cusecs), while that to the Panchet reservoir dropped to 764 cumecs (27,000 cusecs). The inflows to both reservoirs decreased slowly thereafter. The extent to which the potential flooding was moderated by these reservoirs (in a situation in which the downstream area was already under flood) can be estimated from the above description.

Flood Moderation by the Hirakud Reservoir

The Hirakud reservoir has no earmarked flood storage capacity. The entire available storage is utilised during the monsoon season for flood moderation and subsequently used for irrigation. The Hirakud dam benefited flood control in the Mahanadi delta area in two ways. Firstly, it was intended to prevent damage to land and property, which had been estimated roughly at Rs.1.2 million per year (1947 values). Secondly, it was intended to provide land fit for irrigation and cultivation that could not otherwise be used because of periodic flooding. It was also intended to provide substantial flood relief to the town of Sambalpur. The Mahanadi delta periodically experiences high floods, most notably, the floods of 1834, 1855, 1866, 1872, 1933, and 1937, which caused extensive damage. With the construction of the Hirakud dam, the swollen waters of the Mahanadi river during the monsoon period have been tamed to a great extent. In the 90 years prior to construction (1868-1957), there were 27 years with high floods in the delta; but there has only been flooding in 7 of the 41 years since construction (1959-1998).

Flood Moderation by Other Reservoirs

The Bhakra and Beas dams, while not specifically designed for flood moderation, also absorb peak floods and help in moderating flooding. The example of flash flooding in the Sutlej River in Himachal Pradesh was discussed above.

The Ukai multipurpose project was planned for irrigation, hydropower, and flood control. The Ukai reservoir also provides considerable flood relief to the downstream areas, especially to the city of Surat, by using the flood cushion and by moderating releases.

Other reservoirs in which flood moderation is envisaged are the Rengali dam and Bhimkund project in Orissa, the Baigul reservoir in Uttar Pradesh, the Subernarekha multipurpose dam in Bihar, and the Kangsaboti reservoir in West Bengal. India has about 400 large dams with a total reservoir capacity of more than one million cu.m, but with the exception of the Damodar Valley (1867 million cu.m), and the Ukai (1332 million cu.m), few reservoirs have either a provision for flood storage or a specific flood cushion. In spite of this, all the major dams also moderate peak flow in addition to providing other benefits, and in so doing do help to reduce flood damage to people downstream.

Effectiveness of Embankments

Kosi Embankment

Flood embankments on both banks of the Kosi river, which were mostly completed as early as 1957, give flood protection to approximately 213,840 ha (528,000 acre) of land in the Darbhanga and Saharsa districts of Bihar. Before construction of the embankments, the kharif (monsoon) crops on this land were always in peril and even the sowing of rabi (winter, dry season, crops) was sometimes affected by standing water and excessive moisture. Severe damage was also experienced by property like buildings and orchards. This embankment project has prevented flooding and has had the following identifiable benefits:

- reduction of flooding and waterlogging and consequent improvement;
- reclamation of large areas of land for cultivation;
- construction of a network of surfaced roads and other communication systems; and
- opening of various industries/factories.

In addition to the obvious benefits to the state of Bihar from the project, the neighbouring country of Nepal is also benefiting. This project provides Nepal with some measure of flood protection, stability of the river in the upstream, and to some extent better information in times of floods, in addition to the normal benefits from the irrigation facility.

Gandak Embankment

Prior to 1954, the Gandak river was provided with some marginal embankments on both its banks in the districts of Chapra, Siwan, Gopalganj, East and West Champaran, and Muzaffarpur in Bihar. These embankments have served satisfactorily for over a century and will continue to provide substantial flood control over the Gandak in its lower reaches in Bihar. However, the discontinuity in the embankment posed intermittent problems to the people living in its lower reaches. To overcome these, embankments were planned in the discontinuous reaches with a view to arresting large floods within the embankments and providing security and relief to the people in Bihar and Eastern Uttar Pradesh. Eventually the entire length of the Gandak river up to Hajipur was embanked along the eastern bank . A comparative study performed by the Ganga Flood Control Commission showed a considerable decline in damage suffered after the embankments were completed.

Yamuna Embankments in Delhi

The Yamuna river has embankments on both its sides in the reach near Delhi which are intended to provide flood protection to the population and to agricultural land. However, as a result of breaches in the embankments during high floods, the protected area is occasionally flooded. After the severe flood of 1978, the embankments were strengthened and raised giving additional protection to Delhi against flood. There was some apprehension that such strengthening and raising of the embankments would further accentuate the flood problem requiring further raising of the embankments. Studies of gauge and discharge at different river sections after construction of these additional embankments showed no perceptible rise of flood level as compared to pre-embanked periods. They indicate that during high floods, scouring of the bed and banks takes place restricting the rise in flood level, and during falling floods silting of the bed and sides, thereby keeping the regime more or less in its original state.

Dibrugarh Town Protection Works

Dibrugarh town in Assam has faced problems of acute erosion since its inception. The devastating earthquake of 1950 further aggravated the problem and led to the erosion of one-sixth of the town in the 1954 flood alone. Such severe devastation drew the attention of the central and state governments and planned protection works were undertaken thereafter. The work comprised a 24 km dyke system, a 22 km drain through the town, stone/timber spurs, permeable and semi-permeable piles, and bank revetments from upstream of Maijon to Mohonaghat. Later, due to the shifting of river erosion upstream, the protection works consisted of stone bars, bank-heads, revetments, land spurs, and permeable spurs constructed in the reach upstream of the Maijon stone spur. The 24 km dyke system was constructed in stages between 1954/55 and 1979/80 and was designed to prevent water spilling into the town and adjoining area. A 14 km drain was constructed through the town and outfalling into the river in 1956/57 to provide some relief from the water congestion that resulted from the dyke construction. The drain was later extended to about 22 km.

In 1991, the Central Water Commission evaluated the performance of the flood protection work. The study showed that the anti-erosion work had helped to divert the main current towards the north, thereby reducing erosion in the town and downstream areas. Similarly, the system of dykes was functioning well and was adequately checking the spillage of flood water into Dibrugarh and its suburbs providing a sense of security to the local population. However the floods of 1988 alerted the population to the necessity of regular monitoring and further raising and strengthening of these embankments. There is an urgent need to carry out flood plain zoning in the protected areas and to regulate development activities in the town and its adjoining areas. The gradual shifting of development activities from the present vulnerable areas of the town to comparatively safer higher areas will also help to reduce flood damage potential.

Performance of Flood Forecasting in India

According to the present norms of the CWC, a forecast is considered to be reasonably accurate if the difference between the forecast and the actual observed levels of a river lies within ±15 cm. In the case of inflow forecasts, a variation within ± 20 % is considered acceptable. Between 1991 and 2002, an average of about 6,000 flood forecasts per year were issued, with a maximum of 7,943 issued during 1998. The number of forecasts each year and proportion of accurate forecasts is shown in Table 2.

Table 2: Accuracy of Flood Forecasts in India

Year	No of forecasts issued	Accuracy of forecast	
		No. of forecasts within ±15 cm, or ±20 %	% of accurate forecasts
1991	6603	6225	94.3
1992	4764	4567	95.9
1993	6643	6438	96.9
1994	7476	7087	94.8
1995	6417	6189	96.4
1996	6467	6266	96.9
1997	5465	5263	96.3
1998	7943	7775	97.9
1999	7055	6826	96.8
2000	6510	6315	97.1
2001	5463	5342	97.8
2002	4241	4151	97.9

The forecasts issued by the CWC and warning services provided have rendered immense benefit to the people in the flood prone areas.

Like the river stage forecasts, the inflow forecasts issued by the CWC have also been consistent. They have provided adequate warning to the authorities in charge of dams and barrages, and have led to systematic operation of the reservoirs and optimum utilisation of water resources for flood management. However, while the above criteria for accuracy may be reasonable in the case of large rivers, they may have to be revised and modified for small rivers in areas prone to flash floods, since in small hilly catchments a rise of even one metre can occur within a short time. Similar considerations regarding volume of inflow can lead to different yardsticks for different inflow forecasting stations.

Conclusions

A river basin is the most appropriate hydrological unit for the planning and management of water resources. Integrated river basin development aims at the optimum use of basin water resources to best meet all of the water needs of a basin. It is a tool that can be used to address issues related to both the positive and the negative aspects of floods and droughts in a basin. Effective flood management needs to consider the whole basin and requires that methods that can reduce flood losses should be considered and used where appropriate. There should be a master plan for flood management for the basin. Sound watershed management through extensive soil conservation, catchment area treatment, and construction of check dams should be promoted to reduce the intensity of flooding. Adequate flood cushions should be provided in water storage projects wherever feasible to facilitate better flood management.

A judicious mix of structural and non-structural measures would optimise the benefits that accrue from structural measures alone. An extensive network of flood forecasting stations should be established to issue timely warnings to settlements in flood plains. Flood plain zoning and strict regulations on the location of settlements and economic activities in flood zones will help minimise loss of life and property. While physical flood protection work like embankments and dykes will continue to be necessary, the emphasis should be on non-structural measures such as flood plain zoning, to minimise losses and reduce the recurring expenditure on flood relief.

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Use of Short- and Long-term Meteorological Information in Flood Forecasting

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Abstract
Floods are a disastrous phenomena causing considerable loss of life and property. In India, most floods occur in the northern sub-Himalayan region in the Gangetic-Brahmaputra basin during the south-west monsoon and are caused by excessive rainfall in the catchment area. The forecasting of meteorological conditions that will lead to excessive rainfall in these catchments is important since it can provide the information needed to issue flood forecast warnings with longer lead times. The National Center for Medium Range Weather Forecasting has been producing medium range (up to four days) weather forecasts for the past ten years by running global circulation models on supercomputers. These numerical models have full physics capabilities and can utilise both conventional and satellite data whether received from the regional telecommunication hub in New Delhi or downloaded from other sites. The global circulation model can predict several days in advance the meteorological conditions that produce flood conditions, these include the movement of lows and depressions, and monsoon troughs. A multi-institutional programme on mountain meteorology has been initiated to predict the severe weather conditions that can develop over complex mountain regions. To satisfy the requirements of this programme, two meso-scale models – one (MM5) from the National Centre for Atmospheric Research (NCAR) and the other (Eta) from the National Centre for Environmental Prediction (NCEP) – are run daily. The MM5 is run for three separate resolutions – 90 km, 30 km, and 10 km – and the eta model with a resolution of about 40 km. These higher resolution models are able to predict higher rain intensities that are closer to the observed ones and thus have an improved potential for increasing the lead time for flood forecasting. However, the validity of these models for predicting ground precipitation has not yet been tested for the Himalayan region and needs to be tested in cooperation with the relevant neighbouring countries. Furthermore, the utility of the inputs that these models can provide needs additional testing to assess their accuracy in forecasting run-off and stream-flow.

Introduction

Floods represent the most frequent and widespread of all the natural disasters and are responsible for the largest proportion of deaths (20%) and property damage (32%). In India over the last 20 years at least 18 mha have been affected by floods (as reported by the Central Water Commission). The floods, which begin as high streamflows in rivers and streams, are generally caused by excessive rainfall in the river catchments. The time lag between the occurrence of precipitation and increased river discharge depends on the basin characteristics; the size of the basin, the topography, the type of vegetation, the antecedents, and the soil-wetness, among others. The time lag observed in many rivers of the sub-Himalayan region, north Bihar, north-east India, and north-west India is short, around 12 hours in the case of flash floods. The occurrence of such floods cannot be predicted a few days in advance even theoretically. Attempts have been made to derive the streamflow from rainfall data measured at different locations in the mountainous region. The remoteness of many of these locations makes actual measurements problematic and often of limited usefulness since the lead-time is so short. It is thus desirable and advantageous to be able to predict meteorological conditions like atmospheric circulation that cause heavy precipitation a few days in advance in order to provide sufficient lead-time for forecasting the occurrence of floods. Such forecasting can help prevent loss of life and property, and can also be used as a guide to help regulate the waiting volume in reservoirs that are used for flood control and generating hydroelectric power. It is now possible to forecast synoptic scale atmospheric features and their associated precipitation using numerical models. The National Centre for Medium Range Weather Forecasting (NCMRWF) in New Delhi is developing global and regional weather prediction models for short and medium-range weather forecasting. The NCMRWF is the only organisation in India (and in the tropics) where real-time assimilation of global data is incorporated in the routine prediction of weather parameters using state-of-the-art global and meso-scale numerical models. The weather predictions are disseminated to the various user agencies including the India Meteorological Department (IMD), the Agro-Met field units, the Defence establishments, and several other economic sectors. The feedback from these agencies has been encouraging.

In the following, a brief description of the global data assimilation system and the global models used at NCMRWF is given, together with a few examples of significant weather events predicted by these models. Subsequent sections provide brief descriptions of the MM5 meso-scale model together with the results of few case studies; the Eta meso-scale model and the results it yields in some typical cases; the conditions that can cause flooding and the flood monitoring setup that is in place; and a brief outline of planned future work.

Global Data Assimilation and Forecast System

At NCMRWF, global data assimilation and forecasts are carried out at two different resolutions. A forecast suite at T80 horizontal resolution (150x150 km grid) with 18 vertical layers has been operational since 1994. A new forecast suite at T170 (75x75 km grid) with 28 vertical layers has been developed and implemented recently at the Centre. The 6-hourly intermittent (0000 UTC {Coordinated Universal Time}, 0600 UTC, 1200 UTC, and 1800 UTC) global data assimilation system (GDAS) consists of three main components:

i. data processing and quality control;
ii. analysis based on spectral statistical interpolation (SSI); and
iii. a global atmospheric model for preparation of short range forecasts used as a background field.

Figure 1 shows a schematic diagram of the data assimilation system at NCMRWF. Although most of the conventional data used in GDAS are received through the Global Telecom. System (GTS), via the Regional Telecom Hub (RTH) New Delhi, a large amount of data are downloaded through file transfer protocol (ftp) from Special Sensor Microwave Imager (SSM/I), Advanced Tirros Operational Vertical Sounder (ATOVS), and QuickScat, among others.

The analysis scheme operational at NCMRWF is an adaptation of NCEP's early version of the global 3-D variation analysis scheme, the SSI scheme (Parrish and Derber 1992). In SSI, observation residuals are analysed in spectral space on sigma surfaces. The objective function minimised in SSI is defined in terms of the deviations of the

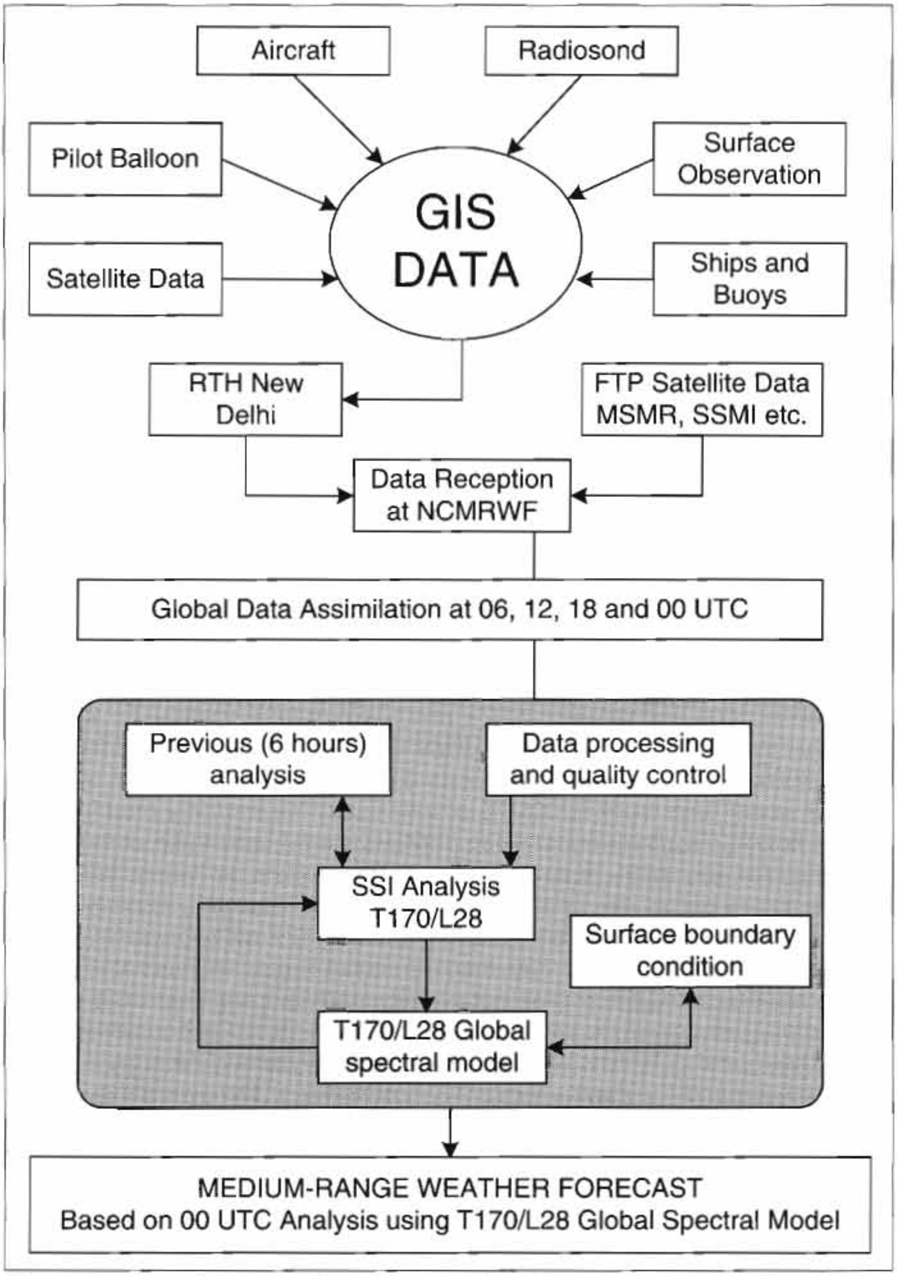

Figure 1: Flow diagram of the global analysis forecast system at T170/L28 Resolution

desired analysis from the first guess field (which is taken as the six hour forecast of the operational T80-Global spectral model) and observations are weighted by the inverse of the forecast and the observational error variances respectively.

Several sensitivity studies have been carried out to improve data analysis, especially using various satellite data over the data sparse regions. Various experimental analyses were carried out at T80 resolution to examine the impact of wind speeds and total precipitable water content (TPWC). Data from the Tropical Rainfall Measuring Mission (TRMM) microwave imager, SSM/I, and the Indian remote sensing satellite IRS-P4 multi-scanning microwave radiometer (MSMR) were analysed and used to predict the Indian summer monsoon. In a study of the Orissa super cyclone of October 1999, Kar et al. (2003) found that the best analysis was obtained using the TMI data. The National Environmental Satellite, Data, and Information Service (NESIDS) derived temperature and moisture information from ATOVS that is now obtained through GTS and an ftp server at 120 km resolution. Several experiments have been conducted to study the impact of these data sets on NCMRWF's analysis and forecasting system for the summer monsoon season. Since these data have correctly defined the initial state of the atmosphere, they have been included in the operational system. The result has been that this data has improved the calculation of wind field characteristics over the northern Indian Ocean and the results are considerably more accurate when compared to those produced by other major centres (Goswami and Rajagopal 2003).

The first guess for the analysis cycle (four 6-hour cycles in a day) is provided from a 6-hour forecast produced by the global spectral models (Kar 2002). The physical processes in the model include the non-local closure planetary boundary layer scheme (Basu et al. 2002), the National Atmosphere and Space Administration (NASA) radiation scheme (John and Begum 1997), and the Kuo-type scheme for cumulus convection, shallow convection, mountain wave drag, and land surface schemes as in Kanamitsu (1989). Medium range predictions are prepared by NCMRWF by integrating the models for seven days from 0000UTC of each day. The monthly mean rainfall patterns from the T170L28 model and the T80L18 model have been compared with the observed rainfall for July 2001. A comparison of the models indicates that the higher resolution one shows better rainfall distribution over the mountainous regions (figure not shown). Figure 2 shows how the model performed for a recent case of heavy rain and snowfall in northern India and over the Himalayan region in February. The model in its 3-day forecast predicted the movement of the westerly trough over the region and predicted precipitation forecasts as shown in the Figure. Tests performed thus far indicate that the model performs well in predicting heavy precipitation events both during the monsoon and during the winter season and that the time range of useful prediction is longer for the winter season.

Prediction Using the MM5 Model

The MM5 model is the 5th generation Pennsylvania State University/National Center for Atmospheric Research (PSU/NCAR) Mesoscale Model (limited area). This model is non-hydrostatic, the terrain follows sigma coordinates and is designed to simulate or predict mesoscale and regional scale atmospheric circulation. It can be configured to run from global scale to cloud scale in one model. It has multiple nesting capabilities and can be run in both 2-way and 1-way nesting mode. It has options for a wide variety of advanced physical parameterisation schemes. The model can be run using routine observations and has provision for 4-dimensional data assimilation.

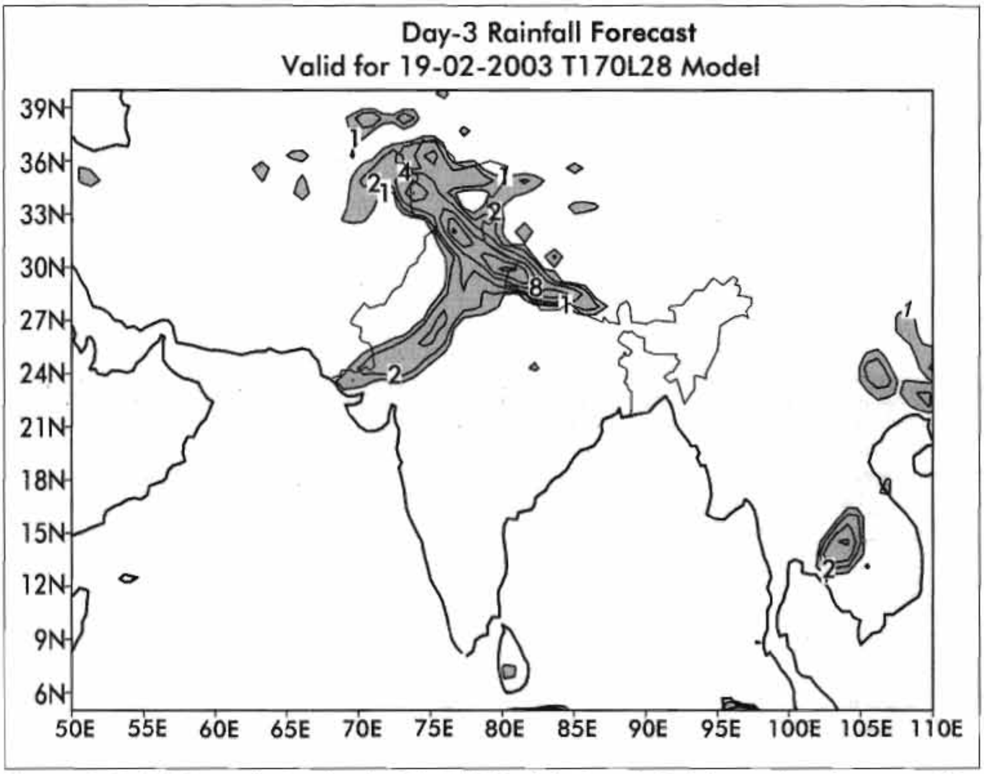

Figure 2: Rainfall prediction by the T170/L28 global model 72 hours in advance valid for 19 February 2003, when a large amount of precipitation was observed over Northern India due to a western disturbance

The model has been installed at NCMRWF on the supercomputers CRAY-SV1 and PARAM-10000 as well as on the workstations SGI-Origin and Dec-Alpha. The model has been tested with double and triple nested domains at 90, 30, and 10 km resolutions over the Indian region. The innermost domain at 10 km resolution has been placed over the Jammu and Kashmir regions. The model is run using the Grell scheme for cumulus parameterisation and, the non-local closure scheme for boundary layer parameterisations. Explicit treatments of cloudwater, rainwater, snow, and ice are performed using a simple ice scheme. Cloud radiation interaction is allowed between explicit cloud and clear air. The initial and lateral boundary conditions are obtained from the operational global T80 model of NCMRWF.

The model has been producing real-time forecasts since the 1st of January 2002. Several case studies of western disturbances, active monsoon conditions, heavy rainfall events, and cyclones over the Bay of Bengal have been studied using this model. Results show considerable improvements in the forecasts compared to the global T80 model. The model has also been studied at cloud resolving scale (1 km resolution) for a specific case study of a heavy rainfall episode over Delhi. In another application, the model has been applied to mountain weather forecasting over the Himalayas. The results indicate that the model can be used for mesoscale weather forecasting over the Indian region with reasonable accuracy.

A sample forecast of a western disturbance that passed over the Himalayan region during 14-17 January 2002 is presented here. The western disturbance extended up to 4.5 km above sea level and moved over Jammu and Kashmir and surrounding areas on the 14th of January 2002. The system propagated eastward during the next three days depositing considerable precipitation and snowfall on its way over the high mountain regions. Cold wave conditions prevailed in most parts of north-west India. The rainfall reported at some of the stations in this period is shown in Table1. Snowfall ranging from 15 to 50 cm was reported at many places in Jammu and Kashmir and Himachal Pradesh. Figure 3 shows the rainfall forecasts for 16-17 January over the central Himalayas. The model was able to forecast the rainfall distributions over different parts of the Himalayas reasonably well as compared to the actual observations.

Table 1: Observed Rainfall (January 2002)

Station (Western Himalayas)	Rainfall (mm) 16th Jan	Station (Central Himalayas)*	Rainfall (mm) 16th Jan	Rainfall (mm) 17th Jan	Station (Eastern Himalayas)	Rainfall (mm) 17th Jan
Delhi (Saf., Pal.)	15, 10	Dadeldhura	30.3	-	Guwahati	12
Chandigarh	5	Dipayal	30.8	-	Shillong	3
Bhuntar	24	Dhangadhi	28.5	-		
Shimla	7	Surkhe	35.4	-		
Srinagar	10	Nepalgunj	27.2	-		
Patiala	1	Jumla	38.5	-		
Jaipur	5	Dang	13.4	T		
Lucknow	8	Pokhara	30.6	1.6		
Dehradun	8	Bhairawa	17.6	1.6		
		Kathmandu	10.2	10.2		
		Okhaldhunga	3.6	6.6		
		Taplejung	5.4	19.2		
		Dhankuta	1.6	10.8		
		Nagarkot	16.0	13.5		
		Jiri	12.2	11.2		
		Bharatpur	16.5	2.5		

*Source: HMGN Dept. of Hydrology and Meteorology

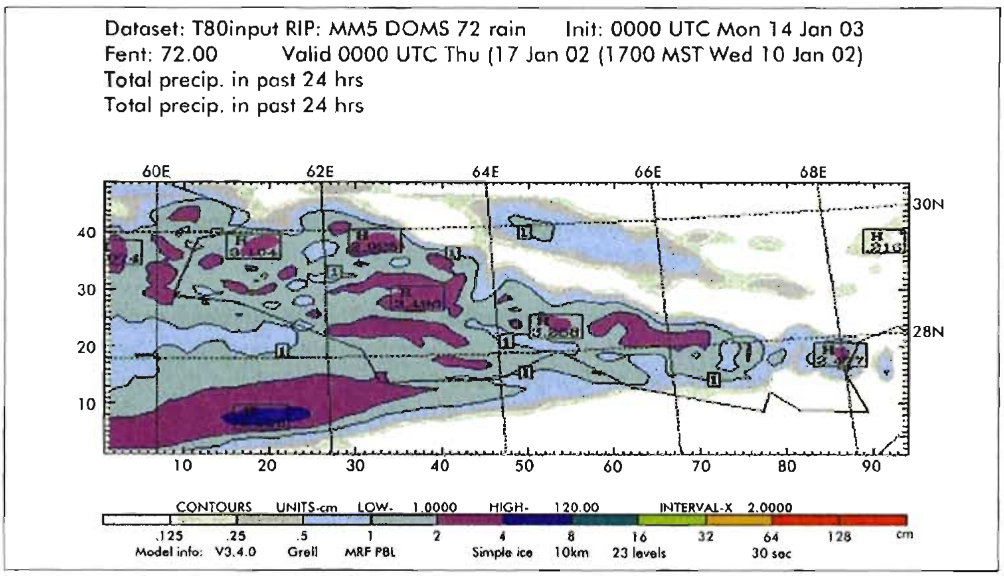

Figure 3: Rainfall forecast (72 hrs) over the central Himalayas valid on 17 January, 2002

Prediction Using the Eta Model

The NCEP in the USA, developed a step-mountain eta (η) coordinate model generally known as the Eta model which was made operational in 1993 (Black 1994). A workstation version of the Eta model (Version 0.2) released in March 2000 has recently been installed on an SGI-Origin 200 workstation at NCMRWF. The model has been run operationally since 1 January 2002, and the forecasts displayed on the NCMRWF website (www.ncmrwf.gov.in).

The Eta model is a hydrostatic mesoscale weather forecast model which accurately treats complex topography using eta vertical coordinates and step-like mountains, eliminating errors present in the sigma coordinate in the computation of pressure gradient forces over steeply sloped terrain (Mesinger and Black 1992). The model employs a semi-staggered Arakawa E-grid in which wind points are adjacent to the mass points configured in rotated spherical coordinates. The mesoscale Eta model is run operationally with a horizontal grid spacing of 48 km and 38 vertical levels, with layer depths that range from 20m in the planetary boundary layer to 2 km at 50 mb. The model top is at 25 hPa. Split explicit time differencing is used with a time step of 120 seconds. Spatial differencing is done with a conserving Arakawa type scheme and the model's step mountains are derived using the official United States Geological Survey (USGS) topographical data.

The physics of the model as described by Janjic (1994) includes a modified Betts-Miller scheme for deep and shallow convection and the prediction of cloudwater/ice. The GFDL scheme is used to calculate radiation. Free atmospheric turbulent exchange above the lowest model layer is computed using a Mellor-Yamada level 2.5 closure and the surface layer similarity functions are derived from Mellor-Yamada level 2.0 closure. A viscous sub-layer is used over water surfaces. The land surface scheme is a version of the OSU scheme modified by Chen et al. (1997).

NCMRWF global (T80/L18) analysis and 6 hourly global model forecasts are used for initial and lateral boundary conditions. Wind, temperature, relative humidity, and geo-potential height are interpolated to 26 pressure levels and a 1° x 1° global resolution is used. Daily NCEP 1° global sea surface temperature (SST) analysis, and 23 km daily NESDIS snow cover downloaded from <ftp.ncep.noaa.gov> are used. Soil moisture at 2 layers (surface and root zone), soil temperatures at 3 layers, and global sea-land-ice mask are extracted/generated from the surface analysis of the NCMRWF global analysis-forecast system.

A new version of the Eta model, which has nesting capability, has been installed on a Linux PC to produce higher resolution forecasts. This version uses the NCMRWF's operational Eta model outputs as initial and lateral boundary conditions. This methodology would be very useful for sharing with other interested neighbouring countries. A sample plot of rainfall forecasts for a recent case from the 2 model runs is shown in Figures 4 and 5.

The Flood Situation in India

India is a vast country with a large variety of weather systems; the extent to which each system affects a given region gives that region its distinct seasonal character. Though floods occur in the southern parts during the north-east monsoon and in coastal areas

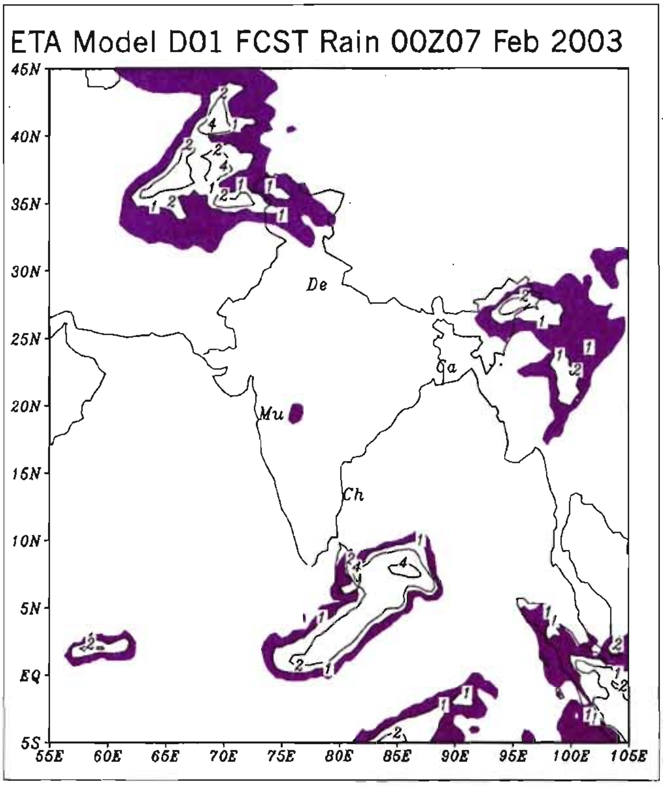

Figure 4: Day 1 rainfall forecast from 48 km Eta model valid for 00z 07 February, 2003

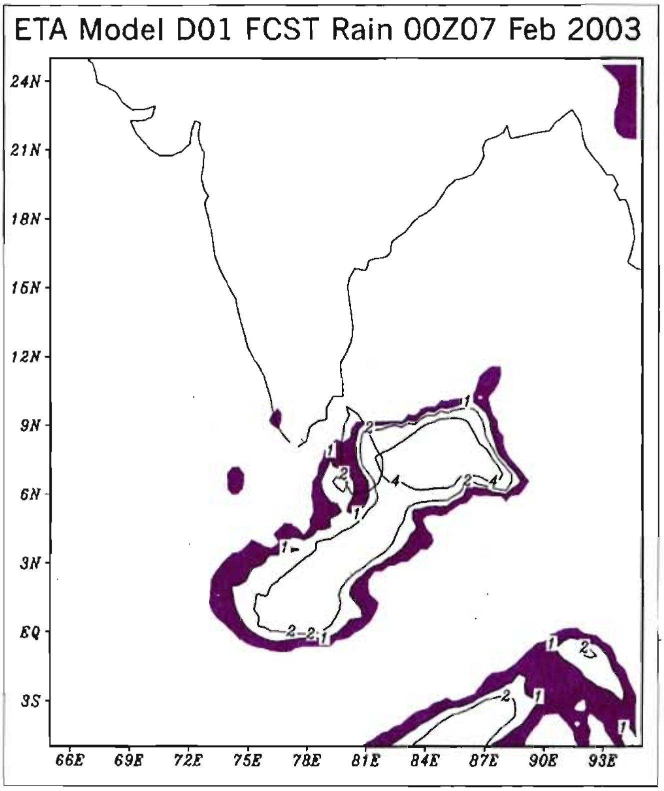

Figure 5: Day 1 rainfall forecast from 32 km Eta model valid for 00z 07 February, 2003

as part of tropical cyclones experienced in the pre and post monsoon seasons, most floods occur during the summer monsoon, which is responsible for 78% of the annual rainfall in the country. Floods commonly occur in the Indo-Gangetic plains in north India, the Narmada and Tapi river valleys in central India, the Krishna, Kaveri, and Godavari valleys in peninsular India, and the Brahmaputra-Barak river basin in north-east India. The most frequent floods occur in the sub Himalayan region from the Ganges-Brahmaputra river systems, and the Indian part of the Indus river system. East Uttar Pradesh and Bihar are the most flood prone states in India. This region contains over 18% of the flood-affected area and nearly 30% of the flood affected population of the country. Some statistics on flood damage are shown in Figure 6.

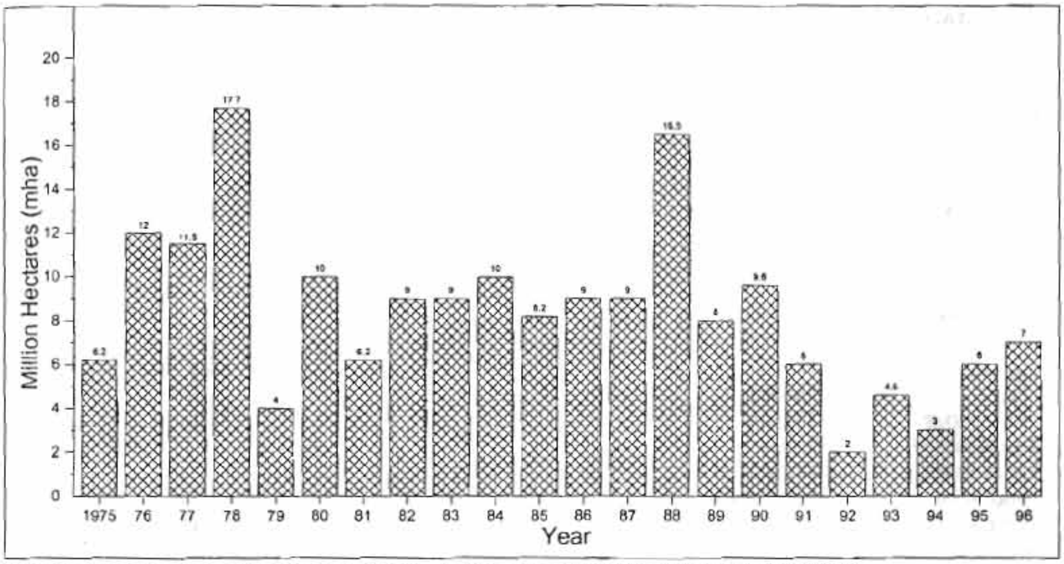

Figure 6: Inter-annual variability of flood damage in India (after CWC 1998)

The tributaries of the Ganges that originate in the Nepal Himalayas (Mahakali, Karnali, Adhawara, Gandaki, Kosi, Luri, Rapti, Kamla, Bhagmati, Mahananda) and join the Ganges in Uttar Pradesh, Bihar, and West Bengal are particularly susceptible to floods due to the geomorphology of the region. Antecedent rains moisten and saturate the subsoil hindering further percolation. The resultant runoff quickly joins the streamflow leading to severe flooding in the affected areas. Similar conditions apply for the Brahmaputra-Meghna-Barak basin. This region receives heavy downpours daily during the monsoon onset (sometimes exceeding 20 cm a day) due to the release of convective instability, and the region can witness multiple floods in the same monsoon season.

Heavy Precipitation Events

Floods are generally preceded by heavy monsoon rainfall, which is highly convective in nature. Nearly 80% of the seasonal rainfall is produced by only 10% to 20% of the rainfall events lasting for 1-3 days. The four main areas that receive exceedingly heavy rainfall are the west coast of India, north-east India, the foothills of the central and western Himalayas, and central India. The first three of these are associated with large-scale vertical motion related to synoptic and mesoscale disturbances and orographic lifting, where it is common to experience up to 40 to 50 cm of rain per day. Cherrapunji, a hill station in Meghalaya in north-east India (which holds several world records), has recorded the highest rainfall accumulations of 104 cm, 165 cm, and 224 cm in 1, 2, and 3 days respectively. The highest rainfall in a plains station – 99 cm, 126 cm, and 145 cm in 1, 2 and 3 days – occurred over Dharampur in Gujarat. Table 2 shows some of the highest 1, 2 and 3 day rainfalls recorded (after Rakhecha and Pisharoty 1996). About 15-50% of daily rainfall can occur during a 1-hour session and rainfall of 6 cm in 1 hour is not uncommon. Such intense precipitation often leads to flash floods particularly in mountainous regions.

Table 2: Highest recorded 1,2 & 3-day rainfall values between 1875 & 1982

Station	State	Height (m)	1-Day (cm)	2-Day (cm)	3-Day (cm)	Date
Mawsynarm	Meghalaya	1401	99	143	201	Jul-1952
Cherrapunji	Meghalaya	1313	104	165	224	Jun-1876
Bhagamandala	Karnataka	876	84	136	136	Jul-1924
Ponnampet	Karnataka	857	52	61	67	Jul-1965
Agumbe	Karnataka	659	62	93	95	Jul-1963
Satna	Madhya Pradesh	549	54	58	61	Jun-1882
Khandala	Maharashtra	539	52	67	73	Jul-1958
Bassi	Rajastan	351	56	84	85	Jul-1981
Rewa	Madhya Pradesh	286	77	77	82	Jun-1982
Dhampur	Uttar Pradesh	258	77	99	99	Sep-1880
Bamanwas	Rajastan	252	51	76	103	Jul-1981
Nagina	Uttar Pradesh	250	82	104	104	Sep-1880
Najibad	Uttar Pradesh	240	72	98	98	Sep-1880
Karjat	Maharashtra	107	61	67	73	Jul-1958
Dharampur	Gujarat	38	99	126	145	Jul-1941
Gopalpur	Orissa	17	51	65	70	Oct-1954
Porbandar	Gujarat	12	51	62	66	Sep-1977
Cuddalore	Tamil Nadu	12	57	82	95	May-1943
Bombay	Maharashtra	11	57	80	88	Jul-1974
Vegurla	Maharashtra	9	53	82	88	Jun-1958
Kakinada	Andhra Pradesh	8	50	53	57	Jun-1941
Quilandi	Kerala	8	91	109	113	May-1961

Meteorological Conditions Responsible for Floods

The intense rainfall that leads to floods occurs in association with sub synoptic and mesoscale circulation embedded in synoptic scale disturbances. The size, speed, and intensity of these disturbances may determine the magnitude and distribution of rainfall during the passage of a weather system. The location of river catchments with respect to the weather disturbance and the topography of a region may ultimately decide the runoff. The meteorological conditions generally associated with monsoon floods are as follow.

- The movement of monsoon disturbances like depressions and low-pressure areas from the Bay of Bengal and the Arabian sea (as well as similar systems generated over the landmass of India) cause heavy rainfall along their tracks, especially in their south-west sectors. The flood situation is aggravated if the monsoon disturbances impact the same areas in succession within a 3-5 day period.
- Formation of a mid-tropospheric cyclone (MTC) along the Goa-Konkan-Gujarat coast causes very heavy rainfall over western India.
- Interactions between the monsoon systems and the baroclinic disturbances (westerly troughs) moving from west to east across northern India.

- 'Active' monsoon conditions for several days and associated orographic ascent.
- 'Break' monsoon conditions over India, which result in heavy rainfall along the foothills that lie in the path of several major rivers and streams across Himachal Pradesh, Punjab, Haryana, West UP, Bihar, West Bengal, and the states of north-east India.
- The occurrence of meso-scale vortices located off the coast of India.

In north-east India severe flooding is experienced during the advance phase of the summer monsoon and later due to the northward movement of the monsoon trough in mid-season. The latter situation is associated with a break in the monsoon activity over central India. Occasionally, monsoon depressions may also move northwards after formation over the head bay or adjoining land regions. The individual flood events are not necessarily associated with the all India scale performance of the monsoon season. For example, extreme flood events occurred in the Brahmaputra area in the deficient monsoon years of 1972, 1984, and 1987, as well as in the excess monsoon years of 1973, 1976, 1983, and 1988. Likewise, the severe rainstorm in Dharampur mentioned earlier occurred in 1941, a year in which the monsoon rainfall was 14.4% below average. Floods in the western Himalayas may result from recurring monsoon depressions after interaction with a trough in the westerlies or movement of the western end of the monsoon trough to the Himalayas. Floods in May and June may also occur as a result of rapid melting of the winter snow.

The Flood Forecasting System

The India Meteorological Department issues warning of heavy rainfall on the basis of the prevailing meteorological conditions, taking into account both the climatology and the intensity and persistence of the ongoing rain producing weather phenomena such as troughs, depressions, and cyclones. For this purpose, it has established 10 Flood Meteorological Offices (FMO) which report on the various catchments in the country (Table 3). The CWC has a network of 157 flood forecasting stations located all over India. Flood forecasts are issued daily from May through October, with an average of about 6,000 flood forecasts per year.

Table 3: Flood Meteorological Offices in India

Name	River catchments
Agra	Lower Yamuna, Chambal & Betwa
Ahmedabad	Narmada, Tapi, Mahi, Sabarmati, Banas & Daman Ganga
Asansol	Ajay, Mayurakshi & Kangsabati
Bhubaneswar	Mahanadi, Brahmani, Baiterini, Bruhabalang, Subernarekha, Rushkulya & Vansdhara
Guwahati	Brahmaputra & Barak
Hyderabad	Godavari & Krishna
Jalpaiguri	Teesta
Lucknow	Ganga, Ramganga, Gomti, Sai, Rapti, Ghagra & Sarada
New Delhi	Upper Yamuna, Lower Yamuna & Sahibi
Patna	Kosi, Mahananda, Baghmati, Kamala, Gandak and Buri Gandak, North Koel & Kanhar & PunPun Upper Sone

Future Work

The precipitation predictions produced by the different numerical models have now achieved a good level of credibility; the next step will be to systematically validate their outputs by testing them in applied flood forecasting situations. The traditional concept of quantitative precipitation forecasting (QPF), pursued until a few years ago, is no longer used. The forecasts may be more accurate for the sub-Himalayan region, which lies near 30°N latitude, but the steep topography and paucity of data in the adjoining Tibetan Plateau region may impede the improvement of forecasts. The forecasts need to be validated against high-density gauge or satellite data. The gauge data may be used along with the satellite derived rain data to initialise the models, leading to improved forecasts. Data from radar may also be used to initialise the mesoscale systems. The availability of faster computers will enable the use of higher resolution, non-hydrostatic or cloud resolving models. NCAR is in the process of amalgamating the MM5 and Eta models. The new model, known as WRF, will have a hybrid coordinate system, which will include potential temperature as a vertical coordinate to treat the orography appropriately. The multi-model mesoscale predictions may be tested to give a probabilistic estimate of weather prediction as was previously done for the large-scale and tropical cyclone predictions. The cooperation by the neighbouring countries will be key for the testing and development of these new models.

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An Integrated Hydrological-Hydraulic Modelling Approach for Flood Forecasting

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Abstract

Flood forecasting systems, producing real-time forecasts of river flows and levels, provide a cost-effective and environmentally acceptable solution to many flood management problems. Modern flood forecasting systems have developed from simple forecasting techniques for local flood warning to sophisticated but user-friendly real-time decision support systems for basin- and region-wide forecasting. After describing the practical requirements of a real-time flood forecasting system, this paper deals with the scientific aspects of a flood forecasting system based on an integrated hydrological and hydraulic modelling approach. The components of a flood forecasting system include data acquisition and management, rainfall-runoff modelling (for simulating catchment processes), hydrodynamic modelling (for modelling the routing of unsteady flows through rivers and flood plains), and predicting water levels and flows. The dissemination of results and warnings pre-designed for transmission to the relevant target groups (both for regional overviews and local information) is part of the integrated modelling system.

Introduction

Sustainable flood management and mitigation are challenges that require advanced engineering technology and a holistic philosophy that focuses on how to manage floods rather than on how to control them. Flood mitigation measures can be broadly classified as either structural or non-structural approaches; flood warning is only one aspect of non-structural flood mitigation. Flood warning systems provide a cost-effective and environmentally acceptable solution to many flood management problems, and flood forecasting models form the basis of many such systems. The role of forecasting models in flood warning is to translate observed channel, catchment, and weather data into forecasts of future conditions and to apply these forecasts to the relevant information by setting them within the context of likely consequences. In this, the forecasting model can be regarded as real-time decision support system for both flood management and flood warning.

Flood forecasting is the prediction of water levels, and the extent and depth of flooding in rivers and flood plains. Flood warning is the preparation of forecasts in a meaningful format that can be either numerical or visual. In order to be effective, the warning has to be disseminated to the media for broadcasting, and to concerned organisations who are prepared to act on the information and provide relief to vulnerable communities.

No single model can cover all scenarios. Models for large basins like the Ganges, Indus, or Brahmaputra are based on the information available in the region, and the intended application. The size of the area under consideration largely determines the model to be used; for example, flash floods in small hilly basins require different inputs than the slowly changing floods more commonly encountered on main rivers. In order to determine the proper forecasting approach, it is necessary to distinguish between:

- short-term forecast models for flash floods, which require rainfall-runoff modelling with very detailed and accurate meteorological information;
- rainfall-runoff type models combined with river routing models which forecast floods in the middle reaches of major rivers by calculating flows from tributaries and losses of flow volume due to overbank flow;
- large river models that can be based to some extent on correlations, but which require routing models for the river reaches between gauges;
- models for delta regions which permit the calculation of the impact of storm surges on the flood levels in the river; and
- long-term planning models, possibly based on climate models, such as are used in general decision support models for regional development plans.

From the early nineties, a flood forecasting and warning system based on an advanced hydraulic model has been in place in Bangladesh. However, this system has been limited to the forecasting of water levels in the major rivers, and possibly because the dissemination system has been insufficient, these forecasts have been either not easily understood or not used by the rural population. During the last five years a new system has been developed which includes depth-area inundation forecasting. In order to meet the requirements of the end users, a new dissemination system has also been developed. This new dissemination system includes a suite of phased warning messages that provides early notification to other agencies and additional phased warning messages as the severity and impact of flooding increases. The new flood forecasting system, MIKE 11, has been integrated with a GIS environment and now provides a very powerful tool for real-time flood forecasting and flood warning. A brief description of the operational flood forecasting system in Bangladesh is given below.

Practical Requirements of a Real-time Flood Forecasting System

Figure 1 shows a schematic of the main activities in a model-based flood forecasting, warning, and dissemination system in a river basin.

The forecasting system should provide a clear overview of the current situation in the catchment areas at any given time and be able to display them using a geographic information system (GIS). It should be able to provide a forecast of river flows, including reservoir inflows, and water levels along tributaries as well as in the mainstream. The system should contain facilities to support decision making on the operation of reservoirs and other major hydraulic structures in the catchments, considering the downstream flood risk both on short and longer terms.

The key prerequisites of such a forecasting system are robustness and reliability. The system should provide accurate forecasts, even in critical situations. The system should, however, be modular and flexible, so that it can be adapted to the specific requirements of a river basin flood-forecasting programme at either the basin or regional level. Ideally a network of local level forecasting systems that are linked to a national system should be able to not only provide detailed forecasts locally but also automatically transmit key data and forecast results to systems covering downstream areas.

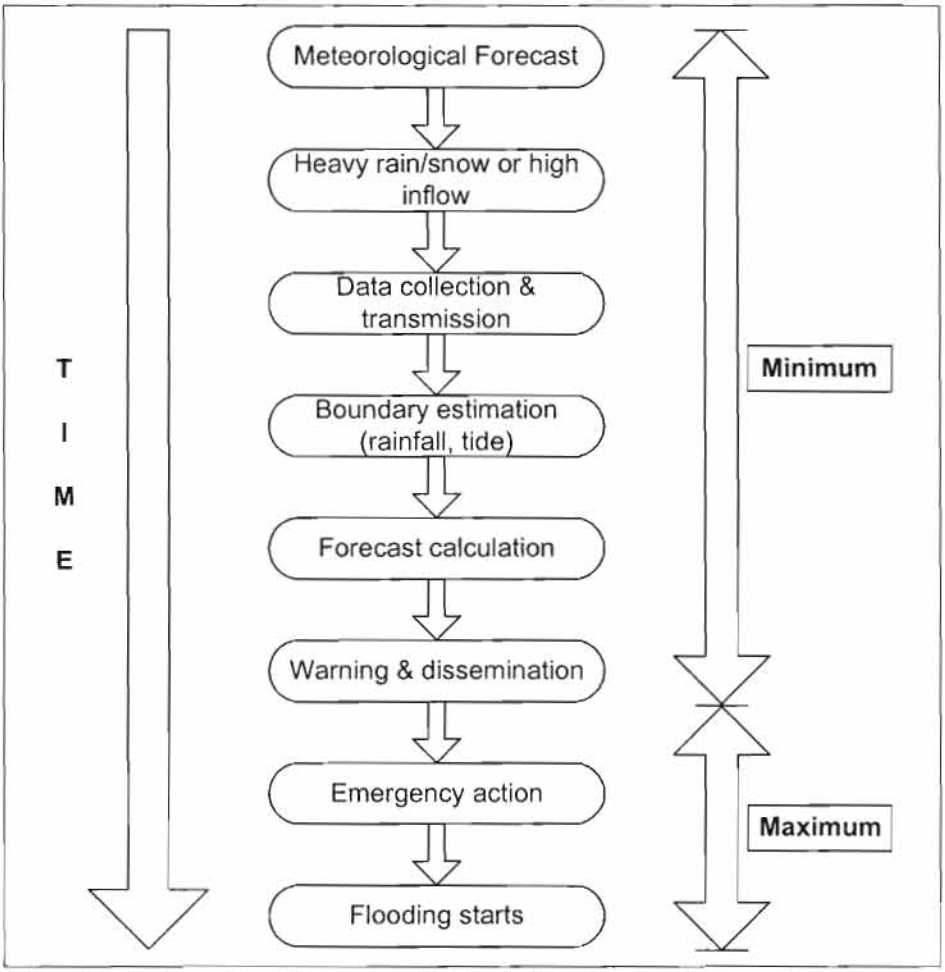

Figure 1: A schematic of the main activities in flood forecasting, warning, and dissemination

The forecast procedure should be fast and reliable and include the following components.

- Import and quality checks of real-time data that are delivered either by a suitable telemetry system or are transmitted manually
- Import of quantitative precipitation forecasts
- Import (or automatic estimation) of expected boundary conditions (such as the tidal variation) for the forecast period
- Rainfall-runoff models to calculate sub-catchment runoff and the automatic transfer of these results to the river model
- A hydrodynamic model for routing the unsteady flow through river channels and floodplains and which can predict water levels and flows. For completeness, the model must include wetlands, flood retention areas, and reservoirs, as well as major hydraulic structures.
- A hydraulic model that is able to describe the effect of movable structures whose gate operations are either operated on the basis of fixed rules or are decided by an operator. The operator's option to overrule fixed rules should also be taken into

account. Furthermore it should be possible to quickly include the effects of a dyke break in the model, whenever this occurs.

- A two-dimensional model that can describe the spreading of water on floodplains in cases where a one-dimensional description is deemed insufficient. A direct link between the 1- and 2-dimensional models is recommended to ensure accuracy and speed in the calculations.
- An automatic updating procedure which utilises the measured and/or calculated discharge or water levels to minimise differences between observed and simulated flow/water levels up to the time of forecast and beyond
- Dissemination of results and warnings pre-designed for transmission to the relevant target groups, both for regional overviews and for local information
- The modelling system should be easy to integrate with other systems so that results can be quickly disseminated where needed (including posting to web-pages).
- A procedure should be put in place for the production of flood inundation maps showing both water depth and extension. A series of pre-generated flood maps for different return periods should also be available so that a quick first indication of the expected inundation can be obtained.
- The whole forecasting procedure should be controlled by a robust and well-tested 'shell', which can be operated either in a fully automatic mode or in a manual mode allowing for different degrees of operator intervention. For example, validation of expected rainfall in a particular catchment should be able to be performed either by the operator or by visual quality checks of new telemetry data.

Integrated Modelling Approach

Most floods are generated by meteorological events that can be forecast by meteorological models. Hydrological and hydrodynamic models which can forecast water flow conditions in catchments and rivers to a very high accuracy need to be based on mathematical descriptions of how catchment rainfall-runoff processes contribute to the propagation of floods along river channels and flood plains. However, these models depend on detailed meteorological forecasts and when these are lacking or incorrect the hydrological model is of limited accuracy. It is thus important to integrate meteorological and hydrological/hydrodynamic forecasting models to make optimum use of the very detailed meteorological forecast information available and to maximise the accuracy and lead time of forecasts made for water flow conditions in a river. Figure 2 shows a schematic of a model based on a real-time flood forecasting system. The overall model is designed to perform the calculations required to predict the variations in discharge and water levels in a river system as a result of catchment rainfall and inflow/outflow through boundaries in the river system. All the model calculations required for issuing a forecast are done automatically by utilising a number of individual modules/sub-systems (MIKE11 FF) (DHI 2002). The essential subsystems of an integrated flood forecast modelling system are discussed below.

Catchment Rainfall-runoff Model

Modelling of the rainfall-runoff process in a catchment (Figure 3) is the first step in flood forecasting. A wide range of modelling systems have been developed and applied around the world (Singh 1981). Models are required to understand both man-made changes in land use and prevailing natural conditions. Over the years these models have been refined by continually improving the representation of the physical processes occurring in the catchments.

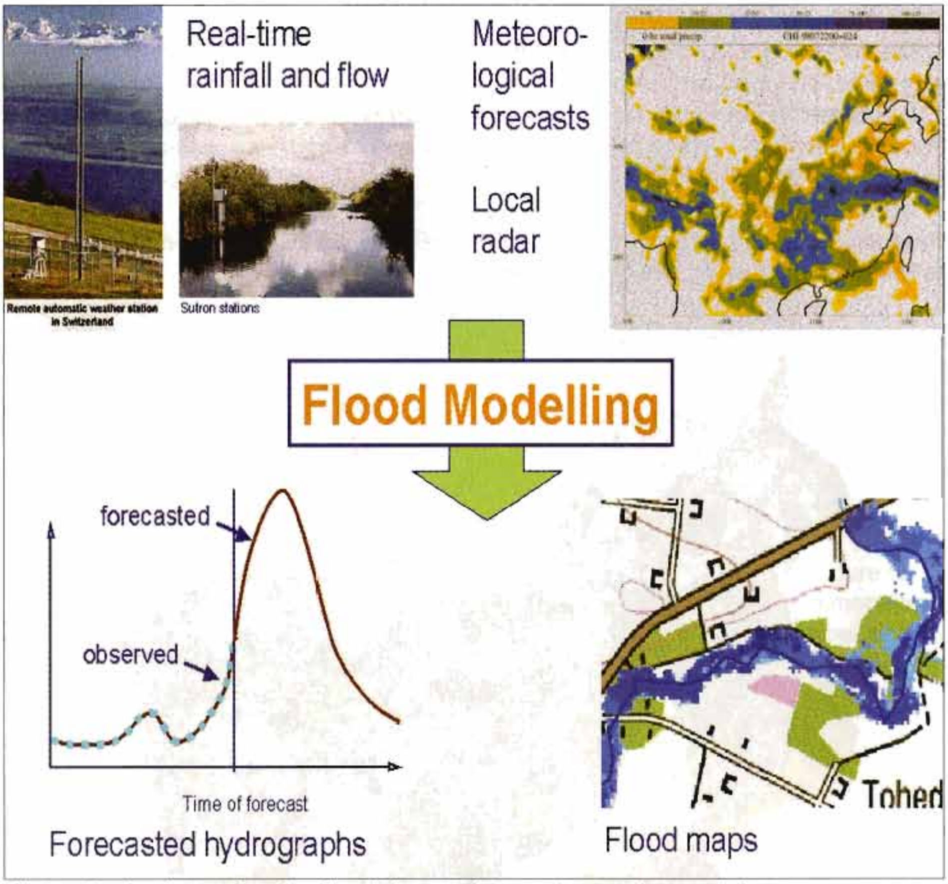

Figure 2: A schematic of a flood forecasting system using models

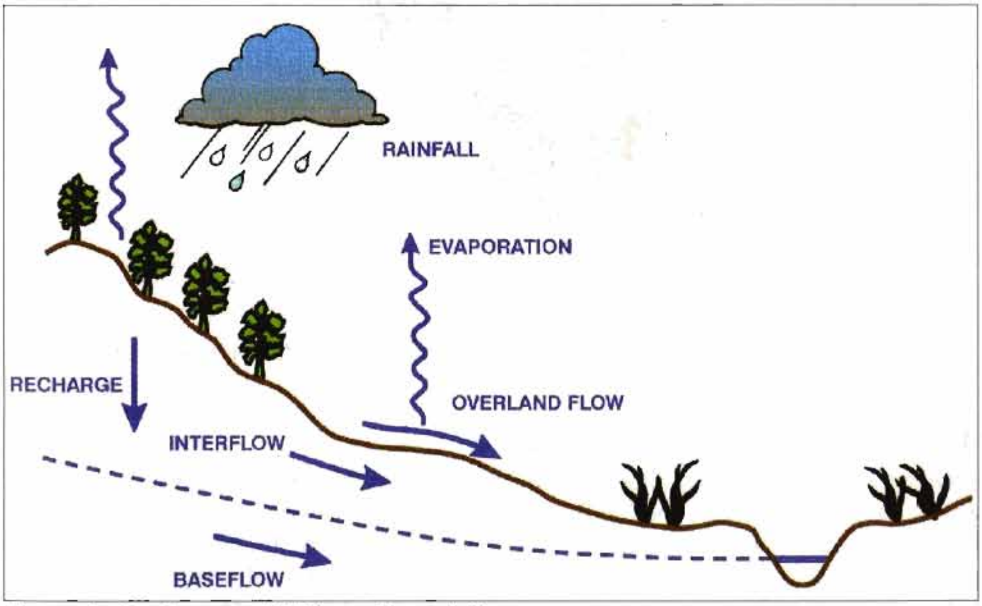

Figure 3: Catchment rainfall-runoff modelling

In Bangladesh, the catchment rainfall-runoff is modelled using a conceptual model called NAM. The NAM rainfall-runoff model (Nielsen & Hansen 1973; DHI 2002) is a deterministic, conceptual, lumped model representing the land phase of the hydrological cycle. It is based on both physical and semi-empirical formulations to describe the inter-relationship between surface storage, intermediate storage, and groundwater storage. Using the mean aerial rainfall and evaporation as inputs, the NAM model calculates the inflow from sub-catchments to the river system. For the calculation of runoff from the catchments, 135 sub-catchments have been identified (Figure 4). The calculated runoff forms the lateral inflow to the river system.

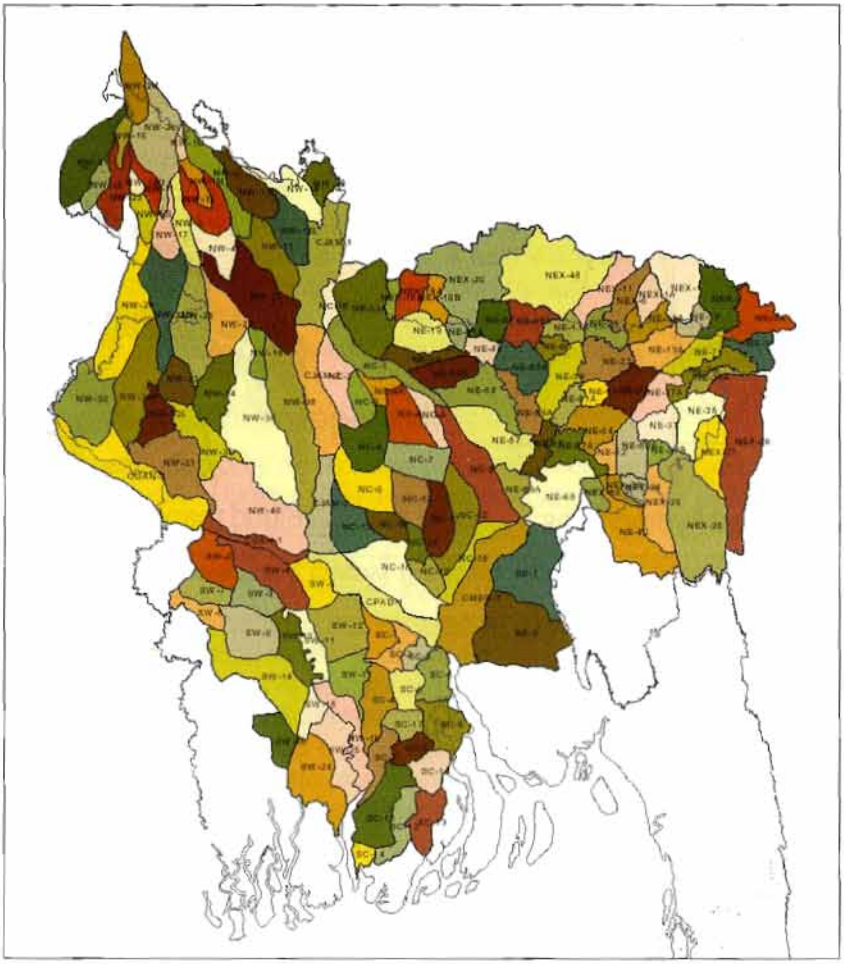

Figure 4: Delineation of subcatchments in Bangladesh for rainfall-runoff modelling (FFWC 2003)

Hydrodynamic Module

The hydrodynamic module contains an implicit finite difference computation of unsteady flows in the rivers based on the Saint Venant equations. The formulation can be applied to branched and looped networks and quasi two-dimensional flow simulations on flood plains (Figure 5). The hydrodynamic module predicts water levels and reservoir inflows based on calculated lateral inflows and additional inflows from external boundaries. All

Figure 5: Two-dimensional flow simulation on a flood plain

major rivers have been included in the flood-forecasting model for Bangladesh. The rivers are described by measured cross-sections for each 1-2 km of the river. Where floodplains are separated from the main river channels, a quasi two-dimensional (2-D) model schematisation has been used, joined to the main rivers by a series of links. Flood cells are used to describe areas which are subject to inundation, but in which water flows are very small or zero. Links are used to connect floodplain branches and flood cells to the main rivers. There are several locations in the model area where breaches in the embankments occur regularly. The model reflects the latest position of breaches. The model has a total number of 23 water level boundary stations. Figure 6 shows the model scheme of Bangladesh rivers used in flood forecasting.

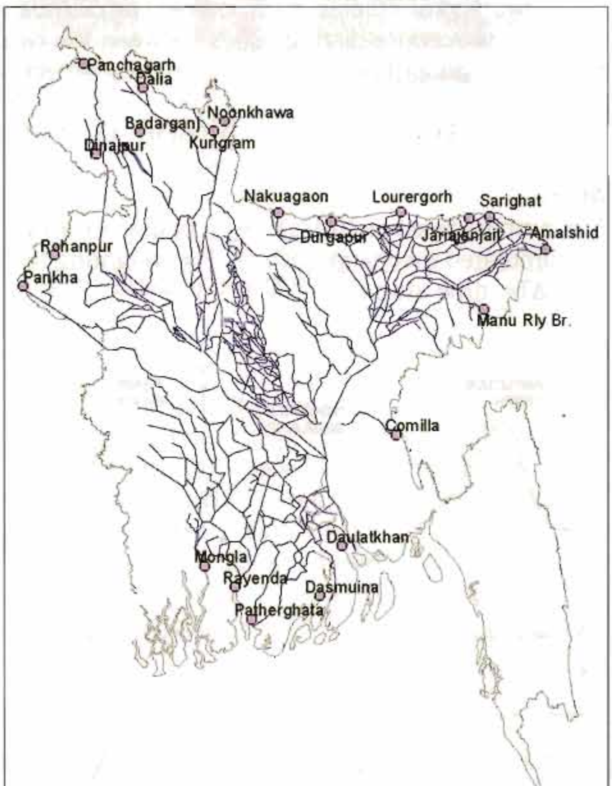

Figure 6: Bangladesh flood forecast model schematic showing boundary stations

Floodplains are modelled using a quasi 2-D approach that requires them to be represented separately from rivers. Unfortunately, floodplains, unlike rivers, do not always follow a defined course and are therefore more difficult to model. Floodplains also behave in a variety of ways, from simple storage basins to major conveyors of floodwaters. Behaviour also varies depending on the height of the flood. Floodplain cells receive, store, and drain flood waters, but do not model conveyance (except via links). They must have at least one link with a river in order to be modelled as a unit that exchanges water between the river and the floodplain. Floodplain branches, like river branches, model flood storage and conveyance. A branch has links at its upstream and downstream ends, and also along its length. Links model the flow between rivers and floodplains. They play an important role in modelling floodplain inundation and drainage. A link may be an embankment, a natural levee, or a channel. Links can be lumped together to reduce the size of the model, for example, several channels and a river levee may be represented as a single link. Flood control and drainage structures may also be incorporated into a link.

Automatic Updating Module

An important feature of any flood-forecasting module within a hydrodynamic modelling system (such as used in the MIKE 11 flood forecast) is its automatic real-time updating procedure (Paudyal 2002). The updating routine is used to minimise any discrepancies between the observed and simulated discharge/water levels at the time of forecast. The updating procedure can identify two different types of deviations or errors between measured and simulated data, namely amplitude and phase errors (Figure 7). The updating procedure distinguishes between the two types of errors and makes corrections accordingly by minimising the objective function given below:

$$\text{Error function} = \sum_{i=1}^{n}(F_i(M_i - (S_i - S_i + 1)/\Delta T * P_e)))^2$$

Where :
A_e = amplitude error (m^3/s) , P_e = phase error (s), M = measured discharge (m^3/s), S = simulated discharge (m^3/s), F = weighting factor, n = number of values included, and ΔT= time step (s).

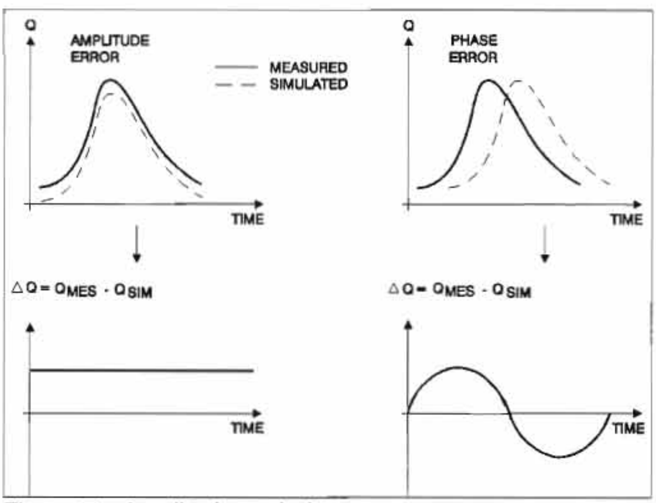

Figure 7: Amplitude and phase errors

The minimum is found by differentiating the equation with respect to the amplitude error A_e and the phase error P_e and solving the equations simultaneously. A series of correction discharges are calculated using the phase errors and amplitude errors identified by the updating routine. The correction discharges are added as lateral inflow/outflow along the rivers at the updating points. Updating can be specified on the basis of discharge or water level measurements and can be carried out at any location in the river system where water level and/or discharge information is available in real time. After the first updating has been performed, a hydrodynamic calculation is performed again including the correction discharges in the river system. This procedure with hydrodynamic calculation followed by updating is repeated until the deviation between the simulated and observed discharge/water levels is minimised.

Integration with GIS for Flood Mapping and Inundation Forecasting

The model results are enhanced for use in flood mapping and inundation forecasting by integrating them with the GIS of the area, especially with the digital elevation model (DEM). Such maps make it possible to calculate the depth-area inundations and show flood duration, as well as to compute flood damage (Figures 8, 9).

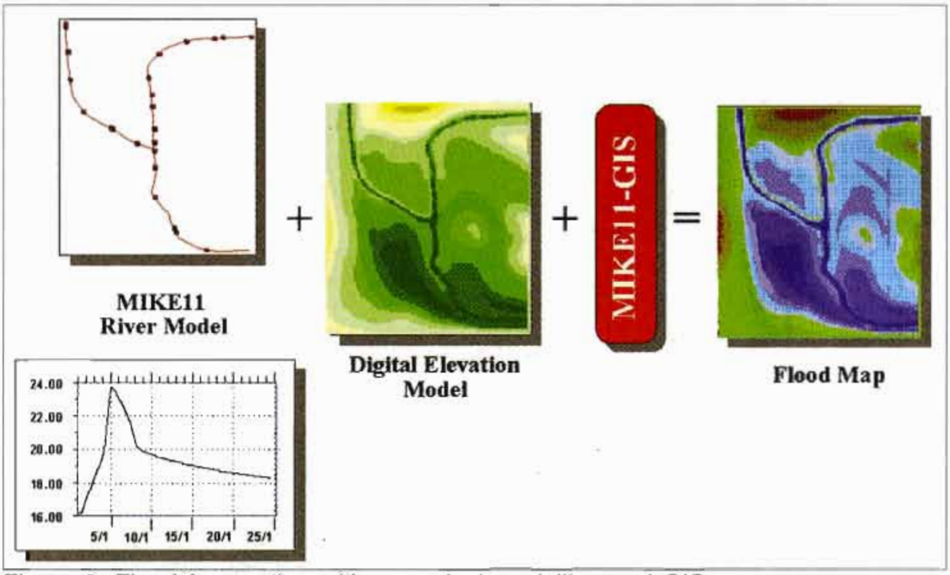

Figure 8: Flood forecasting with numerical modelling and GIS

Model Calibration

Prior to using models for real-time flood forecasting, both the rainfall-runoff and hydrodynamic models are calibrated using observed discharge and water levels. During calibration, model parameters are adjusted to match simulated hydrographs with the observed ones. Flood maps may be calibrated using either satellite or radar images. Model validation is also carried out by comparing model results (without changing the parameters) with observed data. Calibration is possible using either an automatic procedure or a manual trial and error procedure. For flood forecasting models, the calibration is based primarily on high flows during the monsoon seasons. Figure 10 shows sample calibrations for the model in Bangladesh.

Flood Watch

All the subsystems and modules of a flood forecasting system are integrated into a decision support system often called a 'flood watch'. A flood watch system (Figure 11) consists of databases as well as user interfaces for dissemination of flood warnings to affected people as well as to organisations concerned with flood management.

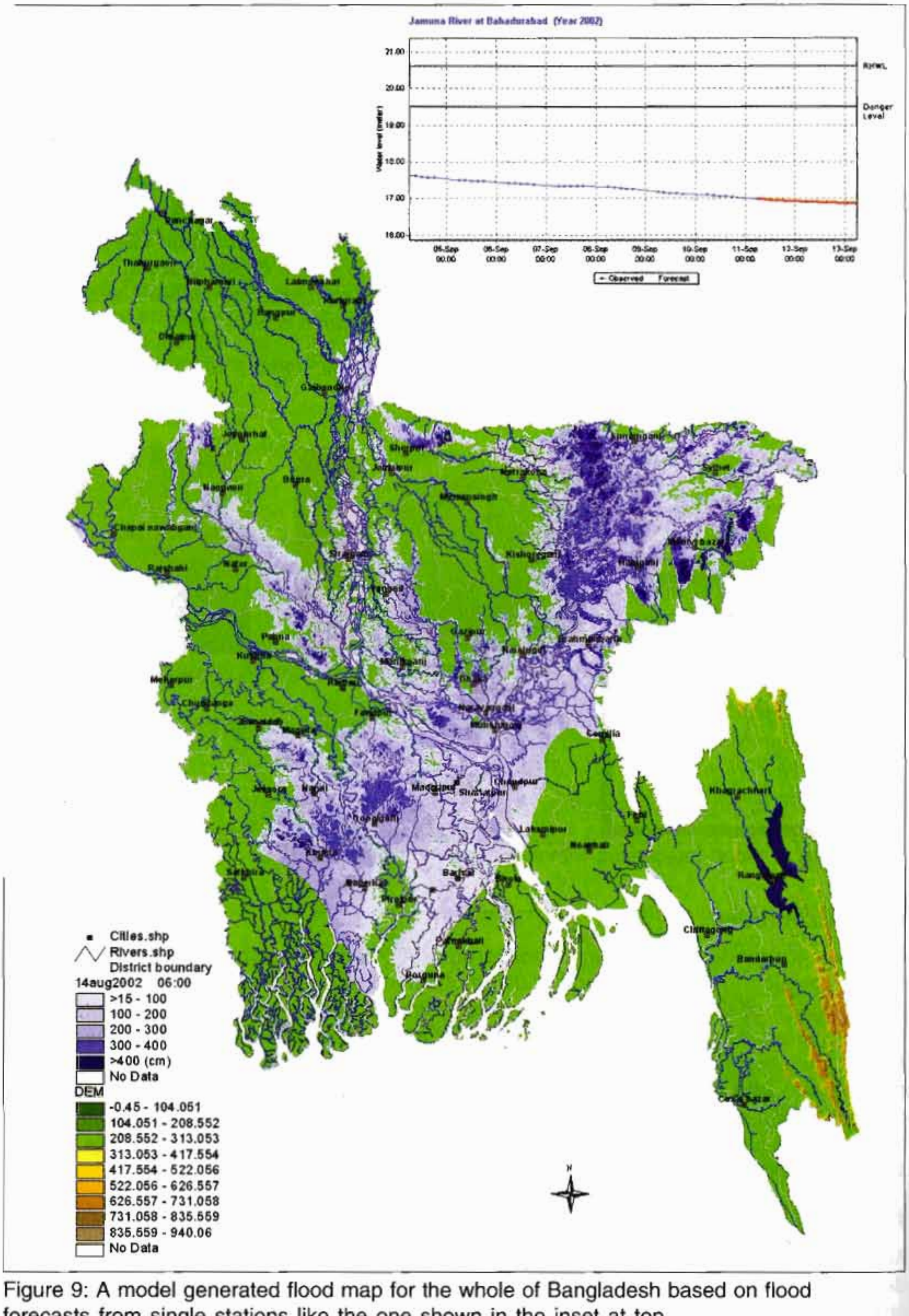

Figure 9: A model generated flood map for the whole of Bangladesh based on flood forecasts from single stations like the one shown in the inset at top

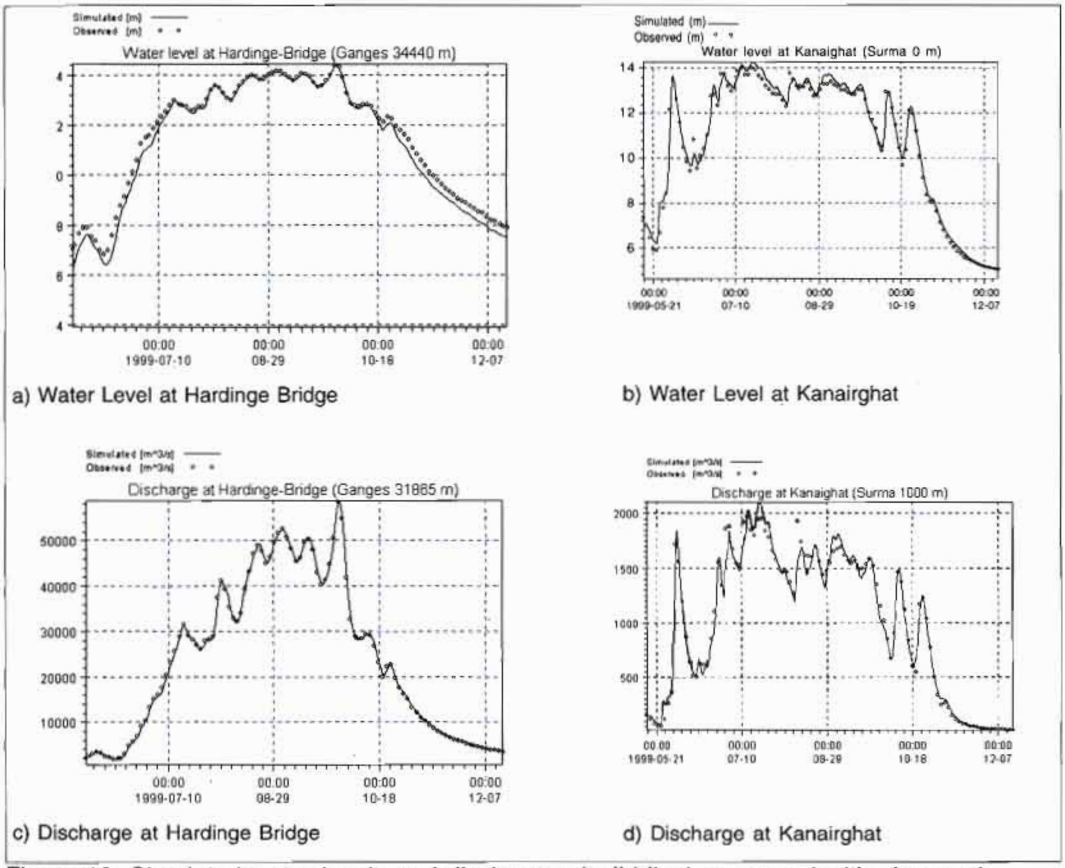

Figure 10: Simulated water levels and discharges (solid line) compared with observed values (dots) at two selected locations in the river system.

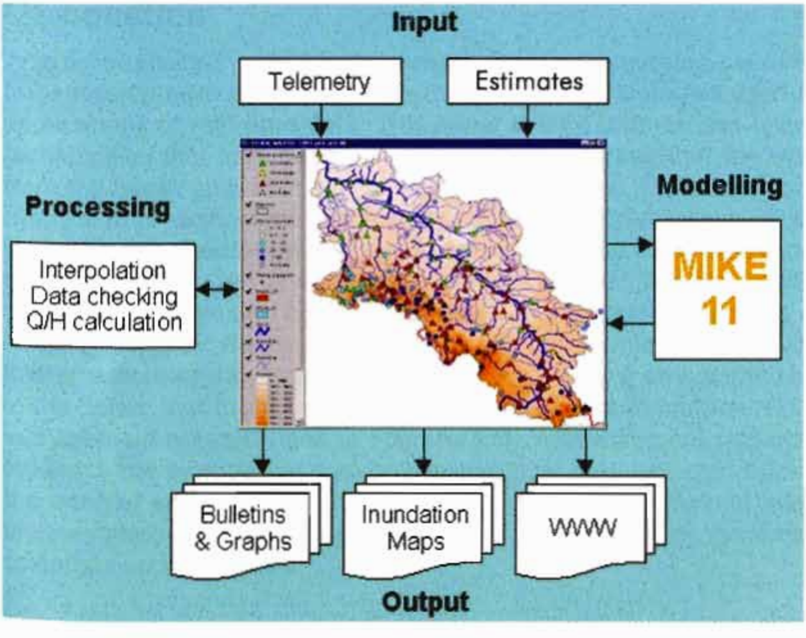

Figure 11: A flood watch system
(Source: DHI Water and Environment)

Conclusions

An integrated flood forecasting system based on a hydrological model for the catchment and hydrodynamic model for the rivers and flood plains has been successfully applied in Bangladesh. Forecasts are routinely produced of water levels in the rivers, and of depth, duration, and area of flooding in the inundated flood plains. The models are used to provide reliable and timely information on floods, and the forecasts they produce form the basis for making appropriate decisions on flood warning and management. The models are also being used in the planning and management of both structural and non-structural flood disaster mitigation measures. The application of these models to real-time flood forecasting has successfully warned people in advance and lives and property have been saved. The modelling approach is applicable to large-scale flooding in river basins and may therefore be extended easily to a regional flood forecasting system.

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Telecommunication Systems for Real-time Hydrometeorological Data Collection and Transmission for the HKH Region

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Abstract

Telecommunication systems for real-time hydrometeorological data collection and transmission have matured greatly, both in the technologies used and the applications of real-time data. Some technologies are appropriate for small-scale monitoring systems that provide warning for local flash-flood prone communities, whereas others are appropriate for large-scale monitoring systems for water management and flood forecasting in international river basins. The Ganges-Brahmaputra-Meghna (GBM) Basin is one of the world's largest international river basins, with 1 percent of the world's land area, and 10 percent of the world's population. Applications appropriate to the GBM Basin for small-scale monitoring networks may include line-of-sight radio or land-line based telephony systems. Increasingly in some small-scale areas, cellular telephones may be appropriate. For monitoring hydrometeorology throughout the entire GMB basin, appropriate technologies include polar-orbiting and geostationary satellites and meteor burst, though there are important cost-of-access and institutional issues with respect to satellite-based systems. Reference is made to the United States and (a) the application of satellite-based technologies, where USGS and NOAA cooperate closely in monitoring hydrometeorology at 6,500 locations nationwide, and (b) a Department of Agriculture meteor burst system for monitoring snow and soil moisture, nationwide. A careful needs analysis is the basis for selecting the most appropriate technology.

Introduction

Telecommunication systems for real-time hydrometeorological data collection and transmission have matured greatly, both in the technologies used and in the applications of real-time data. This paper briefly summarises telecommunication technologies that have become well established throughout the world, largely viewed from the North American experience of the authors. The paper contains a limited discussion of experience in the Ganges-Brahmaputra-Meghna (GBM) Basin, which is based on documentation and verbal communication from colleagues. This paper presents only a brief description of the technologies and the applications, which are still quite dynamic and continue to evolve. Any prospective user is encouraged to carefully consider the requirements for tele-communication of real-time hydrometeorological data when considering applying one of the technologies discussed in the paper. Institutions – ranging from equipment manufacturers and water-management organisations to operators of meteorological satellite systems – all influence the evolution of hydrometeorological data tele-communications. In addition, the Internet sites listed in this paper provide access to current information on technologies, applications, and access policies to satellite systems, and to key scientists and engineers.

Telecommunications Technologies

Real-time hydrometeorological data are required to support numerous water-resources management applications – flood forecasting and warning, municipal and agricultural water supply, hydroelectric power generation, navigation, and environmental protection to name several – and well-established technologies exist to gather such data from automated hydrometeorological networks. There is no universal 'best' telecommunications technology because technology selection is affected by numerous factors, including geographical extent of the networks, meteorological conditions, river-response times, staff capacity, and cost. In the case of satellite-based technologies, institutional and international policies of the organisations that operate the satellites must also be considered. Finally, if real-time data sharing across institutional and international boundaries is part of the criteria for technology selection, then some technologies are more appropriate than others.

In a basin as large and as diverse as the Ganges-Brahmaputra-Meghna (GBM) Basin, numerous technologies are available to gather data from networks. Line-of-sight radio, extended line-of-sight radio (ELOS), telephone, satellite-based, and meteor burst technologies are candidate technologies and are briefly discussed below. The discussion in this paper focuses on the telecommunications aspects of automated data-acquisition systems.

At a typical network station, the sensor data is collected more times in one day than telecommunications and data transmissions convey data from the numerous data-collection cycles. For example, if data is collected at 15-minute intervals from four sensors and telecommunications occur at a three-hour interval, one transmission can convey 48 sensor measurements. Telecommunications can occur in a self-timed mode, wherein the automated network station initiates a transmission to a communications centre, or in an interrogated mode, wherein the automated network station responds to a data request from a communications centre. In the self-timed mode, the transmission may occur at a fixed-time interval – say once every three hours – or when hydrological conditions dictate – say when water levels exceed a predetermined limit or the rate of change of water level or precipitation exceeds selected rates. When hydrological conditions dictate data transmission, thresholds for transmission are programmable and are network-station specific. Finally, regardless of the telecommunications medium selected, they tend to share several common characteristics, such as the following.

Power – each network station typically telecommunicates data only several times a day and telecommunications equipment operates off batteries, recharged by solar panels.

Multiple Communications Media – most equipment suppliers allow multiple communications media at a network station, so that communications redundancy is allowed for.

Vandalism – vandalism of antennas and communications repeaters is a problem everywhere.

Frequency Authorisation – users of all of the radio-based technologies must secure permission to use radio frequencies from their national radio-spectrum management authorities; most countries are members of the International Telecommunications Union (ITU), an international organisation dedicated to promoting standards of communication, worldwide.

Quality assurance – review of real-time hydrometeorological data, using automated as well as human-based approaches, is important.

Annual operational and maintenance costs, which typically are in the range of 10-20 % of the costs needed to implement a hydrometeorological network, must be anticipated. Costs of satellite service can range from nothing to a significant expense in developing countries.

Line-of-sight Radio

As the name implies, this telecommunications technology is possible if the communications centre and the network station are within line of sight of each other. Local-area monitoring systems – such as those that are used for flash-flood monitoring and warning for a city, a small basin upstream of a reservoir, or an irrigation scheme – may be quite well served by line-of-sight radios. Such radios typically operate in the very high frequency (VHF) range – 132-174 Megahertz (Mhz) – or ultra high frequency (UHF) range – 390-512 Mhz.

If the communications centre and a network station are too far apart, and the curvature of the Earth, or mountains or other topographic highs obstruct the view, one or more intermediate repeater stations will be required. Repeater stations add cost and complexity to the network. However, one network station can act as a repeater station for another network station and the topology of network and repeater design can become quite complicated if the network covers a large geographical area or if the terrain is mountainous. This technology has become rather sophisticated over the years and line-of-sight radio networks can be operated in self-timed and interrogated modes, or combinations of the two. Moreover, one communications centre can support the operation of hundreds of network stations and the centre can reprogramme the operation of network stations remotely. Suppliers of line-of-sight radio systems continue to take advantage of improvements in microelectronics to make their systems more compact, cost effective, reliable, and flexible in their application. The number of repeater stations may be reduced significantly by the use of ELOS radio technology. ELOS systems operate in the very low end of the VHF spectrum and are compatible with the meteor burst radio technology discussed below.

Telephone-based Systems

As the name implies, this telecommunications technology relies on the indigenous telephone system, either the traditional landline or increasingly cellular infrastructure. Telephone-based telecommunications media can operate in the dial-up mode or use dedicated lines, and two-way communication between a communications centre and a network station can be supported. Careful consideration must be given to the reliability of the traditional telephone system, especially during flood emergencies when community-based switchboards in flood-at-risk communities can fail and disrupt communication between centres and network stations. Moreover, cellular telephone systems may give priority to voice communication over data communication during flood emergencies and the medium may be least accessible when it is needed most. Of course, dedicated lines and dial-up systems have cost implications that must also be considered. If the issues of reliability and cost can be resolved, suppliers of telephone-based systems provide flexible and reliable systems that are analogous to the systems discussed under line-of-sight radio.

Satellite-based Systems

Several satellite-based systems have come into common usage for real-time hydrometeorological data collection. Although there are commercially based systems such as INMARSAT (http://www.inmarsat.org/) that could be considered, this discussion is limited to government-operated systems. Government satellite systems that support telecommunications of hydrometeorological data are generally operated in support of global weather monitoring. Under the auspices of the World Meteorological Organization (WMO), the Coordination Group for Meteorological Satellites (CGMS) (http://www.wmo.ch/indexflash.html) coordinates planning for and operation of meteorological satellites, and publishes relevant information about them. The following information about these satellites is general in nature and the most up-to-date information can be found in CGMS reports which are available on the Internet at <http://www.eumetsat.de/> under 'Publications'.

Telecommunication of hydrometeorological data via meteorological satellites is very much affected by the orbits of the satellites, which are in either geostationary or near-polar orbits. Both types of satellite provide imagery of the Earth's surface and data on the status of the atmosphere, though this paper focuses only on telecommunication of data from hydrometeorological stations. Figure 1 is a schematic diagram of the orbits of typical hydrometeorological satellites operated by CGMS members.

Geostationary Meteorological Satellite Systems

These satellites orbit the Earth in the plane of the equator at an altitude of 36,000 kilometres. They orbit in the direction of the Earth's rotation, making one orbit around

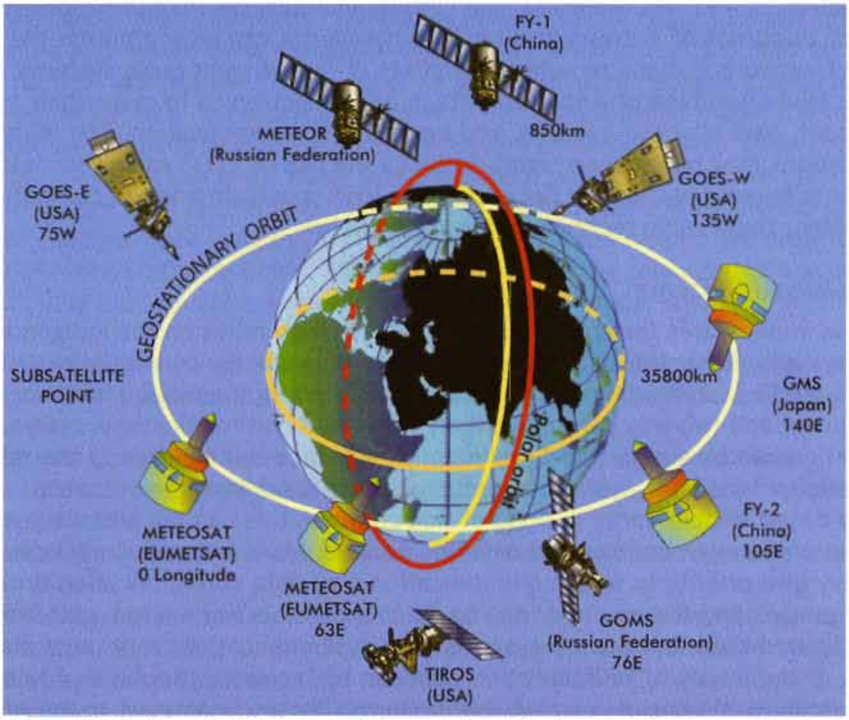

Figure 1: Schematic diagram of the orbits of typical hydrometeorological satellites operated by CGMS members (Source: WMO)

the Earth's centre each day, and appear to hover over fixed points on the equator. The National Oceanic and Atmospheric Administration (NOAA) (http://www.noaa.gov) operates two Geostationary Operational Environmental Satellites (GOES) that have sub-satellite points on the equator at 135° West Longitude (GOES-West) and 75° West Longitude (GOES-East). The European Meteorological Satellite Organisation (EUMETSAT) (http//www.eumetsat.de) operates Meteosat, with a sub-satellite point of 0° Longitude, and the Japanese Meteorological Agency (JMA) (http://www.jma.go.jp) operates the Geostationary Meteorological Satellite (GMS) with a sub-satellite point of 140° East Longitude. All of these systems support a data collection system (DCS) that provides capacity to telemeter environmental data from radios, called data collection platforms (DCPs). The DCS is a frequency division multiple access (FDMA) system that allows concurrent communications by DCPs on 100 or more discrete radio channels on each satellite. Each channel provides time division multiple access (TDMA), which permits many DCPs to use each channel by assigning fixed reporting times and intervals to each DCP. Some of the satellites reserve channels for Alert reporting, so that DCPs that are monitoring potentially hazardous conditions can report such conditions promptly when necessary, while still maintaining routine reporting on their assigned channels. The net result is that the DCS on the satellites can support tens of thousands of DCPs scatted over wide areas of the Earth.

The Indian Government operates a series of geostationary satellites (INSAT), that also supports a DCS and the Indian Meteorological Department (IMD) (http://www.imd.ernet.in/) also launched a geostationary meteorological satellite called METSAT in 2002 (http://www.spacedaily.com/news/020912145126.r84vpm67.html). More current information on these satellites, the full range of data collection they support, and policy related issues are available via the Internet sites included above, and CGMS reports.

Polar-Orbiting Satellite Systems

For many years, NOAA has operated two near-polar orbiting meteorological satellites. These satellites are in orbits that carry them above the Earth's surface at an altitude of about 850 kilometres. In contrast to geostationary satellites, which make one orbit daily, these satellites make about 14 orbits of the Earth each day, from the North Polar Region down over the equator to the South Polar Region and then up again on the far side of the Earth. The orbital planes of the NOAA satellites are sun synchronous, with one making early morning passes over areas of the Earth and the other making afternoon passes.

The Centre National d'Etudes Spatiales, the French National Space Agency (http://www.cnes.fr/) operates a tariff-based DCS called Argos that orbits on NOAA satellites (http://www.noaasis.gov/ARGOS/; http://www.argosinc.com). It is used extensively in support of marine applications. From a radio-communications perspective, the satellites are only in line-of-sight during several of these orbits and for periods that range from a few seconds to ten or more minutes, which means that radio communication via Argos is intermittent. DCP's in the Argos system are referred to as platform terminal transmitters (PTT) and operate in a random-access mode. In this mode, the PTTs merely transmit their data at random times and the data are relayed to communications centres when the satellites are passing by, or the satellites record the PTT data for later downloading to communications centres during a subsequent part of an orbit. Finally, the United States Department of Defense also operates similar satellites and their data are available to civilian users via NOAA. As is the case for geostationary satellites, more complete information about polar orbiting satellites is found in CGMS reports or agency Internet sites.

Meteor Burst Systems

For more than fifty years, a technology known as meteor burst has been used for telecommunication of data from network stations. Initially used for military purposes, this system is now well established for the telecommunication of environmental data. As shown in Figure 2, the system relies on reflecting radio signals off transitory ionised paths in the atmosphere, 90 to 100 kilometres above the Earth, that are left by micrometeorites as they disintegrate in the atmosphere. These ionised paths only persist for a fraction of a second, yet endure long enough to act as repeaters between communications centres and their network stations, which may be as far as 2,000 kilometres away. Typically, VHF radio communications systems use these ionised trails to interrogate and receive data from network stations. A communications centre will repeatedly poll a network station until, by chance – usually within a few minutes – an ionised trail is properly situated for contact to be made, at which time the network station attempts to use the same ionised trail to report its data to the communications centre. Hence there is a probabilistic nature to communication and many operators of meteor burst systems have developed complete statistics on the number of attempts that typically must be made before data collection from a network station can be expected. There is a natural variation in the density of micrometeorite trails, diurnally and seasonally, but for hydrometeorological data collection they are plentiful enough to satisfy many data-collection requirements. Meteor burst communication is also secure, in that it is difficult or impossible for a third party to monitor telecommunications between a communications centre and a network station.

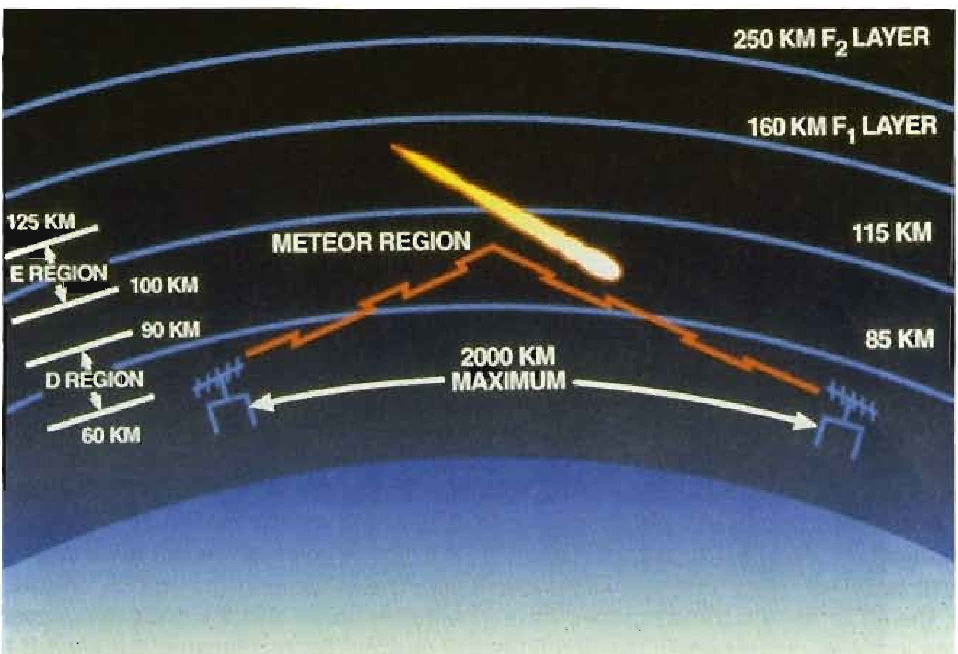

Figure 2: Operational geometry of meteor burst communications technology. (Source: adapted with permission from Meteor Communications Corporation)

Related Institutional Issues

Institutional issues are as important as technical issues with respect to telecommunications of hydrometeorological data. All of the radio-based systems require permission to broadcast from national radio-spectrum management authorities. As opposed to satellite systems, wherein users must negotiate agreements with operators to use the satellites, users of meteor burst technology can access micrometeorites, which are plentiful and free. Nonetheless radio-spectrum management authorities must grant permission to broadcast from meteor burst communications centres and network stations as well.

There are always numerous agencies in a country – and certainly in an international river basin – that collect hydrometeorological data. If these data are to be shared across institutional and national boundaries and their value maximised, data-exchange agreements must be negotiated that define the format, use, and limits of data. In the United States, for example, hydrometeorological agencies have agreed on a standard data exchange format, known as the Standard Hydrometeorological Exchange Format (SHEF) (http://www.nws.noaa.gov/oh/hrl/shef/version_1.3/index.htm). With SHEF, data can be exchanged among communications centres and their values made compatible with both sending and receiving organisations' data-processing systems. The WMO maintains a Global Telecommunications System (GTS) (http://www.wmo.ch/web/www/reports/nyoni_part2-2.html) that supports exchange of selected meteorological observations and products in defined formats from national hydrometeorological services via regional hubs to a main telecommunications network. Some of these links are high speed, though most are medium-speed to low-speed (teletype). Finally, in the case of satellite-based systems, two or more organisations can install 'digital direct readout ground stations' (DDRGS) that simultaneously monitor data being relayed from a satellite and enable them to receive data from DCP, lessening the need for data-sharing mechanisms, such as the Internet or the GTS.

Hydrometeorological Monitoring Applications

This paper briefly cites selected applications of several technologies that are used for the telecommunication of hydrometeorological data. The networks they support range from small, local networks that are well served by line-of-sight radio to national networks that are well served by geostationary meteorological satellite communication. Examples are cited from the United States and South Asia.

USGS Monitoring Network

The U.S. Geological Survey (USGS) stream-gauging programme provides streamflow data for a variety of purposes that range from current needs – such as flood forecasting by the National Weather Service (NWS) – to future or long-term needs – such as detection of changes in streamflow due to human activities or global warming. The development of data on the flow of the nation's rivers mirrors the development of the country. From the establishment of the first stream-gauging station operated by the USGS in 1889, this programme has grown to include 7,292 stations currently in operation. These stations do not represent a single 'network' of stations, but an aggregation of networks and individual streamflow stations that were established originally for various purposes, and that all use a uniform data-collection standard.

The data from about 6,500 of the USGS stations, whose locations are shown in Figure 3, are telemetered in real time to the NOAA GOES DCS. Use of the GOES DCS began in the early to mid 1970s and has gradually grown from about 1,000 stations in 1983 to about 6,500 stations today. Data from the network are received at the NOAA Ground Station at Wallops Island, Virginia, and then immediately retransmitted though a commercial satellite to 20 USGS Local Readout Ground Stations (LRGS) throughout the country. Real-time GOES DCS data are collected, analysed, quality assured, and stored in the National Water Information System (NWIS) and made available in real time to the public. These data are used by a wide range of people and agencies for public and private purposes, such as flood forecasting, water management, recreation, navigation, and water supply. The USGS also collects real-time groundwater and water quality data from selected stations.

The USGS updates the map in Figure 3 in real time and makes it available to the public on the Internet at http://water.usgs.gov/realtime.html. Anyone may access real-time date from any station on the map.

Snow Telemetry and Soil Climate Analysis Network

Since the 1930s, the US Department of Agriculture Natural Resources Conservation Service (NRCS) has been responsible for monitoring the snow pack in the Western United States, where agricultural and municipal water supply is highly dependent upon snowmelt. Beginning in 1976, the NRCS has operated the Natural Resources Conservation Service (NRCS) (http://www.wcc.nrcs.usda.gov/snotel/) to automatically collect data on meteorological and snow pack conditions in remote parts of the mountainous west. SNOTEL is managed from the National Water and Climate Center

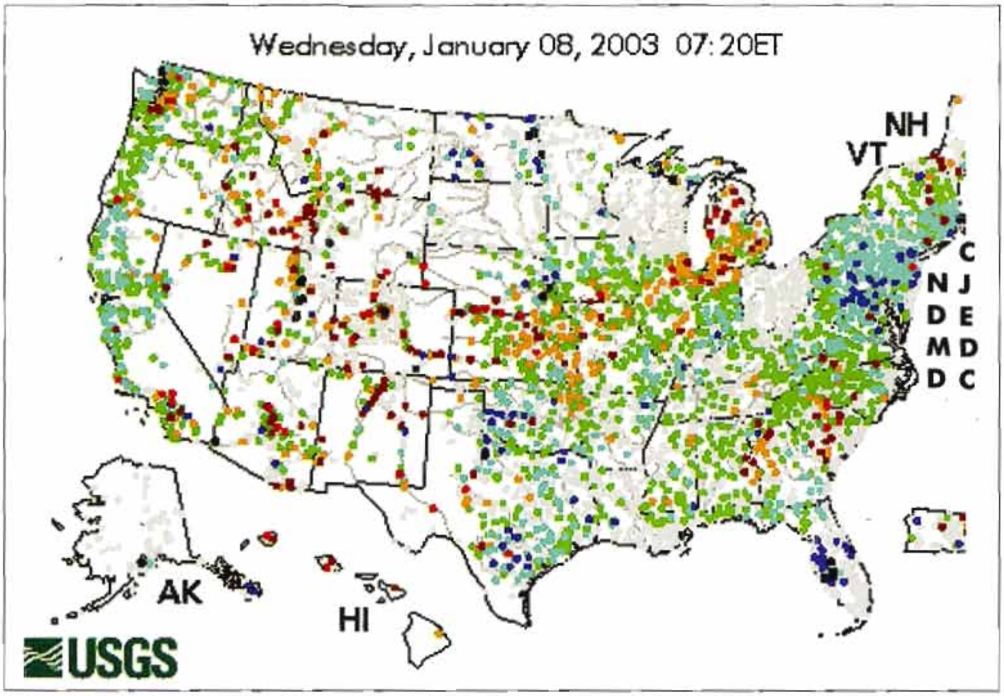

Figure 3: Location of real-time USGS hydrological stations, colour codes indicate streamflow conditions (Source: USGS)

(NWCC) (http://www.wcc.nrcs.usda.gov/) in Portland, Oregon and uses two master communications stations in Boise, Idaho, and Ogden, Utah, to gather data from 670 automated snow monitoring stations in 12 western states. The NRCS and the NWS collaborate on using SNOTEL and other data to prepare seasonal water-supply forecasts for these states. In more recent years, the NRCS has implemented the Soil Climate Analysis Network (SCAN) (http://www.wcc.nrcs.usda.gov/scan/index.htm) to monitor soil moisture and temperature at 72 network stations in 34 states, again using meteor burst technology. An added feature of meteor burst technology is that it can be operated in a line-of-sight mode; in Puerto Rico the stations operate as line-of-sight stations and use the same communications equipment as other meteor burst stations in the SCAN network. The NRCS intent, if funding becomes sufficient, is to increase the geographical coverage of SCAN to as many as 1,000 network stations. With this increased capacity, it could strengthen its capacity for drought monitoring, soil moisture accounting, calibrating satellite-based estimates of soil moisture, providing input to global circulation models, and supporting other water- and agriculture-related issues.

Selected Applications in the GBM Basin

Some selected applications of telecommunications of hydrometeorological network data in South Asia are described below. The list is only illustrative and far from complete.

Line-of-sight and Meteor Burst

An extended line-of-sight communications system has been installed in support of a community-based flash-flood warning system in Nepal. This system is intended to warn of the breakout of the Tsho Rolpa glacial lake in Nepal, which threatens as many as 6,000 downstream residents, a hydroelectric project, and other downstream infrastructure. Several of the monitoring stations will have redundant communications capacity to communicate also with a meteor burst master station over 600 km away in the western part of Nepal. This station provides meteor burst coverage to most of Nepal (written communication from Sandra Garl, Meteor Communications Corp).

Meteor Burst

Inflow forecasting for major reservoirs in the upper Indus Basin for the Water and Power Development Authority of Pakistan (WAPDA) was designed using meteor burst technology as the communications medium. Implemented in the early to mid 1990s, the system design included 20 hydrometeorological stations and a master station that communicated data to the WAPDA office in Lahore for processing. This system was later expanded to include 30 stations of a flood-forecasting network (written communication from Sandra Garl, Meteor Communications Corp; Bell et al 1994).

Geostationary Satellite-based Systems

Several satellite-based communications systems have been implemented in recent years in South Asia (written communication from Raul McQuivey, Sutron Corp), including the following.

- The Andhra Pradesh Hazard Mitigation and Emergency Cyclone Recovery Project (APHMECRP) installed 15 DCPs at remote strategic locations in India from 1997-2002. A follow-on phase includes the additional installation of 78 rainfall and water-level monitoring stations that telecommunicate their data via the INSAT satellite to two digital direct readout ground stations. Also instrumented were five remote stations that measure coastal parameters, including tide height, wind speed and direction, atmospheric pressure, rainfall, temperature, and humidity.

- A Snow and Avalanche Study Establishment project to forecast avalanche potential, which required 29 automated weather stations in high altitude areas that transmit their data via the INSAT
- A Central Water Commission of India project in support of flood forecasting that called for the installation of 55 automated hydrometeorological stations covering two river basins and four DDRGS receive sites – two in each of the Chambal and Mahanadi River basins

Discussion of a Phased-in GBM System

A telecommunications system for hydrometeorological data in the GBM basin – perhaps to be known as the GBM Hydrometeorological Telecommunications System (GBMHTS) – should be implemented via a multi-phased approach. Of course, the pre-implementation preparation for the GBMHTS would require general agreement among the many countries and institutions that would operate or receive data from the system. These players would have to come to consensus on a broad range of issues, such as:

- the geographical extent of the system;
- budget for capital costs, and operational and maintenance costs;
- staff capacity and capacity development requirements;
- density and distribution of hydrometeorological networks;
- data-reporting and sharing requirements;
- other general system attributes; and
- lessons learned from applications of telecommunications technologies in South Asia.

Within that broad agreement, a recommended approach would include the following four phases.

Initial phase: evaluation of communications strategy – Because this paper merely provides an overview of selected telecommunications media that could be appropriate for an international river basin as large and varied as the GBM, a technical team — comprising key player representatives — would have to come to a consensus on the communications medium to support the GBMHTS. This phase could include technical study tours to sites in South Asia, the United States, and other venues where telecommunications of data are well established. This phase would produce a GBMHTS Implementation Plan (GBMHTSIP), which would address implementing the system and maintaining it during a subsequent period of ten years or more.

Pilot phase – During this phase, a small subset of stations would be instrumented and real-world lessons learned. The GBMHTSIP would be revised, based on lessons learned.

Initial Implementation Phase – The first half of the GBBHTSIP would be implemented during this phase. At the end of this phase, the GBMHTSIP would be evaluated once again and finalised.

Final Implementation Phase – During this phase the system would be fully implemented.

Summary

This paper briefly discussed telecommunication systems for real-time hydrometeorological data collection and transmission, which have matured greatly, both in the technologies used and in the application of real-time data. It presented several telecommunications technologies that are being used over a wide range of geographic scales, ranging from the community level to continental scales. There is no universal 'best' technology, but one or more of the technologies discussed will likely be adequate to meet typical hydrometeorological requirements in the GBM, from flood forecasting to water-resources management. There is a large body of experience with these technologies throughout the world and the Internet provides ample access to this experience and to information about current applications. Finally, the authors suggest a possible approach to implementing a hydrometeorological telecommunications system for the GBM.

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State-of-the-art Methods of Hydrological and Meteorological Data Acquisition Systems for Flood Forecasting

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[Editor's Note: The following is taken from a presentation made to participants of the 2nd High Level Consultative Meeting on Establishment of a Regional Flood Information System, held in Kathmandu, Nepal, March 2003. The examples refer to the products of only a few companies; they are intended only to illustrate the type of instruments available and do not imply any endorsement or recommendation on the part of the publisher or any other organisation involved in the preparation of this book.]

Abstract
Effective flood forecasting uses hydrological and meteorological data both as input to computer models that produce extended forecasts and as input to systems that provide instantaneous readings for specific sites and for aerial distribution. Advances in technology have reformed a previously antiquated system by introducing newer and more efficient data acquisition, storage, retrieval, and quick transmission systems. The basic meteorological data for flood forecasting are precipitation, accumulated precipitation, rate of precipitation (and spatial distribution), wind speed and direction, surface and upper air observation of the type and amount of cloud present, weather systems, and cyclone or depression position identification. The hydrological data required to determine flow condition in the channels are based on stage flow data (collected at appropriate time intervals), reservoir level measurements, and channel flow characteristics. Data acquisition can be in situ or remotely sensed. In situ meteorological data is obtained from an observation network of fixed sites; remotely sensed data is required in areas where it is not possible to establish such a network. There is a wide range of equipment available for hydrological and precipitation measurement at different levels of sophistication and cost. Detailed analysis is required before selecting the appropriate equipment for a specific purpose and situation.

Introduction

Hydrological and meteorological instruments provide the input needed to run a flood-forecasting model. Hydrometeorological data is obtained either from compact observation stations or from detailed observations of individual parameters, both of which are recorded either manually or automatically. Specific instruments measure both the meteorological and hydrological parameters and should have the following characteristics: 1) provide precision measurements; 2) be compatible with peripherals; and 3) have capabilities for sensitivity checks and/or error elimination.

An integrated network of hydrometeorological stations not only gives real-time observations but also provides the inputs that are essential for forecasting. The success of any hydrological and meteorological data acquisition system depends upon the reliability, the compatibility and the calibration of the data system in use. The most up-to-date technologies incorporate non-contact observational techniques in order to reduce human error and circumvent frequent servicing of equipment.

Meteorological Data Acquisition Systems

Previously, meteorological data input was primarily restricted to rainfall measurement at fixed points, i.e. observational data only. These were mainly manual observations, although there was also some mechanical self-recording equipment. Over the past few decades, substantial technological development has taken place and now meteorological data can be obtained by satellite based sensors, radar-based sensors, and ground-based remote sensors.

Satellite Data Acquisition Systems

The next generation meteorological satellites have extensive capabilities for high-resolution data. For example, satellites coordinated by the National Polar-orbiting Operational Environmental Satellite System (NPOESS) will carry advanced meteorological sensors with a resolution of 250 metres, four times finer than the current best available weather imagery. The polar orbiters are able to monitor the entire planet and provide data for long-range weather and climate forecasts. The programme is being developed in close cooperation with the meteorological community.

Doppler Radar System (S-Band 3GHz)

The newest Doppler weather radar systems (NEXRAD or Next Generation Radar) can measure both precipitation and wind. They can detect a rainfall centeroid and can follow its movement allowing the operator the possibility of following systems which can lead to cloudbursts and thus flash flooding in a river basin. NEXRAD has a hydrological range of 160 km and a meteorological range of 450 km. It can detect heavy rainfall systems that generate floods, and can do so even in rainfall areas that cross national boundaries. Its 3-D capabilities (Figure 1) can give the exact location of cloud top and its rainfall intensity. This system can also monitor the probable direction and movement of cyclones or depressions.

Precipitation Monitoring

In-situ precipitation monitoring is conducted with different types of precipitation gauges. These gauges measure rainfall and snow according to syphon, weighing or tipping bucket principles. For real-time forecasting it is important that the instrument has electrical signalling capacity, this both for real-time data transmission as well as for the measurement of precipitation rates and duration. Heating devices and heated equipment are available for measurement at sub zero temperatures. There is a large range of available equipment, some examples of more sophisticated instruments are given below. For ease of reference, the examples are drawn from the products of one company, but many others offer similar types of apparatus.

Rain Gauge Using the Weighing Principle with Integral Data Logger or Pulse Output Function

Rain gauges are available in which the weight of precipitation gathered in the collecting container is measured by an electronic weighing cell (resolution 0.01 mm / 0.01 inch). Different versions are available depending on the climatic requirements and areas of application (Figure 2). Beneath the defining ring of the measuring surface, the precipitation directly enters the collecting container. Thus liquid or solid precipitation can be measured immediately, and the time delays customarily associated with tipping buckets, filter screens, or inlet tubing are avoided. A high accuracy is obtained by an automatic self-calibration system, which uses an internal calibration weight. The use of frictionless link-joint elements guarantees a high long-term stability and maintenance-

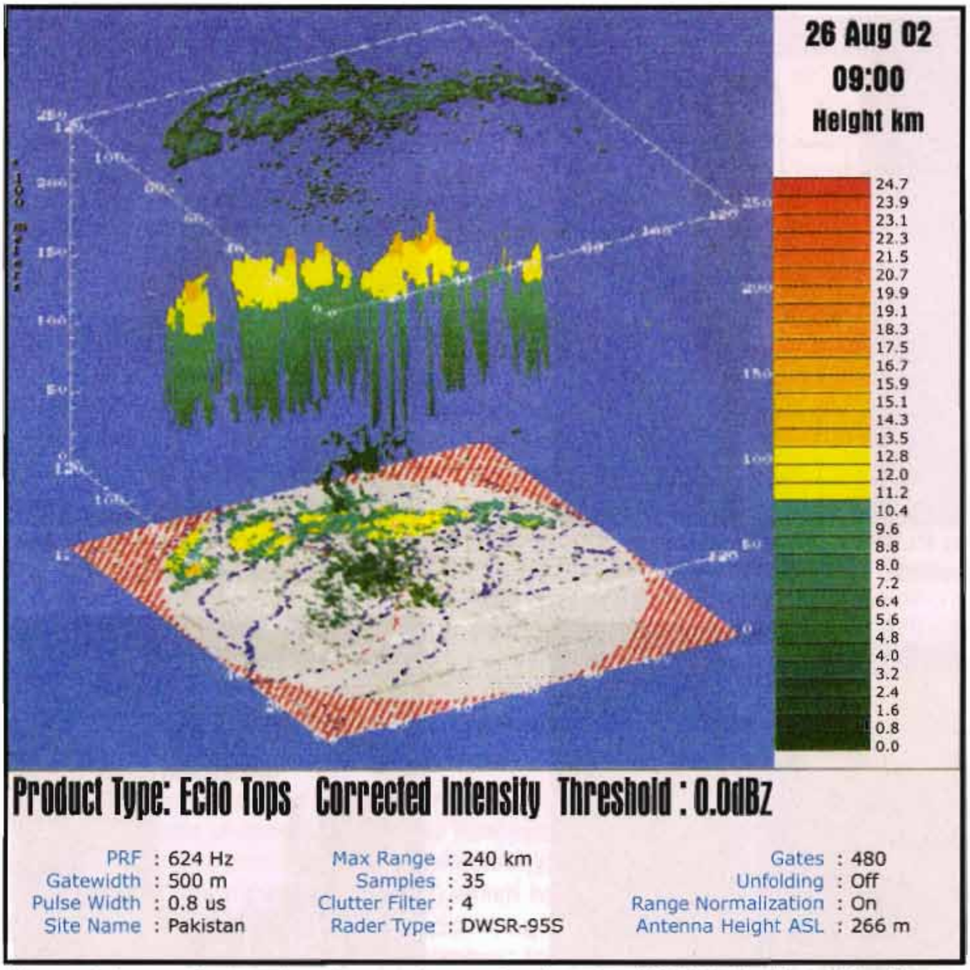


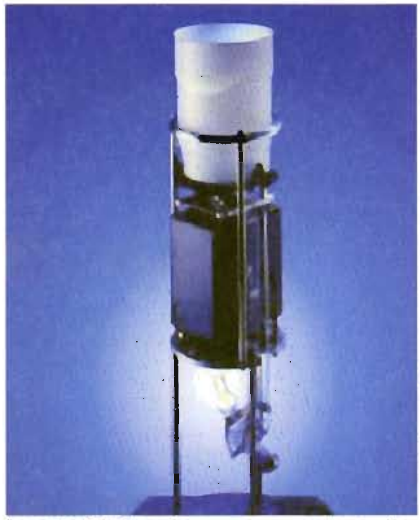
Figure 1: Image from a doppler weather radar detector (NEXRAD). The Echo Tops image shows the maximum height of precipitation echoes. NEXRAD can be used to identify the probable direction of movement of a cyclone or depression.

free operation. Due to the measuring principle and design, the unit is ideally suitable for both, low and high precipitation rates and intensities. In addition, evaporation can be determined on the basis of the recorded precipitation event.

The processor-controlled evaluation unit supplies a temperature-compensated and linearised output signal, which is available either directly as a pulse output or in the integrated data logger. The measuring system consists of a maintenance free electronic loadcell, amplifier, and AD-converter. The loadcell is hermetically sealed against dust, atmospheric pressure, and similar. To achieve high accuracy, a specific mechanical balance construction is used. Accuracy in the measurement of precipitation is guaranteed by eliminating wind effects using an integrated software filter algorithm. The software also automatically compensates for any temperature effects.

Precipitation measurement at subzero temperatures has special requirements. Solid precipitation must be melted before measuring and in a normal rain gauge collected water could freeze and possibly destroy the instrument. If a normal instrument is

a) PLUVIO 250 mm standard version



b) PLUVIO 250 mm incl. automatic drain-off system (siphon)

c) PLUVIO 250 mm extended version with automatic drain-off system

d) PLUVIO 1000 mm with collecting-ring heating device

Figure 2: Different models of a rain gauge with integrated data logger (Source: OTT MESSTECHNIK, Germany)

equipped with an electrical heating device and a snow cross (extra cost), recording is still possible at light frost temperatures. Models with a double-walled case or with a heating device can be used at temperatures as low as -25°C. The heating not only melts solid precipitation, but also protects the siphon and the collecting can from freezing. For hydrometric measurements, the unavoidable minimal evaporation losses and slight retardation between the falling and the recording times is of minor importance.
The advantages of the system described are: 1) since it uses a weighing principle it is capable of high resolution (0.01 mm / 0.01 inch) measurements; in addition, the software allows for temperature compensated measurement of quantity and intensity, including fine precipitation (drizzle, fog catchment; 2) it eliminates sources of error

commonly associated with conventional systems such as tipping buckets, filter screens, collecting inlet pipes, maintenance problems caused by snow, hail, leaves, bird excrement, insects, and so on; 3) easy and cost-effective installation and operation, low maintenance required; 4) 12V DC low power supply enables operation with rechargeable batteries or solar; 5) suitable for solid precipitation like snow, hail, and freezing rain; 6) RS 232 interface (data logger version); 7) siphon device automatic drain-off system (optional); 8) documentation of evaporation in the integral data logger; 9) 40 inch (1,000 mm) collecting bucket for applications in areas with huge quantities of precipitation like mountains and rain forests.

Hydrological Data Acquisition Systems

Discharge is the most important parameter in terms of hydrological data. In general, discharge is measured indirectly by recording the flow velocity and the water level at a given cross-section in a river. For both parameters, different automatic sensors are available. For continuous flow velocity monitoring, currently ultrasonic systems are most frequently used in operational services. Radar technology is being tested for the continuous measurement of flow velocity. Water levels can be monitored applying floating devices, pressure transducers, bubble gauges and radar technology. There is a large range of available equipment, some examples are given below. For ease of reference, the examples are drawn from the products of one company, but many others offer similar types of apparatus.

Ultrasonic System for Discharge Measurement of Open Channel Flow Locations Using Differential Ultrasound Transit Time

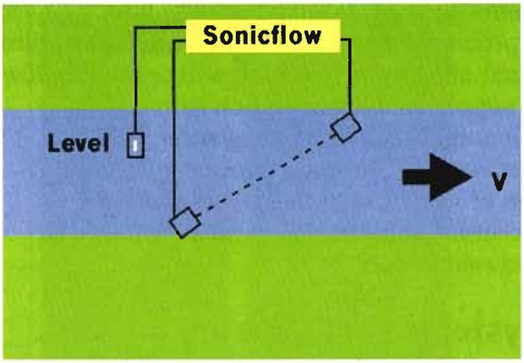
Sonic flow is a new ultrasonic measurement system designed to continuously log the flow velocity in open channels. The sonic flow system exploits innovative technology for signal processing and calculation of flow velocity. This technology is based on an intelligent digital signal processor (DSP) which has a very high measuring accuracy. In addition, it allows differential ultrasound propagation time measurements to be carried out even if the water level above the ultrasonic transducer is low.

An acoustic signal is transmitted at a defined angle so that it is simultaneously directed both towards and against the main direction of flow. The transit time for the signal transmitted against the main direction of flow is longer than the transit time for the signal transmitted in the main direction of the flow. The resulting time differential is directly proportional to flow velocity v in the measuring path. Different configurations can be chosen appropriate to the specific conditions of the river (Figure 3a-e).

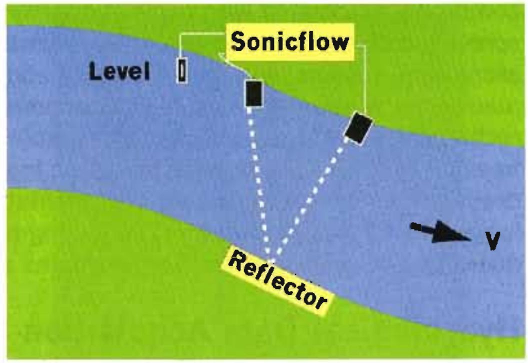
The advantages of this system include the fact that it is also suitable for use in situations where the water level is low since only minimal coverage of the sensors is necessary. Functional design ensures that the system is user-friendly, it is easy to install, operate, and maintain. No complicated equipment is needed to align the transducers. It uses a convenient evaluation software for professional processing and remote transfer of data using a variety of communication methods (serial modem, GSM modem, satellite, and others).

Radar Sensor for the Non-Contact Measurement of Surface Water Level

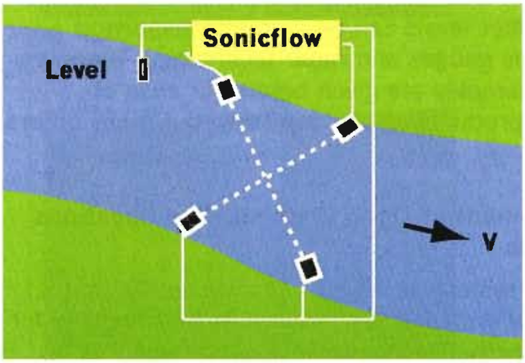
The radar sensor (Figure 4) represents a new type of measurement for surface water level, which offers many advantages in hydrological field applications since the sensor



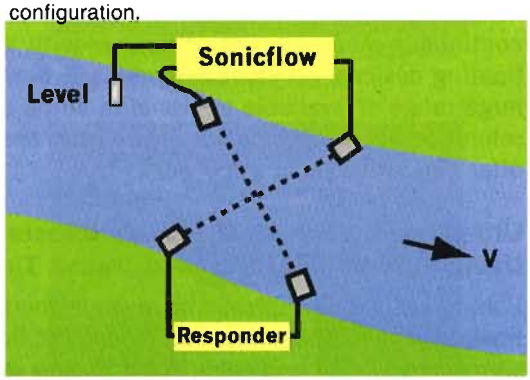
a) The 'single-path arrangement' is the simplest type of set-up. It is particularly suitable for use in waters where the flow angle is constant or bi-directional, e.g., in tidal areas. The water width is the largest measurable value (5... 150m) in this configuration.



b) The 'single-path reflector arrangement' is the preferred choice for waters with difficult inflow conditions where the flow angle is constant or bi-directional, e.g., in tidal areas. The water width is the largest measurable value (5... 150m) in this configuration.



c) The 'two-path cross arrangement' is least sensitive to changes in the flow direction. It is particularly suitable for use for large channel widths (5... 150m) with difficult inflow conditons; river bends; and where high accuracy is required.



d) Where the 'two-path-cross arrangement with responder' is used, laying of a connecting cable in or above the body of water is not necessary.

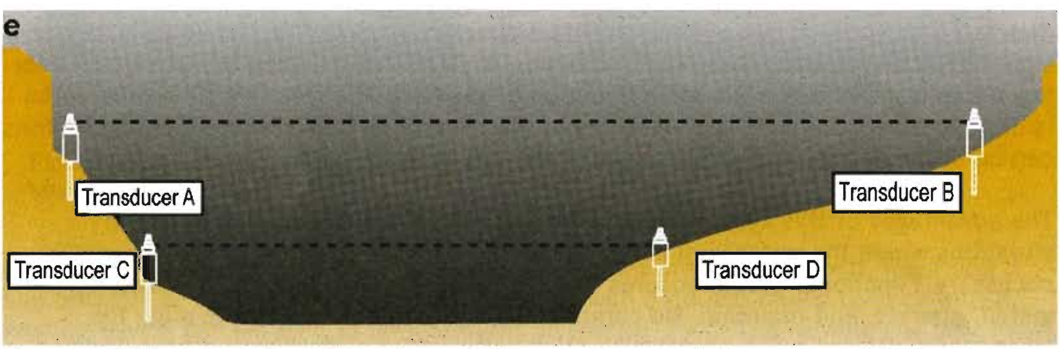


Figure 3: Different configurations for sonicflow measurement (Source: www.ott-hydrometry.de)

itself does not come into direct contact with the water. Its compact design and non-contact measuring principle ensure that the sensor can be installed easily and inconspicuously. Problems like disruption of measurement operation caused by high-water, silt accumulation, debris, and plant growth, as well as time-consuming maintenance, are eliminated.

In the example shown, an integrated software filter for averaging wave motion replaces cumbersome stilling wells. The water level is measured by sending radar waves (microwaves) perpendicular to the water surface and mixing these with the signals reflected on the surface. An intelligent DSP calculates the exact distance x (Figure 5) between the sensor and the surface of the water. Digitally measured values, status values, and any error messages present are transferred to a data logger via an interface and can be relayed over distances of up to 1,000m. The data logger calculates the water level y from the system length b and the distance x and makes the stored values available for further processing. A power supply with a 12V rechargeable battery, solar energy, and low power consumption enable the device to operate independently in the most remote areas. It is particularly suitable for areas where conventional measuring systems cannot be used or where a station needs to be set up quickly and inexpensively.

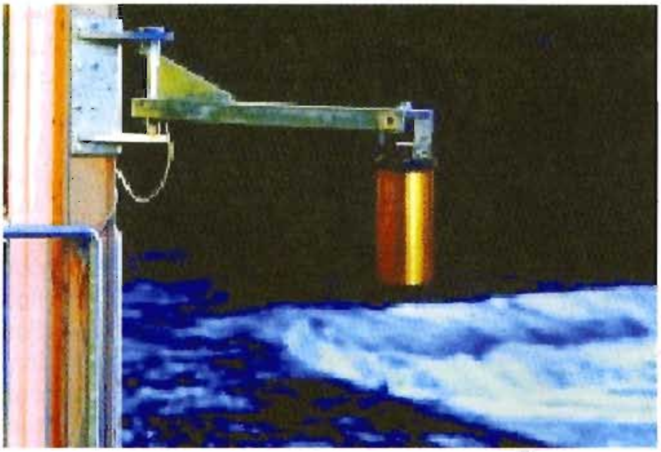


Figure 4: Radar sensor for unattended monitoring of surface water level

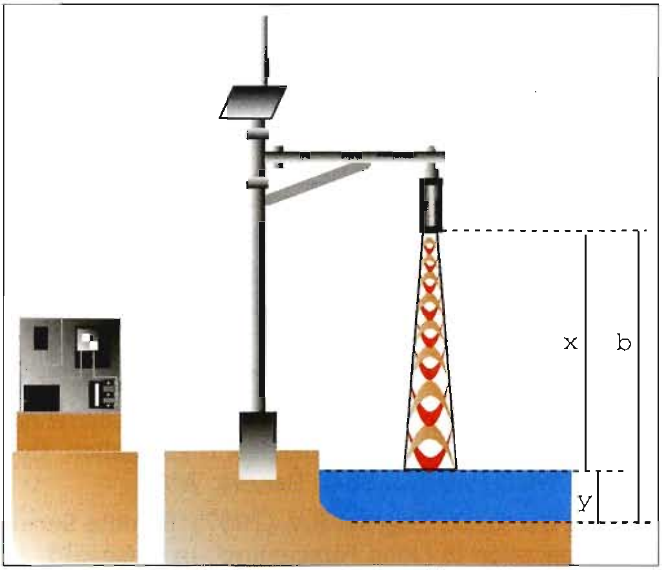


Figure 5: Measurement of water level by radar waves: the water level y is calculated from the system length b and the distance x

The features that make this system interesting are: 1) non-contact measuring principle, no damage caused by silt accumulation or debris; 2) simple, inexpensive installation - no difficult fitting procedure necessary; 3) 12V DC power supply; low power consumption enables operation with rechargeable batteries or solar; 4) cost reduction due to low maintenance requirements.

Autonomous Measurement Station for Collection of Hydrological Data

Some companies offer an integrated set of equipment or compact station which is supplied with all the components required to operate a measurement station: sensor, data-logger, communications equipment, as well as a power supply (Figure 6). In the

Figure 6: A fully equipped stand-alone hydrological measurement station (Source: OTT MESSTECHNIK, Germany)

example shown, these components are mounted on a sub-frame at the factory to the customer's specification. The sub-frame can then be inserted into the station during installation. The housing is constructed using the diving bell principle, this means that an air pocket prevents the unit from flooding even if it is inundated by floodwater and prevents the instruments from being harmed. The design and construction materials of the unit also deter unauthorised access to the instruments and protection against the elements. The compact station can be secured to a concrete foundation or mounted to a bridge or wall. The extension pole can have one or two solar panels as well as the communication antennae. The pole can also be used to mount meteorological sensors. GSM, radio, or satellite can be used for data communication. This is a fully autonomous monitoring station that can be erected quickly and cost-effectively. It can operate as a stand-alone unit with a solar power supply and GSM communication.

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