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SOUTH ASIA WATER INITIATIVE

Proceedings of the Regional Flood Early Warning System Workshop

23-27 November 2015, Bangkok

CONTENTS

ACKNOWLEDGMENTS

This report provides a record of the Regional Flood Early Warning System Workshop, held from 23-27 November 2015 in Bangkok, Thailand.

The workshop was funded by the South Asia Water Initiative (SAWI), a multi-donor trust fund managed by the World Bank. Established in 2009, SAWI's strategic program aims for sustainable, fair and inclusive development and climate resilience through increased regional cooperation on transboundary river management in the South Asian Region.

The workshop was organized by the Regional Integrated Multi-Hazard Early Warning System (RIMES), an international and intergovernmental institution that is owned and managed by its Member States for building capacities in the generation and application of user-relevant early warning information. The workshop brought together National Hydrological Services of four of its Member and Collaborating States – Bangladesh, India, Bhutan, and Nepal – countries that share the Brahmaputra, Ganges, and Meghna river basins.

RIMES would like to thank Dr. William Young, Lead Water Resources Management Specialist, World Bank, and SAWI Program Manager, for his technical guidance to and invaluable support for this workshop. RIMES also acknowledges Dr. Satya Priya's valuable inputs to the design and conduct of the workshop.

RIMES also thanks the International Centre for Integrated Mountain Development (ICIMOD), University Corporation for Atmospheric Research (UCAR), Japan International Cooperation Agency (JICA), and Asian Institute of Technology (AIT) for facilitating technical sessions that updated participants on ongoing initiatives and new and emerging technologies in flood forecasting and warning.

RIMES is grateful for ESCAP's commitment to carry forward the outcomes of this workshop through a Panel on Transboundary Flood Management for South Asian Region, under its proposed Intergovernmental Panel on Transboundary Flood Management, and implementation of the action plan adopted in this workshop through ESCAP and RIMES regional cooperation mechanisms.

EXECUTIVE SUMMARY

South Asia is home to major transboundary river basin systems, such as the Ganges-Brahmaputra-Meghna. The region is also home to 40% of the world's poor, of which two-thirds live in the Ganges and Brahmaputra basins. These river systems support livelihoods of millions of people. The Ganges basin alone supports about 655 million people, of which 30% are very poor. Recurring floods in these river basins have been a major development concern. With changing climate, floods are becoming more frequent, more intense, and less predictable.

Despite occurrence of recurring floods, these river basins have very high population concentrations due to livelihood opportunities that they offer. Relocation of communities away from flood zones, thus, becomes an impractical option. Hence, flood forecasting and early warning, proven to be an efficient and cost-effective alternate instrument for minimizing negative impacts and maximizing potential benefits of flood, is essential.

Countries in the region have differential capacities in flood forecasting and warning. For a region where flooding is transboundary in nature, development of an operational flood forecasting and warning system would require a basin approach. The Regional Flood Early Warning System Workshop, organized jointly by the World Bank (South Asia Office, New Delhi) and Regional Integrated Multi-Hazard Early Warning System (RIMES) from 23-27 November 2015 in Bangkok, brought together professionals and heads of flood warning institutions of Bangladesh, Bhutan, India, and Nepal to explore possibilities for strengthening regional cooperation on transboundary flood forecasting and early warning.

Participants to the 5-day workshop appreciated the cost-effectiveness and socio-economic value of regional cooperation on transboundary flood forecasting and early warning, by adopting a basin approach through sharing of monitoring, forecasting, and warning information. Participants considered the potential value of undertaking basin-wide joint efforts to apply the best of weather/ flood forecast/ observation technologies to enhance forecast/warning lead times to up to 10 days, as demonstrated in Bangladesh. Participants envisioned that transboundary flood forecasting and early warning collaboration could be an entry point in building trust among participating countries. Such collaboration could be gradually enlarged to cover broader flood management issues.

Despite inherent advantages, participants flagged challenges in putting in place a joint monitoring, forecasting, and warning program due to differing perceptions of risk: upstream countries (Nepal and Bhutan) considered flash floods as more important than riverine floods, while downstream countries (India and Bangladesh) considered riverine floods as more important than flash floods. Differing technical and institutional capacities and data sharing policies/collaboration frameworks (though some bilateral technical arrangements exist) were listed as obstacles for putting in place a transboundary flood early warning system.

To overcome these challenges, participants recommended making use of available regional mechanisms by adopting three distinct, but integrated, approaches:

- Integration of flash flood (as most of flash flood subsystems contribute to basin-scale floods) and riverine flood concerns at the basin level for promoting investment in observation/monitoring and for forecasting purposes
- Building of flood early warning capacities to use emerging new-generation flood forecasting technologies and incorporate these into flood risk information user systems
- Use of existing regional mechanisms for capacity building and regional sharing of information/knowledge through institutionalized biannual meetings of senior and middle level professionals

In the above context, it is important to highlight that the United Nations Economic and Social Commission for Asia and the Pacific (ESCAP), a multi-sectoral intergovernmental platform in the

region, has been mandated in May 2015 by its Member Countries, including those from the South Asian region, through Resolution 71/12, to strengthen regional cooperation for flood forecasting in transboundary river basins. ESCAP promotes intergovernmental, multi-stakeholder cooperation, such as the Mekong River Commission, ESCAP-WMO Panel of Tropical Cyclones, and Typhoon Committee, which bring together stakeholders that share risks across common river and ocean basins.

ESCAP's multi-donor Trust Fund supported the establishment of RIMES, which provides technical support for building national capacities for enhanced flood warning systems, and for pilot testing new-generation forecast technologies for community-level application in the South Asian region. RIMES also provides continued backup support to countries to ensure that: a) flood forecast technologies are integrated into national systems and sustained, and b) biannual Monsoon Forums, which bring together early warning information provider and user institutions in a dialogue and provide continuous feedback on forecast technologies and risk communication practices, are institutionalized.

Mandated by the Resolution, ESCAP committed to carry forward this World Bank-supported initiative by establishing a Panel on Transboundary Flood Management for South Asian Region, with RIMES serving as technical secretariat. This is in line with ESCAP's proposal for an Intergovernmental Panel on Transboundary Flood Management that includes key stakeholders – hydrologists, meteorologists, and disaster management authorities – from riparian countries of common river basins. The action plan, as adopted in the workshop, will be implemented through ESCAP and RIMES regional cooperation mechanisms.

INTRODUCTION

Background

The South and Southeast Asian regions are home to big river systems, such as the Ganges-Brahmaputra-Meghna, Indus, Ayeyarwady, Mekong, etc. These river systems provide livelihoods to millions of people in the region. During summer monsoon season, these rivers and their tributaries frequently overtop their banks and create havoc due to flooding. Floods cause loss of lives, livelihoods, and infrastructure; damage the environment, and hinder the development process. With changing climate, floods are becoming more frequent, more intense, and less predictable.

Flood forecasting and early warning has been proven to be efficient and cost effective instrument for minimizing negative impacts of flood and maximizing its potential benefits. To respond to user demands, efforts have been considerable in transforming conventional real-time meteorological and hydrological observation-based flood warning systems into weather forecast-based flood forecasting and warning systems to enhance flood warning lead time, for saving lives and preserving livelihood assets.

In the South Asian region (SAR), countries have differential capacities in flood forecasting and warning. Many have basic infrastructure on hydrological and meteorological monitoring, based on manual observation and conventional data transmission by telephone, VHF radio, and ordinary mail. Customized numerical weather prediction for hydrological forecasting is still lacking. Hence, weather forecasts are not integrated into hydrological models. Customized hydrologic and hydraulic models are not yet available. Warnings are issued based on real-time monitoring, which provide few hours of lead time only. Mechanisms to disseminate warning messages at the community level for taking proper preparedness and immediate response measures are either lacking or weak. In most of the countries in the region, flood warning system is not fully operational.

Development of an operational flood forecasting and warning system in the region requires a basin approach, since flooding phenomenon in the region is trans-boundary in nature. For example, the Ganges and Brahmaputra basins are contiguous, and encompass Nepal, Bhutan, India, and Bangladesh. For an initiative that involves a number of countries, it is important to bring these countries on board to facilitate such undertaking.

Objectives

The Regional Flood Early Warning System Workshop, organized from 23-27 November 2015 in Bangkok, Thailand, is such initiative that brought professionals and heads of flood warning institutions in SAR countries together to strengthen regional cooperation on trans-boundary flood forecasting and early warning. Specifically, the workshop:

a) Took stock of existing flood forecasting and warning efforts in SAR countries;
b) Featured technologies and experiences from other countries/ regions;
c) Introduced operational personnel to new modeling tools;
d) Introduced the elements and requirements of an operational basin-based long-lead flood forecasting and warning system; and
e) Explored possibilities of evolving a program for end-to-end basin-based long-lead flood forecasting and warning system in the South Asian Region.

The workshop had two parts:

a) Training workshop for senior/mid-level professionals, which involved lectures, interactive discussions, participant presentations, group exercise and presentation, and exposure visits to national meteorological and hydrological institutions in Thailand. Resource persons came from University Corporation for Atmospheric Research (UCAR), AIT, International Centre for Integrated Mountain Development (ICIMOD), Bangladesh, and the Regional Integrated Multi-Hazard Early Warning System (RIMES).
b) Workshop involving heads and senior/mid-level professionals of the national hydrological institutions/ national meteorological and hydrological services (NMHSs) for consideration of a regional program on end-to-end basin-based long-lead flood forecasting and warning system in the South Asian Region.

The workshop was held over five days, with the following program:

Day 1: Workshop introduction and contextualization; existing flood forecasting and warning systems in SAR countries; introduction of end-to-end flood forecasting and warning system, learning sessions on real-time observation and monitoring, numerical weather prediction, data requirement for Hydrological modelling

Day 2: Introduction of basin-based long-lead flood forecasting and warning; ongoing regional efforts; proposed regional program for SAR

Day 3: Special learning sessions on sources of hydrologic predictability and useful datasets, followed by warning preparation, dissemination and communication, preparedness and response, and feedback system; orientation on exposure visits

Day 4: Exposure visits to Thai Meteorological Department (TMD) and Royal Irrigation Department (RID); debriefing

Day 5: Learning sessions on flood preparedness and response, and feedback system, followed by developing an action plan for end-to-end basin based long lead flood forecasting and warning system in SAR.

Annex 1 provides the detailed workshop program, while Annex 2 provides the participant list.

OPENING SESSION

Welcome Remarks. *A.R. Subbiah, RIMES*, welcomed all workshop participants.

He noted the increasing incidence of transboundary hazards, particularly in the South Asian region, and emphasized the need for regional cooperation to reduce loss of lives and livelihoods. Improvements in numerical weather prediction (NWP) techniques and integration of NWP outputs into flood forecasting offer opportunities for enhancing flood forecast lead times. Thus, the workshop shall explore a regional mechanism for integrating emerging/new technologies for improved flood forecasting, particularly for transboundary rivers. Towards this end, Mr. Subbiah wished all participants fruitful discussions.

Opening Remarks. *Satya Priya, World Bank*, provided the context of the workshop.

The Ganges-Brahmaputra-Meghna basin is an important region as it is one of the most flood-prone basins in the world, affecting more than 18 million in the Ganges alone. The basin has the largest number of the world's poor. Climate change impacts further add to existing vulnerabilities. Countries in the region have differing flood forecasting capacities. Data availability is a common challenge. It is important to understand the full nuances of flood forecasting, from regional to national, to local levels. The workshop, hence, shall take stock of available capacity, determine existing gaps, and identify suitable measures to address these gaps. The workshop is also a good platform to share and learn from each other's experiences.

Remarks. *Sanjay Srivastava, ESCAP*, shared relevant ESCAP initiatives, particularly the promotion of regional cooperation on transboundary river basins in the Asia-Pacific region.

The recent session of the ESCAP Commission gave ESCAP the mandate to work with Member States on flood forecasting, from data exchange to integration of advances in science and sharing of best practices. ESCAP promotes inter-governmental, multi-stakeholder cooperation, such as the Mekong River Commission, ESCAP-WMO Panel of Tropical Cyclones, and Typhoon Committee, which bring together stakeholders that face common risk. ESCAP's multi-donor Trust Fund has supported Monsoon Forums, NMHS capacity building, and pilot projects that ensure that risk information reaches communities at risk.

Left: workshop opening session; Right: workshop participants

PRESENTATION SUMMARIES

1. SESSION 1: FLOOD FORECASTING AND WARNING SYSTEMS IN SAR COUNTRIES

Country representatives presented an overview of existing flood forecasting and warning system in respective country, the salient features of which are summarized below.

1.1 Flood Forecasting and Warning Services in Bangladesh

Md. Abdul Latif Miah and Md. Amirul Hussain, Bangladesh Water Development Board (BWDB), Bangladesh, presented the country's flood risk context and the evolution of, advances made in, and priorities for further development of the country's flood forecasting and warning system.

Bangladesh is the most flood vulnerable country in the region, with almost one-third of the country flooded every year, resulting to annual economic losses of about 3% to 5% of the country's GDP. Severe floods occurred in 1998, 1988, and 2007. The country's location, topography, and high population density make it vulnerable to floods and other hydro-meteorological hazards. Flood forecasting and warning complement the country's extensive structural flood management measures.

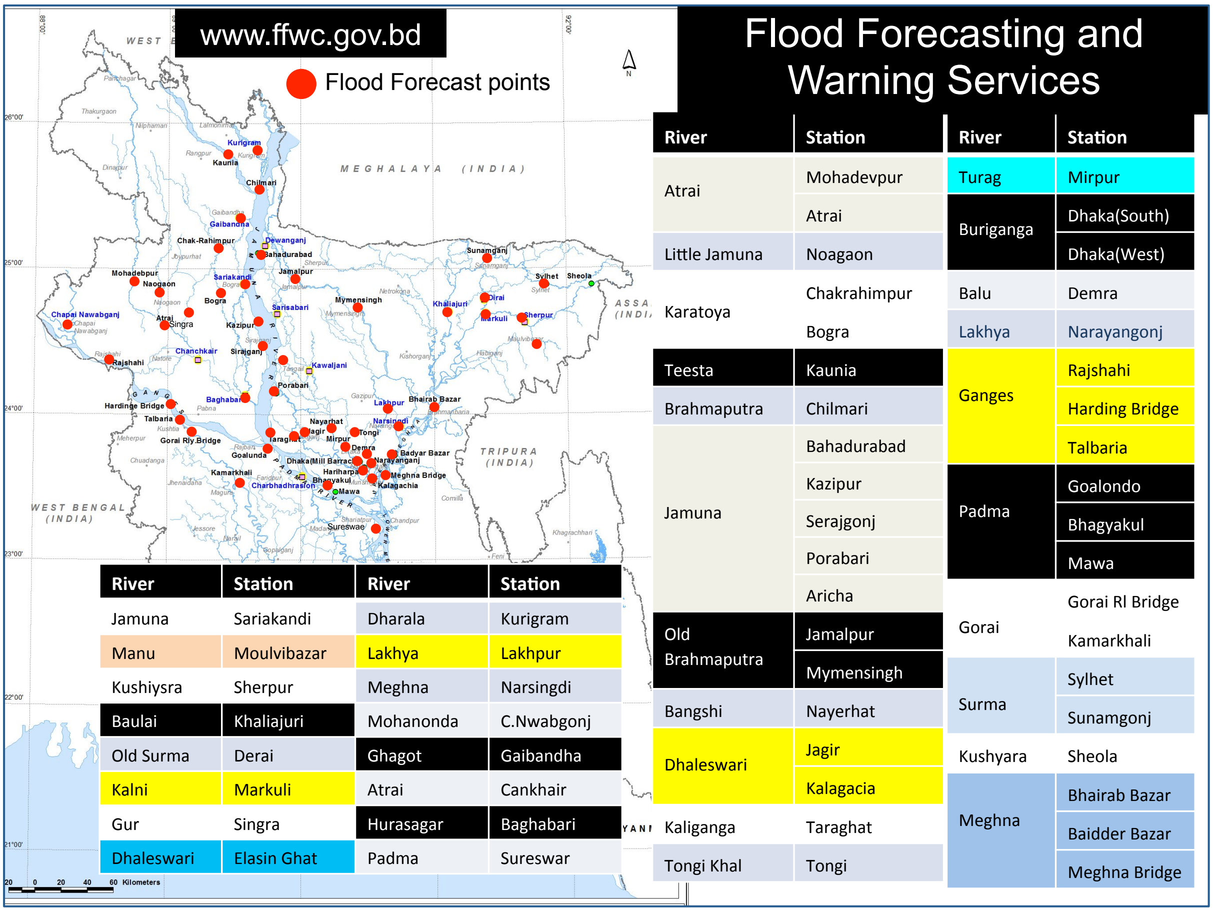
Bangladesh has an operational flood warning system during the monsoon season. The country's hydrological and meteorological observation system is still basically conventional manual type. BWDB maintains a network of 343 water level gauges, of which 37 are automated telemetric stations. Manual stations are equipped with mobile phone, which enables immediate transfer of data through SMS to the head office. Satellite images are also applied to monitor water level conditions upstream.

BWDB's Flood Forecasting and Warning Centre (FFWC) issues 5-day deterministic flood forecast for 52 locations, and 10-day probabilistic flood forecast for 38 locations. Satellite altimetry-based flood forecasting technology has also been developed, providing lead times of up to 8 days for 13 locations. Flash flood forecasts, based on rainfall intensity-duration thresholds, are issued for 2 locations.

The 10-day flood forecast system is based on medium-range rainfall forecast from the European Centre for Medium-Range Weather Forecasts (ECMWF) ensemble prediction system, satellite precipitation data from the U.S. National Oceanic and Atmospheric Administration's Climate Prediction Center Morphing Technique (NOAA/CMORPH) and U.S. National Aeronautics and Space Administration's Global Precipitation Climatology Project (NASA/GPCP), rain gauge data from the World Meteorological Organization's Global Telecommunication System (WMO/GTS), and local meteorological and hydrological data. River discharges are predicted at upstream boundary locations, using data-based and distributed hydrological models. Forecast errors are minimized using simple regression of model outputs against measured discharge. Discharge forecasts at boundary locations are used in Mike 11 hydraulic model, to generate water level forecasts at 38 locations downstream of the Brahmaputra, Ganges, and Meghna rivers (Figure 1.1).

Flood advisories are issued to the public by voice and text messages, phone, social media (Facebook), FFWC website, and display boards installed at selected locations; by email to institutional users; and by fax and hard copies to policymakers and top officials.

Disaster Management Committees and user communities in pilot locations have been trained to respond to warning messages that are based on probabilistic forecasts. Actions are taken corresponding to the level of flood threat. These include: stocking of seeds, delaying of planting, early harvesting, increasing height of fish pond dykes, enclosing fish ponds with nets, raising livelihood assets such as handlooms, increasing elevation of storage areas for goods, moving of livestock to safe locations, temporary sealing of tube wells, stocking of emergency supplies (food, fuel, medicine), and securing bamboo for building temporary bridge to connect houses to high land.



River	Station	River	Station
Jamuna	Sariakandi	Dharala	Kurigram
Manu	Moulvibazar	Lakhya	Lakhpur
Kushiysra	Sherpur	Meghna	Narsingdi
Baulai	Khaliajuri	Mohanonda	C.Nwabgonj
Old Surma	Derai	Ghagot	Gaibandha
Kalni	Markuli	Atrai	Cankhair
Gur	Singra	Hurasagar	Baghabari
Dhaleswari	Elasin Ghat	Padma	Sureswar

River	Station
Atrai	Mohadevpur
	Atrai
Little Jamuna	Noagaon
Karatoya	Chakrahimpur
	Bogra
Teesta	Kaunia
Brahmaputra	Chilmari
Jamuna	Bahadurabad
	Kazipur
	Serajgonj
	Porabari
	Aricha
Old Brahmaputra	Jamalpur
	Mymensingh
Bangshi	Nayerhat
Dhaleswari	Jagir
	Kalagacia
Kaliganga	Taraghat
Tongi Khal	Tongi

River	Station
Turag	Mirpur
Buriganga	Dhaka(South)
	Dhaka(West)
Balu	Demra
Lakhya	Narayangonj
Ganges	Rajshahi
	Harding Bridge
	Talbaria
Padma	Goalondo
	Bhagyakul
	Mawa
Gorai	Gorai Rl Bridge
	Kamarkhali
Surma	Sylhet
	Sunamgonj
Kushyara	Sheola
Meghna	Bhairab Bazar
	Baidder Bazar
	Meghna Bridge

Figure 1.1 Flood forecast points, Bangladesh

Priorities for further improvement of the country's flood forecasting and early warning system include:

- Expansion of areal coverage of existing flood forecasting and warning system
- Monthly and seasonal water level outlooks
- Hydrological drought prediction system
- Application of satellite technology in flood forecasting
- Regional cooperation for transboundary river data sharing
- Basin-wide flood forecasting

1.2 Status of Flood Forecasting and Warning in Bhutan

Karma Tsering and Karma Dupchu, Department of Hydro Met Services (DHMS), Bhutan, provided an overview of the country's flood risk context, and presented the existing flood forecasting and warning system, particularly for glacial lake outburst floods (GLOFs), as well as priorities for its further development.

Bhutan is exposed to flash flood, GLOF, and landslide dam outburst flood (LDOF), with settlements (about 70%), major infrastructure, and important cultural sites situated along river valleys. Recent occurrences were in 2009, 2004, 2000 for flashflood; 1998 for GLOF; and 2004 for LDOF.

DHMS maintains 26 hydrological stations, 92 meteorological stations of which 20 are Class-A, and 15 flood warning stations. Some hydrological and meteorological stations were recently upgraded with GPRS- and Iridium satellite-based telemetry system. DHMC also operates Iridium satellite-based GLOF warning system in 3 basins (Figure 1.2). It was able to forecast and provide advance warning in the 2015 GLOF event.

DHMS runs WRF model for numerical weather prediction, generating forecasts 4 times a day. HBV and IFAS hydrological models for flood forecasting were tested, but not yet made operational. A Standard Operating Procedure (SOP) is in place for flood forecast and warning dissemination at national, local, and community levels. The Department of Disaster Management further helps in information dissemination.

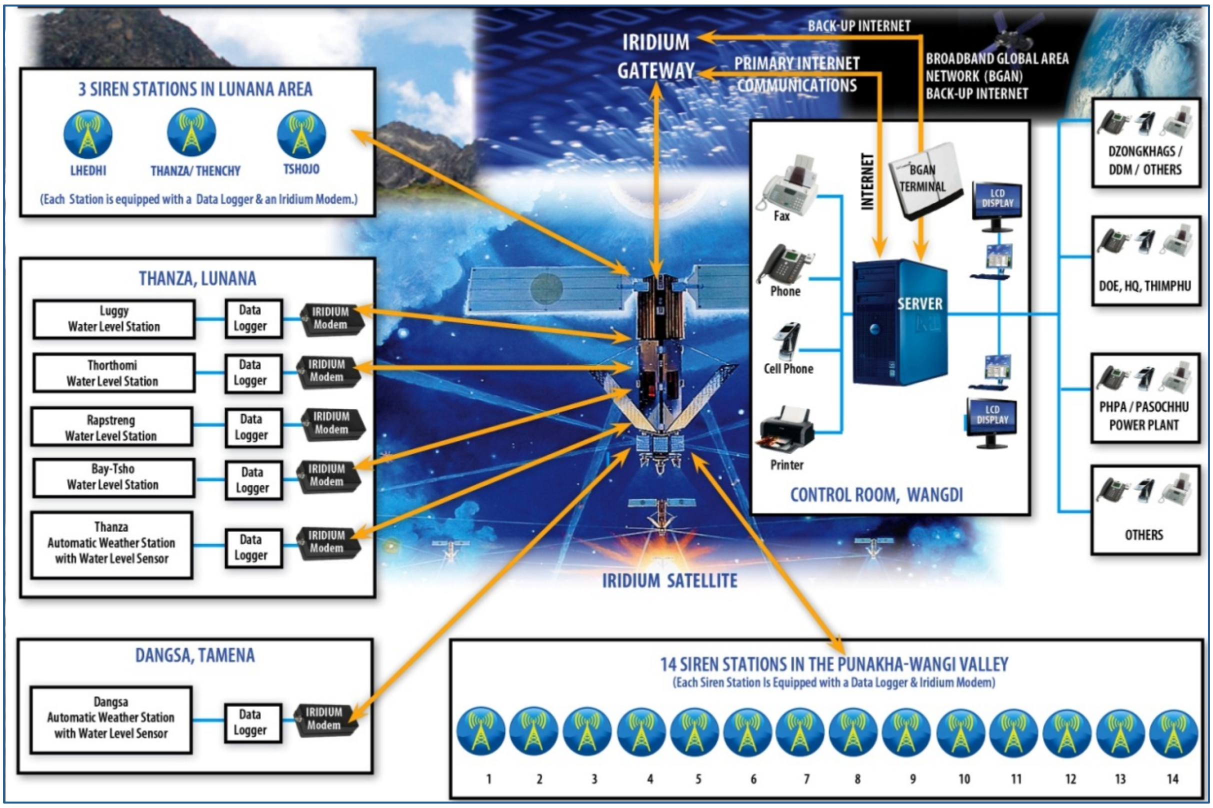


Figure 1.2 GLOF early warning system, Bhutan

DHMS priorities for further development of the country's flood early warning system include:

- Improved density of hydro-meteorological observing network, with real-time telemetry system
- Access to global data for assimilation into NWP models
- Reliable high bandwidth Internet connectivity
- High-speed computing system
- Training and capacity building
- Strengthening of community-based early warning systems

1.3 Flood Forecasting and Warning System in India

Rajesh Kumar, Central Water Commission (CWC), India, presented the country's flood risk context, flood management practices, status of flood forecasting and warning, and priorities for flood forecasting and warning system's further development.

Floods and droughts are recurrent disasters in India, which have led to approximately INR 1800 crores (about USD 18 billion) of losses annually. CWC's national flood forecasting and warning network comprises of 176 flood forecasting sites, which include 28 inflow forecasting sites and 148 water level forecasting sites. Through its 13 regional field offices, CWC issues forecasts by email, SMS, and through the CWC website to various user agencies, which include civil/engineering agencies of State/Central Governments, such as Irrigation, Revenue, Railways, public undertakings, Dam/ Barrage Authorities, and District Magistrates/ Sub Divisional Officers, apart from Defense Authorities involved in flood loss mitigation work.

Forecast formulation requires effective means of real-time data communication network from forecasting stations and base stations. Wireless communication system, installed in almost 550 stations, is the backbone of the communication system in support of flood forecasting activities. So far, 445 stations have been modernized with automatic data collection and transmission systems. Work is in progress to increase the total number of telemetered stations at the end of the XII Plan (2017) to 1,061.

Flood forecasting is mainly based on upstream water level observations. Mathematical models for Jhelum, Alaknanda, Bhagirathi, Ganga, Brahmaputra, Yamuna, Chambal, Baitarani, Vamsadhara, Subarnarekha, Mahanadi, Tapi, Godavari and Krishna rivers have been developed. Flood forecasting comprises of water level forecasting and inflow forecasting. Water level forecasts help user agencies to decide mitigating measures, such as evacuation of people, and shifting people and their movable properties to safer locations. Inflow forecast is used by various dam authorities in optimum operation of reservoirs, for safe passage of flood downstream, as well as to ensure adequate storage in reservoirs for meeting demand during non-monsoon period. India Meteorological Department (IMD) generates 3-day quantitative precipitation forecast (QPF) for several river basins. QPF-based flood forecasting system is developed and operational for Jhelum basin. Also, GLOF inventory has been prepared.

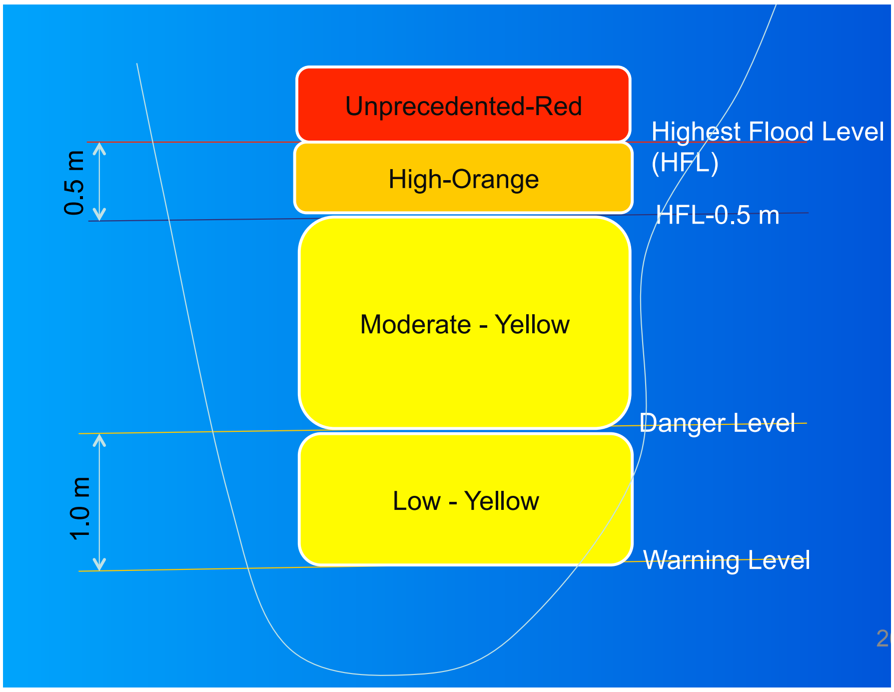


Figure 1.3 Current water level thresholds for flood warning, India

Priorities toward further development of the country's flood forecasting and warning system include:

- 2D inundation modelling for major flood-prone basins
- Updating of water level thresholds based on location, time, and season
- Real-time flood warning system
- Flood plain zoning
- GLOF, LDOF, and cloud burst flood
- Inventory of all glacial lakes and water bodies
- Move from deterministic to probabilistic forecast
- International cooperation for access to upstream data
- Engagement with users, noting users' main focus on water level trend and flood onset, extent, and duration
- Improved coordination with user agencies

1.4 Flood EWS Activities in Nepal

Gautam Rajkarnikar and Rajendra Sharma, Department of Hydrology and Meteorology (DHM), Nepal, presented the evolution, status, and priorities for further development of the country's flood forecasting and warning system.

Continuous heavy rains, flash floods, GLOF, and landslides are major hazards in Nepal. DHM started modernizing its meteorological and hydrological observation system in 2008. Currently, its observation network consists of 75 rainfall and 32 flow gauging stations, with GPRS/CDMA communication system for real-time data transmission. This real-time observation network was primarily developed for flood warning in the Terai plain. The network is sparse in hilly and mountainous areas.

RIMES assisted DHM in developing capacity on Numerical Weather Prediction using Weather Research & Forecast (WRF) model. DHM, however, has not yet made WRF fully operational. At present, Nepal does not run any hydrologic, or hydraulic model for flood forecasting. Flood forecasting system development is in progress for three basins, namely Narayani, Babai and Karnali, with support from RIMES.

Flood warning is issued to downstream communities when water level at the upstream station exceeds a predetermined threshold (Figure 1.4). Flood forecast and warning information are disseminated through DHM website, mobile phones, and siren; satellite communication is used during extreme events. Mobile application is currently being developed for 24-hour flood warning. There are also community-based dissemination and response mechanisms, developed in collaboration with local governments, community-based organizations, and non-government organizations.

Community-level disaster management committees are formed in each disaster prone village, which belong to a network of District Disaster Relief Committee, local media, the Red Cross, local police, military units, and DHM flood monitoring and forecasting station. Disaster management committees are equipped and trained for warning dissemination, preparedness, and immediate response.

RIVER WATCH

S.N	Station Index	Station Name	Water Level (m)	Flow (m^3/sec)	Warning Level (m)	Danger Level (m)	Trend	Status
1	259.5	Seti at Dipayal 2013-08-27 13:15:00	6.70	-	-	-	Rising	-
2	289.95	Babai at Chepang 2013-08-27 13:15:00	4.18	777.80	6.50	7.00	Rising	Below Warning Level
3	339.3	Jhimruk at Cherneta 2013-08-27 13:00:00	2.85	-	-	-	Steady	-
4	375	West Rapti at Kusum 2013-08-27 13:15:00	5.75	2414.00	5.00	5.40	Rising	Above Danger Level
5	425	Seti 2013-08-27 13:00:00	2.05	-	-	-	Steady	-
6	550.05	Bagmati at Khokana 2013-08-27 13:15:00	1.28	24.06	3.50	4.00	Falling	Below Warning Level
7	610	Bhote Koshi at Bahrabise 2013-08-27 13:00:00	2.02	-	-	-	Steady	-
8	630	Sunkoshi at Pachuwarghat 2013-08-27 13:00:00	2.04	-	-	-	Falling	-
9	647	Tamakoshi at Busti 2013-08-27 13:00:00	3.29	-	-	-	Falling	-
10	690	Tamor at Mulghat 2013-08-27 13:20:00	4.45	-	-	-	Falling	-

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Figure 1.4 Web-based dissemination system, Nepal

Priorities for further development of Nepal's flood forecasting and warning system include:

- Identification of flood zones and development of flood inundation maps
- Re-evaluation of danger and warning levels for most rivers
- DHM training and capacity building

SESSION SUMMARY

- All countries have varying capacities for flood forecasting and warning; there is great scope for improving existing capacities
- Countries are ready to share transboundary observation data and flood forecast information for reducing human and economic losses due to floods; sharing would require a regional mechanism
- Flash flood and landslide are major challenges for Bhutan and Nepal, while riverine flood is a major challenge for Bangladesh and India
- Development of a regional program to address flood risks in the region would require consideration of both flash and riverine floods
- Satellite-based observation systems would be very useful for the Ganges and Brahmaputra basins, as large parts of these basins are inaccessible
- Capacity building, in terms of technology and staff training, is a need common to all the countries

2. END-TO-END FLOOD FORECASTING AND WARNING SYSTEM

2.1 End-to-End Flood Forecasting and Warning System: Key Features and Requirements

Dilip K. Gautam, RIMES, presented the key features of an operational flood forecasting and early warning system that is end-to-end, from observation and monitoring to user engagement for preparedness, warning response, and feedback.

Flood forecasting and early warning is an efficient and cost effective method for minimizing the negative impacts of floods. Its purpose is to advise institutions and the general public on impending flooding, for taking mitigating actions. Flood warning should provide information on:

- Time of flood onset
- Magnitude of flood (water levels, discharges at key locations)
- Location and extent of flooding
- Duration of flooding
- Likely impacts

Flood early warning, to be effective, should provide adequate lead time for institutions and communities at risk to undertake preparatory and mitigating actions. The chain that starts with monitoring of extreme weather events, leading up to community level response can be functionally disintegrated into steps, wherein developmental interventions can contribute to preparedness and reduction in disaster risks at the community level. It is end-to-end when it involves a chain of activities that connects the technical and societal aspects of warning, from understanding and mapping of the hazard and monitoring and forecasting/predicting impending/ emerging harmful events, to processing and disseminating understandable warnings to authorities and the population and undertaking appropriate and timely actions in response to the warnings by involvement and participation of all stakeholders. Stakeholder feedback is a key feature, allowing post-event assessment for learning lessons, identifying good practices, and providing recommendations for improving the early warning system. These components of an end-to-end flood early warning system are illustrated in Figure 2.1.

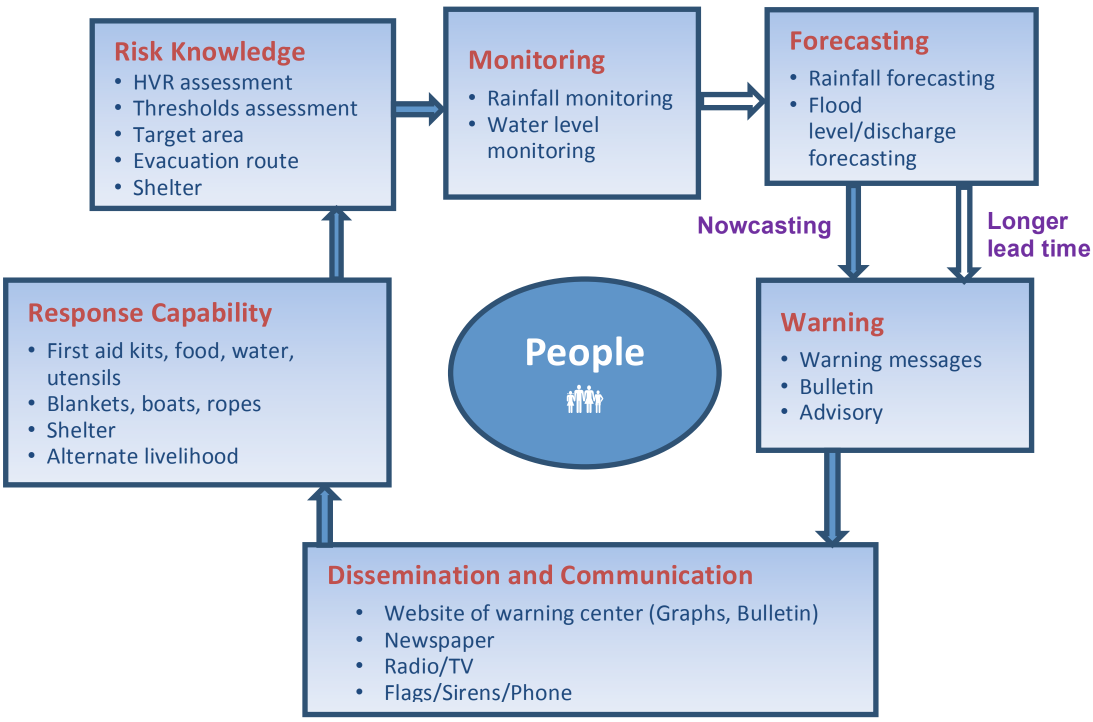


Figure 2.1 End-to-end flood early warning system

An operational end-to-end flood forecasting and warning system has the following basic elements:

a) Risk assessment system. This involves assessment of historical flood depth, extent, and duration; evaluation of local threshold values; and risk mapping.
b) Real-time monitoring system, which includes sensors, and data logging and communication
c) Forecasting system, which includes:
    - Numerical Weather Prediction (NWP) system
    - Data preprocessing system
    - Hydrological modeling system
    - Hydraulic modeling system
    - Error correction system
d) Warning system, which involves forecast interpretation, potential impact assessment, and advisory generation
e) Dissemination and communication system
f) Preparedness and response system
g) Feedback system

2.2 Numerical Weather Prediction for Flood Forecasting

Itesh Dash, RIMES, provided an overview of the NWP process and products, and considerations for using NWP products in hydrological modeling.

Precipitation and temperature forecasts are essential inputs to hydrological modeling to provide discharge information with lead times of days to months. These are generated using NWP methods. Computer models are used to predict the future state of the atmosphere. Calculations are made on synoptic scale, but influences on weather are local. Further, equations used to estimate relevant physical processes are non-linear. Hence, uncertainty or bias (error) exists in NWP products.

NWP products could have time scales of hours to years. RIMES' WRF model is configured covering the four countries, and is run at 6-hourly interval, with lead time of 84 hours. Products are provided to the countries daily. Products from RIMES' 10-day, monthly, and seasonal NWP models are provided to select countries only.

Following are key considerations in using NWP products in hydrological modeling:

- Observation data pre-processing and quality control, before application in NWP models, to manage errors and fill missing data
- Forecast verification to determine and improve forecast skill
- Bias correction to manage errors that are inherent in the NWP model

2.3 Data Requirements for Hydrological Modeling

Anshul Agarwal, RIMES, provided an overview of basic data requirements for developing a hydrological model for a basin, as follows, and the ensuing data preparation process.

- Spatial data
    - Digital Elevation Model (DEM)
    - Land use
    - Soil types
    - Other physiographic properties
    - Station locations
    - Reservoir, bridge locations
- Meteorological data

    - Precipitation
    - Temperature
    - Evapotranspiration
- Hydrological and hydraulic data,
    - Discharge
    - Water level
    - Rating curve
    - Channel and reservoir/ diversion hydraulic data

Data availability is an important consideration in selecting the model that is appropriate for a particular basin. For trans-boundary river basins, it is often difficult to get data from neighboring countries. In such situations, global datasets, available from various organizations, may be used.

Data preparation for use in modeling involves:

- Delineation of catchment and river network
- Acquisition of catchment characteristics data (e.g. area, slope, etc.)
- Construction of Thiessen polygon and obtaining Thiessen weights
- Delineation of elevation bands for snowmelt modeling
- Preparation of basin model file
- Preparation of meteorological model file

2.4 Introduction to Hydrological Modeling

Dilip Kumar Gautam, RIMES, introduced participants to hydrological modeling using the Hydrologic Modeling System developed by the Hydrological Engineering Center (HEC-HMS) of the U.S. Army Corps of Engineers.

Hydrological modelling is the process of mathematically representing the response of a catchment system to hydrologic events during the time period under consideration. Hydrological models are the basis for flood forecasting systems. Hydrological modelling is a very effective tool in generating runoff forecast, based on weather forecast. Hydrologic models use climatic variables, such as precipitation and evapotranspiration, and catchment topography and land use characteristics to simulate runoff.

Hydrological models can be classified as:

- Deterministic or stochastic,
- Empirical, conceptual, or physically-based
- Lumped, semi-distributed, or distributed

Model selection, in most cases, depends on data availability. A complex distributed model should not be used when available data do not support it. Model selection also depends on the characteristics of the basin.

Model development is an iterative process, which consists of data acquisition and preprocessing, selection of model, and calibration and validation (Figure 2.2).

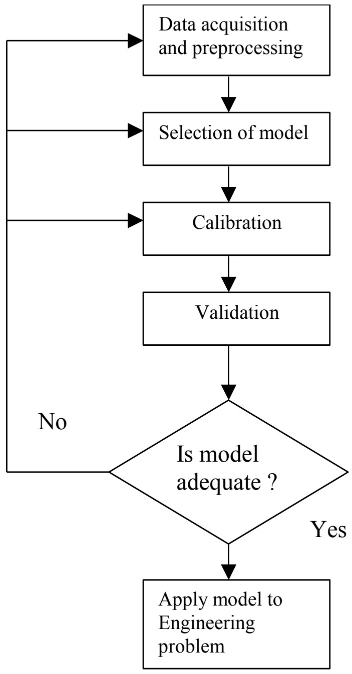


Figure 2.2 Model development process

HEC-HMS is a freely available model, designed to simulate both single event and continuous rainfall-runoff process. It simulates precipitation-runoff and routing processes, both natural and controlled. HEC-HMS uses a separate model to represent each component of the runoff process (Figure 2.3), which include:

- Runoff volume
- Direct runoff (overland flow and interflow)
- Baseflow
- Channel flow

HEC-HMS also includes:

- An automatic calibration package that can estimate certain model parameters and initial conditions, given observations of hydrometeorological conditions
- Links to a database management system that permits data storage and retrieval, and connectivity with other analysis tools that are available from HEC and other sources.

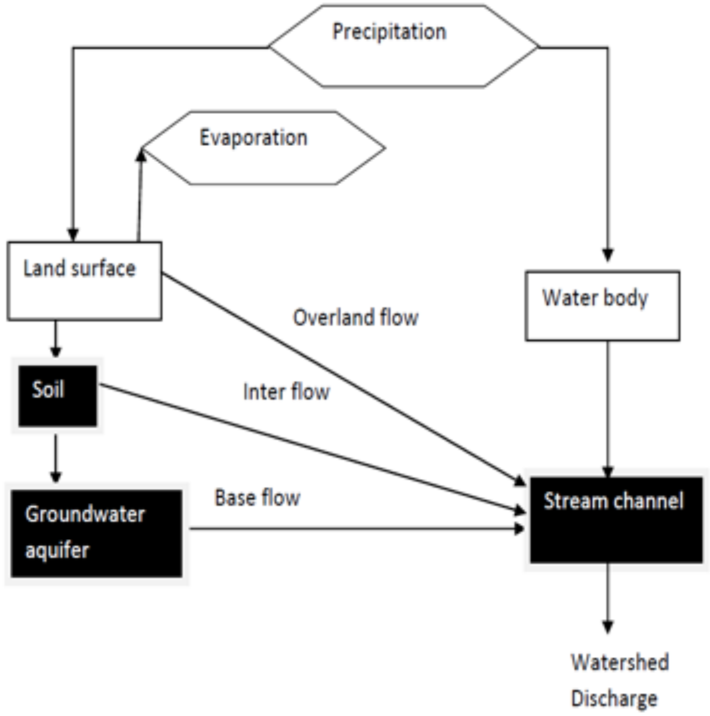


Figure 2.3 HEC-HMS representation of watershed runoff

2.5 Decision Support Systems

Bhogendra Mishra, RIMES, presented the importance of decision support system (DSS) for potential impact assessment and generation and dissemination of flood advisories, and featured RIMES ongoing DSS development work for Myanmar.

Recipients respond better to warning messages that include the hazard's potential impacts. Assessment of potential impacts of a predicted flood, and subsequent generation and dissemination of advisories could be automated in a decision support system that makes use of Geographic Information System (GIS) tools and techniques for integrating spatial data with hazard information (Figure 2.4).

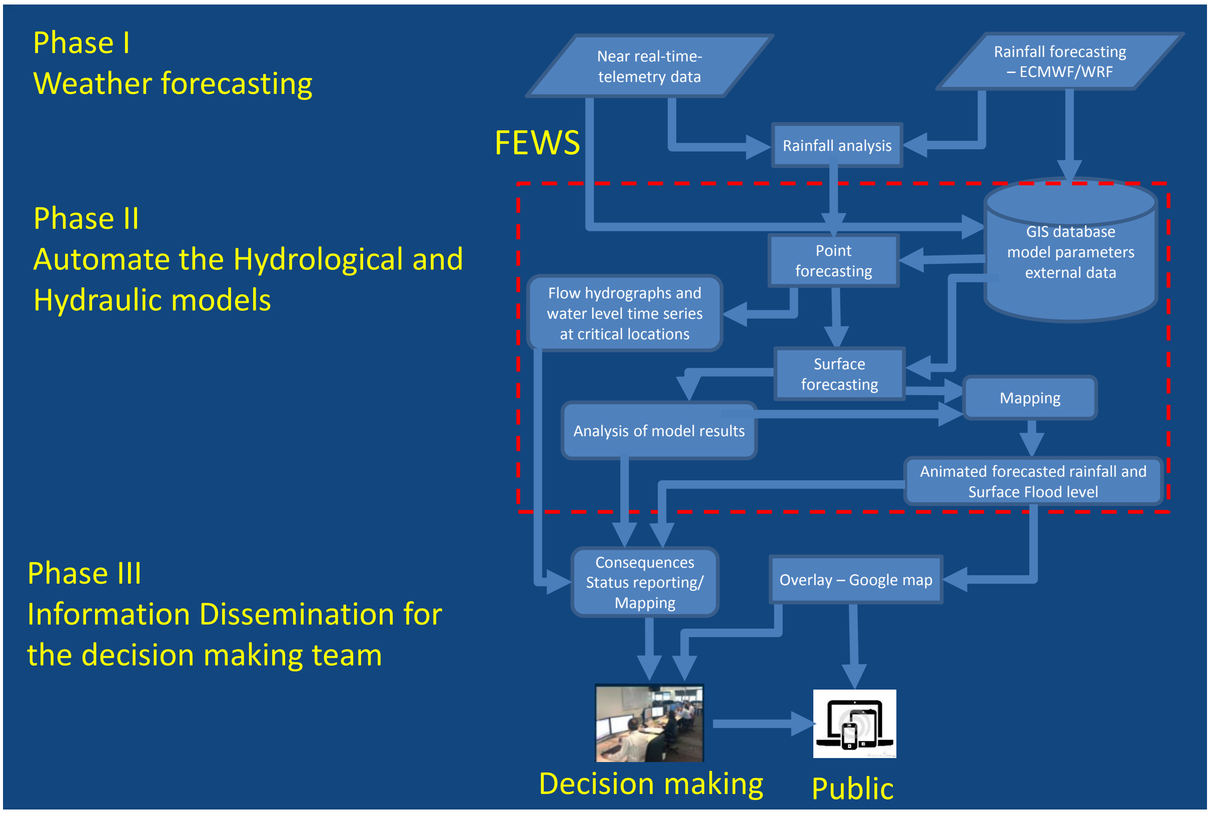


Figure 2.4 Flood forecasting and decision support system

RIMES DSS development efforts for flood warning uses Delft-FEWS, an open source data handling platform that connects observation data and weather forecast inputs with hydrological and hydraulic flood routing models. It has:

- Modules for such multi-source spatial data handling, including data validation, interpolation, aggregation and error correction in forecasts
- A mathematical model for predicting decision outcomes
- A graphical user interface for displaying spatial and tabular reports to assist in decision-making and information dissemination

The DSS is developed using case-based reasoning, hence is unable to quantify constraints, such as social and political.

2.6 Dissemination and Communication Aspects of Flood Early Warning Systems

G. Srinivasan, RIMES, presented considerations for dissemination and communication of forecast and warning information.

Dissemination is the delivery of forecast and warning information, while communication involves the receipt and understanding of forecast and warning information. Communication, thus, depends on the presentation and dissemination of information and recipients' education/ awareness and understanding of risks that they face. The latter requires knowledge of recipients' backgrounds, experiences, perceptions, and priorities.

Three key considerations in warning dissemination are:

a) Communication channels. Warning dissemination should use multiple communication channels to ensure delivery of warnings to threatened communities. Communication systems need to be tested on a routine basis, involving key recipients. As much as possible, dissemination processes need to be automated to improve efficiency and decrease the time required to issue warnings. It is necessary to establish protocols for acquiring information in a timely manner and for seamless transfer of information and data between agencies. This would ensure efficiency and effectiveness of the warning system.

b) Warning frequency. Decision for warning updates shall be based on the nature, intensity, and duration of the threat; available mode of communication; and needs and expectations of the community.

c) Follow-up. A process for follow-up/ confirmation should be in place to ensure that warnings are received and understood by various recipients. In the event that warning was required but not issued, or warning was issued well after hazard impact, a careful explanation of this failure needs to be given to the public. This shall aid public understanding of the limitations of the warning system, and should lead to recommendations to address gaps.

On communication, an individual's perception of risk is enhanced when:

- Warnings are as accurate as the science allows;
- Warning messages have local relevance and meaning
- Warning messages before and during a particular event are issued and updated frequently;
- Warnings are delivered by multiple credible sources;
- Warning messages are consistent;
- The basis for the warning is clear; and
- Suggested response actions that are clear and simple to follow are included.

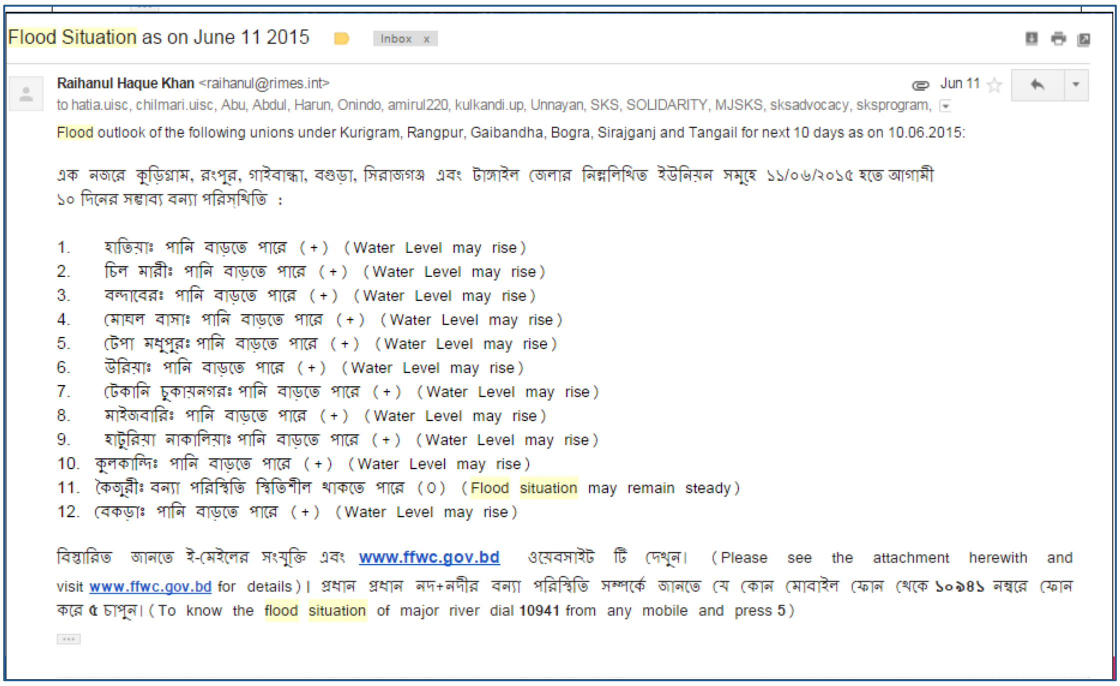
2.7 Early Warning Dissemination: Bangladesh Experience

Raihanul Haque, RIMES, Bangladesh, featured the flood warning dissemination methods in use in Bangladesh.

Bangladesh's FFWC uses the following methods for disseminating flood forecast and warning information:

- Email to about 1,000 focal points in stakeholder institutions at national, district, and union levels
- SMS to Disaster Management Committees in RIMES pilot unions and to 106 FFWC water level gauge readers
- Voice message broadcast to 1,300 focal persons in RIMES pilot unions. This method overcomes the barriers of language and illiteracy. Broadcast frequency depends on the level of flood threat: twice a day when water level has crossed the danger level and is in rising trend; once a day when water level is in rising trend but still below the danger level, or water level is above danger level but has a falling trend.
- FFWC website (www.ffwc.gov.bd), Facebook page (www.facebook.com/ffwcbwdb), and interactive voice response (IVR) system (at a cost) to the general public

The 10-day forecast information includes Union name, river name, date of issue, current water level in meter, forecast water levels in the next 10 days in rise (+) or fall (-) in water level in centimeter, and river gauging station name (Figure 2.5). Interpretation of 10-day water level forecast requires users' training.


Flood Situation as on June 11 2015

Inbox x

Raihanul Haque Khan <raihanul@rimes.int>

Jun 11

to hatia.uisc, chilmari.uisc, Abu, Abdul, Harun, Onindo, amirul220, kulkandi.up, Unnayan, SKS, SOLIDARITY, MJSKS, sksadvocacy, sksprogram,

Flood outlook of the following unions under Kurigram, Rangpur, Gaibandha, Bogra, Sirajganj and Tangail for next 10 days as on 10.06.2015:

এক নজরে কুড়িগ্রাম, রংপুর, গাইবান্ধা, বগুড়া, সিরাজগঞ্জ এবং টাঙ্গাইল জেলার নিম্নলিখিত ইউনিয়ন সমূহে ১১/০৬/২০১৫ হতে আগামী ১০ দিনের সম্ভাব্য বন্যা পরিস্থিতি :

1. হাতিয়াঃ পানি বাড়তে পারে (+) (Water Level may rise)
2. চিল মারীঃ পানি বাড়তে পারে (+) (Water Level may rise)
3. বন্দাবেরঃ পানি বাড়তে পারে (+) (Water Level may rise)
4. মোঘল বাসাঃ পানি বাড়তে পারে (+) (Water Level may rise)
5. টেপা মধুপুরঃ পানি বাড়তে পারে (+) (Water Level may rise)
6. উরিয়াঃ পানি বাড়তে পারে (+) (Water Level may rise)
7. টেকানি চুকায়নগরঃ পানি বাড়তে পারে (+) (Water Level may rise)
8. মাইজবারিঃ পানি বাড়তে পারে (+) (Water Level may rise)
9. হাটুরিয়া নাকালিয়াঃ পানি বাড়তে পারে (+) (Water Level may rise)
10. কুলকান্দিঃ পানি বাড়তে পারে (+) (Water Level may rise)
11. কৈজুরীঃ বন্যা পরিস্থিতি স্থিতিশীল থাকতে পারে (0) (Flood situation may remain steady)
12. বেকড়াঃ পানি বাড়তে পারে (+) (Water Level may rise)

বিস্তারিত জানতে ই-মেইলের সংযুক্তি এবং www.ffwc.gov.bd ওয়েবসাইট টি দেখুন। (Please see the attachment herewith and visit www.ffwc.gov.bd for details)। প্রধান প্রধান নদ+নদীর বন্যা পরিস্থিতি সম্পর্কে জানতে যে কোন মোবাইল ফোন থেকে ১০৯৪১ নম্বরে ফোন করে ৫ চাপুন। (To know the flood situation of major river dial **10941** from any mobile and press 5)

Figure 2.5 Email dissemination of 10-day water level outlook, Bangladesh

Lessons learned from the Bangladesh experience include:

- Dissemination of forecasts and warnings to focal points is more effective than broadcast methods
- Training and capacity building of focal points to interpret and act on the warning (e.g. further dissemination, engage others to undertake preparedness actions), particularly below district level, are required
- Use of mobile services has tremendous potential, but requires time for updating database of phone numbers
- Union Digital Center Entrepreneurs could be one of key early warning information providers at community level

2.8 Preparedness and Response Systems

Raihanul Haque, RIMES, Bangladesh, stressed the importance of warning lead time and consistency, and capacity development of both providers and users of forecast and warning information, with examples on RIMES work in Bangladesh, for appropriate and timely user response to warnings.

To enable a warning recipient to respond timely and appropriately to warnings, he/she should be able to[1,2]:

- Receive the warning in time for response;
- Understand the information presented;
- Believe the information;
- Personalize the risk; and
- Make correct decisions

[1]Mileti, D. & Sorenson, J 1990, *Communication of emergency public warnings – a social science perspective and state-of-the-art*
[2]Mileti, D 1999, *Disasters by design – a reassessment of natural hazards in the United States,* National Academy of Sciences, Joseph Henry Press, Washington.

Lead time. Advances in numerical weather prediction have cascaded into flood forecasting and warning, providing products at different lead times, from days to months. Flash flood and short-range flood forecasts are useful in saving lives; medium-range forecast products with lead times of up to 10 to 15 days are useful for preserving livelihood assets. Monthly and seasonal flow outlooks are useful in sectoral planning. Increasing forecast lead times, however, increases forecast uncertainty (Figure 2.6). Hence, there is need to build capacity of users in utilizing longer lead forecasts in planning and decision-making.

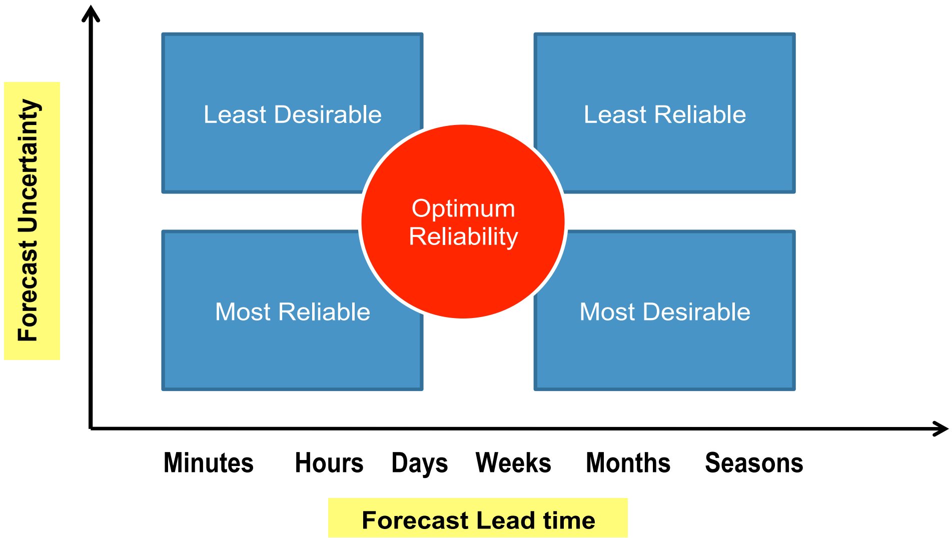


Figure 2.6 Forecast lead time and uncertainty

Understanding warnings and personalizing risks. Public education on hazard characteristics and potential impacts are essential in understanding the warning and personalizing the risk. Direct personal experience of a hazard is a powerful factor in personalizing risks. Where a community does not have such previous experience, particularly of a hazard's intensity and magnitude of impacts, the warning could refer to a historical impact elsewhere. For example, the flood warning could mention inundation levels in a past flood and relate this to the forecasted flood level.

Capacity to respond. People must be aware on appropriate response actions and have the physical and intellectual resources to willingly act on the advisory. Public education and awareness is not the responsibility of disaster management organizations alone, but of the NHS/NMHS as well. Regular NHS/NMHS interaction with the public is thus important. This also allows the NHS/NMHS to understand early warning needs, and for the public to learn of limitations in early warning. This dialogue process shall result to recommendations and actions for improving the end-to-end early warning system.

Public education and awareness may be undertaken:

- Before the flood season
- Through until the end of the season
- During a flood event
- Immediately following an event as this presents the greatest opportunity for people to personalize risk

In Bangladesh, RIMES works with FFWC in:

- Raising public awareness on FFWC responsibilities, functions, facilities, operations, and services
- Improving public awareness, understanding, and use of products available from FFWC
- Increasing public understanding of the nature of floods and their associated risks
- Raising disaster awareness and preparedness
- Involving the public in observation and monitoring (e.g. rainfall and river level measurements) and in providing feedback

Importance of partnerships. Partnerships with various institutions, organizations, and individuals are important in warning communication and response, public education and awareness, and in improving warning information. These include government agencies at various levels, the media, community/ amateur radio groups, emergency responders, emergency relief agencies (e.g. Red Cross), NGOs, academic and research institutions, social scientists, hydrological/ meteorological societies, and businesses.

2.9 Feedback System

Ruby Rose Policarpio, RIMES, highlighted the importance of feedback in people-centered flood early warning system, with example on the Monsoon Forum as national and sub-national level feedback mechanism.

A people-centered early warning system requires a robust feedback mechanism that is embedded in each step of the end-to-end warning system (Figure 2.7).

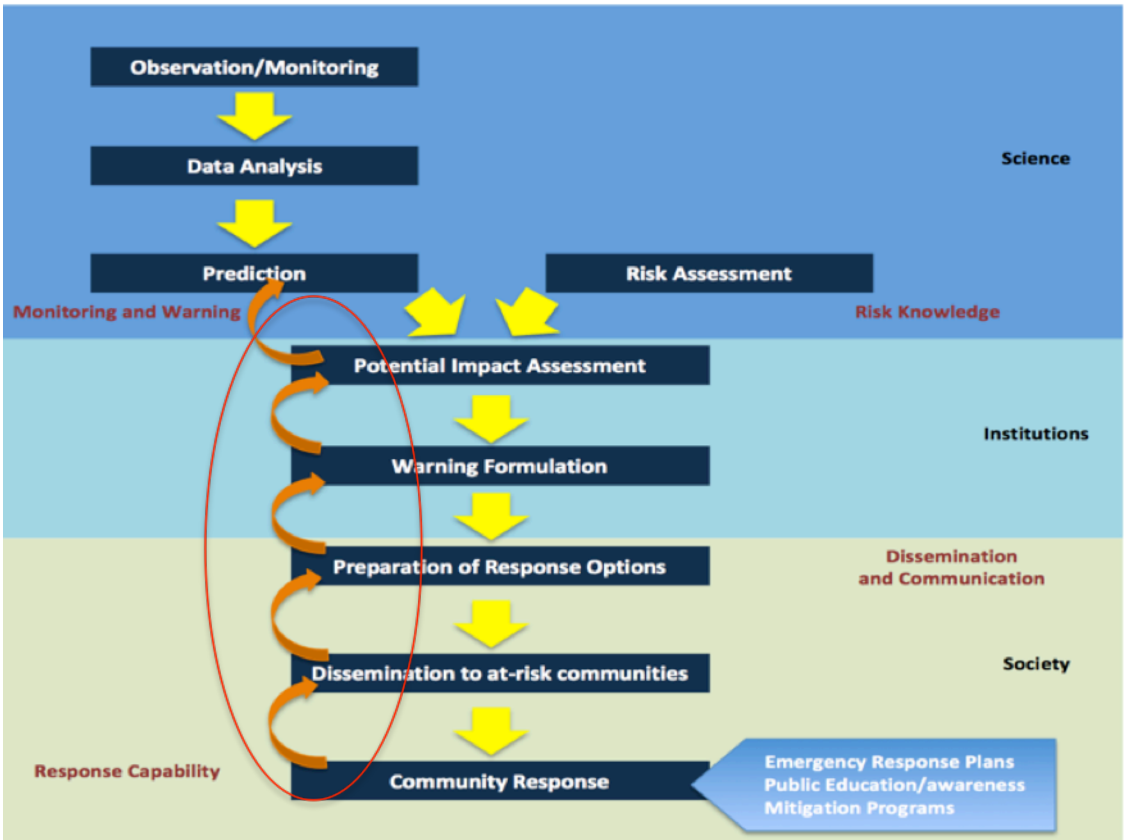


Figure 2.7 Feedback mechanism (indicated by red oval) embedded in the end-to-end early warning system

User feedback mechanism:

- Emphasizes the importance of user inputs, for further developing the early warning system
  - Supports the development/tailoring of information and services
  - Provides opportunities for continued research for product development, to remain aligned with goals, develop new strategies, and develop/improve products and services
- Measures how information has been understood and applied by users
- Supports enhanced decision-making by stakeholders (generators, providers, and intermediary and end users)
- Offers insights on how users value forecast and warning information
- Keeps forecast and warning information providers relevant to users
- Provides opportunities for creating/enhancing NMHS-user partnerships

A feedback mechanism, to be effective, should:

- Be regular
- Be robust and embedded in the end-to-end early warning chain
- Have multi-sectoral participation
- Be sustained
- Be connected to a mechanism that enables dynamic response to/ actions on user recommendations

RIMES, working with institutional systems in its Member and Collaborating States, has evolved vigorous feedback mechanisms that enables articulation of user experiences, lessons learned, and recommendations for improving the early warning system. These feedback mechanisms are implemented and sustained at various levels, national, sub-national, and local levels.

Monsoon Forum. The Monsoon Forum[3] is a regular dialogue between providers and users[4] of forecast and warning information, anchored on relevant climate seasons in RIMES Member and Collaborating States. Conducted at least twice a year in the countries, before and after the relevant seasons, the Monsoon Forum is a cyclical process (Figure 2.8) of:

- NMHS generation and issue of user-demanded forecast
- Analysis of potential impact scenarios based on multi-hazard and multi-timescale information
- Identification of management options vis-à-vis possible seasonal and sub-seasonal conditions
- Implementation of feasible options, for optimizing resources/ managing risks in various sectors
- Monitoring progress of the season and making adjustments, as necessary
- Sharing experiences, management decisions, good practices, lessons learned, and other feedback and recommendations[5] for EWS enhancement

RIMES assists NMHSs in responding to user demands, in the area of product/ system development. Collaboratively, RIMES and NMHS undertake research and development, share outputs on experimental basis, receive feedback and perform validation, improve product/ system, handover product/ system, and build user capacity through training.

[3] Coined based on the main climate driver (the monsoon) in countries in South and Southeast Asia
[4] Information user sectors include agriculture and food security, water resources, livelihoods, public health, infrastructure and transportation, environment, information and communication, power, and disaster management
[5] Community feedback are articulated during the Forum by sub-national/ national user institutions

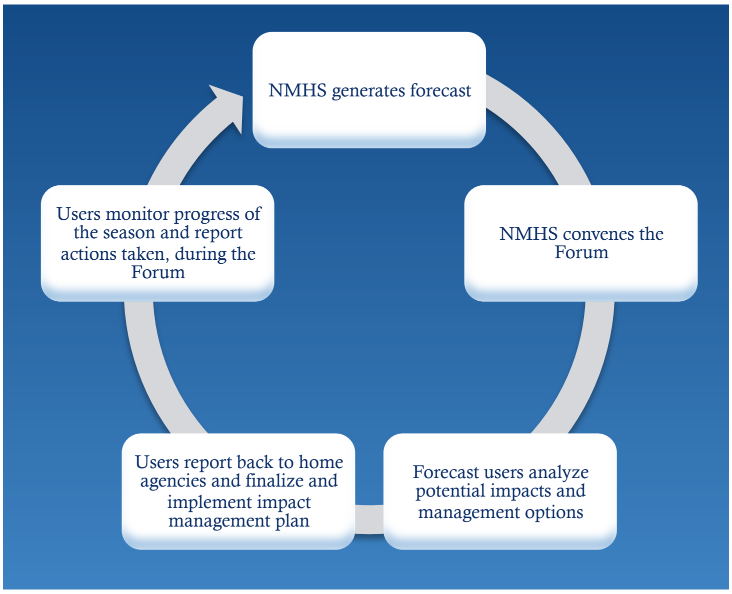


Figure 2.8 The Monsoon Forum process

2.10 Community Feedback on Flood Early Warning

Raihanul Haque Khan, RIMES, Bangladesh, featured RIMES experience in Bangladesh on methods used for collecting community feedback, types of information collected, and challenges and constraints met.

In Bangladesh, FFWC and RIMES, in collaboration with NGO partners and trained volunteers, undertake periodic evaluation of community receipt and understanding of and responses to flood forecasts and warnings. Data collection methods include semi-structured interview, focus group discussions, key informant interview, local level dialogues, and representation in the national Monsoon Forum. Information collected include:

- Community characteristics: Community profile, hazard, flood risk, past experience, preparedness, resources for warning response
- Warning characteristics: Source/s, channel/s, content, frequency, access
- Forecast performance: Forecast lead time, perceived accuracy
- Community response: Actions taken, factors that trigger early action, flood impacts, early warning benefits

Challenges and constraints met include:

- Intensive resource (human, time) requirement
- Data verification
- Data analysis – time consuming and no immediate recommendations
- Communities hardly get the EWS overview in their locality

Learning from these evaluations has led to the following changes:

- Introduction of voice message broadcast to widen reach, particularly to the illiterate segment of communities
- Email dissemination in Bangla to Union Digital Centers
- SMS dissemination in Bangla to key disaster managers
- Generation and dissemination of flood outlook for farmers, based on medium-range forecast
- Localized flood forecasts

- Frequency and length of flood forecast messages and timing of dissemination according to user expectations
- Popularization of IVR system
- Promotion of Union Digital Center as key interpreter of flood forecasts at community level

FFWC and RIMES have developed the Interactive Risk Information Gateway, a mobile phone-based application for facilitating user access to warning/risk information and feedback.

2.11 Capacity Building for End-to-End Long-Lead Flood Forecasting and Warning – Bangladesh Experience

Raihanul Hauqe, RIMES, Bangladesh, featured the development process of FFWC's flood forecasting system and Interactive Risk Information Gateway.

FFWC's flood forecasting system evolved from 2000, with funding support from USAID. RIMES provided back-up support during USAID funding cycle breaks in 2009-2010, and from 2014. Development of the 10-day, 20-25 day, and seasonal models for Ganges and Brahmaputra basins were undertaken from 2000-2005. Pilot testing, in partnership with CARE, was conducted in 5 Unions from 2006-2009. From 2011-2014, geographical area covered by the model was expanded to cover Meghna basin, flash flood guidance system was developed, the seasonal flow outlook model was further developed, technologies (models, equipment, skills/training) were transferred to FFWC, and pilot testing was expanded to 15 Unions. Pilot testing, in partnership with CARE and DDM, included user training, wider dissemination system, and systematized feedback system.

Development of the Interactive Risk Information Gateway was initiated in 2014, with support from Netherlands and Cordaid, and in partnership with Concern Universal, Practical Action, Manob Mukti Songstha (local partner), and Deltares (research). FFWC's 5-day forecast was downscaled in 5 Unions, using gauge-to-gauge correlation, in addition to the dissemination of 7-day forecast from the 10-day forecast system. Potential flood impact system was developed, generating maps of potential inundation in GIS environment. Staff gauges were installed in rivers and in the flood plain for local level monitoring and to support forecast verification, respectively. A dashboard was developed to pull data, display hazard products, and calculate and visualize flood risk. Training was provided on dashboard use and on forecast interpretation and warning dissemination. Community feedback in 2014 showed that 80% of users understand the warning, 78% highly trust the warning, 64% perceived the forecasts to be accurate, and 80% were willing to pay for access to forecast information. Forecasts and warnings proved economically beneficial to the fisheries, livestock, and health sectors.

Challenges faced include:

- Retaining of trained FFWC personnel
- Downloading of large volume of data required for the models, with the limited internet capacity
- Frequent change in warning recipients' mobile phone numbers
- Communicating forecast uncertainty

Following are recommended to address gaps that still remain:

- Increase in number of FFWC professionals
- Updating of the basin discharge modeling system
- Increase in number of discharge measurement stations, to extend model boundaries
- Frequent calibration of models to keep up with changes in river dynamics
- Spatial flood forecasting, 2D modeling, and inundation mapping
- Low-cost survey methodologies for DEM generation in high-risk areas
- Enhancement of FFWC internet capacity

- Research to incorporate basin average rainfall, bias correction of rainfall forecast, and other transboundary basin-relevant factors
- Risk communication
- Training and re-training on forecast interpretation and translation
- Wider and deeper stakeholder involvement in forecast application

SESSION SUMMARY

- An end-to-end flood forecasting and warning system involves a chain of activities that connects the technical and societal aspects of warning, from understanding, mapping, monitoring, and forecasting the hazard to generating and disseminating warnings, communicating associated risks, taking appropriate and timely response, and providing user feedback.
- Integration of multi-timescale NWP products into hydrological modeling could provide flood outlooks and forecasts that could be used in a seamless manner for planning and decision-making. Observation data quality control, bias correction, and forecast verification are necessary to improve forecast quality.
- Data availability and basin characteristics are key factors in selecting an appropriate hydrological model
- A decision support system could automate the assessment of a hazard's potential impacts, based on the forecast, and the generation and dissemination of relevant advisories.
- Dissemination is the delivery of forecast and warning information; communication involves the receipt and understanding of forecast and warning information.
- Dissemination of forecasts and warnings to focal points who are trained to interpret, translate, and communicate these into early preparatory actions is more effective than broadcast methods.
- Timely and appropriate response to warnings requires the warning recipient to receive the warning in time, understand the warning, believe the warning, personalize the risk, and make correct decisions.
- User feedback is essential to determine usability of forecasts and warnings and identify actions for improving the end-to-end flood forecasting and warning system
- User demands, articulated in regular Monsoon Forums, drive NMHS product and service development and innovation
- Development of an end-to-end flood forecasting and warning system that is user-relevant is resource intensive, in terms of time, funding, and people. Stakeholder partnerships provide supplementary/ complementary resources, facilitate user engagement, and contribute to sustainability.

3. FLOOD FORECASTING AND WARNING IN SAR: ONGOING EFFORTS

3.1 Flood Outlook System for the Himalayan Basins

Shahriar Wahid, International Centre for Integrated Mountain Development (ICIMOD[6]), Nepal, presented ICIMOD's flood information for and related programs in the South Asian Region.

Flooding is an annual occurrence in the Himalayan Basins. Many catchments in the region are transboundary. Glacier and snow melt contribute to flooding, while GLOF can cause flash flood. Also, river courses and forms are changing constantly due to erosion and sedimentation. Flood early warning system is, thus, essential for flood management.

ICIMOD has been cooperating with NMHSs in Nepal, Bhutan, Pakistan and China, and disaster management authorities in Bihar, India to develop flood outlook systems for the Ganges-Brahmaputra and Koshi basins, to support national flood forecasting efforts. The pilot flood outlook system, which was tested and showed promising results during the 2014 monsoon, is an integrated hydrological and hydrodynamic model of the basins (Figure 3.1). The outputs of this real-time forecasting system (www.icimod.org/floodoutlook) include a flood stance for the next three days in terms of flows and water levels at key locations in the river system, for use by member countries in their own forecasting activities. Currently the system is upgraded to include more tributaries, major water structures, and more forecast locations to improve the predictive capacity of the system in selected basins.

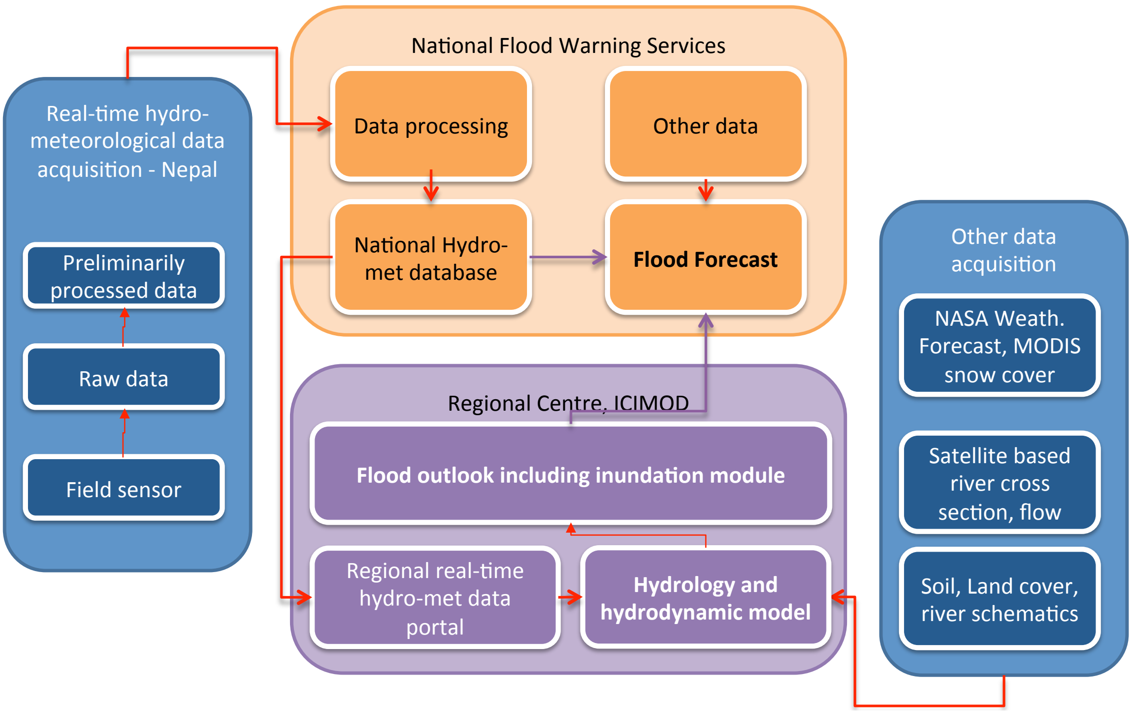


Figure 3.1 ICIMOD flood information system

Also, ICIMOD has a community-based flood early warning system, which consists of upstream water level monitoring, transmission of observation data to downstream communities by wireless radio, warning generation based on established water level thresholds, and warning dissemination by siren

[6] ICIMOD is a regional knowledge development and learning center that serves its eight regional member countries of the Hindu Kush Himalayas – Afghanistan, Bangladesh, Bhutan, China, India, Myanmar, Nepal, and Pakistan

alarm (Figure 3.2). The system could be enhanced by establishing real-time water level monitoring, and warning dissemination by SMS alerts.

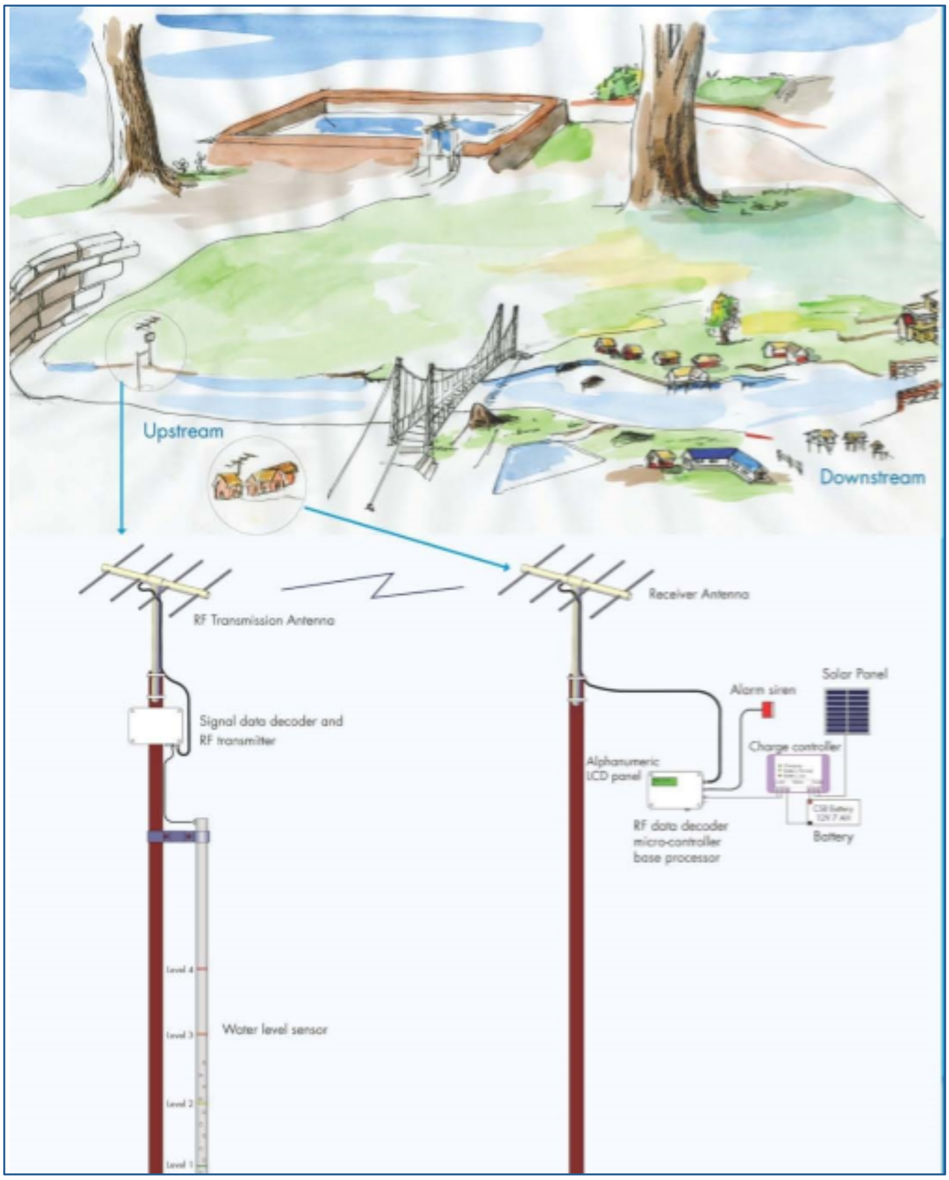


Figure 3.2 ICIMOD's community-based flood early warning system

3.2 SAWI Program on Regional Flood Forecasting

Satya Priya, World Bank, India, presented World Bank's South Asia Water Initiative (SAWI), aimed at improving transboundary dialogue, enhancing the knowledge base on major Himalayan river systems and water resources, strengthening water institutions, and supporting investments for sustainable, fair, and inclusive development[7].

Established in 2009, this strategic program supports Afghanistan, Bangladesh, Bhutan, China, India, Nepal, and Pakistan for improved and shared understanding, management, and development of the

[7] https://www.southasiawaterinitiative.org

Ganges-Brahmaputra River Basin, to support the countries' economic growth and resilience to climate variability and change. Features of the program include:

- Flood risk assessment for the Ganges Basin, covering Nepal, India, and Bangladesh, to guide flood forecasting priorities. This includes:
  - Data collection and visualization of historical flood events in terms of extent of inundation
  - Data analysis to determine population affected and economic losses for 2- and 50-year return periods
- Regional flood forecasting, covering the Ganges and Brahmaputra basins, using ensemble weather forecasts and satellite altimetry to fill data gaps
  - 1-10 day ensemble river discharge forecasting, using satellite-based ensemble precipitation forecasts
  - Water level forecasts in rivers, using satellite-based altimetry

Key expected results include:

- Improved user responses due to longer lead time available
- Prioritized schema of flood forecasting at sub-basin level through ongoing diplomacy
- Move from central to state to sub-basin scale operational flood forecasting

3.3 Flood Forecasting and Warning Initiatives in Nepal and Myanmar

Anshul Agarwal, RIMES, presented RIMES work on improving flood forecasting and warning in Nepal and Myanmar.

RIMES initiatives in Nepal and Myanmar focus on:

- Enhancing meteorological and hydrological monitoring capacities for generation of long-lead locations-specific flood forecasts
- Customization of flood forecast models for select river basins (Karnali, Babai, and Narayani in Nepal; Ayeyarwady, Sittoung, and Chindwin in Myanmar)
  - Uses 3-day WRF and 15-day ECMWF[8] rainfall forecasts
  - Uses HEC-HMS hydrological model and HEC-RAS hydrodynamic model
  - Model integration in Delft-FEWS
- Development of decision support system for impact forecasting and advisory generation and dissemination
- Technology transfer and training
  - Training on secondment to RIMES on rainfall forecast verification and bias correction, hydrological modeling, and DSS development
  - Model transfer

[8] European Centre for Medium-Range Weather Forecast

SESSION SUMMARY

Ongoing related efforts on flood forecasting and warning in the region include:

- 3-day outlook of river flows and water levels at key locations in the Ganges-Brahmaputra and Koshi basins (ICIMOD)
- Development of flood risk atlas for the Ganges basin, an interactive online tool for visualization of risks to floods of different return periods (SAWI, World Bank)
- 1-10 day ensemble river discharge forecasting, using satellite-based ensemble precipitation forecasts, covering the Ganges and Brahmaputra basins (SAWI, World Bank)
- Water level forecasts in rivers, using satellite-based altimetry (SAWI, World Bank)
- Customized flood forecast models for selected river basins in Nepal (Karnali, Babai, and Narayani) and Myanmar (Ayeyarwady, Sittoung, and Chindwin), using 3-day WRF and 15-day ECMWF rainfall forecasts, HEC-HMS/RAS hydrological/hydrodynamic models, and Delft-FEWS (RIMES)
- Decision support system development for impact forecasting and advisory generation and dissemination for above-mentioned river basins in Nepal and Myanmar (RIMES)

Main challenges in the region include:
- Data availability, particularly hydro-meteorological data, cross section along river channels, high resolution DEM,
- Acquisition of quality data on snow and glacier melt

The above highlights the need for regional cooperation and program for sharing of transboundary river data. Other relevant issues discussed include:

- Increase in density of observation networks in the region to improve forecast quality. For transbounary rivers, regional cooperation is necessary.
- Use of mobile signal frequency drop as indicator of precipitable clouds
- Monitoring of risks from extreme weather events, such as the 2013 Uttarakhand floods, which was precipitated by heavy rainfall, along with very soft snow that was about to melt
- Communication of forecast uncertainty. Recent floods in Tamil Nadu (November 2015) had advanced warning, but required precautions were not taken.
- Building policymakers' and planers' confidence in forecasts and warnings

4. SPECIAL SESSION

4.1 Surface Water Level Monitoring via Satellite Radar Altimetry

Charon Birkett, Earth System Science Interdisciplinary Center (ESSIC), University of Maryland, USA, presented the technology on surface water level monitoring using satellite radar altimetry, and its advantages and limitations.

Satellite radar altimeters are able to record variations in surface water level for the largest lakes, reservoirs, river channels, and wetland regions around the world. They do so with temporal resolutions that vary between 10 and 35days, with delivery of datasets as fast as within 24hrs after satellite overpass. Spatial resolution depends on temporal resolution: the lesser the temporal repeatability of the satellite mission, the greater the density of observation tracks (Figure 4.1). These multi-agency instruments have been operating now for almost 25yrs, and the techniques are well refined.

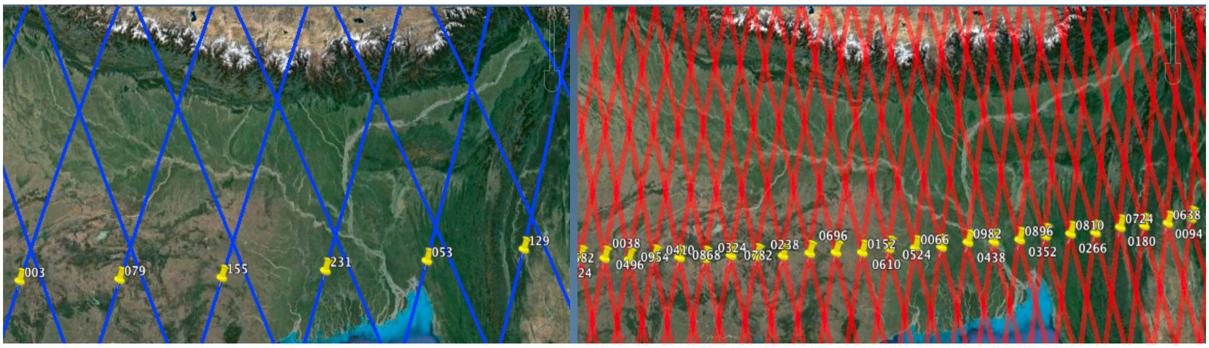


Figure 4.1 Left: NASA/CNES Jason-2/OSTM Ku-Band altimetry from mid-2008 to present day at 10-day resolution and 290m along-track sampling; Right: ISRO/CNES SARAL Ka-Band altimetry from early 2013 to present day at 35-day resolution and 175m along-track sampling

Satellite radar altimeters are best used on large water bodies. They do not distinguish surface roughness. Measurements may be erroneous when ice is present. Although they cannot compete with accuracy of ground-based gauge data, they can supplement regional networks by providing additional data at new locations, and in remote regions where gauge deployment may be prohibitive. They can also continue to monitor rising or falling waters on inundated floodplains during river overbank flooding periods.

4.2 Preliminary Altimetric Observation of the Ganges and Brahmaputra Rivers

***Tom Hopson**, Bob Brakenridge, and Charon Birkett, University Corporation for Atmospheric Research (UCAR)/ University of Colorado Boulder/ University of Maryland collaboration, USA,* presented the potential use of altimetric observations in the World Bank-funded project "Development of flood forecasting for the Ganges and the Brahmaputra Basins using satellite-based precipitation, ensemble weather forecasts, and remotely sensed river widths and height".

Water-level measurements from NASA/CNES Jason-2/OSTM at various locations along the Ganges and Brahmaputra River, as well as select reservoirs in India, were shown (Figures 4.2 and 4.3 as examples).

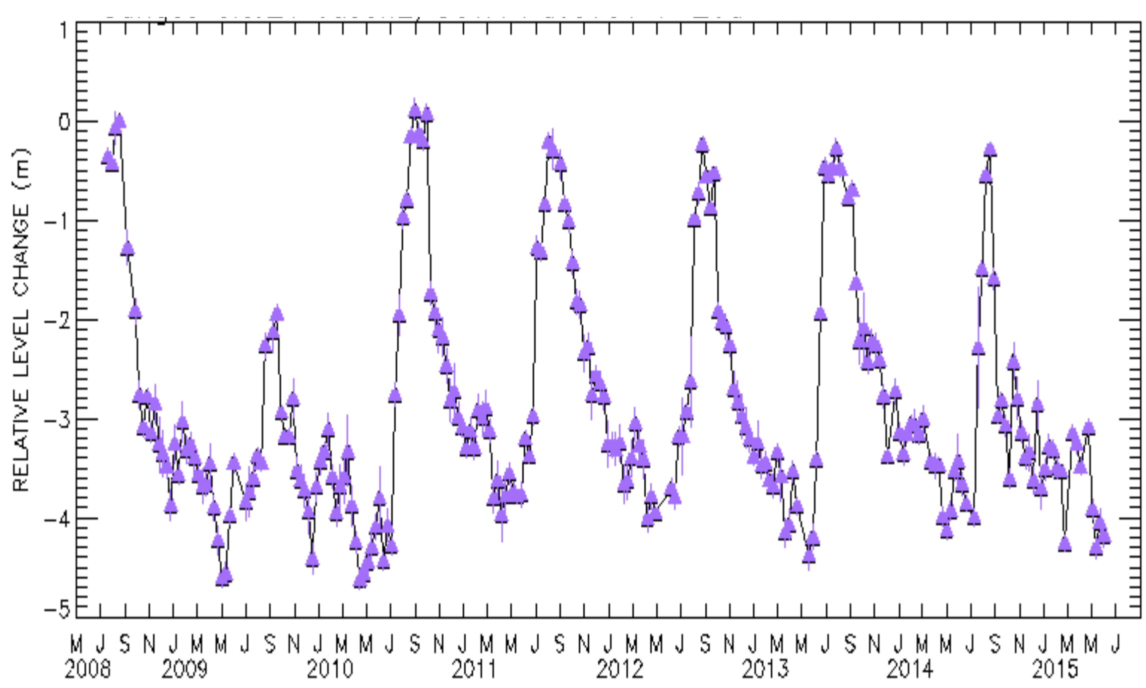


Figure 4.2 NASA/CNES Jason-2/OSTM altimetry measurements in Uttar Pradesh, Ganges Basin (1,700m along-track crossing, 200-700m main channel width, 2008-2015), observing 4m variability

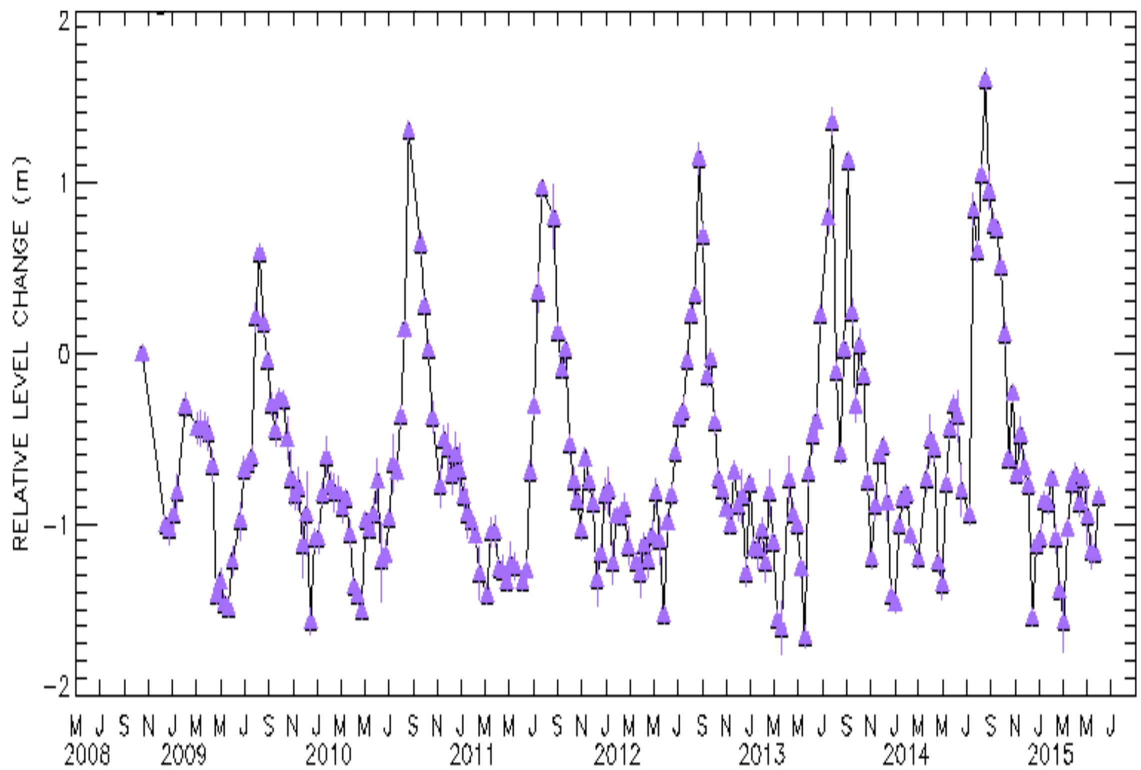


Figure 4.3 NASA/CNES Jason-2/OSTM altimetry measurements in Tibetan Plateau, Brahmaputra Basin (750m along-track crossing, 2 channels at about 100m width, 2008-2015), observing 1m to 2m variability

Participants were introduced to G-REALM, a NASA/USDA-funded lake monitoring project, as an example of an operational system that reveals the current and long-term status of lakes and reservoirs. On-line since 2003, G-REALM assists stakeholders and end users to assess both drought and rising levels/flood conditions. In the future this system could be modified to deliver products for designated river channel locations, with attention on the use of satellite datasets that are delivered to scientists within 24hrs after satellite overpass. Surface water level products for the Ganges River (and others) could then be created within 48hrs, and so be of particular use for real-time flood forecasting programs.

4.3 WRF-Hydro: An operational, large-scale real-time flood forecasting system

David Yates*, Tom Hopson, Dave Gochis, and Wei Yu, UCAR, USA,* introduced the WRF-Hydro, a multi-scale, multi-physics modeling tool for real-time flood forecasting.

WRF-Hydro is a community based and supported coupling framework, designed to provide:

a) Extendable multi-scale & multi-physics modeling for conservative, continuous, coupled and uncoupled assimilation & prediction of water cycle components: precipitation, soil moisture, snowpack, groundwater, streamflow, inundation, glacier, etc.
b) 'Accurate' and 'reliable' streamflow prediction across scales (from 0-order headwater catchments to continental river basins, and minutes to seasons)
c) Open Source system, that runs in a parallel, distributed LINUX computing environment

Figure 4.4 shows the WRF-Hydro model chain. The system is able to provide large-scale water prediction of up to 30 days. WRF-Hydro application in a watershed in the United States was presented, and its applicability for Ganges-Brahmaputra basins was discussed.

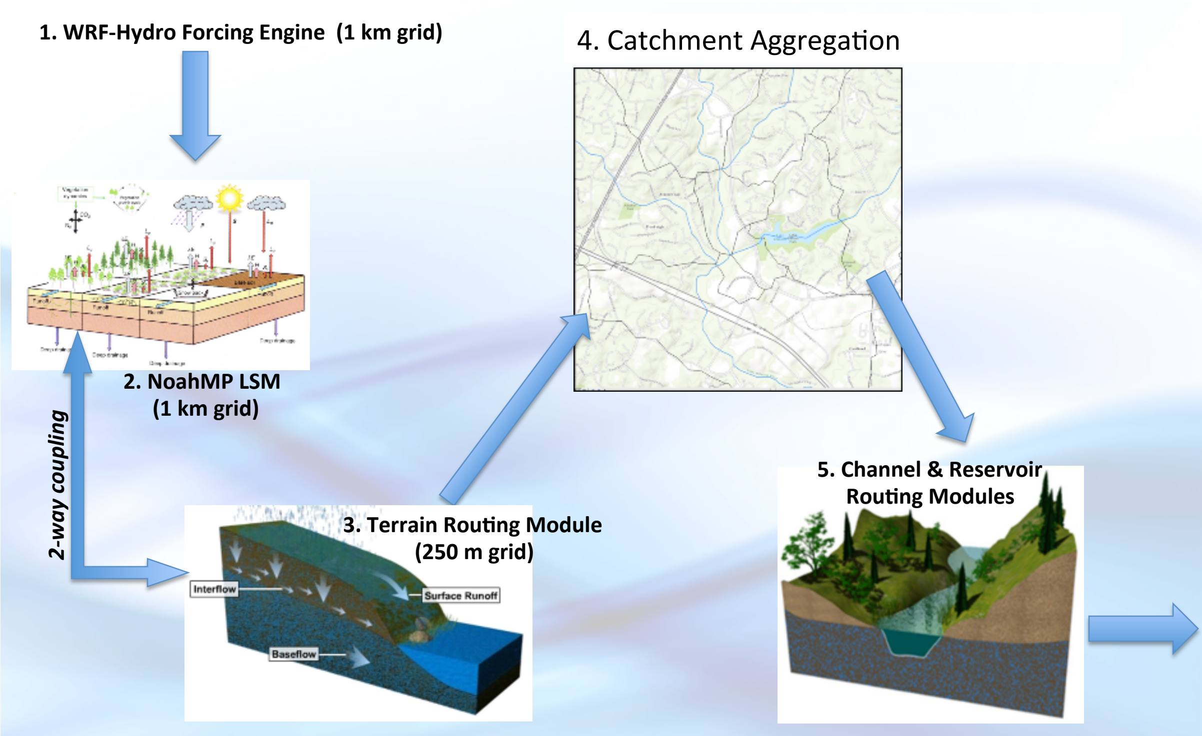


Figure 4.4 WRF-Hydro model chain

4.4 Rating Curves: Potential and Predictability

Daniel Broman *and Tom Hopson, National Center for Atmospheric Research (NCAR), USA,* presented the potential application of rating curves, developed from linking downstream river discharge with upstream river stage, in flood forecasting.

The methodology presented is unlike the conventional technique, wherein rating curves are prepared by relating discharge and stage at the same location. By combining information at several upstream locations, this methodology could provide a more skillful flood forecast. The methodology has been tested in the Ganges (Figure 4.5), with 6 days lag; skill was significantly good. It was also tested at few sites in the Brahmaputra, with 5 days lag.

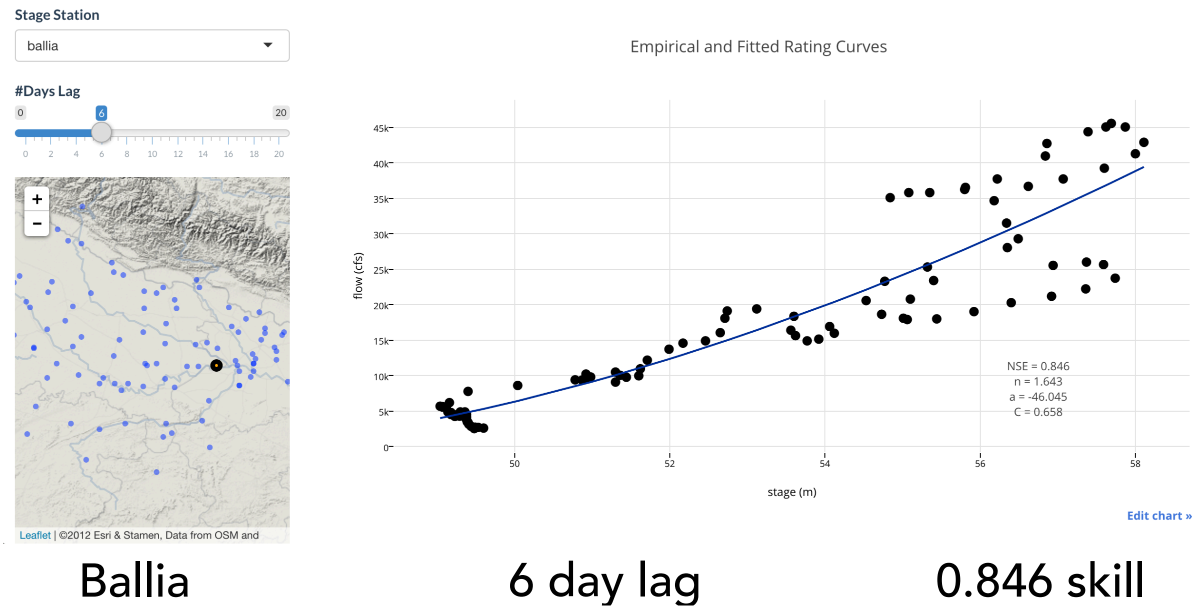


Figure 4.5 Ganges stage and discharge measurements

4.5 Upstream Satellite-Derived Flow Signals for River Discharge Prediction

Tom Hopson*, F.A. Hirpa, T. de Groeve, G.R. Brakenridge, M. Gebremichael, and P.J. Restrepo, NCAR, University of Connecticut, Joint Research Council, University of Colorado, and Office of Hydropower Research and Development, respectively,* presented the use of satellite-based passive microwave radiometer for river stage and flow monitoring, for application in river discharge prediction.

Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) and NASA Tropical Rainfall Measuring Mission (TRMM) data are used to monitor river stage and flow, particularly in limited-gauged basins. Accuracy may not be comparable with altimetry products, but has more temporal coverage. Applications include flood wave velocity estimation, discharge estimation (nowcasting, refer to Figure 4.6), and filling in of missing data. Combined with other methodologies, this method can serve as a useful tool for flood forecasting in large river basins.

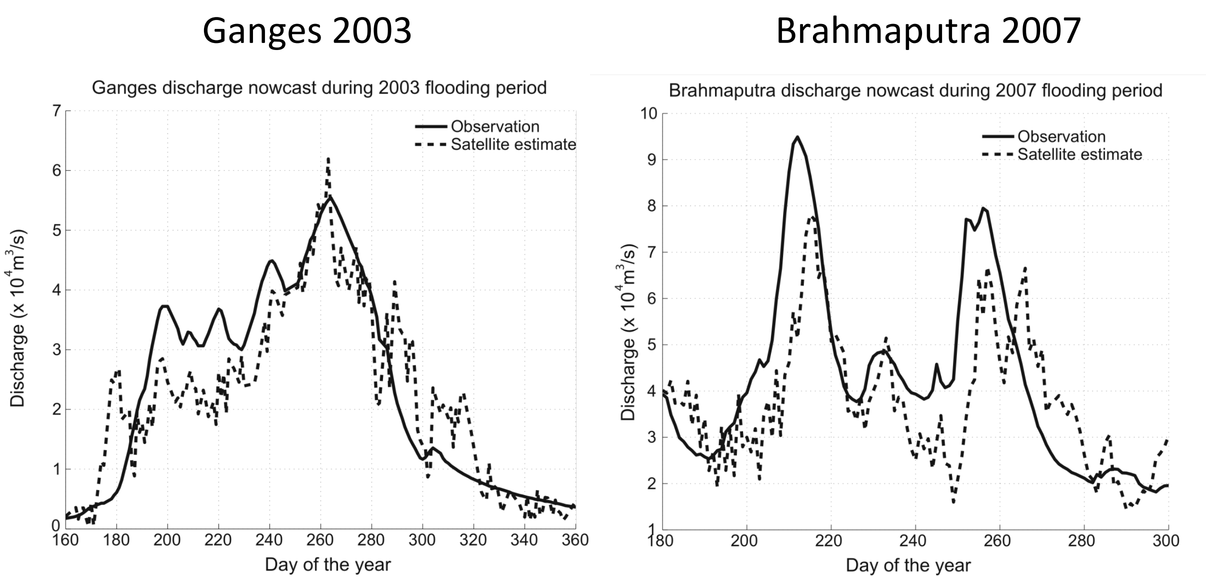


Figure 4.6 Discharge estimation using satellite-derived flow measurements

4.6 Operational Flood Forecasting for Bangladesh using ECMWF Ensembles

Tom Hopson*, Peter Webster, A.R. Subbiah, and R. Selvaraju, NCAR, Georgia Tech, RIMES, and Asian Disaster Preparedness Center, respectively,* presented the development process of Bangladesh's medium-range flood forecasting system.

Bangladesh's medium-range flood forecasting system was developed using up to 10 days ECMWF ensemble probabilistic rainfall forecast, extending the then existing lead time of 2-3 days to 12-13 days. The system (Figure 4.7) provides flood level exceedance at the Ganges and Brahmaputra entry points, which are then incorporated into Bangladesh's routing model.

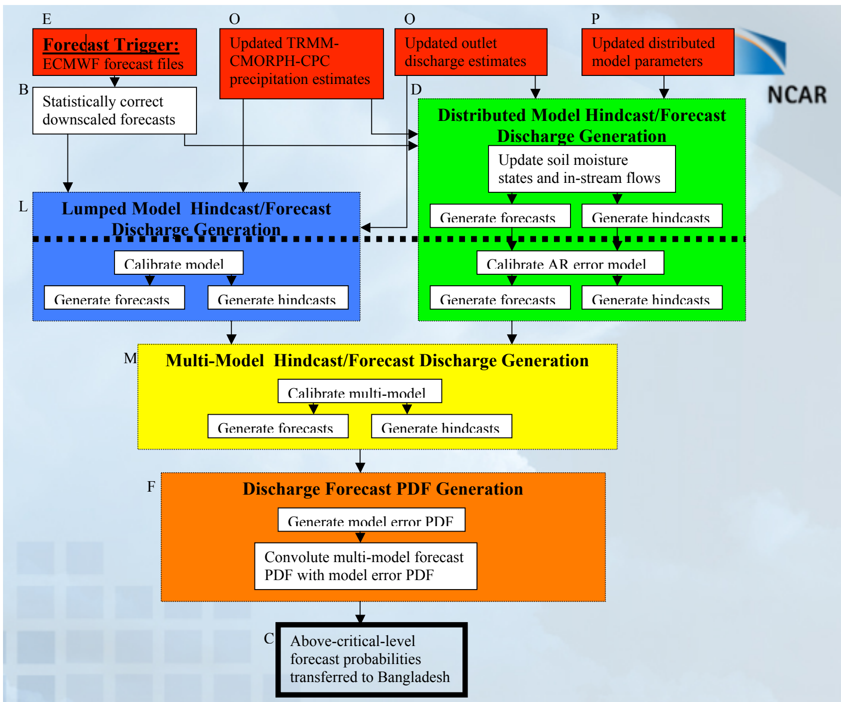


Figure 4.7 Bangladesh's medium-range flood forecasting system: process diagram

Forecast skill is quite good, and captured the 2004 and 2007 Brahmaputra floods well. A good forecast skill was possible because of availability of good data inputs (weather forecast and satellite rainfall), border observation data assimilation, and large catchment size such that weather forecast skill "integrates" over large spatial and temporal scales.

4.7 Rain Gauge Site Selection Tool

Daniel Broman and Tom Hopson, NCAR, introduced a tool for siting rainfall gauges, using analysis of rainfall event size in a region.

The methodology involves: a) dividing a region into grids; b) plotting daily rainfall (from satellite observation) on the grid; c) identifying potential gauge locations, considering spatial rainfall pattern in the grid; d) dividing the region among gauge locations; e) applying rainfall at gauge location to the entire region; f) calculating the difference between gridded and gauge rainfall. Re-siting/ increasing the number of sites (steps c to f) may be done until the difference is minimized.

Siting assumptions include: 0.1^{o} resolution is adequate to capture events of interest, spatial patterns are well captured by the satellite rainfall products used, past conditions are representative of future conditions, and existing gauge networks can be included to limit search for sites. Other considerations are: population, road, and weighting to divide the region by gauage.

4.8 Flood and Water Level Prediction: Japan

Kazumitsu Muraoka, JICA, presented an overview of Japan's early warning and response systems for floods.

Japan's major rivers are short and have steep gradient; thus, floods are short-distance runner type. Japan Meteorological Agency (JMA) is the government agency mandated to generate and provide weather advisories and warnings. Flood information, advisories, and warnings, however, are the responsibility by JMA and the Ministry of Land, Infrastructure and Transport (MLIT).

Japan's rainfall observation system consists of over 3,000 rain gauges that send information every minute; C-band radars, covering a minimum area of 1km x 1km, sending information every 5 minutes; and X-band radars in urban areas, covering a minimum area of 250m x 250m and sending information every minute. Water level monitoring uses radar sensors with wireless and optical fiber cable telemetry. Precipitation and water level data are provided in the MLIT website and updated every 10 minutes. The website also provides information on dam releases.

Flood warnings are issued based on location-specific thresholds and using 4 levels of warning (Figure 4.8) that correspond to specific response actions. Dissemination is by phone and through MLIT website. During floods, warnings are issued through television, cell phones, Internet, voice broadcasts, etc. Constant CCTV monitoring is also practiced at all river reaches. Response teams are assigned for each basin to manage emergencies.

Preparedness activities include scenario-based flood hazard mapping; evacuation modeling, planning, and drills; establishment of flood markers and evacuation signage; and training of emergency responders.

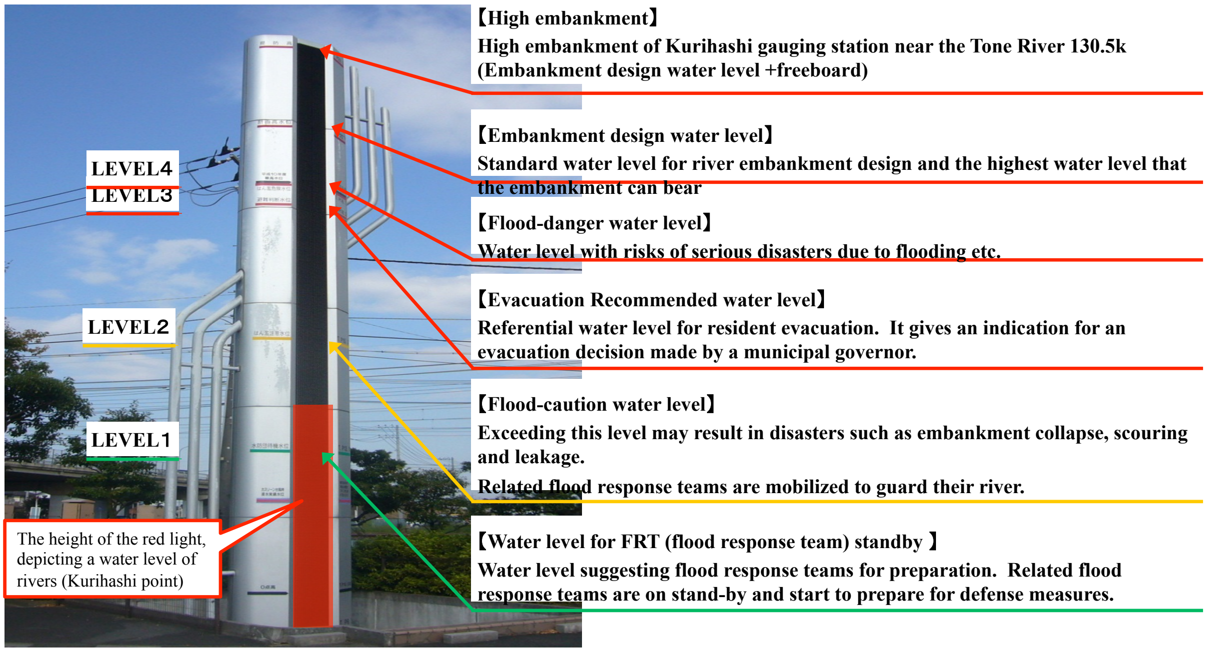


Figure 4.8 Water level display tower, Kurihashi

4.9 Real-Time Flood Forecasting System for Bhakra Beas Management Board – India Case Study

Anish Kumar, World Bank, presented the outcomes of the World Bank-funded project that developed real-time decision support and flood forecasting systems for the Bhakra Beas Management Board, India.

The Bhakra Beas Management Board is custodian for Satluj and Beas rivers, dams, barrages and main canals. The rivers provide irrigation supply to Punjab, Haryana, and Rajasthan, drinking water to Delhi and Chandigarh, and generate 3000 MW of hydropower. Their economic importance required a reservoir inflow forecasting system, as well as a flood forecasting and early warning system.

Development of an operational DSS (Figure 4.9) was a challenge due to data availability, as 2/3 of the catchment lies in China; catchment is snow-laden and India has limited expertise and experience in this area; and the catchment has multiple stakeholders, encompassing several States and user sectors with conflicting interests.

Real-time data acquisition system (DAS) consists of 16 precipitation stations, 52 automatic water level recorders, 12 full climate stations, 9 snow water equivalent measurement, and 6 snow depth sensors, in addition to IMD data and use of various satellite products (TRMM precipitation data, MODIS snow cover imageries) to overcome data availability from the China side of the catchment. Each water level station is equipped with software for real-time discharge calculation. Telemetry data is imported from the DAS server hourly.

Models used include rainfall-runoff, snow melt and accumulation, hydrodynamic (for flow routing), reservoir, flood, and downstream allocation models. User interfaces visualize model outputs. Real-time data are shared to the public via website. Forecasts are disseminated through website, email, and SMS alerts.

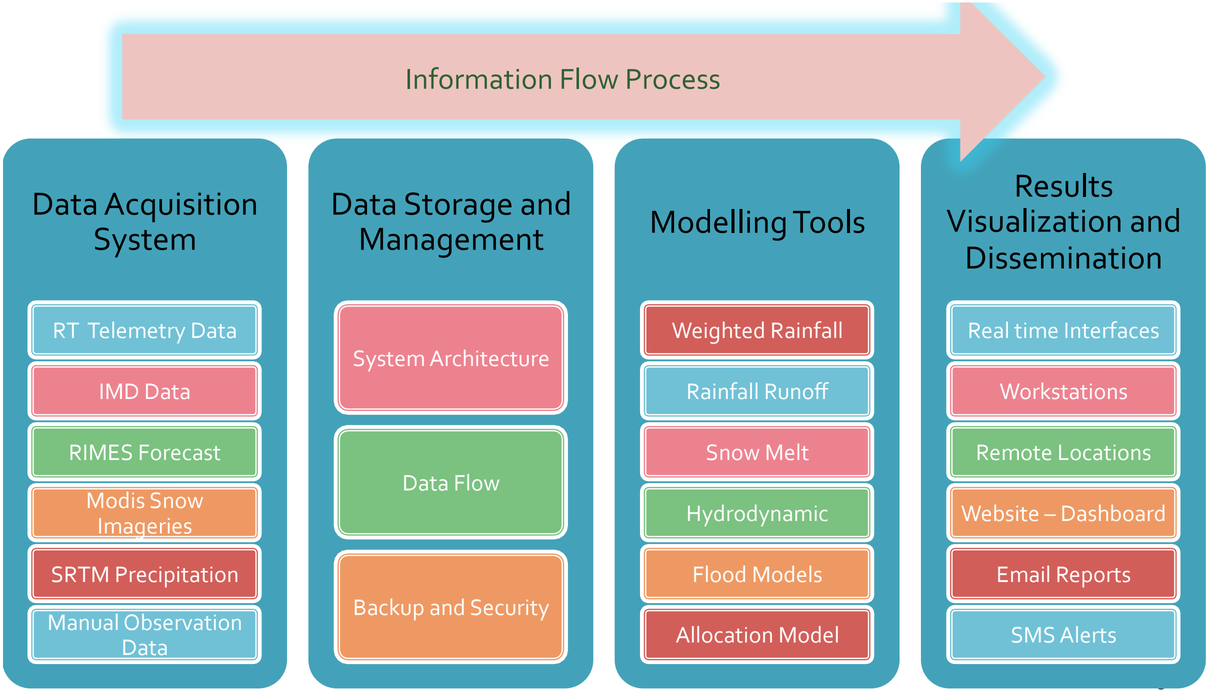


Figure 4.9 Real-time DSS development process

The system improved reservoir management; downstream flooding were avoided during the 2013 monsoon, with optimized water releases using the DSS. Project results are impressive and significantly good for such a difficult terrain.

4.10 Quality Control of India River Level Gauge Data

Tom Hopson *and Joe Grim, NCAR,* presented a methodology for river level gauge data quality control.

Steps involved are:

a) Extract as much valid data as possible from raw gauge level data; if data value is useless, mark data as "missing"
b) Identify multiple reports for same location at the same time; if values are all identical, only keep one report, else quality control rules shall be followed
c) Identify data points with no nearby data points for comparison
d) Identify exceptionally high/ low values
e) Identify data points that suggest very rapid time rate of change on either side.

Similar quality control is also possible for precipitation data, but it will be very challenging as precipitation observations have many zero values and outliers.

4.11 Integrated Flood Risk Assessment: A case study of the Day River diversion area in the Red River Delta, Vietnam

Mukand S. Babel, *Asian Institute of Technology (AIT),* presented an integrated approach to flood risk assessment for flood detention areas in the Day River Flood Diversion Area (DRFDA), in Red River Delta, Vietnam.

The Day River Flood Diversion Area protects Hanoi and the lower delta during extreme floods, upstream dam breaks, or gate control failures. Figure 4.10 shows the conceptual framework used in the flood risk assessment for the DRFDA.

Historical flood and sea levels were analysed, and future flood frequencies and sea level rise were projected. Results from historical data analysis were used in adjusting design flood peaks. Integrated flood risk parameters (hazard: depth, duration, and velocity; vulnerability: economic, social, and environment; risk: hazard and vulnerability) were then developed, involving the use of weightage for each contributing factor. Flood risk indices were then calculated, based on hazard, vulnerability, and risk classification.

Results of the study shall aid authorities in designing better strategies for flood preparedness and mitigation in the study area, and help local residents in actively reducing flood risks by themselves.

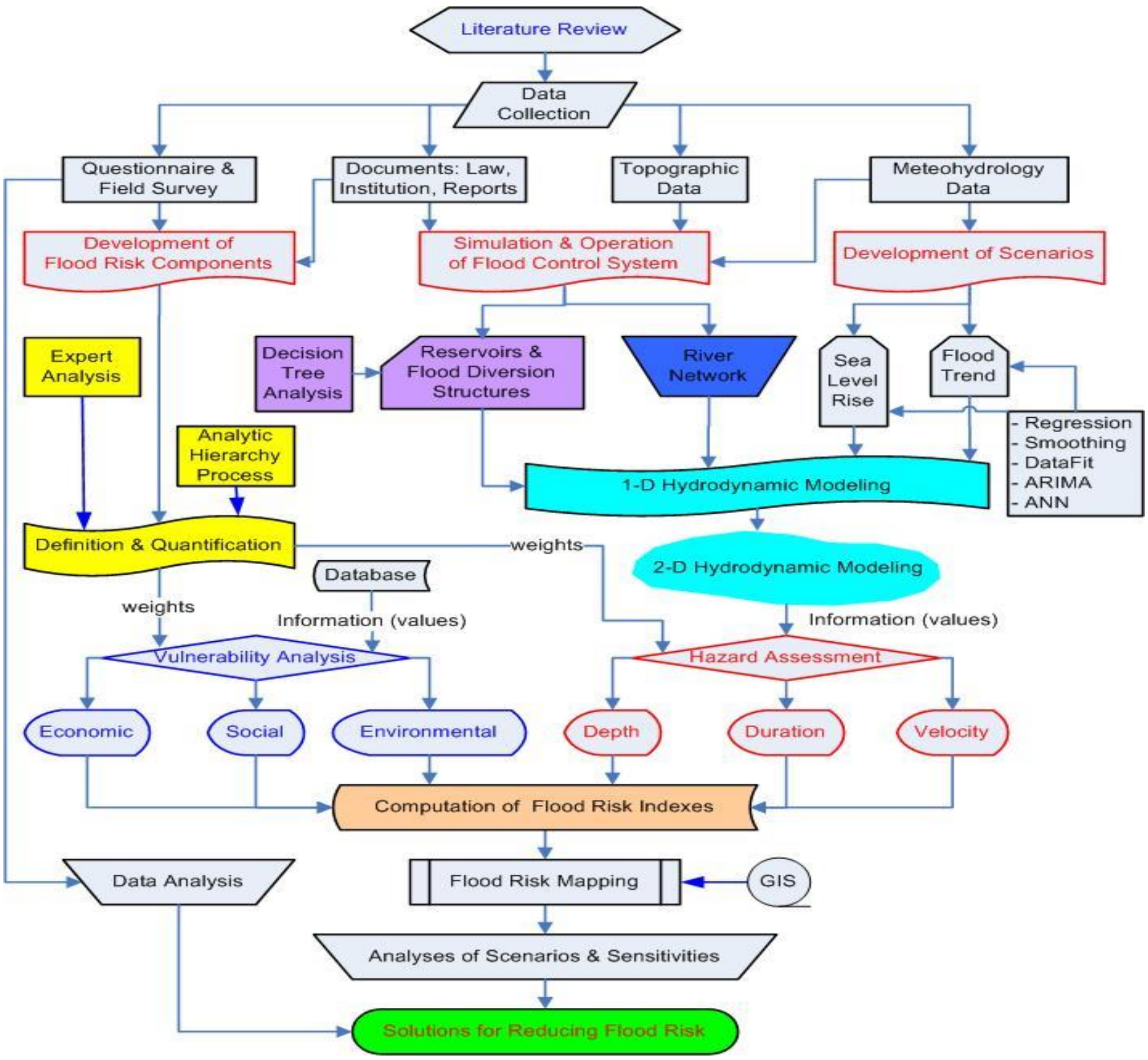


Figure 4.10 Conceptual framework for flood risk assessment in the Day River Flood Diversion Area, Red River Delta, Vietnam

4.12 Present and Future Water Data in India

Ram Jeet Verma, Central Water Commission, India, presented

In India, several central and state agencies maintain water datasets. CWC maintains river flow, water quality, sediment, reservoir, and flood data. The National Water Policy of 2002 and 2012 and the National Water Mission for Climate Change require that all hydrological data, except those classified on national security, shall be in the public domain. In this regard, the Water Resources Information System (WRIS) was developed from 2009-2015 to provide a "single window" solution on all water resources and related data in a standardized GIS format in national framework for water resource assessment, monitoring, planning, development, and management, and provide foundation for advanced modeling purposes.

WRIS has 5 major groups of datasets: watershed atlas, administrative data, water resources projects, thematic areas, and environmental data. It has 30 spatial layers with more than 108 sub-layers of 5- to 50-year data at 1:50,000 scale. Report generation is basin-wise.

The web-based system (www.india-wris.nrsc.gov.in) has tools to assist users in system navigation, dataset display, and system sharing, including analytical tools.

SESSION SUMMARY

The special learning session updated participants on:

- Use of satellite radar altimetry for water level monitoring, particularly for large water bodies in areas where gauge deployment is prohibitive, or in network-thin areas
- Preliminary use of altimetric observations in the Ganges and Brahmaputra basins
- Use of Advanced Microwave Scanning Radiometer – Earth Observing System (AMSR-E) in monitoring river stage and flow, particularly in limited-gauged basins. Although accuracy is lesser than altimetry products, the method has more temporal coverage
- River level gauge data quality control
- Rating curves that are developed by linking downstream river discharge with upstream river stage. Parameters in the equation are site-specific. Rating curves could be developed for each tributary, but the exercise is resource intensive. The technique is helpful in rivers with no downstream measurement station.
- WRF-Hydro, a large-scale open real-time flood forecasting system that combines predictions of water cycle components and streamflow
- Use of up to 10-day ensemble weather forecasts to extend lead time in flood forecast products
- Tool to assist in selecting sites for rain gauge installation
- Flood early warning and preparedness in Japan
- Real-time decision support and flood forecasting system for the Satluj and Beas catchments in India
- Integrated flood risk assessment that uses weightage for analysis of flood contributing factors for determining flood risk index
- Availability of water resources datasets from India through the web-based Water Resources Information System (WRIS)

Highlights of the discussion include:

- Use of Jason-2 data in flood forecasting in Bangladesh in 2014-2015 gave good forecast of flood trend, but not prediction of flood peak timing
- ALTICA and Jason-2 products could complement each other

EXPOSURE VISITS

Exposure visits to the Thai Meteorological Department (TMD) and Royal Irrigation Department (RID) were organized to enable participants to learn about these institutions' activities relating to flood forecasting and warning.

Thai Meteorological Department

TMD, under the Ministry of Information and Communication Technology, is the government agency in Thailand that is mandated to monitor and provide weather and climate information. The visit to TMD exposed participants to:

- TMD administrative and operational structure
- Vast network of observation and monitoring stations that include 13 upper air observation stations, 23 radars, 75 surface stations, 91 automatic weather stations, 31 agromet stations, 16 hydromet stations, more than 1,100 telemetered rain gages, and 2 satellites for data communication
- Variety of NWP models: global (100 km resolution, 19 vertical levels, 15 minute time step, 168 hour forecast), South East Asia model (50 km resolution, 19 vertical levels, 15 minute time step, 72 hour forecast), Thailand model (17 km resolution, 31 vertical levels and 5 minutes time step, 36 hour forecast), and Bangkok model (under development phase, 5 km resolution, 31 vertical levels with 2 minute time step).
- Various forecast products and lead times. Forecasts are issued every day and disseminated to the central government, which alerts the provinces and further disseminate to concerned authorities.

Royal Irrigation Department

RID, under the Ministry of Agriculture and Cooperatives, is the government agency in Thailand mandated for water resource development and management, and prevention, mitigation, and management of water-related hazards. Workshop participants were welcomed by Kanchadin Srapratoom, Director of Foreign Projects Management and International Affairs Division.

The visit to RID exposed participants to:

- RID's history, mandate, and priorities. Among RID's focus areas is public participation in prevention and mitigation of water-related hazards. The concept of integrated water resource management (IWRM) is well established and followed in RID.
- RID's water level monitoring system. More than 200 stations located in 25 basins constantly monitor water levels, with data provided to headquarters every 15 minutes. A database stores observation data.
- Techniques used in water level measurement, telemetry, and forecasting
- 7-day flood forecasting system, using a rainfall-runoff inundation model from JICA, made through regional and provincial offices
- Warnings are issued to the public when flood risk is determined

Figure 5.1 Visits to TMD (top photos) and RID (bottom photos)

EXPLORING POSSIBILITIES FOR A REGIONAL PROGRAM ON END-TO-END FLOOD FORECASTING AND WARNING

Lolita Bildan, RIMES, facilitated the preparation of a program framework to address capacity gaps and needs on flood forecasting and warning, articulated during the workshop.

Capacity gaps and needs identified during the country presentations were collated, and verified by presenting these to participants on the second day of the workshop. Integrating inputs and feedback from the technical sessions, a draft program framework was prepared and presented to workshop participants on the last day of the workshop, for discussion, further inputs, and adoption. The final framework is provided hereunder.

Regional Program on End-to-End Flood Forecasting and Warning in South Asian Region

Program Development Objective: Reduction in loss of lives and economic losses from flash floods and riverine floods in the Ganges-Brahmaputra-Meghna basin		
Intermediate Result 1: Improved user responses in Nepal, Bhutan, India, and Bangladesh to flash flood warnings	*Intermediate Result 2:* Improved user responses in India and Bangladesh to riverine flood warnings	*Intermediate Result 3:* Improved regional coordination, and information and data sharing between National Hydrological Services (NHSs) of Nepal, Bhutan, India, and Bangladesh
Activities: 1.1 Landscaping of institutions involved in the generation and application of flash flood forecasts and warnings – Collect data on relevant institutional mandates, policies, plans, programs, activities, and capacities – Take stock of current use of flash flood forecast and warning information – Analyze user institutions' present planning and decision-making processes to determine potential use of flash flood forecast and warning information – Identify user requirements for flash flood forecast and warning information, including preferred dissemination systems, etc., and explore user participation in rainfall monitoring – Note flash flood information products and services available from NHSs and other sources – Ascertain how user institutions access these products and services, and assess gaps – Evaluate user capacity to make use of these products and services in planning and decision-making – Analyze NHS capacity, including capacity gaps, to meet user requirements – Map relevant ongoing related programs and activities by	2.1. Landscaping of institutions involved in the generation and application of riverine flood forecasts and warnings – Collect data on relevant institutional mandates, policies, plans, programs, activities, and capacities – Take stock of current use of riverine flood forecast and warning information – Analyze user institutions' present planning and decision-making processes to determine potential use of riverine flood forecast and warning information – Identify user requirements for riverine flood forecast and warning information, including user-relevant thresholds, preferred dissemination systems, etc., and explore user participation in water level monitoring – Note riverine flood information products and services available from NHSs and other sources – Ascertain how user institutions access these products and services, and assess gaps – Evaluate user capacity to make use of these products and services in planning and decision-making	3.1 Establishment of portal for trans-boundary data and forecast products 3.2 Regional NMS-NHS forum – Share forecast products, experiences and strengths; discuss application issues; and identify areas for further development. – Technical sessions for NHS operational personnel with aim of improving forecast and warning system to meet user needs. This requires participation of and expert inputs from academic and research institutions. 3.3 Collaborative research on areas prioritized from user need assessments.

external actors Note: This activity could be undertaken at proposal preparation stage, for outcomes to guide final program design. Program may include the following activities: 1.2 Development of flash flood forecasting and early warning system (Nepal, Bhutan, India) – Capacity building on WRF for generating hourly forecasts • Modernization of computing facilities, including internet • Data assimilation for improving forecast accuracy • Use of remotely sensed products for difficult-to-reach areas • WRF calibration, testing, and model run for experimental operation – Identification of rainfall thresholds • Collection of historical rainfall and impact data • Analysis of rainfall intensity and duration that led to flash floods • Establishment of thresholds – Development of flash flood forecast model • Model design and development, integrating WRF outputs and thresholds • Model testing, calibration, validation, refinement, and experimental operation – Development of decision support system for impact forecasting and advisory generation and dissemination • Data collection • DSS design and development, integrating flash flood forecast, DEM, exposure and vulnerability data, and user requirements • DSS testing, refinement, and experimental operation – Enhancement of dissemination infrastructure – NHS training and technology transfer 1.3 Engagement with users for risk awareness and communication to guide response decisions – National flood risk management forum, linked to Monsoon/	– Analyze NHS capacity, including capacity gaps, to meet user requirements – Map relevant ongoing related programs and activities by external actors Note: This activity could be undertaken at proposal preparation stage, for outcomes to guide final program design. Program may include the following activities: 2.2. Development of riverine flood forecasting and early warning system, with lead times that meet user requirements (India and Bangladesh) – Revise water level thresholds • Collect historical inundation data • Establish thresholds, integrating user requirements – Develop basin-based riverine flood forecast model • Model design and development, integrating NWP outputs and user needs • Model testing, calibration, validation, refinement, and experimental operation – Development of decision support system for impact forecasting and advisory generation and dissemination • Data collection • DSS design and development, integrating flash flood forecast, DEM, exposure and vulnerability data, and user requirements • DSS testing, refinement, and experimental operation – Enhancement of dissemination infrastructure – NHS training and technology transfer 2.3. Engagement with users for risk awareness and communication to guide planning and decision-making – National flood risk management forum, linked to Monsoon/ Seasonal Forums – Local level NHS-user	

Seasonal Forums – Local level NHS-user dialogues – Capacity building of users on flash flood forecast application – Capacity building on community-based rainfall monitoring – Evaluation of national and local level user responses to flash flood warnings 1.4 Establishment of telemetered observing and monitoring systems in support of flash flood warning – Site identification and selection – Equipment acquisition – Station installation, testing, calibration – Integration into national network – Capacity building on system operation and maintenance 1.5 Integration of flash flood forecasting and decision support systems into NHS operations	dialogues – Capacity building of users on riverine flood forecast application – Capacity building in community-based water level monitoring – Evaluation of national and local level user responses to flood warnings 2.4. Integration of riverine flood forecasting and decision support systems into NHS operations	
Implementation considerations ○ Institutions include NHS, disaster management, agriculture, infrastructure ○ Identification and selection of pilot sites for forecast system development and local level user engagement ○ Build on ongoing initiatives toward optimum network density requirement ○ Selection of appropriate equipment ○ DEM requirement for impact forecasting	○ Institutions include NHS, disaster management, agriculture, water resources, infrastructure ○ Identification and selection of pilot sites for forecast system development and local level user engagement ○ Availability of historical inundation data ○ Thresholds at different spatial and temporal scales (as threshold could differ with season) ○ Common approach and methodology sought for basin-based flood forecasting and warning ○ Offer by Bangladesh to share its experience in developing longer-lead flood forecasts ○ DEM requirement for impact forecasting	○ Data portal to provide data service ○ Make use of Unidata free software and training from UCAR ○ Offers by Nepal, Bhutan, and India to share upstream water level, glacial lakes, and forecast (Bhutan) data ○ Offers by Nepal and Bhutan to share experience on data management ○ Regional NHS forum shall be a regional cooperation mechanism in the like of WMO/ESCAP Panel on Tropical Cyclone, promoting integrated approach and application of new/ emerging technologies ○ Offer by India to use capacity available from National Water Academy
Implementation arrangement: ○ Regional technical working group, consisting of NMS, NHS, DRM, and other key user sector (e.g. agriculture, water resources)		

CONCLUSION AND WAY FORWARD

Participants adopted the regional program to forward collaboration on transboundary flood forecasting and early warning in the region. Implementation shall adopt the following distinct, but integrated approaches:

- Integration of flash flood and riverine flood concerns at the basin level, noting that most flash flood subsystems contribute to basin-scale floods
- Building of flood early warning capacities, using emerging new-generation flood forecasting technologies and incorporating these into flood risk information user systems
- Use of existing regional mechanisms for capacity building and regional sharing of information/knowledge

Sanjay Srivastava, ESCAP, shared that ESCAP has been mandated in May 2015 by its Member Countries, including those from the South Asian region, through Resolution 71/12, to strengthen regional cooperation for flood forecasting in transboundary river basins. In this regard, ESCAP shall carry forward this World Bank-supported initiative by establishing a Panel on Transboundary Flood Management for South Asian Region, with RIMES serving as technical secretariat. ESCAP proposes to include an intergovernmental Panel on Transboundary Flood Management that includes key stakeholders, namely hydrologists, meteorologists, and disaster management authorities from riparian countries of common river basins.

The regional program, as adopted in the workshop, shall be implemented through ESCAP and RIMES regional cooperation mechanism.

ANNEX 1

REGIONAL FLOOD EARLY WARNING SYSTEM WORKSHOP
23-27 November 2015, Bangkok

AGENDA
ver. 23 November 2015

23 November 2015	Monday
09.00-09.30	**Opening Session** ○ Welcome remarks *A.R. Subbiah, Director, RIMES* ○ Opening remarks *Dr. Satya Priya, World Bank* ○ Remarks *Dr. Sanjay Srivastava, ESCAP* ○ Introduction of participants and resource persons ○ Workshop rationale, objectives and structure *Lolita Bildan, Chief of Program Management, RIMES*
09.30-11.00	**1. Flood Forecasting and Warning Systems in SAR Countries** ○ Bangladesh *Flood Forecasting and Warning Centre, Bangladesh Water Development Board* ○ Bhutan *Department of Hydro Met Services*
11.10-11.30	Group Photo and Tea Break
11.30-13.00	Flood Forecasting and Warning Systems in SAR Countries (continued) ○ India *Central Water Commission* ○ Nepal *Department of Hydrology and Meteorology*
13.00-14.00	Lunch Break
14.00-14.30	**Features of an End-to-End Flood Forecasting and Warning System** *Dr. Dilip Kumar Gautam, Team Leader –Hydrology, RIMES*
14.30-15.00	**Observation, Monitoring and Forecasting** ○ Numerical Weather Prediction for Flood Forecasting *Itesh Dash, Team Leader –Systems Research and Development, RIMES*
15.00-15.15	Tea Break
15.15-17.15	**Data Requirements for Hydrological Modeling** ○ Exercise: Preparation of Digital Elevation Models using ArcGIS *Dr. Anshul Agarwal, Hydrologist, RIMES* *Dr. Dilip Kumar Gautam, Team Leader –Hydrology, RIMES*
17.15-17.30	Wrap-Up and End of Day 1 *Dr. Dilip Kumar Gautam, Team Leader-Hydrology, RIMES*

24 November 2015	Tuesday
09.00-09.45	**Flood Forecasting and Warning in SAR: Ongoing Efforts** ○ Flood forecasting for the Ganges Basin *ICIMOD*
09.45-10.30	○ The South Asia Water Initiative *World Bank*
10.30-11.00	Tea Break
11.00-11.30	○ Flood forecasting and warning initiatives in Nepal and Myanmar *Dr. Anshul Agarwal, Hydrologist, RIMES*
11.30-12.00	**Hydrological Modeling** ○ Introduction *Dr. Dilip Kumar Gautam, Team Leader –Hydrology, RIMES*
12.00-12.30	Discussion
12.30-13.30	Lunch Break
13.30-15.30	**Exploring possibilities for a regional program on end-to-end flood forecasting and warning** ○ Summary of capacity needs from country presentations *Lolita Bildan, Chief of Program Management, RIMES* ○ Discussion • Identification of capacity building needs that could be addressed through a regional program • Implementation considerations
15.30-16.00	Tea Break and End of Day 2

25 November 2015	Wednesday
09.00-10.30	**Special Session:** Sources of Hydrologic Predictability and Useful Datasets *Charon Birkett* *Thomas Hopson* *UCAR*
10.30-10.45	Tea Break
10.45-12.15	**Special Session:** Sources of Hydrologic Predictability and Useful Datasets (continued) *Charon Birkett* *Thomas Hopson* *UCAR*
12.15-13.00	**Special Session:** India Case Study: Real time reservoir operations and flood forecasting system for Bhakra Beas Management Board *Dr. Anish Kumar, Consultant, World Bank*

13.00-14.00	Lunch Break
14.00-14.30	**Special Session: Flood and Water Prediction – Japan** *Kazumitsu Muraoka, JICA Expert, Bangladesh*
14.30-15.15	**Warning Preparation** ○ Decision Support Systems *Dr. Bhogendra Mishra, Application Development Specialist, RIMES* *Itesh Dash, Team Leader –Systems Research and Development*
15.15-15.30	Tea Break
15.30-16.15	**Warning Preparation** ○ Exposure, vulnerability, and risk assessment *AIT* ○ Exercise: Determination of local threshold levels *AIT*
16.15-16.30	Orientation on Exposure Visits, Wrap-Up and End of Day 3 *Dr. Anshul Agarwal, Hydrologist, RIMES*

26 November 2015	**Thursday**
09.00-12.00	**4. Exposure Visits** *Dr. Anshul Agarwal, Hydrologist, RIMES* *Dusadee Moya, Human Resource and Administration Officer, RIMES* ○ Royal Irrigation Department
12.00-13.30	Lunch Break
13.30-15.00	4. Exposure Visits – continued *Dr. Anshul Agarwal, Hydrologist, RIMES* *Dusadee Moya, Human Resource and Administration Officer, RIMES* ○ Thailand Meteorological Department
15.00-15.15	Debriefing, Wrap-Up and End of Day 4 *Dr. Anshul Agarwal, Hydrologist, RIMES*
15.15	Bangkok visit

27 November 2015	Friday
09.00-09.45	**Dissemination and Communication** *Dr. Govindarajalu Srinivasan, Chief Scientist, Climate Applications, RIMES* *Raihanul Haque Khan, Hydrological Modeler, RIMES* o ICT technologies o Local dissemination systems o Communicating risks
09.45-10.30	**Preparedness and Response Systems** *Raihanul Haque Khan, Hydrological Modeler, RIMES* *Ruby Rose Policarpio, Institutional Development Specialist, RIMES* o Importance of lead time and capacity building o Table-top exercise
10.30-11.00	Tea Break
11.00-11.45	**Feedback System** *Ruby Rose Policarpio, Institutional Development Specialist, RIMES* *Raihanul Haque Khan, Hydrological Modeler, RIMES* o Community feedback o Monsoon Forum
11.45-12.30	**2.8 Capacity Building for End-to-End Long-Lead Flood Forecasting and Warning – Bangladesh Experience** o Program Features *Raihanul Haque Khan, Hydrological Modeler, RIMES* o Operationalization *FFWC* o Local level feedback *Raihanul Haque Khan, Hydrological Modeler, RIMES* o Gaps and challenges *FFWC* *Raihanul Haque Khan, Hydrological Modeler, RIMES*
12.30-13.30	Lunch Break
13.30-14.00	**5. End-to-End Basin-Based Long-Lead Flood Forecasting and Warning System in the South Asian Region** o Rationale, requirements, and proposed framework *Lolita Bildan, Chief of Program Management, RIMES* o Regional program proposal *SAR Country Representative*
14.00-15.00	**6. Action Planning and Way Forward** *World Bank* *A.R. Subbiah, Director, RIMES*
15.00-15.15	Tea Break

15.15-16.00	**Closing Session** o Vote of Thanks *A.R. Subbiah, Director, RIMES* o Remarks *SAR Country Participant* o Closing Remarks *World Bank*

ANNEX 2
PARTICIPANT LIST

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