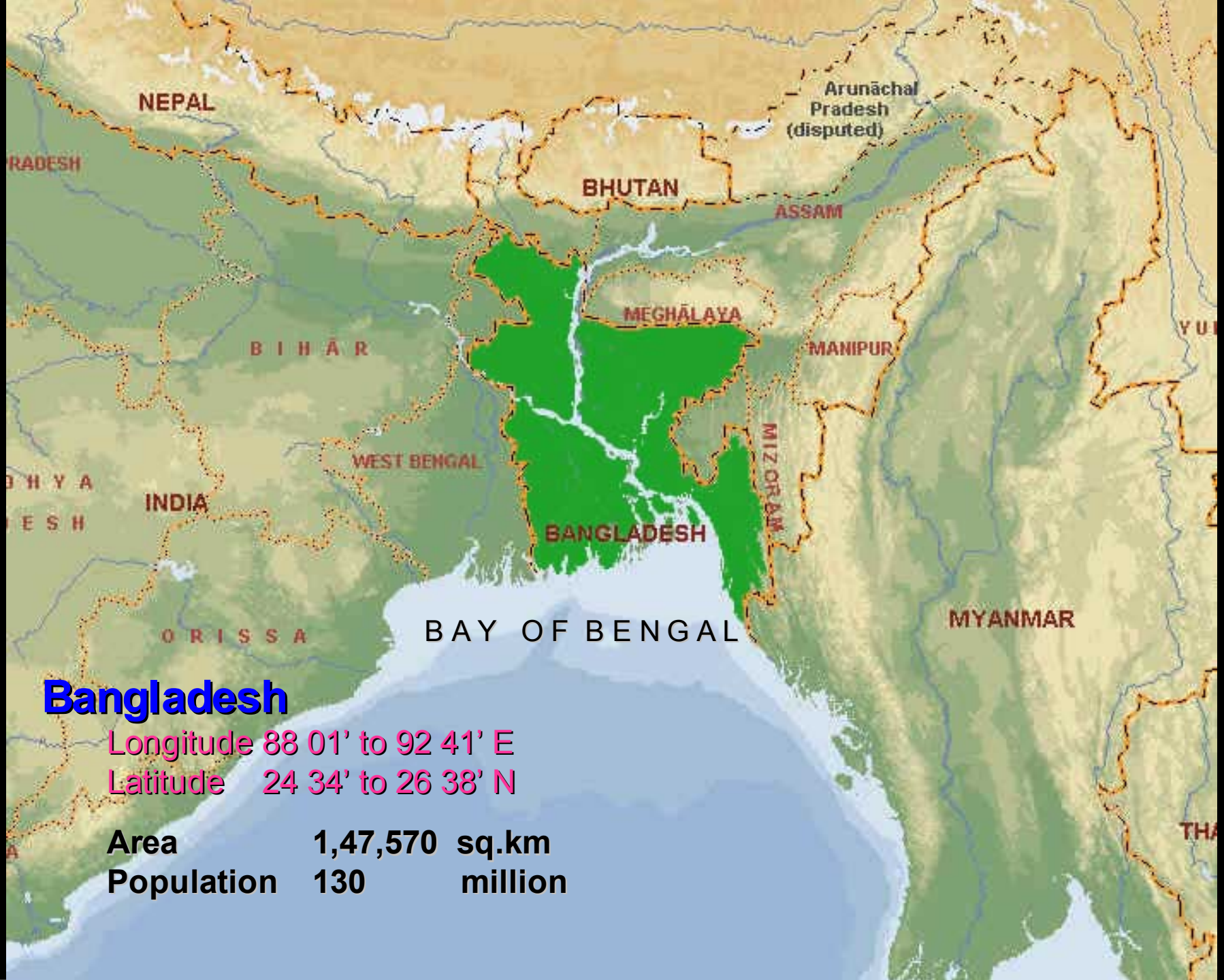
Hydrological Modelling Bangladesh Context

Sardar Mohammad Shah-Newaz
Principal Specialist
Institute of Water Modelling
Bangladesh



Bangladesh

Longitude 88 01’ to 92 41’ E
Latitude 24 34’ to 26 38’ N

Area	**1,47,570**	**sq.km**
Population	**130**	**million**

- **River System :**

  24,000 km

- **Annual Average Rainfall:**

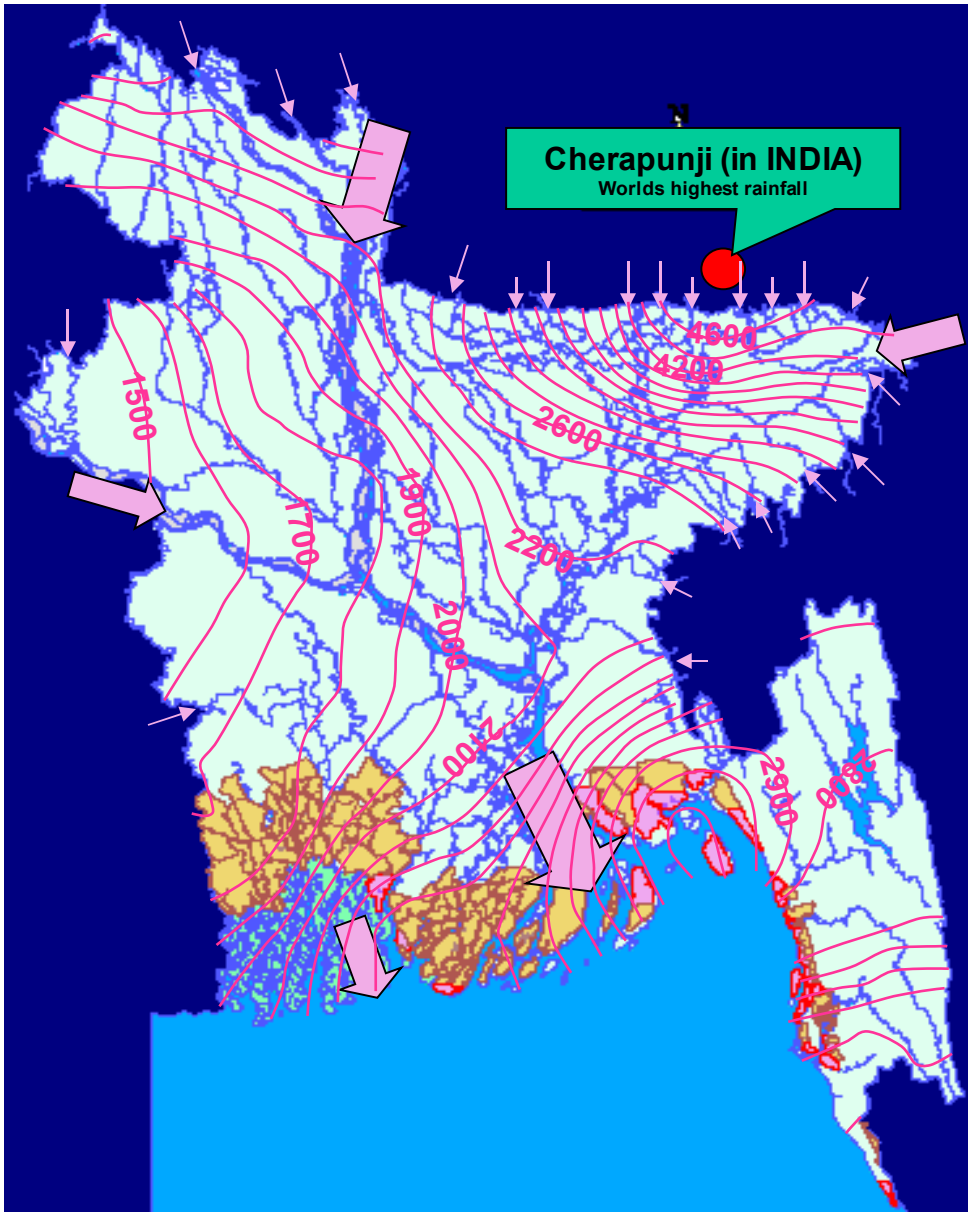
  2600 mm

- **Number of Rivers**

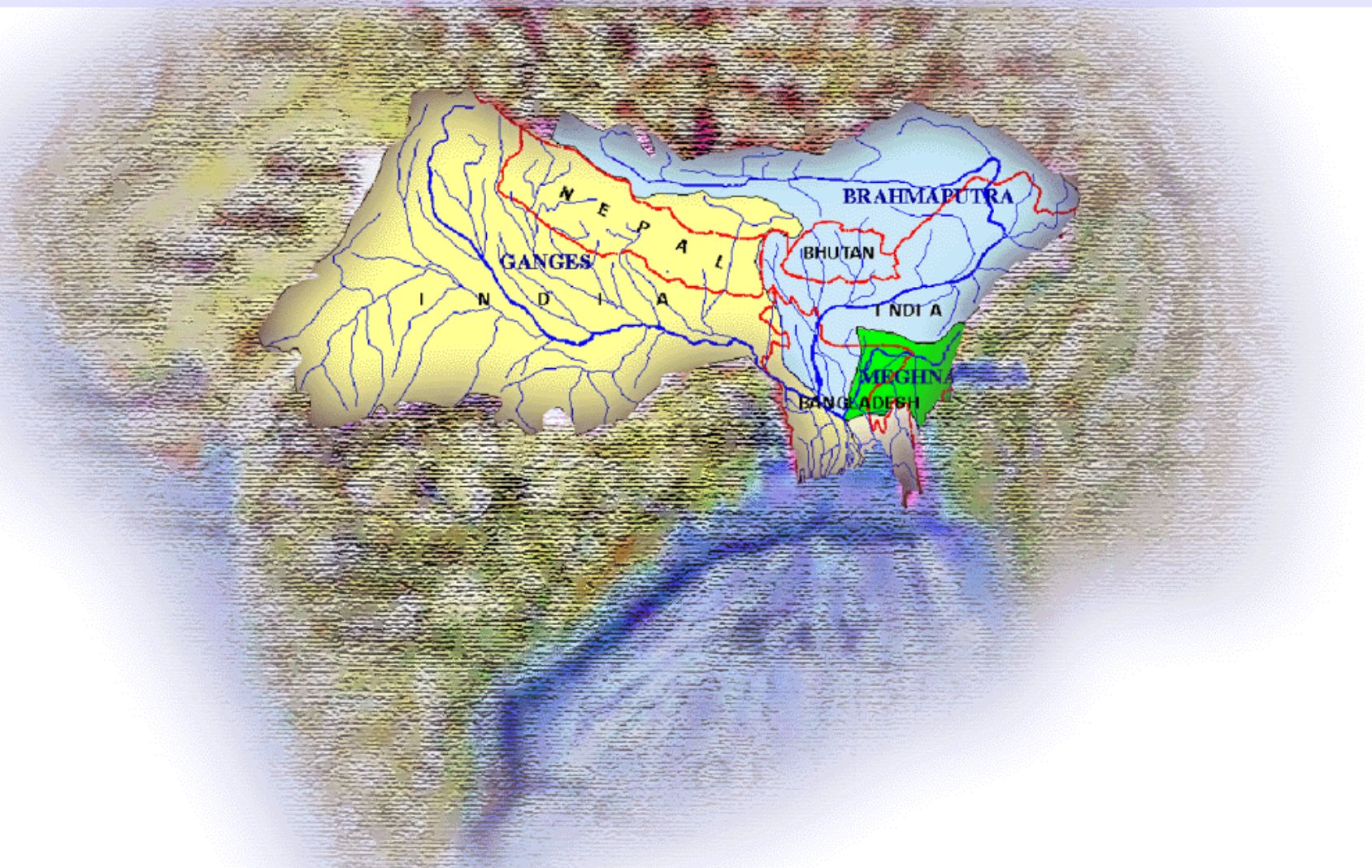
  230 rivers

- **Trans-boundary Flow:**

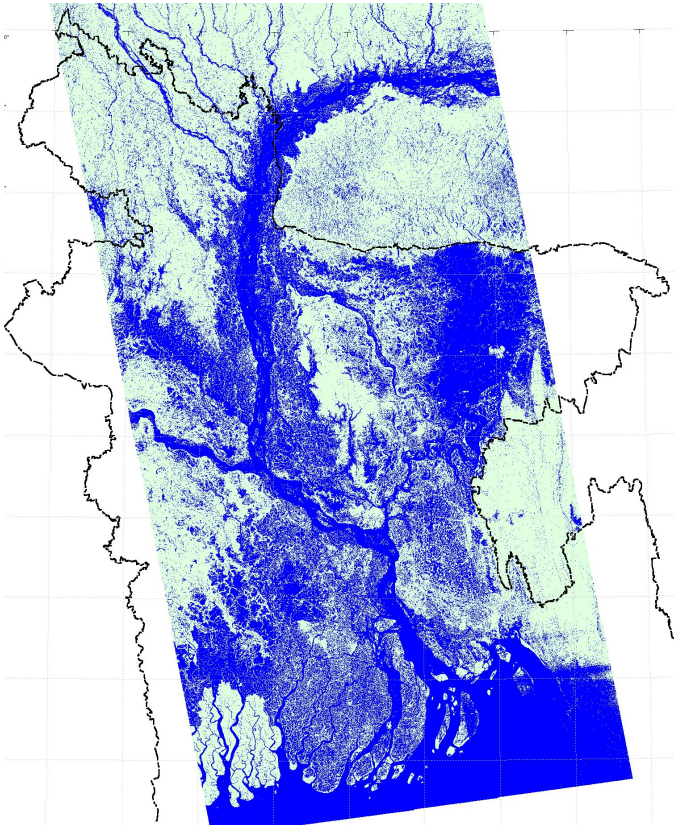
  57 rivers



- Around 1200 Cukm flow passes through the country
- 80% flow in 5 months of monsoon (Jun-Oct)
- 92% flow originates from catchments in India, Nepal, Bhutan & China



Bangladesh: A land of natural calamities



Inundation in a normal year 20% area,
more than 65% area inundated in 1998

Bangladesh: A land of natural calamities

- 1/4th of Bangladesh in the south is susceptible to cyclone
- Storm surge can travel 55km inland

The future - the next 25 years

- Population will increase from 129 to 181 million
- More than 50% population in urban areas; many more in the disaster prone areas
- Food shortfall around 10 million tons

Major concerns: saving human lives and agriculture

What has been achieved so far?

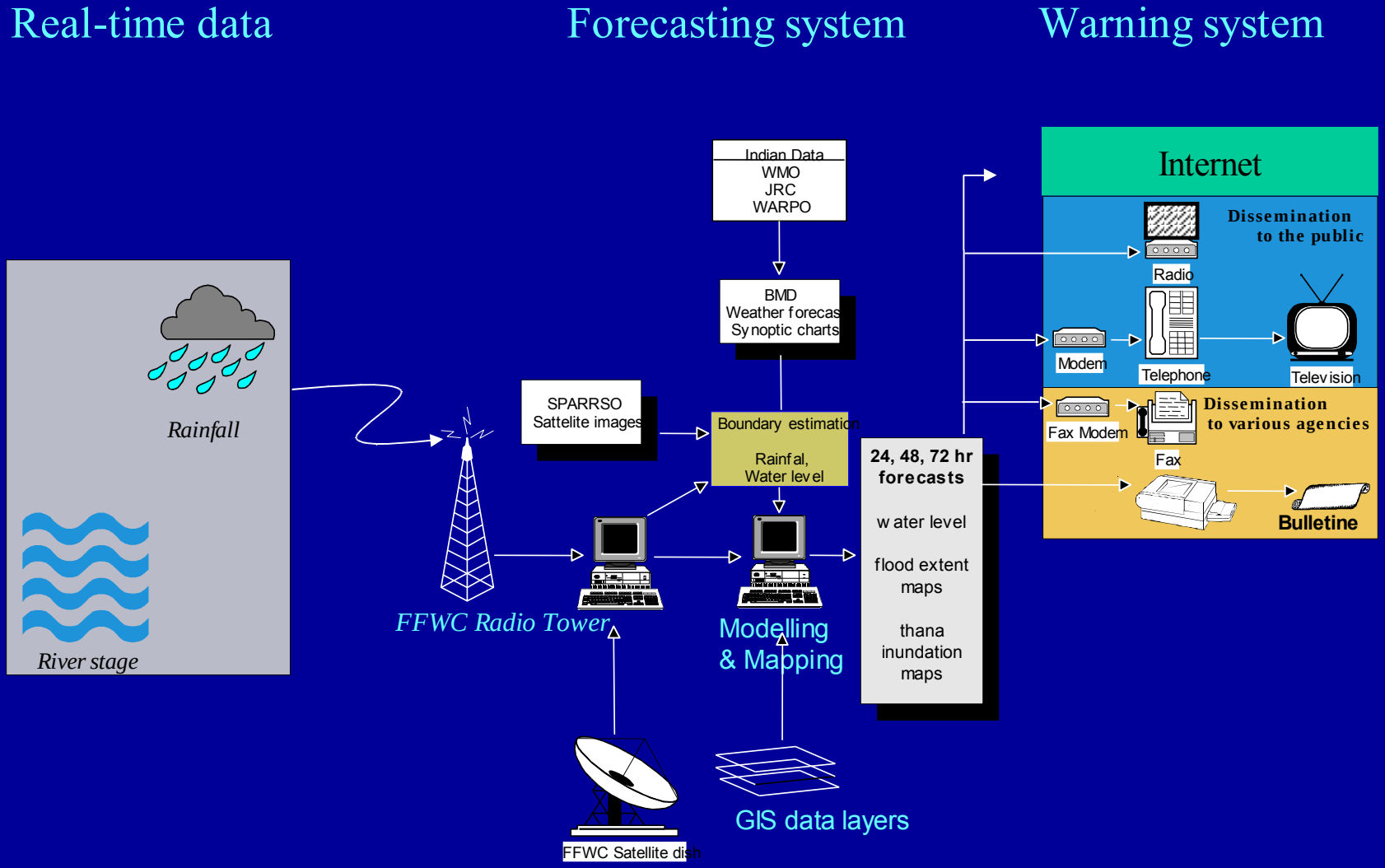
Structural measures:

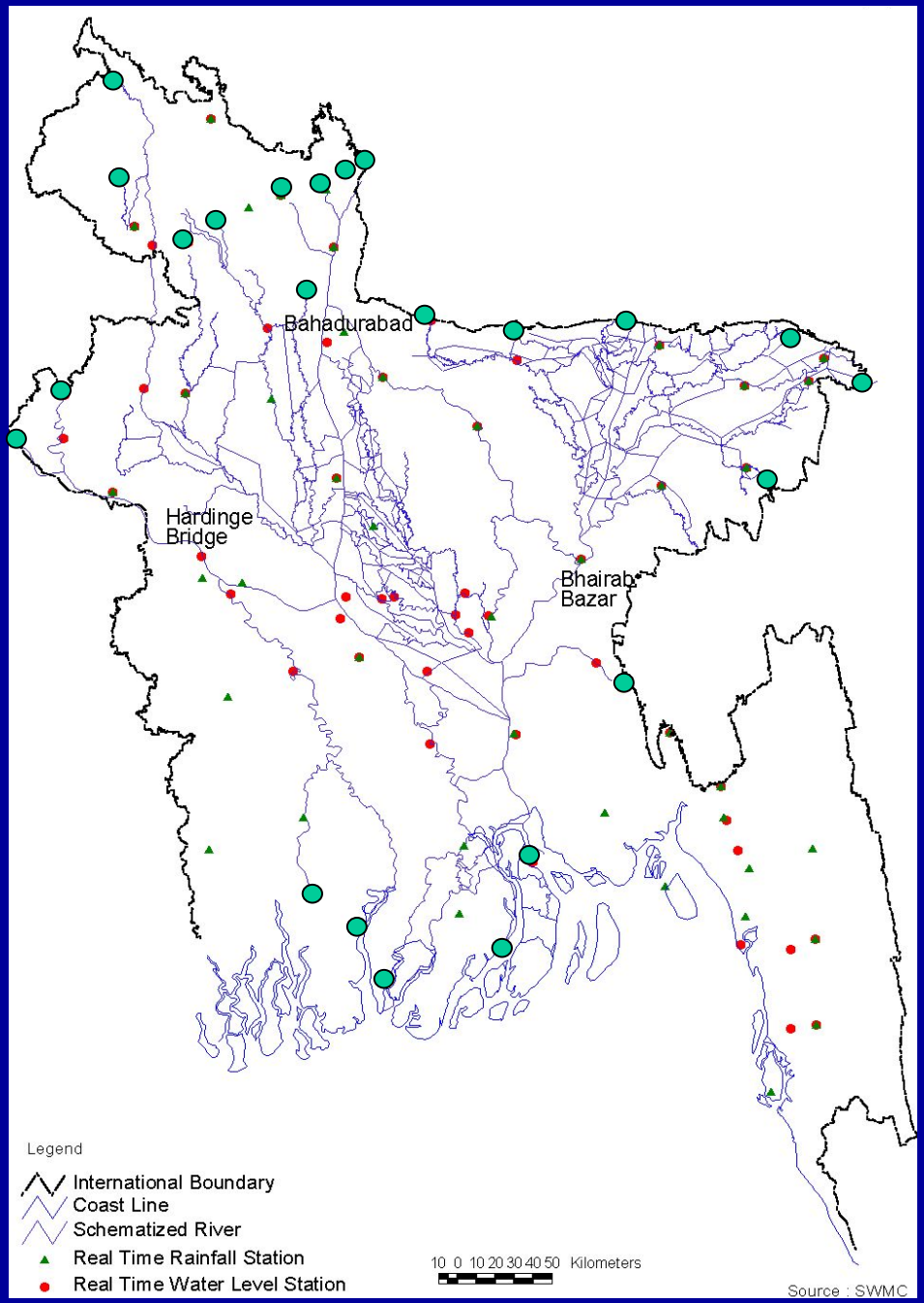
- Flood protection – 9143 km flood protection embankment

Non-structural measures:

- Flood forecasting system
- Cyclone forecasting system

Present Flood Forecasting & Warning System





Flood Forecasting

Present flood forecasting model

Used in short-term forecasting: 24-72 hours

Upstream model boundary:	46
Downstream model boundary:	5
Rivers:	187
Real-time rainfall stations:	37
Real-time WL stations:	58
Forecast stations:	76
Indian WL stations:	11
Indian RF stations:	8

Flood Forecasting

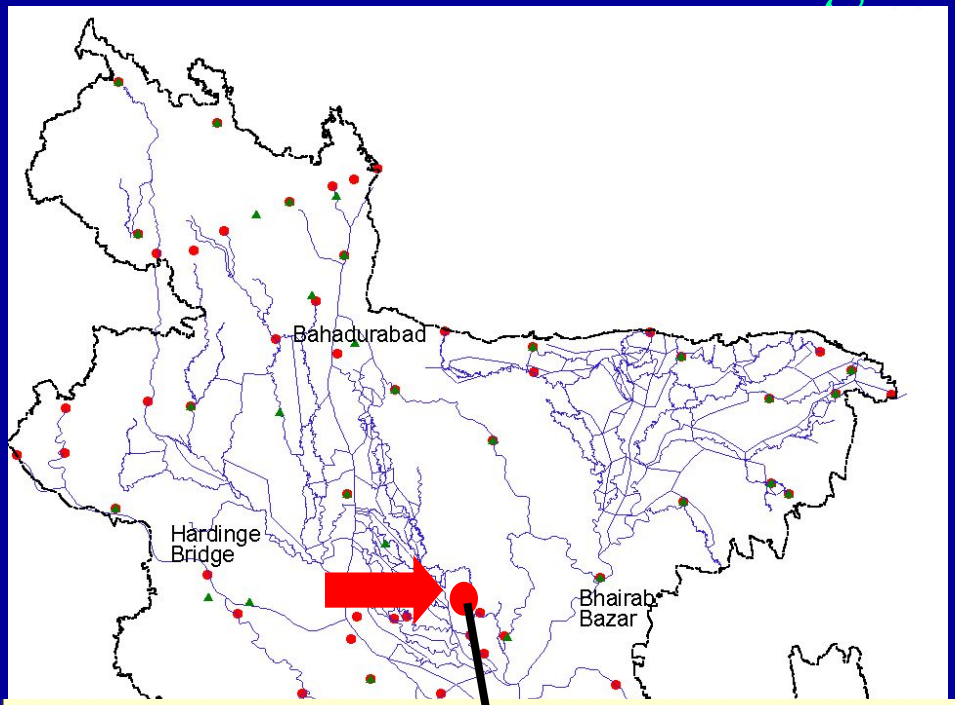
Warning Messages

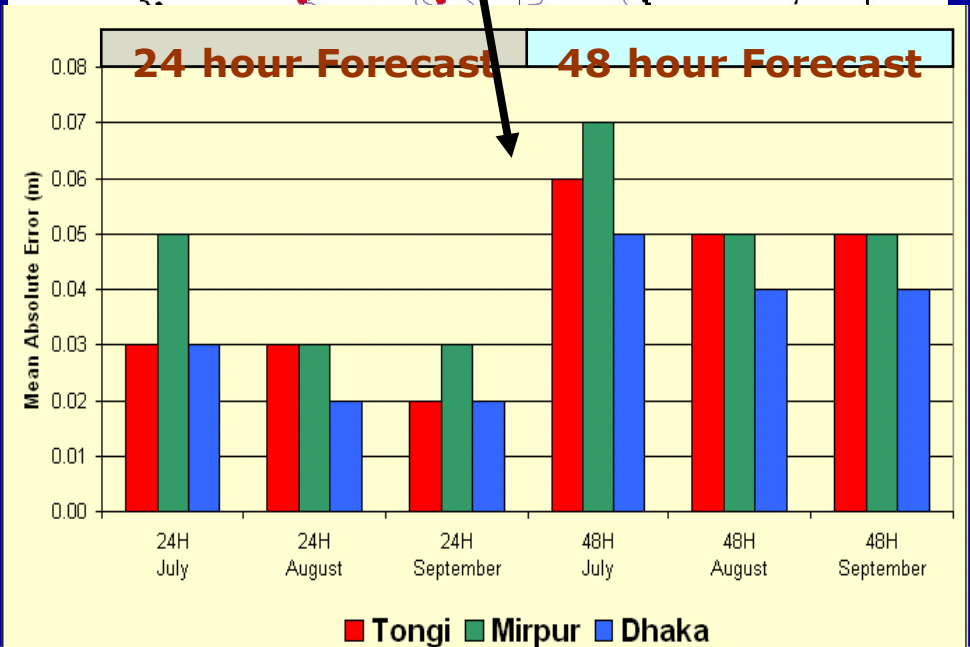
- **Daily Flood Bulletin: flood warnings for the next 48 hours**

Water level at Dhaka will cross danger level in the next 24 hours by 12 cm

FAQ

What is danger level?
12 cm rise at Dhaka? What will be situation in my village?





What people wants?

Medium-range flood forecasts (4 – 14 days)

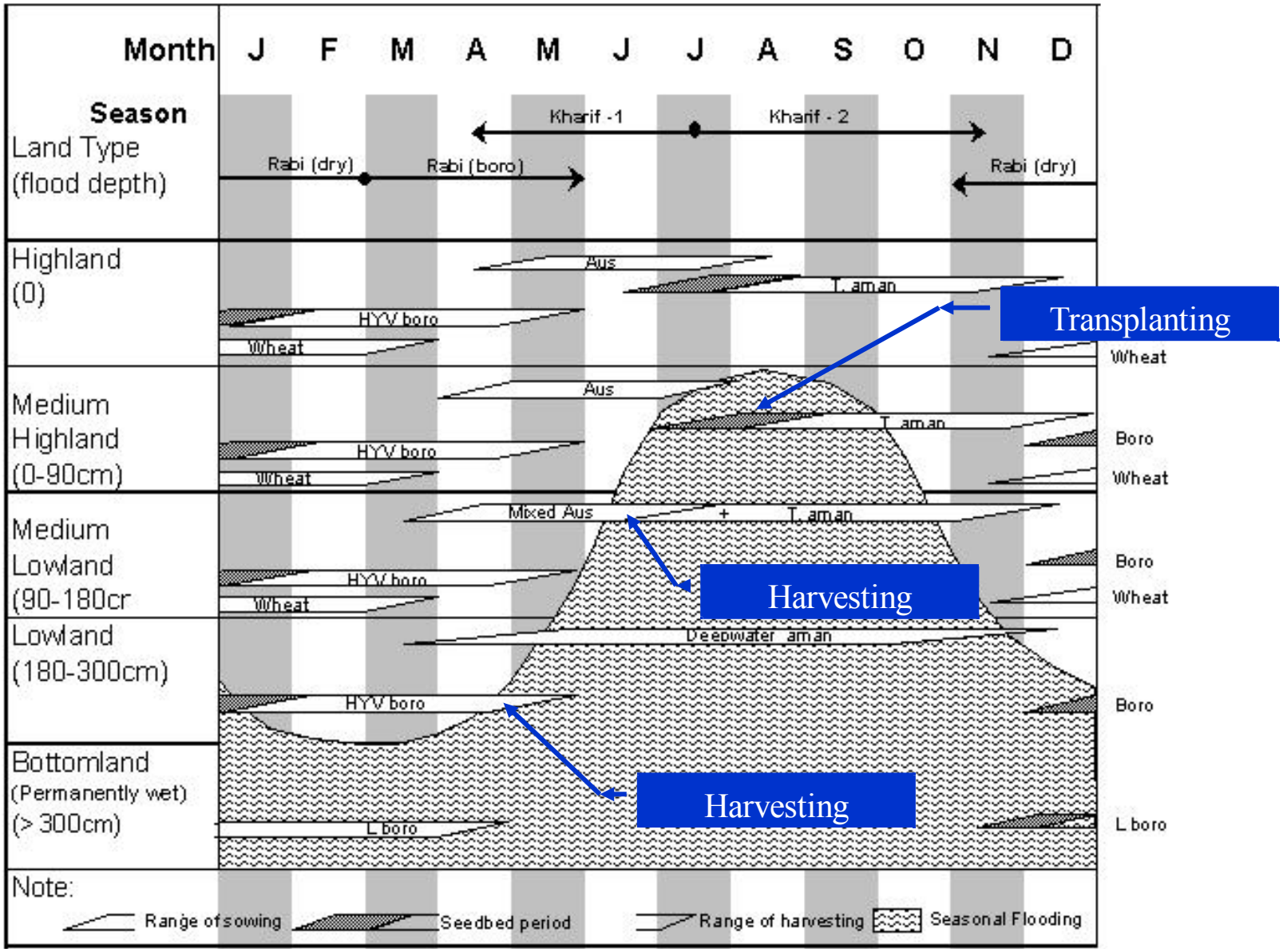
- Taking decisions regarding early harvesting to avoid major crop damage
- Planning of transplanting of rice crops
- Taking protective measures for saving assets and livestocks
- Taking precaution for culture fisheries
- Planning flood response activities
- Taking precautionary measures to protect infrastructures (growth centres, food silos, embankments, Roads etc.)

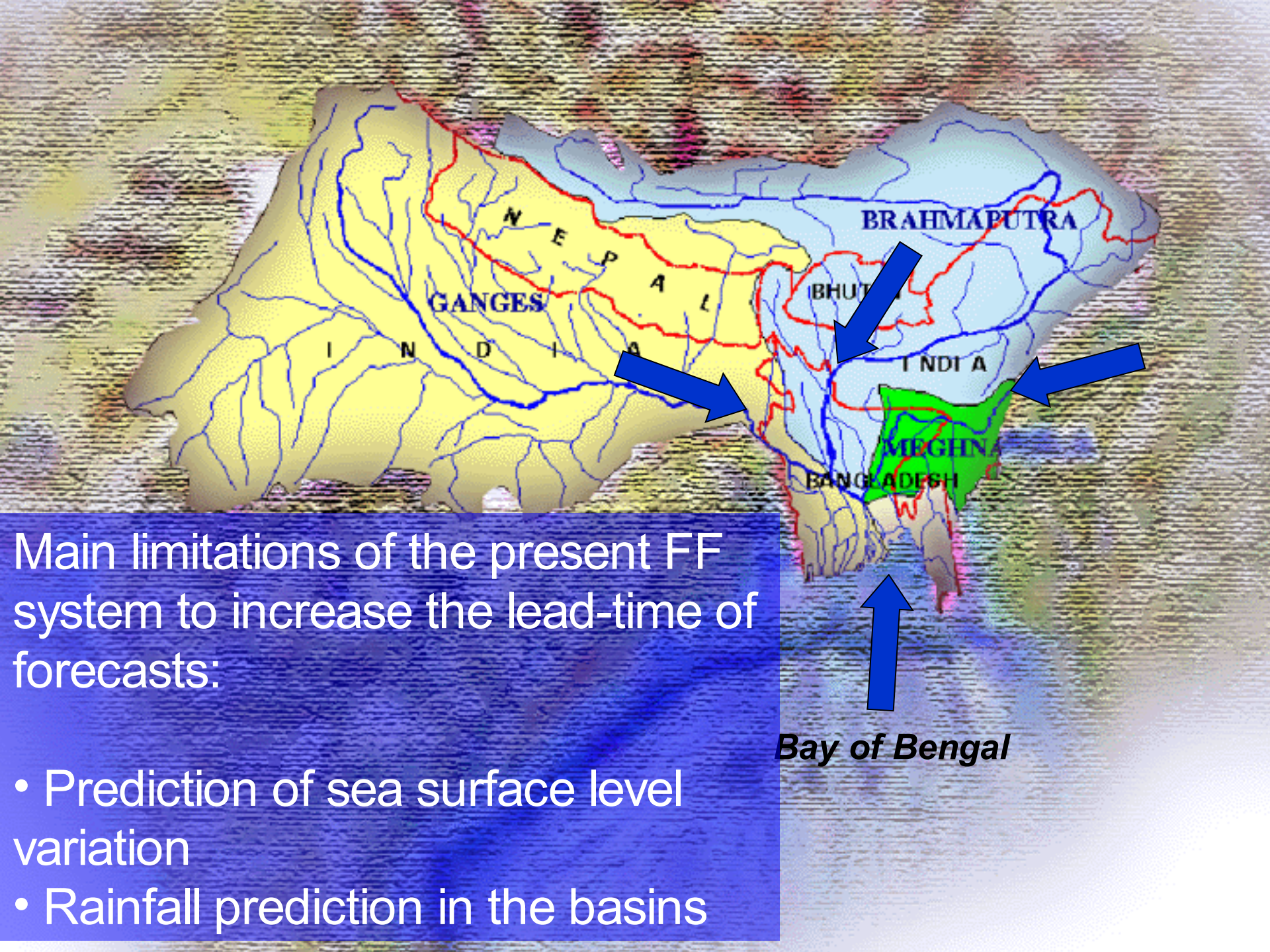
What people wants?

Long-range flood forecasts (monthly, seasonal)

- Planning cropping strategy
- Planning national budget for relief, rehabilitation and reconstruction
- Planning flood response activities

Typical Crop Calender in a Normal Year

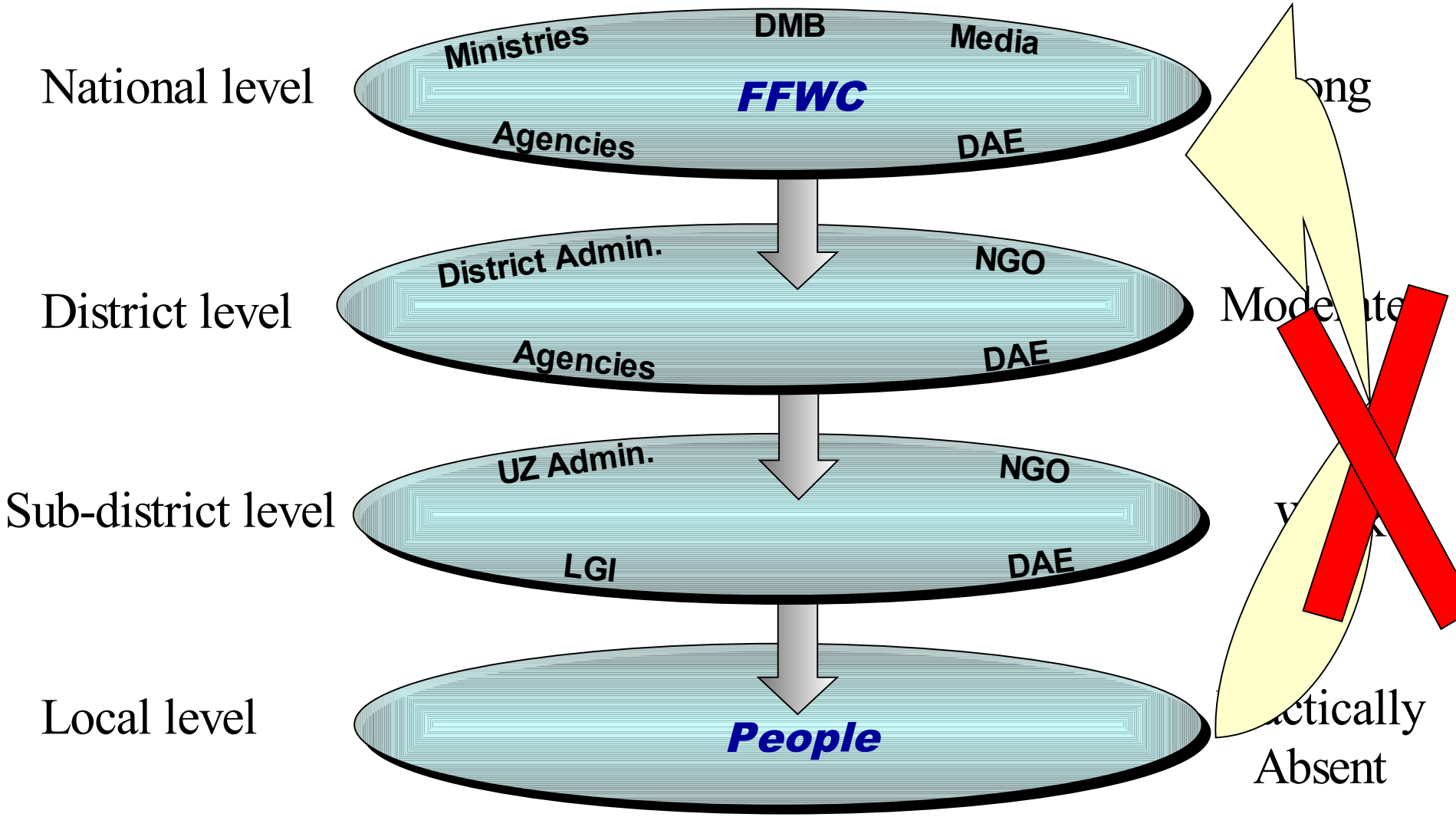




Main limitations of the present FF system to increase the lead-time of forecasts:

- Prediction of sea surface level variation
- Rainfall prediction in the basins

Communication

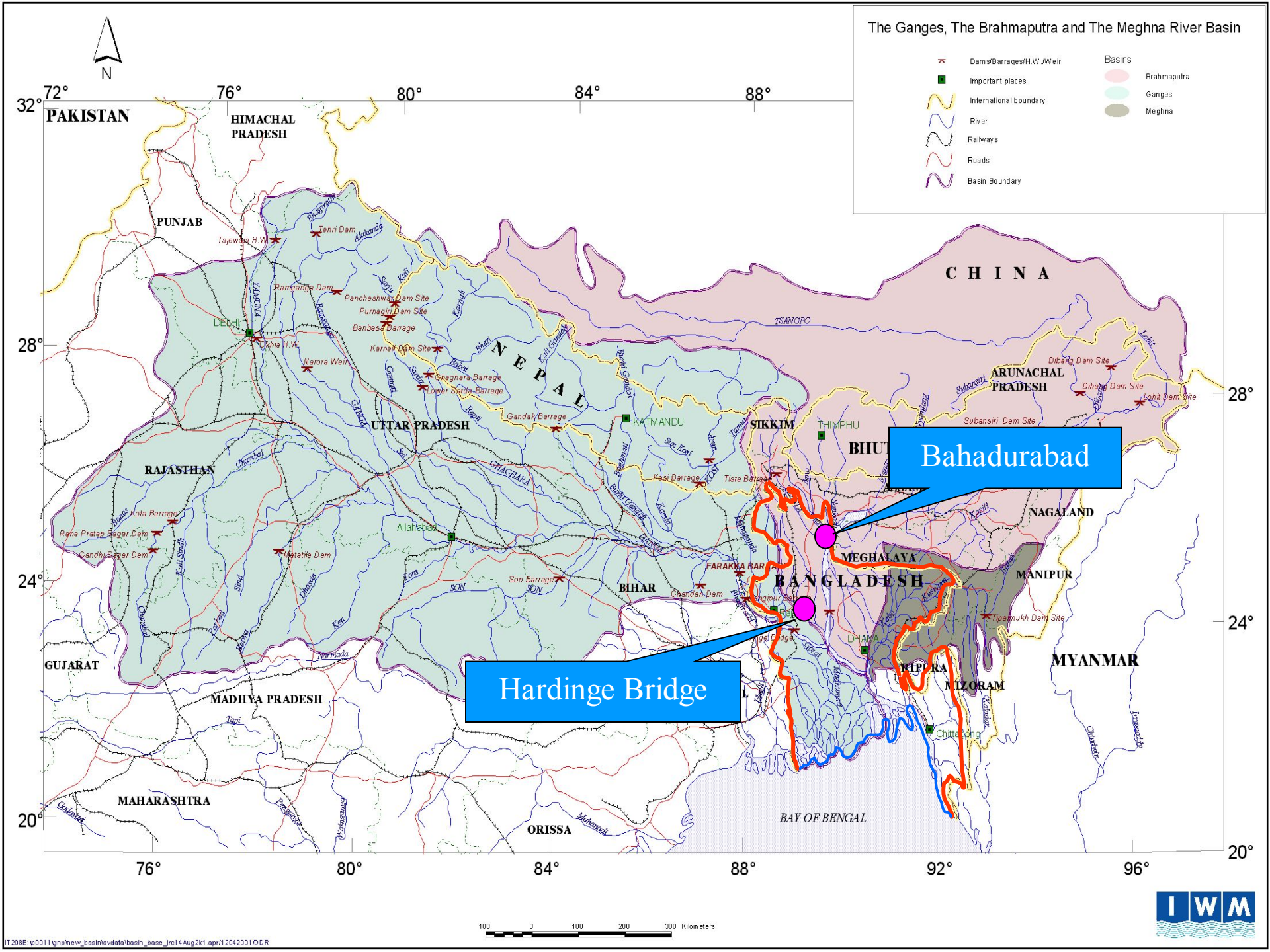


CFAB: Climate Forecast Applications in Bangladesh

PAOS: University of Colorado
ADPC: Asian Disaster Preparedness Centre

in association with

Bangladesh Institutions (FFWC, BMD, DAE, DMB, IWM, CEGIS)

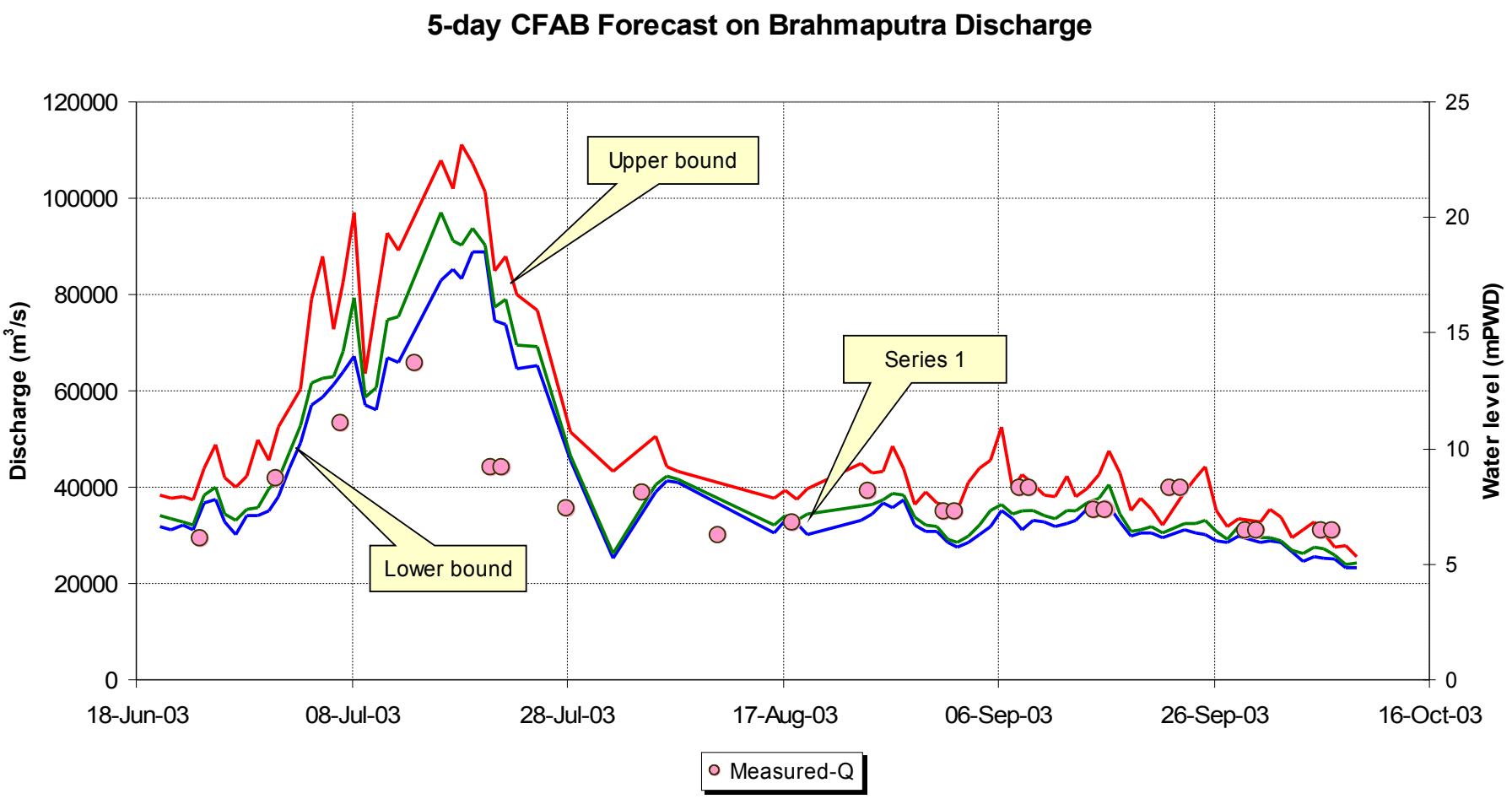

The Ganges, The Brahmaputra and The Meghna River Basin
Dams/Barrages/H.W./Weir
Important places
International boundary
River
Railways
Roads
Basin Boundary
Basins
Brahmaputra
Ganges
Meghna
N
72°
76°
80°
84°
88°
92°
96°
32°
28°
24°
20°
PAKISTAN
HIMACHAL PRADESH
PUNJAB
CHINA
NEPAL
BHUTAN
SIKKIM
ARUNACHAL PRADESH
NAGALAND
MEGHALAYA
MANIPUR
TRIPURA
MIZORAM
MYANMAR
BANGLADESH
UTTAR PRADESH
RAJASTHAN
BIHAR
GUJARAT
MADHYA PRADESH
MAHARASHTRA
ORISSA
BAY OF BENGAL
DELHI
KATMANDU
THIMPHU
DHAKA
Chittagong
Allahabad
Tehri Dam
Ramganga Dam
Pancheshwar Dam Site
Purnagiri Dam Site
Banbasa Barrage
Karnali Dam Site
Narora Weir
Ghaghara Barrage
Lower Sarda Barrage
Gandak Barrage
Kasi Barrage
Tista Barrage
Kota Barrage
Rana Pratap Sagar Dam
Gandhi Sagar Dam
Matatila Dam
Son Barrage
Chandan Dam
FARAKKA BARRAGE
Tipaimukh Dam Site
Subansiri Dam Site
Dibang Dam Site
Dihang Dam Site
Lohit Dam Site
Bahadurabad
Hardinge Bridge
100 0 100 200 300 Kilometers
IWM

```
Last Q observation date:         1       10     2003
       1 day forecast: (Q observed value =       29102.0)
Ensemble mean:        28934.4
      28936.9       28902.3       28793.6       28992.4       28912.1
28905.3
      28921.4       28888.9       29041.5       29065.7       28870.1
28813.6
      28854.6       29172.9       28883.3       28980.3       28944.7
28870.7
      29039.2       28880.7       28980.8       29097.5       29026.7
29063.0
      28838.2       28895.7       28964.5       28937.9       28971.3
28804.9
      29032.3       28824.4       28852.0       28876.0       28932.9
29051.2
      28839.6       29070.0       28866.1       29001.5       28801.6
28920.1
      29101.2       28911.8       28916.9       28814.3       28894.5
29123.0
      28860.8       28825.1       28887.0
       2 day forecast: (Q observed value =           NaN)
Ensemble mean:        28060.9
      28084.3       27898.1       27659.3       28227.2       27978.5
28138.9
      28089.4       27969.2       28154.2       28173.7       27784.9
27678.4
      27784.1       28735.8       27818.6       28037.6       27982.8
28051.5
      28405.4       28036.1       28392.3       28582.9       28420.1
28404.7
      27755.5       27754.7       28505.4       28244.4       27925.4
27760.3
      28352.7       27696.9       27862.6       28115.4       28005.4
28634.2
      27806.4       28355.2       27736.8       28156.3       27630.0
27912.8
      28326.7       27845.0       28258.0       27703.6       27957.9
28740.8
      28039.7       27691.3       27845.9
       3 day forecast: (Q observed value =           NaN)
Ensemble mean:        26880.5
      26845.9       26556.1       26517.5       27309.5       26717.6
26710.6
      26779.9       27317.2       26814.1       26878.1       26421.1
26471.8
      26484.1       28283.8       26324.1       26721.8       26797.5
27779.4
      27496.3       26759.5       27265.2       27238.1       27237.2
27206.4
      26596.8       26511.2       27248.6       27185.2       26649.8
26794.0
      27092.5       26429.7       26522.5       26870.5       26691.9
27427.1
      26812.6       26988.3       26415.8       26953.6       26216.0
26677.8
      26993.3       26790.9       26976.1       26589.7       26818.1
```

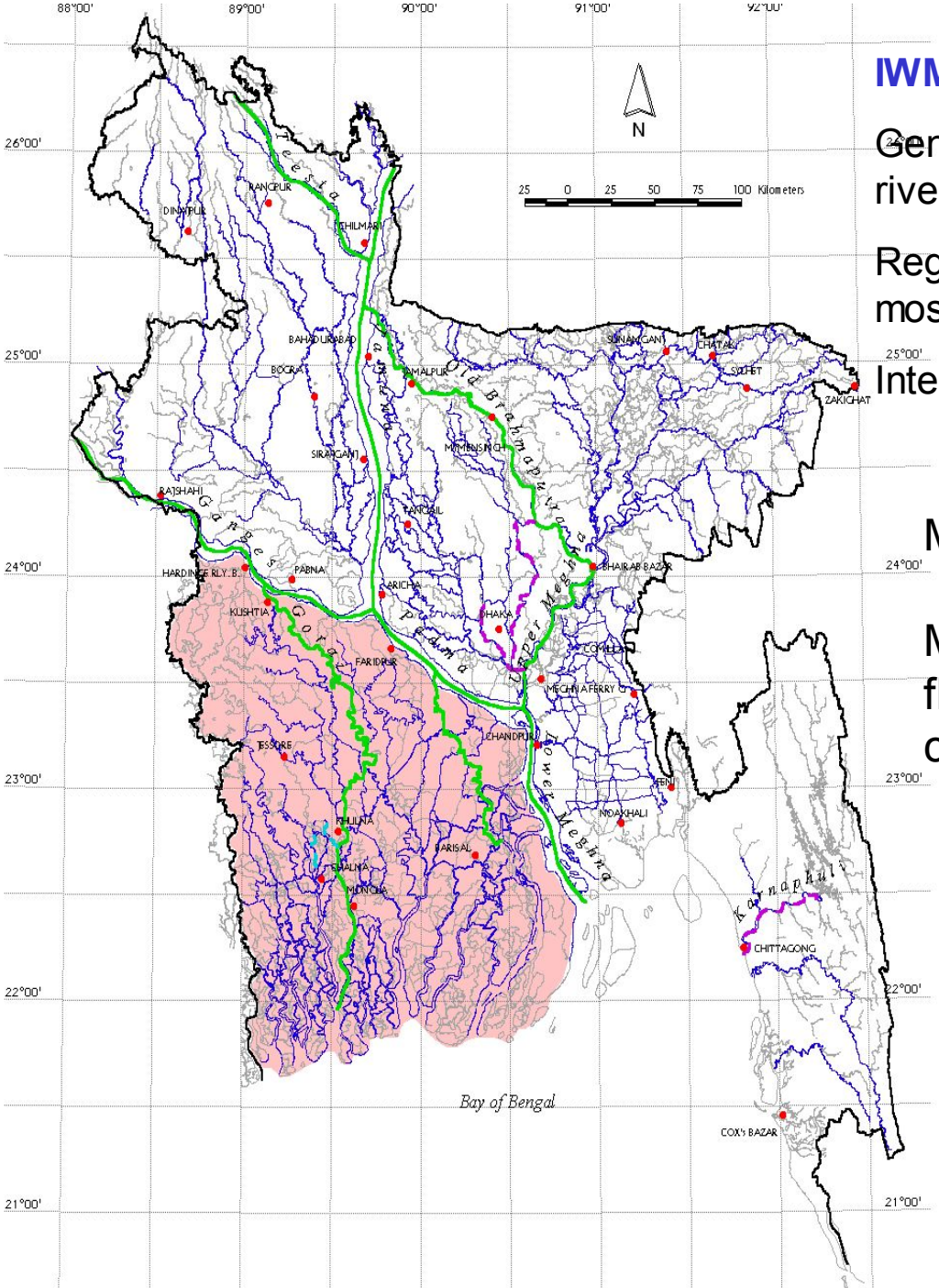
Data received from Program in Atmospheric and Oceanic Sciences (PAOS), University of Colorodo, USA

- 51 series of probabilistic discharge data for Bahadurabad and Hardinge Bridge station
- 51 series of catchment averaged rainfall forecast over Brahmaputra and Ganges basins

Performance of CFAB prediction at Bahadurabad



Modelling in Meghna Basin under MAHASRI



IWM Modelling Strength

General Model: Covers major and secondary rivers.

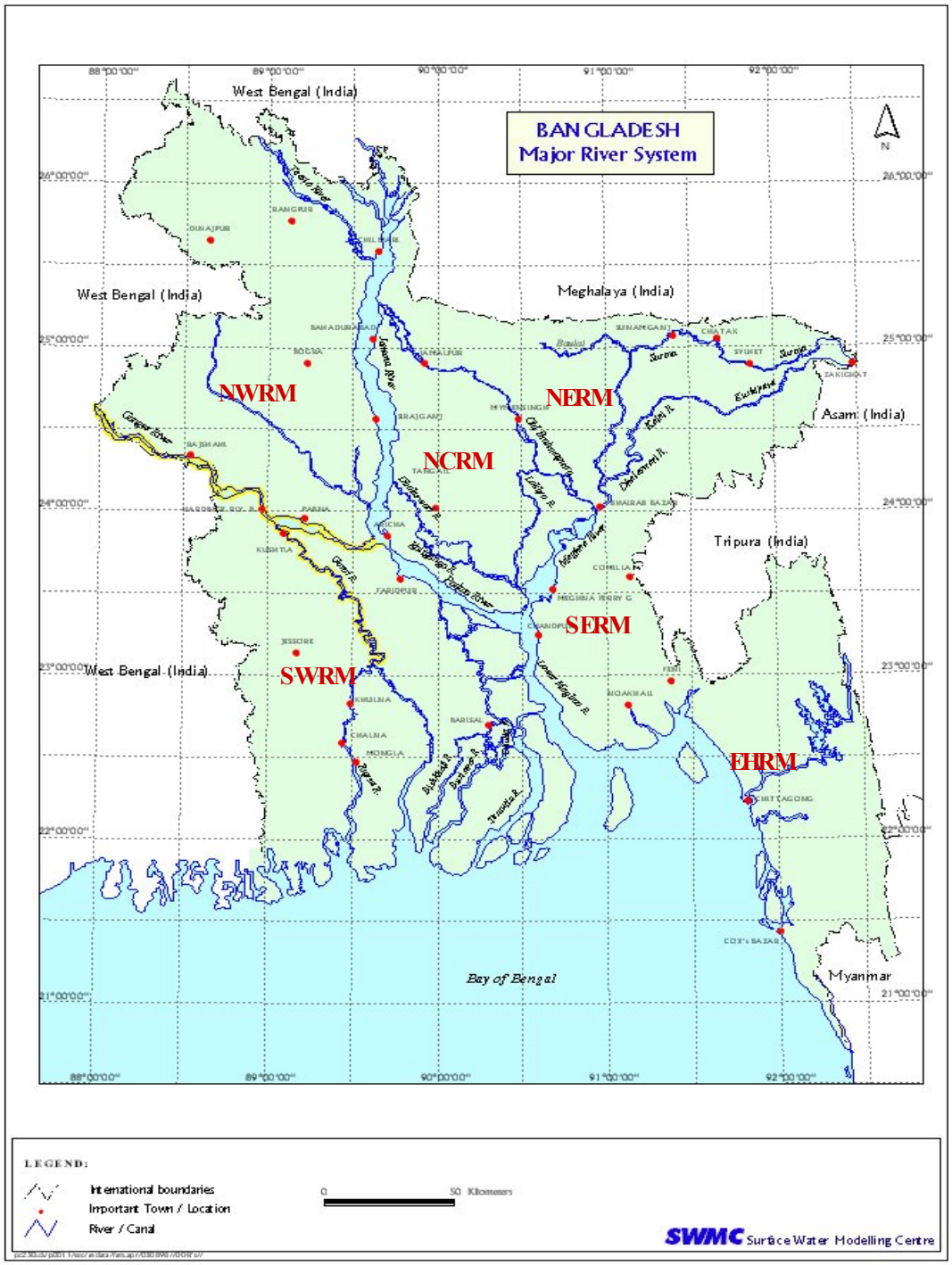
Regional Model: Six regional models cover most of the regional rivers.

Interfaced with GIS provides flood maps

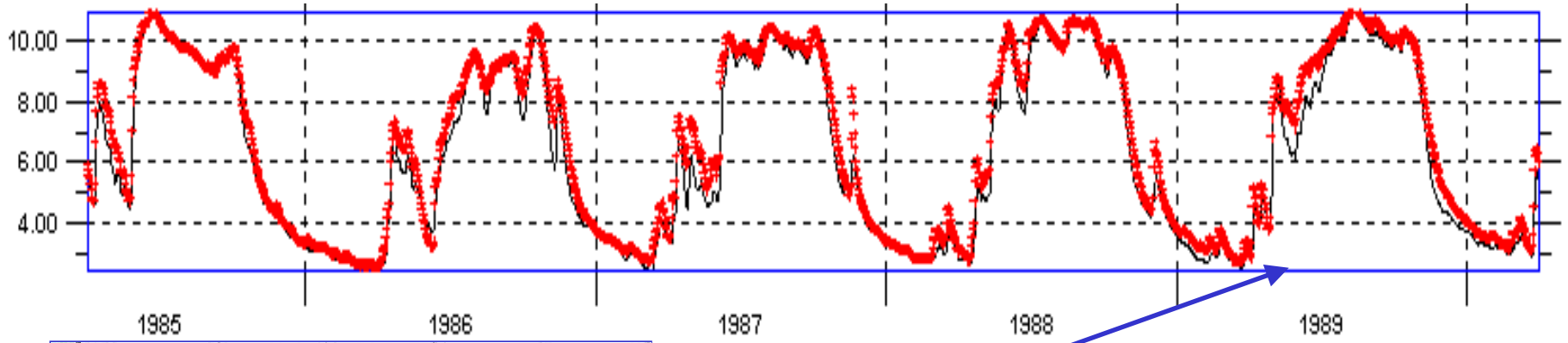
Modelled rivers: over 11000 km

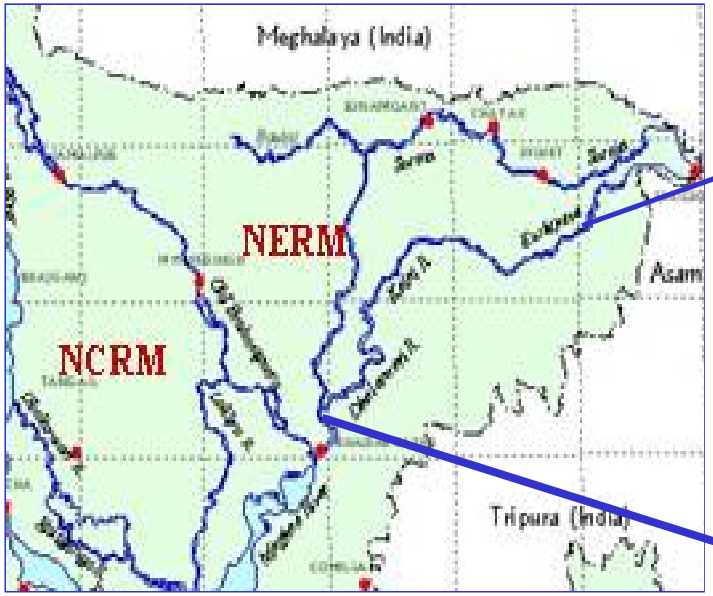
Modelled area
floodplains & rivers: 70,000 km^2
catchment: entire country

Being used in
- flood forecasting,
- flood management
- Drainage management

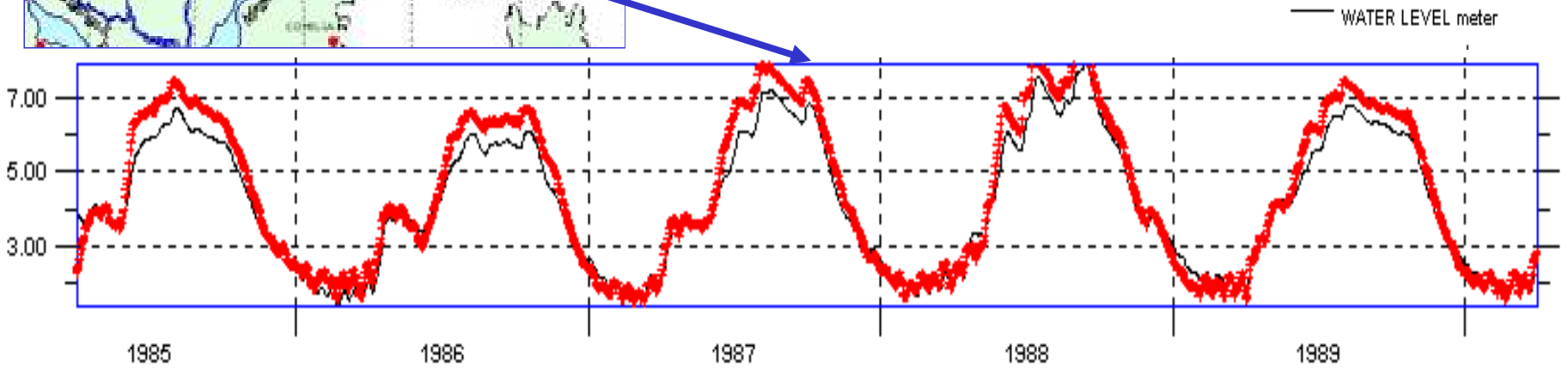


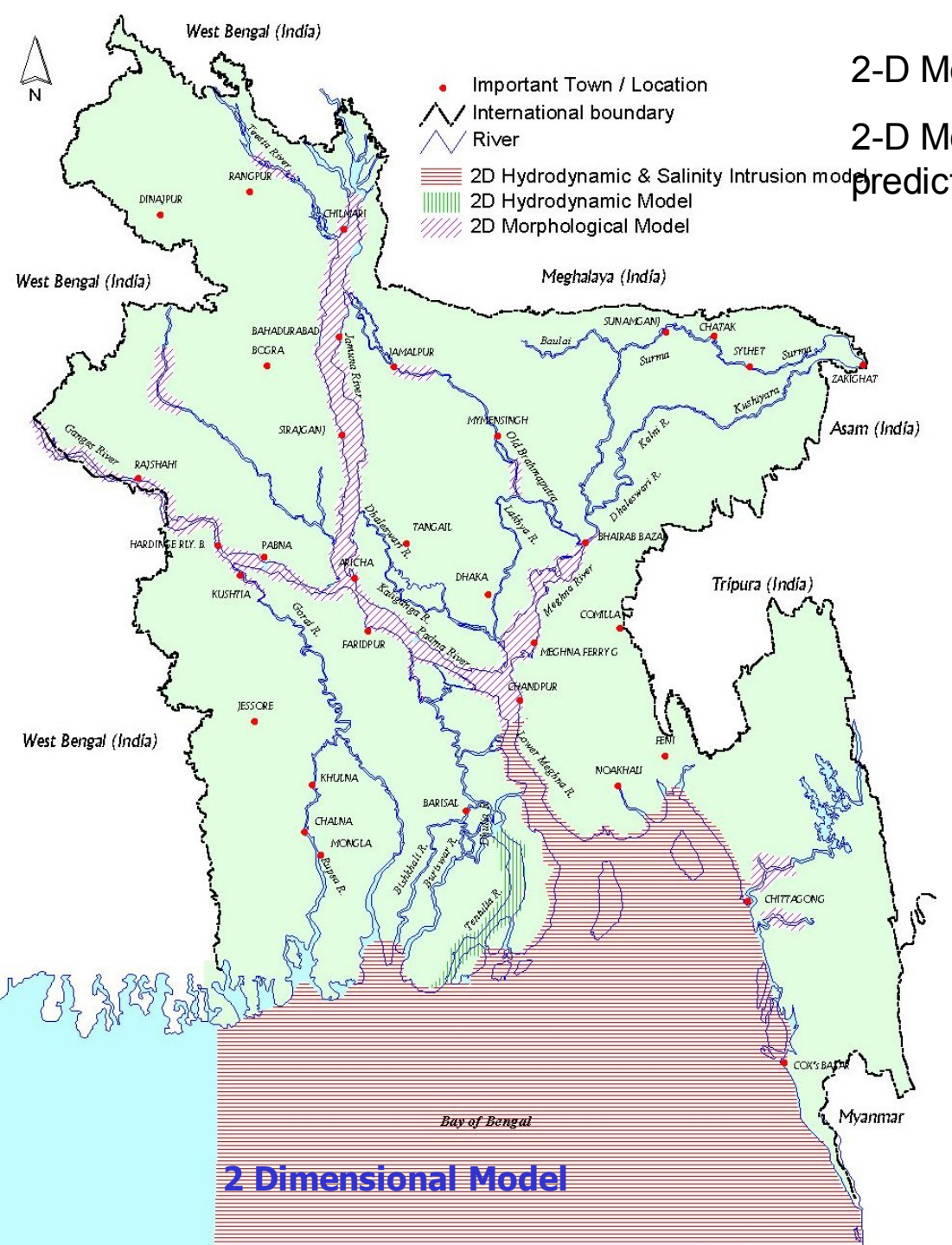
- Development of Models started in 1986 during SWSMP-I
- GM and SERM were the first models developed (1986-89)
- Other models developed: 1990-1993 (EHRM: 1994)





Calibration of NCRM against WL





2 Dimensional Model

2-D Model of the Bay of Bengal and esturies

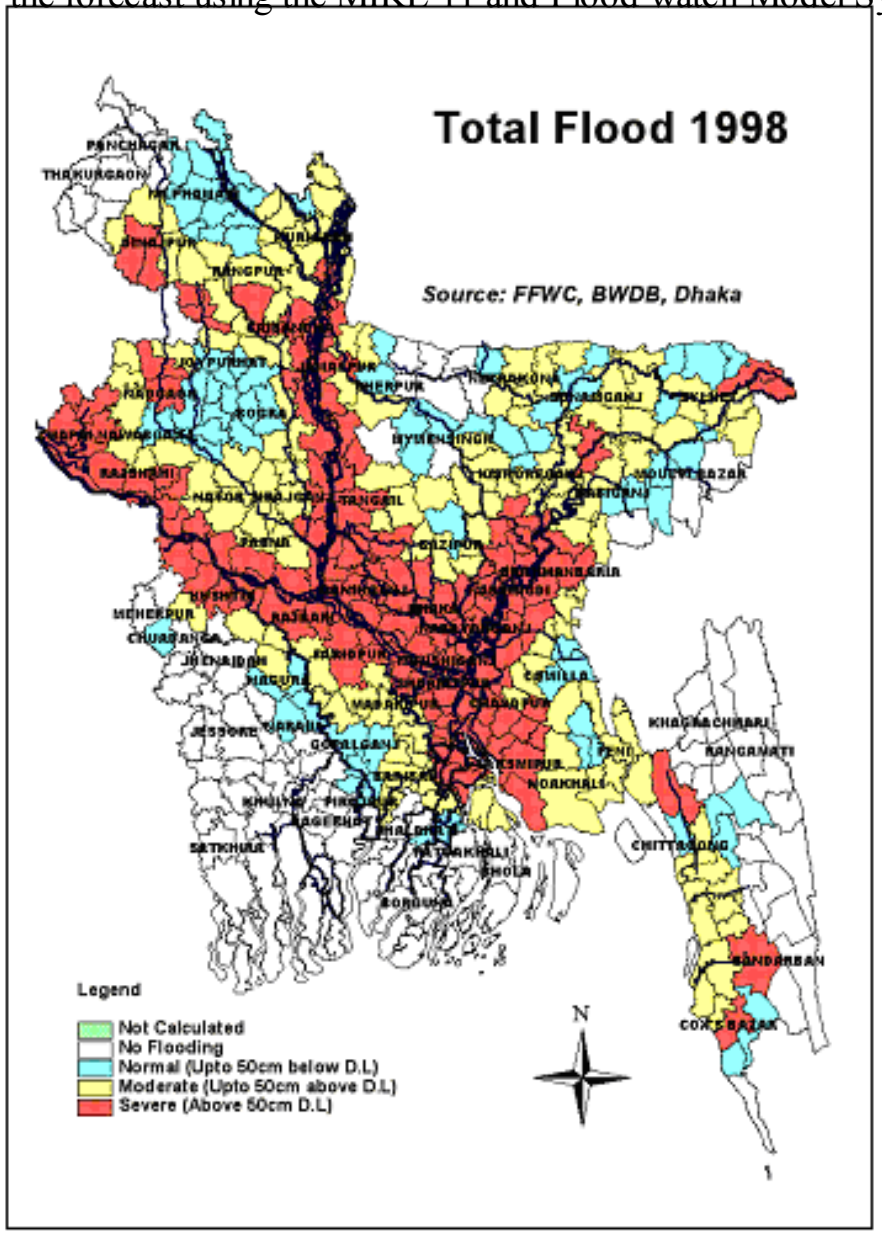
2-D Morphological Models are used in the prediction of the morphological changes

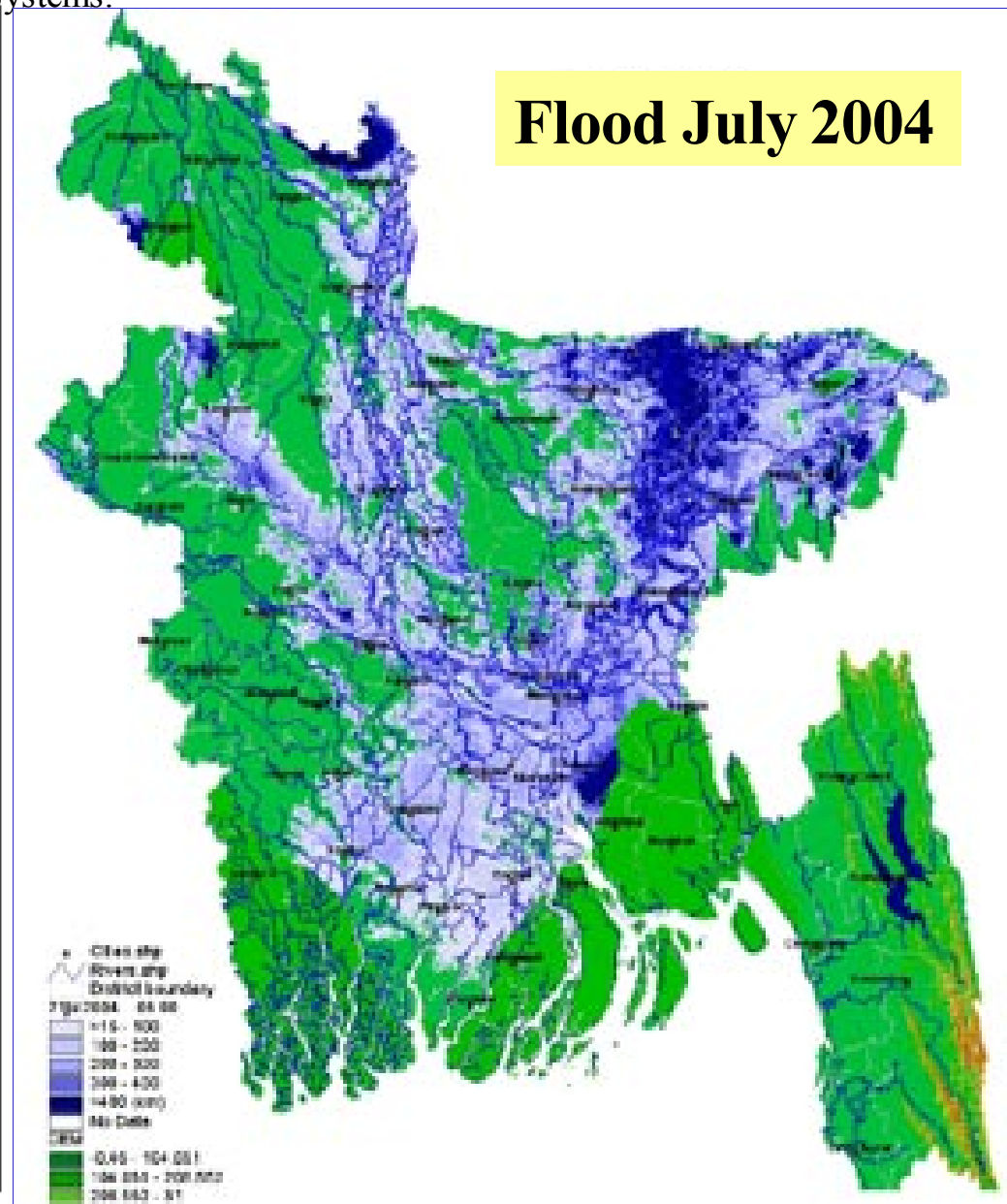
Model of all major rivers, estuaries and the Bay

Applied for
storm surge simulation
Morphological prediction

Evaluation of Forecast of 1998

The recent flood of 1998 has been of unprecedented magnitude and duration causing colossal damages to life, crops, properties and infrastructures of Bangladesh. During the flood '98 the Flood Forecasting & Warning Centre of BWDB issued the forecast using the MIKE-11 and Flood watch Model Systems.

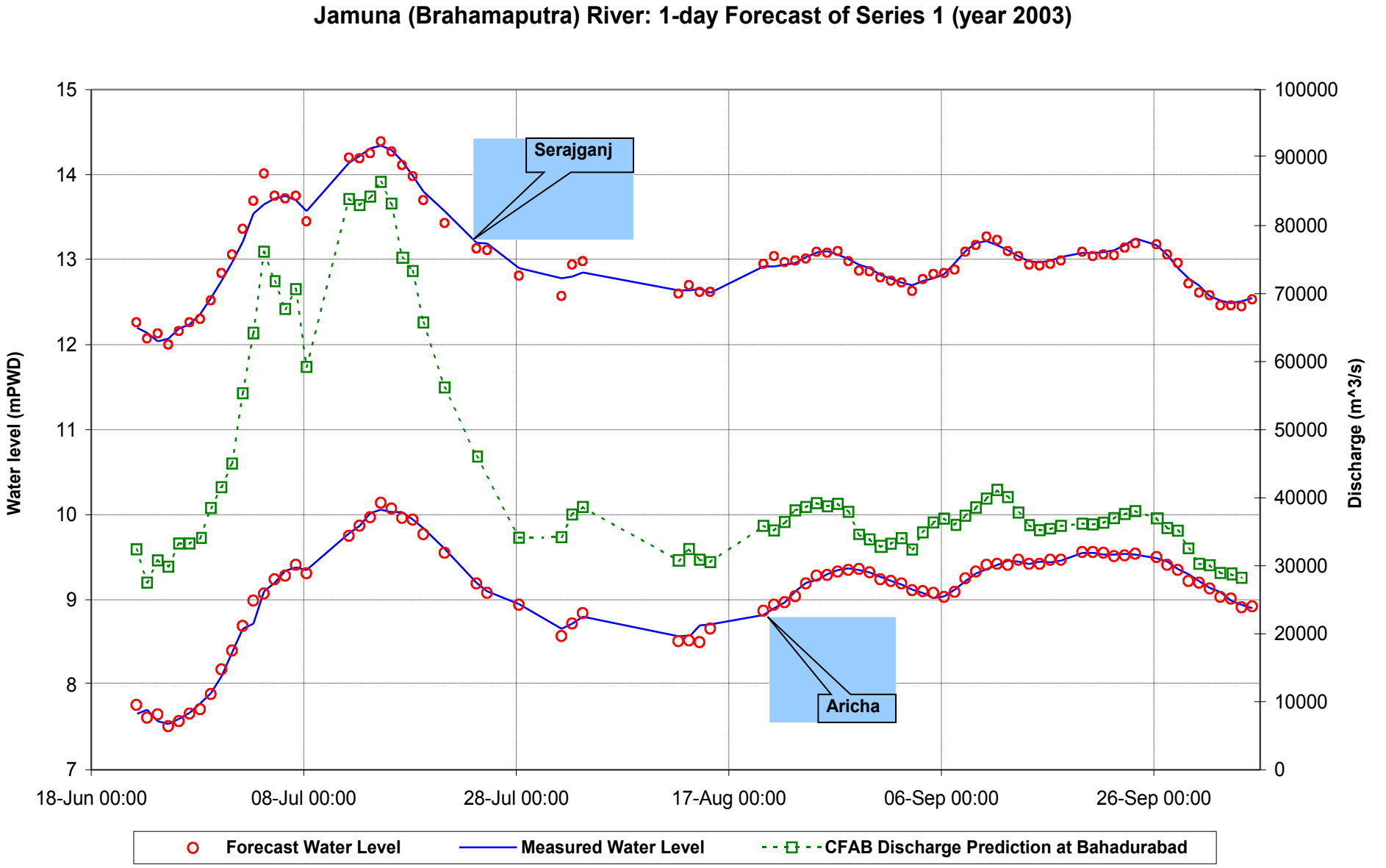




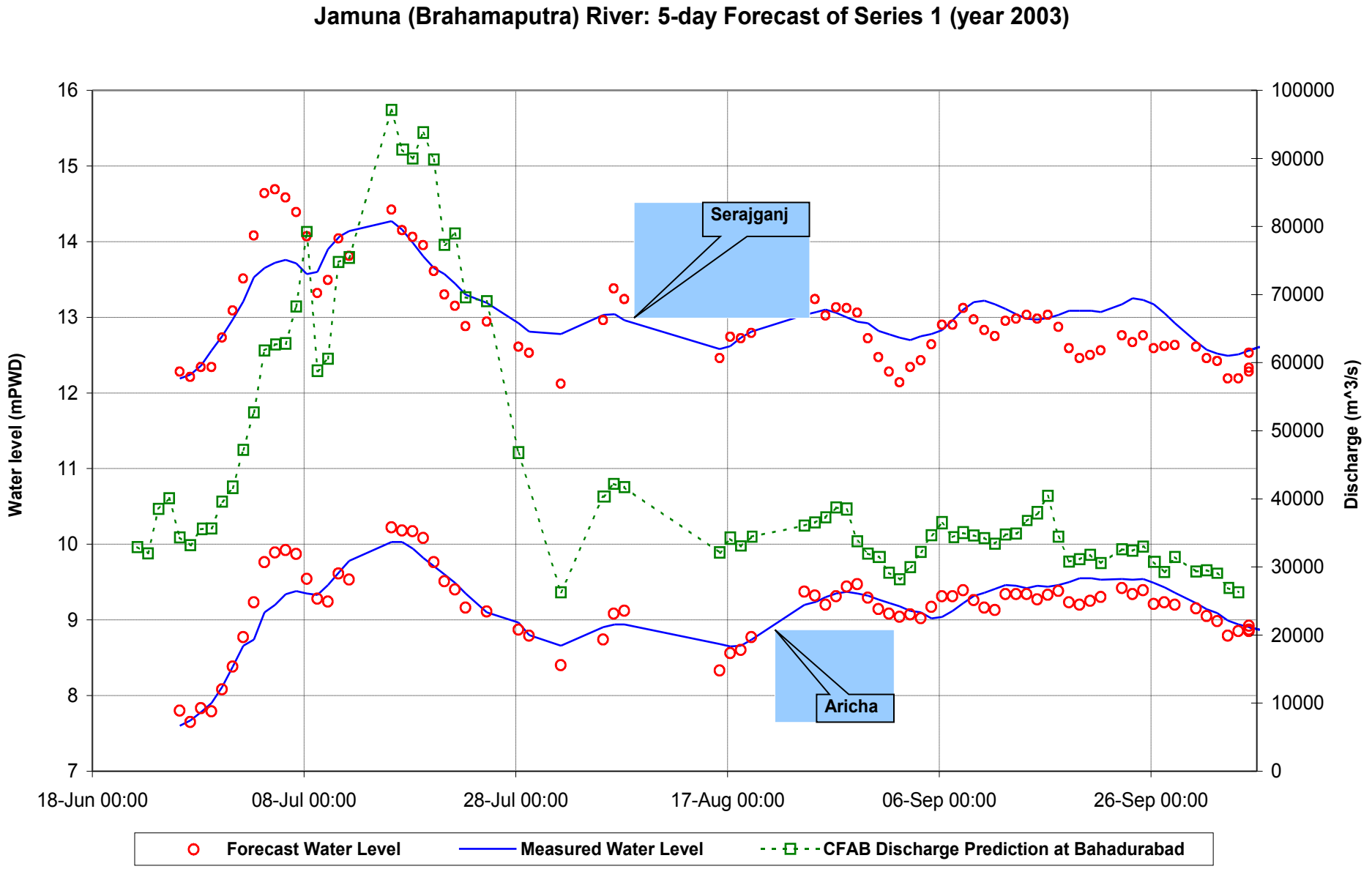
Flood Forecasting Accuracy

- **Lead time 48 hrs - very good**
- **Lead time 72 hrs - good**
- **Lead time beyond 72 hrs - Not operational**

Capability of forecast in predicting correct trend (1-day forecast)



Capability of forecast in predicting correct trend (5-day forecast)



Major Input for FFM

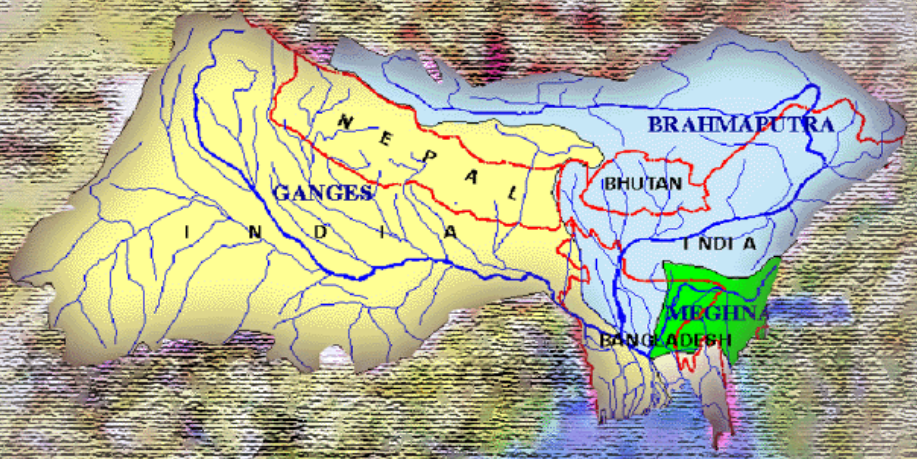
- Rainfall (real time + predicted)
- boundary condition (Q & WL - real time + predicted)

- Rainfall data is expected through MAHASRI
- Q & WL either from GBM model or other sources

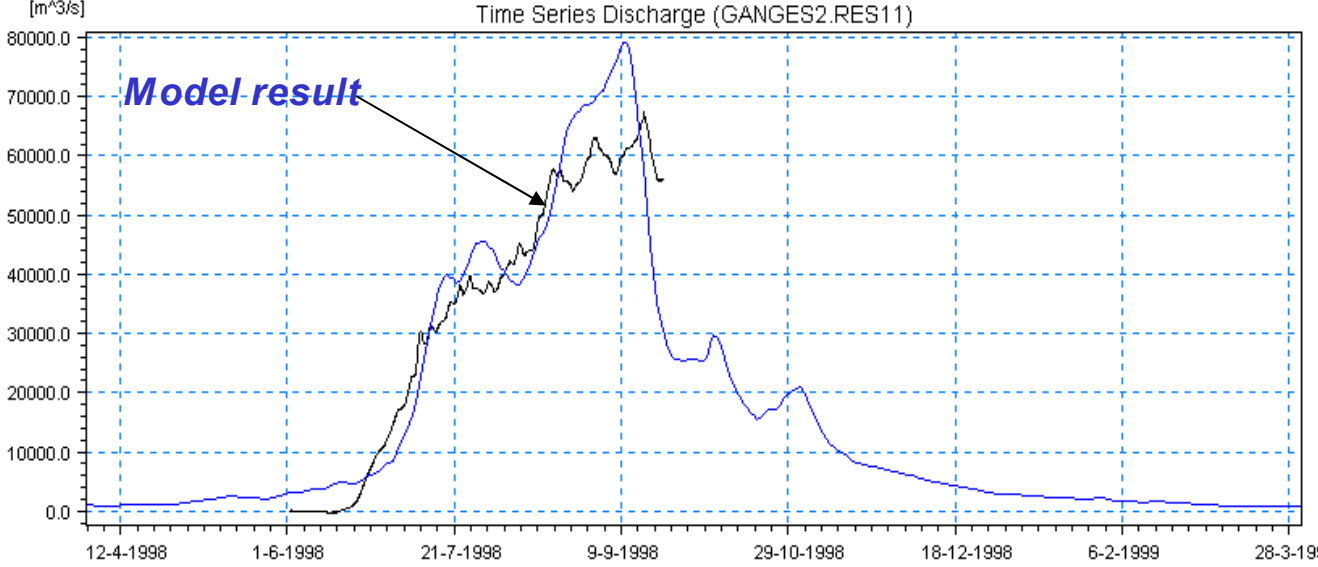
Discussion to overcome the problem

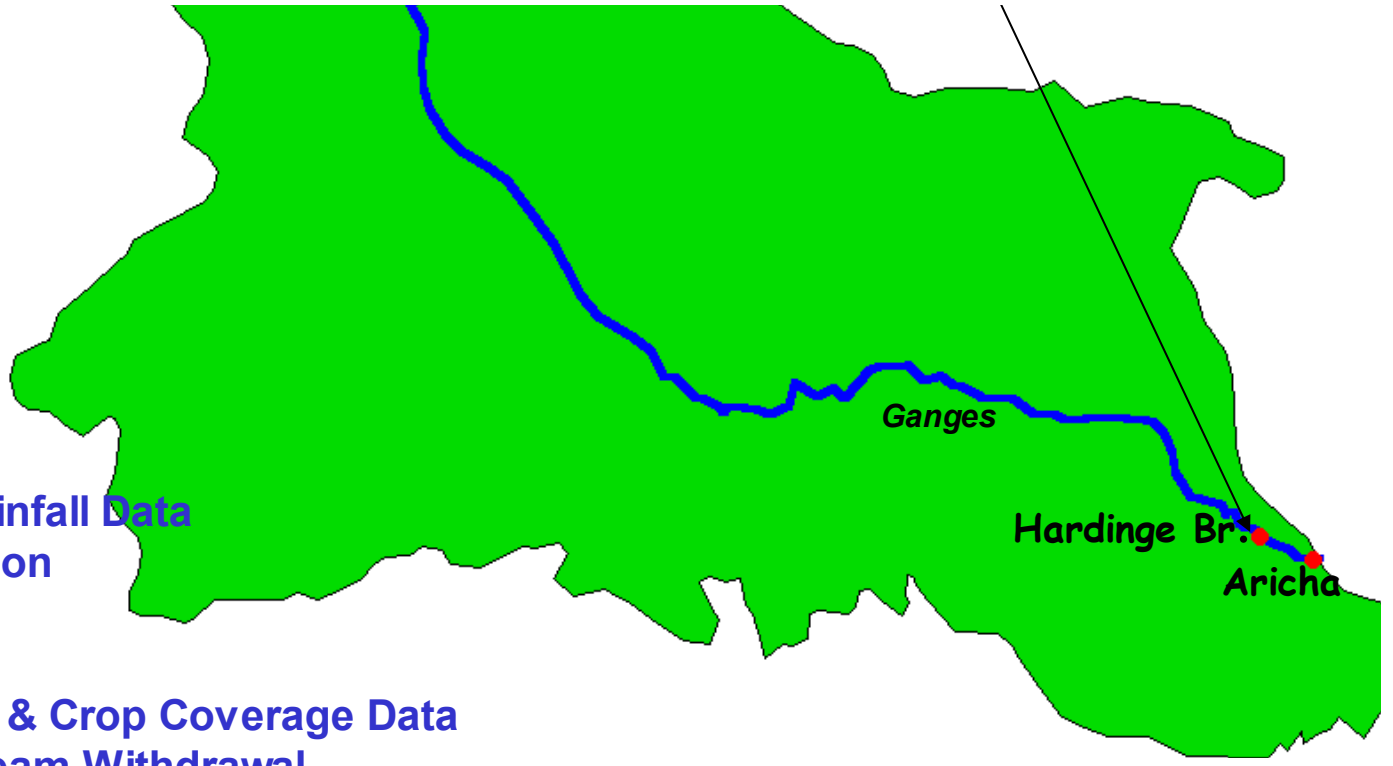
Proposed GBM Basin Model

Forecasting in the mid-term: 4-15 days



Ganges Basin

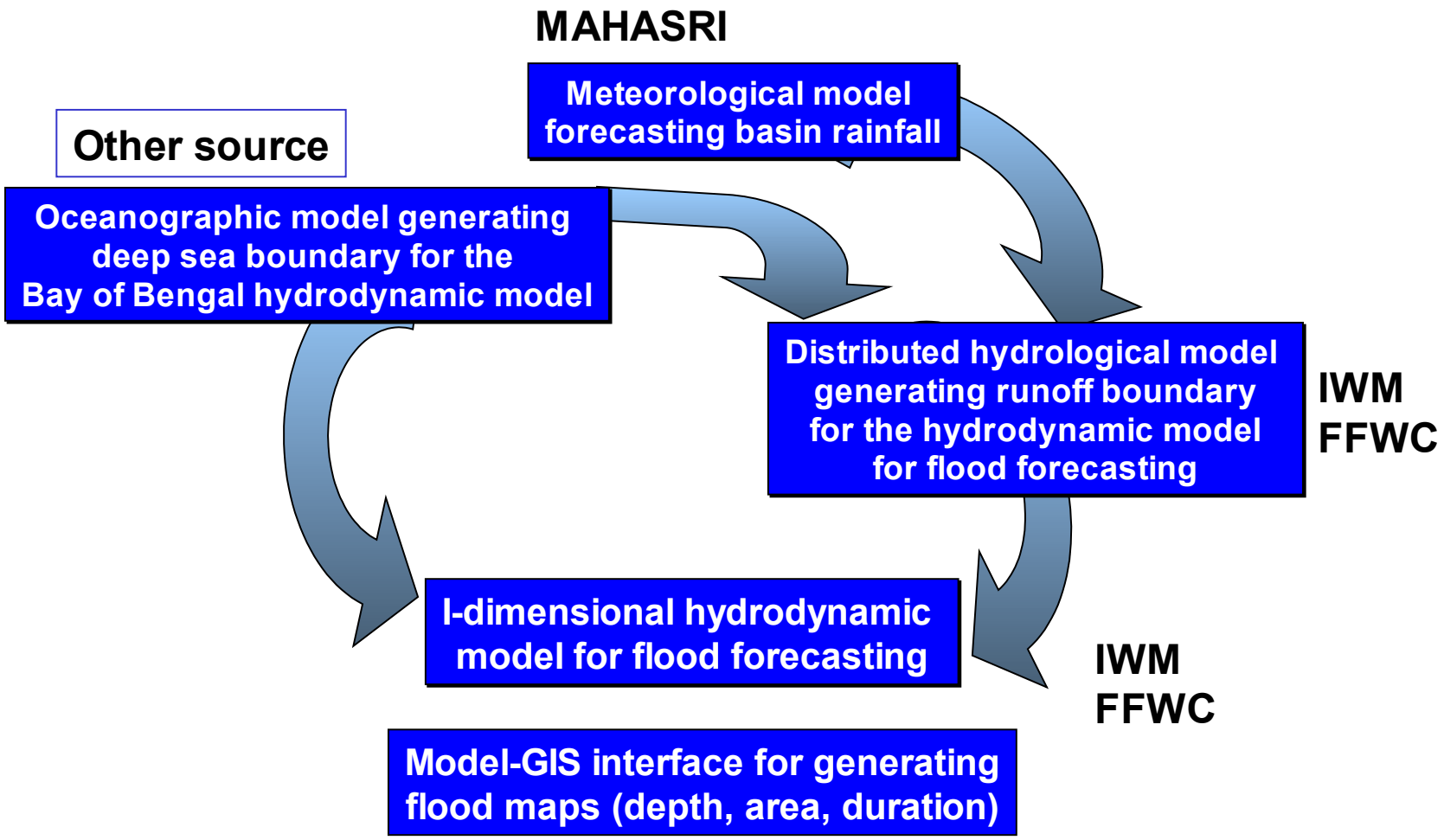




Need for improvement

More Representative Rainfall Data
Actual River Cross Section
Snow Melt Information
Soil Profile Data
More Intensive Landuse & Crop Coverage Data
Water Demand & Upstream Withdrawal

Institutional Linkages



Flood management	Disaster management	Floodplain resources management
BWDB LGED	DMB, BWDB, LGED DAE, RHD, MoF	DMB, BWDB, LGED DAE, RHD, MoF

Proposed Regional Collaborations

Hydrological Model for Meghna Basin

- Real time Rainfall from Remote sensing (Radar/TRMM)
- Predicted Rainfall from Mesoscale Model
- Real time and Predicted Boundary Data (WL/Q); Neural/catchment modelling
- Land use data from upper catchment (watershed delineation)

Proposed Regional Collaborations

Hydrological Model for GBM Basin

- International collaboration is required in the scientific research, data exchange, experience sharing, prediction tool development.
- Institutional Capacity Building in the region
- Basin level institutional network and setup
- Positive mindset of key players in the region
- Each country have a focal person
- IWM have all the capability to be the focal point for hydrological modelling in Bangladesh.

Thank you

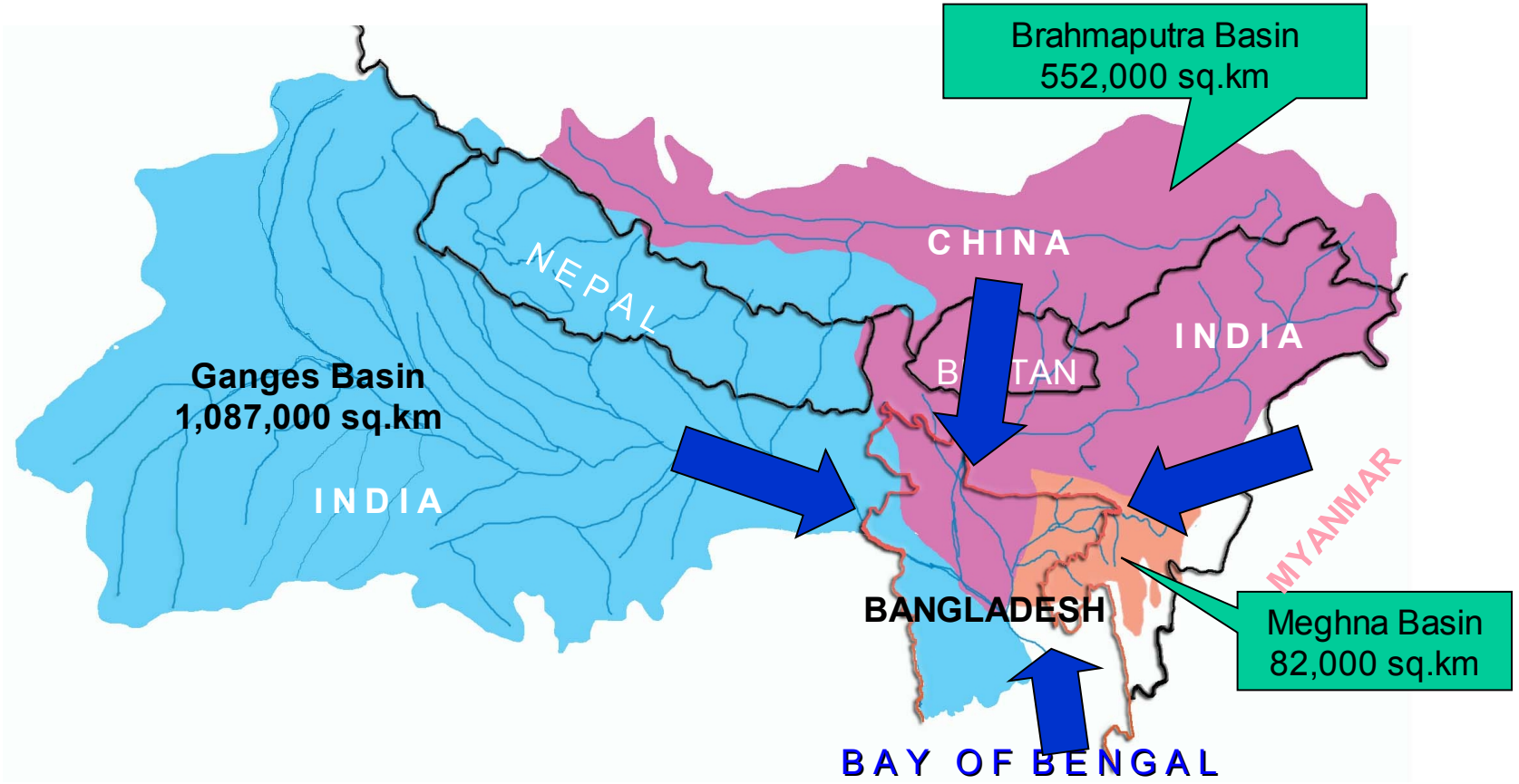
CFAB's basic aims are to:

- Develop forecasts schemes of discharge and sea-level on Short (1-6 days), medium (20-30 days) and long (1-6)months time scales
- Incorporate these schemes into the Bangladesh's flood and weather/climate forecasting systems
- Produce systems that are transportable in the short-term to Bangladesh institutions

CFAB presently focuses on making available the forecast products for agriculture sector which accounts for nearly 30% of the country's GDP

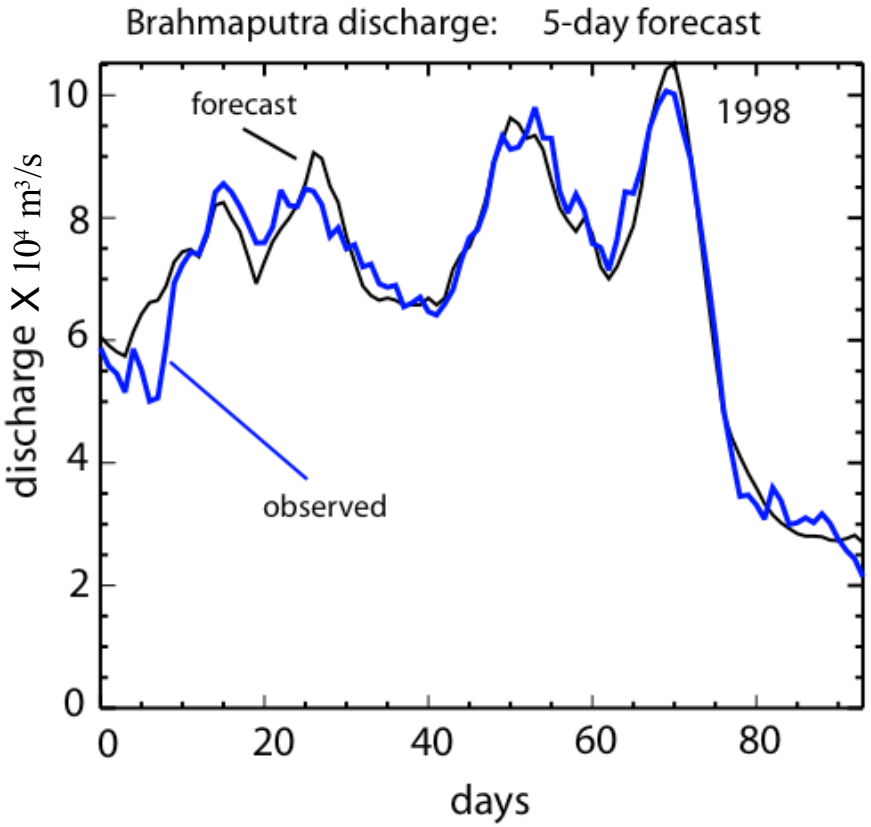
Short-range forecasts of Basin Discharge 1-6 days

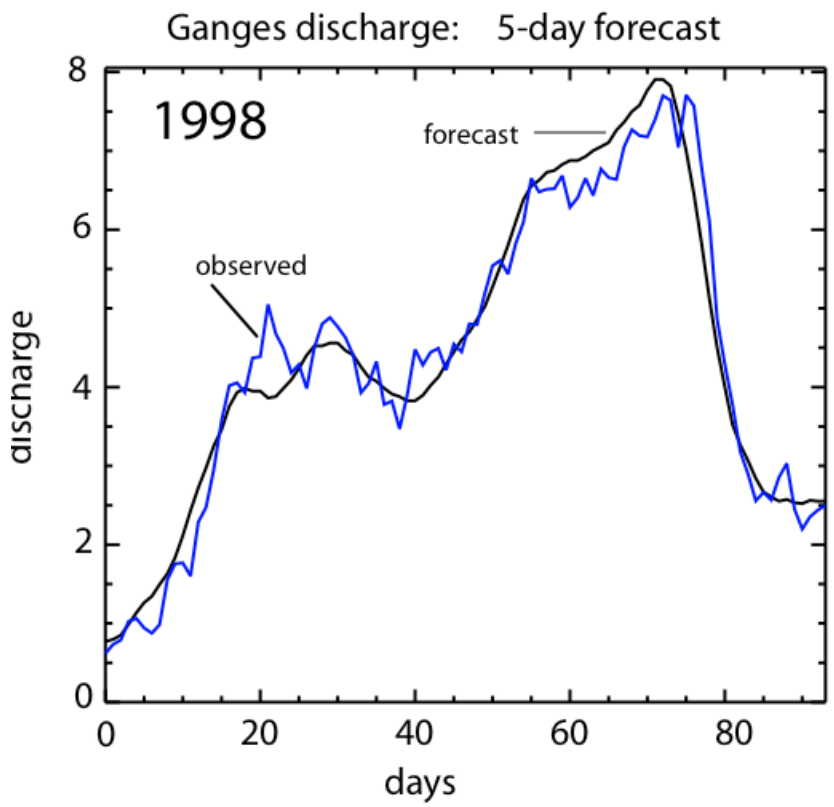
Short-range forecast schemes use rainfall over the Ganges and Brahmaputra catchment areas provided by ECMWF. Statistical Analysis. Provides river discharge into Bangladesh 1-6 days ahead. Schemes will increase FFWC forecast in Bangladesh to 8-10 days



Discharge Forecasts

Method is a purely statistical method where a regression relationship is developed with past associations between integrated rainfall from mean ECMWF forecast and observed discharge.



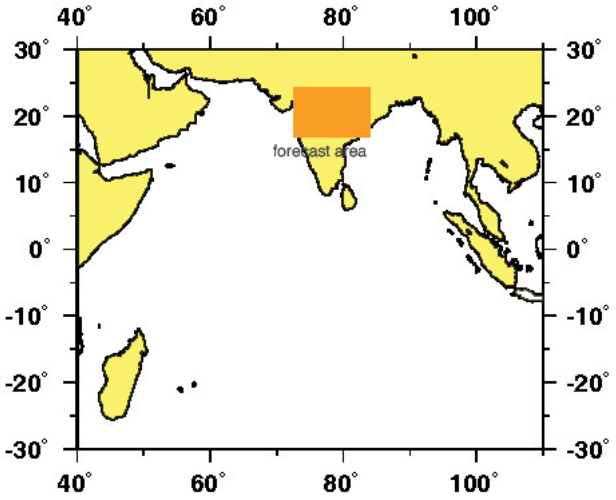


Medium-Range Forecast System
20-30 days

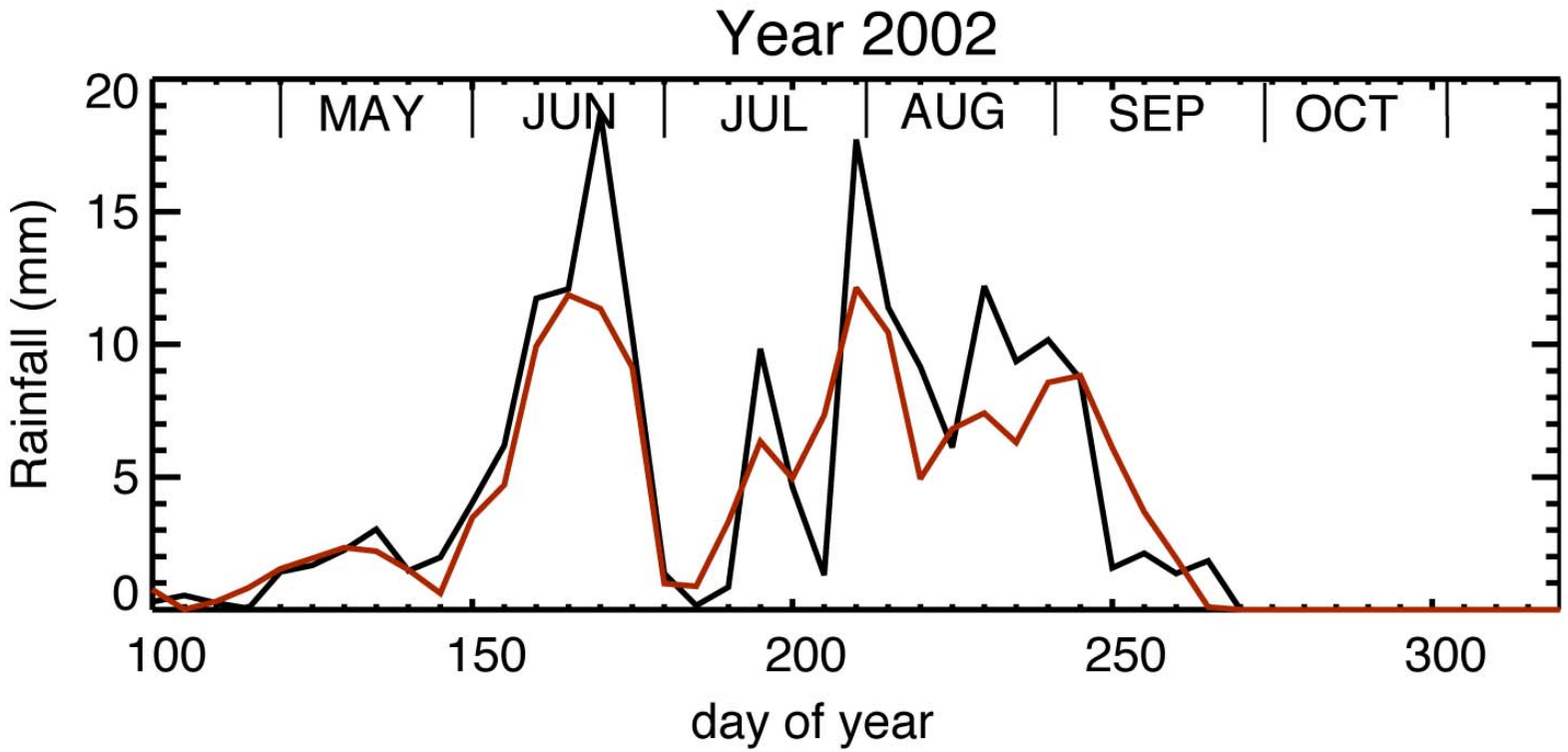
- The medium-range forecast system is a purely nonlinear statistical model.

- System picks predictors that have proven to be very important in physics of intraseasonal oscillation (monsoon active-break sequence)

20-day forecast of 2002 summer Precipitation (5-day average) Over the Ganges Valley

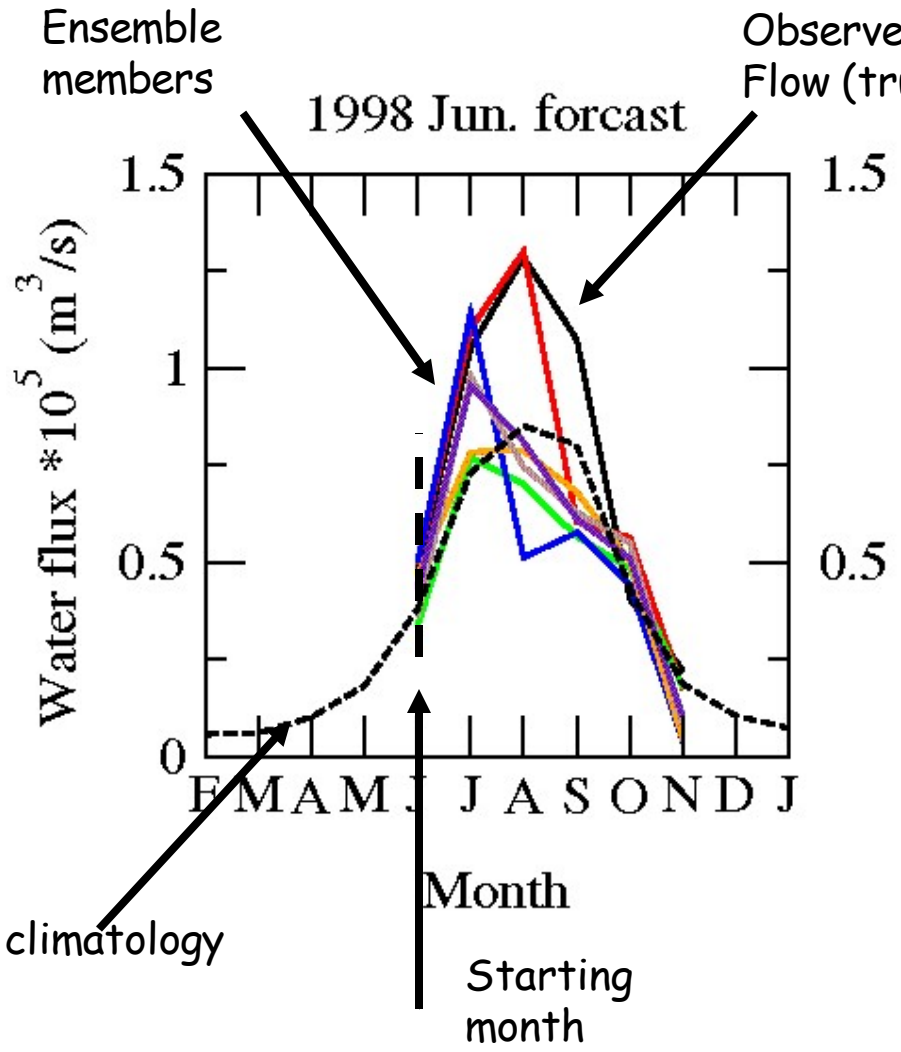


Note that system picks duration And extent of summer drought very well.



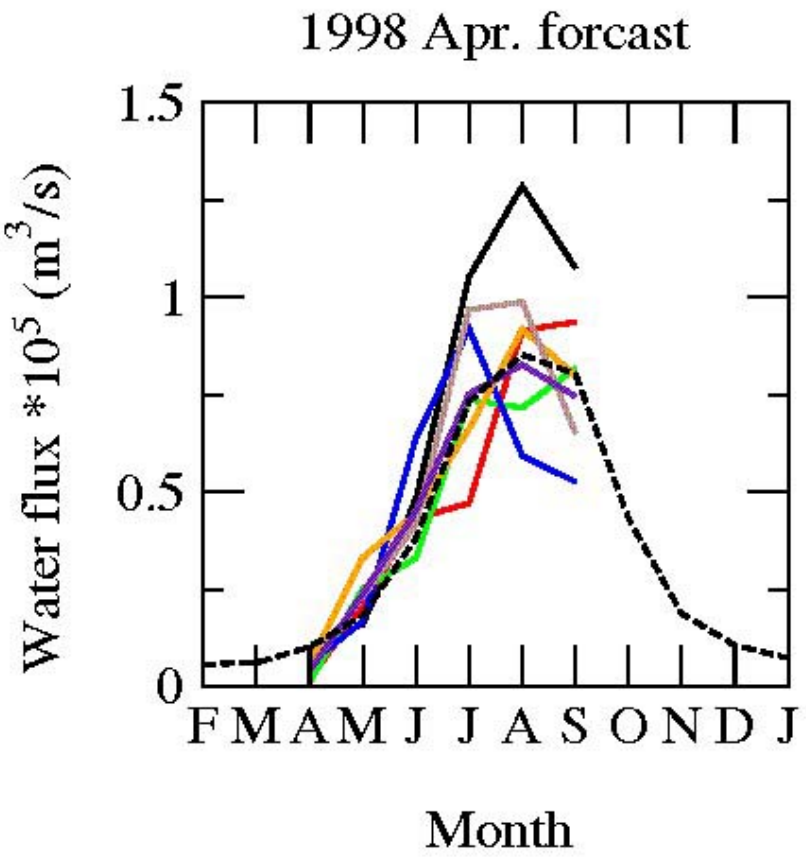
Long-Range Forecast System

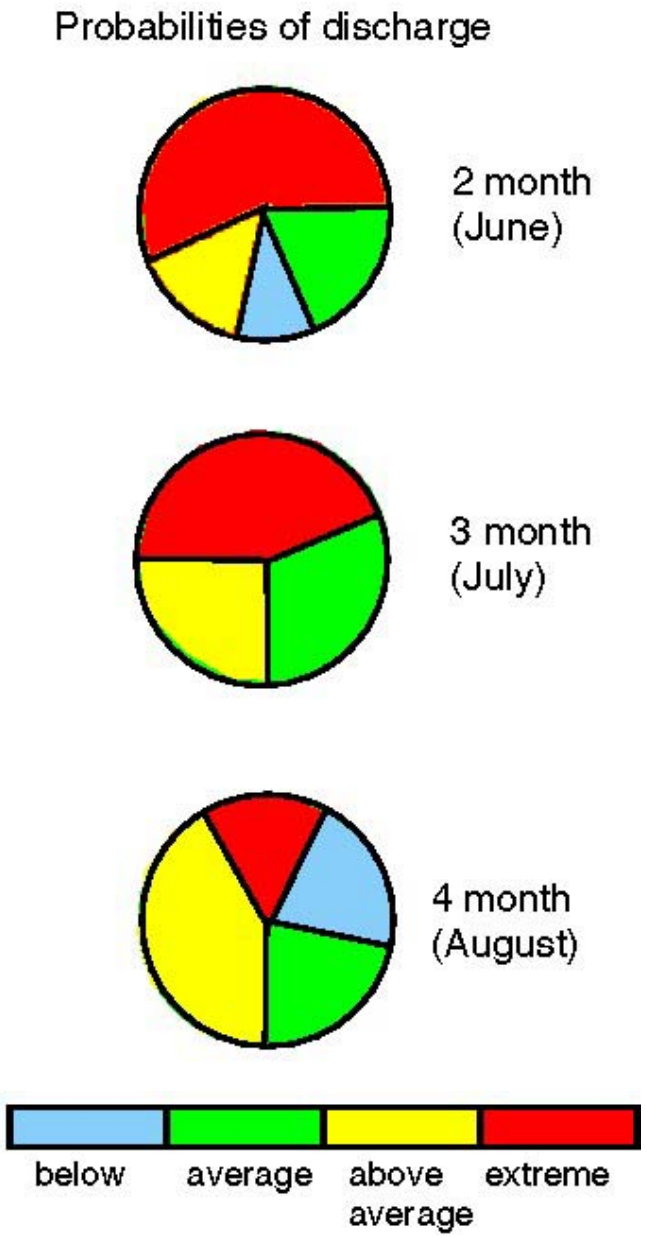
- The long-range forecast system uses forecasts of the ECMWF climate model
- Generates probabilities of discharge 1-6 months in advance



- Consider forecast made June, 1998
- Set of 5 forecasts available for June-November
- The climatological discharge would be known
- Plume of forecasts relative to climatology provide probability of discharge into Bangladesh.

Discharge Probabilities as Computed in April, 1998





The big questions?

- **How the probabilistic forecasts will be used by the end-users?**
- **How acceptable these are to the end-users?**
- **How the forecast information could be made available to the end users?**

Interaction
Consultation
Sharing

Stakeholders
User community

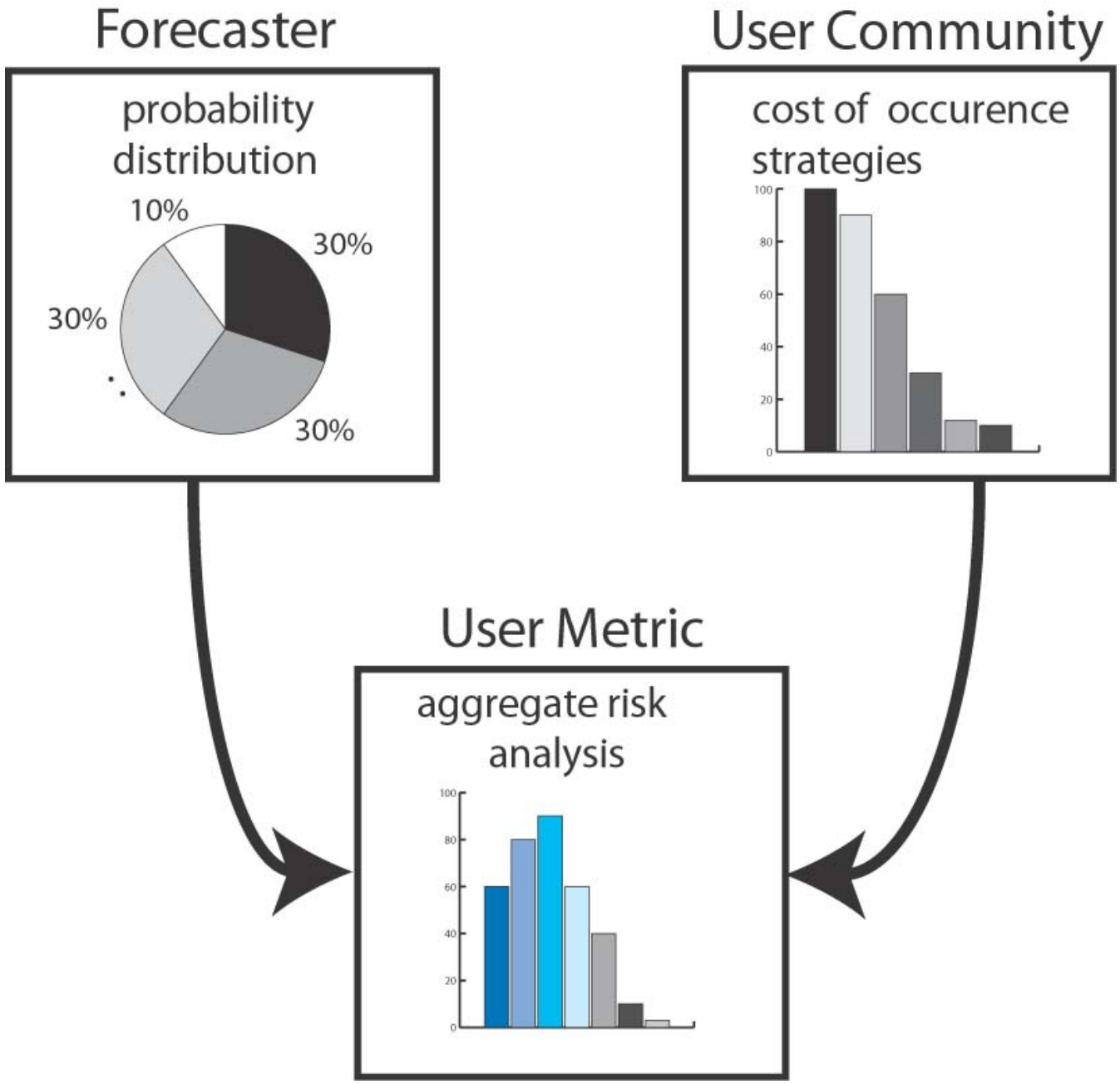
- An assessment of the cost if a certain phenomenon were to occur with a particular intensity
- This may be quantified to provide the cost of occurrence of a phenomenon

Knowledge Consumer
Knowledge provider

Forecaster

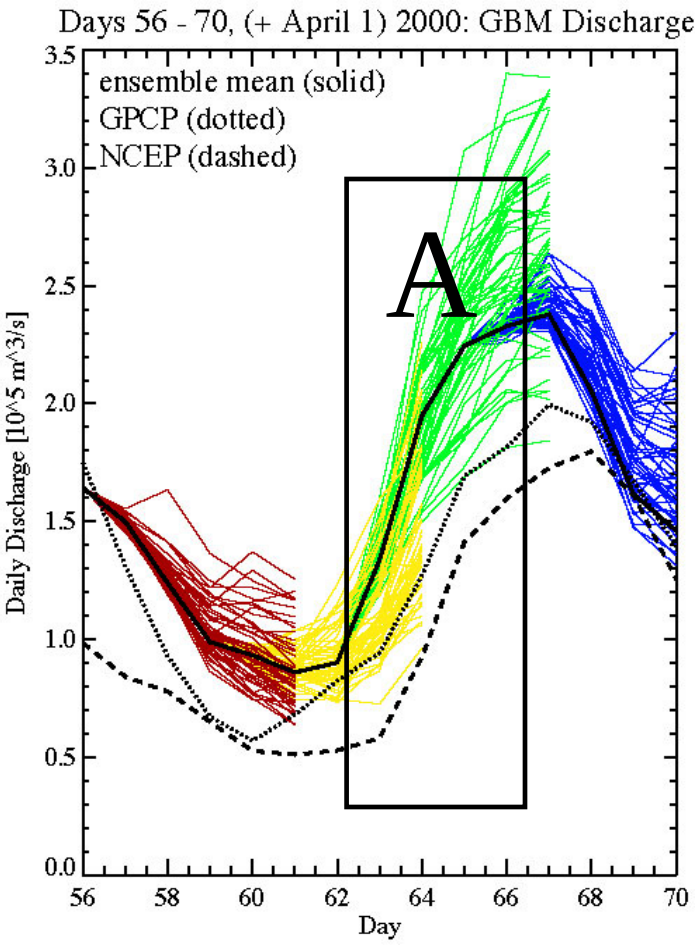
Knowledge provider
Knowledge Consumer

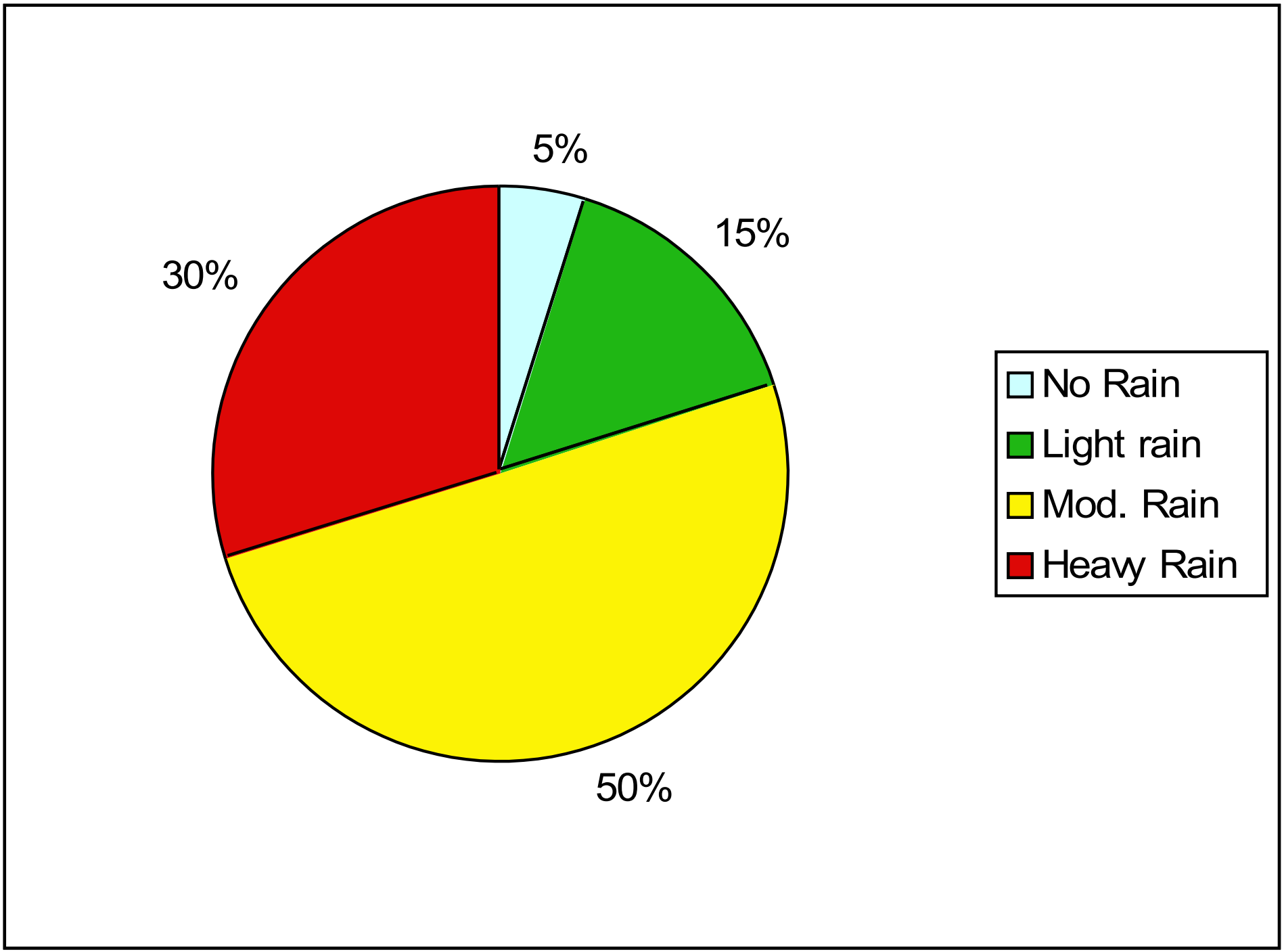
Probabilities of a particular event occurring at a particular time at a particular intensity


Forecaster
probability distribution
10%
30%
30%
30%
User Community
cost of occurence strategies
100
80
60
40
20
0
User Metric
aggregate risk analysis
100
80
60
40
20
0

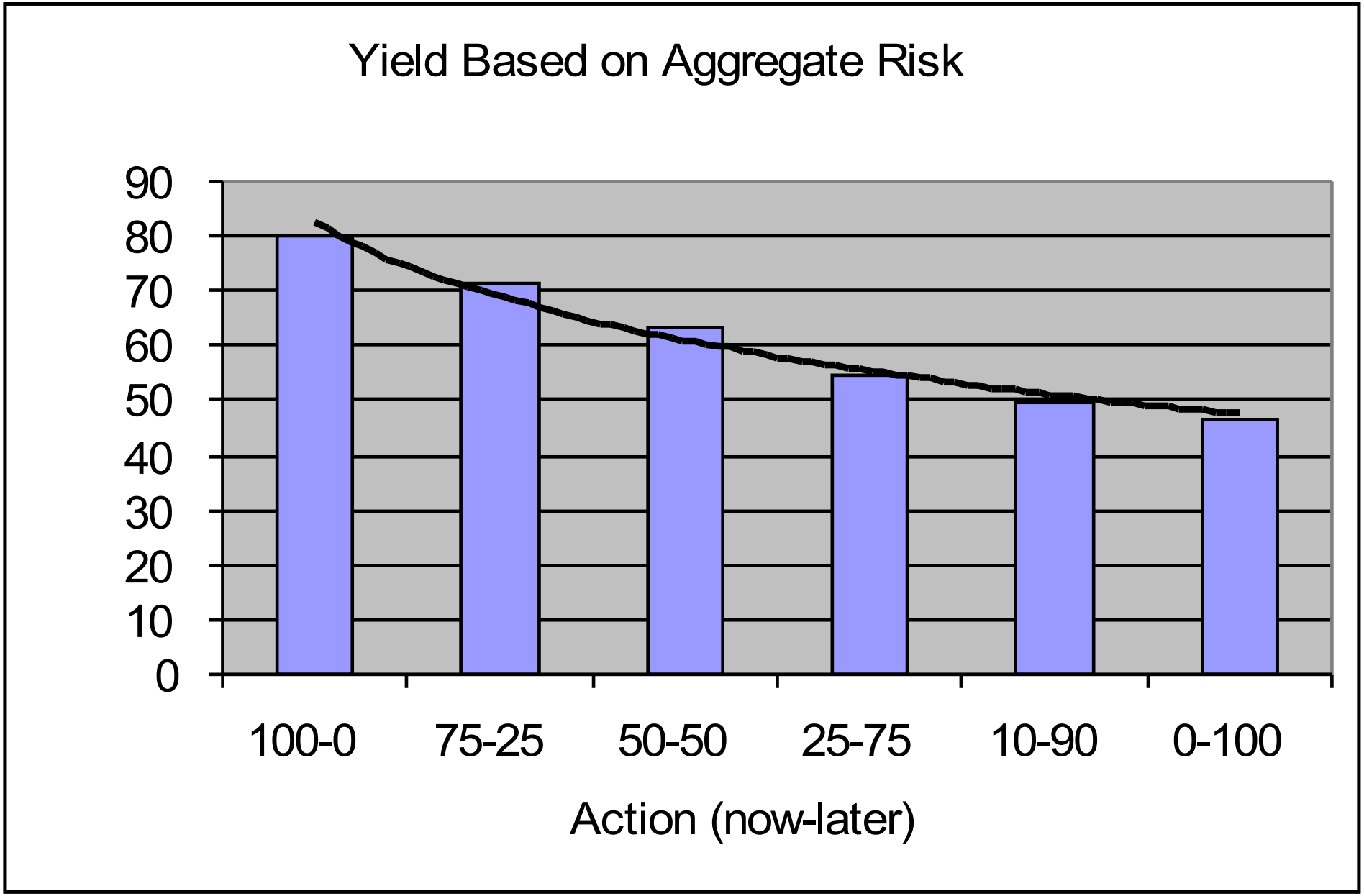
Scenario A

- Rainfall forecast probabilities suggest that rainfall will increase dramatically




5%
15%
30%
50%
No Rain
Light rain
Mod. Rain
Heavy Rain

Best option: Harvest early

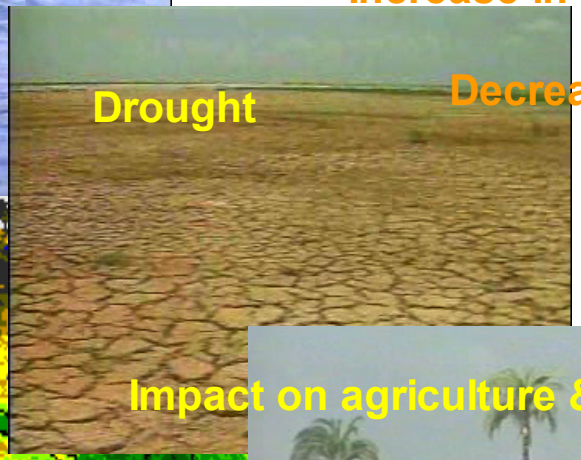


Global Climate Change: A Calamity of the Calamities in Bangladesh

Sea level rise

Increase in evaporation

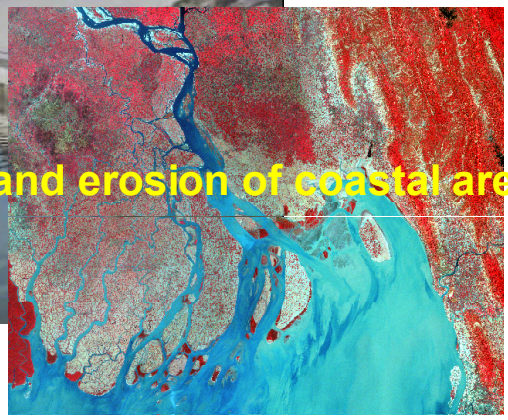
Increase in snow melt in the Himalayas



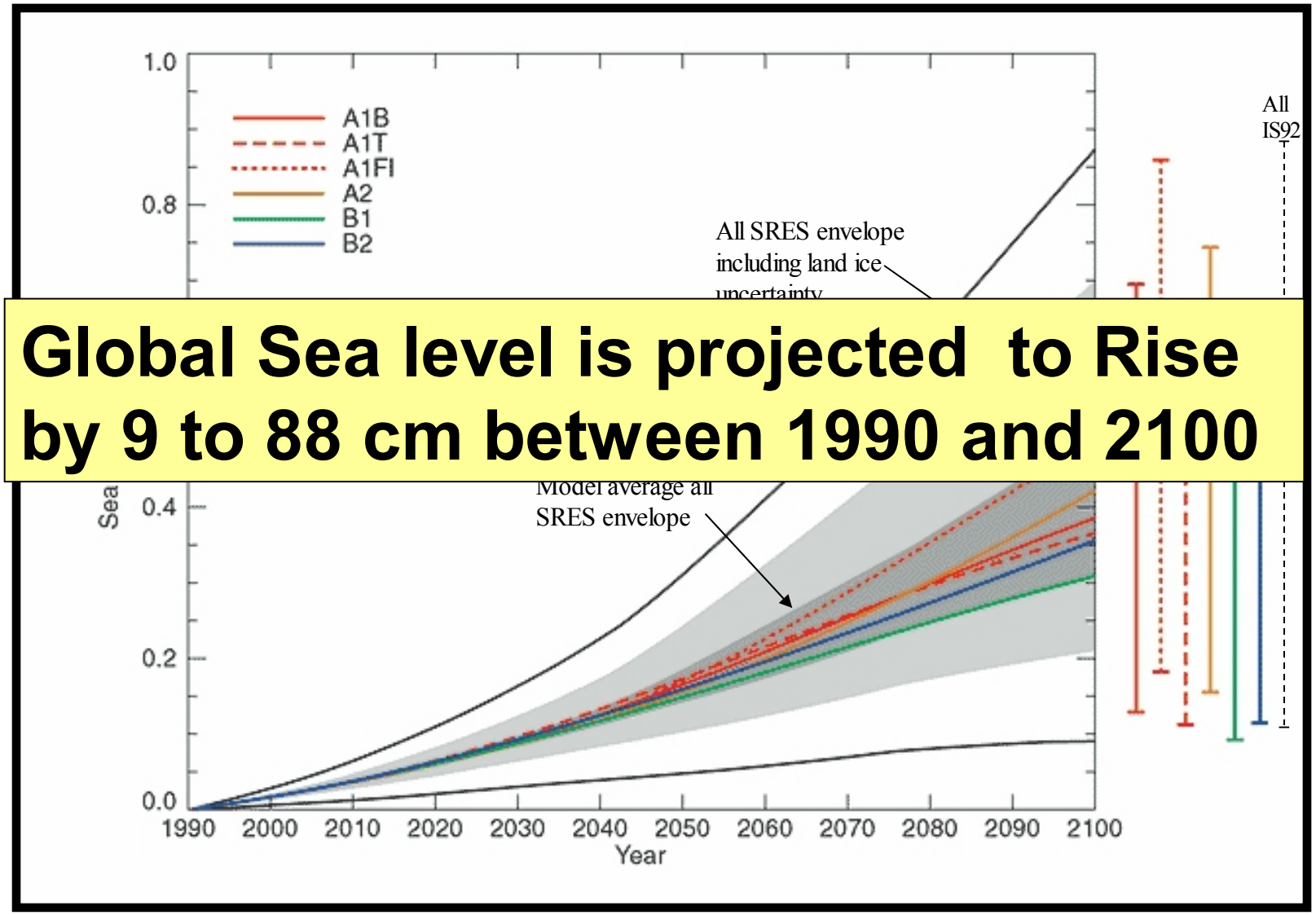
Decrease in precipitation in dry season

Increase in precipitation in monsoon

Prolonged monsoon



3rd IPCC
Predictions on Sea Level Rise



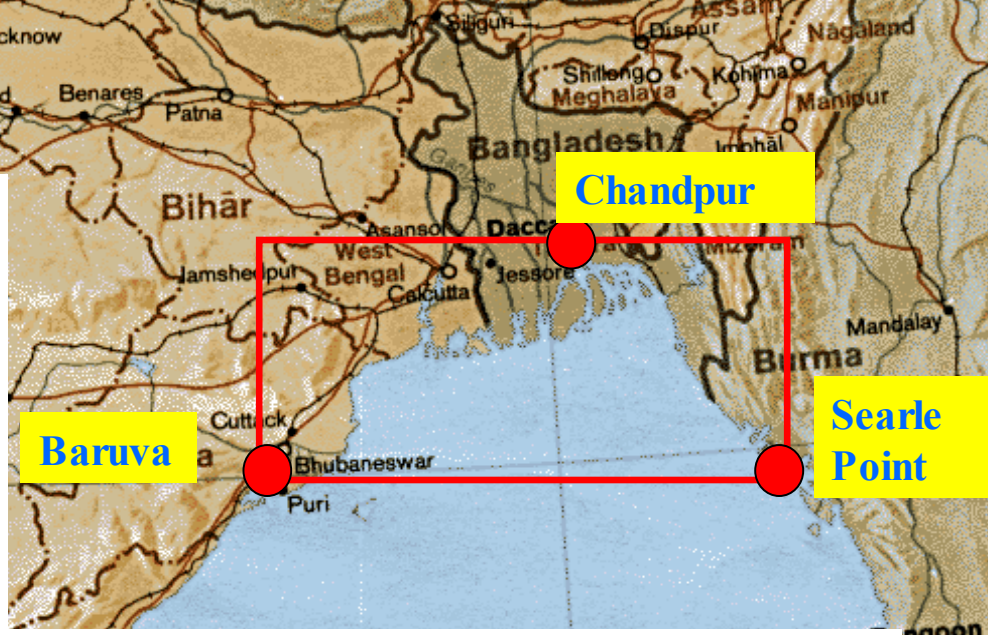
Global Sea level is projected to Rise by 9 to 88 cm between 1990 and 2100

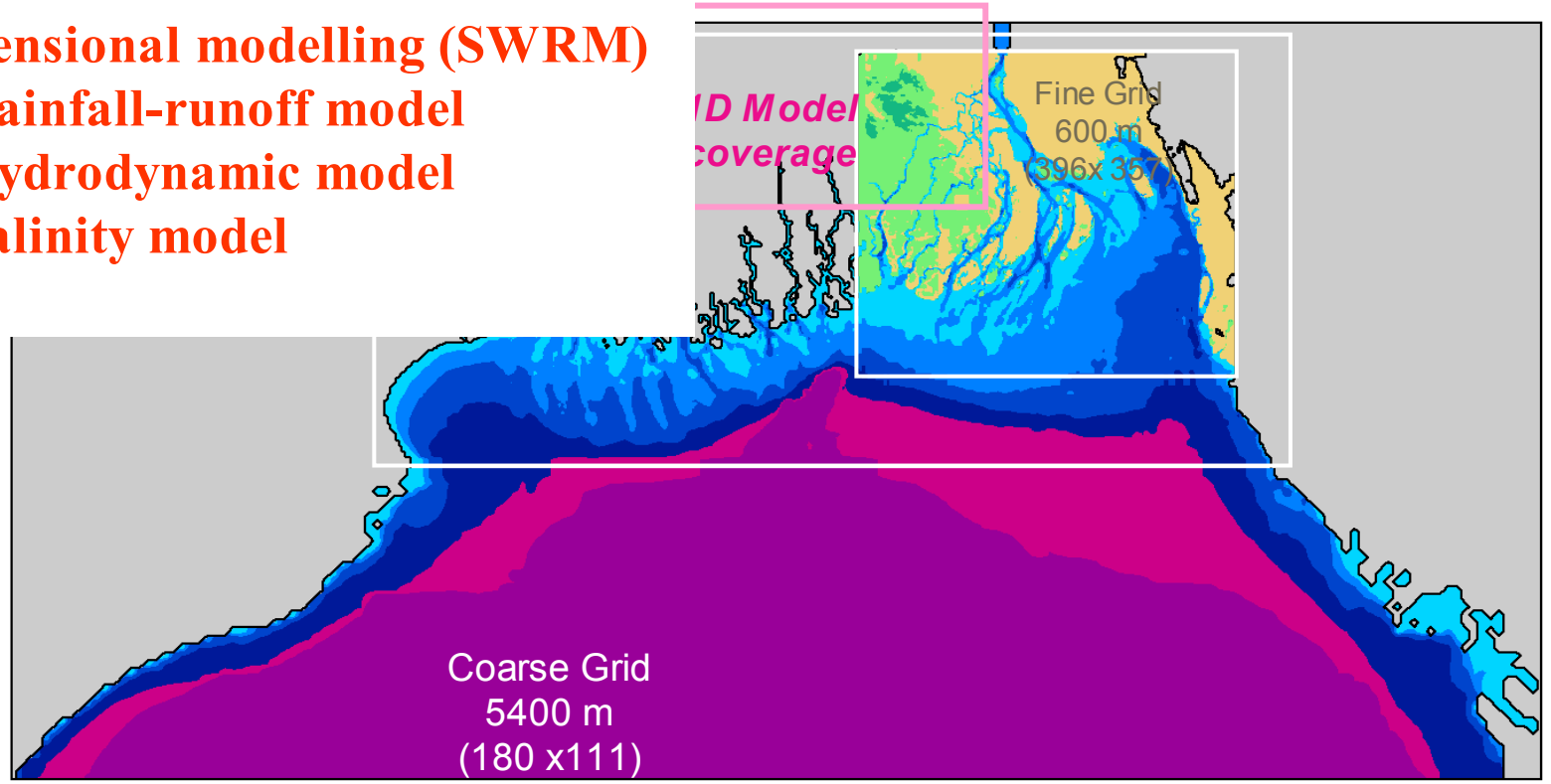
Projection of Climate Change for Bangladesh

Year	NAPA		
	Annual mean temperature	Precipitation (%)	Sea Level Rise (cm)
2030	1.0	5	14
2050	1.4	6	32
2100	2.4	10	88

Modelling CC

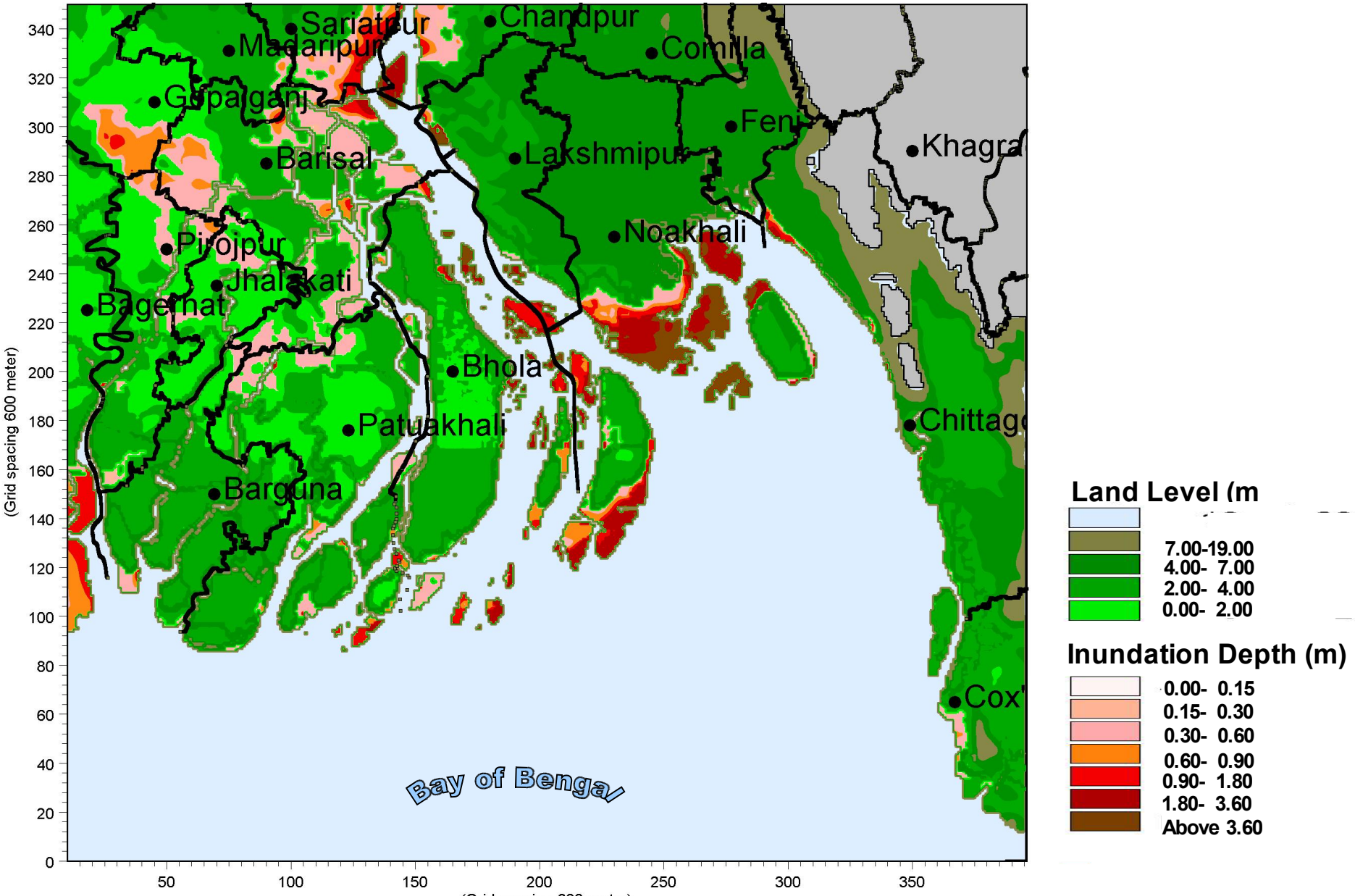
- Two dimensional modelling (BOBM)
  - Hydrodynamic model
  - Salinity Model
  - Cyclone surge model
  - Wave model
  - Sediment transport model
- One dimensional modelling (SWRM)
  - Rainfall-runoff model
  - Hydrodynamic model
  - Salinity model



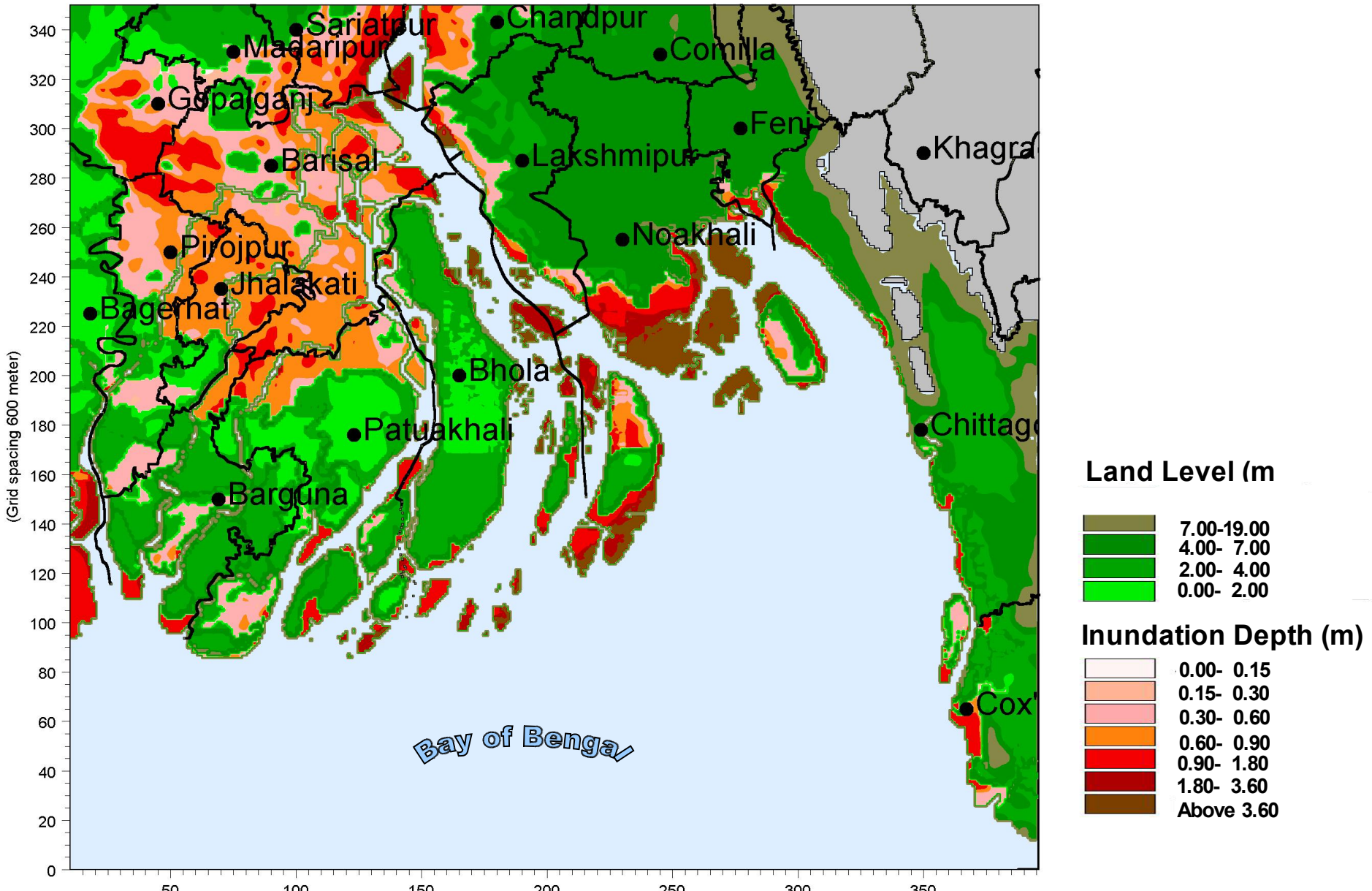


Impact on Inundation

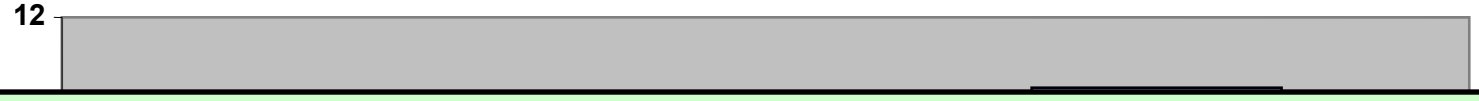
Flood Inundation Depth Map: Present Condition



Flood Inundation Depth Map: Sea Level Rise 88 cm



Land loss due to Inundation for 32cm and 88cm SLR



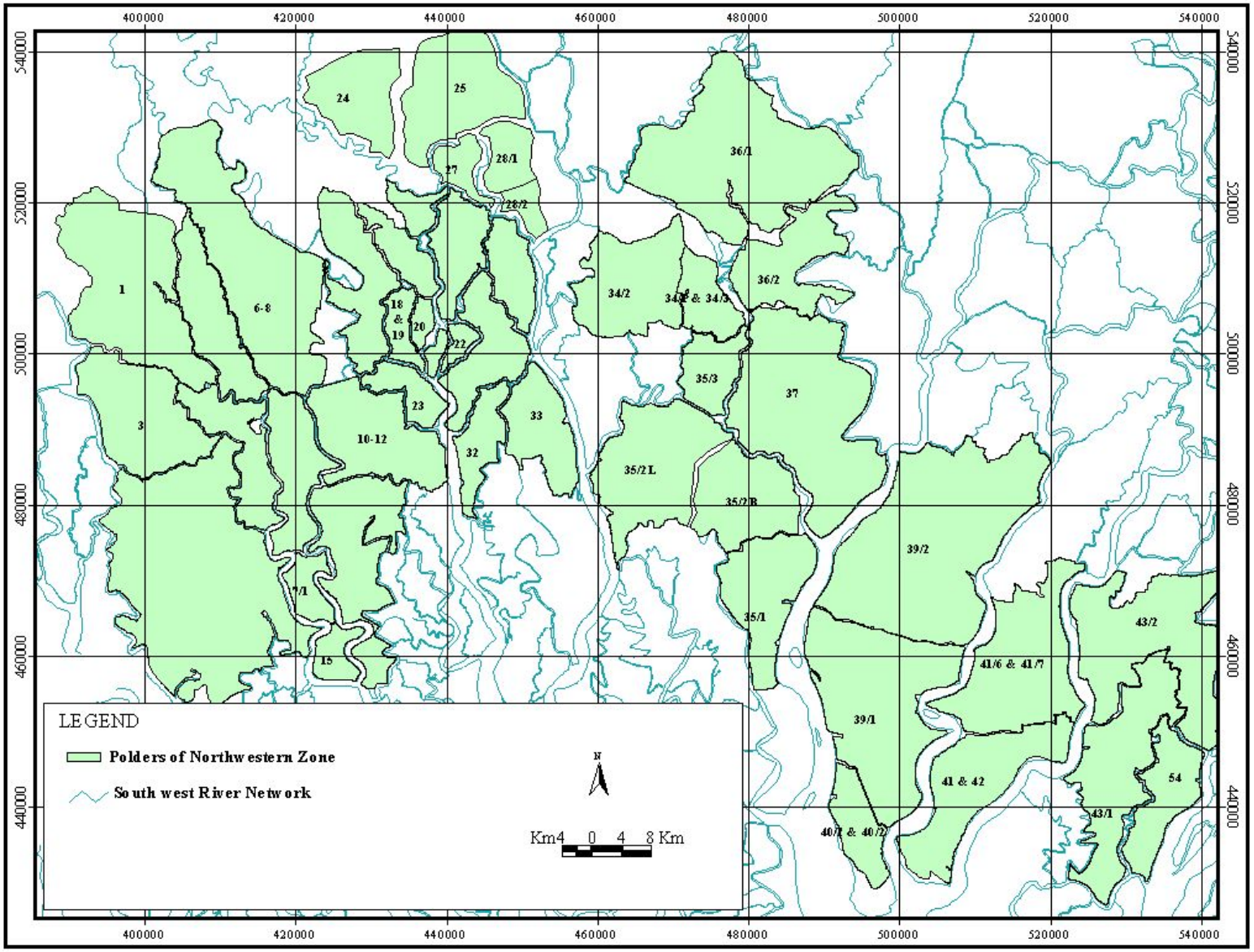
- **More than 13% of total coastal land will be permanently submerged**
- **84% of Sundarbans will be deeply inundated for 32 cm SLR**

For 88 cm, Sundarbans will be lost

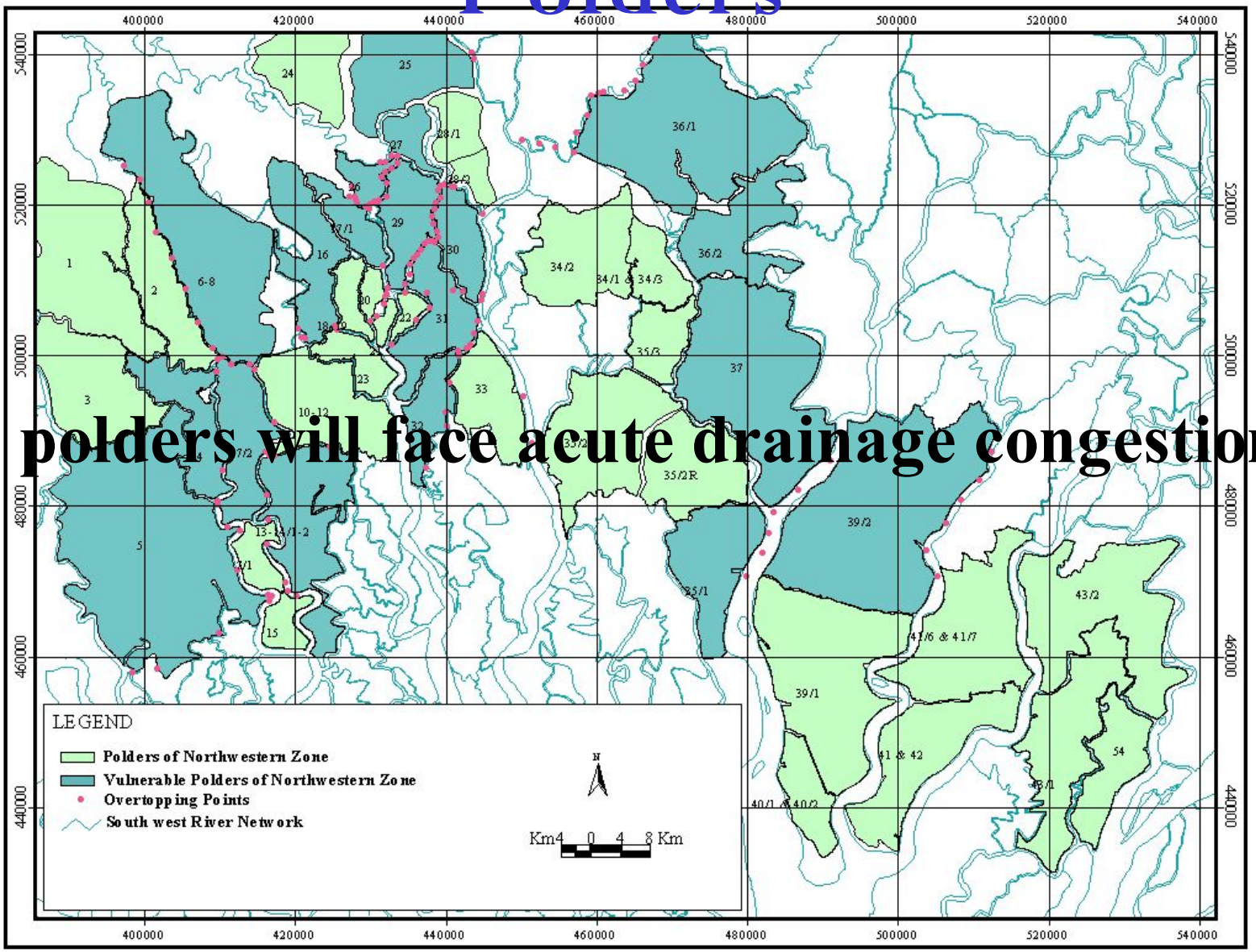
- **In two urban town, 0.5 and 1.4 million people affected in 2050 & 2100**

Impact on Drainage Congestion in the polders

Drainage Congestion of Polders

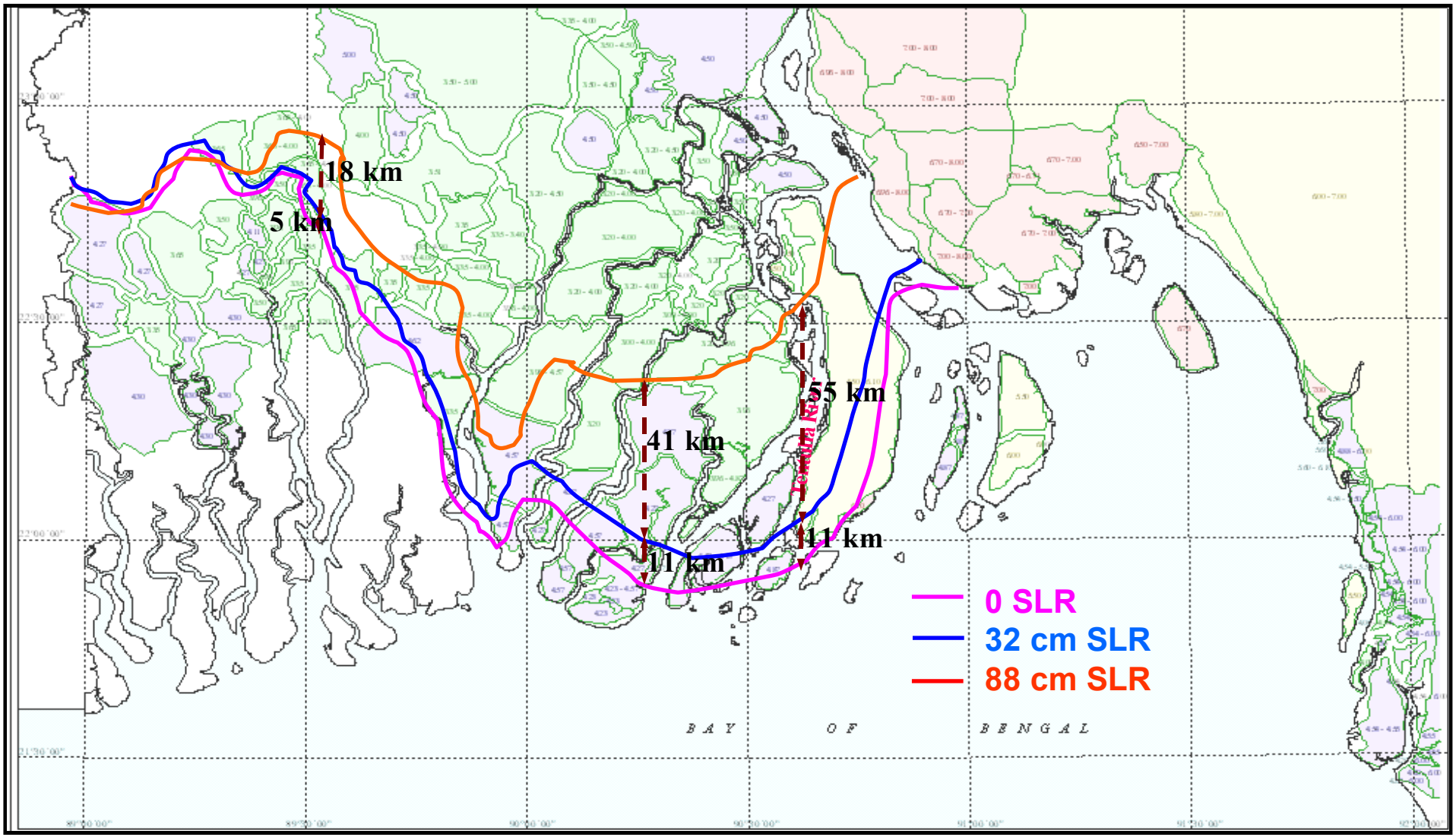


Drainage Congestion of Polders



17 polders will face acute drainage congestion

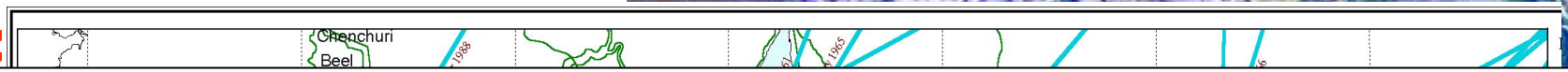
Intrusion of 5ppt Salinity line
Dry Season



Impacts

- Only Freshwater pocket in coastal area will be lost for 88 cm SLR
- penetration of salinity front would completely change the symbiotic process in the entire ecosystem
- critical salinity level for agriculture is 1-1.5 ppt, and shrimp production 10-20 ppt
- Increased salinity will reduce effect 30%

Coastal Area of Ba C



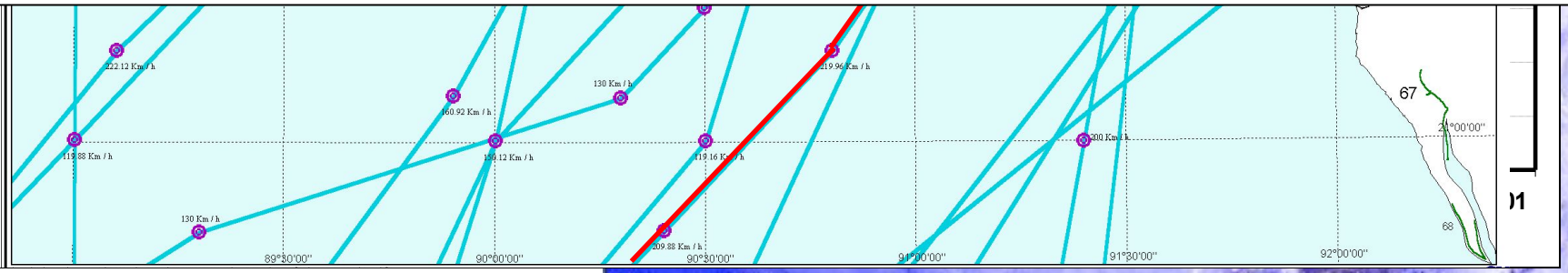
Death due to major cyclones:

1970: 300,000
1991: 138,000

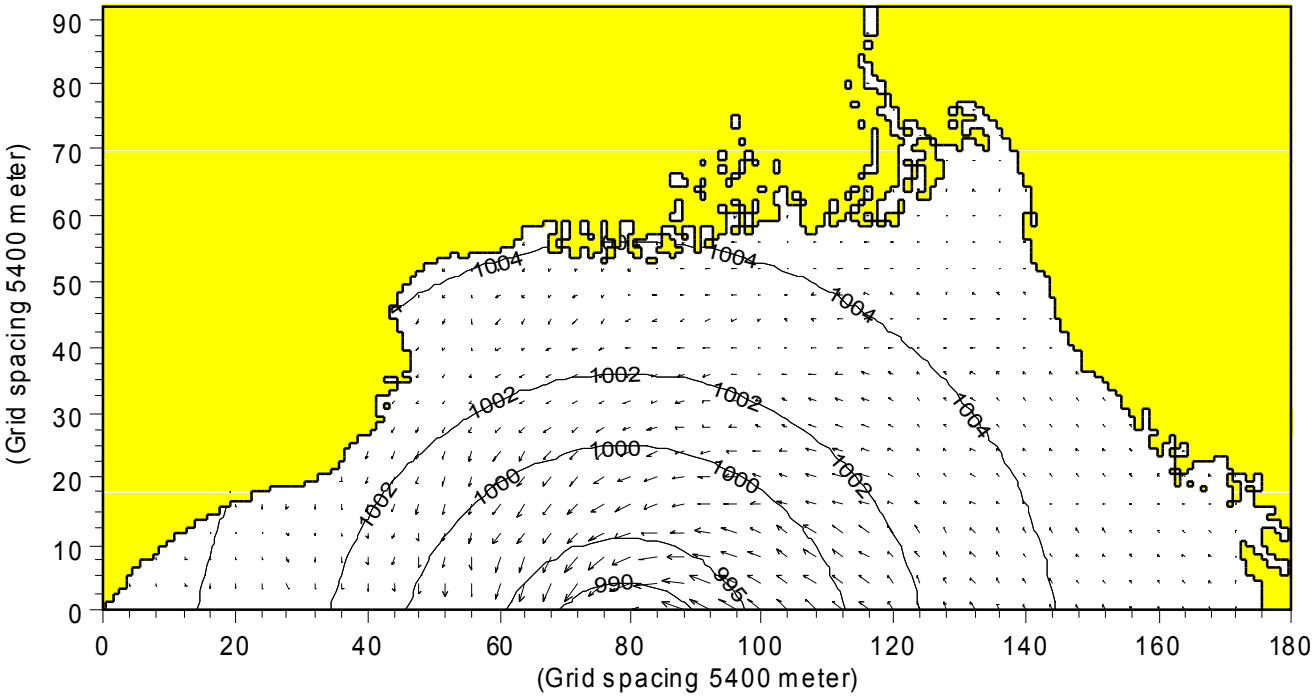
Table III.3 Extent of Damages to the Economy due to 1991 Cyclone and Storm Surge

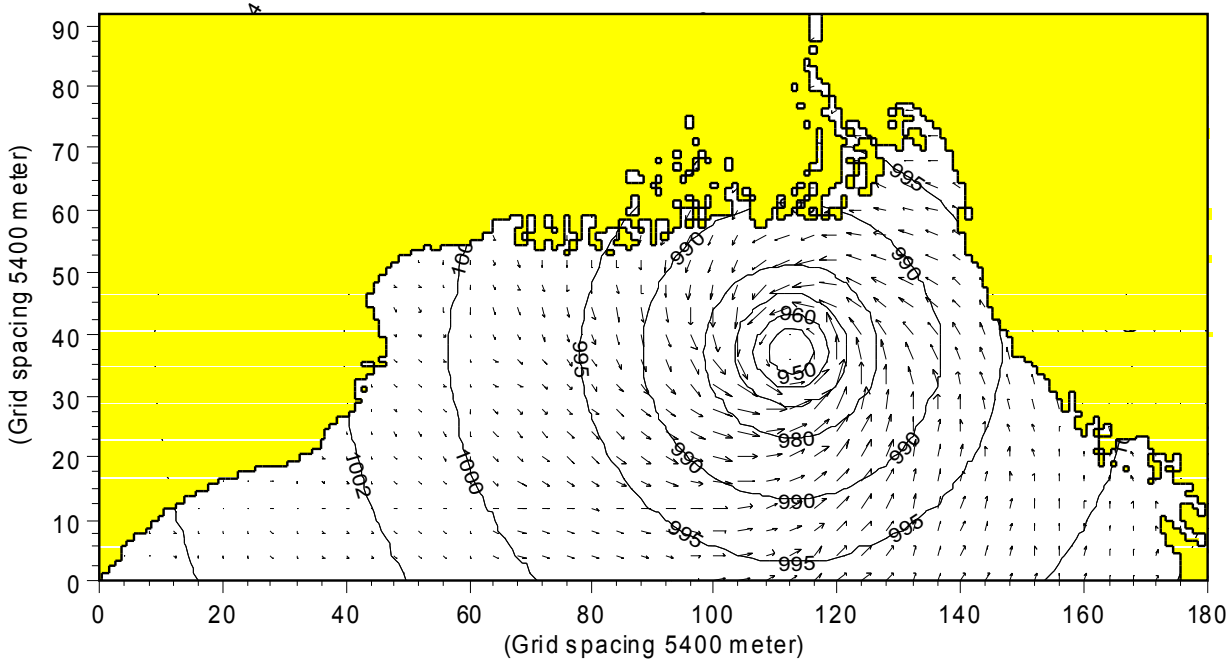
Sector	Estimated damage (million U.S. dollars)	In per cent of total damages
Agriculture	363.57	26.66
Industry	388.27	28.03
Physical Infrastructure	360.01	26.01
Socio-economic Infrastructure	267.35	19.30
Other	5.72	0.41
Total :	**1,384.92**	**100.00**

Source: Cyclone Disaster of April 1991 and Relief, Rehabilitation/Reconstruction Requirements. Planning Commission, Ministry of Planning, Government of Bangladesh, May 1991



Generation of cyclone wind and pressure field

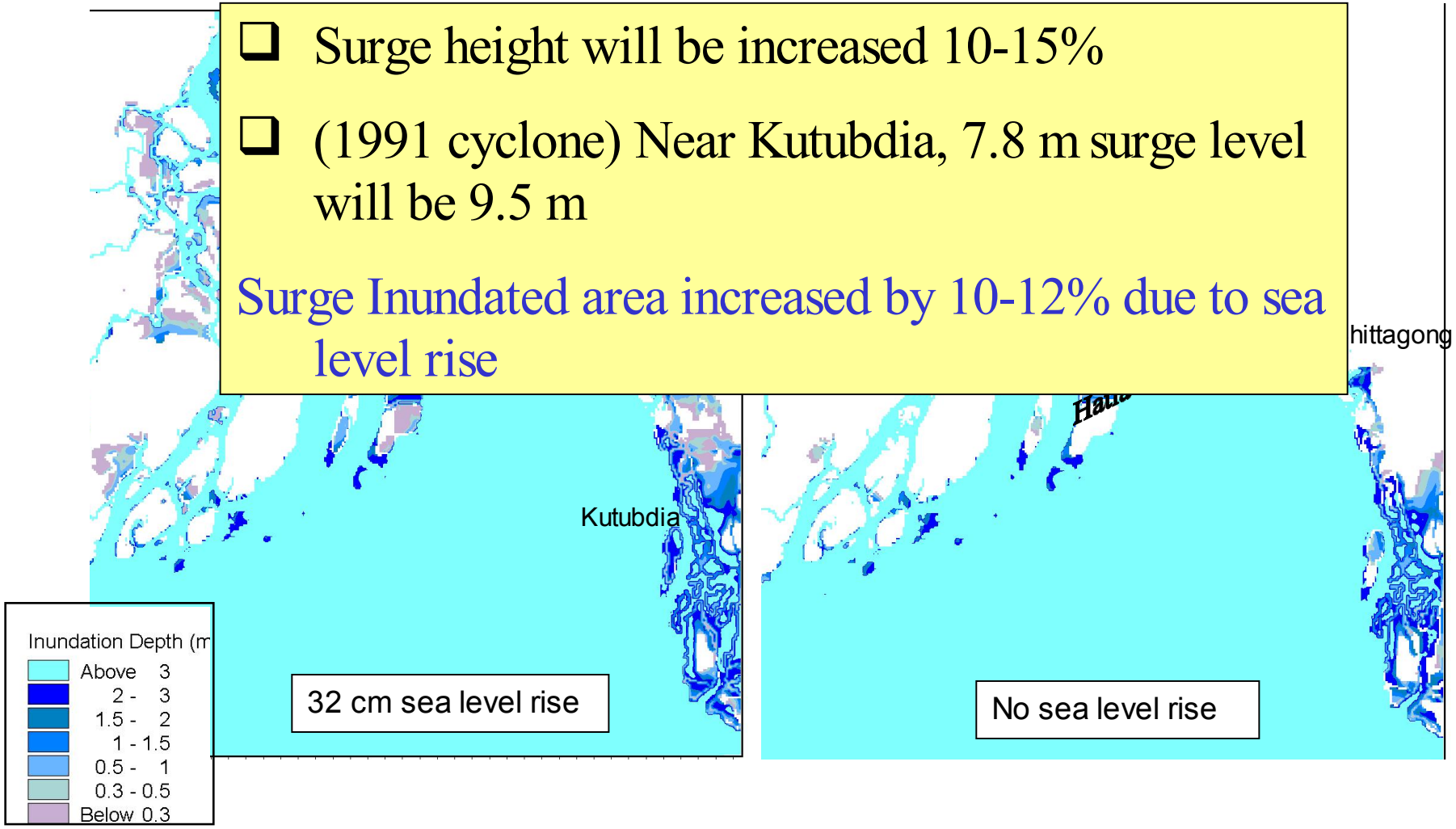




Impact on storm surge

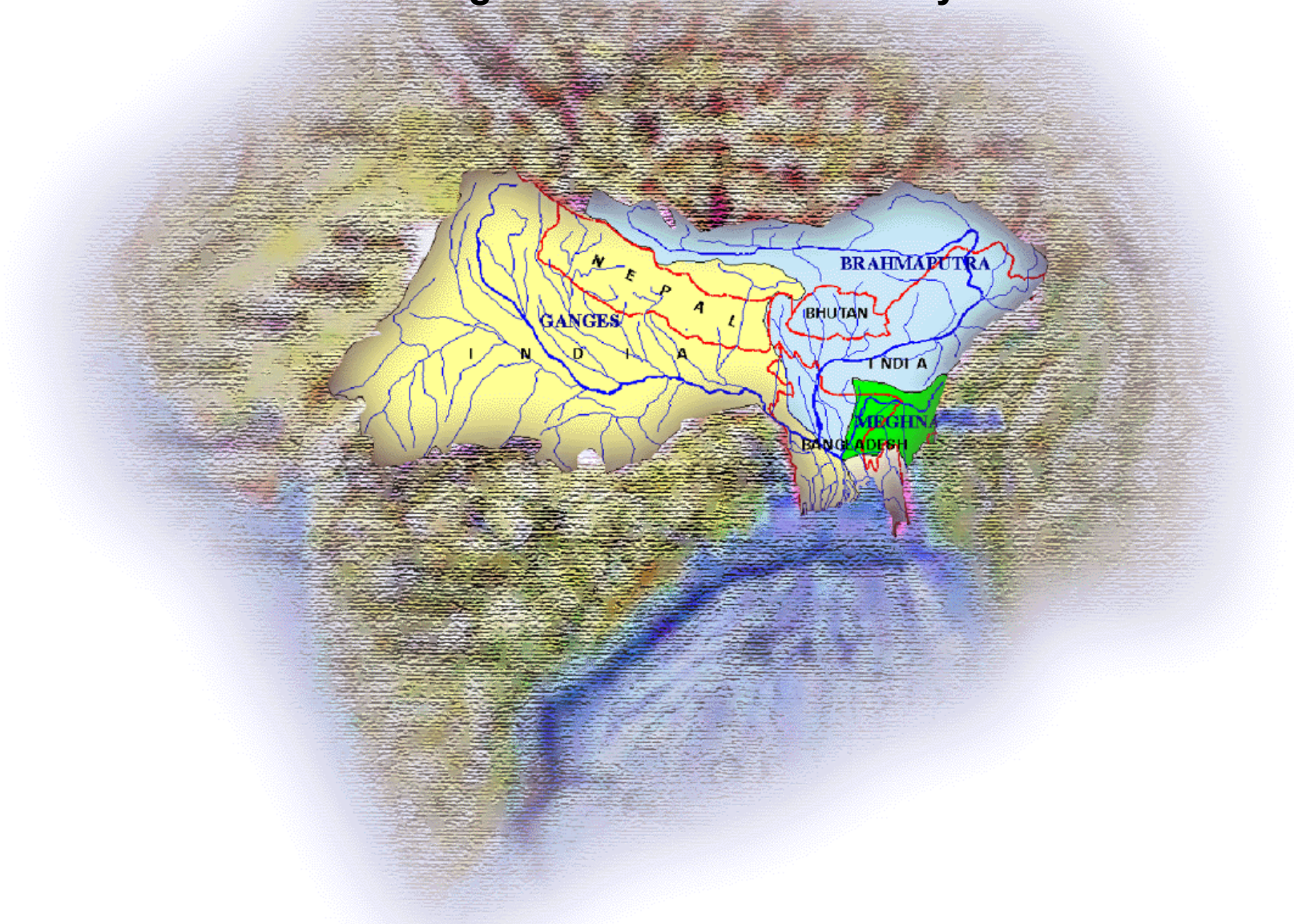
- Surge height will be increased 10-15%
- (1991 cyclone) Near Kutubdia, 7.8 m surge level will be 9.5 m

Surge Inundated area increased by 10-12% due to sea level rise

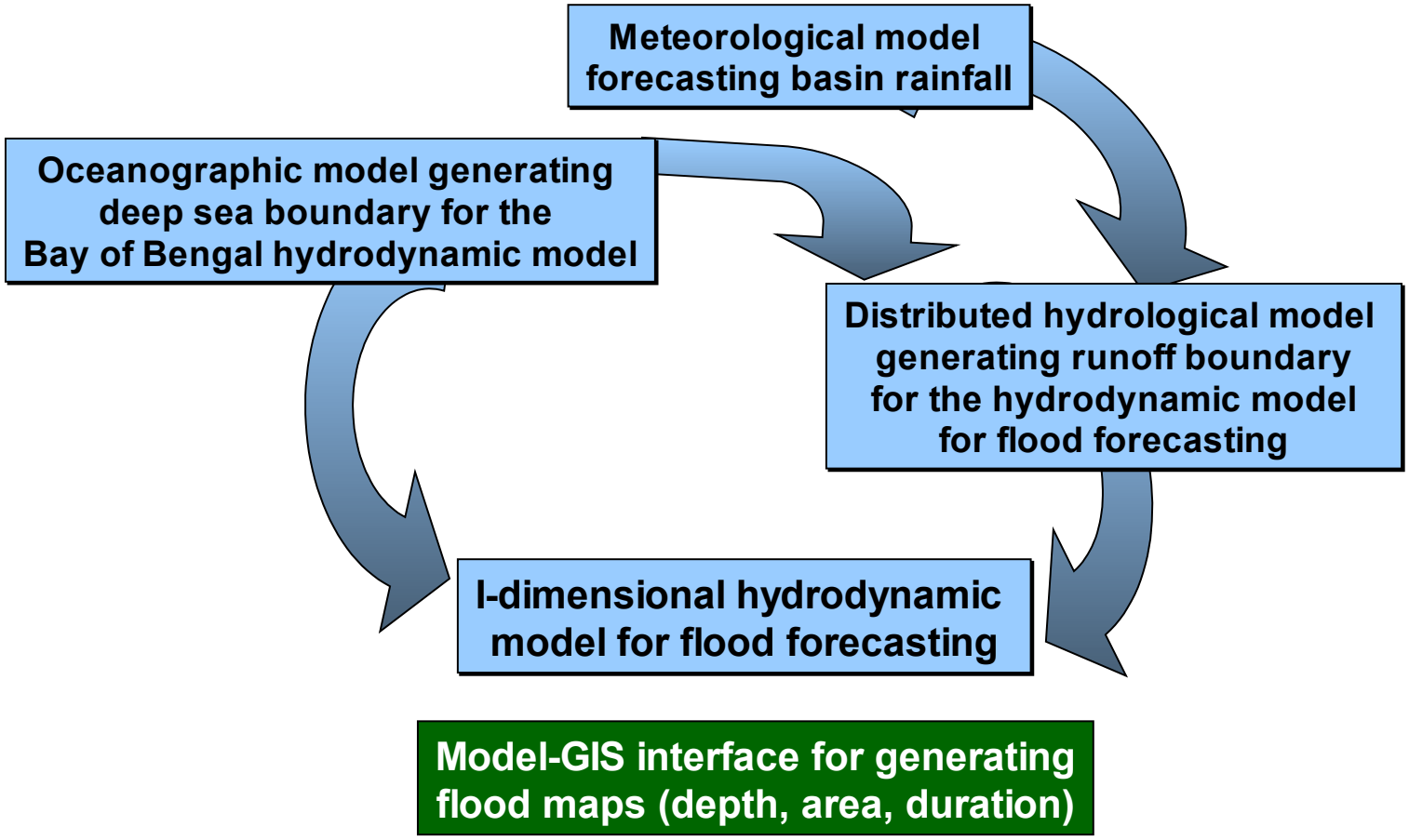


New development: Basin Model

Forecasting in the mid-term: 4-15 days

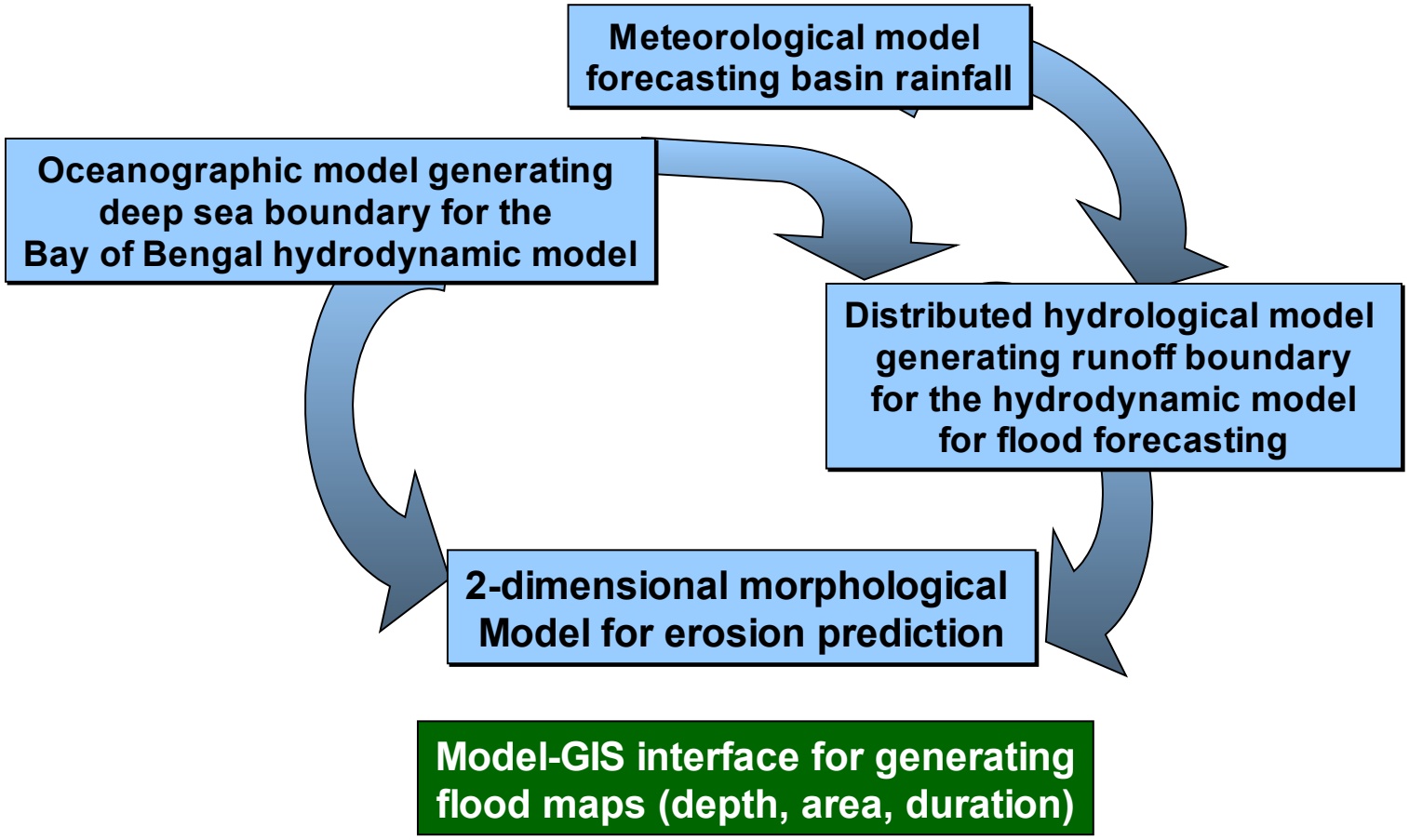


Requirement for mid-term forecast

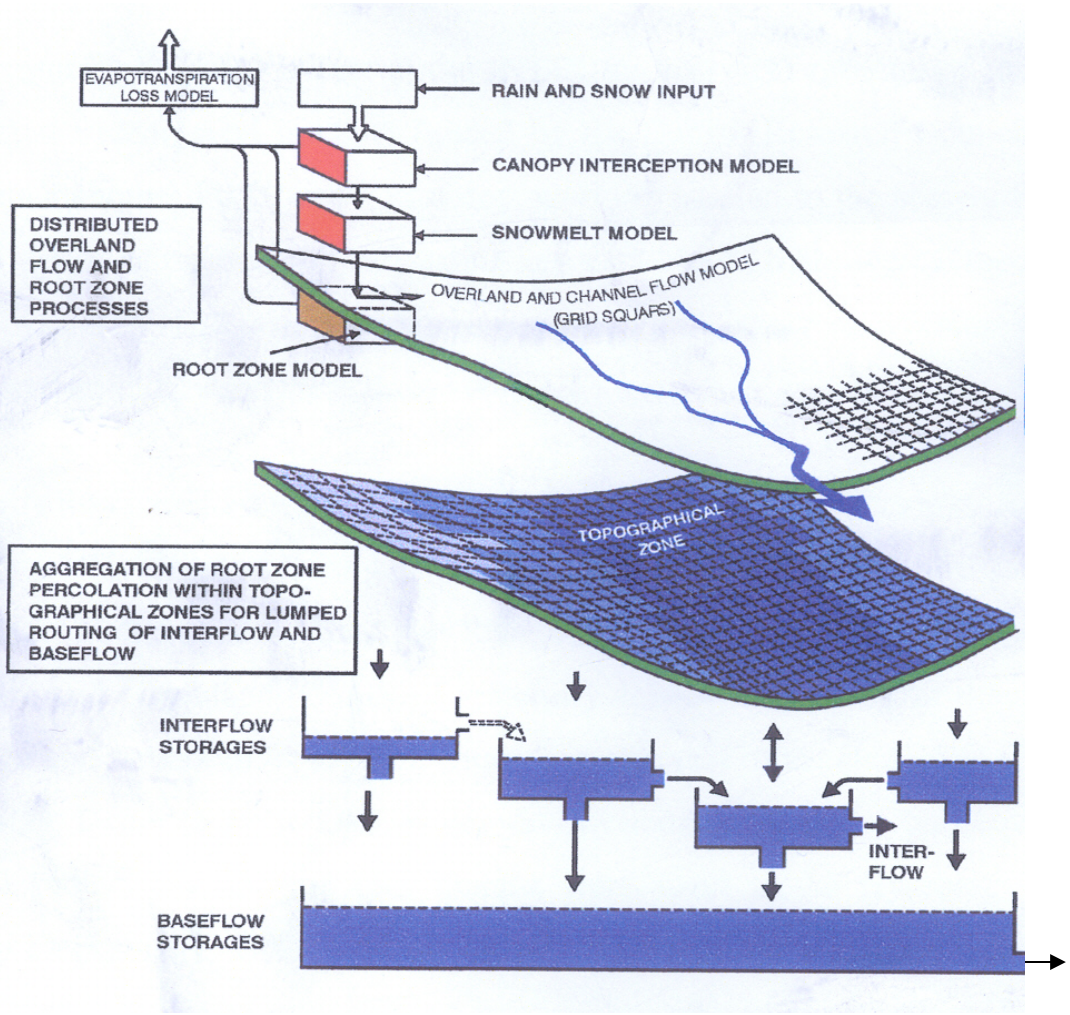


Flood management | Disaster management | Floodplain resources management

Requirement for mid-term forecast

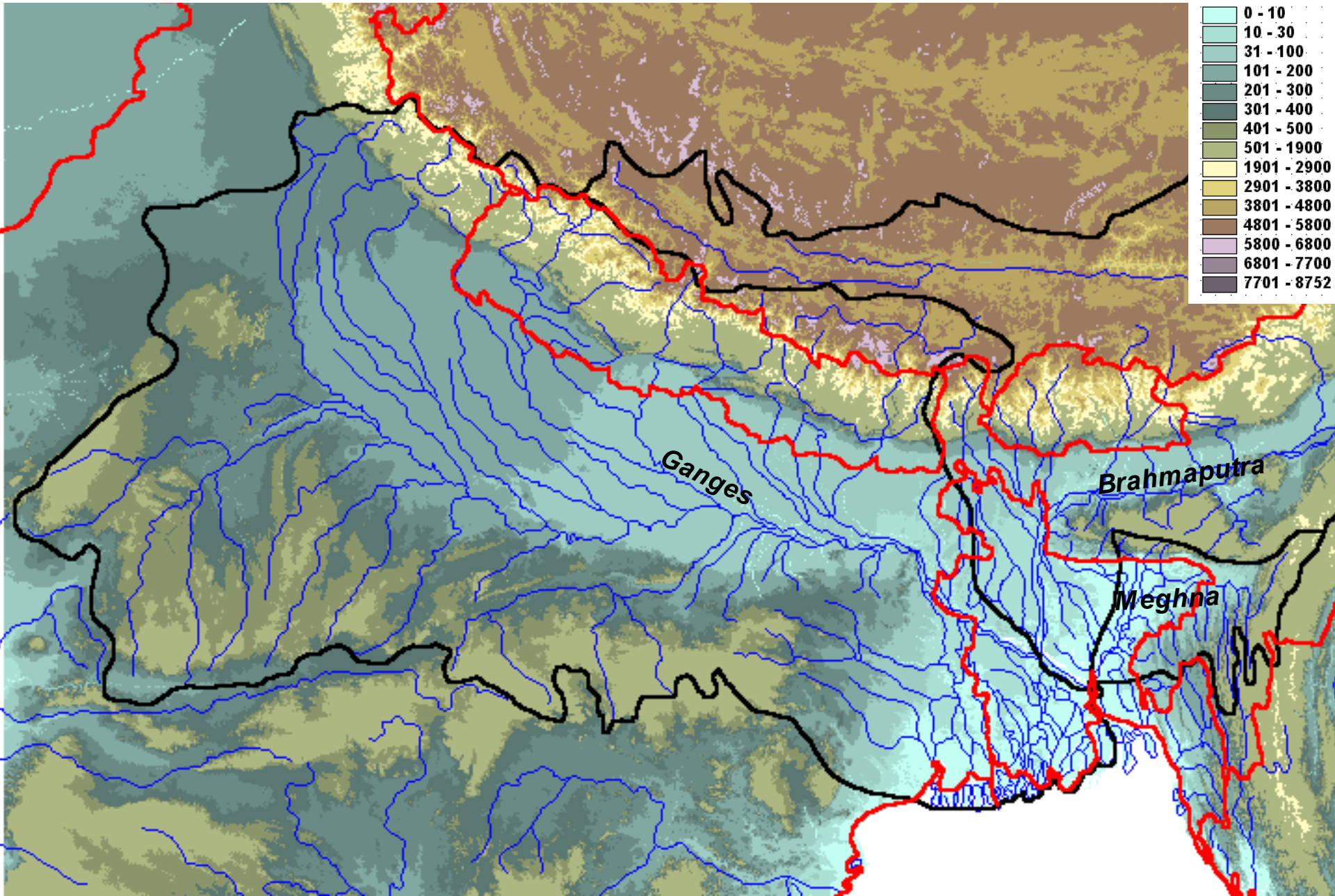


Flood management | Disaster management | Floodplain resources management

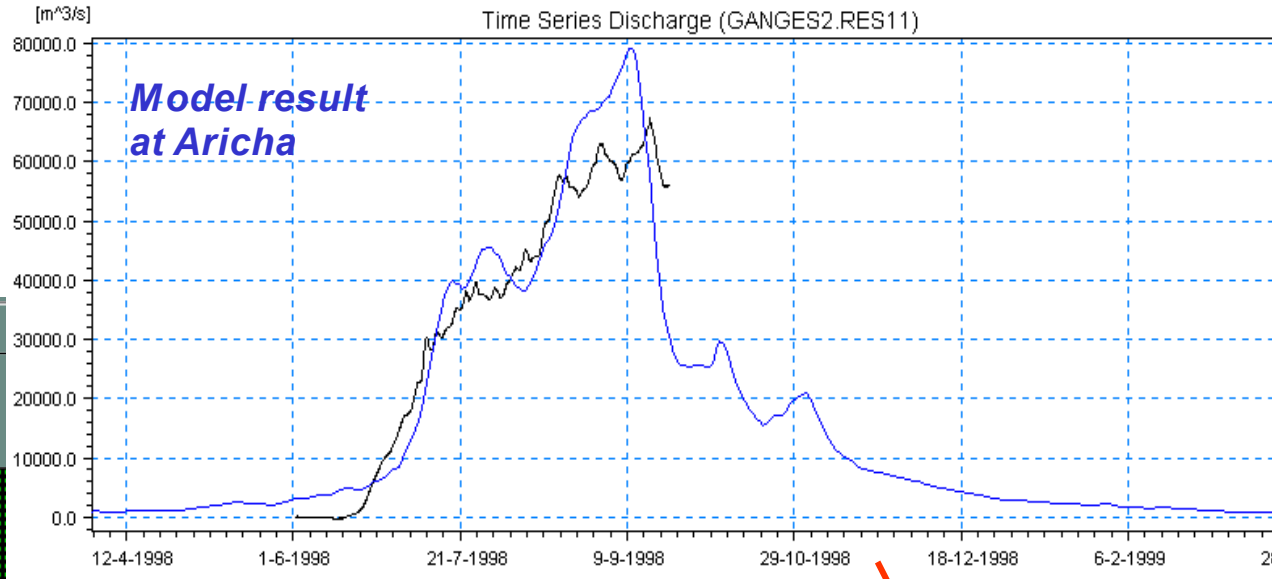


MIKE SHE LR Model

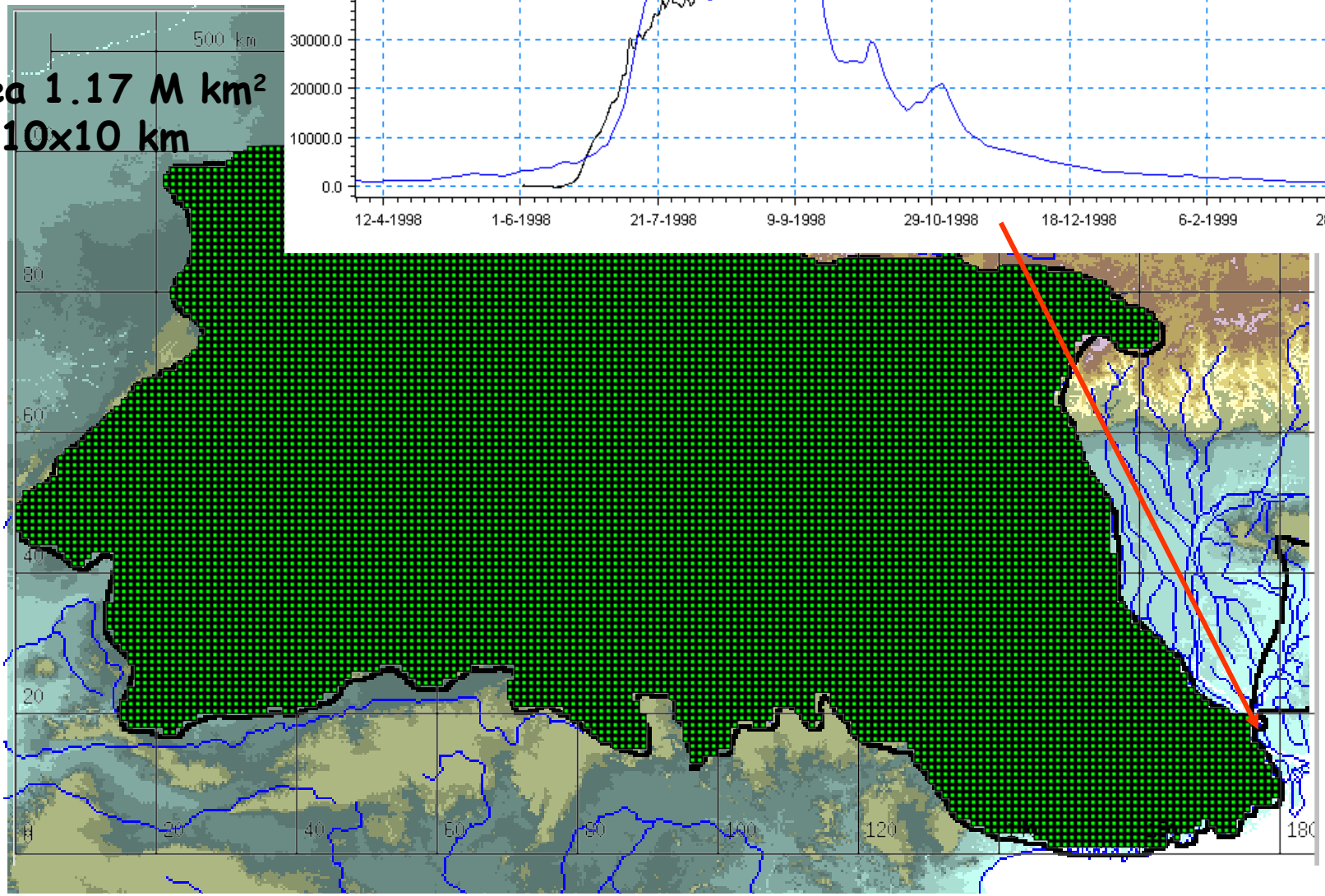
Ganges-Brahmaputra-Meghna Basin



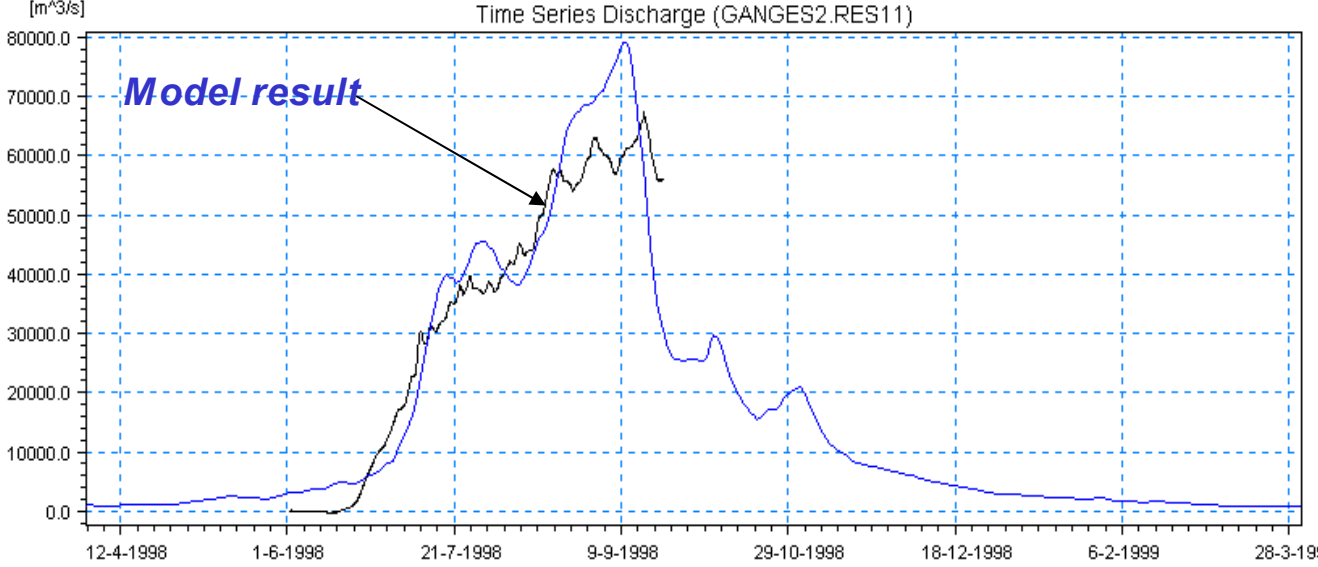
Ganges Basin

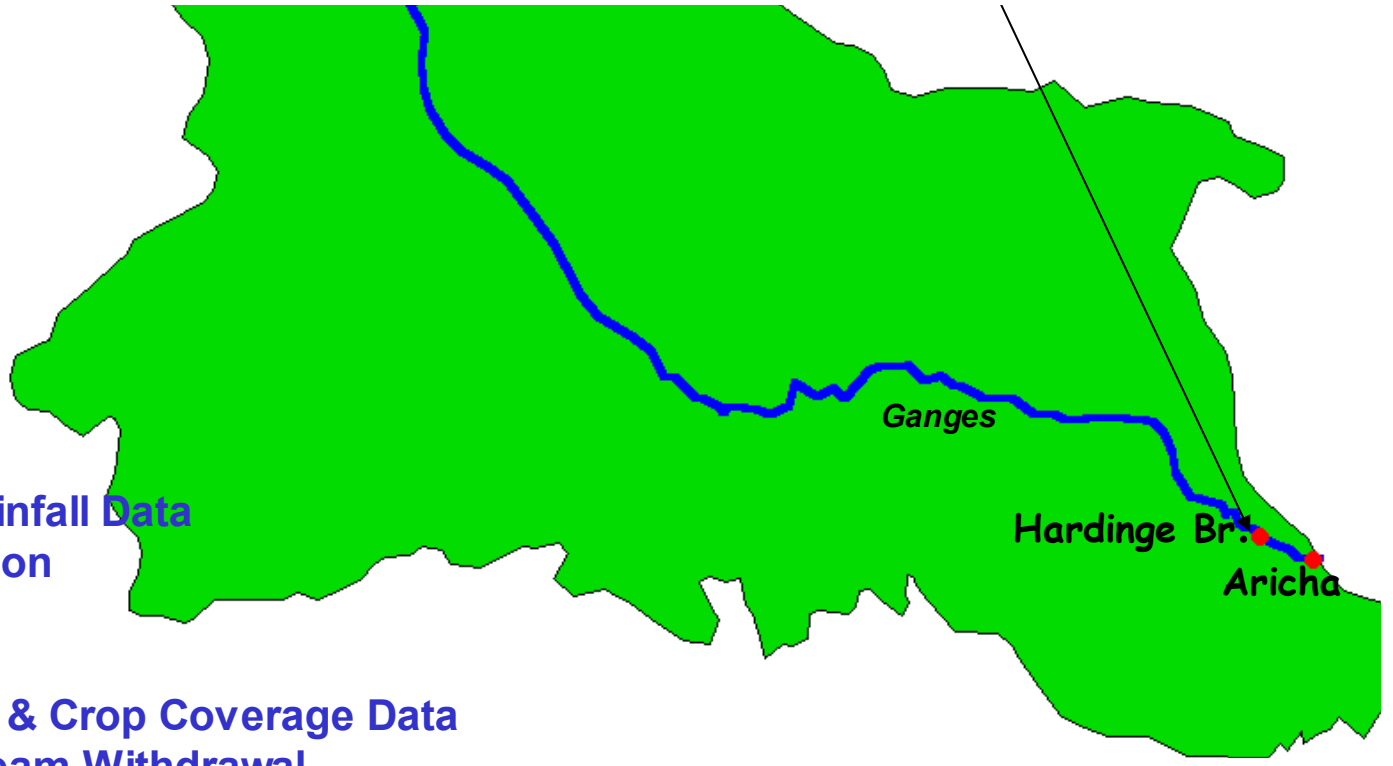


Model Area 1.17 M km²
Grid Size.10x10 km



Ganges Basin

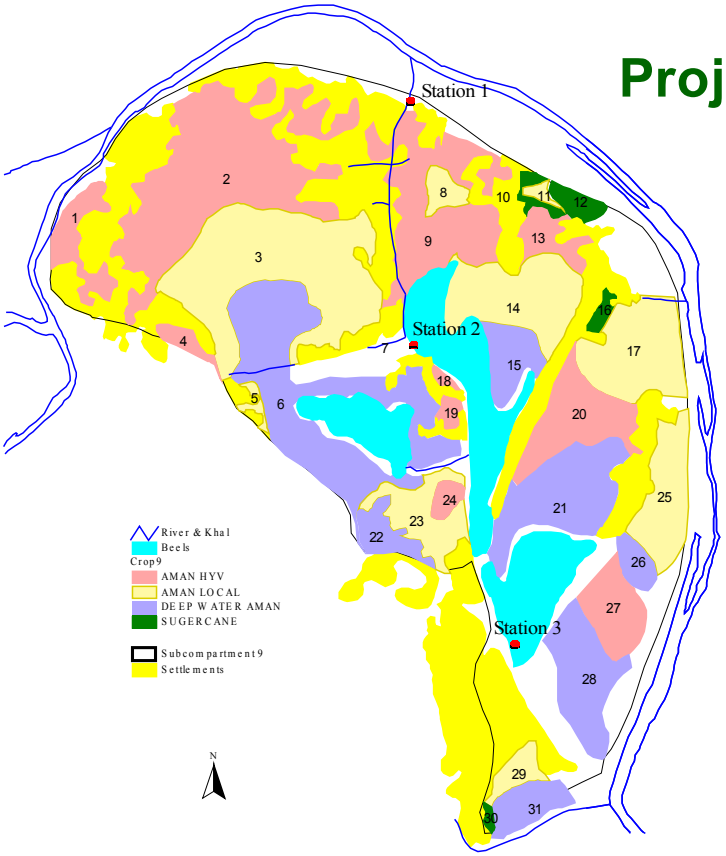


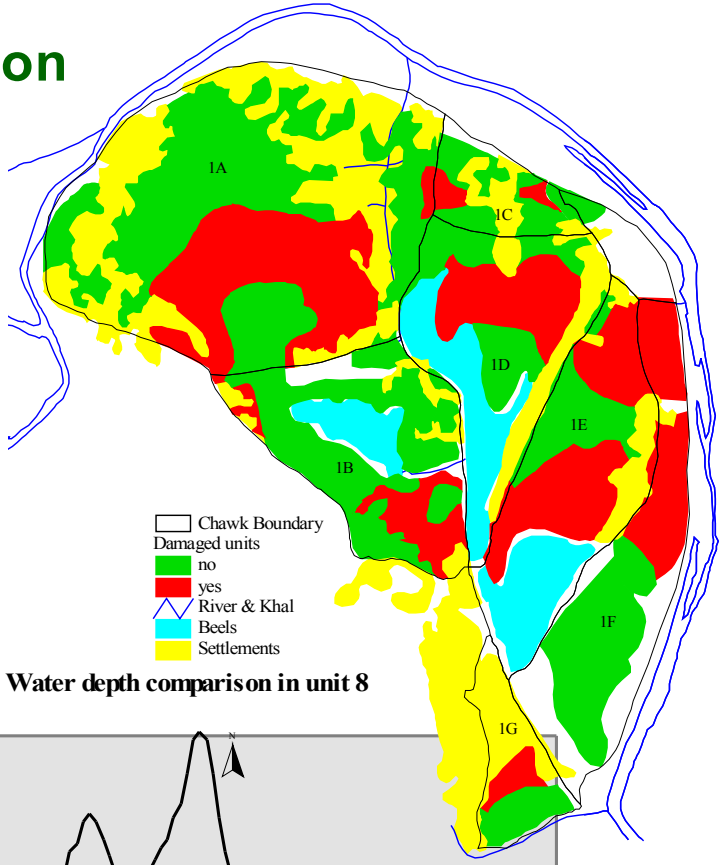


Need for improvement

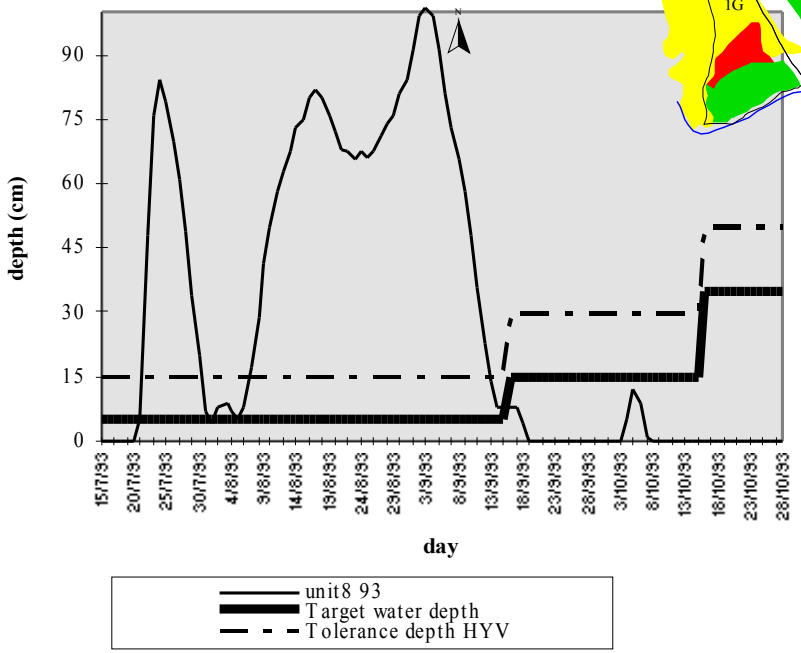
More Representative Rainfall Data
Actual River Cross Section
Snow Melt Information
Soil Profile Data
More Intensive Landuse & Crop Coverage Data
Water Demand & Upstream Withdrawal

Project level application





Water depth comparison in unit 8



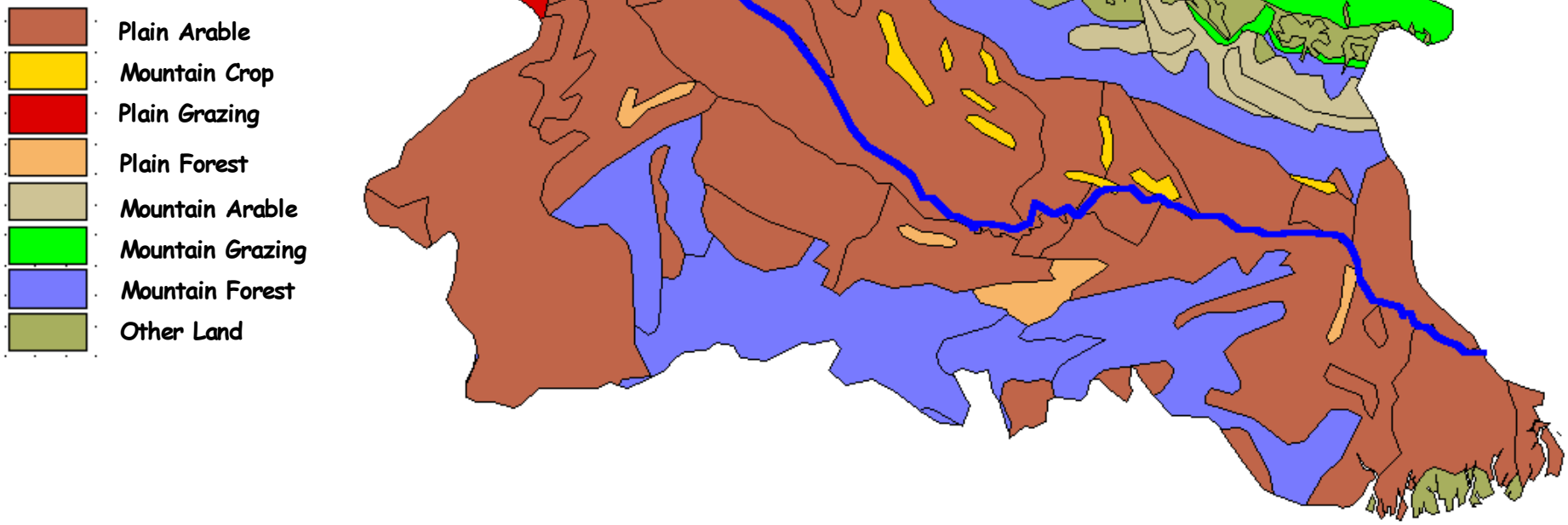
Yield reduction as a function of growth stage and number of days exceeding the flood tolerance depths.

	Yield reduction			
Days of Submergence	1-2	3-4	5-7	7
20 days after transplanting	10%	20%	30%	50%
Young panicle formation	25%	45%	80%	90%
Meading stage	15%	25%	30%	70%
Heading stage	0%	!5%	20%	20%

Source : BWDB, 1993.

Drought forecast

Landuse



Development needs

Short-term Forecasting: 1-3 days

Upstream information (rainfall/water level) for better boundary estimation
Downstream tidal boundary prediction
Rainfall forecasts within the country
Recent topographic information

Use:
Flood response/minimise threat to lives, property, agriculture etc.

Development needs

Mid-term Forecasting: 4-15 days

Rainfall forecast in the drainage basin
Basin hydrological model to generate boundary data for FF model
Bay of Bengal model for generation of tidal boundary
Oceanographic model to generate deep sea boundary for BoBM model
Prediction of wind speed and direction

Use:
Flood management/Disaster management
Flood plain resources management
minimise damage, eg. early harvesting of crops, infrastructure protection
Sufficient lead time for evacuation/relocation

Development needs

Tidal surge forecasting

Oceanographic model to generate deep sea boundary for BoBM model
Prediction of wind speed and direction
Prediction of cyclone track

Use:
Flood management/Disaster management
Sufficient lead time for evacuation/relocation

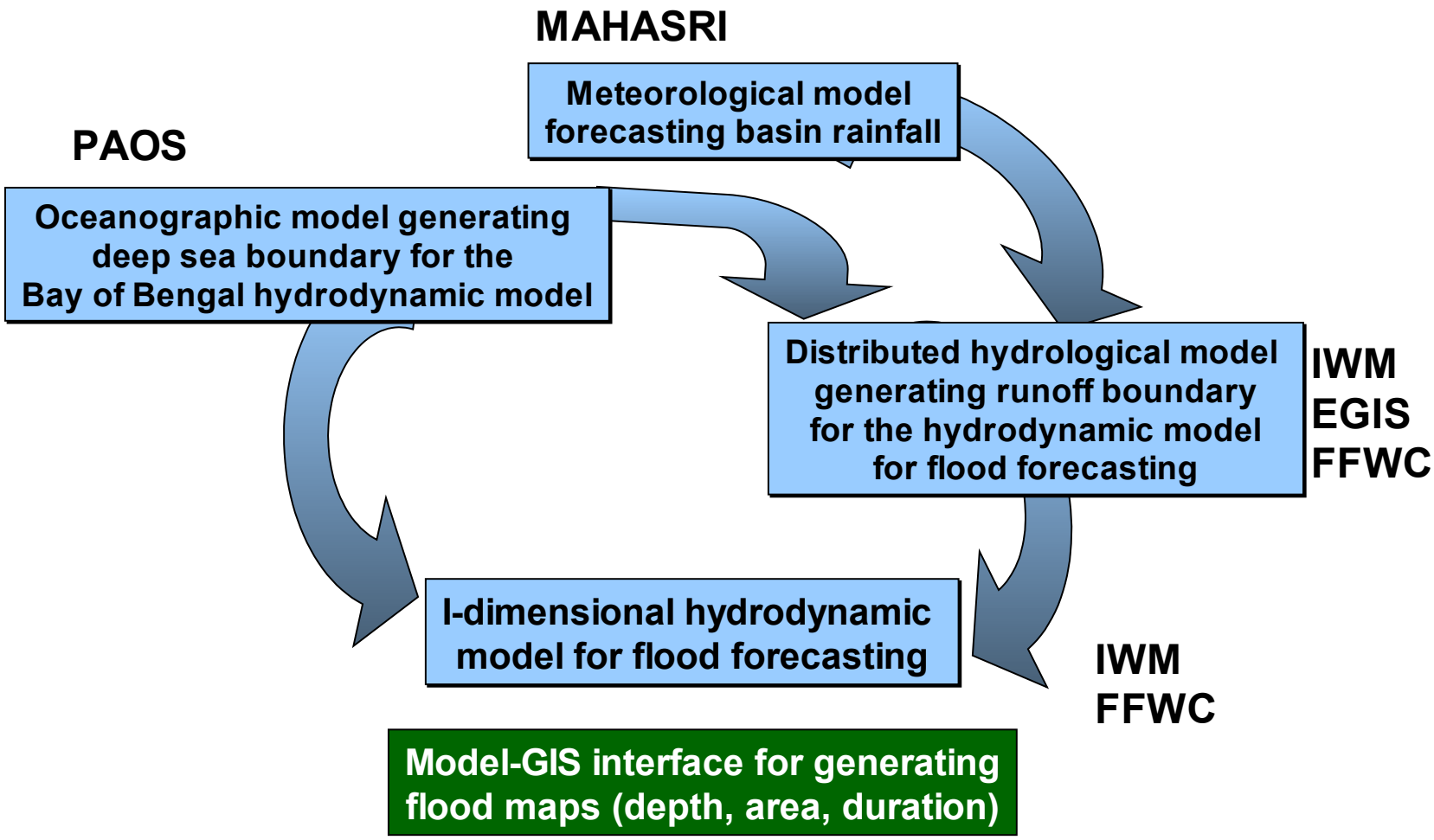
Development needs

Erosion prediction

Rainfall forecast in the drainage basin
Basin hydrological model to generate boundary data for Morphological model
Sediment transport
Bay of Bengal model for generation of tidal boundary
Oceanographic model to generate deep sea boundary for BoBM model

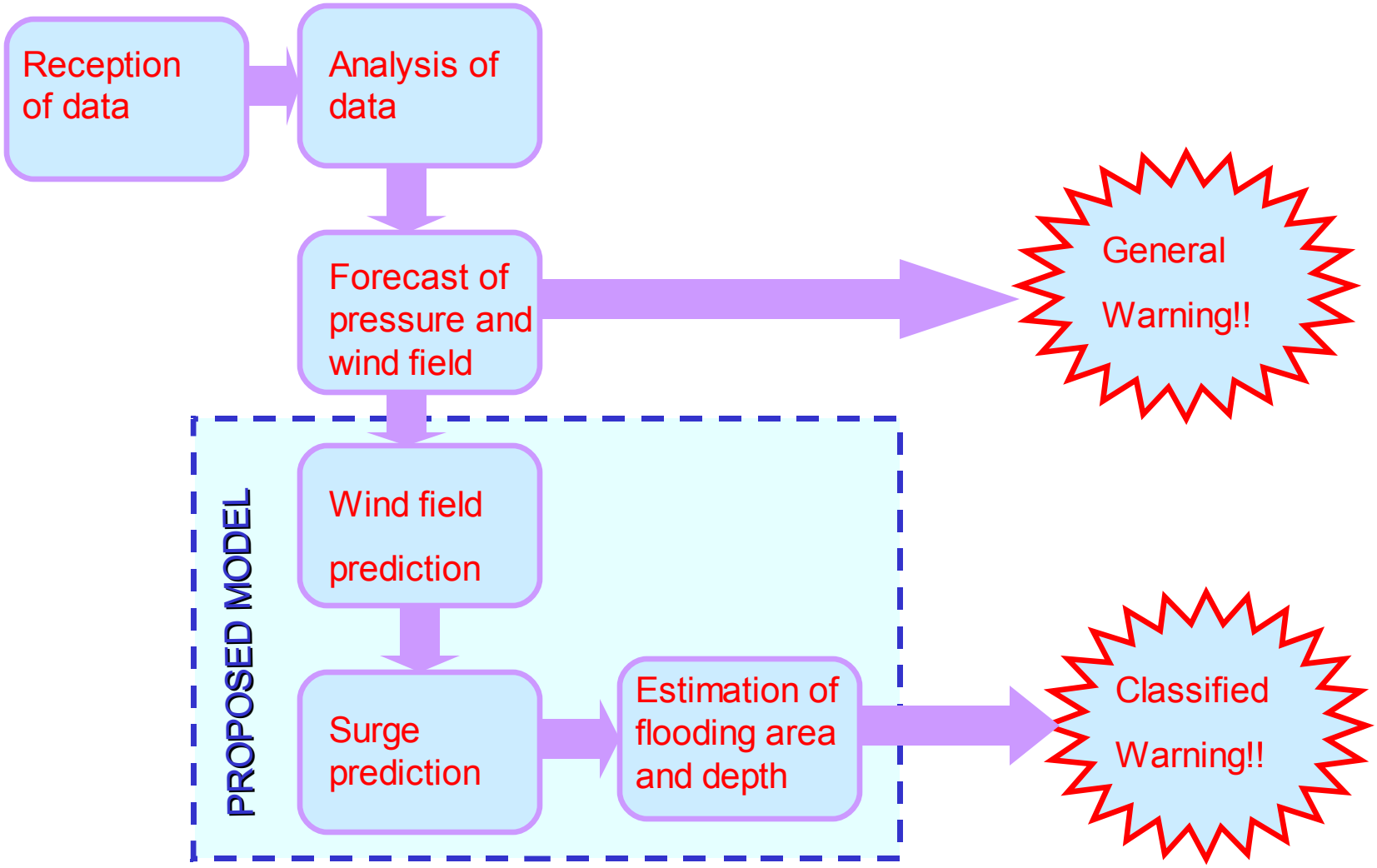
Use:
Saving life and property
Sufficient lead time for evacuation/relocation
Protective measures

Institutional Linkages



Flood management	Disaster management	Floodplain resources management
BWDB LGED	DMB, BWDB, LGED DAE, RHD, MoF	DMB, BWDB, LGED DAE, RHD, MoF

Surge forecasting system



Conclusion

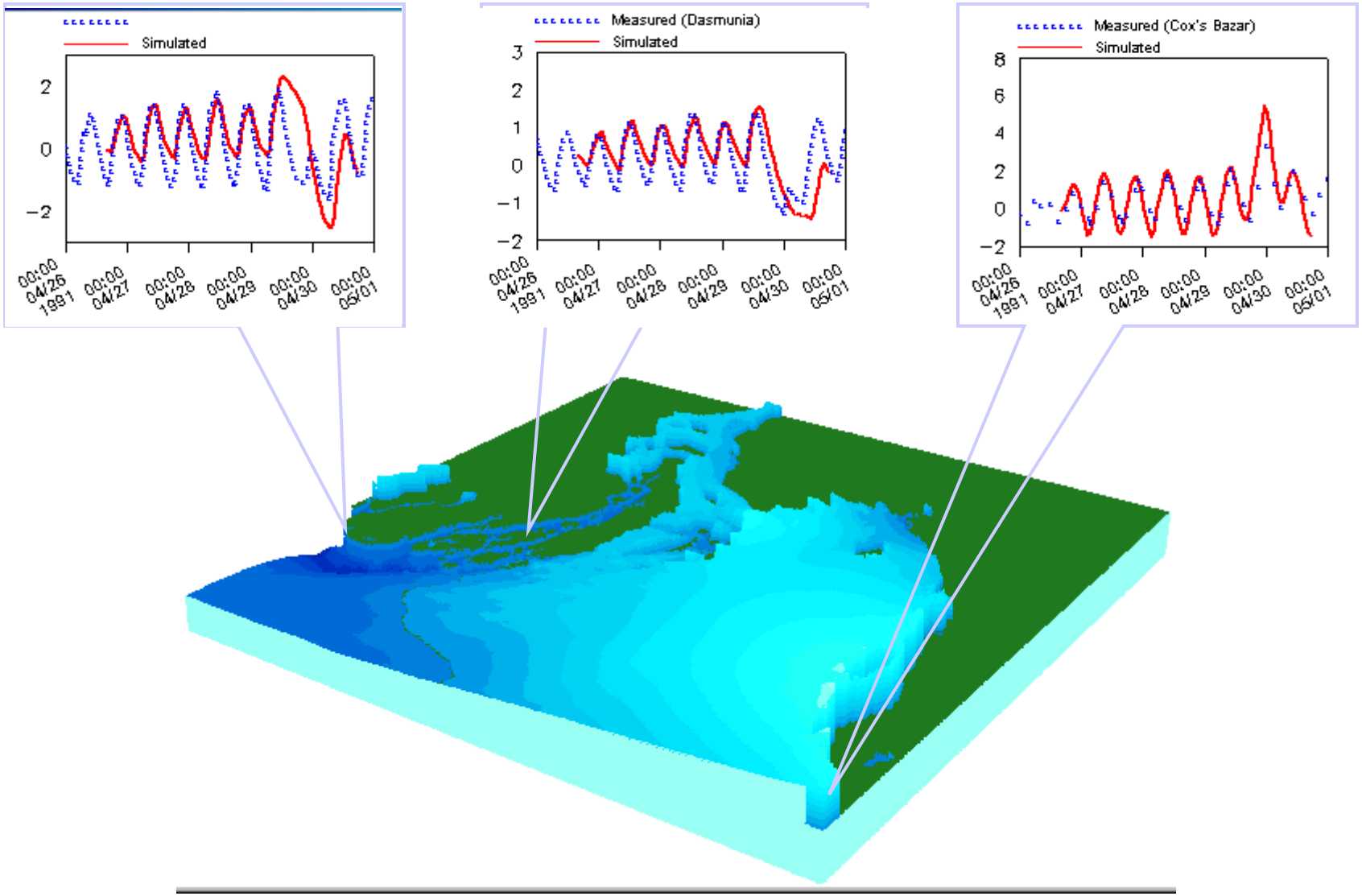
- Disaster usually affects the poorer community and especially the most vulnerable group in the society, women and children.

- Disaster does not only mean fall in GDP but it forces the government to divert its limited resources towards relief and rehabilitation and reconstruction of damaged infrastructure.

- This means postponement of vital social and economic development programmes. This further hinders the government's initiative towards poverty reduction.

Thank you

Cyclonic Surge Model Calibration



Simulated Surge Height Distribution (1991)

What are the likely constraints?

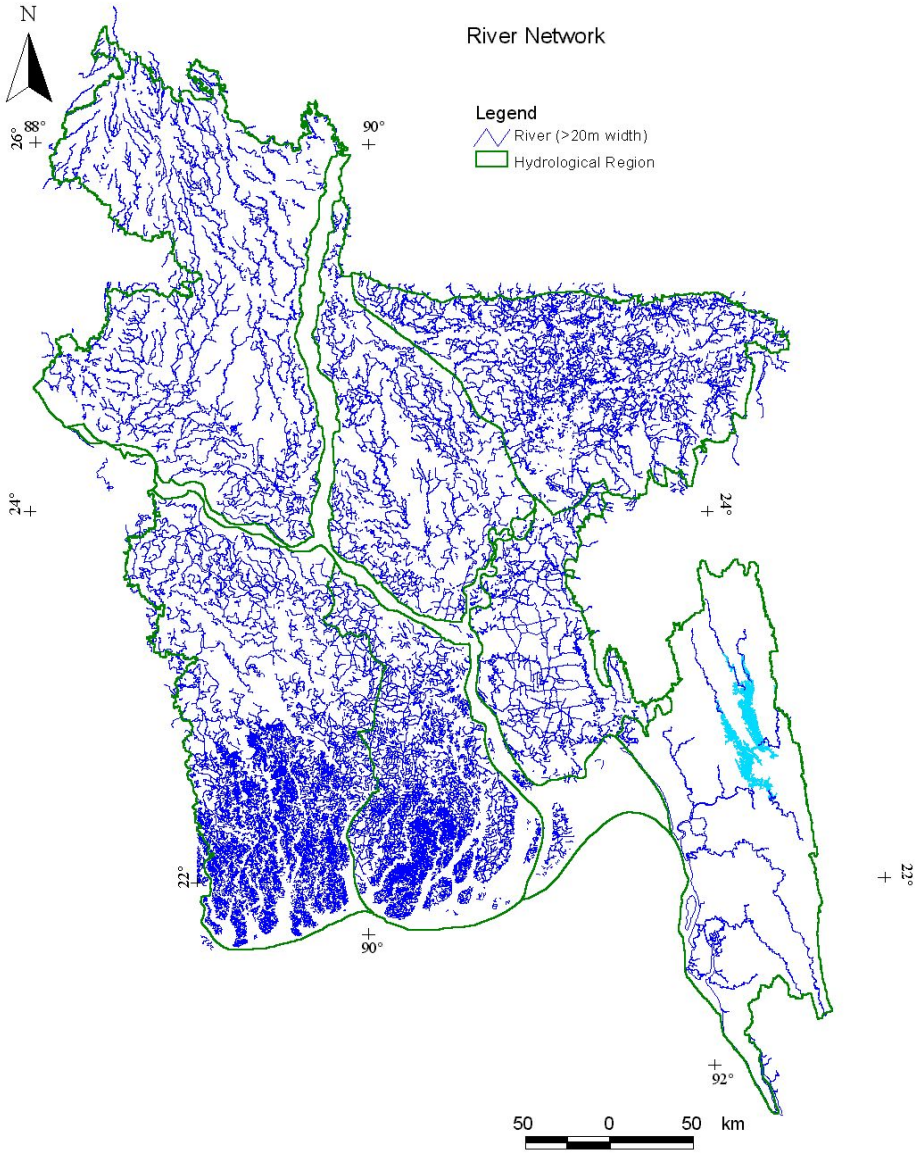
Institutionalization
Acceptance of the forecast products by the end users

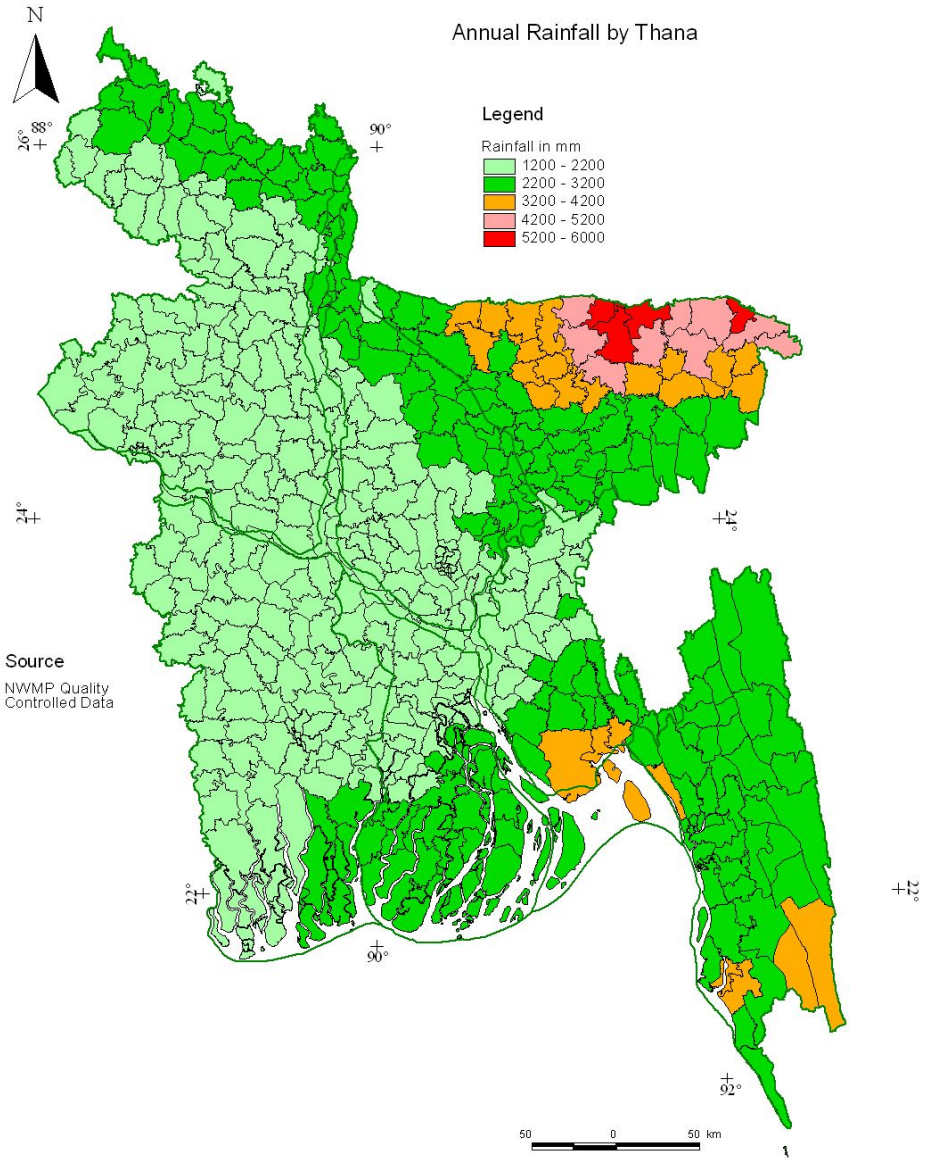
1954 floods	Affected 55% of country
1970 cyclone	500,000 deaths
1974 flood	over 2,000 deaths, affected 58% of country, followed by famine with over 30,000 deaths
1984 flood	Inundated 52,520 sq-km, cost estimated at US$378 million
1985 cyclone	11,069 deaths
1987 floods	inundated over 50,000 sq-km, estimated damage US$640 million, 2055 deaths
1988 floods	Inundated 66% of country, more than 45 million homeless, between 2,000-6,500 deaths
1988 cyclone	5,708 deaths
1991 cyclone	138,000 deaths
1998 floods	1,100 deaths, inundated nearly 100,000 sq-km, rendered 30 million people homeless, damaged 500,000 homes, heavy loss to infrastructure

Rainfall distribution

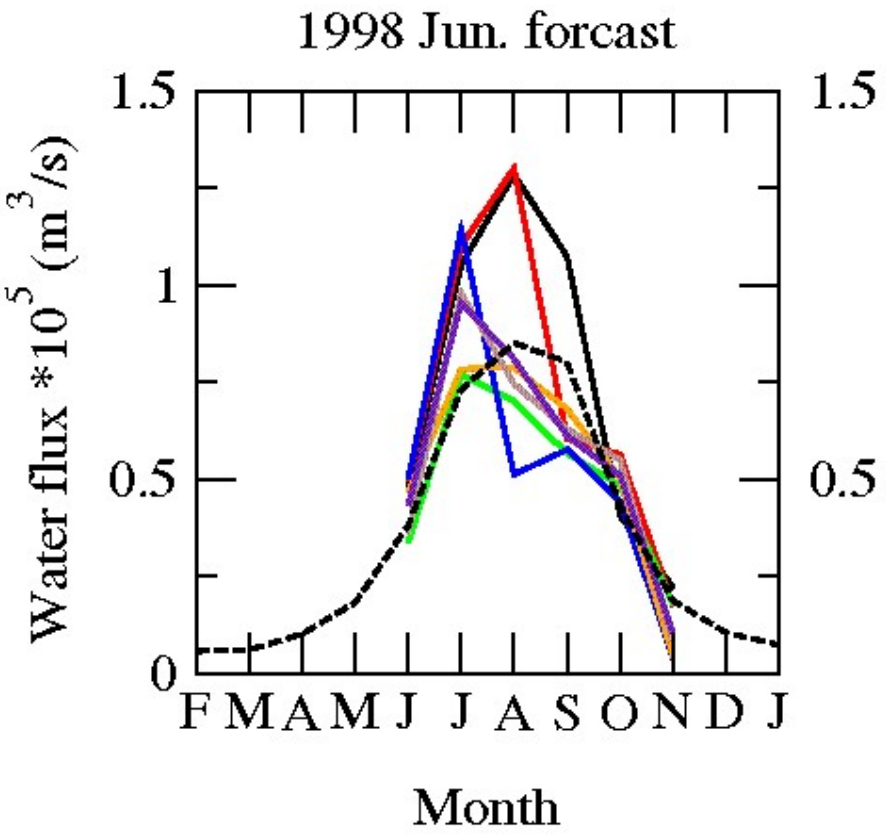
Inter-seasonal variability

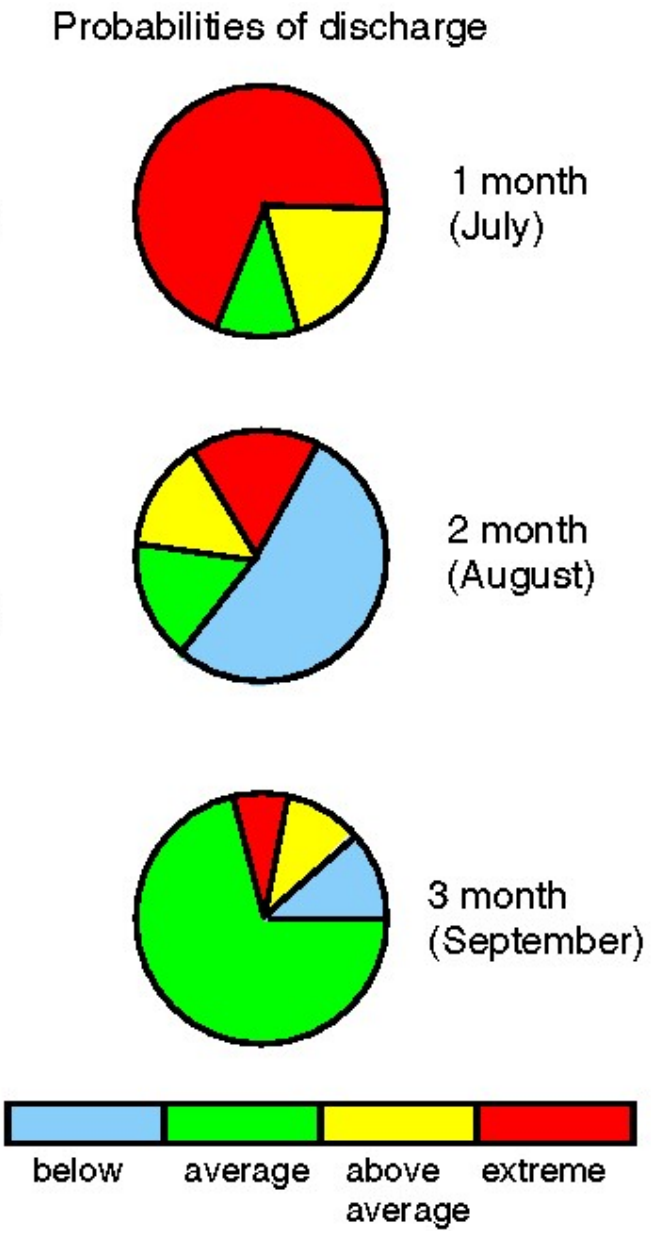
Intra-seasonal variability


N
River Network
Legend
River (>20m width)
Hydrological Region
26°
88°
90°
24°
24°
22°
22°
90°
92°
50 0 50 km


N
Annual Rainfall by Thana
Legend
Rainfall in mm
1200 - 2200
2200 - 3200
3200 - 4200
4200 - 5200
5200 - 6000
Source
NWMP Quality Controlled Data
88°
90°
92°
26°
24°
22°
50 0 50 km

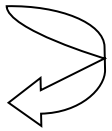
Discharge Probabilities as Computed in June, 1998

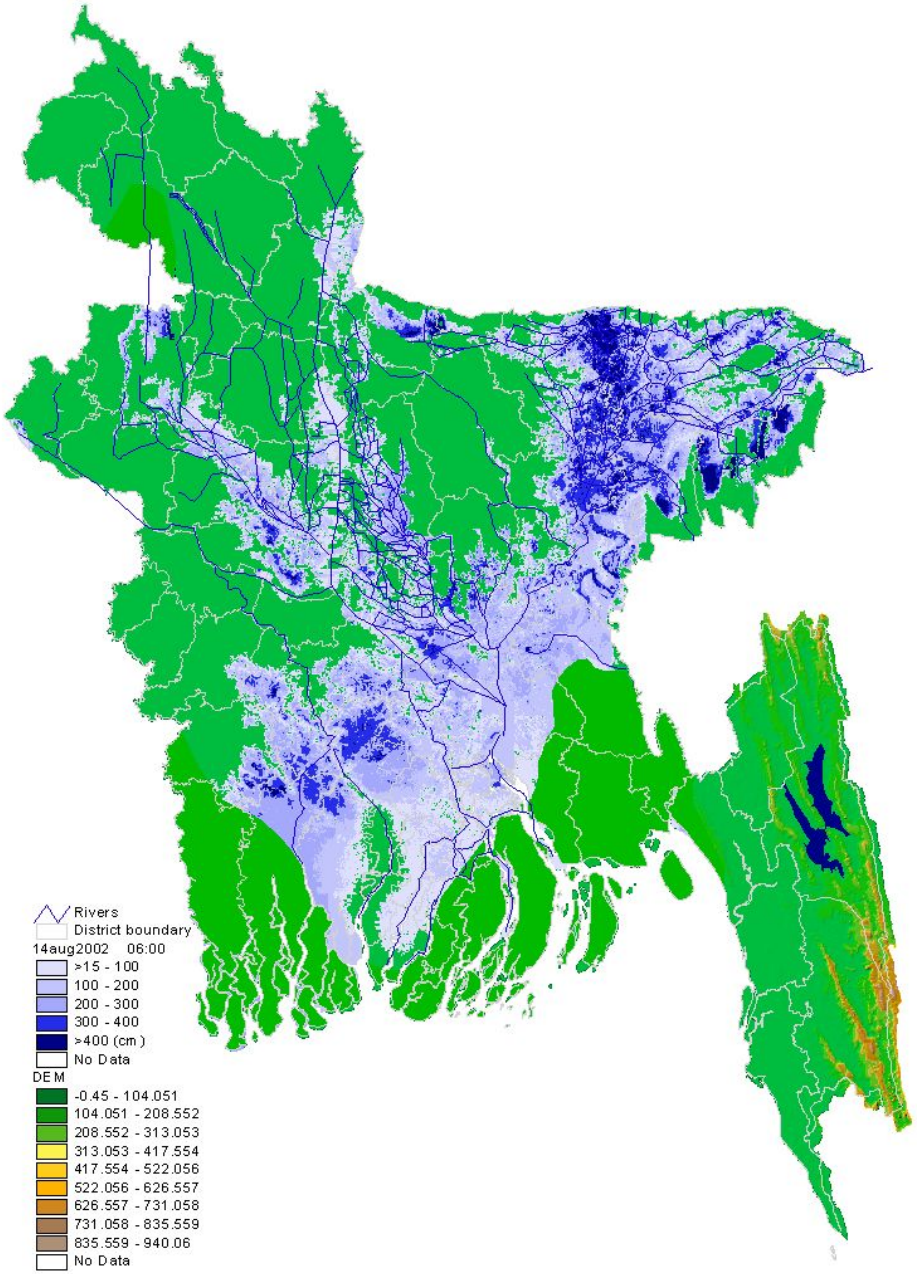


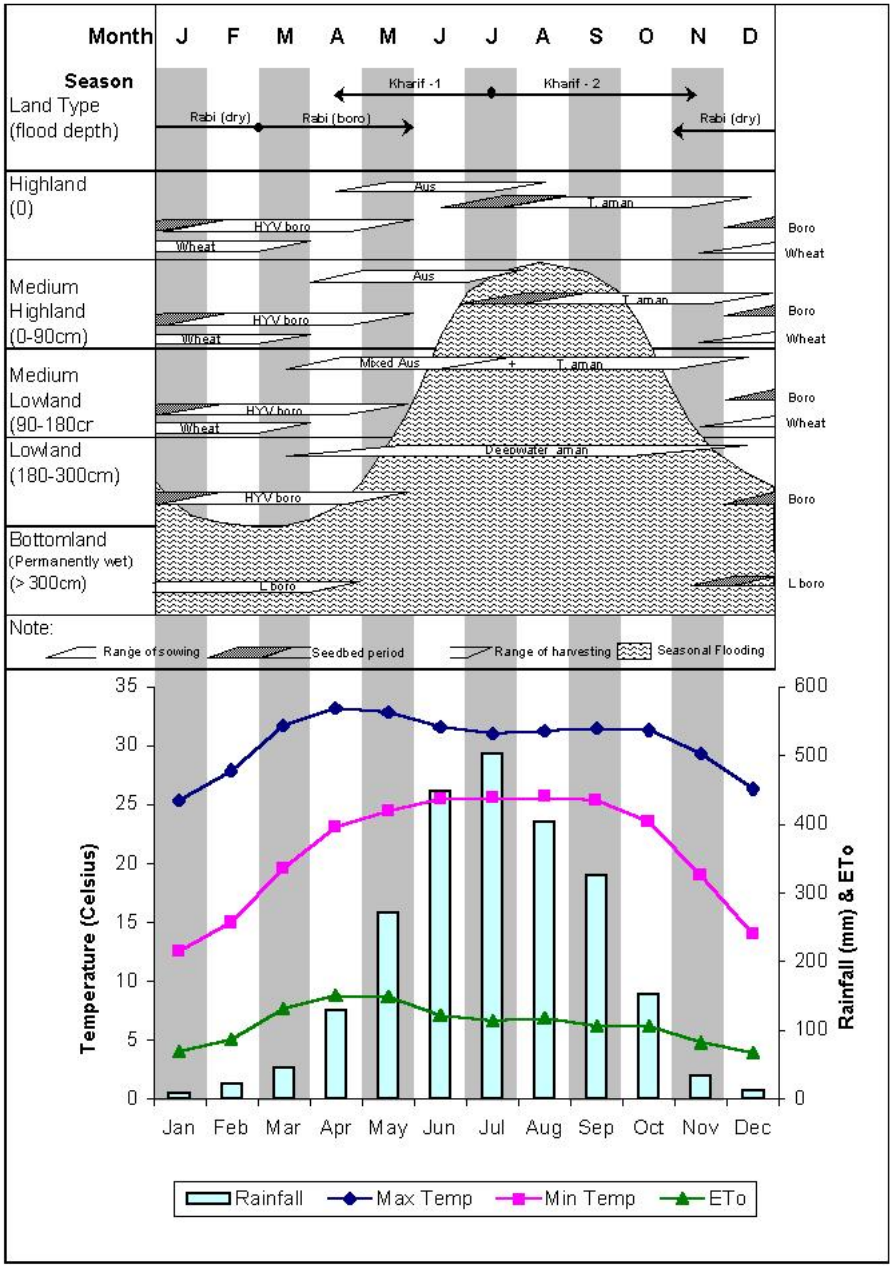


Danger level of a river is a level above which it is likely that the flood may cause damages to crops and homesteads. In a river having no embankment, danger level is about annual average flood level. In an embanked river, danger level is fixed slightly below design flood level of the embankment. Danger level is defined for a particular measuring station for the area to its immediate vicinity.

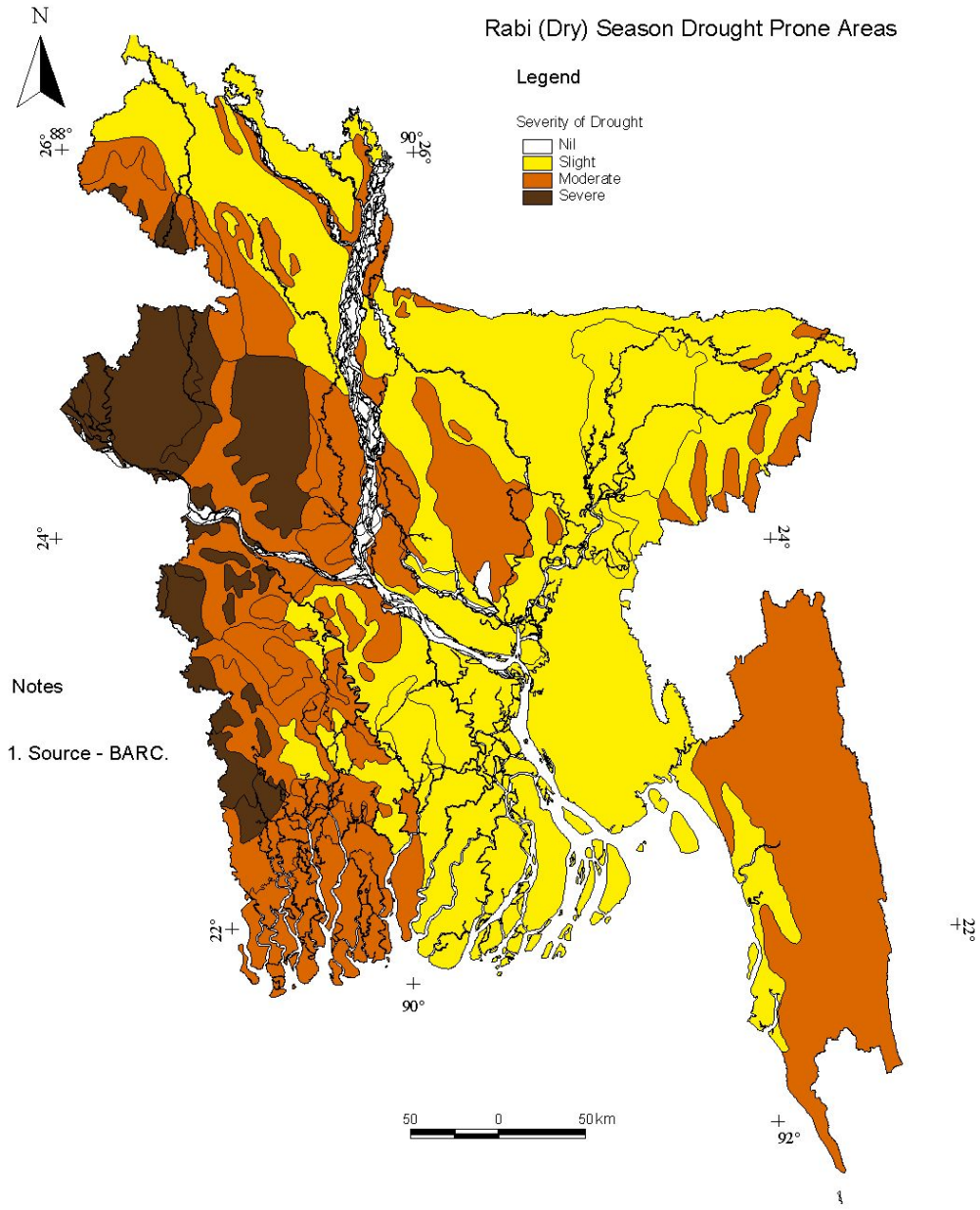
Normal flood: water level within 50 cm below Danger level
Moderate flood: water level up to 50 cm above Danger level
Severe flood: water level above 50 cm Danger level




Rivers
District boundary
14aug2002 06:00
>15 - 100
100 - 200
200 - 300
300 - 400
>400 (cm)
No Data
DEM
-0.45 - 104.051
104.051 - 208.552
208.552 - 313.053
313.053 - 417.554
417.554 - 522.056
522.056 - 626.557
626.557 - 731.058
731.058 - 835.559
835.559 - 940.06
No Data


Month
J F M A M J J A S O N D
Season
Land Type
(flood depth)
Kharif -1
Kharif - 2
Rabi (dry)
Rabi (boro)
Rabi (dry)
Highland
(0)
Aus
T. aman
HYV boro
Wheat
Boro
Wheat
Medium
Highland
(0-90cm)
Aus
T. aman
HYV boro
Wheat
Boro
Wheat
Medium
Lowland
(90-180cr
Mixed Aus
+
T. aman
HYV boro
Wheat
Boro
Wheat
Lowland
(180-300cm)
Deepwater aman
HYV boro
Boro
Bottomland
(Permanently wet)
(> 300cm)
L boro
L boro
Note:
Range of sowing
Seedbed period
Range of harvesting
Seasonal Flooding
Temperature (Celsius)
Rainfall (mm) & ETo
0
5
10
15
20
25
30
35
0
100
200
300
400
500
600
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Rainfall
Max Temp
Min Temp
ETo

Water Related Disasters



1. Flood

   20% annual inundation

   66% extreme event (1998)

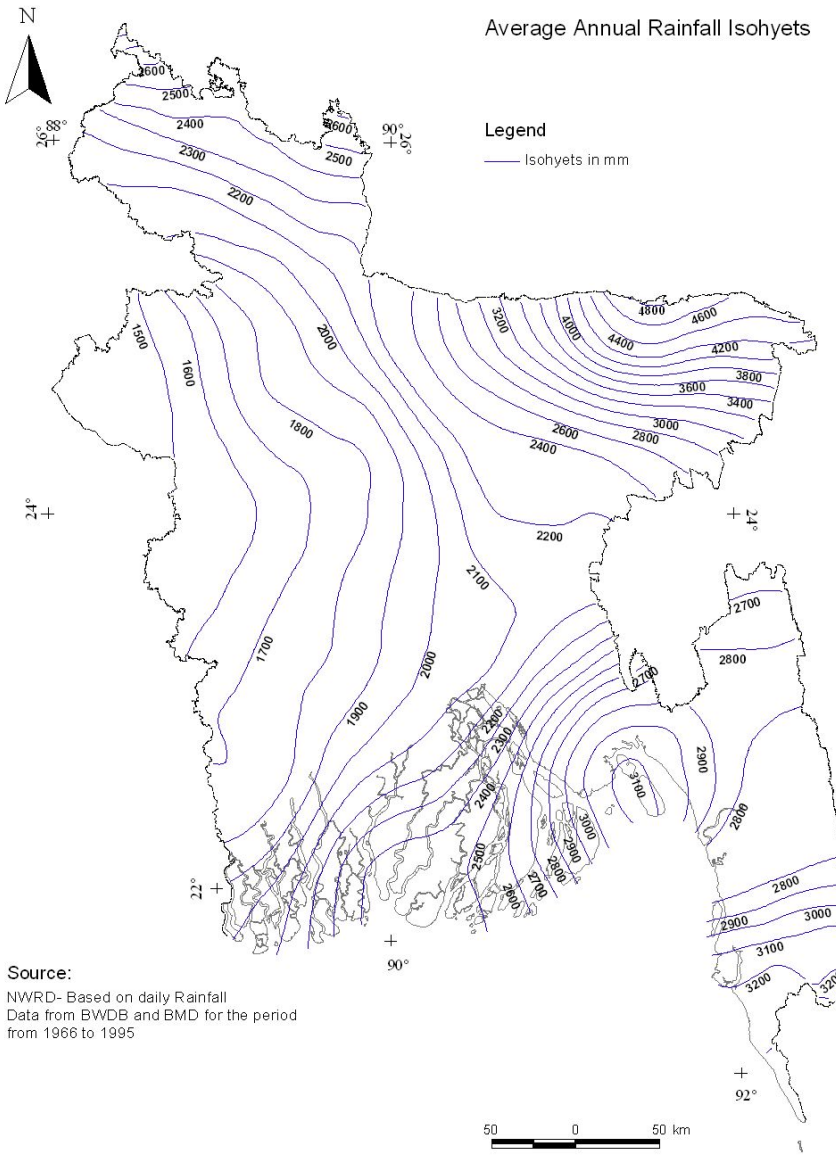
1. Cyclone

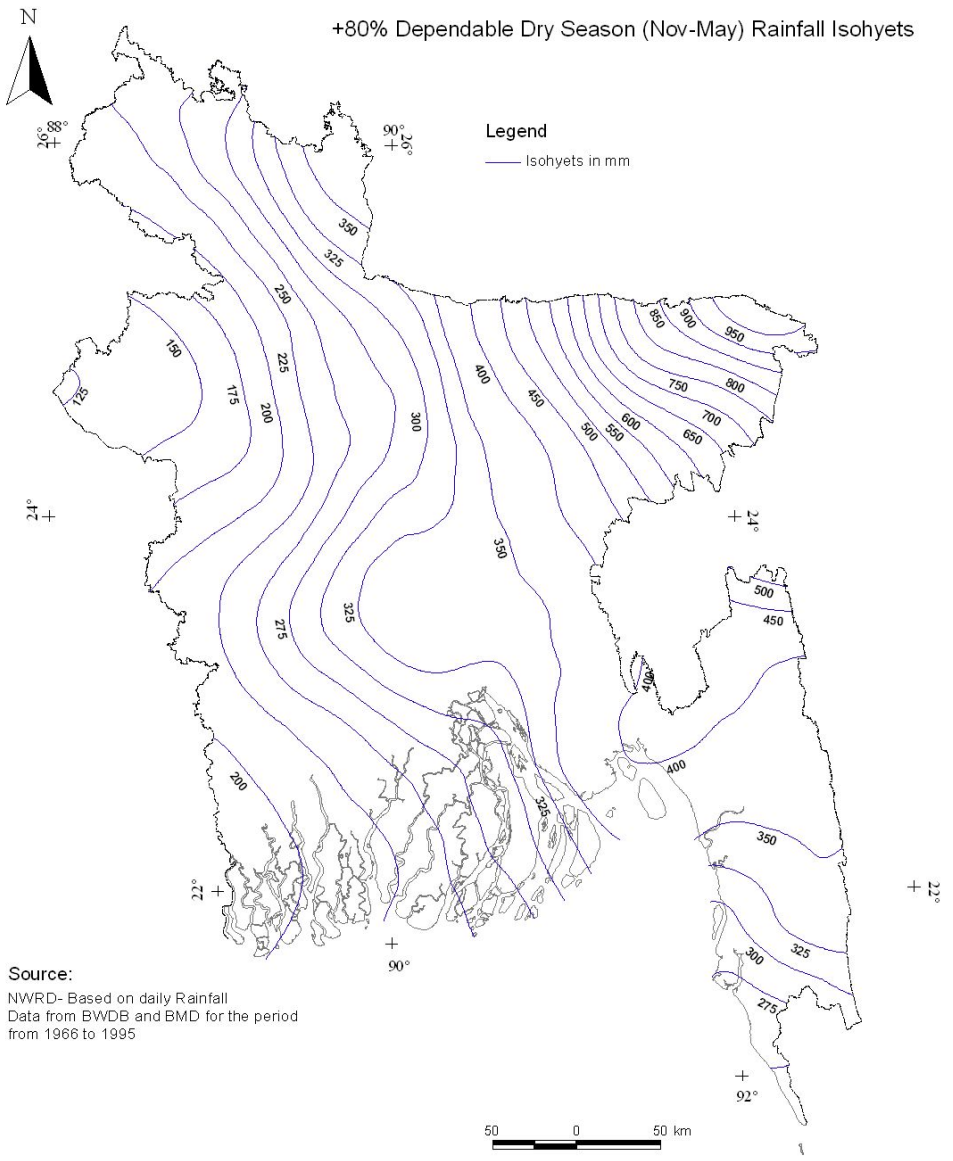
   1.3 no (avg) per yr

1. Drought

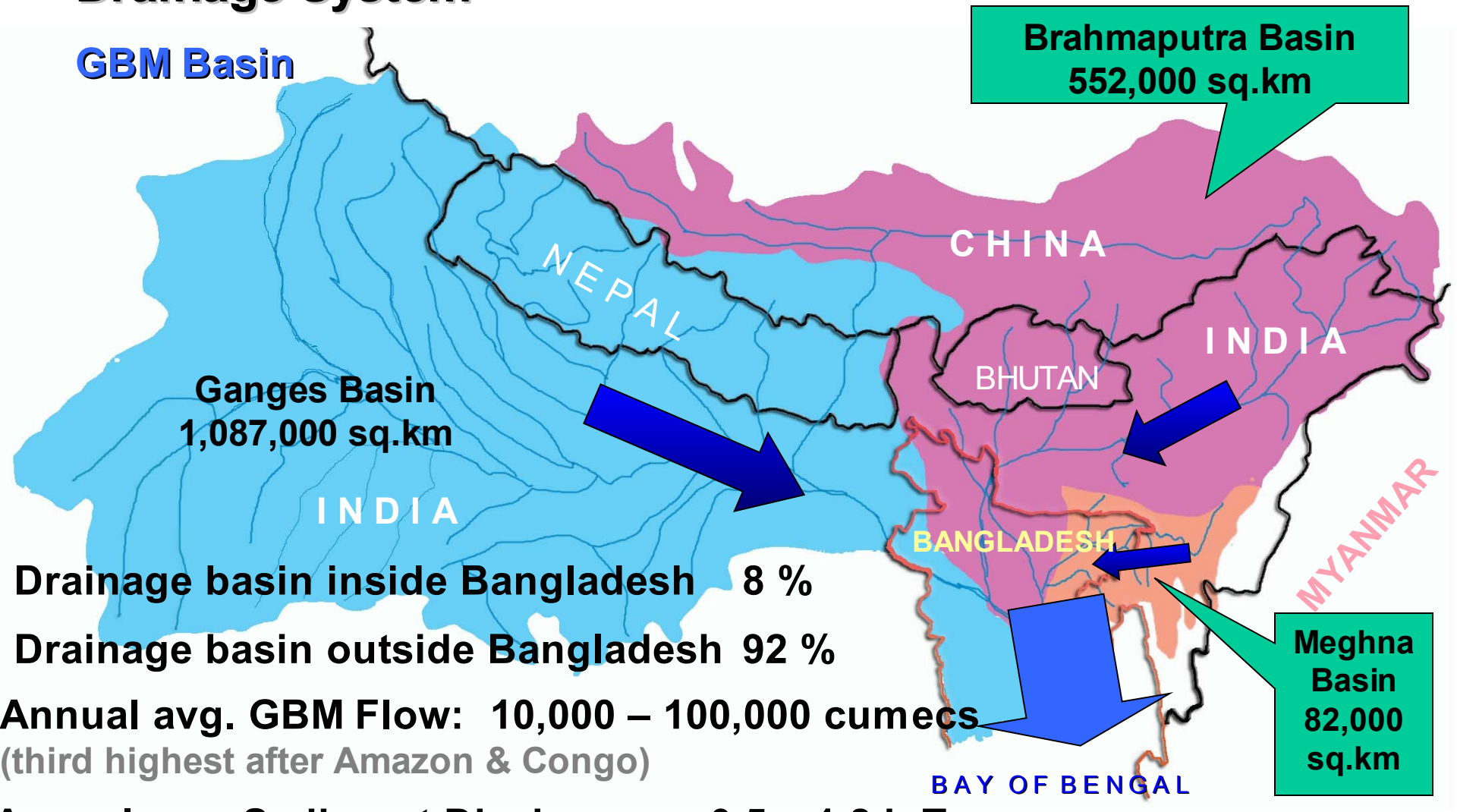
   33% affected

Distribution of rainfall





Drainage System



Drainage basin inside Bangladesh 8 %

Drainage basin outside Bangladesh 92 %

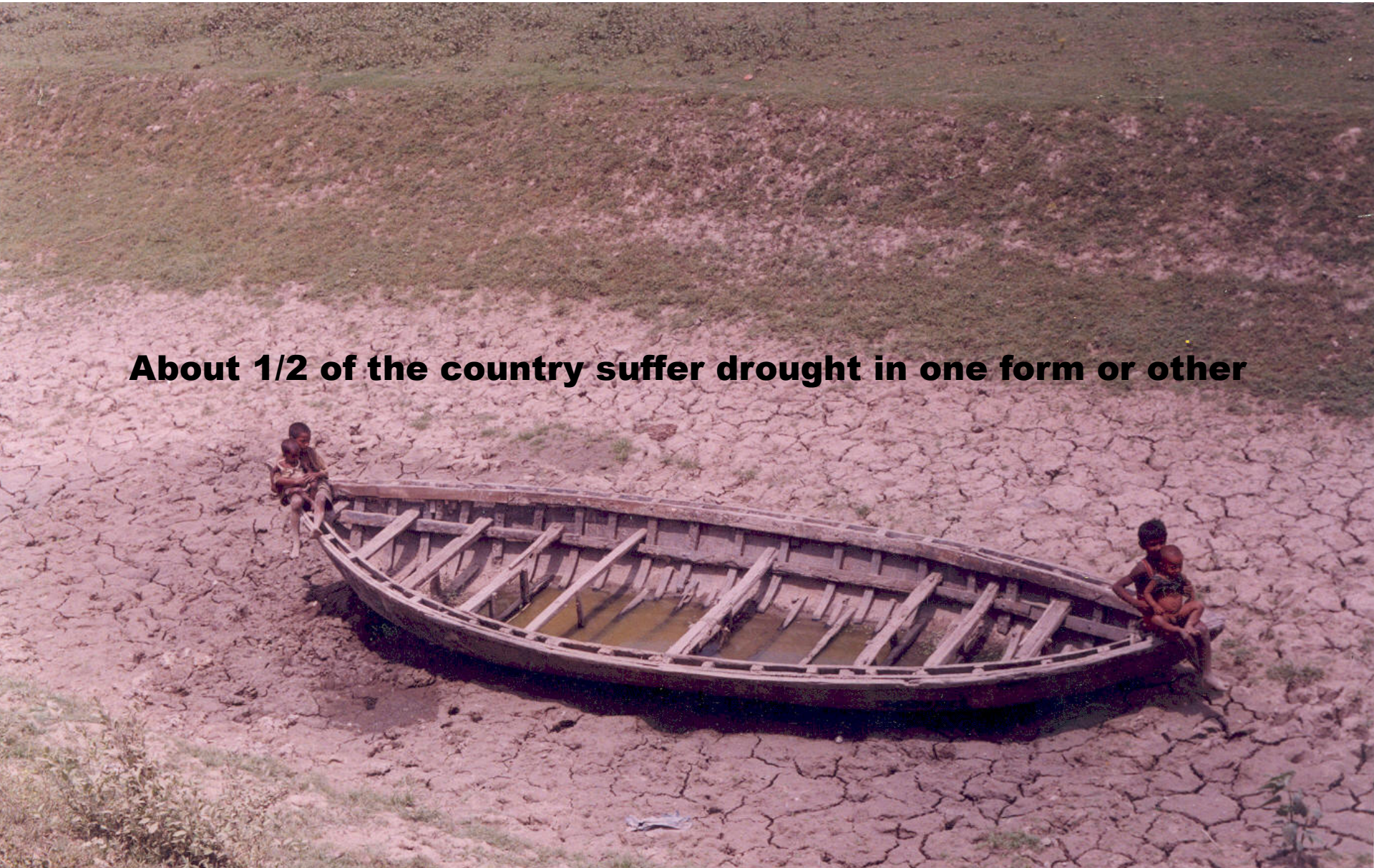
Annual avg. GBM Flow: 10,000 – 100,000 cumecs

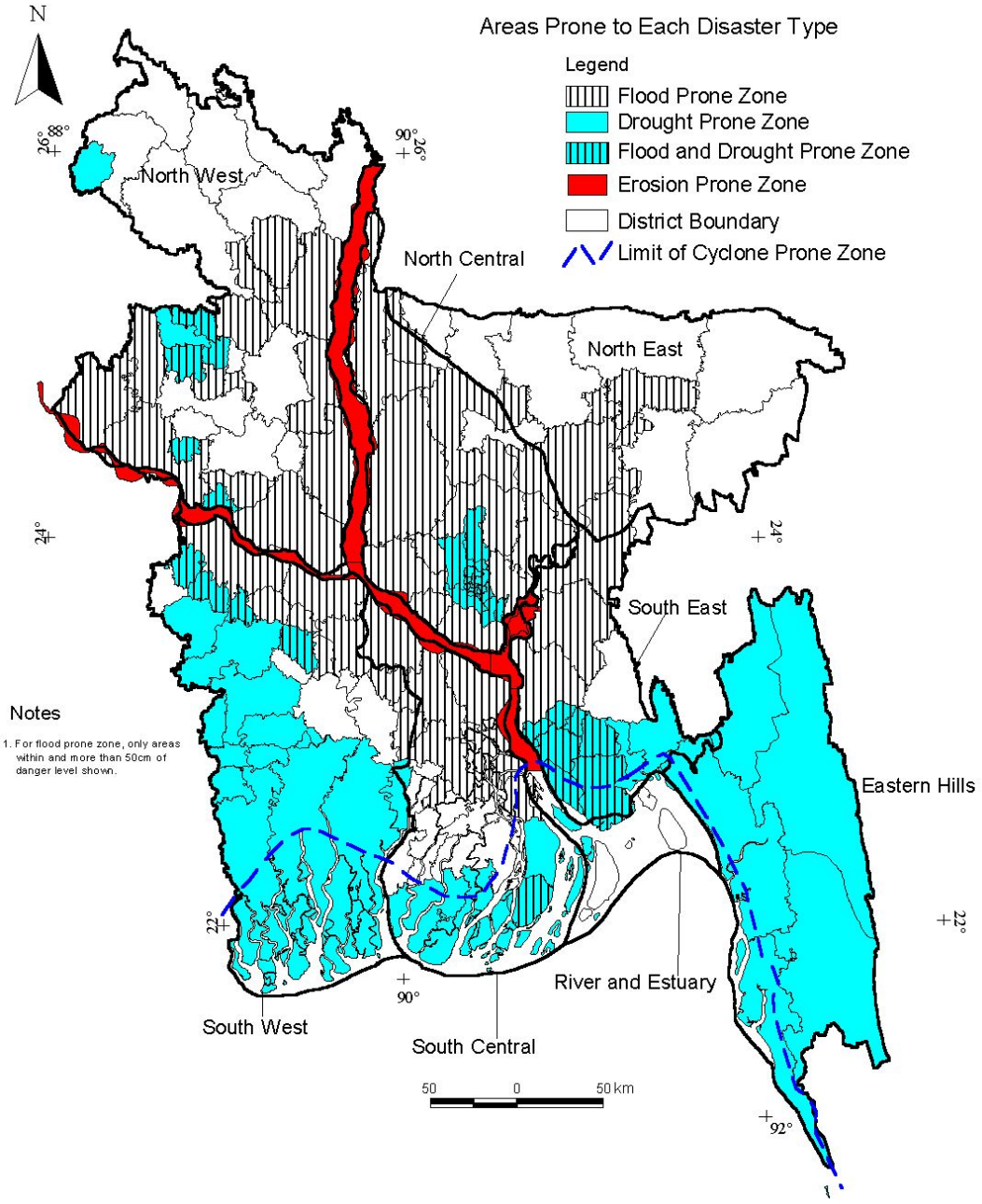
(third highest after Amazon & Congo)

Annual avg. Sediment Discharge: 0.5 – 1.8 b.Tons

(world's highest)

Bangladesh: A land of natural calamities




N
Areas Prone to Each Disaster Type
Legend
Flood Prone Zone
Drought Prone Zone
Flood and Drought Prone Zone
Erosion Prone Zone
District Boundary
Limit of Cyclone Prone Zone
North West
North Central
North East
South East
South West
South Central
River and Estuary
Eastern Hills
Notes
1. For flood prone zone, only areas within and more than 50cm of danger level shown.
50 0 50 km
26°
90°
24°
22°
92°

On one side : abundance of water
On the other : large scale water scarcity