COASTAL INUNDATION FORECASTING DEMONSTRATION PROJECT

- NATIONAL CAPACITY ASSESSMENT FOR BANGLADESH -
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JCOMM Technical Report No. 73

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NOTES

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1 Introduction

1.1 Description of the CIFDP

Coastal disasters are a major concern for the lives and livelihoods of people, and socio-economic development, in low-lying, highly-populated coastal areas. The management of risk for coastal disasters represents a great challenge to scientists and policy makers in meteorology, hydrology, oceanography, emergency management and coastal planning. With a view to improving safety-related services for the community, as a fundamental priority of the WMO, the Joint WMO-IOC Technical Commission for Oceanography and Marine Meteorology (JCOMM) and the WMO Commission for Hydrology (CHy) have initiated this Project in order to meet the challenges of coastal communities’ safety and socio-economic sustainability through the development of coastal inundation forecasting and warning systems at a regional scale.

The objective of the WMO Coastal Inundation Forecasting Demonstration Project (CIFDP) is to help countries with issues of coastal inundation from oceanographic and/or hydrological phenomena, resulting from severe hydro-meteorological events, to operate and maintain a reliable forecasting system that helps national decision-making for coastal management.

The main focus of the CIFDP will be to facilitate the development of efficient forecasting and warning systems for coastal inundation based on robust science and observations.

In doing so, the CIFDP aims at integrating cross-cutting scientific models into an open forecasting environment for the purpose of improving/ expanding/ developing the forecasting and warning systems for storm surges, hydrological response to heavy rainfall and Tropical Cyclone landfall on coastal areas, and other phenomena causing coastal inundation.

The project will focus on integrating the forecasting models already in operational use as modular components, which can be easily replaced or updated as enhanced versions become available. The modelling components will be developed and adapted to fit in an open, flexible and easily extendable forecasting system: the future coastal inundation forecasting system. The new system is expected to underpin a significant improvement of flood disaster management in coastal areas.

Upon completion of national sub-projects of CIFDP, countries will implement an operational system for integrated coastal inundation forecasting and warning, providing the basis for coastal disaster (flooding) management. This will contribute to saving lives, reducing loss of livelihood and property, and enhancing resilience and sustainability in coastal communities. More detailed information can be found in the CIFDP Implementation Plan (JCOMM Technical Report No. 64).

A schematic diagram for the overall forecast system is shown in Figure 1. As can be seen here, information obtained from responsible national / regional agencies, including the Regional Specialized Meteorological Centre (RSMC), is used as the basis for these forecasts, including 1) regional atmospheric models (providing winds, pressures, and precipitation), 2) inputs from large-scale ocean circulation and wind-wave models (providing information on large scale sea-surface height anomalies and on waves generated outside the region) 3), a coastal inundation model (using information on wind wave and wind stress, tidal and large-scale sea-level anomaly), and 4) hydrologic models to handle inflow into the coastal domain from rivers and streams when local rainfall is a dominant contributor to coastal flooding. All of these dynamic models must be set upon a digital terrain model, which includes bathymetric and topographic information at an appropriate accuracy and resolution. The goal of this system of models is to be able to provide accurate forecasts of inundation from hazardous
meteorological forcing in different areas around the world affecting the local coasts, including storm surges produced by direct wind and wave forcing, wave set-up from large swell events, and inundation from high river/stream flows interacting with sea-level variations in coastal areas.

Figure 1: Conceptual diagram of forecast systems recommended for application within the CIFDP effort

1.2 National Capacity Assessment

The objective of the National Capacity Assessment is to review the existing technical capacity and capability within a country in order to apply the results to the development of a sustainable, operational coastal inundation forecasting system. The capacity assessment will address the observational requirements for key variables, existing operational forecast practices and capabilities, access to global, regional and local forecast products, relevant research and development activities and links to coastal zone management activities. In particular, the assessment will address the gaps in that capacity in relation to the requirements needed to implement a robust and sufficiently accurate forecast system. This assessment, particularly the identification of gaps, will be a key element in the development of the system design specification prior to commencing Phase 2 of the sub-project.

This National Capacity Assessment is carried out in the context of the CIFDP Bangladesh sub-project, and it should not be viewed as a general assessment of forecast capability within Bangladesh. Issues that fall outside of the scope of the sub-project, e.g. improving tropical cyclone track and intensity forecasts, augmenting the various observational networks for Bangladesh, developing new models for oceanographic or hydrological response will not be explicitly described in this assessment. While this National Capacity Assessment is primarily a technical assessment, the needs of end users should be kept in mind; the primary assessment of the end user requirements will be done through a separate assessment of end user requirements and capabilities. This assessment also covers the capacity of other institutions, their strength and weakness to support the CIFDP Bangladesh sub-project.
2  CIFDP in Bangladesh

2.1  Description of Cyclones in Bangladesh

Natural disasters are common in Bangladesh, especially along its 710 km coast. Bangladesh is situated at the northern tip of the Bay of Bengal. The long continental shelf, shallow bathymetry, complex coastal morphology with many kinks and islands, and long tidal range between the east and west coasts of Bangladesh are well-known features for generating the highest storm surge, and the longest duration. About 5% of the global tropical cyclones form over the Bay of Bengal. On average, 5 to 6 storms are formed in this region every year. But casualties here account for 80% of the global casualties. Loss of life and property is mainly attributed to storm surges.

Bangladesh receives about 40% of the impact of total storm surges in the world (Murty and El Sabh, 1992). The reasons for this disproportional large impact of storm surges on the coast of Bangladesh are:

- The phenomenon of recurvature of tropical cyclones in the Bay of Bengal
- Shallow continental shelf, especially in the eastern part of Bangladesh
- High tidal range
- Triangular shape at the head of the Bay of Bengal
- Almost sea level geography of the Bangladesh coastal land
- High density of population and very few coastal protection systems.

The triangular shape at the head of the Bay of Bengal helps to funnel the sea water pushed by the wind towards the coast and causes further amplification of the surge on the Bangladesh coast. The Meghna estuarine region is the area where most of the surge amplifications occur.

The coast of Bangladesh is prone to various natural disasters, with tropical cyclones and resultant tidal surges and floods being the most common disaster affecting life and property.
These cyclones form in the Bay of Bengal, which is situated to the south of the country and is a favourable breeding ground for tropical cyclones. UNDP has identified Bangladesh to be the most vulnerable country in the world to tropical cyclones (UNDP, 2004). The high number of casualties in Bangladesh is due to the fact that cyclones are always associated with storm surges. Historical (time series) records of storm surge height are scarce in Bangladesh; however, existing literature indicates a range of 1.5 to 9.0 meter high storm surges during various severe cyclones. Storm surge heights in excess of 10m above mean sea level are not uncommon. For example, in 1876, the greatest Bakerganj cyclone had a surge height of 13.6 m and in the 1970 cyclone the height was 10 m (SMRC, 2000). The cyclone prone area of Bangladesh is shown in Figure 3.

From 1970 to 2011, the total number of major cyclones striking Bangladesh was 26, where the number of occurrences increased significantly since 1990. It should also be noted that the highest number of affected people has been recorded after 1990. In 2007, the country was ravaged by Cyclone Sidr, which displaced 650,000 people and killed 3,447 (official record). In the year 2009, two cyclones hit (cyclone Bijli, April 2009, and cyclone Aila, May 2009). About 200,000 people were displaced by cyclone Bijli. The intensity of the damage caused by the cyclones in 2009 might not be as high as cyclone Sidr, but the country was hit twice in the same year. There is an adverse effect on physical and economic prosperity due to cyclonic storms occurring in the coastal region of Bangladesh.

Table 1: Recorded cyclones over the last 200 years

<table>
<thead>
<tr>
<th>Period</th>
<th>Occurrences of major cyclones</th>
</tr>
</thead>
<tbody>
<tr>
<td>1795-1845</td>
<td>3</td>
</tr>
<tr>
<td>1846-1896</td>
<td>3</td>
</tr>
<tr>
<td>1897-1947</td>
<td>13</td>
</tr>
<tr>
<td>1948-1998</td>
<td>51</td>
</tr>
<tr>
<td>1999-2011</td>
<td>3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>73</strong></td>
</tr>
</tbody>
</table>

Sources: GoB

Records from the last 200 years show that at least 73 major cyclones have hit the coastal zone (Table 1). There appears to be an increase in the frequency of occurrence but it is not clear whether the data between periods are fully comparable. Detailed information regarding the month of occurrence and the area of landfall of 82 cyclones occurring between 1582 and 1997 (i.e. cyclonic storms and severe cyclonic storms) is shown in Table 2.

Table 2: Distribution of cyclone landfall over the coasts and months (1582-1997)

<table>
<thead>
<tr>
<th>Month</th>
<th>Khulna-Sundarban</th>
<th>Barisal/Patuakhali-Noakhali</th>
<th>Noakhali-Chittagong</th>
<th>Chittagong-Cox’s Bazar</th>
<th>Frequency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>February</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>March</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>April</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>May</td>
<td>1</td>
<td>3</td>
<td>11</td>
<td>6</td>
<td>26</td>
</tr>
</tbody>
</table>
2.2 Climatology of Bangladesh

Bangladesh is an agriculture-based country having a peculiar geographical condition with the Bay of Bengal to the south and the Himalayan mountain range to the north. The country is affected by severe weather and climate events, which have tremendous impacts on the national economy. (Of ultimate benefit to the country would be the ability of Bangladesh agricultural interests, from individual farmer to large companies or cooperatives, to anticipate both beneficial and disastrous climate variations).

Bangladesh is located in the tropical monsoon region and its climate is characterized by high temperature, heavy rainfall, often excessive humidity, and fairly marked seasonal variations. The most striking feature of its climate is the reversal of the wind circulation between summer and winter, which is an integral part of the circulation system of the South Asian subcontinent. From the climatic point of view, three distinct seasons can be recognized in Bangladesh - the cool dry season from November through February, the pre-monsoon hot season from March through May, and the rainy monsoon season which lasts from June through October. The month of March may also be considered as the spring season, and the period from mid-October through mid-November may be called the autumn season.

The dry season begins first in the west-central part of the country by mid-December, where its duration is about four months, and it advances toward east and south, reaching the eastern and southern margins of the country by mid-March where its duration is about one month.

The pre-monsoon hot season is characterized by high temperatures and the occurrence of thunderstorms. April is the hottest month when mean temperatures range from 27°C in the east and south to 31°C in the west-central part of the country. In the western part, summer temperatures sometimes reach up to 40°C. After the month of April, the temperature is lower due to increased cloud cover. The pre-monsoon season is the transition period when the northerly or northwesterly winds of the winter season gradually changes to the southerly or southwesterly winds of the summer monsoon or rainy season (June-September). During the early part of this season, the winds are neither strong nor persistent. However, with the progression of this season wind speed increases, and the wind direction becomes more persistent.

<table>
<thead>
<tr>
<th></th>
<th>June</th>
<th>July</th>
<th>August</th>
<th>September</th>
<th>October</th>
<th>November</th>
<th>December</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>1</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td></td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>5</td>
<td>28</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>16</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>13</strong></td>
<td><strong>14</strong></td>
<td><strong>33</strong></td>
<td><strong>22</strong></td>
<td><strong>100</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: Rahman et al., 2001

Figure 4: Climate of Bangladesh (Source: http://www.ngof.org)
The rainy season, which coincides with the summer monsoon, is characterized by southerly or southwesterly winds, very high humidity, heavy rainfall, and long consecutive days of rainfall which are separated by short spells of dry days. Rainfall in this season is caused by the tropical depressions that enter the country from the Bay of Bengal.

On the other hand, during the summer season, a centre of low pressure develops over the west-central part of India because of intense surface heat. As a result, a stream of warm and moist air from the Bay of Bengal flows toward the above-mentioned low pressure through Bangladesh (similar flow prevails from the Arabian Sea toward India). This wind is the part of the summer monsoon circulation of the sub-continent. So, the prevailing wind direction in Bangladesh during the summer season has generally a southerly component (flowing from the south, southwest or southeast). However, wind directions during the transition seasons (in spring and autumn) are variable. Generally, winds are stronger in summer (8-16 km/hr) than in winter (3-6 km/hr). The mean pressure is 1,020 millibars in January and 1,005 millibars during March through September.

2.3 Hydrology in Bangladesh

Bangladesh has a unique hydrological regime. It has been divided into 7 hydrological zones, as shown in figure 5. According to recent publication by Bangladesh Water Development Board, it has 405 rivers of which 57 are trans-boundary Rivers (BWDB, 2011). In almost all cases, Bangladesh is a lower riparian country. A picture of its river network is also given in Fig. 3. Three large rivers systems, e.g. Ganges, Brahmaputra and Meghna, covering a combined total catchment area of about 1.7 million sq. km. extending over Bhutan, China, India and Nepal, flow through this country. Out of these huge catchments only 7% lies in Bangladesh.

Rivers are classified into three broad categories depending on the flow range. They are:

a) Major Rivers: 300 to 120,000 cumec, e.g Ganges, Brahmaputra, Padma, Meghna
b) Semi major Rivers: 100 to 15000 cumec, e.g. Old Brahmaputra, Dhaleswari, Gorai, Arial Khan, Surma, Kushiyara, Teesta etc.
c) Minor River: 1 to 1000 cumec, e.g. Sitalakhya, Buriganganga, Khowai, Manu, Gumti, Dharla, Dudkumar, Karnafuli, Halda, Sangu etc.

Rivers of different morphological characteristics, e.g. meander, braided, incise etc., are found in this country. Major rivers having length of 500 to 2500 km and width range from 1km to 20 km can also be found in this country. Water surface slopes of the major rivers are also very flat, e.g. the average slope of the Ganges is 5-6 cm/km, the average slope of the Brahmaputra is 8-9 cm/km and the average slope of the Meghna is 4-3.5 cm/km. The annual flow volume of the rivers is to the tune of 1200 billion cumec. Rivers of Bangladesh carry huge sediment annual amounts of 1.8 to 2.0 billion tons.

The rivers of Bangladesh mark both the physiography of the nation and the life of the people. About 405 in number, these rivers generally flow south. The larger rivers serve as the main source of water for cultivation and as the principal arteries of commercial transportation. Rivers also provide fish, an important source of protein. Flooding of the rivers during the monsoon season causes enormous hardship and hinders development, but fresh deposits of rich silt replenish the fertile but overworked soil. The rivers also drain excess monsoon rainfall into the Bay of Bengal. Thus, the great river system is at the same time the country's principal resource and its greatest hazard.
Figure 5: Rivers system in Bangladesh (Source: CEGIS)
3 Observing Systems

This section describes the current operational observing systems in Bangladesh for key variables relevant to coastal inundation forecast and warning systems.

3.1 Data Required in Advance of an Event

Data required in advance of an event are those which are generally static, or relatively slowly changing. This includes critical elements of the physical setting, including bathymetry, topography and digital elevation models (DEM). The optimal information requirements for existing state-of-the-art systems are as follows:

- Off- and near-shore bathymetry: resolution 100 m (horizontal) / 1 m (vertical), update every 5 years on shelf
- Coastal elevation: resolution 5 m (horizontal) / 0.5 m (vertical), update every 10 years
- Parameters of river – cross section; flow length and mean bed slope
- Important infrastructure, land use;
- Evaluation of tidal dynamics/constituents at each coastal location under consideration.

3.1.1 Bathymetry data

The last bathymetric survey conducted by BIWTA was in 1980 (Department of Hydrology, BIWTA, Nov 1979- Jan1980), and it was sufficiently extensive. Recently, the Bangladesh Navy began to maintain a similar bathymetric survey program of its own. It takes about a year to cover such wide water area to survey (about 150 N up to the coast). The bay is very turbulent during about 9 months, from March to November due to high waves. Bangladesh has a bathymetry map of scale 1:250,000 and topography map of 1:10,000 scale. Figure 6 shows the sample bathymetry map for the Chittagong coast. Other than this, data has been collected for different projects such as the Meghna Estuary Study, Phase II (MES II, 1998-99), Mongla Port Study (2004), IPSWAM (2008) and other projects of the Bangladesh Water Development Board (BWDB), which could be utilized to enhance the Bathymetry of Bangladesh.

3.1.2 Digital Elevation Model (DEM)

Under the Flood Action Plan (FAP) 19 project, updated land elevations on a 300 m grid are available for all of Bangladesh from surveys, except Sundarbans (set at 0.5m) and Madupur Forest (by interpolation using IDW method). The data are stored in the National Water Resources Database of WARPO. The Institute of Water Modeling also customized a DEM with 50 m x 50 m resolution based on the FINNMAP land survey, FAP 19- National DEM (1952-64), and projects of the Bangladesh Water Development Board (i.e. Khulna Jessore Drainage Rehabilitation Project, 1997; Beel Kapalia project, 2008; and Beel Khuksia project, 2004).
3.1.3 Other data

River and water bodies’ data available in WARPO are shown in Table 3 below.

<table>
<thead>
<tr>
<th>Data Set Details at WARPO</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rivers and Water bodies</strong></td>
</tr>
<tr>
<td><strong>Rivers</strong></td>
</tr>
<tr>
<td><strong>River names</strong></td>
</tr>
<tr>
<td><strong>Standing Water Bodies</strong></td>
</tr>
</tbody>
</table>

Socio-economic, male/ female and urban/ rural census data from 1961, 1974, 1981, 1991 and 2010 year is available at BBS. Forecasts (by CEF) of urban and rural populations 2000 to 2050 at 5 year intervals are also available from BBS.

3.2 Data Required During an Event

In order for the overall inundation system to function effectively, be objectively assessed and to improve its accuracy and value through time, it will be critical to include a set of observations (both in situ and remotely sensed, real-time and non-real time) into the overall system. These measurements should include information on conditions prior to, during and after the different inundation events. Pre-inundation information is essential to improved forecasts of the event which generates inundation, and to evaluate which models in an ensemble are tracking better with the developing scenario (if an ensemble approach to forecasting is used). Data taken during the event is necessary to enable quantitative comparisons between the modeled inundation being generated by the hydro-meteorological forcing and the inundation response
to this forcing. It is also important in enabling updated warnings in rapidly changing situations. These measurements should include both forcing functions (winds, pressures, rainfall, waves, etc.) and response functions (water level, stream discharge, etc.). It should also be noted that continuous, long-term measurements will be important to establishing the overall climatology of extremes in this area and to detect any long-term changes which are occurring.

3.2.1 Tide Gauge Measurement

At present, there are in total 53 tidal stations operated by Bangladesh Inland Water Transport Authority (BIWTA). Of the 53 stations, one station (Chittagong Port, lat/long 22.33333/91.83333) is real time and part of the GLOSS database (GLOSS no 36) (source: BIWTA). The Hydrography department of BIWTA monitors and maintains these data. For inland river tidal gauge monitoring, BIWTA is the mandated agency under the Government of Bangladesh. Other than BIWTA, the Hydrographic Department of the Bangladesh Navy (BN) has the mandate to ensure availability of reliable and updated information of the marine environment in order to derive maximum benefits from Bay of Bengal. Thus, BN also conducts hydrographic survey, data collection and tide table publication activities using a wide range of equipment and systems fitted on board survey ships/craft/boats. The BN has well manned, maintained and equipped survey vessels. At present they have 5 survey vessels (Anushandhan, Saibal, Agradoot, Tallashi, Darshak); all are equipped with auto tide gauges (sources: BN, 2012).

3.2.2 Wave Measurement

There is no data available for wave measurement, but BMD stores hindcast data for waves in the Bay of Bengal.

3.2.3 Streamflow Measurement

The Bangladesh Water Development Board is the authorized agency for stream flow measurement. The following streamflow data are available from BWDB.

<table>
<thead>
<tr>
<th>Table 4: Surface Water Data available from BWDB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of WL and Discharge stations</td>
</tr>
<tr>
<td>Time series of WL and Discharge</td>
</tr>
<tr>
<td>River cross sections</td>
</tr>
<tr>
<td>Sediment</td>
</tr>
<tr>
<td>Salinity</td>
</tr>
<tr>
<td>Salinity Map</td>
</tr>
<tr>
<td>River modeled levels</td>
</tr>
<tr>
<td>River modeled discharges</td>
</tr>
<tr>
<td>MPO surface water resources</td>
</tr>
<tr>
<td>Depth-Duration-Frequency curves</td>
</tr>
</tbody>
</table>
3.2.4 Surface Meteorological Measurements

The Bangladesh Meteorological Department (BMD) collects all meteorological data. Other than BMD, BWDB also collects rainfall data, but not according to WMO standards. BMD's present data observation and collection capacities are limited. For general routine activities they have:

- Synoptic observatories: 35
- Pilot Observatories: 10
- Rawinsonde Observatories: 3
- Agro-met observatories: 12
- RADAR Stations: 5 (operational, 3 are Doppler Radars)

Observations for enhancing detection of cyclonic storms in the Bay of Bengal are still lacking. The following data are available at present.

<table>
<thead>
<tr>
<th>Table 5: Meteorological information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall station locations</td>
</tr>
<tr>
<td>Rainfall</td>
</tr>
<tr>
<td>Monthly rainfall</td>
</tr>
<tr>
<td>Dependable rainfall</td>
</tr>
<tr>
<td>Climate station locations</td>
</tr>
<tr>
<td>Climate</td>
</tr>
</tbody>
</table>

3.2.5 Weather Radar Information

There are five radar stations in Bangladesh operated by BMD, three of which are Doppler radars and two are conventional radars. All five radars are implemented for meteorological purposes. Information on these five radars is shown in Table 6 and Figure 8.

<table>
<thead>
<tr>
<th>Table 6: RADAR information of Bangladesh Meteorological Department</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI No.</td>
</tr>
<tr>
<td>--------</td>
</tr>
<tr>
<td>1.</td>
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<tr>
<td>2.</td>
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<tr>
<td>3.</td>
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<tr>
<td>4.</td>
</tr>
<tr>
<td>5.</td>
</tr>
</tbody>
</table>
3.2.6 Satellite Observation

The Bangladesh Space Research and Remote Sensing Organization (SPARRSO) have the mandate to provide effective and peaceful application of Space & Geo-information Technology (GIT) for sustainable development and human safety, security and benefits in Bangladesh. The available satellite ground stations with SPARRSO are shown in Figure 9.

![Figure 8: RADAR Location Map of Bangladesh (Source: BMD)](image)

Figure 9: Satellite ground stations at SPARRSO (source: http://www.sparrso.gov.bd)

3.3 Data Required after a Coastal Inundation Event

Post-event measurements, including surveys of inundation extent, depth and duration will be critical to understand the nature of the coastal inundation, and to validate the performance of the integrated forecasting system. Such surveys should preferably have a horizontal resolution of 25 m. Post-event measurements are generally very limited for Bangladesh inundation cases, although there are several specific events for which some data do exist. Annex-1 summarizes some damage data for past events.
4 Analysis of Capacity Gaps with Respect to Future CIFDP System Design

4.1 Context of Gap Analysis

As noted in Section 1 of this report, the objective of the Coastal Inundation Forecasting Demonstration Project (CIFDP) is to help countries with issues of coastal inundation from oceanographic and/or hydrological phenomena, resulting from severe hydro-meteorological events, to operate and maintain a reliable forecasting system that helps the national decision-making for coastal management.

The focus of the CIFDP Bangladesh sub-project (CIFDP-B) is to facilitate the development of efficient forecasting and warning systems for coastal inundation, integrating forecasting models already in operational use, developed and adapted to fit in an open, flexible and easily extendable forecasting system: the future coastal inundation forecasting system for Bangladesh.

The objective of this National Capacity Assessment is a review and analysis of the existing technical capacity and capability within Bangladesh, as it will be applied to the development of a sustainable, operational coastal inundation forecasting system, by using what is available, and what can run in the national operational environment. This analysis will form the basis for the system design in Phase 2 of the Bangladesh sub-project.

This analysis should not be viewed as a general assessment of forecast capability within Bangladesh, or a general assessment of the scientific adequacy of forecast models and techniques, e.g. tropical cyclone track and intensity forecasting, which are global research issues investigated in other programs.

The previous sections described the existing observational systems in Bangladesh. This section will assess the current capacities and gaps between the present observational and forecast and warning systems. The global system and recommendations to enhance the Bangladesh system described in the following sections to provide an accurate and robust coastal inundation forecast and warning system.

4.2 Cyclone Models

At present, BMD doesn't have any cyclone model. For any cyclone formation and warning, BMD rely on the regional and global systems (RSMC, JTWC, RIMES, etc.). The Indian Meteorological Department (IMD), which is the WMO designated Regional Specialized Meteorological Centre (RSMC), provides the official tropical cyclone forecasts and warnings in the North Indian Ocean. As mandated by the WMO, the IMD is required to coordinate and release their forecasts daily with each member country within the North Indian Ocean.

However, ultimate responsibility for forecast development and warning dissemination lies with each country’s national meteorological service. At present, BMD have established their NWP system. They operationally run a Weather Research and Forecasting (WRF) model with 27X27 km grid resolution using NCEP initial conditions for daily operational weather forecasts.

4.3 Storm surge, Wave and Inundation Models

The height of storm surge is dependent on characteristics and behavior of the cyclone, wind strength and direction, as well as bathymetric features. For areas where the wind is blowing towards land, the wind drags the water towards the coast and elevates the local sea level. This process is called wind set-up and is generally the principal cause of storm surge. A
second important factor is the deep water wave height, which also causes an increase in mean sea level as it breaks at the coast. This process is called wave set-up. There are also effects of the low pressure – the so-called inverted barometer effect. It is not as severe as the wind stress, but probably worth approximately 0.4 m. A further issue influencing the total water level is the tidal range of the location, and the time within this cycle that the cyclone makes landfall. In its simplest terms, the storm surge is superimposed upon the current tide, so if the cyclone makes landfall at high tide the maximum surge height will be greater than if it occurred at low tide. In areas where rivers flowing toward the coast interact with surges propagating inland (such as in some critical areas within Bangladesh), it is important to include the effects of this interaction within the inundation model.

For storm surge and wave forecast, BMD uses the MRI (Meteorological Research Institute) storm surge model. It is an experimental model implemented by the Japan Meteorological Agency (JMA) for the Bay of Bengal and run by the Bangladesh Meteorological Department. The storm surge model is based on a two-dimensional ocean model, vertically integrated. The governing equations are the usual momentum equations and the continuity equation. In this model, the main mechanism of storm surges, inverse barometer effect and wind set-up are considered for storm surge estimations. The astronomical tides are not included in the previous old version but have been included in the newer one. Other influences, such as ocean waves, the effects of stratification, and river inflows, which may also affect storm surges, are not considered. Wave condition (and wave setup) are currently calculated by other models and referred in operational forecasts. The boundary condition at land/sea margins are assumed as fixed rigid walls and no inundation is considered. The model covers with the domain 15 - 23.5 N, 87.0 -93.0 E, with a grid resolution of two minutes. The model domain can be changed to any specific location.

With the MRI model, products (surface wind, pressure) from other models can be ingested as input. Currently, Japan Meteorological Agency's Global Spectral Model data are used to run the model along with conventional parameters. The boundary at land assumes the boundary as rigid walls and any inundation and dry up is not considered. The latest MRI model has the capability to calculate inundation, rather than treating the coastline as a wall. For avoiding dry up, the water depth holds a minimum value. The default value is set as 3m. Boundaries at the open ocean assume that the sea levels are balanced to the static level of local surface pressures. A difference of sea level is supposed to make inflow or outflow currents which move as gravitational waves. In this treatment, higher (lower) sea level makes outflows (inflows). The Generic Mapping Tool (GMT) software is used for visualization of storm surge. The model output includes significant wave height (m), significant wave period (sec); wave direction; sea surface wind speed (m/s), swell height (m) and sea surface pressure (hPa). Performance of the model is quite good, but underestimates the peak surge height. No major cyclone has hit Bangladesh’s coast since the installation of the MRI storm surge model in BMD. In the latest cyclone Mahasen, the MRI model provided quite accurate forecasts.

At the same time, the IIT Delhi storm surge model (IIT-D) has been operationalized at BMD. The major inputs of the model are vector motion of the storm centre; radius of maximum wind; pressure drop and topographic and bathymetric data (ETOPO2). The Generic Mapping Tool (GMT) software is used for visualization of storm surges as well. Model output includes surge height contours along with different latitude and longitude. The resolution of the IIT-D model is high (\(\Delta x = 3.7 \text{ km}, \ \Delta y = 3.5 \text{ km}, \ \Delta t = 60 \text{ sec}\)). The model performance is good. Predicted maximum surge height is found to be in good agreement with the reported surge height. The IIT-D storm surge model is validated for North Bay of Bengal by using Unisys cyclone track data and Saffir-Simpson Scale. The IIT-D model does not include inundation of the coast at present.

At present, BMD does not have any capacity to forecast the storm surge-related inundations in the coastal areas, due to the lack of coastal inundation models as well as real time
observation systems. This is one of the major areas where the community expects reliable information for local level response.

4.4 Flood Models

The Flood Forecasting and Warning Center (FFWC) of BWDB is the responsible organization for riverine flood forecasts. FFWC does not have any operational coastal flood forecasting system as well. The existing techniques or models for hydrology and/or river floods available at FFWC of BWDB are as follows:

- 1-5 days flood forecasting model covering rivers and flood plains of the north, north-east, central and north-west part of the country. Output of this model could be used as the input boundary of the proposed coastal model.
- 1-10 days ensembles probabilistic forecasts model for Ganges, Brahmaputra and Meghna Basin.
- MIKE BASIN and MIKE 11 (version 2003 by DHI) for 1d-Hydrodynamic and rainfall run-off simulation
- Hydrodynamic regional models covering the rivers and flood plains of the south-west and south-east hydrological zone of Bangladesh (not operational at present). This model could utilize to couple the storm surge model (the weather model) with the hydrological and hydrodynamic model to cover the coastal zone of Bangladesh.
- In some selected locations and limited time series data of water level and discharge of the coastal rivers and estuary
- Limited Bathymetry data (river cross section and long profile etc) of the coast of Bay of Bengal, old DEM with coarse resolution (300m×300m)
- Design data related to all water resources management infrastructure (polders, sluices, regulators, etc.)
5  Global Models to Support CIFDP-B

There is a strong inter-relationship between the tropical cyclone hazard and its impacts, firstly in terms of directly-induced hazards on the land and in the ocean environment, and secondly in terms of indirect impacts on communities, infrastructure and the environment. Harper (2001) provides a schematic overview shown in Figure 10:

![Figure 10. Inter-relationship between the tropical cyclone hazard and its impacts (source: Harper, 2001).]

5.1  Tropical Cyclone Models

WMO already recommended that all tropical cyclone-related Numerical Weather Prediction (NWP) products, including a full set of ensemble forecasts, should be made available to all operational and research users in real-time (IWTC-VII, 2010). Within WMO, the World Weather Research Programme and the Tropical Meteorology Research Programme are cooperating to advance the International Tropical Cyclone Landfalling Programme, linking to the US Landfalling Project but broadening the goals for the global community. Meanwhile, there are many research studies, and progress has been made by NOAA, ECMWF, JMA, KMA, UKMO (i.e. THORPEX GIFS-TIGGE Working Group; the hurricane forecast
improvement project, ECMWF EPS, etc.) in providing real-time ensemble data and products in support of high impact weather prediction, including prediction of tropical cyclones. Nowadays, climatic condition ensembles TC forecasts and multiple models are essential to increase the confidence of forecasters. Numerous models have been developed to simulate hurricane wind forecasts (Sheng et al., 2010): GFDL (Geophysical Fluid Dynamic Laboratory model, (Bender et al., 2007), HWRF (Hui et al., 2013; Skamarock et al., 2005), NAH (North Atlantic Hurricane wind-wave model, Alves et al., 2005), WINDGEN (WIND GENeration program, Graber et al., 2006), and the Xie et al. (2006) model. On the other hand, the H*wind (Powell et al., 1998) provides reanalyzed 10-m hurricane winds produced by the NOAA/AOML/HRD (National Oceanic and Atmospheric Administration/Atlantic Oceanographic and Atmospheric Laboratory/Hurricane Research Division). KMA (Korea Meteorological Agency) is now working on ensemble TC forecasting; the NOAA-HFIP (Hurricane Forecast Improvement Project) uses a number of approaches to create initial states for global and regional models. Table 7 shows the HFIP regional models (BAMS, 2013).

Table 7. HFIP regional models (source: BAMS, 2013)

<table>
<thead>
<tr>
<th>Models</th>
<th>Nesting/Horizontal Resolution (km)</th>
<th>Vertical levels</th>
<th>Cumulus parameterization</th>
<th>Initial and Boundary conditions</th>
<th>Initializations</th>
</tr>
</thead>
<tbody>
<tr>
<td>HWRF(OPS)</td>
<td>227/9</td>
<td>42 NMM</td>
<td>Simplified Arakawa-Schubert</td>
<td>GFS</td>
<td>GSI 3DVAR</td>
</tr>
<tr>
<td>GFDL (OPS)</td>
<td>3:30/15/7.5</td>
<td>42 GFDL</td>
<td>Arakawa-Schubert</td>
<td>GFS</td>
<td>GFDL synthetic bogus vortex</td>
</tr>
<tr>
<td>HWRF-HRD/EMC 27-9-3</td>
<td>3:27/9/3</td>
<td>42 NMM</td>
<td>Simplified Arakawa-Schubert</td>
<td>GFS</td>
<td>EnKF with aircraft data</td>
</tr>
<tr>
<td>WRFARW (NCAR)</td>
<td>3:12/4/1.3</td>
<td>36ARW</td>
<td>New Kain-Fritsch (12 km only)</td>
<td>GFS</td>
<td>EnKF Method in a 6-h cycling mode</td>
</tr>
<tr>
<td>COAMPS-TC</td>
<td>3:45/15/5 (15/5 km following the storm)</td>
<td>40 COAMPS</td>
<td>New Kain-Fritsch on 45 &amp; 15-km meshes</td>
<td>NOGAPS Cloud (use GFS if desirable)</td>
<td>3DVAR Data assimilation with synthetic observations</td>
</tr>
<tr>
<td>Wisconsin Wisconsin Model</td>
<td>UWNMS (3D enstrophy/entropy/KE conserving dynamics core)</td>
<td>3-4: 90/45/9 km 90/45/9 /3km</td>
<td>52 ensembles</td>
<td>RRTM</td>
<td>GFS/GFDL</td>
</tr>
<tr>
<td>PSUARW</td>
<td>3:40.5/13.5 /4.5 for ensemble forecast 1.5- km nest for control</td>
<td>35 ARW</td>
<td>Grell-Devenyi ensemble scheme (40.5 km only)</td>
<td>GFS</td>
<td>EnKF with NOAA airborne radar</td>
</tr>
</tbody>
</table>
5.2 Storm Surge, Wave and Inundation Models

Storm surge induced by tropical cyclones (TCs) is one of the major threats to the life and property in coastal regions. On average, roughly 5 TCs every 3 years would strike the U.S. coastline, causing 50–100 casualties and billions of property damage (http://www.nhc.noaa.gov/HAW2/english/basics.shtml). The impact in terms of lives and property are much higher over the Asian region. Thus, accurate prediction of storm surge has been listed as a high priority by the coastal disaster planning and mitigation agencies. It is determined primarily by meteorological forcing, such as TC intensity, path, spatial and temporal scales, and topographic parameters including the width and slope of continental shelf, geometry and character of local coastal and shelf features (e.g., barrier islands, headlands, bays, sounds, inlets, marshes, channels, levees, and barriers). Thus, the predictive skill of any storm surge model depends critically on the input of TC winds and the representation of local bathymetric and topographic features. The latter requires adequate model grid resolutions, and high-resolution geographic data translated to model computational grids. Various 2D/3D models have been developed and used for storm surge simulations, including the SLOSH (Sea, Lake, and Overland Surges from Hurricanes, Jelesnianski et al., 1992), IIT-Delhi model (Dube, 2012), JMA-MRI model (Kohno, 2011), ADCIRC (Luettich et al., 1992), CH3D (Sheng, 1990, Sheng et al., 2010 and Sheng and Paramygin, 2010), POM (Princeton Ocean Model, Peng et al., 2004 and Oey et al., 2006) and FVCOM (Finite Volume Coastal Ocean Model, Rego and Li, 2009 and Weisberg and Zheng, 2008). These models use orthogonal curvilinear grids (SLOSH and POM), non-orthogonal curvilinear grids (CH3D), or unstructured triangular grids (ADCIRC and FVCOM).

Some of these models (ADCIRC, CH3D, FVCOM, and POM) are being compared in a regional storm surge and inundation model on a pilot basis (http://ioos.coastal.ufl.edu). While a storm surge model usually simulates the wind-driven and pressure-induced surge, wave-induced surge can be simulated by including the effects of waves on storm surge via one-way coupling (e.g., IPET, 2008) or two-way coupling (e.g., Sheng et al., 2010) between a storm surge (2D or 3D) model and a wave model such as SWAN (an acronym for Simulating WAves Nearshore) (Booij et al., 1999), STWAVE (Resio, 1987), and WAVEWATCH III® (Tolman, 2009). WAVEWATCH III® has been used mainly for deep water, while SWAN and STWAVE have been used for shallow water. SWAN is a third-generation wave model, which is incorporated as a module into the Delft3D modelling system for obtaining realistic estimates of wave parameters in coastal areas, lakes and estuaries from given wind, bottom and current conditions. The model is based on the wave action balance equation with sources and sinks.

The Delft3D (http://oss.deltares.nl/web/delft3d) is also a leading hydrodynamic, sediment transport and water quality modelling system developed by Deltares in The Netherlands. It has been applied in major coastal and ocean investigations and engineering studies related with current, wave and/or sediment transport around the globe. The Delft3D modelling system includes wind, pressure, tide and wave forcing, three-dimensional currents, stratification, sediment transport and water quality descriptions. It is capable of using irregular, rectilinear or curvilinear coordinates. Delft3D comprises several modules that provide the facility to undertake a range of studies. All studies generally begin with the Delft3D-FLOW module. From Delft3D-FLOW, details such as velocities, water levels, density, salinity, vertical eddy viscosity and vertical eddy diffusivity can be provided as inputs to the other modules. The wave and sediment transport modules work interactively with the FLOW module through a common communications file. Delft3D can be operated in 2D (vertically averaged) or 3D mode. In this type of coupling, results are cyclically transferred between the two model systems at appropriate time steps. That is, the Delft3D Model runs, and at specified intervals, the Delft3D model stops and its results (e.g. for water level, tidal currents etc.) are transferred into the SWAN wave model, where these results are incorporated into the SWAN wave calculations. After these SWAN wave calculations are then performed, its results are then transferred back to the Delft3D flow model (e.g. for wave setup, wave induced currents etc.) where they are
incorporated into the Delft3D flow calculations and so forth. In this way the results between
the two model systems transfer back and forth for the durations of the model run, with the
transfers taking place at appropriately specified intervals. The Delft3D storm tide model
system has extensive scope of calibration and validation. However it requires quality
bathymetry data. Its shallow shelf is very sensitive to finite-depth water wave celerity and tide,
wave and storm surge interactions are highly nonlinear.

SWASH (an acronym of Simulating WAves till SHore) is a non-hydrostatic wave-flow model
and is intended to be used for predicting transformation of surface waves from offshore to the
beach for studying the surf zone and swash zone dynamics, wave propagation and agitation
in ports and harbors, and rapidly varied shallow water flows in coastal waters. The governing
equations are the nonlinear shallow water equations, including non-hydrostatic pressure, and
it provides a general basis for describing complex changes to rapidly varied flows typically
found in coastal flooding, resulting from e.g. dike breaks and tsunamis and wave
transformations in both surf and swash zones. This is caused due to nonlinear wave-wave
interactions, interaction of waves with currents, and wave breaking, as well as run-up at the
shoreline. SWASH is closely related to SWAN, with respect to the pragmatism employed in
the development of the code. Furthermore, like SWAN, the software package of SWASH
includes user-friendly pre- and post-processing does not need any special libraries. In
addition, SWASH is highly flexible, accessible and easily extendible concerning several
functionalities of the model. SWASH does not have any numerical filter nor dedicated
dissipation mechanism to eliminate short wave instabilities. Neither does SWASH include
other ad-hoc measures like the surface roller model for wave breaking, the slot technique for
moving shoreline and source functions for internal wave generation. Again, at this moment
SWASH does not account for wind effects on wave transformations.
6 Recommendations for System Design for CIFDP-B

The proposed system design for CIFDP-B is prepared based on the global, regional and existing BMD capacity and on experts’ discussions in the CIFDP-B kick-off meeting in May 2013. This section highlights state-of-the-art modern technology that is feasible for the Bangladeshi context at this moment. The best possible scenario is to develop an advanced state-of-the-art technology to predict cyclones with longer lead times and higher accuracy to define its landfall, intensity and severity. This includes a storm surge, wave and inundation model that produces accurate surge height and coastal inundation scenarios for community-level response. However, given the present situation, researchers need to think realistically about the current infrastructure, trained man-power and resources of BMD to sustain such activities. In that sense, the system needs to be flexible enough to support existing technologies and simple to adopt with the current capacity. Considering the above criteria, the CIFDP-B could be implemented.

The system design discussion initially focused on a manageable approach to storm surge forecasting, while building the framework to include the hydrology and integrated forecast systems and inundations. The enhanced DEM will not be available until 2015/16 but the framework can be built to incorporate it at that time. Initially for the storm surge model, but eventually for all model components, the following checklist should be used to determine the optimum approach:

- Availability
- Familiarity
- “Open source” access
- Available capacity – personnel and infrastructure
- Upgradeability
- System support – external
- Likelihood of training support
- Ability to link to other models (hydrology, inundation)
- Ability to extend to ensembles
- Input required – NWP, parametric
- Output produced
- Demonstrated performance – validation

6.1 Cyclone Model

BMD may follow the existing system for cyclone forecasting depending on the regional and global system (e.g. RSMC, JTWC, ECMWF, RIMES, etc.), while at the same time the department may install, customize and test a cyclone model over the Bay of Bengal. The existing WRF model could be utilized for this purpose. The WRF model could be tested with both options for a dynamic core; namely the ARW-WRF core by NCAR and the Non-hydrostatic mesoscale model (NMM) built by EMC (http://www.dtcenter.org/HurrWRF/users/docs/index.php). The model could also use several options for physical boundary as well as initialization and post processing system to enhance the model accuracy.

It needs to be mentioned here that, while having the capability to use WRF (or HWRF) obviously enhances BMD’s capacity, it may not necessarily lead to forecast improvements in the short term. The system may be developed with the flexibility to use either wind fields directly from a numerical model like WRF, or track and intensity parameters from a forecast combined with an internal parametric wind model. The system could develop somewhat
independently of the TC forecast system, so that changes in the TC forecast system can be made without requiring changes to the surge and inundation forecast system - and also so that it is possible to experiment with different TC forecast inputs to see which works best. BMD also proposed to initially test the WRF with ECMWF initial conditions. The data access for the ECMWF will be processed through WMO.

A single forecast from a particular numerical model (often called deterministic) has an inherent level of uncertainty. An ensemble or collection of forecasts all valid at the same time, however, can potentially provide information on the amount of confidence that can be associated with that forecasts situation. In addition, the mean forecast of a well-constructed ensemble is often superior to the forecasts from any individual member of the ensemble. Ensembles, therefore, offer the potential to improve both forecasts accuracy and forecasts lead time. BMD could develop a platform to plug in all the models' outputs to generate ensembles and make decisions based on probability distribution functions.

### 6.2 Storm Surge, Wave and Inundation Models

For a storm surge model, BMD may operationalize both existing models (IIT-Delhi and MRI). The MRI model has an updated version which could generate wave height as well as inundation. The updated MRI model will be transferred to BMD to validate the model with past cases. Using a parametric wind model with track, intensity, and storm size parameters from BMD’s own source (i.e. WRF) or other forecast sources (e.g. RSMC, JTWC, etc.) could enhance the storm surge forecasts capacity, as well as assisting in the generation of probabilistic forecasts. This is because it is much easier to generate perturbations to the track and intensity parameters than it is to generate perturbations to the whole wind field in WRF itself.

The eSurge project of the European Space Agency (http://www.storm-surge.info/) is implemented in close cooperation with the CIFDP, with a view to improving storm surge forecasting systems and applications through the innovative use of ocean, land and atmospheric satellite observations. Common goals from these coordinated activities include a comprehensive definition of data requirements - both in-situ and remotely sensed - and the establishment of an integrated information system to support the operation; BMD could be part of the eSurge project to apply this research into experimental application.

Close coordination should be established and maintained with other project initiatives mentioned in the project Implementation Plan (JCOMM, 2013), e.g. JCOMM Expert Team on Waves and Coastal Hazard Forecast Systems (ETWCH), UNESCO project on “Enhancing regional capabilities for coastal hazards forecasting in North Indian Ocean” (http://www.jcomm.info/SSIndia2); Multi-hazard Early Warning System (MH-EWS) projects, Integrated Coastal Area Management (ICAM).

The Institute of Water Modelling (IWM) customized a Bay of Bengal Model (BoBM). Herein tides, storm surges and coastal inundation are regarded in a depth-integrated two-dimensional hydrodynamic model. The numerical modelling system MIKE 21 FM is applied, which is based on an unstructured flexible mesh consisting of triangular and quadrangular elements. The model has two open boundaries; one is in the Lower Meghna River at Chandpur, the other in the open sea located along the line extending from Vishakapatnam in India to Gwa Bay in Myanmar. BMD could operationalize this model taking tides, storm surges and coastal inundation into account at BMD as well.

For inundation scenarios along the Bangladeshi coast, where thousands of small tributaries, embankment and tidal effects make a complex situation, a highly sophisticated hydrodynamic model is essential to get realistic inundation scenarios. At present, BMD doesn't have any capacity on hydrology or hydrodynamic modelling. The Flood Forecasting and Warning Center (FFWC) of the Bangladesh Water Development Board operates a flood forecasting system,
which is using a coupled scheme combining MIKE BASIN (for water resources) and MIKE 11 (1D-hydraulic model including inundation). MIKE Basin, a GIS-based modelling tool for water resources, includes the management of droughts to allocate water to the most needy areas and uses. While MIKE 11 is an approach for the rainfall-runoff and river and flood plain flows, including control structures, dam break, water quality, and flood and pollution forecasting. In addition, the MIKE 11 GIS module maps the extent, depth and duration of flooding. This flood forecasting model at FFWC is covering rivers and flood plains of the north, north-east, central, and north-west part of the country. Output of this model could be used as the input boundary of the proposed coastal model. And this system includes updated hydrodynamic regional models covering the rivers and flood plains of the south-west and south-east hydrological zone of Bangladesh (http://www.ffwc.gov.bd).

At the same time, on R&D basis, Delft-3D, SOBEK has also been customized by many University and research organizations (e.g. BUET, CEGIS, etc.). Delft3D could be a suitable option in this case to make a coupling model for coastal inundation, since Delft3D is open source model which presents major opportunities to apply process-based modeling to a large number of scenario simulations. Considering the features of the models, an integration of the models can be suggested for inundation forecasting. To obtain the winds and pressures a WRF/HWRF model can be used. Although the SWASH model has some additional features than SWAN model, SWAN model might be better suit considering the SWASH model is in a developing stage and it has some limitations which cannot be overlooked in this case. Again, the coupling of Delft3D and SWAN can finally be used to provide the inundation scenario.

The integrated model will be forced by forecasted results coming from surge model. Estimated local precipitation and evaporation over the model domain based on actual meteorological observations provide hydrological forcing to the hydrological model, which in turn simulates local runoff into the hydrodynamic model. The integrated hydrology-hydrodynamic model will be used to simulate the effects where it is influenced by the combination of both river inflows and surges within the river basins of Bangladesh. For such areas it is very important that the surge model have a capability to considered flooding and drying (i.e. inundation) within its numerical framework. The river model should consider forecasted rainfall amounts and utilize boundary conditions from upstream discharges, wherever such discharges are significant. The river model could be set up to run independently in areas where the flows are not influenced by backwater effects due to coastal surges; however, it will likely be very important to consider both the surge and the river contributions to flooding in most coastal regions.

6.3 Integrated Decision Support System (for cyclones)

An integrated Decision Support System could be developed, enabling a Web-GIS based system with an integrated GIS based mapping environment. The application could be written using language such as PHP, Javascript, Fortran and Perl. The whole system architecture is shown in Figure 11. The system could be used severe cyclone forecast 3 to 5 days in advance using the above mentioned models for cyclone, storm surge, wave and inundation. This could be associated with the severity (wind speed and surge height), projected track, etc. with the historical cyclone data (which could be stored in a database) to identify the risk zones on coastal areas of Bangladesh. Once the risk zone is identified, and surge height and velocity are known from the surge models, the system will run the inundation model to generate coastal inundation maps. These coastal inundation maps, along with wind speed and other local data (building, population, land-use, etc.) are then used by the system to generate potential impacts on each of the vulnerable commodities (building, population, agriculture, livestock, etc.). The system will be capable to project impact outlooks along with suggestive response option (such as evacuation to shelters, critical road infrastructure during emergency, agro response etc.). This information can be used by Governance and Planning groups for decision making purposes. Primarily, the system is broadly divided into three components based on functionality:
6.3.1 Early Warning Component

The Early Warning System uses a combination of indicators and tools. The JMA/IIT storm surge model could be used to generate synoptic information of tropical cyclone three to five days in advance along with the storm system movement and projected path. The calculation of impact likelihood for any individual coastal area is the function of the projected track and storm size (diameter) using storm surge forecast data. Using cyclone and storm surge model, the movement of cyclone and potential impacts on the coastal belt can be identified. This information will further be associated with the inundation modeling to identify the coastal inundation; historical cyclone database with extent of damage; and GIS layers such as Land-use and DEM to identify the maximum potential risk zones. The severity of the cyclone will be computed as a function of maximum wind speed and cyclone surge height on the coastal areas.

<table>
<thead>
<tr>
<th>Wind-Speed(km/h)/Diameter (km)</th>
<th>( &lt;= 100 )</th>
<th>( &gt; 100 )</th>
<th>( &gt; 240 )</th>
<th>( &gt; 420 )</th>
<th>( &gt; 600 )</th>
<th>( &gt; 700 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>90-125</td>
<td>Gales</td>
<td>Gales</td>
<td>Gales</td>
<td>Gales</td>
<td>Gales</td>
<td>Gales</td>
</tr>
<tr>
<td>125-165</td>
<td>LD</td>
<td>Destructive</td>
<td>Destructive</td>
<td>Destructive</td>
<td>Very Destructive</td>
<td>Very Destructive</td>
</tr>
<tr>
<td>165-225</td>
<td>Destructive</td>
<td>Very Destructive</td>
<td>Very Destructive</td>
<td>Very Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
</tr>
<tr>
<td>225-280</td>
<td>Very Destructive</td>
<td>Very Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
</tr>
<tr>
<td>( &gt; 280 )</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
<td>Severely Destructive</td>
</tr>
</tbody>
</table>
It can be observed that large, slow-moving systems represent a greater risk than small, fast-moving systems, even if both storms are the same category.

Forecasting of tropical cyclones is a particular challenge for urgent computing because of the need for consistency and reliability. The need for reliability stems from the fact that the supply of highly detailed guidance for these events motivates end-users to quickly promote them from nice-to-have to must-have with a concomitant increase in demand. The major challenge for urgent computing of tropical cyclone guidance is accuracy. Reasonably accurate and timely skill in forecasting of storm surge, waves, and winds from cyclone and extra-tropical storms requires several key elements to be available:

1. Sufficiently high spatial resolution of the region of interest. It is critical to explicitly represent features of the coastal region that have a fundamental impact on surge and wave propagation, such as levees, roadways, and sand dunes.
2. Representations of the surface wind and atmospheric pressure fields that describe the storm.
3. Infrastructure resources available to complete the forecast in a specified time frame. This includes resources to compute the forecast solutions, process the output, generate, store, and online publish the end-user products.
4. Use of an interoperability framework to provide and share geospatial information and model results. This can be achieved by using publicly available and widely accepted interface standards like the Open Geospatial Consortiums (OGC) specifications as a way for data access and visualization (Web Mapping (WMS) and Web Feature Services (WFS) (Google Earth files, GeoTIF and shape files, image files for custom visualization applications, (Blanton et al., 2012))

### 6.3.2 Risk Analysis Component

As soon as the potential risk zones, impact severity and impact likelihood are determined, the system will estimate potential impacts on vulnerable commodities within the cyclone impact zone to project the damage and to identify the commodities that are highly vulnerable. The system will generate impact outlook using GIS maps and data for each individual commodity (population affected, agriculture, livestock, buildings and houses etc.) affected. Susceptibility of the vulnerable commodities would be determined as potential impact and spatial extent of the cyclone.

| Table 9: Potential impacts due to cyclones and its extent categorized. |
|---------------------------------|---------------|---------------------------------|
| **Element** | **Severity** | **Description** |
| POTENTIAL IMPACTS | minor | Cyclone category of either 1 or 2 moving either fast (>20 km/hr) or slow (<20 km/hr) |
| | Moderate | Cyclone category of 3 or 4 moving fast |
| | Severe | Cyclone category of 3 or 4 moving slow or 5 moving either fast or slow |
| SPATIAL EXTENT | Localized | Impact area limited to a narrow track with destructive and gale force winds not extending more than 75km on either side of the track |
| | Extensive | Very wide path with destructive and gale force winds extending |
To accurately determine the extent and severity of cyclone impacts for each vulnerable commodity and subsequent extent of damage, the severity of impacts for each vulnerable commodity is associated with a damage function or metric. This identifies the extent of damage. For example, the damage extent for a particular building type could be associated with the following metric.

<table>
<thead>
<tr>
<th>Damage Severity Description</th>
<th>Score</th>
<th>0%</th>
<th>1-10%</th>
<th>11-30%</th>
<th>31-50%</th>
<th>51-75%</th>
<th>76-100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lightly Damage</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate Damage</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy Damage</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Complete Damage</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Damage levels represent impact groupings and encapsulate both group and individual similar structures. For example, Damage Level 3 applies to either minor structural Damage (e.g. 11-30% damaged) or High Structural Damage (31-50%).

GIS based potential hazard/risk maps of all the vulnerable commodities, with the extent of damage, could be generated. These maps can be used by planners and management staff for decision-making purposes.

### 6.3.3 Incident Response Component

Specifically, the incident response component identifies the governance, planning, operations, logistics, and financial and inter-agency liaison arrangements for a cyclone response. The actual response level is determined based upon the situation analysis. The governance group assesses the information presented within the situation analysis to make a final decision on the required level of response. Once the potential inundation/hazard maps and data are generated, these data will be used along with stored data regarding the shelter locations, road networks, dykes and other data for response options. It will be applied to sectors like agriculture: it generates evacuation information for population to the nearest shelters and advisories to minimize the loss of agriculture to plan in advance.

### 6.3.4 Data-Management component

Site-specific data such as DEM, land use data, population, infrastructure data, shelter locations, road network, and river network will be stored as GIS layers and database tables and can be accessed dynamically during runtime to retrieve values of various input parameters for any location. The database will also include knowledge base of historical cyclone characteristics, model parameters, damage functions and building inventory.
6.4 General Model Representation

The Bay of Bengal is the breeding place of catastrophic cyclones. It is presumed that the Inter Tropical Convergence Zone (ITCZ), which is situated near the equator and where winds from the two hemispheres meet, plays a vital role in the formation of the tropical cyclones in this area. A severe tropical cyclone hits Bangladesh every 3 years on average, and it is generally formed in the months just before and after the monsoon and intensified as they move north over the warm waters of the Bay of Bengal. They are accompanied by high winds of over 150 km/h and can result in storm surges up to ten meters high, resulting in extensive damage to houses and loss of human life and livestock in coastal communities. Moreover, in a flat country such as Bangladesh, water is almost everywhere, on the surface and underground. The coast of Bangladesh also has thousands of tributaries with tidal fluctuations. Thus, an integrated model for coastal inundation in the Bangladesh is quite challenging but not impossible.

For CIFDP, demarcation is required between the main rivers, including those ones in the floodplains, and water flow, taking into consideration the wind, storm surges and tides. The main rivers could be represented in a hydrodynamic model in 2D grid system. The storm surge and wave model could be represented by 2D surge/wave models, as the final boundary condition of the river model. Figure 12 illustrates the adopted approach for the model.

The upstream boundary, an inflow, is provided by the Ganges-Brahmaputra-Meghna model induced by hydrological model runoff output, while the downstream boundary, the storm surge height, is prepared using the storm surge model.

As limited computation time is a major requirement, the models could initially be based on a coarse grid with 1×1 km cells. The model algorithms should be tested to check if the computation performance of a less coarse grid would be acceptable to use.

As can be seen in the figure 12, the river will have a lateral flow point at every grid spacing, enabling at every grid cell a lateral exchange, such as discharge to the river, withdrawal from the river, or overflow to the extended floodplain. In addition, a cross-section is also preferred on specific grid spacing. The core modules of the system apply different spatial representations, namely a 2D-grid (square cells) and a 1D-network.

Delft 3D or similar approaches such as SWASH and MIKE 21/3 are also able to solve 2D hydrodynamics for storm surges, tides and runoff.
6.4.1 Data Flow

Within the design of the integrated Decision Support Framework, various issues need to be tackled. This section addresses the main issues on the software architecture, with focus on the data flow and the engines underlying the different computation jobs. Analyzing the flow of data is essential, as each piece of data has to come from somewhere and each transformation has to be done by some piece of software. The commitment from the NCT on data sharing is a major achievement in this regard.

With respect to data flow, it is also essential the notion of difference in data types. A distinction needs to be made between data which varies over space and time, data varying over space only, and data that does not vary over space and time. However, the core modules of the system apply different spatial representations, namely a 2D-grid (square cells) and a 1D-network. Therefore, a distinction needs to be considered between grid-based data or network-based data. This report does not describe in detail the data flows, but it could be included in the full implementation plan once the system design has been finalized. For an example, based on the proposed system design, the global condition could be described as it follows:

![Figure 13: Global condition of data flow](image-url)
6.4.2 System Requirements

This section describes some of the freely available software's minimum system requirements. This could give an idea about running some different software's basic requirement. Users can set up any of these models or similar category as a research model.

Requirements for WRF (Cyclone modeling software)

The WRF code is written in Fortran and newly developed WRF portal software is written in Java. The general system requirements are:

- Minimum (Java) JRE 1.5
- FORTRAN 90/95 compiler
- JRE 1.6 recommended for best performance
- Runs on local computer or remote computer
- Uses SFTP/SSH-2 to connect to remote computers
- Can be run “locally” on a remote computer with X display forwarding
- Can be run from web page as a Java Web Start application or downloaded and run from the command line
- 390 MB of RAM (memory) available
- 1024 x 768 (or better) video display

Requirements for HWRF (Cyclone modeling software)

While the majority of the HWRF source code is written in FORTRAN, the HWRF system relies on ancillary programs written in Perl, shell script, and C. These tools, along with gnuMake, are required. In addition, the HWRF I/O API requires netCDF, so that library should be available on the system. For a basic build of the HWRF system, the following system tools/libraries are required:

- FORTRAN 90/95 compiler
- C compiler
- MPI V1+
- Perl
- netCDF V3.6+

In addition to the system tools listed above, the HWRF system also requires the wgrib program to manipulate and decode GRIB files. The source code can be obtained from NOAA on their website: http://www.cpc.noaa.gov/products/wesley/wgrib.html

The HWRF system has been successfully built and runs on two types of computer hardware:

- IBM with xlf Fortran compiler
- Linux (both 32 and 64-bit) with
- PGI pgf90 (v9 – v11)
- Intel ifort (v7 - v9)

Requirements for SWAN (Wave modeling software)
The minimum system requirements for SWAN are moderate compared to typical modern computer hardware. SWAN runs on these operating systems: Windows 2000, Windows XP, Windows Vista and Windows 7. SWAN can run on a PC with Windows 2000 as OS, a 1 GHz Pentium 3 as CPU, 256MB as RAM. The hard drive needs to have less then 100MB available to let install SWAN, and to save raw data and processed output files. There are no special requirements on the video, audio, network cards or on other devices. It is only necessary the use of an USB port to plug the security dongle while SWAN is running. These can be considered the minimum requisite, but for a more comfortable use of the software, any upgraded computer is suggested.

Requirements for Delft3D (Hydrodynamic modeling software)

Delft3D is supported on both Microsoft Windows and Redhat/Linux. The advised minimum requirements are:

- Processor minimum 1.5 GHz but preferred 3 GHz
- Memory minimum 2 GB but preferred 4 GB
- Free Space minimum 10 GB but preferred 100 GB
7 Institutional Arrangements for CIF Bangladesh

The general strategy adopted by CIFDP to operate this project is the establishment of a National Co-ordination Team (NCT) that includes operator(s) of the National Meteorological and Hydrological Service (NMHSs) and the organizational end user community. NMHSs, in cooperation with other national stakeholders, should play a key role in developing, implementing and applying the results of this project. The NMHSs and other national stakeholders including responsible national agencies will establish a Sub-Project National Coordination Team (NCT) to lead the Sub-Project implementation, with the guidance of the PSG for each phase. Closer cooperation with the national authorities for coastal disasters risk and emergency managers will also ensure that user requirements are fully taken into account. A detailed description of the end user requirements for coastal inundation forecast and warning systems in Bangladesh is provided in the User Requirements Plan (URP) for CIFDP-B.

7.1 Generation of Forecasts

Prediction of tropical cyclone and cyclonic storm in the Bay of Bengal and the dissemination of timely warning is the task of the Bangladesh Meteorological Department. The Storm Warning Centre (SWC) of BMD detects and monitors depression or cyclones formation until landfall, and forecasts the cyclone’s future track and storm surge height. Modern technology has provided the means for early detection and constant tracking of cyclone and storm surge at BMD.

The cyclone warning system from BMD is well known and recognized in Bangladesh. Warnings include the following information:

- Position of storm centre
- Direction and rate of movement
- Area likely to be affected specifying upazillas (administrative unit in Bangladesh) of the district if possible
- Approximate time of commencement of gale winds (speed more than 32 km/h or 52 km/h).
- Maximum wind speed expected
- Approximate height of storm surge/tide and areas likely to be affected

The Bangladesh Water Development Board Flood Forecasting and Warning Centre (FFWC) provides river flood forecasts for 24, 48 and 72 hr deterministic and 1-10 days experimental probabilistic forecasts. FFWC has updated hydrodynamic regional models covering the rivers and flood plains of the south-west and south-east hydrological zone of Bangladesh, 19 districts from Satkhira to Teknaf in total.
Figure 14: Organizational Structure of BMD (source: BMD)

Figure 15: Flood forecasting and warning system for river floods of FFWC (source: BWDB)
Table 11. Existing Flood Warning Product Dissemination Routes.

<table>
<thead>
<tr>
<th>Dissemination Medium</th>
<th>FFWC Product</th>
<th>Recipient Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hard Copy (hand delivered), Fax and Email</td>
<td>Bulletins</td>
<td>Prime Minister’s Office, government ministries, BWDB officials, government organizations</td>
</tr>
<tr>
<td>Fax and/or Email only</td>
<td>Bulletins</td>
<td>DMB, DMIC-CDMP, NGO’s, embassies, international donor and aid organizations, news media</td>
</tr>
<tr>
<td>Internet</td>
<td>Bulletins, plots, flood map, Thana status</td>
<td>General public, international</td>
</tr>
</tbody>
</table>

**Product-1.** A sample FFWC regular flood bulletin – “River Situation” (shown for a basin only).

---

**FLOOD INFORMATION CENTRE**
**FLOOD FORECASTING & WARNING CENTRE**
**BANGLADESH WATER DEVELOPMENT BOARD**
**WAPDA BUILDING, 8TH FLOOR, DHAKA.**
E-mail: floodinfo@gmail.com, F flood@bwdb.gov.bd, Site: http://www.fwbc.gov.bd Tel: 9553119, 9550755 Fax: 9557306

**FLOOD AND RAINFALL SITUATION SUMMARY AS ON SEPTEMBER 23, 2013**

**OUTLOOK**
- The Padma, the Brahmaputra, the Jamuna, the Ganges and the Meghna Rivers are in falling trend.
- The Kobadak at Jhikargacha is flowing above its respective danger level by 44 cm recorded today at 06:00 AM.
- The Brahmaputra-Jamuna, the Ganges-Padma and the Meghna may likely to fall in next 72 hours.
- All the monitoring water level stations are below their respective danger levels except kobadak at Jhikargacha.

**STATION ABOVE DANGER LEVEL:**

<table>
<thead>
<tr>
<th>Rivers Name</th>
<th>Station name</th>
<th>Rise (+)/Fall (-) cm</th>
<th>Above Danger Level in cm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kobadak</td>
<td>Jhikargacha</td>
<td>-2</td>
<td>44</td>
</tr>
</tbody>
</table>

**RAINFALL**

<table>
<thead>
<tr>
<th>Station name</th>
<th>Rainfall in mm</th>
<th>Station name</th>
<th>Rainfall in mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rangamati</td>
<td>40.0</td>
<td>Comilla</td>
<td>30.0</td>
</tr>
</tbody>
</table>

**General river condition**

<table>
<thead>
<tr>
<th>Monitored water Level stations</th>
<th>73</th>
<th>Steady</th>
<th>03</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rise</td>
<td>11</td>
<td>Not reported</td>
<td>00</td>
</tr>
<tr>
<td>Fall</td>
<td>59</td>
<td>Above danger level</td>
<td>01</td>
</tr>
</tbody>
</table>

**Figure 16:** Sample of FFWC regular flood bulletin
7.2 Warning Dissemination

In the event of a tropical cyclone, the Cyclone Preparedness Program (CPP) receives the cyclone warning signals from Storm Warning Centre (SWC) of BMD as soon as a depression is formed in the Bay of Bengal. The information is transmitted to the six Zonal offices over HF radio. The Assistant Directors in turn pass it on to Unions through VHF radio. Where VHF radio has not yet been installed, messenger then passes on the message (Figure 17). The Union team Leaders contact the Unit Team Leaders immediately after (Figure 18). The Unit Team Leaders with their volunteers spread out in the villages and disseminate the cyclone warnings, almost door-to-door, using megaphones, hand sirens and public address systems. The Team Leaders at the same time keep track of the approaching cyclone by listening to national radio broadcasts over transistor radios. The team leaders are thus alerted and start work without losing time. The volunteers keep on announcing the special weather bulletins on the characteristics of the approaching cyclone, following their action plan.

The Cyclone Preparedness Program has a total of 159 full-time personnel, and 28,450 trained male and 14,225 female volunteers. In Dhaka, the program office counts with 31 staff, headed by the program Director with the main function of managing the program. At field level, the implementation of the program is divided into four levels. At the unit level, there are 2,845 teams of volunteers. Each team has 10 male and five female members headed by a team leader. The unit teams are in the frontline of the warning system to disseminate cyclone warning signals among villagers and assist in their evacuation. The teams are equipped with basic warning equipment such as hand sirens, megaphones and transistor radios to receive meteorological information and cyclone warning signal bulletins transmitted by Radio Bangladesh. Volunteers are selected by the villagers using a defined set of criteria. Full-time offices based in 32 Upazilas support the activities of the volunteers; each office is equipped with a transceiver radio. Between the two cyclone seasons, the Assistant Directors conduct training sessions for the volunteers.
THE SEVERE CYCLONIC STORM “SIDR” (ECP 968 HPA) WITH A CORE OF HURRICANE WINDS OVER EAST CENTRAL BAY AND ADJOINING SOUTH EAST BAY MOVED SLIGHTLY NORTHWARDS AND NOW LIES OVER EAST CENTRAL BAY AND ADJOINING AREA WAS CENTERED AT 06 AM TODAY (NOVEMBER 14, 2007) ABOUT 860 KMS SOUTH-SOUTHWEST OF CHITTAGONG PORT, 880 KMS SOUTH-SOUTHWEST OF COX’S BAZAR PORT AND 925 KMS SOUTH OF MONGLA PORT (NEAR LAT 14.0°N & LONG 90.2°E). IT IS LIKELY TO INTENSIFY FURTHER AND MOVE IN A NORTHLY DIRECTION.

MAXIMUM SUSTAINED WIND SPEED WITHIN 74 KMS OF THE STORM CENTER IS ABOUT 165 KPH RISING TO 185 KPH IN GUSTS /SQUALLS. SEA WILL REMAIN VERY HIGH.

MARITIME PORTS OF CHITTAGONG, COX’S BAZAR AND MONGLA HAVE BEEN ADVISED TO KEEP HOISTED WARNING SIGNAL NUMBER FOUR (R) FOUR.

ALL FISHING BOATS AND TRAWLERS OVER NORTH BAY HAVE BEEN ADVISED TO REMAIN IN SHELTER TILL FURTHER NOTICE.

[Source: Bangladesh Meteorological Department – BMD]
Various types of information take place in the content of cyclone early warning information. The types of information generally included in the content are:

- Severity
- Wind speed within the cyclone
- Speed of the cyclone
- Direction
- Distance from the coast
- Signal
- Possible areas to be inundated by tides and surges.

7.3 Institutional Arrangements for Cyclone Warning Dissemination

The institutional arrangement for cyclone/storm surge early warning dissemination down from upazila to household level can be articulated in following diagram. The responsibilities for each of the agencies in respective tiers are shown in a synchronized manner below.

![Cyclone/Storm Surge Warning Dissemination Flow Diagram](Figure21).

EW section incorporation is needed. Particularly for the role assignment and accountability of the institutions at community level and specifically to hazards needs to be clearly mentioned.
in Standing Order for Disaster (SOD). It would allow the agencies to have a clear mandate what to do for local level EW. Hazard specific Standard Operating Procedures (SOP) following the SOD and other hazard specific standards need to develop as emphasized by CDMP (Comprehensive Disaster Management Program of Bangladesh Government) as well.

7.4 Community Capacity Building

A warning system cannot be effective unless the end users of the warning know what to do with the information. This local awareness and understanding can only come from community partnerships and pro-active education and outreach efforts before warnings are issued. Effective education and outreach can be achieved by fostering partnerships among community organizations and local agencies to help BMD, DDM and other relevant agencies (i.e. CPP) educating the public about the warning system and how to respond. The uncertainty of forecasts and their challenges need to be shared with communities and local governments in order to create a common understanding between users and the forecast providers.

Some of the IEC materials that can be recommended for the cyclone prone areas are as follows, which are widely used at the community level for capacity building and refreshing their knowledge about the cyclone warning codes and meanings. These are collaboratively prepared on the basis of the existing materials that are used earlier by the CPP in the coastal areas.

![Figure 22. Various types of IEC materials developed for community awareness and interpretation of the cyclone early warning messages at community level.](image-url)
### 8 Assessment of Capacity Gaps of Institutions Related to CIF in Bangladesh

This section summarizes the roles and responsibilities of each agency for the project implementation. This information has been collected through group meetings as well as interviews with the individual organizations.

#### Table 12: Roles and Responsibilities of the NCT

<table>
<thead>
<tr>
<th>Technical Partners</th>
<th>Major Roles and Responsibilities</th>
<th>Current Capacity</th>
<th>Future Needs</th>
</tr>
</thead>
</table>
| BMD                | • General coordination of the work by NCT will be led by BMD  
                    • Met and Ocean data input (in real time and hindcast) and part of model development, validation and calibration.  
                    • Will integrate with cyclone forecast to storm surge and inundation extent and depth  
                    • Develop coastal inundation forecasting by coupling tides, storm surges, and river flood forecast models  
                    • Develop optimum mode of operation (run time, etc.)  
                    • The technology for air observatories, radar and satellite stations, agro-meteorological observatories, geomagnetic and seismological observatories & meteorological telecommunication system  
                    • Different kinds of meteorological NWP models (WRF, NHMS), storm surge and wave models operational.  
                    • Technical, experienced and skilled personnel who have a vast knowledge on Bangladesh meteorology.  
                    • Wide coverage of meteorological stations which cover different hydro-met data.  
                    • Radars and satellite image cover overall country. |  
|                    | • Technical support and training for storm surge and inundation modelling including advanced WRF  
                    • Data assimilation  
                    • Large computing power to increase resolution and decrease run time.  
                    • Some tide gauge with telemetry for initialization and validation  
                    • Validation using different statistical technique.  
                    • GIS facility for graphical presentation and for easy understandable to end user |  
|                    | • Some tide gauge with telemetry for initialization and validation  
                    • Validation using different statistical technique.  
                    • GIS facility for graphical presentation and for easy understandable to end user |  
| BWDB               | • BWDB will also need to take major leading role in the NCT.  
                    • Contribute water level, discharge data (in real time and hindcast), data | • Having technical capacity and skilled professionals for the development and operation of the water level forecast/flood model |  
<p>|                    | | | • Need to couple the storm surge model with the hydrological and hydrodynamic model to cover the coastal zone of Bangladesh. |</p>
<table>
<thead>
<tr>
<th>Technical Partners</th>
<th>Major Roles and Responsibilities</th>
<th>Current Capacity</th>
<th>Future Needs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>on infrastructure, coastal polders, embankments, roads, etc.</td>
<td>forecasting model (Hydro-Dynamic Model)</td>
<td>Capacity development of the FFWC, in equipment support and technical support on coastal flood forecasting</td>
</tr>
<tr>
<td></td>
<td>• Develop coastal inundation forecasting by coupling tides, storm surges, and river flood forecast models</td>
<td>• Flood forecasting model covering the rivers and flood plains of the north, north- east, central and north- west part of the country. Output of this model could be used as the input boundary of the proposed coastal model.</td>
<td>• Capacity development of the professionals (through training)</td>
</tr>
<tr>
<td></td>
<td>• Develop optimum mode of operation (run time, etc.) schedules</td>
<td>• Updated hydrodynamic regional models covering the rivers and flood plains of the south-west and south- east hydrological zone of Bangladesh, covered the entire zone total 19 districts from Satkhira to Tekhna</td>
<td>• Strengthening human resources of the FFWC.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• In some selected locations there are limited time series data of water level of the coastal rivers and estuary</td>
<td>• Improved internet connectivity, with very high speed data transmission.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Limited Bathymetry data (river cross section and long profile etc.) of the coast of Bay of Bengal</td>
<td>• Finer resolution and recently developed DEM for flooding module.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Design data related to all water resources management infrastructure (polders, sluices, regulators, etc.)</td>
<td>• Real time meteorological, oceanographic and hydrological data (rainfall, water level, tide level, discharge etc.) exchange and sharing with national and international organization (WMO)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Old DEM with coarse resolution (300m×300m)</td>
<td>• High capacity, high speed computer system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Licenced copy of the MIKE 11 (version 2003) developed by DHI for Hydrodynamic and rainfall run-off simulation</td>
<td></td>
</tr>
<tr>
<td>Technical Partners</td>
<td>Major Roles and Responsibilities</td>
<td>Current Capacity</td>
<td>Future Needs</td>
</tr>
<tr>
<td>--------------------</td>
<td>----------------------------------</td>
<td>------------------</td>
<td>-------------</td>
</tr>
</tbody>
</table>
| RIMES              | • Assess national capabilities for coastal flood risk / inundation forecasting and related emergency management structures together with national stakeholders (i.e. BMD, BWDB, DMB, CPP, etc.)  
• Compile high level inventory of the institutional end-users’ information and communication needs for emergency management during extreme coastal flooding events together with NTC;  
• Facilitate to introduce models possible to be operated in Bangladesh, such as MRI storm surge model, SLOSH, ADCIRC, DHI, Wave Watch 3 and others | • Office accommodation for the proposed work with network connection, telephone, email, internet and fax, needed for the project.  
• Operational tsunami inundation models for the region.  
• Operational flood forecasting models for the region.  
• Operational WRF model for the region.  
• Operational storm surge models | • Capacity to generate coastal inundation. |
| BUET/IWFM          | • Participant to Identification of the best-suited models for Bangladesh  
• Attend periodic NCT meeting and provide academic guidance | • Laboratory support for prototype modelling  
• Expertise in modelling knowledge related concept | • Training on new state of art technology for further research incubators. |
| BIWTA              | • Share database on tide gauges and other water communication information as required.  
• Participate NCT meetings and assist for any support required | • Disseminate navigational and meteorological information including publication of river charts  
• Provided pilotage and hydrographic survey services. | • Need capacity development on tidal/ ocean mathematical modeling  
• Telemetric tide gauge for observations |
<table>
<thead>
<tr>
<th>Technical Partners</th>
<th>Major Roles and Responsibilities</th>
<th>Current Capacity</th>
<th>Future Needs</th>
</tr>
</thead>
</table>
| NAVY               | • Coordinate with BMD and FFWC for the application  
• Share data, Naval chart and other marine database (i.e. current data)  
• Participate NCT meetings and assist for any support required | • Provide published Naval Charts of the coastal area and share available marine meteorological data like current, wind, etc.  
• Participate NCT meeting and provide coordinated support as requested by BMD through Armed Forces Division (AFD) | • Capacity building on new technology, data collection process. |
| SoB (Survey of Bangladesh) | • Share data on topography, coastal bench mark, tidal analog and digital data, DEM other database  
• Participate NCT meetings and assist for any support required | • Conducting survey for new DEM generation  
• stored all country maps  
• Social and demographic data | • Training and survey techniques. |
| SPARRSO            | • Share satellite data  
• Participate NCT meetings and assist for any support required | • Capacity to provide images for any disaster period  
• Availability of Island data, erosion, accretion, land use data; long term erosion and accretion data (1973 to 2011) for land and island; afforestation data and temperature mapping data which could be an useful tool for research work | Training on GIS applications for coastal risk management. |
| BBS                | • Share demographic and Socio-economic data  
• Participate NCT meetings and assist for any support required | • Availability of socio-economic data which can be useful for the implementation  
• Availability of damage data after an aftermath | Advanced data collection and analysis process. |
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Annex-I: Past Cyclonic Disaster Profile

Bangladesh is a disaster-prone country that is affected almost every year by some form of natural disaster, be it floods, torrential rains, erosion, or cyclones. Of the 508 cyclones that have originated in the Bay of Bengal in the last 100 years, 17 percent have hit Bangladesh, amounting to a severe cyclone almost once every three years. Of these, nearly fifty three percent have claimed more than five thousand lives. The geographical setting of Bangladesh makes the country vulnerable to natural disasters. The mountains and hills bordering almost three-fourths of the country, along with the funnel shaped Bay of Bengal in the south, have made the country a meeting place of life-giving monsoon rains, but also make it subject to the catastrophic ravages of natural disasters.

On 15 November 2007, Cyclone Sidr struck the coast of Bangladesh and moved inland, destroying infrastructure, causing numerous deaths, disrupting economic activities, and affecting social conditions, especially in the poorer areas of the country. However, the Government’s recent investment in an early warning system served to limit these damages and led to timely evacuation of the affected populations.

I.1 Cyclone SIDR:

The Super Cyclone ‘Sidr’ was first observed on 9 November 2007 near the southeast of the Andaman Islands with a weak low-level circulation near the Nicobar Islands. It showed indication of the formation of a tropical cyclone on 11 November while located a short distance south of the Andaman Islands. Bangladesh Meteorological Department (BMD) advised maritime ports of Chittagong, Cox’s Bazar and Mongla to keep hoisted distant cautionary signal number one which is the lowest level of preparedness on a scale of 1 to 11. On 13 November, the depression had turned into a cyclonic storm with a core of hurricane force winds. Maritime ports of Chittagong, Cox’s Bazar, and Mongla were advised by the BMD to hoist warning signal number four, which meant that all fishing boats and trawlers over North Bay were advised to take shelter immediately.

Cyclone Sidr moved northwards and was centred at 9 p.m. on 14 November 2007 about 725 kms south-southwest of Chittagong port, 645 km South-southwest of Cox’s Bazar port and 670 km South of Mongla port. BMD predicted that it was likely to intensify further and move in a Northerly direction and may cross Khulna-Barisal coast by noon of 15 November 2007. Maximum sustained wind speed within 74 kms of the storm centre was about 190 kph rising to 210 kph in gusts/squalls. Maritime port of Mongla was advised to keep hoisted great danger signal number ten. The coastal districts of Bhola, Barisal, Patuakhali, Barguna, Pirojpur, Jhalakathi, Bagerhat, Khulna, Satkhira and their offshore islands and chars were also put under great danger signal number ten. Chittagong and Cox’s Bazar were put under great danger signal number 9. Bangladesh Meteorological Department was responsible for the issuance of cyclone warnings which included advisory messages on the level of warning using the government warning signal system. Warnings were being regularly sent to communities and once warning signal number 4 was hoisted the Cyclone Preparedness Programme (CPP) mobilised its 44,000 volunteers who immediately began to implement a community based warning system utilizing megaphones and other devices. Overall, the Early Warning System worked well. Three million people were evacuated and 1.5 million were accommodated in cyclone shelters. Cyclone Sidr hit Bangladesh’s offshore islands at approximately 18:30 hours on the evening of 15 November and made landfall across the Barisal coast at 2100 hours local time during ebb tide. Wind speeds reached up to 240 km per hour (JTWC) affecting 15 districts with 15 others partly affected. The category 4 storm was accompanied by tidal waves up to five meters high and surges up to 6 meters in some areas, breaching coastal and river embankments, flooding low-lying areas and causing extensive physical destruction. High winds and floods also caused damage to housing, roads, bridges, and other infrastructure.
Electricity and communication were knocked out, and roads and waterways became impassable. Drinking water was contaminated by debris and many sources were inundated with saline water from tidal surges, and sanitation infrastructure was destroyed. The cyclone SIDR was the second natural disaster to affect Bangladesh in twelve months of 2007. Monsoon floods had previously caused extensive agricultural production losses and destruction of physical assets, totaling near US$ 1.1 billion. The occurrence of these events in close succession is a reminder of the country's extreme vulnerability to frequent hydro-meteorological hazards, which stand to be further, exacerbated because of climate change.

I.2 Cyclone AILA:

Cyclone Aila was the second tropical cyclone to form within the Northern Indian Ocean during 2009. The disturbance that was to become Cyclone Aila formed on 21 May 2009. Over the following days the disturbance slowly intensified into a cyclonic storm, named Aila, located approximately 350 kms offshore. Cyclone Aila became a severe cyclonic storm on 25 May. The system maintained a cyclonic intensity for approximately 15 hours after making landfall.

Hitting during high tide, the cyclone brought with it tidal surges of up to 6.5 metres, affecting 11 coastal districts. This surge of water damaged and washed away over 1,742kms of embankments, removing the only protection available to many people along the coast. The storm lingered over the coast of Bangladesh for a comparatively longer time than Cyclone Sidr (2007), which further increased its impact. In many areas the damage to the network of embankments has resulted in a prolonged continuation of what affected communities faced in the immediate aftermath of the cyclone – flooding. Breeches in the embankments, which become severe during daily high tides, and particularly during periods of full moon, have prevented the high levels of self-recovery normally seen in Bangladesh following disaster events.

Table I: A Casual Risk Assessment of Past 2 Cyclones

<table>
<thead>
<tr>
<th>Year</th>
<th>2007</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>DISASTER</td>
<td>CYCLONE (SIDR)</td>
<td>CYCLONE (Aila)</td>
</tr>
<tr>
<td>District</td>
<td>30</td>
<td>11</td>
</tr>
<tr>
<td>Upazila</td>
<td>200</td>
<td>64</td>
</tr>
<tr>
<td>People</td>
<td>8923259</td>
<td>3928238</td>
</tr>
<tr>
<td>Crops damaged Fully (Acre)</td>
<td>743322</td>
<td>77486</td>
</tr>
<tr>
<td>Crops damage Partially (Acre)</td>
<td>1730317</td>
<td>245968</td>
</tr>
<tr>
<td>No. of House damage Fully</td>
<td>564967</td>
<td>243191</td>
</tr>
<tr>
<td>No. of Dead People</td>
<td>957110</td>
<td>370587</td>
</tr>
<tr>
<td>No. of Dead Livestock, cattle and goats</td>
<td>3363</td>
<td>190</td>
</tr>
<tr>
<td>Road Damage Fully (Km)</td>
<td>1778507</td>
<td>150131</td>
</tr>
<tr>
<td>Road Damage Partially (km)</td>
<td>1714</td>
<td>2233</td>
</tr>
<tr>
<td>Embankment Damages</td>
<td>6361</td>
<td>6621</td>
</tr>
<tr>
<td>Crops damaged Fully (Acre)</td>
<td>1875</td>
<td>1742.53</td>
</tr>
<tr>
<td>Crops damage Partially (Acre)</td>
<td>2007</td>
<td>2009</td>
</tr>
</tbody>
</table>

Source: DMB