159 cyclones since 1877 or (1.2 cyclones per year)
Cyclone Risk spans the entire coastline.
Height of storm surges during a cyclone historically 1.5 to 9 m.
Damage from Cyclone **Sidr** (2007)

- Number of Death: 3,406
- Number of Injury: 55,282

In addition,
Estimated Total damages and indirect losses: $1.67 billion or 2.6% of GDP

**Of which**
- Housing $839 million (50%)
- Agricultural $438 million (26%)
- Transport $141 million (8%)
- Water Resource Control $71 million (4%)
- Education infrastructure $69 million (4%)
- Other sectors $117 million (8%)

Source: Govt. of Bangladesh (2008)
Climate change is expected to increase tropical cyclones and storm surges

- Storm surges and related floods are likely to be more severe in intense tropical cyclones in future.
  ---IPCC AR4 (2007)

- Large increases in the frequency of highest storm surges (despite no significant frequency of cyclones) is expected in the Bay of Bengal by the RCM.

- Significant increase in the percentage change in landfall power of tropical storms for North Indian ocean by 2100 projected by the MIROC GCM.
  ---Emanuel (2009)

▶ Vulnerability of Bangladesh may increase even more in a changing climate.
Methodology of the Research

1. Project inundation depth from storm surges and demarcate potential vulnerable zone
   a. Baseline without climate change
   b. With climate change.

2. Identify assets & activities exposed to inundation risk in 2050.

3. Project potential damage (& loss) from a cyclone with a 10-year return period 2050.

4. Identify additional adaptation measures beyond what currently exists to protect against potential damages.

5. Estimate costs of additional adaptation measures.
Baseline Scenario: 19 historical severe cyclone tracks with actual observed meteorological parameters (*Maximum wind speed; radius of influence, cyclone tracks, forward speed and direction and central and neutral pressure*).

Climate Change Scenario: Five cyclone tracks spanning the coast line, meteorological parameters same as Sidr for the artificial track, 10% increase in wind speed, 27 cm sea level rise, Land fall at high tide.
Vulnerability to Storm Surge Inundation
(Maximum inundation depth under all simulated cyclone tracks)

Baseline Scenario

With Climate change

Low Vulnerability Area (less than 1m)

High Vulnerability Area greater than 1m)

Climate change affects:

a) expands vulnerable zone inland
b) increases depth of inundation
High Vulnerability Area in a Changing Climate

<table>
<thead>
<tr>
<th>Inundation Depth (m)</th>
<th>2050 without Climate Change</th>
<th>2050 in a Changing Climate</th>
<th>Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 m – 3 m</td>
<td>20,876 m²</td>
<td>23,764 m²</td>
<td>+14 %</td>
</tr>
<tr>
<td>More than 3 m</td>
<td>10,163 m²</td>
<td>17,193 m²</td>
<td>+69 %</td>
</tr>
</tbody>
</table>
In the early sixties and seventies, 123 polders (of which 49 are sea-facing) were constructed to protect low lying coastal areas from tidal flood & salinity intrusion.
Coastal Polders at Risk of Overtopping

Baseline Scenario

With Climate change

- Baseline scenario: 30 sea-facing and 14 interior polders
- With climate change: 33 sea-facing and 26 interior polders
Projection of Damage & Loss in a Changing Climate – 2050: Building Blocks

- **Exposure:** GIS overlays of projected Population, Assets & Activities living vulnerable areas.
  - Population growth in coastal population: 1% per year.
  - Projection of GDP growth: 6% - 8% per year.
  - Structural changes in economy consistent with above.

- **Affected population and activities**
  - Damage and Loss coefficients based on Cyclone Sidr
  - Adjusted for differential areal extent of Sidr (2007) compared to a historical 10 year return period cyclone of Bangladesh. (Extent of storm surge inundation during Sidr was 8.7% more).
  - Expected areal extent of future storms (At present, average inundation area from a 10 year return period cyclone covers 26% of the total vulnerable area; but it is likely to cover 43% of the total vulnerable area in a changing climate -2050).
## Vulnerable Population Estimates (million)

<table>
<thead>
<tr>
<th>Inundation Depth</th>
<th>(a) At Present</th>
<th>(b) 2050 without Climate Change</th>
<th>Percent Change between (a) and (b)</th>
<th>(c) 2050 in a Changing Climate</th>
<th>Percent Change between (b) and (c)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1m – 3m</td>
<td>16.83</td>
<td>28.27</td>
<td>+68%</td>
<td>35.33</td>
<td>+25%</td>
</tr>
<tr>
<td>More than 3m</td>
<td>8.06</td>
<td>13.54</td>
<td>+68%</td>
<td>22.64</td>
<td>+67%</td>
</tr>
</tbody>
</table>
## Death & Injury from Storm Surges - 2050

<table>
<thead>
<tr>
<th></th>
<th>2050 without Climate Change</th>
<th>Addition due to Climate Change</th>
<th>2050 in a Changing Climate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deaths</td>
<td>5,274</td>
<td>4,637</td>
<td>9,911</td>
</tr>
<tr>
<td>Injury</td>
<td>85,609</td>
<td>75,268</td>
<td>160,877</td>
</tr>
</tbody>
</table>

- **Additional damage from increased number of lives at-risk:** $1.03 billion.
- **Conservative cost of treatment of injuries:** $0.352 million.

### Projection based on

1. Risk of Fatality and Risk of Injury same as Sidr (2007);
2. World Bank estimate of VSL in Bangladesh (Taka 2008): 15.5 million;
3. WHO estimate of cost per outpatient visit at a secondary hospital in Bangladesh: $4.86
### Additional Potential Damage & Loss in Changing Climate out to 2050 (10-year Return Period Cyclone)

<table>
<thead>
<tr>
<th></th>
<th>Estimated Damage (Million $)</th>
<th>Estimated Loss (Million $)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing</td>
<td>1,947.3</td>
<td>-</td>
</tr>
<tr>
<td>Education Infrastructure</td>
<td>9.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Agriculture</td>
<td>75.4</td>
<td>835.4</td>
</tr>
<tr>
<td>Non-Agriculture</td>
<td>87.9</td>
<td>1,084</td>
</tr>
<tr>
<td>Productive Sectors</td>
<td>87.9</td>
<td>1,084</td>
</tr>
<tr>
<td>Roads</td>
<td>239.5</td>
<td>52.7</td>
</tr>
<tr>
<td>Power</td>
<td>60.2</td>
<td>150.0</td>
</tr>
<tr>
<td>Coastal Protection</td>
<td>17.3</td>
<td>-</td>
</tr>
<tr>
<td>Others</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>2,436.6 million</strong></td>
<td><strong>2,122.9</strong></td>
</tr>
</tbody>
</table>
Adaptation Measures

- Height enhancement of Coastal Polders
- Afforestation to protect sea-facing polders
- Construction of Multipurpose Cyclone Shelters
- Construction of Cyclone-Resistant Private Housing
- Strengthening the early warning & evacuation system
Many of these cyclone shelters are in dilapidated condition.
65% of the shelters with no provision for the special needs of women.
80% of the shelters have no provision for livestock.
Adaptation Cost Components

- Coastal Polders: Earth work, Turfing, Vetivera Plantation, Land Acquisition, Slope Protection, Toe Protection.

- Afforestation to protect sea-facing polders: Mangrove Plantation.

- Construction of Multipurpose Cyclone Shelters: Standard Capacity for 1600 occupants with provision for livestocks & safe drinking water.

- Construction of Cyclone-Resistant Private Housing: Brick Houses with Concrete Roofs (on stilts, if necessary), Proper Building Codes.


Source of cost/unit: World Bank, Bangladesh Water Development Board, Bangladesh Meteorological Department, Institute of Water Modeling, Red Crescent Society, Local architects & Civil Engineers.
### Adaptation Cost
(Investment Cost & Recurrent Cost)

<table>
<thead>
<tr>
<th>Adaptation Option</th>
<th>Without Climate Change</th>
<th>Additional Cost with Climate Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polders</td>
<td>2,462 million</td>
<td>893 million</td>
</tr>
<tr>
<td>Foreshore afforestation</td>
<td></td>
<td>75 million</td>
</tr>
<tr>
<td>Cyclone Shelters</td>
<td></td>
<td>1,219 million</td>
</tr>
<tr>
<td>Cyclone Resistant Housing</td>
<td></td>
<td>200 million</td>
</tr>
<tr>
<td>Strengthening of Early Warning &amp; Evacuation System</td>
<td></td>
<td>39 million</td>
</tr>
<tr>
<td>Total</td>
<td>2,462 million</td>
<td>2,426 billion</td>
</tr>
</tbody>
</table>
Summary of Findings

- Storm surge-induced inundation area estimates indicate a potential 69% increase in the vulnerable zone with more than 3m inundation depth and 14% increase in the vulnerable zone with 1m – 3m inundation depth with climate change by 2050.

- Additional 9.12 million coastal inhabitants will be exposed to storm surge inundation depth of more than 3m in a changing climate in 2050.

- The projection of damage suggests a 10-year return period cyclone out to 2050 will result in an additional financial damage and loss of $4.560 billion in a changing climate.

- In addition, a conservative estimate of monetized loss from additional deaths and injuries is $1.03 billion.
Summary of Findings (continued)

- Bangladesh has an adaptation deficit of $2.462 billion.
- The estimate of additional investment necessary to cope with climate change is $2.407 billion with an annual recurrent cost of more than $50 million.
- The comparison of even a conservative* damage estimate from one single 10-year return period cyclone with the adaptation cost indicates the incremental cost of adapting to climate change by 2050 is small compared to the potential damage, and strengthens the case for rapid adaptation.

* This comparison is conservative as damages from more frequent but less intense cyclones (nonetheless destructive) have not been considered.
Photographs have been downloaded from Google Images.
Adaptation Cost for Polders

- Polders at risk of storm surge inundation in a changing climate were identified from positive differences between projected surge heights and existing height of polders.
- Difference between the projected storm surge height and the crest level of embankment of each polder at risk quantified the required height enhancement of the polder.
- The amount of earth needed for this purpose has been derived from engineering designs.
- The BWDB provided current local price for earthwork (Tk 109.96/ m³ if collected from 300m to 1km distance; and Tk 133.44/ m³ if collected from 1km to 5 km distance), compaction and turfing cost (Tk 7.07 per sq meter).
- To prevent “toe-erosion”, cost of hard protection using cement concrete blocks with sand filters and geo-textile, Tk. 224,100/meter has been used.
- Height enhancement of polders will require more land for strengthening the bases. Cost of land acquisition has been added.

- Height enhancement of 26 interior and 33 sea-facing polders to prevent overtopping in a changing climate will cost $892 million.
Foreshore Afforestation

- At present, total length of embankments of 49 sea facing polders in Bangladesh is 957 km, of which only 60 km has forest belts.
- Estimation from Google Earth using GIS methodology indicates 897 km length of existing sea facing polders would require mangrove forests for protection.
- A minimum of 500 meter width of mangrove forest is recommended for protection of sea facing polders.
- According to The Ministry of Water Resources, Bangladesh and the BWDB Current cost of afforestation of mangroves is $168,000 / sq km.

Foreshore afforestation to protect sea-facing polders will cost $75 million.
Adaptation Cost for Emergency Shelters

- In coastal Bangladesh, 8.06 million people were exposed to storm surge inundation depth of more than 3m.
- In 2050, with 1% per year projected growth of coastal population, 13.6 million inhabitants will be exposed to storm surge related inundation depth of more than 3m even without climate change.
- In a changing climate with the projected expansion of the inundation zone as well as an increase in inundation depth coupled with a projected population growth, an additional 9.1 million inhabitants will be exposed to a similar inundation risk.
- At present, a World Bank-funded multipurpose cyclone shelter, under-construction, with provisions for 1,600 people costs $214,000.
- In order to accommodate 9.1 million inhabitants exposed to inundation risk due to climate change, additional 5,702 multipurpose shelters would be required at the estimated cost of $1.2 billion.
- In addition, program to promote cyclone/storm surge resilient housing for areas at risk of inundation less than 3m at an estimated cost $200 million.
  - Subsidize credit facility
  - Subsidized construction material