Exploring Flood Mitigation Strategies in Bangladesh

Pallab Mozumder

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Exploring Flood Mitigation Strategies in Bangladesh

By

Pallab Mozumder

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Water Resources Program
The University of New Mexico
Albuquerque, New Mexico
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Exploring Flood Mitigation Strategies in Bangladesh

By

Pallab Mozumder
Water Resources Program, University of New Mexico, Albuquerque, NM

Professional Project Committee
Dr. Michael E. Campana, Chair
Dr. Janie M. Chermak
Dr. Robert P. Berrens
Committee Approval

The Professional Project Report "Exploring Flood Mitigation Strategies in Bangladesh"

by Pallab Mozumder is approved by the committee:

Michael C. Campas
Chair

Date 10/6/05

Date 10/6/05

Date 10/6/05
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Abstract

As the lowest riparian in a huge transboundary river basin, Bangladesh faces increasing threat of massive flood exposure. This project explores effective flood mitigation strategies for Bangladesh. First it describes the basic characteristics of flooding in Bangladesh, the largest delta in the world. Then it highlights the major flood mitigation strategies so far adopted in Bangladesh. The study provides a holistic framework for describing flood mitigation strategies and discusses the strength of some components that have received little attention. It discusses the consequence of imbalance between short-run and long-run flood mitigation strategies. Given the transboundary nature of the flooding problem in an active delta with a massive hydrologic system, the study recognizes the limitation of piecemeal stand-alone structures to adopt flood control measures. The gigantic scale of the delta formation needs to be taken into account in long-term flood mitigation plan for Bangladesh. The long-term solution to flood mitigation relies on ensuring participation of all basin countries instead of piecemeal intervention. The study emphasizes that while stand-alone strategies should not be ignored, equal effort should be given to a cooperative solution with other basin countries.

Thus, an attempt is made to provide a conceptual framework to extend the bargaining space to facilitate effectively negotiating a cooperative flood mitigation solution among downstream and upstream countries. The project proposes that linking the water-sharing issue with other non-water issues (e.g. transshipment through seaport access) will give more bargaining power to the downstream player. Using insight from basic game theory literature to support this proposition, first the water-sharing issue and the transshipment issue are represented as two separate prisoner's dilemma games. These two issues are then presented
as one linked prisoner’s dilemma game. The gain from linking two games is identified in the bargaining space implying that linking will make the cooperative solution more attractive. In other words linking these two separate issues will make non-cooperation more costly. However, the implementation of this framework will not be an easy job. It will face obstacles from the upstream country. Since the non-water issue (e.g. transshipment) may have a higher stake to the upstream country, cooperation may still be attractive.
1. Background

Bangladesh is prone to various types of natural disasters (mainly floods and cyclones) with consequent impact on human health and survival because of its geographical location and topographical features. Bangladesh is located in the southern part of Asia with a total area of 147,570 square kilometers. Most of Bangladesh lies within the broad delta formed by the Ganges, Brahmaputra and Meghna (GBM) rivers. The country is largely a flat, low-lying, alluvial plain traversed by innumerable rivers and has a coastline of about 580 kilometers along the Bay of Bengal. Eighty percent of the country’s land area lies within the floodplains of the major rivers with very low elevations above the sea level (Ahmad and Ahmed 2003). Figure 1 provides the location of Bangladesh.

Home to 135 million people, Bangladesh is the eighth most populous country in the world with the highest population density (950 people/square kilometer). Almost half of its population still lives below the poverty line (World Bank 2003). Over the last three decades, Bangladesh experienced more than 170 large-scale natural disasters that have killed half a million people and affected more than 400 million (UNDP 2001). It is argued that massive flooding is one of the major contributing factors to the poverty situation in Bangladesh (Sen 2003). In other words, extreme poverty and high population density largely exacerbate the impact of flooding.

Bangladesh, known as a land of rivers, is comprised of a complex network of 230 rivers (of which 57 major rivers are cross-boundary) that flow across the country and finally empty into the Bay of Bengal. More than 92% of the combined GBM basin area (1,750,000 square kilometers) is outside the boundary of Bangladesh (located in China, Nepal, Bhutan and India). Being the lowest riparian area, Bangladesh acts as a drainage outlet for the huge
Figure 1. Location of Bangladesh
cross-border runoff and has very little unilateral ability to practice effective flood management (Chowdhury 2000a).

In the past two decades, extensive flooding has occurred in Bangladesh (in 1987, 1988, 1998, 2004) leading to colossal damages to private and public assets, infrastructure and the destruction of crop yields. Figure 2 provides an historical account of flooded area in Bangladesh. A view generally held by climatologists is that due to global climate change, catastrophic floods in Bangladesh will appear more frequently and with increasing severity (Intergovernmental Panel on Climate Change (IPCC) 2001). The recent history of flooding in Bangladesh indicates that the interval between catastrophic floods is decreasing and the intensity and duration of such floods are both increasing (Ahmad and Ahmed 2003). Table 1 provides the historical account of return period of floods in relation to area covered. As seen in Figure 2, Bangladesh experienced two hundred-year floods in 1988 and 1998.

This project explores effective flood mitigation strategies for Bangladesh. A basin-wide flood management approach through the cooperation between upstream and downstream countries is highlighted as a long-run solution. A framework is provided to extend the bargaining space to effectively negotiate a cooperative flood mitigation solution among downstream and upstream countries in the GBM basin. The study proposes that linking water-sharing issue with other non-water issues will give more bargaining power to the downstream player, which will make the cooperative solution more attractive.
Table 1. Return Period of Floods in Relation to Area Affected

<table>
<thead>
<tr>
<th>Return Period (Years)</th>
<th>Affected Areas (% of the Country)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>10</td>
<td>37</td>
</tr>
<tr>
<td>20</td>
<td>43</td>
</tr>
<tr>
<td>50</td>
<td>52</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
</tr>
<tr>
<td>500</td>
<td>70</td>
</tr>
</tbody>
</table>

Figure 2. Historical Account of Flooded Area in Bangladesh

2. Research Methodology and Organization

Massive flooding is one of the main contributing factors to poverty and underdevelopment in Bangladesh. Sustainable development strategies that incorporate effective flood mitigation strategies have the potential to protect Bangladesh from natural catastrophes. However, research exploring flood mitigation strategies from Bangladesh’s perspective is relatively scant (Nasreen 2004). For effective mitigation, a holistic flood management approach is necessary that will include both structural and non-structural measures. Ex-ante and ex-post flood mitigation (both in the short-run and long-run) needs to be articulated for devising a future action plan. Flood mitigation actions need to include both stand-alone and cooperative flood management strategies with other basin countries.

Figure 3 provides a structure of a holistic flood management approach. For instance, in addition to ex-ante structural measures (e.g. drainage, forestation, planned infrastructure for flood management), ex-post non-structural measures (e.g. effective coordination between voluntary activities rendered by NGOs, community organizations, donors and public institutions) can increase the social resilience to cope and adapt with massive flooding. Non-structural measures such as flood forecasting and warning through regional cooperation with upstream countries (e.g. Nepal and India) can reduce human suffering significantly.

This project focuses on exploring ex-ante and ex-post mitigation strategies that include structural and non-structural measures to articulate an integrated holistic flood management approach. Possible actions against severe flooding in Bangladesh at various levels (e.g. regional and national levels) are reviewed. This project reviews the existing literature on flood management, and analyzes and synthesizes it to explore the most effective
Figure 3. Flowchart of Flood Mitigation Strategies

Flood Mitigation Strategies

Structural Measures
- Ex-ante (e.g. dam, embankment, remote sensing etc.)
- Ex-post (e.g. shelter, rehabilitation center etc.)

Non-structural Measures
- Ex-ante (e.g. regional cooperation for flood management-building storage dam upstream, warning and forecasting)
- Ex-post (e.g. adaptation, coping, developing resilience capacity)
flood mitigation strategies for Bangladesh. Specifically, the review analyzes and synthesizes the following types of documents: (1) publications (reports, workshop proceedings etc.) prepared by the government, donor agencies, NGOs, independent groups and think tanks; (2) published journal articles on flood and natural disaster management; and (3) international case studies of transboundary flood management elsewhere.

The existing flood management knowledge and options can be fully utilized by an agency as best as their resources will allow when it is dealing with floods within a single administrative territory. However, the situation is more complicated in the case of transboundary flood management. In this case floods generally start in one jurisdiction (country) and then propagate into another jurisdiction(s) further downstream. The transboundary nature of flooding cannot be any more prominent than in the GBM basin. Thus, in addition to technical aspects of flood management, other issues include joint actions and cooperation among the GBM basin countries.

Commonly, countries sharing the same basin do not have similar incentives to pursue cooperative flood management. Though a cooperative management approach may be economically efficient, countries may not reach an effective agreement to optimally use the available water resources and reduce related adverse impacts. Given the situation in the GBM basin, after reviewing the existing flood management options, a basin wide flood management approach through cooperation between upstream and downstream countries is highlighted as a long-run solution. So an objective of this research is to provide a framework to extend the bargaining space to effectively negotiate a cooperative flood mitigation solution among downstream and upstream countries. Issues like how a cooperative solution can be more attractive or what makes non-cooperation more costly are addressed in my bargaining framework.
3. Main Features of the Bangladesh Delta

Bangladesh is criss-crossed by 230 rivers, most of which are either tributaries or distributaries to three great rivers of the world: the Ganges, the Brahmaputra and the Meghna. Bangladesh is a lower riparian country for all these three major rivers. These three rivers form the GBM basin, one of the largest transboundary river basins in the world. Fifty-seven rivers originate outside the boundary of Bangladesh. The total length of the river courses is approximately 24,000 km and their area (9,770 km²) covers 7% of the country’s area (Elhance 1999). The total catchment area of the Ganges-Brahmaputra-Meghna river system stands at 1.74 million square kilometers covering areas of China, India, Nepal, Bhutan, Myanmar and Bangladesh, of which less than 7% lies within Bangladesh. Figure 4 provides a complete view of the gigantic river basin distributed across six countries. An account of areas distributed in each of the basin countries is provided in Table 2.

The climate in Bangladesh is greatly influenced by the monsoon wind that originates in the Indian Ocean and carries warm, moist and unstable air to the country to cause a very humid and tropical climate. The climate in Bangladesh can be described by three seasons: (1) a hot summer (March to June) characterized by high average temperature (up to 40°C) with high evapotranspiration and occasional heavy rainfall; (2) a rainy season (June to October, when 80% of the mean annual rainfall occurs) characterized by hot and humid monsoon with heavy rainfall; and (3) a dry winter (November to March) with a temperature ranging from 5-20°C (Ahmad and Ahmed 2003).

Bangladesh may be classified into three distinct regions: (1) floodplain; (2) terrace; and (3) hill areas, each having distinctive characteristics (Banglapedia 2004). The floodplain of the three major rivers and their numerous tributaries and distributaries covers about four- fifths of
Figure 4. Location of Ganges-Brahmaputra-Meghna (GBM) Basin
Table 2. Distribution of GBM Basin Area

<table>
<thead>
<tr>
<th>Countries</th>
<th>Area of Basin in Country</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Square km</td>
</tr>
<tr>
<td>India</td>
<td>948,400</td>
</tr>
<tr>
<td>China</td>
<td>321,300</td>
</tr>
<tr>
<td>Nepal</td>
<td>147,400</td>
</tr>
<tr>
<td>Bangladesh</td>
<td>107,100</td>
</tr>
<tr>
<td>India, claimed by China</td>
<td>67,100</td>
</tr>
<tr>
<td>Bhutan</td>
<td>39,900</td>
</tr>
<tr>
<td>India control, claimed by China</td>
<td>1,200</td>
</tr>
<tr>
<td>Myanmar (Burma)</td>
<td>80</td>
</tr>
</tbody>
</table>

Source: Transboundary Water (2004), available at

site accessed 03/12/05.
Figure 5. Bangladesh, the Largest Delta in the World Formed in the GBM Basin.

Note: This true-color image shows both the delta and sediment flowing into the Bay of Bengal (Source: Moderate-resolution Imaging Spectroradiometer, MODIS 1999).
the country.\footnote{Floodplains in Bangladesh have been divided into the following sub-units: (1) Old Himalayan Piedmont Plain; (2) Tista Floodplain; (3) Old Brahmaputra Floodplain; (4) Jamuna (Young Brahmaputra) Floodplain; (5) Haor Basin; (6) Surma-Kushiyara Floodplain; (7) Meghna Floodplain, divide into: (a) Middle Meghna Floodplain, (b) Lower Meghna Floodplain, (c) Old Meghna Estuarine Floodplain, and (d) Young Meghna Estuarine Floodplain; (8) Ganges River Floodplain; (9) Ganges Tidal Floodplain; (10) the Sundarbans; (11) Lower Atrai Basin; (12) Arial Beel; (13) Gopalganj-Khulna Peat Basin; (14) Chittagong Coastal Plain; and (15) Northern and Eastern Piedmont Plain (Banglapedia 2004).}

The major part of Bangladesh is deltaic which was built up and gradually raised through several million years by the silt carried by the rivers from the mountains on the three sides of the Bengal Basin, mainly the Himalayas. The hydraulic and geomorphological processes of the delta system formed by these three major rivers shape the basic characteristics of the land and riverine system of Bangladesh.\footnote{According to a 1968 marine seismic study, the undersea fan of sediment from the Himalayas deposited in the Bay of Bengal by the rivers is 1000 km wide, over 12 km thick and 3000 km long. This deposit extends far to the south and goes beyond Sri Lanka. The size of this undersea fan testifies the scale and vigor of Bengal delta (Islam 2001).}

Figure 5 provides a view of the delta. The rivers frequently change their courses and influence the morphology of the alluvial floodplain. Bank erosion and deposition are continuous processes associated with the rivers of Bangladesh.\footnote{River bank erosion, which is associated with floods, is a severe hazard in the country. Every year almost one million people are affected by eroding banks along 75 rivers at about 130 different locations. On average about 87 km$^2$ of mainland was lost each year due to erosion by the major rivers during 1984 to 1993 while about 50 km$^2$ of land accreted per year (ISPAN 1993). Between 1970 and 1990, at least 7 million people were displaced by riverbank erosion (MacDonald 1993).}

Land in a delta crosses broadly several stages of life. As described in Islam (2001), in the first stage, the deposited silt still remains undersea, though rising steadily toward the sea level. In this stage, land remains permanently inundated. As rivers deposit more silt, a second stage is reached. New tract of land emerges from under the sea. At this stage, the land can be seen only during the low tide and remains submerged during the high tide. As more silt is deposited, elevation of the land increases further and the frequency of inundation decreases. Most of the rivers that form the delta have a peak and a lean season in a year. Accordingly,
the frequency of inundation stabilizes and ultimately it becomes mostly an annual phenomenon. This is the third stage, and lands at this stage are known as floodplains.

With continued siltation, the elevation of floodplain increases, and after a certain point of time parts of it gets beyond the reach of overflow even during the peak season. These lands then become part of the old or moribund delta, which is generally no longer inundated. Most of Bangladesh consists of floodplain, i.e., of lands belonging to the third stage of delta life. It is estimated that about two-thirds of Bangladesh’s cultivated area falls into the category of floodplain, and remaining is the moribund part. Most of the moribund delta is located in the Barind tract of North Bengal and in Kushtia and in Jessore districts of western Bangladesh.

While most other deltas are the creation of single rivers (like the deltas of the Nile, Mississippi, Yangtze, etc.), the Bengal delta is the creation of three mighty rivers: the Ganges, Brahmaputra and Meghna. This makes the dimensions of the Bengal delta simply enormous. The combined channel of the Ganges, Brahmaputra, and Meghna is about three times the size of the Mississippi. The combined catchment of the Ganges, Brahmaputra and Meghna is 1,758,000 square kilometers, which is more than 12 times the size of Bangladesh. The amount of rainfall in the catchment basin of the Bengal rivers is more than four times the rainfall in the Mississippi basin, although in terms of area the former is less than half of the latter. The amount of sediment carried annually by the rivers of the Bengal delta is about 2.9 billion metric tons (Rogers et al. 1989). This is far more than any other river system anywhere in the world. Under average conditions, from June to September, 775 billion cubic meters of water flow into Bangladesh through the main rivers and an additional 184 billion
cubic meters of streamflow is generated by rainfall in Bangladesh (Islam 2001).\footnote{This may be compared with the annual flow of only 12 billion cubic meters of Colorado River at Yuma, Arizona, US (Islam 2001).} These numbers clearly show that a massive hydrologic system is at work in the Bengal delta.

In addition, Bangladesh has certain unique features that distinguish it from other countries with deltas. Some of these need to be noted here. As mentioned in Rogers et al. (1989) first, in most other countries deltas form only a small part of their total area. The Mississippi delta constitutes a tiny part of the total US land area. Similar is the case with Yangtze delta in China. Even in Egypt, the Nile delta constitutes a small part of the country. For Bangladesh, the situation is different. Except for hill tracts in the eastern region of the country, almost the entire country is part of the delta. Second, in most cases, the delta and the catchment area of the river lie in the same country.\footnote{The entire catchment of the Mississippi lies in the US. The catchment areas of Yangtze, Ho, or Yellow Rivers lie in China as do their deltas. Similarly, Brazil contains both the Amazon delta and most of Amazon’s catchment (Rogers et al. 1989).} But, this is not the case with Bangladesh. Most of the catchment area of Bangladesh’s rivers (almost 93%) lies outside of Bangladesh. Third, unlike other deltas, Bangladesh’s rivers are characterized by unusually large fluctuation of water-flow between lean and peak seasons. Eighty-five percent of the precipitation in the catchment basin of Bengal river system occurs in just one-third of the year implying the larger extent of overflow and inundation compared to other deltas in the world (Islam 2001).
4. Flooding in Bangladesh: Events and Characteristics

4.1 Flooding in Bangladesh

As a result of flat topography of the floodplain and the characteristics of delta formation mentioned earlier, one-fifth to one-third of the country is annually flooded by overflowing rivers during the monsoon. At this time the rainfall within the country is also very high. This annual phenomenon of river flooding plays a vital role in the floodplain ecosystem.

Huge amounts of sediments are carried by alluvial rivers which build new land, fill in subsidence and improve soil fertility. The annual sediment transports are 590 and 548 million tons in the Jamuna and the Ganges, respectively, and 897 million tons per year downstream of their confluence in the Ganges River (Delft Hydraulics 1996). Floodplain sedimentation takes place as floods spread out onto the floodplain, with coarser sediments (sand) being deposited near the bank with the highest thickness, eventually forming natural levees over 1 km wide standing up to 3 meters above floodplain (Bristow 1987).

In general, the seasonal flooding contributes to soil fertility and agricultural productivity. For generations, floodplain inhabitants of Bangladesh have adapted to the annual floods through numerous ingenious strategies to benefit from this recurring natural phenomenon. However, it becomes a major public concern when their adjustment ability is surpassed by occasional large floods that cause damage to their subsistence resource base. With the increase in population and growth of physical infrastructure, vulnerability of the society to such floods has also grown considerably over the last several decades.

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6 According to the Economic and Social Commission for Asia and the Pacific (ESCAP 2003), the catchment inside the country can be inundated to about 6 meters by river water carried from outside
The coast of Bangladesh is flooded by high tides that originate in the Indian Ocean and travel through the Bay of Bengal. These tides are predominantly semi-diurnal and cover all the estuaries in the coastal region. The interconnected estuaries and rivers form an intricate network. Through this network tidal waves are felt up to 325 km inland during dry season and up to 225 km inland during wet season (Chowdhury and Rahman 1999). Most of the area in the Ganges Delta is below the high water level of spring tides.

The Bay of Bengal is the breeding place for tropical cyclones associated with storm surges. Approximately 12,000 square kilometers of coastal land are prone to cyclonic storm surge floods. In the southwest region, a storm surge can intrude as far as 60 km through the network of estuaries (Karim and Chowdhury 1995). The funnel-shaped coast line makes the country more vulnerable to the surge hazards. However, the long coastline also provides Bangladesh some economic advantages. An important economic feature of the Bay of Bengal for Bangladesh is the seaport facilities. In addition, the estuaries of the Bay of Bengal are a source of huge marine fisheries resources for Bangladesh.

4.2 Types of Floods in Bangladesh

One-fifth to one-third of the country is flooded to varying degrees in each year between May to September. About two-thirds of the food grain (mainly rice) is produced and harvested at this time. Bangladesh experiences the following types of flooding: (1) river floods resulting from the bank overflows in the major rivers and their tributaries and distributaries during the monsoon months from June through September (around 30% of the country is prone to river floods); (2) rainfall floods due to intense rainfall occurring over long periods of time in the monsoon months and the consequent drainage congestion as the river

the country each year, a situation that is further aggravated by rainfall inside the country that can add another 2 meters of water.
water level is already very high; (3) flash floods in the piedmont areas in the northeast and southeast parts of the country during the pre-monsoon months (April and May) often cause damage to crops just before or at the time of harvesting; (4) tidal floods characterized by twice-a-day flooding in areas adjacent to estuaries and tidal rivers in the southwest and southcentral regions due to astronomical tides from the Bay of Bengal and fortnightly flooding over a vast area due to spring tides; and (5) storm surge floods in the coastal area generated by tropical cyclones in the Bay of Bengal in April to June and September to November. River floods and rainfall floods are frequently exacerbated by spring tides and monsoon winds originating in the Bay of Bengal which slow down drainage and cause prolonged flooding. Furthermore, simultaneous occurrence of peak flood flows in the Ganges, Brahmaputra and Meghna rivers cause extreme flood events which sometimes affect most of the country as occurred in 1998.

4.3 1998 Flooding in Bangladesh

As a prominent example of recent flooding, in 1998, Bangladesh experienced the “flood of the century.” Two-thirds of the country remained under water for more than four months, risking food security and shelter for millions of people. Households exposed to flooding had major crop failure, suffered from water-borne diseases, lost their shelter and other basic assets (del Ninno et al. 2001). Figure 6 provides the 1998 flood affected areas in Bangladesh. Major factors responsible for the 1998 flooding include abnormally high monsoon precipitation due to ENSO (El Niño Southern Oscillation), snow and glacier melt, backwater effects (elevated sea level in the Bay of Bengal), synchronization of flood peaks in major rivers, loss of drainage capacity (siltation), upland deforestation and unplanned infrastructure development (Mirza et al. 2003).
Figure 6. 1998 Flood Affected Areas in Bangladesh

The 1998 flood displayed certain additional alarming characteristics. One of these was the unusually slow pace of floodwater recession. This prolonged human suffering and exacerbated damages to infrastructure. In particular, the slow recession left farmers with little time to replant their aman crop and resulted in unusually high crop loss. An acute problem of drainage and water-logging was another alarming phenomenon people witnessed in 1998, which was deadly for sanitation and public health.

4.4 Future Scenarios of Flooding in Bangladesh

According to IPCC, climatic changes caused by global warming will lead to more rainfall, massive floods, cyclones and droughts in Bangladesh. By 2050, the temperature in Bangladesh is expected to rise by 1.5°-2.0°C (IPCC 2001). As global temperature increases, the hydrologic cycle will intensify and the rate of evaporation is expected to increase by 12%. This may increase the level of precipitation in Bangladesh. Climate models developed by the IPCC indicate that Bangladesh may experience 10 to 15% more rainfall by 2030. An increase in rainfall will increase the frequency and severity of flooding in Bangladesh in the future (IPCC 2001). The flooding situation may also be worsened by the sea level rise due to the climate change. Figure 7 illustrates the impact of a sea level rise in Bangladesh and potential area of inundation.

The increased flooding will reduce crop production threatening the food security of millions of people. More people will be vulnerable as people will be forced to live in the floodplains. The damage by flooding will increase as more houses and infrastructure will be exposed to severe flooding to cripple the economy. Extreme poverty and high population density largely will exacerbate the impact of flooding. Increased knowledge and understanding for effective flood management measures is an urgent need for Bangladesh.
Figure 7. Potential Impact of Sea-level Rise in Bangladesh

Note: The data given here are coarse estimates based on the same parameters used by Delft Hydraulics (UNDP 1989). Digital terrain modelling techniques have been used to display the Bangladesh scenarios. A three dimensional view of the country has been overlain with the current coastline and major rivers and potential future sea levels at 1.5 meters.

5.1 Various Plans and Studies

5.1.1 Flood Mitigation Measures

In principle, flood management measures can be grouped into two categories: structural and non-structural measures. Non-structural measures include finding ways to cope with floods through regulations and policies and adaptation and mitigation measures. On the other hand, structural measures attempt to reduce flood volumes and peaks through different structural measures to protect people and property against floods. Table 3 provides a list of major flood mitigation studies conducted in Bangladesh with year of initiation.

5.1.2 Structural Measures

For several decades Bangladesh has been regularly spending about 20 percent of its annual budget on water development projects (Islam 2001). Numerous Flood Action Programs (FAPs) have been implemented, yet Bangladesh does not have a good handle on the flood problem. Many conventional flood mitigation measures like flood control reservoirs, flood diversions or flood by-passes are not feasible within Bangladesh because of its extremely flat topography. Lack of innovative flood mitigation programs and ineffectiveness of conventional flood mitigation measures may be a reason there has not been a good success story in dealing with floods in Bangladesh.
Table 3. Major Flood Mitigation Studies Conducted in Bangladesh

<table>
<thead>
<tr>
<th>Study</th>
<th>Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Master Plan</td>
<td>1964</td>
</tr>
<tr>
<td>Land and Water Sector Study</td>
<td>1972</td>
</tr>
<tr>
<td>National Water Sector Study</td>
<td>1972</td>
</tr>
<tr>
<td>Flood Action Plan</td>
<td>1989</td>
</tr>
<tr>
<td>Water and Flood Management Strategy</td>
<td>1995</td>
</tr>
</tbody>
</table>
5.1.3 The Master Plan (1964)

Following severe floods in 1954 and 1955, a report was submitted by the Krug Mission (a United Nations Water Control Mission requested by the Government of Pakistan) in 1957. The report recommended the establishment of an autonomous organization to conduct data collection and flood studies and to prepare a master plan for flood problems. Subsequently, the EPWAPDA (East Pakistan Water and Power Development Authority) was created in 1959 to prepare a comprehensive plan for the development and utilization of the water and power resources in East Pakistan (currently Bangladesh). The EPWAPDA completed the master plan in 1964. The 1964 master plan proposed building large-scale public works projects including embankments for flood control, gravity irrigation through canal systems, and pumping stations for drainage and irrigation (ESCAP 2003). After Bangladesh became independent, the EPWAPDA was split in 1972 into Bangladesh Power Development Board (BPDB) and Bangladesh Water Development Board (BWDB).

5.1.4 Land and Water Sector Study (1972)

In 1972, the IBRD (International Bank for Reconstruction and Development) report recognized the problems with large scale flood control, drainage and irrigation schemes in a setting with high population density and a complex water regime. The IBRD recognized the unique nature of the problem: flooding during the wet season and the scarcity of water during the dry season (IBRD, 1972). The study recommended small-scale short term flood control and drainage (FCD) projects such as low lift pump irrigation and small drainage improvements and some medium-scale projects (e.g. tube-well irrigation and double-lift pumping etc.). In the IBRD study winter irrigation and flood control and drainage (FCD)

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7 The 1964 Master Plan had a portfolio of 58 projects and it was structured to be spread over the 20 years period (1965-1985) with an estimated cost of US$ 2.1 billion (ESCAP 2003).
projects in shallow flooded areas received priority to match with increasing demand for food production. However, in the meantime many of the large-scale projects proposed in the master plan of 1964 had either been implemented or were under implementation (Chowdhury 2000b).

5.1.5 National Water Plan (1987 and 1991)

In 1983, the Government of Bangladesh initiated the National Water Plan (NWP) project with assistance from the United Nations Development Program (UNDP) and the World Bank. The objective of the NWP was to maximize agricultural production while meeting the basic water needs of other users (Harza 1991). The NWP proposed raising the total flood-protected area from 32 to 73% by providing flood control and drainage facilities over the 20 year period (1991-2010). Almost half of the flood protection development has been targeted in the northeast region, an area in which only a small area of land was protected earlier (Harza 1991). It proposed to develop barrages on the main rivers (the Ganges barrage and Brahmaputra barrage within Bangladesh) to expand irrigation to areas which cannot be served by the available regional surface water and development of a groundwater based irrigation system.

5.1.6 Flood Action Plan (1989)

Bangladesh experienced a disastrous flood in 1987 followed by another one of even greater magnitude in 1988. Soon after the 1988 flood, the Ministry of Water Resources prepared the NFP (National Flood Protection) report which was followed by several other studies. The Flood Policy Study by the Government of Bangladesh (assisted by UNDP) set an action plan comprising of eleven guiding principles for future flood management studies (World Bank 1989). Surprisingly, the situation is very similar to the 1954 and 1955 floods.
which were the driving force behind the formulation of the master plan of flood control in 1964. The action plan which subsequently named the Flood Action Plan (FAP) involved 26 studies including 5 regional studies based on regions with an estimated cost of nearly US$150 million (ESCAP 2003).

The FAP (1990-1995) was targeted to develop a flood plan that would be a durable solution to the recurrent flood problems. As mentioned in (ESCAP 2003), the main objectives of the plan were: (1) safeguarding life and livelihoods; (2) minimizing potential flood damage; (3) improving agro-ecological conditions for higher crop production; (4) meeting the needs of fisheries, navigation, communications and public health; (5) promoting commerce and industry; and (6) creating flood-free land for a better living environment. The FAP has emphasized controlled flooding for rural areas, round-the-year water management, a relatively high degree of protection for urban areas, the need to integrate river training with water development projects and the approach of integrating structural intervention with non-structural measures (ESCAP 2003).

5.1.7 Water and Flood Management Strategy (1995)

The Water and Flood Management Strategy (WFMS) for Bangladesh was built based on the studies done under the FAP and NWP. It identified that one of the shortfalls of earlier projects (NWP and FAP) was that concurrent programs in other ministries (e.g., fisheries, navigation, public health, municipalities, etc.) were not well-coordinated with flood management projects. Requirements of non-flood projects were considered as constraints rather than incorporating them as integrated components of water management. It recommended a 5-year (1995-2000) program to prepare the national water management plan (NWMP). The NWMP (1997-99) examines the supply of water in the context of international
rivers and groundwater storage and the demand from irrigation, fisheries, navigation, drinking and municipal needs, and other important sectors. It provided an outline of the institutional framework for developing and managing water resources with an emphasis on people's participation and environmental aspects (Rahman 2001).

5.2 Types of Flood Control Projects

Depending on the measures adopted, various projects related to flood control measures can be classified as follows: (1) Flood Control (FC); (2) Flood Control and Drainage (FCD); (3) Flood Control, Drainage and Irrigation (FCDI); and (4) Drainage (D). In addition to general flood control projects some other related issues, e.g. development and scales of flood control projects, specific measures to protecting cities and some other option for flood mitigation, are also discussed in this section.

5.2.1 Flood Control (FC) Projects

This type of project involves the building of embankments alongside rivers to prevent river flooding. Twenty-nine FC projects were constructed by BWDB (Bangladesh Water Development Board) to cover an area of 2070 square kilometers (ESCAP 2003). The Brahmaputra Right Embankment (BRE) is such a large-scale FC project employing about 220 km of embankments and covering an area of around 2,260 square kilometers. There are a number of low-height embankments that are considered partial flood control projects. In the northeast region, there are 33 such projects covering about 900 km of submersible embankments and an area of 1,720 square kilometers (ESCAP 2003).

5.2.2 Flood Control and Drainage (FCD) Projects

In most cases, drainage provisions are incorporated into flood control embankments to evacuate the excessive rain water from the area protected by embankments. One hundred
seventy-three FCD projects were constructed by BWDB covering an area of 20,190 square kilometers. The Coastal Embankment Project (CEP) is the biggest FCD project extending over approximately 13,000 square kilometers in the southwest, southcentral and southeast and in Chittagong. It includes 120 km of drainage channels and about 4,000 km of embankments (ESCAP 2003).

5.2.3 Flood Control, Drainage and Irrigation (FCDI) Projects

FCDI projects build embankments around the periphery of the project areas to prevent inundation of cropland by riverine floods and tidal floods. Drainage is done through sluice gates in the embankments at the outfalls of the natural channels. Irrigation to farming land is made available by directing river water elevated by a barrage or lifting by pumps into a distribution canal network. Drainage is done mostly by gravity flow, particularly in smaller projects, or by pumps in bigger selected projects. Forty-two FCDI projects were constructed by BWDB covering an area of 7,110 square kilometers. Examples of some of the larger FCDI projects are the Pabna Irrigation Project (Phase I covers an area of 1,845 square kilometers) in the northwest region, the Chandpur Irrigation Project (464.37 square kilometers) in the southeast region and the Bhola Irrigation Project (Phase I covers an area of 526.32 square kilometers) in the southcentral region (Banglapedia 2004).

5.2.4 Drainage Projects

This type of project aims to improve drainage through the construction of drainage channels, drainage regulators and sluices. One hundred twenty-eight drainage projects were constructed by BWDB covering an area of 7,590 square kilometers. Examples of some big drainage projects are the Gumti River Dredging Project in the southeast region covering an area of 1,388.66 square kilometers and the Comprehensive Drainage Structure Project in
Faridpur in the southcentral region covering an area of 1518.22 square kilometers (Saleh and Mondal 1999).

5.2.5 Development and Scale of Flood Control Projects

Based on project coverage, the FCDI projects are delineated into two groups: (1) large-scale projects (covering over 25 square kilometers); and (2) small-scale projects (covering fewer than 25 square kilometers). The BWDB has implemented 372 medium-scale and large-scale flood control, drainage and irrigation projects through 1994. There has been a steady growth in the coverage area since mid 1960s. There are now approximately 7,668 km of embankments, 5,072 km of drainage channels and 493 sluices and regulators (Chowdhury 2000b). The coverage area of about 37,000 square kilometers by these projects is equivalent to nearly 25 per cent of the total area of the country, and 60 per cent of total flood potential area. The LGED (Local Government and Engineering Department) has implemented 1,335 small-scale schemes including the construction of about 400 km of embankments, 4,000 km of canals and 300 regulators and sluices. The area covered by these projects is approximately 2,700 square kilometers (Chowdhury 2000b).

5.2.6 Protecting Cities

Dhaka, the capital city of Bangladesh, is becoming increasingly vulnerable to flooding. One emerging question is whether a different flood control strategy should be adopted to protect big cities. Currently, Dhaka is cordoned by Greater Dhaka Embankment and it has been partially successful in reducing flood in the south and southwestern parts of the city. One view is that if Dhaka is entirely cordoned off, and there will be no more floods within the city. The alternative view is that cordonning off Dhaka will encourage below flood
level dwelling construction, putting pressure on the embankments. Dhaka’s cordon may encourage the neighboring towns to build their own cordons. Every town’s embankment will increase pressure on someone else’s embankment. This may lead to an ultimate collapse of the entire structure.

According to the alternative view, the cordon may also create problems of drainage and sanitation. Whenever the surrounding river level rises, normal gravity-flow drainage needs to be replaced by a very costly option of drainage through pumps. On the other hand, there are examples of cities (e.g. Venice) that have developed through an extensive systems of canals. Excavation of canals to connect with rivers and the sea has made these cities more attractive. Excavation of canals will create more passage and storage of water to mitigate flood in the adjoining areas.

5.2.7 Other Options for Flood Mitigation

Rogers et al. (1989) indicated some alternative options for flood mitigation in Bangladesh. He points out that the Ganges basin is like a sponge, and in the monsoon the water level comes up to the surface. If more water can be pumped out of the sponge before the monsoon then more water would be absorbed during the monsoon. The high flow could be taken care of this way. The rivers are connected to the water in the sponge. When the water in the sponge is high, it drains to the river, and when the water level in the sponge is low it drains out of the river. If the water table in the sponge is too low, it may get below the bed of the river and the river will drain. However, the transboundary nature of the basin makes it very difficult to imagine the Indian government pumping water out of the Ganges and putting it back in it just before the Ganges enters Bangladesh.

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8 The embankment could not save Dhaka from 1998 flood. Flooding in northern parts of the city were more serious in 1998 than in 1988. Efforts to save one part of Dhaka have aggravated flooding
Another option is to intensify the flooding in areas that are flooded already. For instance, storing water in areas like Sylhet (an area remaining submerged most of the year in the northeast part of the country) by building low embankments. This is a way to direct floods to a particular place that is already submerged. The big storages that the Chinese built on the Yangtze were done similarly. With the help of 300,000 people, China built a large dam upstream (7 billion cubic meters of storage) in 75 days. The Sylhet depression may be used to store almost 3 billion cubic meters of additional water. This also may have some potential for various types of fishery projects.

5.3 Non-Structural Measures

5.3.1 Flood Forecasting and Warning

The FFWC (Flood Forecasting and Warning Centre) operates under the Bangladesh Water Development Board (BWDB). Established in 1972, the FFWC is responsible for providing flood forecasts and warnings. The FFWC issues forecasts of water levels at 21 key stations on the major rivers (providing 24 hour, 48 hour and 72 hour forecasts). The Bangladesh Meteorological Department (BMD) is responsible for forecasts and warnings of tropical cyclones and storm surges from the Bay of Bengal.\(^9\)

5.3.2 Flood Proofing

Flood proofing of homesteads is a traditional precaution in the rural areas of Bangladesh. Homesteads are generally raised above maximum flood levels. The Bangladesh National Building Code (1993) sets the standard that any area with a potential for being flooded to a depth of 1 meter should be designated as a Flood Prone Area (FPA). The code impacts in other parts (Islam 2001).

\(^9\) The USAID is supporting a flood forecasting project in Bangladesh through the University of Colorado's Program in Atmospheric and Oceanic Sciences (PAOS). The program aims to develop a
specifies that the lowest floor (including the basement) of any building located in the FPA should not be below the designated flood level. The roof of one or two storied buildings and the floor immediately above the designated flood level for three or more storied buildings should be accessible via an exterior stairway.

Cyclone shelters are constructed in the coastal zone where human lives are at high risk due to storm surge floods caused by cyclones. Shelters stand on stilts so that flood water can pass through. Currently there are about 1,500 cyclone shelters (Sener et al. 1998). The Multipurpose Cyclone Shelter Master Plan (BUET-BIDS 1993) estimated that Bangladesh would require 2,500 new shelters with an accommodation capacity of 4.4 million persons. Over the years, there has been a significant change of emphasis from designing the shelters solely for flood to designing them for multipurpose use. Flood shelters are now designed to be used as schools, health centers and other community service centers when there is no flood.

5.3.3 Flood Preparedness

There exists an institutional arrangement for flood preparedness under a National Guideline called ‘Emergency Standing Order for Flood’. It outlines the actions of flood preparedness to be taken by a large number of ministries (e.g. Ministries of Disaster Management and Relief, Water Resources, Agriculture, Information, Health, Public Works, Local Government, Communication and Defense). It also includes local councils and non-governmental organizations (NGO) in the three defined phases of a flood event (the phases are before, during, and after floods). The overall flood management programs are coordinated by a National Coordination Committee. The recently formed Disaster flood forecasting system that combines monsoon climate prediction with a hydrodynamic model of the Bay of Bengal to predict conditions contributing to prolonged and destructive flood events.
Management Bureau under the Ministry of Disaster Management and Relief executes programs at the grass-roots level. Nearly 21,000 volunteers of the Bangladesh Red Crescent Society take part in the flood preparedness programs in the flood-prone areas in Bangladesh (ESCAP 2003).
6. Regional Cooperation in Flood Management

Over time, as opposed to stand-alone options, cooperative management options are receiving more prominence to resolve water-related problems. For instance, the current Secretary General of the United Nations, Kofi Annan, recently mentioned that “But the water problems of our world need not be only a cause of tension; they can also be a catalyst for cooperation. If we work together, a secure and sustainable water future can be ours” (Carius et al. 2004).

6.1 Cooperative Basin-wide Management

Often time it is observed that the struggle for economic and social development for many countries is increasingly related to water. Flood, water scarcity, and water quality are dominating problems that require greater attention and action among countries with conflicting interests. A cost-effective and sustainable solution is an urgent need to assist countries to deal with severe water issues. Such a solution is feasible if the respective rights to use water (whether consumptive or non-consumptive), along with the relevant obligations of each riparian state, are agreed among all of the states sharing the resource. A basin-wide management approach among the basin states is the best way to set such rights and responsibilities. International law allows each riparian state an equitable and reasonable share of the uses of transboundary waters, with an obligation not to cause significant harm to fellow riparians (Wouters 2003). Ecosystem protection including preservation of in-stream environmental uses can be integrated in the water-sharing agreement among the countries sharing the river basin.

Agreements try to establish the institutional framework to provide ‘rules of the game’ in transboundary water resource sharing. The ‘rules of game’ include comprehensive
provisions for dispute resolution, preferably by a supra-national body independent of the states involved. To secure effective governance, mechanisms must be put in place to verify compliance by participating states in accordance with the requirements of the agreement (Allan and Wouters 2004). Such efforts require strong regional institutions, legal structures and strategies to ensure equitable benefit of basin resources which is unfortunately missing in many cases.

6.2 Cooperative Flood Management and Present Situation in GBM

To facilitate water-sharing agreements between Bangladesh and India, the Joint Rivers Commission (JRC) was established on 19 March 1972 in Dhaka. There is a counterpart JRC for India, which is based in New Delhi, India. According to the statute of JRC, the commission is appointed by the governments of India and Bangladesh and is composed of a chairman and three members. The chairmanship of the commission is held annually in turn by Bangladesh and India and usually is assigned to the Minister for Water Resources. According to the statute, the functions of JRC are as follows: to maintain liaison between the participating countries to ensure effective joint efforts in maximizing the benefits from common river systems; to recommend and jointly formulate flood control works; to formulate detailed proposals on advance flood warnings, flood forecasting and cyclone warnings; to study flood control and irrigation projects so that the water resources of the region can be utilized on an equitable basis; and to formulate proposals for conducting coordinated research on problem of flood control affecting both the countries (Banglapedia 2004).

Other major responsibilities of the JRC include the following: negotiating with the neighboring countries on development, management and sharing of water resources of the
international/transboundary rivers; holding regular meetings of different committees of the JRC (e.g. meetings of Joint Committee of Experts, Joint Committee on Sharing the Ganges Waters at Farakka Barrage); monitoring the meetings of the different local level committees with India; monitoring and implementation of the arrangements for sharing of dry season Ganges waters available at Farakka as mentioned in the 1996 Ganges Water Sharing Agreement. The JRC also works jointly with basin countries (Nepal and Bhutan in addition to India) on exchange of relevant data and information and formulation of detailed proposals on advance flood warning, flood forecasting, and cyclone warning to develop the common water resources for optimum utilization and to conduct coordinated research and studies on flood control and water management in the transboundary rivers. However, over the years the major activities of the JRC concentrated on negotiating the sharing of waters of the Ganges, Tista, and other common rivers, and also sharing and exchange of hydrological data between India and Bangladesh (Banglapedia 2004).

6.3 The Ganges Water Sharing Agreement

The Ganges Water Sharing Agreement between India and Bangladesh for running the feeder canal of the Farakka Barrage was signed in 1975. In 1977 the agreement was extended to augment the water flows of the Ganges water at Farakka. The agreement was valid for 5 years. Then through Indo-Bangladesh Memorandum of Understanding (MOU) the agreement was kept in effect till 1985. Finally, the JRC successfully negotiated the Ganges Water Sharing Treaty in 1996. The treaty was signed by the then Prime Ministers of India and Bangladesh (on 12 December 1996 at New Delhi, India). The Treaty is valid for 30 years and is renewable on the basis of mutual consent. Table 4 provides the details of the Ganges Water Sharing Treaty.
Table 4. Ganges Treaty, 1996: Water Sharing at Farakka Barrage (January-May)

<table>
<thead>
<tr>
<th>Flow at Farakka (m³/sec)</th>
<th>India’s share</th>
<th>Bangladesh’s share</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;70,000</td>
<td>50 percent</td>
<td>50 percent</td>
</tr>
<tr>
<td>70,000–75,000</td>
<td>Balance of flow</td>
<td>35,000 m³/sec</td>
</tr>
<tr>
<td>&gt;75,000 x</td>
<td>40,000 m³/sec</td>
<td>Balance of flow</td>
</tr>
</tbody>
</table>

Source: Salman (1997)
Regarding water sharing in other rivers, at the 25th JRC meeting (held at Dhaka on 20 July 1983), Bangladesh and India agreed to an ad hoc sharing of the Tista water during the dry season. The ad hoc sharing was initially valid till 1985, which was later extended till 1987. The JRC has also agreed to build the Tista right-bank embankment at the India-Bangladesh border from Kaliganj (Bangladesh) to Jharsingheswar (India), which was successfully completed in June 1998.

6.4 Experience of Transboundary Water Management from Elsewhere

Around 40% of the world’s population lives in 263 river basins that are shared by more two or more countries (USAID 2003). These basins cover almost one half of the earth’s surface and account for 60 percent of the global freshwater flow. One hundred forty-five nations include territory within transboundary basins and 21 countries lie entirely within these international basins (Giordano and Wolf 2003). Examples of these are: the Mekong river basin in Southeast Asia (shared by China, Laos, Thailand, Myanmar, Cambodia and Vietnam), the Sava River basin in Eastern Europe (shared by Croatia, Bosnia and Herzegovina, Serbia and Montenegro, and Slovenia), the Okavango River basin (Angola, Botswana, Mozambique, Namibia, and South Africa), and the Nile River basin in Africa (shared by Burundi, Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda). After the political disaggregation process, the Central Asian Republics (Kyrgyzstan, Tajikistan, Turkmenistan, Kazakhstan, and Uzbekistan) are striving to develop a framework for cooperative sharing of water resources.

The Mekong River Commission (MRC) has developed a system to improve flood preparedness in the four riparian countries throughout the Lower Mekong Basin (Laos and Thailand). The MRC has taken initiatives to strengthen regional cooperation for flood management and mitigation. Floods in the Mekong Basin are a recurring event and cause
tremendous economic damage. Since the magnitude of flooding in the Mekong Basin cannot be fully controlled, people continue to live with floods and try to reduce the damage from floods.

To provide an effective planning tool, the MRC generates flood hazard maps that provide physical baseline information for flood prone areas (information on depths, extent, duration and velocity of floods) combined with socio-economic indicators. These maps are an important planning tool to prioritize reaches of the river for different types of intervention. The MRC has begun work on developing an inundation database in 2000 and by 2001 it launched the application of this database to flood forecasting. The inundation database and maps have been compiled from various sources including remote sensing data, field surveys, topographic and hydrologic data (Mahaxay 2003). The flood maps are designed to compile and organize information that can be used for land classification, flood planning, management and mitigation.

In 2001, the MRC Council adopted a Flood Management and Mitigation (FMM) strategy to promote regional cooperation among the riparian countries to achieve better management of floods in the Lower Mekong Basin. The MRC now has been engaged in the preparation of an implementation program for the FMM strategy which includes 9 components (Mahaxay 2003). Two components are: (1) flood risk and flood impact analysis, and (2) flood forecasting, warning and dissemination services, which will build on and extend the work that the MRC has been doing. Other components include the establishment of a Regional FMM Center, strengthened technical and institutional approaches to land use management, structural measures and flood proofing; transboundary flood management and mediation; strengthening of flood emergency management; and capacity building for FMM.
7. Exploring Effective Strategy for Cooperative Flood Management in the GBM Basin

In the twenty-first century, water is increasingly considered as a strategic resource (Correia and da Silva 1999). Disputes regarding water are ubiquitous and so there are plenty of water-related bargaining issues, especially in a transboundary setting. However, we see very few applications of bargaining or negotiation frameworks in analyzing such cases. Analysis based on bargaining theory can be very helpful in identifying the nature and characteristics of any plausible agreement and its stability. This type of analysis also can help the policymakers to set up the ‘rules of game’ to achieve a mutually beneficial agreement (Carraro et al. 2005). Bargaining analysis in order to reach a cooperative solution in a transboundary context is likely to be extremely helpful in South Asia.¹⁰

Bargaining studies in water allocation include Supalla et al. (2002), Bhaduri and Barbier (2003), Ambec and Sprumont (2002) and Kilgour and Dinar (1995, 2001). Supalla et al. (2002) apply auction theory to determine the water allocation in the Platte River among three states: Colorado, Wyoming and Nebraska. The water allocation decision specifically deals with allocating water to provide instream flow for environmental and ecosystem services in the Middle Platte ecosystem. They use a sequential auction with repeated bidding to determine how much instream flow water each of three states (Colorado, Nebraska, and Wyoming) will provide and at what price. They show that the use of auction mechanisms can be useful to reach to a multi-state agreement given that the auction is structured to discourage misrepresentation of costs.

¹⁰ "Nowhere is the problem of cooperation between riparian neighbors as critical as in the Ganges-Brahmaputra basin in South Asia. Nowhere are the benefits from cooperation as spectacular for the future of the countries involved, and nowhere is the penalty for non-cooperation as devastating" (Elhance 1999).
Bhaduri and Barbier (2003) study the negotiation of international water allocation in the context of the GBM basin. They attempt to extend the recent Ganges water sharing agreement between Bangladesh and India. The main point is that surplus water could be released to the Ganges in the drought periods by creating water storage facilities in Nepal. They argue that such a scheme would improve the negotiating power for the downstream country, Bangladesh, to deter India from further diverting water upstream. This augmentation scheme needs to be negotiated by three countries: India, Bangladesh and Nepal. India and Bangladesh will both be required to pay Nepal to develop storage facilities and transfer water to any one of the other countries. However, they also show such an augmentation scheme is unlikely since India is better off without it, i.e. it is not in their interest.

To understand the actions, incentives and the bargaining power of the upstream and downstream country in the GBM basin, the following flood game is sketched (Figure 8). In the flood game, first nature decides the amount of water in the whole basin through precipitation and other related factors (e.g. snow and glacier melts). Then the upstream country (India) gets to respond to nature’s move by diverting or not diverting water in the upstream watershed. India’s best interest is to divert water when there is a drought (or water shortage situation) and drain all the water downstream when there is a flood (or situation of water abundance).

The downstream country gets to respond at the very end of the sequence. In fact, there are not many options to respond for the downstream player in the flood game. In case of a flood, the downstream country can build an embankment inside its border to partially offset the flood impacts, which may or may not be successful depending on the situation. Other than finding various ways to live with drought or flood, the downstream country’s other option is to ask for cooperation with upstream country to take actions to reduce the damage caused by flood or
Note: Nepal is not considered in this flood game since Nepal does not have any direct border with Bangladesh. So no agreement can take place between Bangladesh and Nepal without the consent of India. See Bhaduri and Barbier (2003) for a detailed discussion of this issue.
drought in the downstream country. However, *ceteris paribus* the upstream agent will not have any incentive to cooperate with the downstream agent. Given the geographic disadvantage of the downstream country, the study provides a framework to extend the bargaining space to effectively negotiate a cooperative flood mitigation solution. There is of course possibility for the downstream country to compensate the upstream country to undertake protective actions. Such compensation would have to take place in actuation of very unequal bargaining power. However, equity or and fairness concern and poor economic condition of the downstream country (Bangladesh) may preclude such possibility of compensating the upstream country (India).

7.1 Linking Games

In game theory literature, a game is described to define a situation where several agents strive to maximize their payoffs by choosing particular courses of action and each agent’s payoffs depend on not only on their own courses of action but also on actions chosen by others. In this interactive situation, a representation of the possible courses of action of each agent and the set of all possible payoffs is called a game. Agents playing a game are called the players.

Recently, linking different games together have drawn increasing attention as a promising option for sustaining cooperation. Just and Netanyahu (2000) discuss that the potential for linking games produce a larger feasible choice set compared to the aggregated isolated games in the context of water sharing between Palestine and Israel. They hold the view that successful linking is possible particularly when linked issues have an asymmetry of similar magnitude and prisoner’s dilemma characteristics. Kroeze-Gil (2000) argues that reverse interests are required to exploit the gains from linking two separate games. Though perfect reversibility has dominated in the interconnected games literature, Kroeze-Gil (2000) analyzes the cooperation through
interconnected games when interests in linked issues are not perfectly reverse to the involved players.

The prisoner’s dilemma game has two characteristics. First, for each player, defection is the dominant strategy. In the game theory literature, the notion of a dominant strategy is a technical term used to indicate that following this strategy leaves the player better off regardless of other player’s choice. In the ‘cooperate or defect’ type prisoner’s dilemma game, defection is often shown as the dominant strategy, that is the unconditional best strategy for each player. Second, playing the dominant strategy (i.e., defection by both players) leads to both being in a suboptimal (non-Pareto optimal) outcome compared to the cooperative strategy.

Bennet et al. (1998) provide a bargaining framework in which two players are engaged in negotiating two separate issues and show that both players may gain by linking two issues in a nested game framework. In the nested game literature, it is argued that countries with a weak negotiating position have higher incentives to improve their status by linking issues. It is also argued that analyzing water allocations as interconnected games can generate outcomes that may not be achieved under the scenario of separate individual games. In many cases, linking two separate games enlarges the bargaining space. Linking a water game with a non-water game allows countries to bargain for water allocation contingent upon the outcomes from non-water game (Carraro et al. 2005). Here, this strategy is used to analyze the bargaining situation for water allocation in the GBM basin between India and Bangladesh.

As previously mentioned in the literature, a successful linking requires some asymmetry in two different games in terms of bargaining power. In fact, the upstream and downstream players in the GBM basin (Bangladesh and India) are facing these types of asymmetric issues. These issues can be seen as separate games between these two countries. Since these games are
of asymmetric nature, they can be linked together to expand the bargaining space to achieve a cooperative solution for flood mitigation in this large transboundary river basin.

As discussed earlier, due to locational advantage India has higher bargaining power in deciding whether to divert water upstream (in the case of drought) or drain water downstream (in the case of potential flooding). India is one of the fastest growing countries in the world. However, the northeast part of the country is landlocked, which makes any type of large shipments to and from the outside world relatively expensive. On the other hand, the Chittagong port (the largest port in Bangladesh) is close to the seven northeastern Indian states. On the other hand, Bangladesh has very limited set of options when India shifts negative externalities associated with water management to its downstream neighbor. To keep up with its recent growth rate, India is trying to make an agreement with Bangladesh for transshipment of various goods through using the Chittagong port. Most recently, India is also asking for an agreement to import gas from Myanmar through Bangladesh. So far India is offering various a package of various financial incentives to obtain consent from Bangladesh. However, Bangladesh is not responding to these requests. It is argued that this reticence is caused by its frustration over the water-sharing issue with India (Elhance 1999).

Table 5 defines two prisoner’s dilemma (PD) games are defined: the water allocation game and transshipment game. In each cell, the first entry gives the payoff to player A and the second entry gives the payoff to player B. Here, player A refers to the upstream country (India) and player B refers to the downstream country (Bangladesh). Generally, player A and B each have two strategies, cooperate and defect in each game. Payoffs for various strategies in the water allocation game and in the transshipment game are presented in Table 5. We assume the following conditions regarding the payoff structure: in the first game $q < 0$, $r > 1$, $s > 1$, 

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Table 5. Payoff Structure of the Separate Prisoner’s Dilemma Game

<table>
<thead>
<tr>
<th>1. The Water Allocation Game</th>
<th>Bangladesh (Player B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperate</td>
</tr>
<tr>
<td>India (Player A)</td>
<td></td>
</tr>
<tr>
<td>Cooperate</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Defect</td>
<td>s</td>
</tr>
<tr>
<td></td>
<td>t</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2. The Transshipment Game</th>
<th>Bangladesh (Player B)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cooperate</td>
</tr>
<tr>
<td>India (Player A)</td>
<td></td>
</tr>
<tr>
<td>Cooperate</td>
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<tr>
<td>Defect</td>
<td>y</td>
</tr>
<tr>
<td></td>
<td>z</td>
</tr>
</tbody>
</table>

Note: Player 1 represents India which is the upstream country and Player 2 represents Bangladesh which is the downstream country. Payoffs in the upper left corner correspond to India and payoffs in the lower right corner correspond to Bangladesh. Without losing generality, the prisoner’s dilemma characteristics in both games can be represented by imposing following assumptions regarding the payoff structure: in the Water Allocation Game, $q < 0$, $r > 1$, $s > 1$, and $t < 0$ and in the Transshipment Game, $w < 0$, $x > v$, $y > u$, and $z < 0$ where $u > 0$ and $v > 0$. 

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and $t < 0$ and in the second game $w < 0$, $x > v$, $y > u$, and $z < 0$ where $u > 0$ and $v > 0$. The Nash equilibriums for both games are defect-defect $(0, 0)$. Table 6 shows the payoff structure of the linked game. Payoffs reported in each cell in Table 6 correspond to the integrated payoff from the water allocation game and transshipment game reported in Table 5. For instance, when both players cooperate in two games, corresponding payoffs of the linked game are $(1+u, 1+v)$ which are derived from the simple addition of payoffs when both players cooperate in the water allocation game $(1, 1)$ and the transshipment game $(u, v)$.

Figure 9 represents the area of feasible payoff set for two separate prisoner's dilemma games: the water allocation game and the transshipment game. In other words, figure 9 graphically represents payoffs from these two separate games reported in Table 5 in a Euclidean space. Figure 10 shows the gain from linking the two games in the bargaining space (the region between solid and dotted line). The region covered by solid lines represents payoffs from the linked game reported in Table 6 whereas the region covered by the dotted lines is formed by aggregating the separate payoff spaces of the water allocation game and the transshipment game from Figure 9. The region of the set of feasible payoffs dominates in the linked game compared to that of aggregation of the separate games. This example thus illustrates the expansion of the bargaining space, which in turn makes cooperation more likely. The implication is that the downstream player with little bargaining power in the water allocation game can increase his or her bargaining power by imposing credible threats from the transshipment game (in which it has greater bargaining power). In this case, linking two separate games provides a framework for achieving a self-enforceable agreement. The self-enforceable framework will aid in ensuring cooperation across basin-wide flood management through some credible threats to the upstream country.
Table 6. Payoff Structure of the Linked Game

<table>
<thead>
<tr>
<th>Bangladesh (Player B)</th>
<th>C</th>
<th>D</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
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<td>C</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>1+u</td>
<td>q+u</td>
<td>1+w</td>
<td>q+w</td>
</tr>
<tr>
<td>C</td>
<td>1+v</td>
<td>r+v</td>
<td>1+x</td>
<td>r+x</td>
</tr>
</tbody>
</table>
| D                     | s+u| u  | s+w| w 
| C                     | t+v| v  | t+x| x 
| C                     | 1+y| q+y| 1  | q |
| D                     | 1+z| r+z| 1  | r |
| D                     | s+y| y  | s  | 0 |
| D                     | t+z| z  | t  | 0 |
Figure 9. Representation of the Two Separate Prisoner’s Dilemma Games

Note: Slopes are calculated from the horizontal and vertical coordinates of the corresponding line. Payoffs (1, 1) and (u, v) correspond to the situation when both players cooperate in the water allocation game and in the transshipment game while payoffs (0, 0) correspond to the situation when both players defect in both games. In the water allocation game, payoffs (0, Y₁) and (X₁, 0) respectively correspond to situations when B defects and A cooperates and vice versa. Similarly, in the transshipment game payoffs (0, Y₂) and (X₂, 0) respectively correspond to situations when B defects and A cooperates and vice versa.
Note: The region covered by solid lines represents payoffs from the linked game reported in Table 6 whereas the region covered by the dotted lines is formed by aggregating the separate payoff spaces of the water allocation game and the transshipment game from Figure 9.
8. Discussion and Conclusion

Bangladesh is one of the most densely populated countries in the world and one of the poorest. It is also often referred to as the most disaster-prone country in the world. Exposed to the Bay of Bengal, it is crossed by extensive rivers draining neighboring countries covering an area ten times larger than its own. The location makes the country extremely vulnerable to the impact of cyclones, tidal surges and floods. The tapestry of the nation’s delta landscape is constantly changing. The great meandering rivers annually consume around 90 square kilometers of fertile occupied land, which leads to severe erosion that takes away land and shelter for millions of people living along the collapsing banks. It is a phenomenon that directly affects the lives of an estimated one million people each year. Half of these people become homeless and marginalized, rarely finding adequate and alternative shelter elsewhere (Hutton and Haque 2003).

The basic geomorphologic fact regarding Bangladesh is that it is a delta and most of it still falls into the active part of the delta. The scale of the hydrologic system of the lower Ganges basin is staggering.\(^{11}\) It is very difficult rely on man-made structures to control nature at such a scale. Furthermore, floods are very likely to increase their severity with each passing year as the rivers are continuously being silted, and the landscape deforestation is increasing upstream (Mirza et al. 2003). The gigantic scale of the delta formation needs to be taken into account in long-term flood mitigation plan for Bangladesh. The long-term solution to flood mitigation relies on ensuring participation of all basin countries instead of piecemeal intervention.

\(^{11}\) The monsoon hits India every year with the same amount of energy as 15,000 50-megaton H-bombs, the total tonnage we have in the world. The largest delta in the world is in this area where 2.9 billion metric tons of sediment per year are deposited into the ocean. The underwater delta goes down some 3,000 km south, 2,000 km below Sri Lanka (Rogers et al. 1989).
However, under the existing institutional arrangement, the incentive for the upstream country (India) to cooperate is not great, coupled with a very limited bargaining power for the downstream country (Bangladesh). In this study, an attempt has been to provide a very preliminary framework to extend the bargaining space to effectively negotiate a cooperative flood mitigation solution among downstream and upstream countries. Linking the water-sharing issue with another bilateral issue will give more bargaining power to the downstream player. Using insights from basic game theory literature, it is shown that this will make the cooperative solution more attractive, or in other words, will make non-cooperation more costly. Having said that, implementation of this framework will not be an easy task. It will face obstacles from the upstream country. However, since the non-water issue (e.g. transshipment) has a higher stake to the upstream country cooperation may still be attractive.

Recently, India has been planning to link the major rivers upstream including the Ganges and Brahmaputra to divert water from the north of the country to the drought-prone southern and western states. The Indian government is seeking international funds to implement this mega-project, which would redraw the hydrologic map of the subcontinent with potentially adverse ecological, social, and economic consequences downstream. As it will allow India to transfer the water-related negative externality downstream in an even greater magnitude, the livelihoods of more than 100 million people will be threatened. Preliminary estimates suggest that more than 20,000 square kilometers of land could be flooded and 3 million people will be forced off their land (Vidal 2003). In various forums, Bangladesh is actively protesting against India's giant river linking project, but so far it has not produced any direct response from India. The framework discussed here that proposes linking the water-sharing issue with other non-water issues (e.g.
seaport access) to give more bargaining power to the downstream player and can be used as a counter threat against such unilateral actions.

The environmental security of many countries rests on enhanced cooperation regarding transboundary water issues (Duda and La Roche 1997). According to Correia and da Silva (1999), a new framework is required to overcome persistent conflicts in international river basins. When spatial, geopolitical and strategic considerations are the dominant issues in natural resources management, game theoretic framework can be useful not only to better manage a common resource but also to identify conditions under which agreements that ensure better management are likely to emerge. As viewed by Carraro et al. (2005), the existence of a negotiated settlement of a Pareto-superior outcome is not a guarantee of cooperation. In that case, a shift in the bargaining space may lead to a self-enforcing condition under which a cooperative agreement may emerge. In the GBM context, the proposed framework of linking the water-sharing issue with other non-water issues (e.g. seaport access) has the potential to generate a cooperative agreement to deal with transboundary water conflicts.
References


