بسم الله الرحمن الرحيم

FLOOD CONTROL IN A FLOODPLAIN COUNTRY

EXPERIENCES OF BANGLADESH

by

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FOREWORD

Torrential rains and overflowing rivers cause floods with devastating effects. Flooding is a natural disaster which confronts many countries.

Nearly 80 per cent of Bangladesh is a riverine deltaic floodplain located at the lower part of the basins of three mighty rivers : the Ganges, the Brahamaputra, and the Meghna. The landmass of Bangladesh is annually flooded by overflowing rivers during monsoon season when the rainfall in the country is very high. Sometimes the abnormal floods turn out to be a cataclysm accompanied by tremendous loss of life and property as in the case of disastrous floods of 1987 and 1988 in Bangladesh.

One of the Science Programmes of the Islamic Educational, Scientific and Cultural Organization (ISESCO) deals with the preparation of studies directed towards prevention of natural disasters. Within the scope of this Programme, ISESCO invited the Institute of Flood Control and Drainage Research (IFCDR), Bangladesh University of Engineering and Technology, Dhaka for the preparation of a study on floods in Bangladesh.

The Study Team comprising Prof. Jahir Uddin Chawdhury, Dr. Mohammad Rezaur Rahman and Mr. Mashfiqus Salehin of IFCDR, Dhaka has prepared the present study which describes the experiences of Bangladesh in dealing with the flood hazard. We are grateful to the members of the Study Team for preparing this study for ISESCO.

This study provides an objective assessment of the evolution of the concepts and strategies of flood control in Bangladesh. It emphasizes that in dealing with flood as a natural hazard, the focus should shift from flood control to flood management through round-the-year integrated water management dealing with issues related not only to flood but also drainage, irrigation, agriculture, fisheries, water transport, environment and socio-economy in the context of the overall development of the country.

ISESCO is publishing this comprehensive study on flood control activities which have taken place in Bangladesh over the years and the general guidelines for flood management based on the experience gained in this regard.

May Allah protect us all from calamities.

July 1997

Dr. Abdulaziz Othman Altwaijri
Director General,
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ABBREVIATIONS

AFPM	- Active Flood Plain Management
B/C	- Benefit/Cost
BIWTA	- Bangladesh Inland Water Transport Authority
BPDB	- Bangladesh Power Development Board
BWDP	- Bangladesh Water Development Board
CG	- Chittagong
cumec	- cubic meter per second
EIRR	- Economic Internal Rate of Return
EPWAPD	- East Pakistan Water and Power Development Authority
FAPA	- Flood Action Plan
FC	- Flood Control
FCD	- Flood Control and Drainage
FCDI	- Flood Control, Drainage and Irrigation
FPCO	- Flood Plan Coordination Organization
GEV	- Generalized Extreme Value
ha	- hectare
HYV	- High Yielding Variety
IFCDR	- Institute of Flood Control and Drainage Research
IRR	- Internal Rate of Return
ISESCO	- Islamic Educational, Scientific and Cultural Organization
IWT	- Inland Water Transport
kg	- kilogram
Km	- kilometer
LGED	- Local Government Engineering Department
LGRDC	- Local Government, Rural Development and Cooperatives
Mha	- Million hectare
mm	- millimeter
MPO	- Master Plan Organization
MSL	- mean sea level
NC	- North-Central
NE	- North-East
NEMAP	- National Environment Management Action Plan
NGO	- Non-Governmental Organization
NWMP	- National Water Management Plan
NW	- North-West
NWP	- National Water Plan
O&M	- Operation and Maintenance
ppt	- parts per ton
PWD	- Public Works Department
SC	- South-Central
SE	- South-East
sq.km	- square kilometer
SW	- South-West
undp	- United Nations Development Programme
WARPO	- Water Resources Planning Organization

LOCAL EXPRESSIONS

Aman	- Monsoon variety rice
Aus	- Pre-monsoon variety rice
B. Aman	-Broadcast aman
Baor	- Abandoned ox-bow lake
Beel	- Perennial water body
Boro	- Dry season variety rice
Char	- Sand bars, alluvial islands
District	- Administration unit
Haor	- Large depression in NE region
Kharif 1	- Premonsoon dependent (April to July/ August) crop season
Kharif 2	- Monsoon (July to December) dependent crop season
Rabi	- Dry period (December to May) crop sason
T. aman	- Transplanted Aman
Thana	- Lowest adminstrative unit
Union	Conglemerate of villages

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This study has been sponsored by the Islamic Educational, Scientific and Cultural Organization (ISESCO), Rabat, Morocco. We express our gratitude to ISESCO for selecting our Institute to carry out this study. We thank the Director of our Institute, Professor A. F. M. Saleh, for his whole-hearted cooperation in carrying out this study. We also thank our colleagues who have helped us by giving many valuable suggestions during different stages of the study.

Water Resources Planning Organization, Bangladesh Water Development Board, Local Government Engineering Department, Bangladesh Inland Water Transport Authority, Roads and Highways Department, Department of Fisheries, Bangladesh Meteorological Department, Ministry of Relief and Rehabilitation and many other organizations have helped us immensely by providing us with many of their reports and giving us access to up-to-date data bases. Many individuals have also provided us with valuable old documents. Their cooperation in this regard has improved the quality of the report and is sincerely appreciated.

SUMMARY

Bangladesh is a deltaic country located at the lower part of the basins of the three great rivers, the Ganges, the Brahmaputra and the Meghna. The extensive floodplain of these rivers and their numerous tributaries and distributaries is the main physiographic feature of the country. In fact about four-fifths of Bangladesh is floodplain. As a result of flat topography of the floodplain, one-fifth to one-third of the country is annually flooded by overflowing rivers during monsoon when the rainfall within the country is also very high. On the other hand, the country suffers from scarcity of water during dry season.

This annual phenomenon of rainfall and river flooding has played an active role in shaping the landscape of the floodplain, nourishing its soil and sustaining its production system. The fertile floodplain and availability of abundant water during monsoon have made the country a predominantly agrarian one. Soon after the major floods of 1954 and 1955, the Government adopted a policy of protecting agricultural land from the river flood in order to secure agricultural production. Since then about 8,000 km of earthen embankments parallel to the river bank and 500 sluices and regulators have been built. After the disastrous floods of 1987 and 1988, the flood hazard has again become the major concern to the policy makers. The impacts of flood control interventions on the water regime, environment and society in a floodplain country have become apparent in the meantime. The water regime has also been significantly affected by the construction of about 16,000 km of highways and feeder roads, 12,000 km of rural roads and 3,000 km of railways. Based on the experiences with flood control and other infrastructures, new insights have been gained and consequently new concepts of flood management have evolved.

Large scale investment on flood control projects began with the adoption of a 20-year Master Plan in 1964. The objective of the plan was to increase agricultural (mainly rice) production to satisfy increasing national demand. The plan had a portfolio of 58 large scale projects many of which have since been implemented. The International Bank for Reconstruction and Development conducted a land and water sector study in 1972. It recommended quick yielding small scale projects and subsequent investment programme of water sector received priority on small and medium scale projects. In 1983, the Government of Bangladesh initiated a National Water Plan (NWP). The objective of the NWP was to maximize agricultural growth and production and contribute to achieving foodgrain self-sufficiency. After the floods of 1987 and 1988, the Government initiated a Flood Action Plan (FAP). At the initial stage of FAP, the focus was on flood mitigation. Gradually it was recognized that FAP should pay attention to integrated water management covering issues relevant to not only flood but also drainage, irrigation, navigation, environment and socio-economy. A framework for the development and implementation of a strategic National Water Management Plan (NWMP) for Bangladesh has been approved recently. The NWMP project of three years duration is expected to start from January 1997.

On average, the coverage by flood control and drainage projects has grown by approximately 120,000 hectares per year over the last 30 years which resulted in a decreasing trend of approximately 80,000 hectares per year in the flooded area. More than half of total project benefitted area have 25 to 100 km of embankment with 2 to 8 km of embankment per 1,000 ha of benefitted area. The experiences of flood control interventions in a floodplain country have proved that it is difficult to attain stated objectives of intervention without giving due consideration to the hydro-morphologic features of the floodplain and the socio-economic condition of its inhabitants.

While many projects have been successful in raising agricultural output, which is the major objective of flood control projects, the impact of these projects on the overall foodgrain production is rather ambiguous. Flood control projects with irrigation component have been more successful. The objective of increasing rice production by providing flood protection to agricultural land got so much priority that the consequential stress on the floodplain eco-system received little attention. Interventions are causing increase in flood risk elsewhere, reducing post-monsoon flow in the river and deteriorating morphology of the rivers. They are depleting floodplain resources such as fisheries and impeding floodplain functions such as water transport. This in turn is causing conflict between different users of floodplain such as farmers, fishermen and boatmen. On the other hand, natural floodplain processes such as river bank erosion and floodplain sedimentation which are difficult to contain have frequently compromised project performances.

It is seen that prevention of flood in floodplain has many negative environmental consequences. On the other hand, population in general do demand protection against flood damage. Again, such protection has repercussion on the water use during dry season. Therefore a balanced approach requires a shifting of policy from flood control to flood management that even under a broader framework of round-the-year water management.

The flood control projects were undertaken mainly on their technical and economic viability. Experiences have shown that environment, society and culture play equally strong role in their sustenance. Therefore calculation of economic return should not be the only guide in selecting water resource projects. Decisions should be based on multi-criteria framework of economic costs and benefits, and social and environmental impacts. Indigenous technologies and production systems should get priority, preservation of floodplain environment should be considered as constraint and peoples participation in planning decisions should be ensured for the sake of efficiency and equity. Vulnerability of the society to large floods can be reduced by making communication lines, essential utility services and other infrastructures flood proofed. There should be coordinated planning and construction of flood control projects and other water regime affecting infrastructures especially roads. A floodplain land use regulation can be formulated so that planning, design, construction and maintenance of infrastructures account for flood factor and preservation of floodplain resources and environment.

It is essential to take an integrated view of the hydrologic cycle and the interactions of human interferences. Multi-objective water resource planning approach is required to optimize the water needs of agriculture, public health, fisheries, ecology, navigation and industries. Proper macro-planning of water resources projects requires development of an institution capable of dealing with a task which is multi-dimensional and multi-disciplinary in nature. Finally, sustainable development in the floodplain can be ensured only when flood management itself is addressed from the context of overall development of the country.

CHAPTER 1

INTRODUCTION

1.1 Setting of Bangladesh

Bangladesh is a deltaic country located at the lower part of the basins of the three great rivers, the Ganges, the Brahmaputra and the Meghna. The extensive floodplain of these rivers and their numerous tributaries and distributories is the main physiographic feature of the country. In fact about four-fifths of Bangladesh are floodplain. As a result of flat topography of the floodplain, one-fifth to one-third of the country is annually flooded by overflowing rivers during monsoon. This annual phenomena has played a vital role in shaping the economy, society and culture of the country.

The high fertility of alluvial floodplain has supported an expanding population of the country having an area of approximately 144,900 sq.km. The population has grown from 42 million in 1951 to 111 million in 1991. Available estimates suggest that the population will increase to 136-140 million by 2000 AD. The present average density of population is 755 people per sq.km and it becomes nearly 1,020 people per sq.km when net land area is considered. The literacy rate is 33%.

The country has been able to achieve near self-sufficiency in foodgrain production. But nearly half of the population is still below poverty line defined on the basis of daily calorie intake. The per head gross national product in Bangladesh is Taka 9,300 (US$ 230 approximately). The agricultural sector which is dominated by floodplain agriculture accounts for approximately 30% of the gross domestic product while manufacturing accounts for 10%. The agriculture sector employed about 60% of the labor force of around 51 million in 1991.

Abundant floodplain supports rich fisheries resources. Fish provides the major share of protein and calorie intake of the population. The shallow aquifer which underlies most of the floodplain supports drinking water supply to 90% of the rural population through tubewells. Due to riverine nature of the country, the inland water transport has always been a natural and cheap means of transport. It is the second largest employer in the country.

More than four-fifths of the population of Bangladesh is rural. Traditionally the rural Bangladesh is a farming society. Favorable floodplain environment including extensive rainfall during monsoon, dietary habit and socio-cultural preferences have made rice as the dominant crop. The rural people especially farmers in their day to day activities are more used to the calendar based on the Bengali year than to that based on English year. The Bengali year begins on 14th April and water levels in most rivers start rising around the same time. The water year for hydrological data collection and analysis in Bangladesh is counted from the 1st of April. The official accounting of land taxes in Bangladesh is still based on the Bengali year.

1.2 Flood Control in Bangladesh

For generations, floodplain inhabitants of Bangladesh have adapted to the annual flood through numerous indigenous strategies in order to reap the benefit from this recurring natural phenomenon. It becomes a major public concern when their adjustment ability is surpassed by occasional abnormal floods which cause damages to the marginal resources. With the increase in population and growth of physical infrastructure, vulnerability of the society to such floods has also grown considerably. As a result public demand for mitigating flood hazards grew rapidly.

The focus of flood control, drainage and irrigation projects was to secure and increase food production by protecting agricultural lands from river floods. This grew out of the aim for achieving self sufficiency in food grain in a largely agrarian, populous and under developed country. The major floods of 1954 and 1955 brought the issue of flood control and water development firmly onto the development agenda of the Government. Since then about 8,000 km of earthen embankments parallel to the river bank and 500 sluices and regulators have been built. After the disastrous floods of 1987 and 1988, the flood hazard has again become the major concern to the policy makers.

The positive and negative impacts of large scale flood control and drainage intervention on the water regime, environment and society in a floodplain country have become apparent in the meantime. The water regime has also been significantly affected by the construction of about 16,000 km of highways and feeder roads, 12,000 km of rural roads and 3,000 km of railways. Based on the experiences with flood control and other infrastructures, new insights have been gained and consequently new concepts of flood management have evolved. Such will be discussed in this report. This study has been carried out during the period of June to October 1996, at the request of Islamic Educational, Scientific and Cultural Organization (ISESCO). Although some preliminary analyses have been carried out in this study, most of the observations have been made on the basis of published reports.

1.3 Objective of the Study

This study addresses the gradual evolutions of the concepts and strategies of flood control in Bangladesh most of the land area of which is basically floodplain. An assessment of impacts of these flood control activities is made and future direction is provided.

1.4 Structure of the Report

Chapter 2 discusses the geologic, morphologic and hydrologic setting of Bangladesh. These features which are unique in many ways have immense bearing on the performances of flood control projects as will be elucidated in later chapters. Floodplain supports many functions of important economic and ecological values. Such are discussed in Chapter 3. Chapter 4 deliberates the gradual evolution of concepts and strategies regarding flood control in Bangladesh. Flood control activities which have taken place in Bangladesh over the years are presented in Chapter 5. Experiences that have been gained with such activities are discussed in Chapter 6. Based on these experiences, Chapter 7 provides guidelines for future.

CHAPTER 2

GEOMORPHOLOGY AND HYDROLOGY OF BANGLADESH

2.1 Location and Topography of Bangladesh

Bangladesh stretches between 20o34'N and 26o33'N latitudes and 88o01'E and 92o41'E longitudes (Figure 2.1). The tropic of cancer passes over Bangladesh. It has an area of approximately 144,900 sq. km bounded by India in the west, north and east, Mayanmar in the south-east, and the Bay of Bengal in the south. The Himalayas is close to the northern border of Bangladesh. Three major rivers, the Ganges, the Brahmaputra and the Meghna meet inside Bangladesh before discharging to the Bay of Bengal through a single outfall. Most part of Bangladesh is the floodplain of these three mighty rivers. The 64 administrative regions (Districts) of Bangladesh are shown in Figure 2.1. This Figure will serve as the index map in this report to indicate an area.

A generalized relief contour map is shown in Figure 2.2. It is seen that most of Bangladesh consists of extremely low and flat land. The capital city Dhaka which is about 225 km from the coast is within 8 meters above the mean sea level (MSL). The land elevation increases towards north-west and reaches an elevation of about 90 meters above the MSL. The lowest part is the coastal tidal land. The highest areas in Bangladesh are the hill tracts in the eastern and Chittagong regions.

2.2 Formation of Bengal Delta

2.2.1 Delta building

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, and mainly from the Himalayas. The surrounding mountains are Rajmahal Hills on the West, the Himalayas and the Meghalaya Plateau on the north and Tripura-Chittagong Hills on the east (Figure 2.3). The delta building process has been mainly due to the Ganges, the Brahmaputra and the Meghna. But the most important delta builder is the Ganges. The Brahmaputra was originally a comparatively small river, but since its connection with the Tsang Po of Tibet through its tributary, the Dihong in upper Assam, and subsequent additions of the floods of the Teesta river, it has been a formidable rival of the Ganges and promises to play more and more important part in future (Majumdar, 1941).

2.2.2 Subsidence and uplift

The delta appears to have been affected by tectonic movements of earth crust. A generalized tectonic map of Bangladesh and adjoining areas has been prepared by Alam et al. (1990) as shown in Figure 2.4. Large areas within Bangladesh have been uplifted in recent times and some areas are still subsiding. It has been postulated that these tectonics may be due to the presence of a major fault. This fault lies along a line connecting Calcutta and Mymensingh and passes slightly above the confluence of the Ganges and the Brahmaputra as shown in Figure 2.4. This fault is called as Hinge zone. Examples of areas of uplift are the Barind tract in Rajshahi area and the Madhupur tract in Mymensingh-Tangail area which lie on either side of the Hinge zone. In general, there has been subsidence in the south of this zone due to crustal downwarping and the compaction of recent sediments e.g. the Faridpur depression. While the Madhupur tract is thought to be rising at a rate of between 0.1 and 0.6 mm annually, the adjacent Sylhet depression basin in the east is subsiding at a maximum rate of upto 21 mm annually (Halcrow et al, 1992). In the South-West deltaic region at the head of the Bay of Bengal, according to Morgan and Mclntire (1959), annual subsidence rate at Khulna is between 2 and 5 mm and in the Sundarban forest area is between 0.75 and 1.4 mm.

Bangladesh has been affected by major earthquake occurrences in the surrounding areas as well as moderate to severe earthquakes within its territory. Events that affected Bangladesh occurred in 1762, 1869, 1885, 1897, 1918, 1930, 1934 and 1950 (Anwar, 1987; French Engineering Consortium, 1989). Of these, the hypocenters of the earthquakes in 1885 and 1918 were located within Bangladesh with magnitudes of 7 and 7.6 respectively on the Richter scale (Anwar, 1987).

2.3 Physiography

Bangladesh comprises hill, terrace and floodplain areas (Figure 2.5). A brief description of these three broad physiographic regions is given below:

(i) Hill areas: These include the northern and eastern hills and occupy about 12% of the country. These are underlain by Tertiary and Quaternary sediments which have been folded, faulted and uplifted, then deeply dissected by rivers and streams. There is an overall pattern of long, linear ridges running approximately north-northwest to south-southeast with the highest elevation as high as 900 m above MSL.

(ii) Terrace areas: These include Madhupur Tract in the centre and Barind Tracts in the north-west. Terraces occupy about 8% of the country. These areas are not true alluvial terraces but are almost level surfaces appearing above the recent deposits. The Madhupur Tract is closely dissected and broken by faults. The Barind Tract is composed of an uplifted and locally tilted series of fault blocks interrupted by a few major river valleys occupying fault troughs.

(iii) Floodplain areas: These include alluvial floodplain and estuarine areas and occupy the remaining 80% of the country. They are composed of predominantly recent alluvial deposits transported from the hills by the rivers. There are numerous natural depressions some of which are abandoned channels formed as a result of change in river courses, and some have been formed in the process of delta building and as a result of tectonic movements of earth.

2.4 Types of Floodplain Landscape

Four main types of landscape can be recognized (Brammer, 1996) in the flood-plain areas discussed earlier (Figure 2.5). They are briefly discussed below.

(i) Piedmont plains: These are characterized by gently sloping land, composed of mainly sandy deposits, at the foot of hills with riverain colluvial and alluvial deposits and a drainage pattern of a braided river. The main areas occupied by them are most parts of Dinajpur (Old Himalayan piedmont plain) and north-western part of Rangpur region (Teesta floodplain) (Figure 2.6).

(ii) Meander floodplains: These floodplains have been formed by the big meandering rivers which deposit sediments within the channel on river beds and also alongside the channels. Gradually high river banks (levees) build up. A meandering river constantly shifts its course, eroding the outside banks of bends and depositing new sediments on the inside bends. This process goes on repeatedly and accounts for the complex patterns of relief and sediments and abandoned channels. Meander floodplains cover greater part of Teesta, Atrai-Karatoya, Brahmaputra, Jamuna, Ganges, and Meghna river floodplains (Figure 2.6).

(iii) Tidal floodplains: They cover mainly the South-West part of the country (Ganges Tidal Floodplain) and part of Chittagong Coastal Plain (Figure 2.6). These are characterized by a distinctive, almost-level landscape crossed by innumerable, interconnecting tidal rivers and creeks following zigzag patterns and flood levels lower than on meander plains. Inundation of lands happens twice a day at high tide and most of the area is flooded during spring tide.

(iv) Estuarine floodplains: They cover most parts of Comilla and Noakhali regions, adjoining parts of Barisal, Patuakhali and Faridpur and the recently developing Meghna Estuary (Figure 2.6). They are characterized by almost horizontal level underlain by silts deposited uniformly both in the lateral and vertical directions under estuarine conditions.

2.5 Aquifer

The Bengal delta formed by alluvial deposit constitutes a huge aquifer. A schematic geological cross-section of the Bengal Basin is shown in Figure 2.7. The aquifer system which underlies most of the floodplain, normally consists of three lithological units: (1) an upper silty clay/silt layer, (2) a middle layer of fine to very fine sand, and (3) a lower layer of fine to coarse sand, constituting the main aquifer. Though there are significant regional variations in much of the floodplain area, the aquifer occurs at usually 30 to 60 m depths; exceptions are the up-faulted blocks of the Barind and Madhupur tracts, part of the Sylhet Basin and all of the south, where the fine surface deposits can be considerably thicker. In contrast, in Dinajpur and Rangpur Districts the main aquifer extends almost to ground surface. The middle layer of aquifer is often about 20 m thick. Deep aquifers are present in much of Bangladesh but occur at depths between 300 and 2,500 m. Present day groundwater development is confined to the very recent shallow sediments with wells seldom exceeding 150 m depth. In absolute terms, transmissibility of the alluvial aquifer is mainly in the range of 500 to 3,000 cubic meters per day per meter width of aquifer and storage coefficient (or specific yield for water table aquifer) varies from about 1 to more than 15%.

2.6 Climate

Bangladesh has a tropical monsoon climate. In general, the climate is characterized by high temperature, heavy rainfall, often excessive humidity during monsoon (June to September) and marked inter and intra seasonal variation.

Temperature: The mean annual temperature is about 25^oC within the country. Mean monthly temperatures range between 18^oC in January and 30^oC in the months from April to May. The highest and lowest temperatures throughout the year range between 43^oC and 4^oC with the exception in the areas near the coast where the range is narrower.

Day-Length and Sunshine: Except a little variation in the bordering areas in the east and the coastal fringe, day-length and sunshine hours throughout the whole country are in general almost same. Day-length at Dhaka varies from 10.7 hours in December to 13.6 hours in June. Sunshine at Dhaka ranges from 5.4-5.8 hours/day in the monsoon season to 8.5-9.1 hours/day in the winter (from December to February) and pre-monsoon (from March to May) seasons.

Wind: The wind direction is mainly south-west and south-east during the pre-monsoon and monsoon seasons, and from between north-west and north-east during the post-monsoon (from October to November) and winter seasons. The advent of occasional Nor'westers with velocity of 50-100 km/hr changes the wind direction in the pre-monsoon season. Tropical cyclones from the Bay of Bengal with high velocity of more than 115 km/hr are liable to hit the coastal areas in the pre-monsoon and post-monsoon seasons.

Humidity: The humidity is relatively high throughout the year. It is over 80% during the months from June to September, i.e. the monsoon months. The humidity is around 58% in most of the western areas of Bangladesh in March and April and in the eastern areas in January, February and March.

Evaporation: Evaporation rates range from about 50-75 mm per month in the dry season to 100-175 mm per month in the pre-monsoon season. In the monsoon, they are generally about 100-125 mm. Annual potential evapo-transpiration rates (modified Penman) range from about 1,180 mm in the north-east to 1,285 mm in the centre-west.

2.7 Rainfall

2.7.1 Rainfall distribution

Rainfall within the country is mainly caused by the South-Westerly-Trades, known as the 'monsoon', during the months of June to September. The two other sources of rainfall are the western depressions of winter which cause rainfall mainly from the end of January to the end of February, and the Nor'westers (the early summer thunderstorms) which cause rains mainly within the first week of May. Average annual rainfall for the country is about 2,200 mm. About 80% of the rainfall occurs during the months of May to September. The isohytal pattern of the average annual rainfall is shown in Figure 2.8. The mean annual rainfall is the lowest near the western border. The advancement of isohytes is towards the north, east and south reaching more than 2,500 mm in the extreme north-west, near and within the northern and eastern hills and near the coasts, and exceeding 5,500 mm near the border in the north-east. There is wide variability of rainfall from year to year. Again, distribution of rainfall within the year is highly skewed (Figure 2.9). Rainfall during the dry season is negligible.

2.7.2 Rainfall drought

Although 80% of the annual rainfall occurs during May to September, long spells of rainless days ranging upwards from two weeks can cause droughts (Figure 2.10). Drought is a hazard for the rainfed cultivation in Bangladesh. The occurrence of prolonged droughts necessitates supplemental irrigation in monsoon season. Almost 5 Mha of agricultural land in the districts of Rajshahi, Natore, Chapai Nawabganj, Rangpur, Dinajpur, Bogra, Kushtia, Jessore and Dhaka are susceptible to droughts of varying degree. The yield losses of rice crops may range from 20 to 70% depending on the severity of droughts (Harza et al, 1991).

2.8 Major River Systems

Bangladesh is basically a land of rivers. It is criss-crossed with around 200 rivers, which forms a complex and ever changing pattern on a north to south trajectory (Figure 2.11). One dominant feature of the hydrological regime of Bangladesh is that most of these rivers are either contributory or distributory to the Ganges, Brahmaputra and Meghna rivers. Another important feature is that 57 rivers originate outside the boundary of Bangladesh as shown also in Figure 2.11. The total length of the river courses is approximately 24,000 km and cover 9,770 sq.km or 7% of the country area.

2.8.1 Drainage outlet of Ganges-Brahmaputra-Meghna (G-B-M) river system

The three large rivers of Bangladesh namely Ganges, Brahmaputra and Meghna rank among the major rivers of the world. Table 2.1 shows a comparison of these three rivers with other major rivers of the world. The total catchment area of the G-B-M river system stands at 1.74 million sq. km covering areas of China, India, Nepal, Bhutan and Bangladesh as shown in Figure 2.12. The G-B-M river system drains to the Bay of Bengal through a single outlet in Bangladesh while only 8% of the catchment area lies within Bangladesh. Figure 2.13 shows the hydrograph of monthly mean discharge downstream of Ganges-Brahmaputra confluence. The river system carries enough water from outside the country each year to inundate the catchment inside the country with 6 meters of water. The rainfall inside the country can add another 2 meters of water. Since Bangladesh is basically floodplain of these three rivers, the flood hydraulics is dominated by them. These rivers carry about one billion tons of sediment each year which can cover the country with 1 cm thick layer of sediment. Principal hydro-morphologic characteristics of the three major rivers are presented in Table 2.2.

Table 2.1: Comparison of some of the world's major rivers (Source: Delft, 1996 and Rashid, 1991)

River	Length (km)	Catchment (sq.km)	Average discharge (cumec)
Ganges	2,200	1,090,000	11,300
Brahmaputra	2,900	573,500	20,200
Meghna	900	77,000	4,600
Amazon	6,600	5,782,000	214,200
Mississippi	6,200	3,223,00	12,900
Congo	4,700	4,016,000	40,000
Nile	6,700	2,849,000	1,900
Indus	3,100	972,000	6,600
Yangtze	5,500	1,940,000	21,900

Table 2.2: Principal hydro-morphologic characteristics of the Ganges, the Brahmaputra, and the Meghna rivers (Source: Barua, 1994 and Delft, 1996).

Parameters	Ganges	Brahmaputra	Meghna
Catchment (sq.km)	1,090,000	573,500	77,000
Length (km)	2,200	2,900	900
Mean annual raifall within catchment (mm)	1,200	1,900	4,900
Average discharge (cumec)	11,300	20,200	4,600
Annual sediment transport (million tons/year)	548	590	13
Bed material grain size (d 50 mm)	0.12	0.22	0.18
Average width (km)	5	11	1
Average depth (m)	4.5	5	4.7
Bed slope (X in 10,000)	5	7	2
Planform	Point-bar meandering	Braided	Meandering canaliform

2.8.2 Changes in major river courses

The swingings and avulsions of the courses of rivers in recent history have significant influence on the morphology of the alluvial floodplain of the Ganges-Brahmaputra-Meghna river system. Excellent accounts of these river changes are given in many literatures and some of them are Majumdar (1941), Law (1968), Rahman (1993) and Brammer (1996). The major changes have been shown in Figure 2.14. The recent diversion of the Teesta occurred in 1787 towards east to an old abandoned course which joined the Brahmaputra. The Brahmaputra moved 60 km westward from the Old Brahmaputra to the present course of the Jamuna during 1780 to 1830. At one time the main course of the Ganges considered to flow through the Bhagirathi river which is at the west side of the Ganges Delta, but in the 15th or 16th century the river swung eastward to follow a course close to that of the Gorai river in Kushtia. By the mid-18th century the river had migrated further east to the Arial Khan river in Faridpur. Between 1830 and 1860, the Padma which carries combined flow of the Ganges and the Jamuna joined the Meghna and the combined course is presently known as the Lower Meghna which is at the east side of the Delta.

Several concepts have been put forward to explain the major changes in river course. They are thought to be caused by tectonic activities like uplift and down-warping of earth layer and earth-quakes, and/or by trigger action of very large flood from steep gradient to flat slope.

The drastic changes in river course as well as the periodic change of river reach due to meandering behavior have played the role in determining the nature and the topography of the floodplain. These river changes have significant effect on the distribution of soil parent materials (Brammer, 1996). Abandoned channel reaches are valuable wetland resources.

2.8.3 Description of major rivers

The Brahmaputra-Jamuna: The Brahmaputra originates in the Tibetan Plateau and collects snowmelt and runoff from the catchments in China, India and Bhutan before reaching Bangladesh. Its catchment area stands at 573,500 sq. km. of which only 7% lies in Bangladesh. Its total length is 2,900 km, 270 km being within Bangladesh. The Brahmaputra starts rising in March/April due to snowmelt in the Himalayas and attains a peak in June. It rises again and reaches the annual peak in late August from heavy monsoon rainfall. The maximum peak discharge was 98,300 cumec in 1988 and minimum low flow discharge was 2,860 cumec in 1971. The Brahmaputra is a large alluvial, braided, multi-channel river with an average width of 11 km within Bangladesh. It is morphologically very active with severe bank erosion, resulting in frequent shifts of banklines. Shift of 1 km in a single year has been recorded. The river has strong chaotic tendencies which means that it is inherently unstable and that small changes in the boundary conditions can result in major changes in geometry over a matter of one or two seasons (Halcrow et al, 1993a). Its ever changing cross-sectional geometry, planform and bedform affect the stage-discharge relationship (Chowdhury and Islam, 1996).

Previously its main course was old Brahmaputra but 200 years ago it changed its course into the present one. The downstream of old Brahmaputra off-take, Brahmaputra is known as the Jamuna. The Jamuna meets the Ganges at Manikganj.

The Ganges-Padma: The Ganges river rises from the Himalayas near Indo-China border. Its catchment area covers China, India, Nepal and Bangladesh. The total catchment area stands at 1,090,000 sq. km out of which only 5% lies within Bangladesh. The length of the Ganges is about 2,200 km of which 230 km lies within Bangladesh. The Ganges starts rising in June/July and attains the peak in late August or early September. When this peak coincides with the peak of Brahmaputra as it did in 1988, severe flooding occurs. The maximum peak discharge of the Ganges was 76,000 cumec in 1987 and minimum low flow was 261 cumec in 1993. The Ganges is a wide meandering river the width of which is about 5 km. After meeting with the Jamuna, the combined flow of the Jamuna and Ganges takes on the name Padma. The Padma runs about 120 km before meeting Meghna at Chandpur. The width of the Padma varies between 12 to 15 km. The discharge varies from a minimum of 10,000 cumec to a maximum of about 120,000 cumec.

The Meghna and the Lower Meghna: The Meghna rises in the hills of Manipur in India where it is known as Barak. Barak enters Bangladesh through its north-eastern corner and bifurcates into two channels known as Surma and Kushiyara. These two channels meet again further downstream and takes on the name Meghna. The catchment area of Meghna is 77,000 sq. km out of which 35,000 sq.km lie within Bangladesh. The total length of the river is about 900 km of which 400 km is in Bangladesh. The average width is 1 km. The Meghna is a rainfed river and usually attains its peak in August/ September. Although it is a relatively small river, severe flooding occurs in the Meghna basin due to heavy rainfall in its catchment frequently aggravated by the backwater effect of the Ganges-Padma. The maximum peak discharge of the Meghna was 19,800 cumec in 1988. After meeting with Padma, the Lower Meghna flows about 160 km before discharging to the Bay of Bengal as a single outlet of the Ganges-Brahmaputra-Meghna river system. It is a wide estuary that is influenced by both freshwater runoff and tidal action. The net discharge through this river varies from 10,000 cumec in the dry season to 160,000 cumec in the wet season.

2.9 Hydrological Regions

Bangladesh can be divided into seven hydrological regions considering surface water flow process and major rivers as boundaries (FPCO, 1995b). The regions are North-West, North-Central, North-East, South-West, South-Central, South-East and Chittagong as shown in Figure 2.15. The hydrological characteristics of these regions are discussed below.

North-West (NW) region: The NW region covers an area of 34,600 sq.km and is bounded by the Ganges in the south and the Brahmaputra-Jamuna in the east. Within the region major physiographic feature is the presence of Barind tract with an area of about 4,300 sq. km. and with relatively high ground level and scarcity of surface water. Another important feature is the presence of large depression covering an area of 3,120 sq.km locally known as Chalan Beel. The average annual rainfall ranges from less than 1,500 mm to just over 3,000 mm, with a regional average of about 1,900 mm. Within the region, the rivers in the extreme northern area, Teesta, Dudhkumar and Dharla have steeper gradients of 1 in 2000 and most of their catchments lie in India. These rivers frequently cause flash floods with annual peak discharges of 5,240, 1,830, and 1,610 cumec respectively. The rivers in the remainder of the area have catchment areas basically within Bangladesh and have very flat gradients of 1 in 5000. The rivers meander heavily and have limited flood discharge capacity. Internal rainfall flooding is therefore common in the region. The Karatoa-Atrai-Gur-Gumani-Hurasagar is the largest internal river system with an annual maximum discharge of 1,850 cumec and passes through Chalan Beel. This river system brings floods to the central part of the NW region. All rivers except Teesta, Dudhkumar and Dharla drain to the Jamuna through a single outlet at Hurasagar which is just upstream of the Ganges-Jamuna confluence. The flooding in the south-eastern part of the region is frequently exacerbated by the fact that the flood levels in the Ganges and the Brahmaputra are often higher than the internal river levels for long periods during monsoon.

North-Central (NC) region: The NC region covers 12,000 sq.km in an area bounded by the Jamuna in the west, the Padma and Meghna in the south and the old Brahmaputra in the north and east. The average annual rainfall ranges from 1,400 mm in the southwest to 2,200 mm in the northeast. There are three interior river systems: Dhaleswari-Kaliganga in the south-west, Bangshi-Turag in the center and Banar-Lakhya in the east with annual maximum discharges of 3,030, 1,830 and 375 cumec respectively. These rivers are distributaries of Jamuna and old Brahmaputra and are tributaries to Meghna. The main physiographic units are the Brahmaputra floodplain, the Old-Brahmaputra floodplain, the Padma floodplain and the Madhupur tract, which is an alluvial outcrop raised above the floodplain. Floods generally occur from spills from the Jamuna river and from internal rainfall. Dhaka, the capital of Bangladesh, is situated in the NC region.

North-East (NE) region: The NE region has an area of 24,200 sq.km with the Old-Brahmaputra as boundary. This region is at the foot of Meghalaya and Tripura Hills. About 55% of the area is covered by lowland floodplain. The Sylhet depression covers another 25%. About 50% of the area lies within 8 meter of MSL and 25% lies within 5 meter. The annual rainfall ranges from 2,200 mm to 5,800 mm, with the higher values in the northeast of the region. The major rivers are Surma, Kushiyara, Manu and Khowai. All the rivers in this region originate in India with two-thirds of the catchment area being in India and rise in areas with the world's highest rainfall. They are flashy in nature, and during the wet season, there is an enormous inflow of water from India. Between May and November, almost 60% of the region is flooded to depths exceeding 1 meter, the deepest flooding being upto 5 meter in the Sylhet depression. Flash floods also occur in the pre-monsoon months of March and April causing widespread damage. The NE region is dotted with multitude of large lake-like depressions called Haors covering an area of 4,500 sq.km. Most of the Haors retain water throughout the year and during the monsoon the Haor basin looks like a vast inland lake.

South-West (SW) region: The SW region covers about 26,600 sq.km and is bounded by the Ganges in the north, Kumar in the east and the Bay of Bengal in the south. This region is part of the Ganges Delta. The average annual rainfall ranges from 1,500 mm in the north to 2,900 mm in the south. A unique ecological resource of this region and that of Bangladesh is the coastal mangrove forest known as the Sundarban covering an area of 6,000 sq.km. The rivers in this region are the distributaries of the Ganges river. The important internal river is Gorai with annual maximum discharge of 5,960 cumec. This region is relatively free from fluvial flooding, however, tidal flooding is quite common. About 13% of the area consists of rivers and depressions locally known as Beels and Baors. The coastal zone comprises the extensive, flat deltaic land which is crossed by large estuaries from the Bay of Bengal. The important estuaries are Malancha, Passur-Sibsa and Baleswar rivers. The average tide range varies from approximately 3.0 meter on the coast to 0.5 meter at 275 km inland. The region is in a state of transition from actively developing delta of the Ganges to a semi-moribund delta partially sustained by local rivers. The rivers in the delta receive very small amount of upland fresh water flow. The saline water from the Bay of Bengal penetrates about 100 km.

South-Central (SC) region: The SC region covers an area of 13,900 sq.km and is bounded by Kumar on the west, Padma on the north and Lower Meghna in the east and Bay of Bengal in the south. The average annual rainfall is similar to that of the SW region. Like the SW region, this region is also vulnerable to tidal flooding. The northern part of this region suffers from fluvial flooding. Moreover, this region is also vulnerable to periodic cyclonic storm surge flooding from the Bay of Bengal. As a result of extreme flatness of the delta, storm surge can propagate as much as 60 km inland. All the internal rivers are distributaries of the Padma and the Lower Meghna, the Arial Khan being the principal among them with a peak discharge of 2,290 cumec. This region is part of the Meghna delta and as such is not showing any moribund tendencies. Bishkhali, Buriswar and Tetulia are large estuaries in the region the width of which at the mouth can be as large as 5 km. The entire coastal region is criss-crossed with extensive interconnected network of rivers and estuaries making waterway as the main mode of transport in this region. This is the only region where there is no railway and roads are few and far in between. Unlike the SW region this region does not suffer from severe saline intrusion due to freshwater flow from the Lower Meghna. There are a number of large islands in the estuary of Lower Meghna.

South-East (SE) region: The SE region covers an area of 9,550 sq.km and is bounded by the Feni to the south, Meghna and the Lower Meghna to the west, the Titas to the north, and also the Bay of Bengal to the south. Almost the entire region is low lying and flat. The average annual rainfall ranges from 3,900 mm in the coast to 2,000 mm in the north. The main internal rivers are Gumti and Muhuri with annual peak discharges of 474 and 283 cumec respectively. The northern part of the region is dissected by a number of rivers which bring flash floods from the Tippera hills above the Indian border to the Meghna. These rivers carry large quantities of sediment. The region frequently suffers from drainage congestion due to high water level in the Lower Meghna.

The coastal areas contain number of large islands and are subject to storm surge flooding from tropical cyclones mainly in April/May and October/November.

Chittagong (CG) region: Chittagong region is different from the rest of the country, having generally elevated relief and being independent in terms of hydrological response from the Ganges-Brahmaputra-Meghna river system. The region covers an area of 20,639 sq. km out of which 13,600 sq. km is covered with forest. The rainfall in this region is heavy and the annual rainfall amounts to 2,540 mm. All the rivers have catchment areas mostly within Bangladesh and drain directly to the Bay of Bengal. The important rivers are Karnaphuli, Halda, Sangu and Matamuhuri. They all have comparatively steeper slopes and cause flash floods. Chittagong is the only region which has hydro-electric potential. The lone hydro-electric plant in Bangladesh is sited on Karnaphuli. The coastal areas are quite vulnerable to storm surge flooding.

2.10 Sources and Magnitude of Flood

2.10.1 Causes of floods

About one-fifth to one-third of the country is flooded to varying degrees each year during May through September when about two-thirds of the food grain (mainly rice) are produced. Such a large extent of flooded area is due to extreme flat topography (Figure 2.2) of the country. The sources of natural flood in different parts of the country are shown in Figure 2.16. The causes of natural floods are briefly mentioned below.

River flood: The main source of flooding is the bank overflow from the major rivers the Ganges, the Brahmaputra and the Meghna, and their tributaries and distributories during June to September. A broad strip of land adjacent to the rivers is subjected to this type of flood as shown in Figure 2.16.

Rainfall flood: About 80% of annual rainfall in Bangladesh occurs during May to September when the rivers flow at high stage due to huge inflow of water from catchments outside the country. As a result, drainage is impeded. Besides high intensity and long duration rainfalls cause local flooding when the local river cannot drain quickly.

Flash flood: In the northern and eastern hill streams, flash flood occurs during the pre-monsoon months of April and May. Flash floods in the NE region cause damage to dry-season boro rice crop just before or at the time of harvesting and also to towns and other infrastructures.

Tidal flood: The areas adjacent to estuaries and tidal rivers in the SW and SC regions get flooded twice a day due to astronomical tide from the Bay of Bengal. During spring tide which occurs fortnightly, large area is flooded by tidal water.

Storm-surge flood: The storm surges due to tropical cyclones in the Bay of Bengal occasionally cause severe disaster in the coastal areas. This flood can occur during April to June and September to November. Approximately 12,000 sq.km. of coastal land is prone to cyclonic storm surge floods.

River flood and rainfall flood are frequently aggravated by the following two factors:

Backwater effect from sea: The spring tide and the monsoon wind setup in the Bay of Bengal cause strong backwater effect in the Lower Meghna river which is the single drainage outlet of the Ganges-Brahmaputra-Meghna river system. As a result, drainage is slowed down causing increase in the duration of flood.

Time of peak flows in major rivers: An important phenomenon that determines the extent of river flooding is the time difference between the occurrences of peak flood flows in the Ganges and the Jamuna (the Brahmaputra) rivers. When the peak flows of these two major rivers reached their confluence almost at the same time in the first week of September 1988, more than half of the country was flooded. Occurrence of this phenomenon during the time of spring tide resulted in long duration of the flood. Occurrences of simultaneous flood peaks in the Ganges and the Jamuna is not a rare event (French Engineering Consortium, 1989).

2.10.2 Magnitude and frequency of river floods

Frequency analysis of annual maximum discharge data from 36 stations have been performed by fitting the three parameter Generalized Extreme Value (GEV) distribution to every sample of data. The GEV distribution is appropriate for frequency analysis of flood data in Bangladesh (Chowdhury, 1994a; Karim and Chowdhury, 1995; IFCDR, 1995). The spatial distribution of annual maximum flood discharge of 2, 20 and 100 year return periods in major and medium rivers is shown in Figure 2.17 using 764 station-years of data record. Figure 2.17 illustrates that the three major rivers, the Ganges, the Brahmaputra and the Meghna, dominate the flood flow in Bangladesh. The spatial distribution of average values of annual maximum, annual average and annual minimum discharges are shown in Figure 2.18. This illustrates that the seasonal variation in flow is highly skewed with abundant water during monsoon while very small flow during dry season.

The variation in annual maximum flood levels of different return periods is not large. This is because the rise in water level in rivers becomes slower when the flood water spreads into the floodplain. Figure 2.19 shows that the difference between 20- and 2-year annual maximum flood levels remains within 2 meter while the difference between 100- and 20-year annual maximum flood levels remains within 1 meter. The analysis has been done by fitting GEV distribution to every sample in 2518 station-years of data from 92 locations from six hydrological regions which are hydraulically linked to the Ganges-Brahmaputra-Meghna river system (Figure 2.15); the Chittagong area which is mostly hilly has not been included. Figure 2.20 shows hydrograph of average water level in the Padma river downstream of the confluence of the Ganges and the Jamuna rivers.

2.10.3 Tidal and storm-surge floods

The coast of Bangladesh is subjected to astronomical tide which originates in the Indian Ocean and travels through the Bay of Bengal. The tides are predominantly semi-diurnal that is the tidal period is 12 hours 25 minutes. In the SW region of Bangladesh, tidal action is experienced upto 225 km inland in the wet season and 325 km inland in the dry season (Halcrow, 1993c). Most of the area in the SW region is below the high water level of spring tide. Extensive coastal embankments and polders have been constructed in the region to prevent tidal flooding. The average tidal range in the area varies from approximately 3.0 m on the coast at the entrance of Passur river to 0.5m at 275 km inland. In addition to daily tidal fluctuation at the coast, there are half yearly variations in sea level of 60 to 80 cm due to seasonal changes in salinity and atmospheric pressure (Halcrow et al, 1993c).

Occasional storm surge floods generated by tropical cyclones in the Bay of Bengal cause severe disaster in the coastal region of Bangladesh. More than 700,000 people have been killed by floods due to 15 cyclonic storm surges since 1960. Approximately 9,100 sq.km. of coastal area, which is more than 6% of the total area of Bangladesh, is prone to flood depth of at least 1 m. Intrusion of storm surges in the SW region can be upto 55 km while in the Chittagong area it can be upto 15 km. Estimated surge depths of 100 year return period are 7.8, 5.2 and 4.5 m at the entrance of the Lower Meghna estuary, at the SW region coast and at Chittagong coast respectively (Chowdhury, 1994b).

2.11 Erosion and Sedimentation

2.11.1 Sediment transport

The alluvial rivers of Bangladesh carry enormous amount of sediment load. The transported sediment builds new land, offsets subsidence and adds to the soil fertility. The annual sediment transport in the Jamuna and the Ganges are 590 and 548 million tons per year (Delft, 1995). It is 897 million tons per year in the Padma river which carries combined flows of the Jamuna and the Ganges (Delft, 1995). Most of the sediment is carried to the sea. The combined sediment load of the rivers has created the largest submarine fan which slopes almost uniformly southward for about 3,000 km (Halcrow et al, 1993c).

2.11.2 Floodplain sedimentation

As the flood spreads out onto the floodplain, a layer of sediment is deposited on the floodplain with the highest thickness and coarser sand near the bank. Through this process, natural levee forms near the bank. These levees stand upto 3 m above the floodplain and are upto 1 km wide as cited from Bristow (1987) in Delft (1996). The measured sedimentation over the floodplain of the Jamuna was 1 to 4 mm in the year 1995 (Delft, 1996). The study of Jamuna floodplain sedimentation by Delft (1996) indicates that majority of the floodplain sediment originates in the Jamuna river and more than 90% of the sediments in the over bank flow will deposit.

2.11.3 River bank erosion

River bank erosion is a common and severe hazard in Bangladesh. Every year almost one million people are affected by eroding banks along 75 rivers including the major ones in about 130 different locations (Mott MacDonald et al, 1993a). On average about 87 sq.km of mainland was lost each year due to erosion by the major rivers during 1984 to 1993 while about 50 sq.km. of land accreted per year (ISPAN, 1993a). Between 1970 and 1990, at least 7 million people were displaced by riverbank erosion (Mott MacDonald et al, 1993a). The towns of Sirajganj and Chandpur are under constant threat from the Jamuna and the Lower Meghna respectively. Dumping boulders and concrete blocks has not been very effective. Even dumping of old railway goods wagons could not stop erosion at Sirajganj. Future strategies for bank protection, river training and active floodplain management have been discussed by Halcrow et al (1993a) and Rhein-Ruhr et al (1992, 1993).

2.12 Salinity

High salinities are present in estuaries in the western part of SW region during dry season. Simulation studies by Halcrow (1993c) show salinity concentration of 27 ppt at the mouth of Passur river and 10 ppt at approximately 250 km inland. The saline water intrusion in the Lower Meghna is obstructed by the large quantity of fresh water inflow and the salinity at 125 km inland is negligible (Chowdhury and Haque, 1990). Salinity in the SC region is low due to large fresh water supplies from the Padma and the Lower Meghna through spill channels. Salinity is also present in the groundwater of most shallow aquifers in the coastal region.

Figure 2.1 : Administrative regions (Districts) of Bangladesh

Figure 2.2 : Generalized relief contours in meters [Source : Harza, 1986]

Figure 2.3 : Bengal Basin

Figure 2.4 : Generalized tectonic map of Bangladesh and adjoining area
[Source : Alam et al, 1990]

Figure 2.5 : Floodplain landscape

Figure 2.6 : Generalized physiographic map of Bangladesh
[Source : Alam et al, 1990]

Figure 2.7 : Schematic geological cross section through Bangladesh [Source : Harza, 1986]

Figure 2.8 : Isohyte of annual rainfall [Source : Brammer, 1996]

Figure 2.9 : Distribution of monthly rainfall within a year (Source of data:BMD)

Figure 2.10 : Distribution of rainfall at Dhaka during monsoon, 1996, showing rainfall drought

Figure 2.11 River system of Bangladesh

Figure 2.12 : Ganges - Brahmaputra - Meghna basins

Figure 2.13 : Variation in mean monthly discharge in the Padma downstream of the confluence of the Ganges and the Jamuna

Figure 2.14 : Evolution of the river of Bangladesh [Source : ISPAN 1993]

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Figure 2.15 : Hydrological regions

Figure 2.16 : Flood types [Reproduced from FPCO, 1995 b]

Figure 2.17 : Spatial distribution of annual maximum discharge of 2,20 and 100 year return periods in major and medium rivers

Figure 2.18 : Spatial distribution of average annual maximum, average annual and average annual minimum discharge in major and medium rivers

Figure 2.19 : Plot of difference between 100- and 20-year annual maximum water levels against difference between 20- and 2-year levels based on frequency analysis at 92 stations in all hydrological regions except Chittagong region.

Figure 2.20 : Variation in mean monthly water level in the Padma downstream of the confluence of the Ganges and the Jamuna.

CHAPTER 3

FLOODPLAIN RESOURCES

Floodplain has many resources of economic and ecological importance, most notably the fisheries resource. It also supports many functions most important among those being the agriculture. In this Chapter only those functions and resources which are affected by flood control projects in a major way are discussed.

3.1 Water Resources

3.1.1. Surface water

The annual surface water flow through Bangladesh is impressively large. However, the availability of this water throughout the year is not uniform at all as discussed in Chapter 2. There is abundance of water during wet season (June through September) often resulting in flood. The situation completely changes during the dry months (November through May) when the flows in the major rivers fall down drastically and most of the small rivers dry up leading to scarcity of fresh water. A region-wise comparison between wet season flow and dry season flow is made in Table 3.1.

Table 3.1: Regional surface water flow in million cubic meter (Source: Harza et al, 1991)

Region	Wet season flow (June-October)	Wet season flow (June-October)	Ratio
NW	52,840	10,660	20%
NE and NC	148,140	20,030	14%
SW and SC	178,980	34,140	19%
SE and CG	20,270	5,530	27%
Total	400,230	70,360	18%

It is seen that the ratio of dry season flow to wet season flow varies from 14% for NE region to 27% in SE region. For Bangladesh as a whole dry season flow is less than one-fifth of wet season flow. Similar temporal variation in rainfall further aggravates the situation; more than 80% of the rainfall occurs during the wet season. The scarcity of water has been further worsened by withdrawal of dry season flow beyond the boundary of Bangladesh. The effect of withdrawal of Ganges water by India through Farakka Barrage is well documented (For example, see Crow et al, 1995).

3.1.2 Groundwater

Groundwater is one of the major natural resources of Bangladesh. The quaternary alluvium of Bangladesh constitutes a huge aquifer, mainly with good to reasonable transmission and storage properties. Because of the high rainfall and widespread annual flooding, the groundwater level rises almost to the ground level during wet season. The groundwater is mainly of good quality except in SW region where, under the influence of tidal conditions, most of the shallow aquifers are saline. The region-wise usable recharge as calculated by National Water Plan is shown in Table 3.2.

Table 3.2: Region-wise usable recharge (Source: Harza et al, 1991)

Region	Recharge area in Mha	Usable recharge in million cubic meter
NW	3,016	12,100
NE and NC	3,569	23,100
SW and SC	3,988	7,500
SE and CG	3,007	9,000

The groundwater levels are highest from August through October and lowest in April and May. A sharp rise in water level generally begins in May and continues until July. The range of fluctuation is from 3 to 6 meters in most areas. After July, the rate of rise decreases and in many areas the groundwater levels remain almost stationary from August to October, indicating rejection of recharge because the aquifer is filled to capacity.

3.2 Land Types

3.2.1 Extent of floodplain

About 80% of Bangladesh is floodplain. Again, 80% of floodplain is cultivable area. The homestead, roads and wetlands occupy the remaining floodplain area.

3.2.2 Inundation land types

Bangladesh has 9.562 million hectares of cultivable land which is about two-thirds of the land area of Bangladesh. The depth of flooding is a key factor in the choice of rice crops to be grown in a cultivable land. For water resources planning, the cultivable land is classified into five land types depending on the inundation depth (Harza, 1984). This land classification is shown in Table 3.3 while the regional distribution of inundation land types is shown in Table 3.4. In feasibility studies of water resources projects, the benefit of flood protection and drainage is assessed by the change in spatial distribution of inundation land types as a result of reduction in flood depth. The indicated inundation depths in Table 3.3 are for normal floods which the farmer generally expects. However, the peak levels may vary significantly between individual years.

Table 3.3: Classification of cultivable land by flood depth (Source: Harza, 1984)

Land type	Flood depth (cm)	Description of land	Area (Mha)	Suitability of land to rice cultivation
FO	0-30	High land	3.514	HYV rice in wet season
F1	30-90	Medium highland	3.288	Local varieties of Aus and T. Aman
F2	90-180	Medium lowland	1.558	B.Aman in wet season
F3	Over 180	Lowland	1.124	B. Aman can be grown
F4	Over 180	Very lowland	0.076	Depth, duration and/or time of flooding do not permit growing of B.Aman

Table 3.4:Regional distribution of inundation land types
(Source of data: NWP and FAP regional studies)

Region	Cultivable area (sq.km)	Percentage of regional cultivable area				
		F0	F1	F2	F3	F4
NW	24,510	53	33	8	6	0
NC	9,090	34	29	18	19	0
NE	16,640	29	18	22	30	1
SW	16,660	33	43	17	7	0
SC	10,260	23	58	13	3	3
SE	13,130	29	36	23	10	2

3.2.3 Wetlands

Bangladesh has more than 16,000 sq.km. of wet lands which include rivers and estuaries, lakes and ponds. A list of wetlands in Bangladesh is given in Table 3.5. Not included in the list is the extensive paddy fields which remain under water for more than three months during rice cultivation. The area of wetlands in Table 3.5 is approximately 11% of the area of Bangladesh. Such coverage by wetlands is quite high when compared with the outside world. Wetlands cover an estimated 6% of the earth's land surface (Maltby and Turner, 1983). The wetlands in Table 3.5 have not been included in the seasonally inundated land types in Table 3.3. The wetlands provide habitat for fish. They are sources of many unique species of plants and animals. They support biodiversity and provide resort to migratory birds. An excellent compilation of wetland resources in Bangladesh is available in Khan et al. (1994).

Table 3.5: Surface water bodies of Bangladesh
[Source: *BBS (1996), ** Pramanik (1990), * IUCN (1994)]**

Water bodies	Approximate area (sq. km)	Hydrological region
Flowing water		
Rivers and canals	4800**	All regions
Estuaries	5520**	SW, SG,CG
Mangrove forest water body	107**	SW
Linked to river		
Flood plain depressions (Beels and Haors)	1410*	NE,NW,NC,SW,SC
Reservoir of hydro-electric dam	570*	CG
Closed water		
Ox-bow lakes (Baor)	55*	SW, SC
Ponds and derelict tanks	3600*	All regions

Major floodplain depressions are concentrated in the NE region and in the southern part of the NW region. These water bodies are known as Haor in the NE region and Beel in the NW region. Documentation of key wetlands in the NE region has been made by Shawinigan Lavalin et al (1995) as per Ramsar format approved at Montreux, Switzerland in July 1990. Oxbow lakes in the floodplain are the abandoned reaches of meandering rivers. Such water body is known as Baor in the SW and SC regions. Natural levees near the river bank also create swamps in the floodplain.

Ponds are dug in rural areas and their size varies from 0.1 to 5.0 acres. They are important sources of domestic water supply. They are extensively used for fish culture. They have been very successful in alleviating drought in rainfed rice lands (Saleh et al., 1996).

3.2.4 Charlands

The Brahmaputra-Jamuna and parts of the Ganges-Padma and the Lower Meghna have braiding characteristics i.e. they have multiple channels separated by alluvial islands. The subsidiary channels have meandering courses which continuously erode their banks and islands, and deposit new materials on existing island or on other bank to form point bar or within the channel to form new island. The mainland is also eroded and accreted causing shift in the main bank of the river. The islands and accreted lands on the bank are generally known as Char which is a Bengali word meaning sand bar and low-lying islands. The whole of the braided channel, including subsidiary channels and Chars is called the active river floodplain (Brammer, 1996). There is approximately 5,330 sq.km of cultivable land in the active floodplain which is not included in Table 3.4.

There can be Island Chars and Attached Chars. The Island Chars are the land that, even in dry season, can only be reached by crossing a channel of the main river. The Attached Charland is accessible from the mainland without crossing a channel during the dry season yet is inundated or surrounded by water during flood season. In many rivers of Bangladesh, flood protection embankments have been constructed by keeping a setback land on the river side. So the setback land which was with the mainland becomes the part of floodway. From hydraulic point of view setback lands can be considered similar to the Attached Charlands.

There is approximately 8,500 sq.km of active river floodplain which is almost 6% of Bangladesh as interpreted from 1992 and 1993 Landsat images (ISPAN, 1993a). Out of total active floodplain, nearly 40% is Island Chars. Approximately 45% of the active floodplain is with the Brahmaputra-Jamuna river. Almost 4.3 million people, which is about 4% of total population of Bangladesh, lived in the active floodplain in 1992-93 and 22% of them lived on Island Chars, and they were concentrated in the Jamuna and Meghna (ISPAN, 1993a). During the period 1981-1993, almost 64,000 people per year were displaced on average by river erosion. Depending on the river to which the active floodplain belongs, 43 to 46% of the population cultivate land for a living and another 23 to 40% depend on predominantly agricultural day-labor. A significant part of the remaining population works as fishermen and boatmen. Generally Broadcast Aus rice which is early monsoon season paddy and also tolerant of deep water is grown while groundnuts and pulses are grown during dry period.

3.3 Hydraulic Functions of Floodplain

3.3.1 Flood storage and peak attenuation

An important beneficial hydraulic function of floodplain is that it moderates the flood flow by acting as storage. The floodplain storage also acts to reduce the peak discharge in the river. This is illustrated in Figure 3.1(a) where it is seen that the peak outflow from the NE region is nearly two-thirds of the peak inflow of flash floods. Thus the peak flood discharge is reduced by about one-third. Storage of flood water in floodplain is illustrated in Figure 3.1(b).

3.3.2 Augmentation of post-monsoon flow

Another beneficial function of floodplain is that it augments the post-monsoon river flow by gradually releasing water from its flood storage as illustrated in Figure 3.1(c). This is advantageous for irrigation. Figure 3.1(a) shows that the receding outflow in the NE region during late October and November is increased. Similarly attenuation as a result of flooding and filling of natural depressions in the SW region creates a marginally increased outflow during November through January (Halcrow et al, 1993b).

3.3.3 Flushing of tidal river

Storage function of floodplain is also very helpful to maintain the channels in the coastal region of Bangladesh where tide occurs twice a day. During flood tide,huge volume of water is stored in the floodplain. During ebb tide, which is principally a process of drainage under gravity, water is released from the floodplain and favorable condition in the channel remains due to flushing effect of greater quantity of outflow during low water. In the absence of floodplain storage, the river water level rapidly falls during ebb tide and siltation occurs due to decreased ebb water velocity.

3.3.4 Groundwater recharge

In a deltaic country like Bangladesh, surface water and groundwater are in continuous interaction primarily through two mechanisms: the infiltration-percolation process and the river-aquifer interaction. Rainfall and flood water over the floodplain infiltrate and percolate vertically through the pervious soil to reach the relatively shallow groundwater table and recharge the unconfined aquifer. Lateral recharge also occurs from rivers at high water level. During dry season, when the rivers are at low water levels, major portion of their flow comes from groundwater discharge from the upper aquifer.

The shallow aquifer is a source of water supply for the inhabitants of floodplain. As of 1991 there were approximately 2.45 million drinking water tubewells (Mitra & Associates, 1992). The operational tubewells serve nearly 90% of the rural population with an average of 115 persons per tubewell (Ministry of LGRDC, 1994). The range of per capita use is from 17 to 50 liters per day and the total abstraction for rural areas is estimated to be approximately 2.43 million cubic meter per day (Harza et al, 1991). These tubewells can only lift water from about 7 meter below the ground level. The upper aquifer is also a source of irrigation by shallow tubewell. There is approximately 0.847 Mha of area which is irrigated by approximately 258,000 mechanized shallow tubewells (Harza et al, 1991).

3.4 Agriculture

Bangladesh's climate with a warm wet summer and cool dry winter, provides conditions suitable for growing a wide range of annual and perennial crops: tropical (e.g. rice and jute) in summer; temperate (e.g. wheat, potato) in winter; and sub-tropical (e.g. sugarcane, banana) throughout the year. There are nearly 100 different types of crops grown in Bangladesh (Harza, 1991) rice being the dominant crop. The area and production of major crops in 1993-94 are shown in Table 3.6. Flood hydrology, soil and seasonal distribution of rainfall largely determine the land use including types of crops to be grown and intensity of its use.

Table 3.6: Area and production of major crops in 1993-94 (Source: BBS, 1996)

Crop	Area (Mha)	Production (million tons)	Yield (tons/ha)
Aus	1.65	1.85	1.12
Transplanted Aman	4.83	8.54	1.77
Deepwater Aman	0.91	0.88	0.97
Boro	2.58	6.77	2.62
Total rice	9.97	18.04	1.80
Wheat	0.62	1.13	1.82
Other cereals	0.08	0.07	0.88
Total cereals	10.67	19.24	
Jute	0.48	0.81	1.68
Pulses	0.71	0.53	0.75
Oilseeds	0.56	0.47	0.85
Potato	0.13	1.43	11.00
Sugarcane	0.18	7.69	39.52

3.4.1 Soil

Floodplain soils vary from calcerous to strongly acid in different regions (Rahman et al, 1990). The Gangetic alluvium is rich in calcium, magnesium and potassium. They also contain free calcium carbonate. The soils are characterized by nitrogen and phosphate deficiency and locally by strong alkalinity. The pH range is 7.0 to 8.5. The Teesta silt tract soils are sandy to sandy loam in texture, without any profile development. They are flooded every year and as a result are replenished by fresh deposit every year. The pH varies from 5.5 to 6.8. The coastal floodplain is subject to flooding by saline water at high tide. The soil is saline and in general neutral but tends to be on the alkaline side. The pH varies from 6.9 to 7.5.

The seasonal flooding characteristics have an important influence on physical and biological properties of soil and therefore has an important bearing on the land use and agricultural potential. The agro-ecological zones study of Bangladesh recognized 30 agro-ecological regions and 88 sub-regions separated on the basis of important differences between them in physiography, soils and flooding characteristics (FAO, 1988).

Floodwater in its unique way keeps the floodplain fertile. The river-borne sediments which are dispersed over the floodplain are valuable sources of soil nutrients (ISPAN, 1992a). Standing rainwater provide the conditions for nitrogen fixing blue-green algae to proliferate in the water column, the remnants of which release nutrients to plant roots (Brammer, 1995a). Natural long stemmed rice in contrast with modern high yielding variety (HYV) of rice also produces significant amounts of crop residue which act as natural fertilizer. Agriculture in the floodplain has therefore prospered for centuries without the use of agro-chemicals. Although natural soil fertility has declined over the years due to extensive agricultural practices, physical properties of the soils still remain highly favorable for plant growth in Bangladesh (Rahman, 1994).

3.4.2 Cropping pattern

Favorable agro-climatic conditions including abundance of water during the rainy season which is the pre-condition for rice cultivation, dietary habit and socio-cultural preferences have made rice as a dominant crop. About 84% of the total cropped area is under rice cultivation. Different varieties of rice grown in Bangladesh include Aus rice in kharif-1 season (April-July/August), Aman rice in kharif-2 season (July-December) and Boro rice in rabi season (December-May). These seasons are indicated in Figure 3.2. Aus and Aman are rainfed crop. The water requirement of Boro crop during the dry season is met through irrigation. Besides rice, jute is an economically important crop in Bangladesh. Like rice, jute also grows under rainfed condition. Almost 50% of the cultivable area is single cropped (mainly deep water Aman/Boro/Sugarcane); 42% is double cropped area (mainly Aus/Jute + Aman/Jute + Pulse/summer vegetables) and 8% is triple cropped (mainly Aus + Aman + Pulses). Cropping intensity currently stands at 1.51 (BBS, 1996).

3.4.3 Floodplain cultivation

Out of 9.562 Mha of cultivable area, about 6 Mha is subject to flooding, depth of which may vary from 30 cm to in excess of 2 meters. Suitable varieties of rice that can be grown in different inundation land types during wet season are shown in Table 3.3.

Aman is traditionally the main rice crop constituting more than 50% of the rice production, though Boro is now a close second. Aman is still grown primarily under rainfed condition. Aman paddy consists of two groups: Transplanted Aman (both HYV and local varieties) and Deep water Aman (also known as Broadcast Aman). The HYV Aman are confined to the areas where shallow flood depths occur during the rainy season covering 21% of the cultivable area (BBS, 1996). Usually uses of lands which are deeply flooded and flooded for prolonged periods are limited to single crop having low yield like the Deep water Aman. Deep water Aman is one of the remarkable examples as how nature and farmers in Bangladesh have adapted themselves to its unique water regime in many sophisticated ways. Although not high yielding, this variety of rice is able to float on the rising tide of the flood, growing at a rate of up to 10 cm/day to a height of 6 meter then ride the flood down as it recedes. These can survive complete submergence of 72 hours. There are about 1500 indigenous broadcast Aman varieties in Bangladesh (Kanter et al, 1982). The area under deep water Aman rice is 0.91 Mha (BBS, 1996) or 10% of net cultivable area.

Many floodplain soils retain sufficient moisture after the end of the rainy season for farmers to grow a dry season rabi crop (such as potato, pulses, oilseeds etc) without irrigation. Extensive natural recharge of aquifer during the wet season also allows farmers to abstract groundwater at quite shallow depth to irrigate and produce dry season rice that is Boro. The production of Boro through irrigation practices has risen quite significantly during the last few years. Harza (1991) notes that when adequate moisture can be supplied through irrigation, the winter season (rabi) has favorable conditions for achieving full potential yields due to high solar radiation, low humidity, and wide variation in day and night temperature.

3.5 Fisheries

The rivers and their tributaries, the seasonally inundated floodplains, the Beels, Haors and Baors, the estuarine and brackish waters in the south, provide a hospitable abode for a rich fisheries resource. Bangladesh is the world's leader in openwater fish production per unit area (FPCO, 1995b) and ranks third in the total production, only China and India producing more than Bangladesh (Ali, 1990). About 260 species of finfish, over 20 species of prawn and 20 species of fresh water turtles inhabit the inland water system. The number of fish species found in Bangladesh is more than the number of species found in all of Europe (Capistrano et al, 1994).

Breeding, multiplication and sustenance of the inland water fish and prawn populations are intimately bound to the sequence of annual flooding. The monsoon floods link up the different components (rivers, floodplains, Haors, Beels and estuaries) of the inland open waters, creating a single integrated biological production system where the fish and prawn populations breed and grow in numbers. This integrated single production system lasts for upto 5 months, providing suitable aquatic habitats for reproduction, migration, feeding and growth of aquatic organisms (Figure 3.3).

In this integrated single production system, the inundated floodplains play the most significant role in expanding and maintaining the open inland water capture fishery production. During the monsoon floods, recently hatched fish and shrimps, born in rivers and estuaries, migrate into the vast floodplain. The nutrient and food-rich floodplain provides rich nursery and feeding grounds for the hatchlings, fry and juveniles of host of species. At the end of monsoon, the fish and prawn return to the rivers and Beels from the floodplains, with the receding water. The life cycle of floodplain dependent species are shown in Figure 3.4. These populations are self sustaining as long as the natural regime is not disrupted and the population are not harvested beyond their biological limit.

The BBS (1996) estimate of the yield of fish from different types of fisheries for the period of July 1992 - June 1993 is presented in Table 3.7. It is seen that during this period 770,162 metric tons of fish were harvested from the inland waters, representing 76% of the total fish harvest of the country. Again, out of the harvest from the inland waters, a total of 532,419 metric tons or 69% were taken from the inland water capture fishery system, floodplains alone contributing about 62% of that amount.

In Bangladesh, fish is second only to rice as a source of food, representing 50% of caloric intake and 80% of animal protein intake (ISPAN, 1993b). Most importantly, fish is virtually the only source of free animal protein for the poorer section of the community, who catches fish from open water bodies including inundated floodplain, rivers and swamps. During the flood season, subsistence fishing is carried out throughout the inundated floodplains on an extensive scale by members of rural households, for home consumption as well as for sale. For that matter, fishing in the monsoon inundated floodplains is practically the only opportunity for the poorer section of rural people to obtain free fish to meet their animal protein needs. According to BBS (1996), about 10 million subsistence households catch fish from the flood lands. ODA (1995) estimates that during monsoon 70-80% of the rural population are engaged in fishing.

Table 3.7: Total catch and area productivities by sectors of fisheries for July 1992 - June 1993 (Source: BBS, 1996)

Sector of fisheries	Water area (ha)	Total catch (million tons)	Catch/area (kg/ha)
A. Inland fisheries			
(a) Capture			
(1) Rivers & Estuaries (except Sundarban)	1,031,563	138,746	135
(2) Sundarban		6,939	464
(3) Beels	114,161	53,019	60
(4) Kaptai lake	68,800	4,142	116
(5) Flood land	2,832,792	329,573	
Capture total	4,047,316	532,419 (52.2%)	
(b) Culture			
(1) Ponds	146,890	202,167	1,376
(2) Baors	5,488	1,803	329
(3) Shrimp farms	108,280	33,773	312
Culture total	260,658	237,743 (23.3%)	
Inland total	4,307,974	770,162 (75.5%)	
B. Marine Fisheries		12,227	
(a) Industrial fisheries		238,265	
(b) Artisanal fisheries		250,492	
Marine total		(24.5%)	
Country total		1,020,654	

3.6 Wetland Flora and Fauna

Because of its deltaic location, Bangladesh has an extensive system of wetlands as shown in Table 3.5. Despite the intensity of human use, many floodplain wetlands continue to harbor and support significant bio-diversity. In fact the great majority of our wildlife species are directly or indirectly more intimately associated with the aquatic habitat. A number of globally endangered species depend upon the floodplain wetlands of Bangladesh (Sarker and Hussain, 1990).

Sarker (1993) reports that currently there are 282 freshwater wetland species of fauna in Bangladesh. There are 207 species of birds out of which 78 species are migratory, 33 species of reptiles, 18 species of mammals and 10 species of frogs and toads. Gangetic Dolphin was very common even a decade ago in riverine water. But its population has rapidly declined in recent years. A few years ago Otters were also common in the plains during flood season but now they are rare. There is an abundance of waterfowl and wetland dependent birds. Among them are Ducks, Herons, birds of prey, Storks and Kingfishers.

Karim (1993) reports 158 species of flora belonging to 49 families which are inhabitant of freshwater wetlands. The ecological value of these wetland plants is being increasingly recognized because it provides habitat to a large number of wildlife animals and acts as escape cover and flood-safe nesting sites for many birds and other wild animals. Marsh plants and their associated habitats provide important breeding areas for a wide variety of water fowls and important staging areas for a large number of resident and migratory birds. Plants also contribute to the biological cycling and mobilization of chemical elements. The dry matter and nutrients in wetland plants and other food chain of the eco-system directly support a wealth of fisheries resource. Aquatic vegetation beds act as spawning grounds and shelter juveniles of a large variety of fishes and prawns. Dense vegetation and hydrologic regime of the wetlands provide vital nutrient elements not only within but beyond their immediate boundary downstream. A wide range of wetland plants and species are harvested for firewood, timber, thatching, matmaking and livestock fodder. Wetland plant species are also harvested as a supplementary food source. This wild harvest can be particularly important to the poor during periods of stress, such as during deep flooding.

3.7 Mangrove Forest

The Sundarbans, the single largest mangrove forest in the world, is located in the estuarine floodplain of the river Ganges spanning an area of one million hectares in the SW region of Bangladesh and the south-eastern portion of the State of West Bengal in India. The mangrove forest consists of tropical trees that have developed a tolerance for saline and swampy conditions. In Bangladesh, the present Sundarban covers an area of 580,000 ha of which 402,000 ha is land and the remaining 176,000 ha is under water in the form of rivers, canals and creeks of widths varying from a meter to several kilometers. The forest is very rich in biotic diversity and supports 330 species of plants, possibly as many as 400 species of fishes, at least 35 species of reptiles, over 270 species of birds and 42 species of mammals including the Royal Bengal Tiger (IUCN, 1994). The area is not merely a repository for bio-diversity, it plays an important role in the economy of the SW region of Bangladesh as well as in the national economy. In the 1980s the forest was producing about 45% of the total timber and fuelwood output from the forests of the country. Large scale harvest of thatching material, honey, bee-wax and fish resources takes place regularly. The forest therefore provides employment to large number of people which can be as high as one million. The Sundarban also acts as a natural barrier to storm surge and is potentially a major area for tourism development in Bangladesh.

3.8 Water Transport

Bangladesh is literally a land of rivers. A dense network of rivers, canals and creeks serves large parts of the country and provides a cheap means of transport. In certain areas, it is the only means of transport. Presently some 8,000 km are navigable by larger sized mechanized vessels during the wet season, but this is reduced to about 4,800 km in the dry period (DHV, 1989).

Due to the riverain, flood prone and low lying nature of the country, the cost of building and maintaining roads and railways is very high. The inland water transport (IWT), on the contrary, has always been a natural and relatively cheap means of transport in Bangladesh. Estimates of shares of freight and passenger traffic by different modes of transport are shown in Table 3.8. At the national level, water transport is the second largest employer in the country, next only to agriculture.

Table 3.8: Estimated modal share of freight and passenger flows for 1995 (Source: DHV, 1989)

Mode	Freight (million ton-km)	Passenger (million passenger-km)
Road	4,137 (57%)	40,257 (69%)
Railway	850 (12%)	9,281 (16%)
Inland water transport (IWT)	2,252 (31%)	8,963 (15%)

The IWT in Table 3.8 does not include the contribution of numerous country boats which still play a significant role in moving passengers and freights and providing employment opportunities specially in rural area. Shawinigan Lavalin (1993) reports that there are about 850,000 country boats in Bangladesh. These boats have a carrying capacity of 3 million tons, 20 times the capacity of all the trucks in the country. They carry almost 16 billion ton.km per year which is twice as much as all the formal modes (rail, road, and formal IWT) combined. Foodgrains, salt and construction materials constitute nearly 70% of the country boat cargo closely followed by jute and jute products (Rasheed, 1995). Country boats alone offer 60% of all employment in the transport sector. A total of two million people relies on country boats as their main source of income.

Country boats are able to reach outlying rural areas which are otherwise more or less inaccessible. During floods, homesteads in many low-lying parts of the country often remain isolated by water for four to five months, and boat transport is the only means of movement during this time. About 80% of Bangladesh's 68,000 villages are largely dependent on such traditional transport (Jansen et al, 1994).

a) Effect of flood storage on outflows from the NE region
[Source: Shawingan Lavalin and others, 1994a]

(b) Flood storage during rising flow

(c) Release from storage during receding flow

Figure 3.1: Installation of flood storage function of floodplain

Figure 3.2: Rice crop calendar in relation to seasonal flooding, rainfall and temperature
[Source: Brammer et al, 1993]

Figure 3.3: Floodplain fisheries [Source : Harza, 1987a]

Figure 3.4: Life cycle of floodplain fish species [Source : Harza, 1987a]

CHAPTER 4

FLOOD MANAGEMENT POLICY

4.1 Historical Information on Flood Management and Studies

History provides quite elaborate evidences of ancient flood management practices in the Bengal. Such evidences are found in the History of Bengal written by Akbaruddin (1974) which is based on the translation of `Reaz-us-Salatin' (in Persy) written during the period 1766 to 1788 by the Persian writer Hossain Salim. It describes that people used to construct earthen embankment around cultivated land to protect from flood water. The homesteads of the local rulers of Bengal were built by raising earthen mounds of 5 meter high which were used to be called by the people as `Bangala'. The people used to grow long-stem rice which rises with the rise of flood water. W. Willcocks (1930) mentioned that construction of dikes along the rivers and irrigation by planned excavation of canals were the practices during Mughal rule in the sixteenth to eighteenth century. Islam (1993) and Nandy (1993) give descriptions of an ancient institutional setup which was responsible for construction and maintenance of roads, bridges and embankments, and re-excavation of canals, and water management with peoples participation during the Mughal period.

There are also quite old evidences of concerns on the harmful effects of human interventions in the floodplain. Williams (1919), who was a Superintending Engineer of the Public Works Department of Bengal, concluded after examining the past history of the tidal rivers in the Ganges Delta that the construction of railways, roads and private embankments caused the death of many streams. He further observed that wherever embankments existed they raised problems as great if not greater than those with which they were intended to deal; either in course of time they raised flood levels or led to the extinction of the rivers by causing silting and brought about water-logging. It may be mentioned here that similar effect is now observed in the SW region of Bangladesh where polders have been constructed to prevent tidal flooding. The review of impacts of Coastal Embankment Project by Halcrow et al (1993b) says that the effects of empoldering is clearly drainage congestion; the channel bed and tide levels have risen relative to the land levels inside the polder thereby obstructing drainage, and in some areas the situation is worse than before the project was implemented.

The first systematic study of floods in Bengal was done by Mahalanobis (1927) who was a member of the North Bengal Flood Committee which was appointed by the Government of Bengal after a devastating flood in the northern part of Bengal in September 1922. The flood was caused by rainfalls of unprecedented magnitude. The rainfall in one week was about 10 times the normal weekly precipitation. The report observed that railway embankments hampered quick draining away of the flood water, and thus served to prolong the duration of the flood. The report suggested improvement of drainage and development of systematic flood warning system. It is interesting to mention here that a devastating flood that occurred in September-October 1995 in the NW region of Bangladesh was also caused by heavy rainfall in the area. A committee formed by the Ministry of Water Resources (1995) of the Government of Bangladesh found that the abnormally high rains of late September could only be termed as an act of nature and any scheme designed to combat such event would be uneconomic. The committee observed that the development of roads and other infrastructure in the area prevented the spontaneous overland flow exacerbating the flooding condition. Like Mahalanobis (1927), this report recommended for improved flood warning and disaster preparedness, channel improvement for drainage and coordinated planning and construction of rural roads, highways and railway embankments with provision for unimpeded drainage.

Majumdar (1941) who was the Chief Engineer of Bengal, opined that the most effective preventive measure against floods was to prevent the harmful acts of man within the catchment basin so as to reduce the rate of surface run-off which determines the intensity of floods. He went on saying that after the flood entered the river channels, the most effective remedial measure against flood damages was to allow the flood to spread over as large a portion of its spill area as possible and not to oust it from what might be called the river's domain, by means of controlling works.

4.2 The Master Plan, 1964

Following severe floods in 1954 and 1955, a report was submitted by the Krug Mission in 1957 which was a United Nations Water Control Mission at the request of the Government of Pakistan. The report recommended for establishing an autonomous organization for data collection and flood studies and to prepare a Master Plan for flood problems. Subsequently, the East Pakistan Water and Power Development Authority (EPWAPDA) was created in 1959. The main duty of the EPWAPDA was to prepare a comprehensive plan with regard to the development and utilization of the water and power resources of East Pakistan on a unified and multi-purpose basis and to implement them after approval had been accorded by the Government. There were also two other reports on flood problems; one by American consulting engineer General J.R. Hardin in 1963 and the other one by Dutch Professor Thijsse in 1964.

A Master Plan was completed in 1964 by an American consulting firm, International Engineering Co. (IECO, 1964) which was engaged as the general consultant of the EPWAPDA. The Master Plan was focused on flood control. The objective of the plan was to increase agricultural (mainly rice) production to satisfy increasing national demand. Its proposals centered on large scale public works involving embankments for flood control, gravity irrigation through canal system and pumping stations for drainage and irrigation. The plan had a portfolio of 58 projects many of which have since been implemented. The implementation of the Master Plan was designed to spread over the 20 years period of 1965 to 1985 with an estimated cost of US$ 2.1 billion at the 1964 price. A Committee of Parliament Members (Government of East Pakistan, 1964, P-15) criticized the Master Plan and observed that many new schemes were taken without any coordinated planning which would make the Master Plan a collection of haphazardly placed projects.

After the independence of Bangladesh, the EPWAPDA was splitted in 1972 into Bangladesh Power Development Board (BPDB) and Bangladesh Water Development Board (BWDB). Presently BWDB is a very large organization with approximately 18000 staff.

4.3 Land and Water Sector Study, 1972

The International Bank for Reconstruction and Development prepared a report in 1972 on a land and water sector study (IBRD, 1972) conducted during the period from the year 1971 when the Liberation War of Bangladesh was going on to early 1972. After reviewing the Master Plan of 1964, the report emphasized the need for reorientation of policy for flood control, drainage and irrigation programs. The report recognized the problems of large scale flood control, drainage and irrigation schemes in a setting with high population density and a complex water regime due to flooding during the wet season and scarcity of water during the dry season. It recommended quick yielding small scale projects such as low-lift pump irrigation and small drainage improvements, minor to medium size drainage works, tubewell irrigation and double lift pumping etc. Subsequently the investment programme of water sector received priority on small and medium scale projects. But in the mean time many of the large scale projects proposed in the Master Plan of 1964 were either implemented or were under implementation.

4.4 National Water Plan, 1987 and 1991

In 1983, the Government of Bangladesh initiated a National Water Plan (NWP) project with the assistance from the United Nations Development Programme (UNDP) and the World Bank. The purpose was to prepare a comprehensive master plan for development of water resources. The NWP project was carried out by setting up a Master Plan Organization (MPO) and by appointing an American consulting firm Harza Engineering Co. Int. as the principal consultant. The project was completed in 1987. A second phase for the project was initiated in 1988 to produce an updated and upgraded NWP and the project was completed in 1991. Afterwards a permanent organization called Water Resources Planning Organization (WARPO) was established by the Government. Its objectives are to upgrade the NWP with an inter-sectoral focus and an interdisciplinary approach.

The objective of the NWP (Harza, 1987 and Harza et al, 1991) was to maximize agricultural growth and production and contribute to achieving foodgrain self-sufficiency while ensuring allocations of water to other users. The plan period covered 20 years from 1990 to 2010. The plan proposed raising the total flood protected area from 32 to 73% by providing flood control and drainage facilities over the 20 year period, almost half of the development of flood protection being targeted in the NE region, an area in which only a small area of land was protected. As per plan, the development of flood protection particularly in the Sylhet depression of the NE region would be primarily by submersible embankment.

The NWP identified substantial potentials of groundwater irrigation by tubewells and surface water irrigation by lowlift pumps. It proposed full development of the main rivers by barrages (Ganges barrage and Brahmaputra barrage within Bangladesh) to expand irrigation to areas which cannot be served by the available regional surface water (short and midterm) and full groundwater development. The NWP recommended a number of water sector policies.

4.5 Flood Action Plan, 1989

The country experienced a disastrous flood in 1987 followed by another one of greater magnitude in 1988. Soon after the 1988 flood, the Ministry of Water Resources prepared a report entitled National Flood Protection Programme which was followed by several studies with donor support. Two of the widely discussed studies are Rogers et al (1989) and French Engineering Consortium and BWDB (1989). The Flood Policy Study by the Government of Bangladesh and the UNDP set the eleven guiding principles for future flood management studies. Ultimately an Action Plan for Flood Control was undertaken (World Bank, 1989). The situation is strikingly similar to that after 1954 and 1955 floods which were the driving force behind the formulation of a master plan of flood control in 1964. The Action Plan involved 26 studies at an estimated cost of nearly US$ 150 million (at the 1989 price) covering the 5 years period of 1990 to 1995. Subsequently the Action Plan for Flood Control was termed as Flood Action Plan (FAP). A list of 26 studies is given in Table 4.1. The World Bank coordinated the support of several donors. An organization called Flood Plan Coordination Organization (FPCO) was set up in 1990 to coordinate the 26 FAP studies. It may be mentioned that at the same time the NWP project was being carried out under MPO. There were 5 regional studies among the 26 FAP studies. The aim of the FAP was to set the foundation of a long term programme to achieve a permanent and comprehensive solution to the flood problem and to create an environment for sustained economic growth and social improvement. The FAP has introduced a concept of compartmentalization which involved controlled flooding and controlled drainage in a protected area. Controlled flooding and controlled drainage in a compartment would be achieved by means of water regulating structures along the peripheral embankment and road. The concept is still under experimentation by two pilot projects in Tangail and Sirajgonj districts which are in the floodplains on two sides of the Jamuna river.

Table 4.1 Studies conducted under Flood Action Plan [Source: FPCO, 1995b]

FAP No	The Studies	Cost (million US$)
1.	Brahmaputra Right Embankment Stregthening	3.36
2.	**Northwest Regional Study**	4.6
3.	**North Central Regional Study**	3.56
3.1	Jamalpur Priority Project	2.85
4.	**Southwest Area Study**	3.83

Table 4.1 continued

5.	**Southeast Regional Study**	2.2
6.	**Northeast Regional Study**	14.6
7.	Cyclone Protection Project	1.0
8A.	Greater Dhaka Protection Project	3.0
8B.	Dhaka Integrated Flood Protection Project	0.57
9A.	Secondary Towns Integrated Protection Project	0.55
9B.	Meghna River Bank Protection Project	1.15
10.	Flood Forecasting and Warning	5.7
11.	Disaster Preparedness	1.10
12.	FCD/I Review	1.6
13.	Operation and Maintenance Study	0.6
14.	Flood Response Study	0.92
15.	Land Acquisition and Resettlement Study	0.4
16.	Environmental Study	4.04
17.	Fisheries Study and Pilot Project	3.4
18.	Survey and Mapping	6.71
19.	Geographic Information System	4.36
20.	Compartmentalization Pilot Project	17.09
21/22.	Bank Protection, River Training and AFPM Pilot Project	40.0
23.	Flood Proofing Pilot Project	0.3
24.	River Survey Programme	14.70
25.	Flood Modelling and Management	4.39
26.	Institutional Development Programme	3.60

The FAP sparked off unprecedented public debate within the country as well as among international communities. Based on experiences of past flood control, drainage and irrigation projects, a discussion forum at the Bangladesh Agricultural Research Council (BARC, 1989) urged to exercise caution in proceeding with FAP. Afterwards FAP faced persistent questions about the environmental impacts and people's participation. Should not the FAP studies be carried out under NWP framework? Can the FAP reach a viable solution by concentrating on the flood season instead of complete hydrological cycle? Does the proposed compartmentalization threaten the long term ecological and natural resource productivity of the floodplain? Will the embankments increase flood hazards elsewhere? Will the social costs and benefits be equally distributed? Will the opinion of those who will be at greater risk due to project implementation be accounted for in the planning process? Many of the issues were raised by a Government

Task Force (Task Force Report, 1991). A good number of books have been published which documented these concerns. Some of them are Adnan et al. (1992), Hughes et al. (1994) and Haggart (1994). There are several articles which addressed the concept and approach of FAP. Some of them are Boyce (1990), Rasid (1993), Haque and Zaman (1993), Rahman (1993), Chowdhury (1993), Rahman and Chowdhury (1994), Chowdhury and James (1995) and Rasid and Mallik (1995).

All FAP studies except component number 3.1, 20, 21, 22, 24 and 26 in Table 4.1 were completed by 1995. A report summarizing the findings of various FAP components has been prepared by FPCO (1995b). The FAP studies have followed a multi-criteria analysis which has brought costs, benefits, and social and environmental impacts in a single framework. At the initial stage of FAP, the focus was on flood mitigation. Gradually it was recognized that FAP regional studies should pay attention to the complete hydrological cycle and develop an integrated water management plan covering issues relevant to not only flood but also drainage, irrigation, navigation, environment and socio-economy. It has also realized the need for integration of FAP regional studies with the NWP prepared by MPO (presently WARPO). The FAP approach was based on eleven guiding principles. It has been suggested in the FAP summary report that the guiding principles should be evaluated, revised and updated so that they represent the future strategy for formulation of water management plans in Bangladesh. It has been emphasized that the rationale of the revised guiding principles should stem from the importance of controlled flooding for rural areas, 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.

The FPCO ceased functioning with effect from January 1996. All its activities have been taken over by WARPO.

4.6 Water and Flood Management Strategy, 1995

A framework for the development and implementation of a strategic National Water Management Plan (NWMP) for Bangladesh presented by FPCO (1995a) has been approved by the Government. It builds on the studies done under the FAP and the NWP. It recommends a 5-year (1995-2000) programme involving (a) preparation of a national water management plan, (b) strengthening of water sector organization responsible for planning, construction, operation and maintenance, and (c) implementation of a compact portfolio of high priority projects. The water management plan will examine the supply of water in the context of international rivers and groundwater, and the demand from irrigation, fisheries, navigation, drinking and municipal needs, and other important areas. It has given an outline of institutional framework for developing and managing water resources. The NWMP project of three years duration is expected to start from January 1997.

CHAPTER 5

FLOOD CONTROL ACTIVITIES

5.1 Approaches to Flood Control and Drainage

Many conventional flood mitigation measures like flood control reservoirs, flood diversion or flood by-passes are infeasible inside Bangladesh because of its extreme flat topography (see Figures 2.2 and 2.3). The flood control in the country has been based mainly on construction of embankments parallel to the river banks as illustrated in Figure 5.1. In general, the following flood control and drainage approaches have been exercised in Bangladesh:

5.1.1 Full protection against river flooding

In general, schemes designed to provide full protection aim to prevent spill of river waters by constructing embankments along the rivers, and to minimize internal flooding by the provision of appropriate drainage structures. Full protection is provided to protect agricultural lands and urban areas.

5.1.2 Partial protection against river flooding

Partial protection from river flooding is provided by constructing low, submersible embankments. These are designed to delay pre-monsoon floods so as to ensure a safe winter rice harvest and create a favorable condition for HYV rice which requires a longer growing season. Submersible embankments are allowed to be overtopped during monsoon and remain submerged for the entire monsoon season. Along with the embankments, overflow spillways are used to withstand erosion during overtopping, and regulators are preferably incorporated to allow river water to enter protected area without spilling over the embankments when there is a big difference in water levels between the river and interior which can erode embankments. Partial protection by submersible embankments is favoured in deeply flooded areas.

5.1.3 Gravity drainage to reduce rainfall flooding

The unwanted rain water from behind the embankment or from within the poldered area is evacuated mainly by gravity flow through drainage regulators and sluices incorporated with the embankments. The regulators and sluices prevent backflow from high river levels into the low-lying areas during monsoon and drain the water from the area to be protected when the river water level gets below than that inside as illustrated in Figure 5.1. Gravity drainage is favoured in highland and medium highland areas and in area free from large variations in land level.

5.1.4 Pumped drainage to prevent rainfall flooding

Drainage by pumps is expensive and has been provided in selected large Flood Control, Drainage and Irrigation (FCDI) projects to pump out accumulated rain water from the project area. Reversible pumps are generally used in order to serve both drainage and irrigation with drainage rate requirements much higher than irrigation rates. The pumped drainage is provided in areas consisting of higher percentage of deeply or moderately flooded areas.

5.1.5 Dredging of rivers and canals

Dredging is done to increase discharge capacity of rivers and canals. Loop cuts are applied for highly meandering river through excavation of pilot channels. Due to high cost, limited dredging is done at critical locations like offtakes and confluences to remove sand bars for drainage improvement. Effort has been made at the offtake of Gorai river which is an important distributary of the Ganges. Manual digging of canals is being practiced under the Food-For-Work (FFW) programmes and is an important source of employment for the rural people.

5.2 Structural Elements in Flood Control Projects

5.2.1 Earthen embankments

Earthen embankment forms the primary structural element of flood control, drainage and irrigation projects in Bangladesh. They are constructed using soil available at the site of construction. Most of the flood embankments have been constructed by BWDB. Some general geometric design parameters of embankments are presented in Table 5.1. Typical sections of major, medium and sea embankments are schematically presented in Figure 5.2. As displayed in the Figure, along major rivers large areas are required for constructing embankments with base width of 27 to 40 meter. As per the Standard Design Manual of BWDB (1996), a design flood return period of 20 years is chosen in designing the embankment height where agricultural damage is predominant and that of 100 years is chosen where loss of human lives, properties and installations are predominant. In general, 1:100 years flood are considered for major rivers Jamuna, Padma and Meghna. For coastal embankments, 1:20 year floods are considered. Coastal embankments are designed to prevent tidal inundations. The minimum crest width is 2.50 m, and a minimum of 4.3 m is provided if the embankment is to be used as inspection roads. Larger widths are provided depending on the road structure if it is to be used as road. LGED also constructs flood embankments for very small projects. The embankment is provided with crest level of 1:20 year flood level plus 0.6 m freeboard (minor rivers) or 1.0 m freeboard (medium rivers), countryside slope and riverside slopes of 1:1.5 to 3 depending on the soil condition, minimum crest width of 3 m and 4 m if vehicles are to be allowed as per the Design Manual of LGED (1990).

Table 5.1 Geometric design parameters of embankments (Source: BWDB, 1996; BCL and Halcrow, 1988; Kampsax International A/S and Others, 1992)

Embankment type	Geometric parameters			
	River side slope	Country side slope	Free board (m)	Crest width (m)
Embankment along major rivers	1 : 3	1 : 3	1.5	4.3-7.3
Embankment along medium/ small rivers	1 : 2 to 3	1 : 2	0.9	2.5-4.3
Submersible embankments	1 : 3	1 : 3	0.3	2.5-4.3
Sea facing coastal embankment	1 : 7	1 : 2	1.50	4.3
Interior coastal dikes	1 : 3	1 : 2	0.9-1.50	4.3
Marginal coastal dikes	1 : 2	1 : 2	1.50	2.5

Setback distance: The setback distance is required to keep the embankment some distance away from the river bank (Figure 5.1) considering the bank scour. At places where erosion has taken place regularly over years, the minimum setback distance is based on present annual erosion plus an extra 10 years of erosion. Where embankments are provided on both sides of the river, the minimum setback is calculated from the requirement of floodway to pass the design flood. In cases where the above criteria cannot be fulfilled, a minimum of 6 m is used as setback from the eroded bank along with bank protection measures. For sea dikes, the foreland of setback is chosen wide enough to be afforested with adequate plants to reduce wave actions during the flood condition (BWDB, 1996).

5.2.2 Flow regulating structures

Drainage regulators and sluices have been incorporated with the embankments in most of the cases to effect drainage of water from the land behind the embankment or from within the poldered area by gravity flow (Figure 5.1). Drainage regulators in the non-tidal areas are constructed considering 10-day rainfall with 1:10 year return period and 1:10 year peak river stage for effective drainage in the pre-monsoon season and 1:10 year rainfall and 1:10 year 10-day average water level for effective drainage in the post-monsoon season (BWDB, 1996). The structural stability is analyzed on the basis of 1:25 year pre-monsoon storm. Flushing regulators are provided in submersible embankments in the haor areas to fill the protected area in the monsoon to such a level that allows overtopping of embankments at safe hydraulic head. In the coastal polders, sluice gates are used to take advantage of tidal river fluctuations. Tidal drainage sluices are used with lowest possible crest levels and flap gates at the river outfall. These are sometimes used also as inlet structures.

5.2.3 Bank protection and river training works

In general, the bank protection works practiced in Bangladesh may be classified into two types: (i) soft recurrent measures or active floodplain management (AFPM), and (ii) hard measures.

Soft recurrent measures: These are indigenous measures that intervene in the active floodplain by diverting the flow away from the reaches threatened by bank erosion and outflanking river channels. The following soft recurrent measures have been traditionally employed in Bangladesh:

- Surface (floating) screens widely used in the form of 'bamboo bandals' in the Jamuna river and in other similar types of rivers. These are the cheapest and have been found effective in the offtake of an outflanking channel.
- Bottom (fixed) screens along river banks below water extending from river beds.
- Recurrent revetments in the form of mattress composed of sand filled bags or tubes at outer banks.
- Permeable groynes made of bamboo and wooden poles used mainly on smaller and medium rivers, preferably at bifurcations.
- Sills made of bags, tubes or sand or a combination of the three i.e. a protected sand dike, found effective at the outer channels.
- Artificial cutoffs for highly meandering small and medium rivers along very sharp bend by loop-cutting (excavating pilot channels).

Hard measures: These correspond to the classical approach to prevent river erosion and train the river in order to achieve a stabilized channel. The following hard measures have been employed in Bangladesh.

- Flexible bank revetments and retaining structures for medium rivers.
- Brick mattressing, concrete blocks and boulder pitching for medium and major rivers.
- Impermeable groynes built on smaller as well as large rivers (Ganges, Jamuna, Lower Meghna, Teesta).
- Porcupines (bamboo crates filled with clay bricks) in smaller silt laden rivers. These are being used as emergency measures.
- Closure dams for redirecting river water flow in some desired direction.

5.3 Types of Flood Control Projects

FC (Flood Control) projects: This type of project involves building of embankments alongside rivers to prevent river flooding. There have been 29 FC projects constructed by BWDB covering a benefitted area of 0.207 Mha as of 1994. The Teesta

Right Flood Embankment is an example of FC project employing about 43 km of embankments and covering a benefitted area of around 39,000 ha. Submersible embankments in the NE region are the examples of partial flood control projects. There are 33 such projects employing about 900 km of submersible embankments and covering an area of 172,000 ha.

FCD (Flood Control and Drainage) projects: In most of the cases, drainage provisions are incorporated with the flood control embankments in order to evacuate the unwanted rain water from behind the embankment or from within the poldered area. Drainage provisions are mainly governed by gravity flow drainage through regulators and sluices. There have been 173 FCD projects constructed by BWDB covering a benefitted area of 2.019 Mha as of 1994. The Coastal Embankment Project (CEP) is the biggest FCD project extending over approximately 1.3 Mha, comprising of around 115 polders in the SW, SC, SE and Chittagong (CG) regions and employing about 4,000 km of embankments and 120 km of drainage channels.

FCDI (Flood Control, Drainage and Irrigation) projects: In general, FCDI schemes constitute earthen embankments around the periphery of the project area (polders) to prevent inundation of cropland by riverine floods and tidal floods; drainage through sluice gates in the embankments at the outfalls of the natural channels; and irrigation water 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 pump in bigger selected projects. There have been 42 FCDI projects constructed by BWDB covering a benefitted area of 0.711 Mha as of 1994. Examples of some big FCDI projects are Pabna Irrigation Project Phase-I in the NW region, Chandpur Irrigation Project in the SE region and Bhola Irrigation Project Phase-I in the SC region covering benefitted areas of 184,534, 46,437 and 52,632 ha respectively.

D (Drainage) projects: This type of project is aimed at drainage improvement by constructing drainage channels, drainage regulators and sluices. There have been 128 drainage projects constructed by BWDB covering an area of 0.759 Mha as of 1994. Examples of some big drainage projects are Dredging of Gumti River Project in the SE region benefitting an area of 138,866 ha and Comprehensive Drainage Structure Project for Faridpur in the SC region benefitting an area of 151,822 ha.

5.4 Urban Protection

Over the last 30 years (mostly in 70's and 80's), around 20 town protection schemes have been carried out by BWDB. Most of the schemes were aimed at providing protection against river erosion through bank protection and river training works. Some schemes were developed with a view to providing flood control through construction of embankments and drainage channels. The only city protection scheme developed in Bangladesh is the Dhaka City Flood Control Project with the aim of protecting around 143 sq.km of area. The first phase comprised of 30 km of earthen embankment, 37 km of flood wall, 7 regulators and 2 pump stations in the western part of the city.

Major underground storm sewers of 110 km have been constructed. The second phase is expected to cover the eastern part of the city. Besides, there is a plan to provide flood protection to six priority secondary towns in near future.

5.5 Growth of Flood Control, Drainage and Irrigation Projects

5.5.1 Project coverage area

The BWDB is entrusted with the task of planning and implementing water resources projects within the country. Over the years, it has completed a large number of flood control, drainage and irrigation projects and some of them are under implementation. The growth of flood control and drainage projects developed by BWDB until 1994 is exhibited in Figure 5.3. There has been a steady growth in the benefitted area since mid 60's through the construction of 7,668 km of embankments, 5,072 km of drainage channels and 493 sluices and regulators as per BWDB list of completed projects as of 1994. The net benefitted area of about 3.7 millions hectare by flood control and drainage projects at the end of 1994 is equivalent to nearly 25% of the total area of the country, and 60% of total flood potential area.

5.5.2 Investment

The pattern of investment over the years is presented in Figure 5.4 which has been drawn based on the reply of the Minister of Water Resources to the Parliament as quoted in the economy page of the Daily Ittefaq of May 16, 1993. Although the inflation rate is not reflected in Figure 5.4 (b), yet it is apparent that investment has increased considerably, specially in recent years while the average growth of benefitted area after the 70's has remained almost the same as that of prior to 70's as displayed in Figure 5.4 (a).

5.5.3 Construction period

Figure 5.5 shows the distribution of projects with respect to construction period. More than 50% projects (mainly FCD and D) have been constructed within 3 years. About 30% projects required 4-6 years and 15% projects required more than 6 years to be constructed. As seen from Figure 5.5 (b), bigger projects required larger construction time. On average, projects having more than 5,000 and 10,000 ha of benefitted area required more than 3 and 6 years to be constructed respectively.

5.5.4 Regional distribution of projects

Figures 5.6 (a) and (b) show the distribution of projects and project benefitted area among the hydrological regions. Figure 5.6 (c) displays the comparison between flood potential area and project coverage area among the regions. Evidently extensive interventions have been made in the NW, SW, SC, SE and CG regions. Locations of major projects in these regions are shown in Figure 5.7.

5.5.5 Distribution of project type

Figures 5.8 (a) and (b) show the distribution of projects of various types and sizes respectively. As displayed by Figure 5.8 (a), 'FC' projects have been few; 'FCD' projects have been developed in the largest numbers followed by 'D' and 'FCDI' projects. It is apparent that emphasis has been put on projects covering smaller areas as exhibited in Figure 5.8 (b). The FCD projects have been developed in almost all ranges from small to very large areas. The FCDI projects were concentrated on mainly medium to large areas while drainage (D) projects mostly on smaller areas. About 35% projects appear to have benefitted area less than 2,000 ha, around 50% projects less than 4,000 ha and about 75% projects less than 8,000 ha. The FCD projects have given the most coverage followed by D, FCDI and FC projects, but the FCDI projects rank first with respect to average area benefitted by individual project as seen from Figure 5.8 (c).

5.5.6 Intensity of embankment and drainage channel

Figure 5.9 shows the distribution of projects and benefitted area for various lengths of embankment. The projects employing embankments correspond to mainly FCD projects. Among the total number of projects having embankments, about 38% projects corresponding to 18% of total benefitted area have embankment length less than 25 km, and about 14% projects corresponding to 34% of total benefitted area have embankment length less than 2 km per 1,000 ha benefitted area. Again, it is seen that more than 50% of total number of projects as well as of total benefitted area have embankment of 25-100 km length with 2-8 km of embankment per thousand ha of benefitted area. About 6% projects corresponding to 30% of total benefitted area have embankment length more than 100 km, and about 32% projects corresponding to 6% of total benefitted area have embankment length more than 8 km per 1,000 ha benefitted area.

Figure 5.10 shows the distribution of projects and benefitted area for various lengths of drainage channels. The projects employing drainage channels correspond to mainly drainage (D) projects followed by FCD projects. Among the total number of projects having drainage channels, about 64% projects corresponding to 86% of total benefitted area have drainage channels length of 5 km or more. About 81% projects corresponding to 49% of total benefitted area have drainage channel length of 1 km per 1,000 ha benefitted area.

5.6 Non-structural Approach to Flood Mitigation

5.6.1 Flood forecasting and warning

The Flood Forecasting and Warning Centre (FFWC) of BWDB, established in 1972, is responsible for making flood forecasts and flood warning during the flood season. The monitoring of floods and issue of flood forecasts are carried out in relation to Danger Levels (above which it is likely that the flood may cause damage to crops and homesteads) specified for each river gauging stations. The FFWC collects real-time data of water level (3 hourly) from 55 observation stations and rainfall from 54 observation stations which are transmitted through 61 Single Side Board Wireless stations and 14 Telemetric stations. Currently a hydrodynamic mathematical model (MIKE-11) is used to forecast water levels. At present, the FFWC issues river stages forecast for 21 stations on major and medium rivers where slowly rising floods occur, formulated for lead time of 24 hours, 48 hours and 72 hours with different ranges of accuracy. The forecasts in the form of daily water level bulletins are transmitted to national radio, television, news agencies, news papers, concerned ministries and government offices and field wireless stations.

5.6.2 Flood preparedness

In Bangladesh, there is an institutional arrangement for flood preparedness under a National guideline entitled 'Emergency Standing Order for Flood'. It outlines the actions of flood preparedness to be taken up by a large number of Ministries (Ministries of Relief and Rehabilitation, Water Resources, Agriculture, Information, Health, Public Works, Local Government, Communication and Defence), subordinate agencies, local councils and NGO's in the three defined phases viz. before, during and after the flood. The overall flood management programmes are coordinated by a National Coordination Committee. The recently formed Disaster Management Bureau of the Ministry of Relief and Rehabilitation is entrusted with the task of executing action programmes at the grass root level. Around 20,000 volunteers of Bangladesh Red Crescent Society take part in the flood preparedness programme in the storm surge flood prone area in the coastal region.

5.6.3 Flood proofing

Flood proofing of homestead is a tradition of the rural settlements in Bangladesh. Homesteads are generally raised above unusual flood level. Ponds are dug in the homestead area and banks are raised to prevent intrusion of flood water. They are the source of domestic water supply. They are also used for fish culture and for conservation of water for irrigation during droughts.

Recently Bangladesh National Building Code (1993) has been prepared. As per this Code, any area having a potential for being flooded under at least 1 m deep water due to flooding should be delineated as Flood Prone Area (FPA). The Code specifies that the lowest floor including the basement of any building located in the FPA shall not be located below the design flood level, and the roof of one or two storey buildings and the floor immediately above the design flood level for three or more storey buildings shall be accessible with an exterior stair.

Flood shelter: Schools or health centers built on high mounds serve as flood shelters where flood vulnerable people can take refuge.

Cyclone shelter: Cyclone shelters are constructed in the coastal zone where human lives are at high risk due to cyclonic storm surge floods. Currently there are around 1500 cyclone shelters (Sener et al, 1996). Multipurpose Cyclone Shelter Master Plan (BUET and BIDS, 1993) estimated that 2500 new shelters with a capacity of 4.4 million persons would be required. Over the years, there has been a significant change of emphasis from designing the shelters for single purpose use as flood shelter to design them for multipurpose use. Shelters are now designed as schools, health centers and other community service centers during normal life.

5.7 Agencies involved in Water Resources Sector

5.7.1 Macro planning agencies

The formulation of long term national water resources development plan at the macro level is entrusted with the Water Resources Planning Organization (WARPO) under the Ministry of Water Resources. The Planning Commission of the Ministry of Planning makes five year plans providing guidelines for all sectors including water resources.

5.7.2 Project planning, construction and maintenance agencies

The BWDB, under the Ministry of Water Resources, is the key agency in planning and implementing all large and medium scale flood control, drainage, surface water irrigation projects (projects having benefitted area greater than 2500 ha), town protection, river training works and other water resources projects. The Local Government Engineering Department (LGED), through its Rural Development Programmes, develops very small scale projects (FCDI, FCD, DI and I) with benefitted area equal to or less than 2,500 ha. Its flood control and drainage (FCDI, FCD and DI) projects have covered a net benefitted area of 61,165 ha and irrigation projects (I) 6,000 ha upto 1995. The LGED has been responsible for formulation of Thana Plans, in cooperation with thana officials, including maps of roads, flood control and drainage facilities and irrigation schemes. Union Councils carry out similar activities on a local scale under FFW programme.

5.7.3 Water user agencies

Bangladesh Inland Water Transport Agency (BIWTA) is responsible for maintaining river channel navigable, regulating waterway traffic, ensuring operation of inland ports and jetties and their protection, keeping records of stage of rivers, and establishing rules and regulations governing freight including rates and fares. Dhaka Water and Sewerage Authority (WASA) and Chittagong WASA are responsible for water supply by tubewells and surface water plants, storm drainage and domestic sewer in the respective cities. The Department of Public Health Engineering (DPHE) is responsible for water supply and sanitation for other cities, towns, municipalities and for all rural areas through mechanized tubewells and hand tubewells. The Bangladesh Agricultural Development Corporation, Department of Agricultural Extension and some NGO's have been supplying low lift pumps, shallow tubewells and deep tubewells to the farmers for irrigation. Bangladesh Rural Development Board (BRDB), an agency of Ministry of LGRDC, also serves in irrigation development through its Irrigation Management Programme. The Department of Fisheries is the chief executing agency in the fisheries sector. It gives lease of inland open waters and borrow-pits to local fisher-folks, landless and marginal farmers, unemployed youths and professional trained fisheries people.The Bangladesh Power Development Board (BPDB) is in charge of hydro power generation from the Kaptai lake in the Chittagong region. The gas-based power plants of BPDB use large volume of river water as cooling water. Besides, industries under Bangladesh Chemical Industries Corporation and many private and public industries use river water.

5.7.4 Water regime affecting agencies

The LGED is one of the main water regime affecting agency through the construction of an extensive network of rural roads, bridges and culverts in recent years. NGO's like CARE also construct rural roads. The Roads and Highway Department (RHD) constructs feeder roads and regional highways and national highways which affect water regime. Bangladesh Railway maintains a big network of railways. Currently there are about 11,000 km of rural roads, 16,000 km of national and regional highways and feeder roads, and about 3000 km of railways in the country.

5.7.5 Data collection agencies

Various Government agencies collect primary hydrological, meteorological, sedimentological and morphological data in Bangladesh. The BWDB has over 400 river water level stations, over 100 river discharge stations, over 250 rainfall stations, about 1,230 ground water level stations and around 40 evaporation stations. It also measures suspended sediment transport in a few selected stations in the main rivers and carries out surveys of Standard Cross-sections in the major rivers in the lean season (from November to May). The BIWTA measures some water levels and performs bathymetric surveys regularly in the rivers of Bangladesh for navigational purpose. The Bangladesh Meteorological Department (BMD) is the sole agency in collecting meteorological data which include surface data (rainfall, air temperature, relative humidity, pressure, wind direction, wind direction etc.) of 34 stations and aerological data (wind speed, wind direction, relative humidity, air temperature etc.) of 10 stations. It takes radar echo images from three radars at Dhaka, Khepupara and Cox's Bazar. The Space Research and Remote Sensing Organization (SPARRSO) receives weather satellite imageries (NOAA, GMS). The Soil Resources Development Institute collects soil samples for determination of various soil properties. The Geological Survey of Bangladesh performs the geological exploration in Bangladesh.

(a) Elements of flood control projects (not to scale)

(b) Regular closed during high river stage (not to scale)

(c) Gravity flow drainage during receding river stage (not to scale)

Figure 5.1 : Schematic representation of the concept of flood control project

Figure 5.2 : Typical design sections of major medium and sea-facing coastal embankments [Source : BCL and Halcrow 1988 ; Kampsax International and others, 1992 ; Halcrow et al, 1993 a ; Mott MacDonald et al, 1993c]

Figure 5.3 : Growth of flood control projects.

Figure 5.4 : Annual investment in flood control projects.

Figure 5.5 : Distribution of projects for various construction periods

Figure 5.6 : Regional distribution of projects

Figure 5.7 : Major flood control projects in Bangladesh [Source : Harza et al, 1991]

Figure 5.7 continued

Figure 5.7 continued

Figure 5.7 continued

Figure 5.8: Distribution of project type, size and benefitted area

Figure 5.9: Distribution of projects and benefitted area for various lengths of embankment

Figure 5.10: Distribution of projects and benefitted area for various lengths of drainage channels

CHAPTER 6

EXPERIENCES WITH FLOOD CONTROL AND DRAINAGE PROJECTS

Experiences with flood control projects cover a wide range of issues. In this Chapter some important issues are discussed. Discussion is based on available reports and some preliminary assessments carried out under this study.

6.1 Hydrological and Morphological Impacts

Flood protection and drainage facility have been provided to about one-fourth of the country. There has been an average growth of approximately 120,000 hectares per year in the area covered by flood control and drainage projects as can be seen from Figure 5.3. This resulted in a decreasing trend of approximately 80,000 hectares per year in the flooded area during the period 1964 to 1995 as can be seen from Figure 6.1. It is seen from the analysis in Figure 5.9 that more than half of total project benefitted area have 25 to 100 km of embankment with 2 to 8 km of embankment per 1,000 ha of benefitted area. These are obviously big modifications in the water regime of the floodplain.

It is seen from Figure 5.6 that all regions except NE and NC regions have been subjected to extensive interventions. The effect of interventions is reflected in water level of rivers. Time series of annual maximum, average and minimum water levels from 107 stations show trends at 63 locations of which 21 locations have trends in all annual maximum, average and minimum series (IFCDR, 1995). Two examples of the trends are shown in Figure 6.2 which can be directly correlated with the interventions. The rising trend in the annual maximum water level series while decreasing trend in the annual minimum water level series for the Atrai river in the NW region is the consequence of preventing storage of flood water in the floodplain depressions (Beels) by constructing polders. To reduce the impact, retention of some of the Beels for flood storage has been proposed (Islam and Chowdhury, 1989; Mott MacDonald and Others, 1993b). Storage of flood water in floodplain depressions moderates peak floodflow while augments post-monsoon flow (see Section 3.3.1 and 3.3.2). The rising trends in annual maximum, average and minimum series in Figure 6.2 for the Gumti river in the SE region indicates rise in river bed. The river beds between embankments have undoubtedly, risen in the case of Bangladesh's eastern rivers (Brammer, 1995b). The country may become more vulnerable to large floods as a consequence of the increase in the extreme flood level.

The Coastal Embankment Project in the SW, SC and Chittagong regions is the biggest flood control project in Bangladesh and the project area is approximately 6% of the area of Bangladesh. The general ground level in the coastal area is below high tide. Without the embankment, enormous volume of tidal water would have been stored in the floodplain during rising tide which would have allowed sediment in suspension to be deposited over the floodplain. During ebb tide, the stored water is drained through the tidal rivers providing a flushing action as explained in Section 3.3.3. This process of tidal flooding and drainage occurs approximately twice a day. As a consequence of the embankments in SW and SC regions, around 2000 million cubic meter of flooding volume has been lost during spring tide (Halcrow et al, 1993b). This is equivalent to an additional average inflow of about 100,000 cumec during 6 hours rising period of spring tide. This indicates that enormous volume of tidal water would have entered the area twice a day during spring tide in addition to what is entering presently.

As a consequence of the decrease in the tidal volume, the water level drops quickly during ebb tide, and both the ebb tide velocity and the low water depth has decreased. This resulted in siltation in the river causing rise in the river bed which is the main cause of deterioration of waterways in SW and SC regions (Jansen et al., 1994; DHV, 1989). Prevention of lateral storage of tidal water causes increase in the longitudinal penetration of tide along the river which in turn increases saline water intrusion. This process pushes the shoaling towards upstream. Reduction in upstream freshwater inflow is also an important factor for the reduction in ebb tide velocity and increase in saline water intrusion. As a result of the rise in the channel bed relative to land levels in the flood protected area, serious problem of drainage congestion and waterlogging has developed in Beel Dakatia in the SW region. Some of the channels are almost dead due to siltation. The siltation of tidal rivers is progressively spreading southwards i.e. seaward (Halcrow et al, 1993b). To provide an indication of the changes occurring, cross-sections of two rivers at about 3 years intervals, as obtained by recent surveys, are shown in Figure 6.3. In some areas the situation is worse than before the Coastal Embankment Project was implemented (Halcrow et al, 1993b). This is exactly what was cautioned by Williams (1919) approximately 77 years ago.

The SW Area Water Resources Management Project (FAP 4) by Halcrow and Others (1993b) proposes that present drainage congestion problems be tackled by dredging at Satkhira and Bagerhat, implementation of Second Coastal Embankment Rehabilitation Project and amalgamation of selected polders (macro poldering) at Khulna.

6.2 Agriculture

The objective of FCDI projects had been to increase foodgrain (mainly rice) production. Bangladesh is an overpopulous and developing country. Therefore the major concern of all governments has been to meet ever-growing demand of foodgrain. Achieving food self sufficiency was stated to be the major goal of Fourth Five Year (1991-1995) Plan (GOB, 1991). The FCDI projects were expected to contribute towards this end by two principal ways. Firstly, by securing crops against floods and secondly, by providing irrigation to crops. How far the FCDI projects have been successful in fulfilling their stated objective is investigated in this section.

6.2.1 Impact on Aman

Aman is the main wet season crop. It contributes about 50% to the total rice production of Bangladesh (Table 3.6). FCD projects were designed to protect this important crop from flood hazard. The present coverage of HYV Aman is only 27% which illustrates the potential scope of further increase in production through adoption of high yielding varieties (Huq, 1995; FPCO, 1995b). The same study notes that increasing foodgrain production through irrigation during dry season is nearly exhausted.

Figure 6.4(a) shows the growth of FCD coverage since 1973. The year 1973 has been chosen as the base year as the First Five Year Plan of newly independent Bangladesh commences in that year. Figure 6.4(b) shows the growth in Aman production since 1973. The growth of FCD coverage and growth of Aman production is strongly correlated (correlation coefficient is 0.78). If the data for major flood years of 1974, 1987 and 1988 are omitted then the correlation coefficient improves to 0.84. Such results indicate a positive contribution of FCD projects in general.

To investigate further, a regional analysis of Aman production was made. The results are presented in Table 6.1. It is seen that there has been wide variation in incremental increase in Aman production with respect to incremental increase in FCD coverage. While the NW, SW+SC and SE+CG regions show positive relationship between increase in intervention and increase in Aman output although not according to extent of intervention, the NE+NC regions actually show a decrease in output with increase in intervention. It needs to be pointed out here that NE+NC regions have the least intervention with respect to flood potential area as shown in Figure 5.6.

Table 6.1: Region-wise analysis of Aman production in comparison with FCD growth (Source of data: BWDB Project Completion Report, 1995; Hamid, 1991; BBS, 1996)

Region	FCD Potential area (ha)	FCD Project coverage area (ha)		Average annual increase in FCD coverage during 1973-93 (ha/year)	Average annual increase in Aman production during 1973-93 (tons/year)	Incremental rise in Aman production per incremental increase in FCD coverage during 1973-93 (tons/ ha)
		1973	1993			
(1)	(2)	(3)	(4)	(5)	(6)	(7)=(6)/(5)
NW	1,261,201	12,924	963,595	31,700	33,000	1.04
SW and SC	2,013,104	15,054	1,695,474	56,000	30,000	0.54
NE and NC	1,887,950	5,868	363,497	12,000	-18,500	-1.54
SE and CG	966,073	254,107	674,308	14,000	14,300	1.02

Therefore it is difficult to draw any definite conclusion from Figure 6.3 and Table 6.1 regarding the performances of FCD projects in rice production. BARC (1989) and Khan (1991) also expressed their reservations regarding the performances of FCD projects.

Project based evaluations show some definite improvement in crop production. Hunting (1992) made a comprehensive study of 17 FCDI projects. It found an increase in rice output ranging from 7% to 241%. This increase is due to reduced flood hazard and the switch to HYVs in many cases. Various regional studies carried out under FAP, however, differ in their opinion regarding the achievement of FCD projects.

The NW regional study (Alam and Franks, 1993) reports that experience from previous FCD projects shows that the increases in crop production that appear to be possible are in reality often difficult to attain. While assessing the impact of FCD projects in the NE region, Shawinigan Lavalin (1992) reports that it is not clear whether agricultural production has increased in the region. The SW regional study (Halcrow, 1992a) reports that there was initial rise in crop production in coastal polders but stagnated or declined later on.

The difficulty in integrating the project based evaluations and regional evaluations gives rise to possibility that while individual projects have been successful in raising output, the hydrological impact of these projects in a floodplain environment may have negated the output in unprotected areas. Then the increase in output that is observed in Figure 6.4(b) might be due to factors largely autonomous of FCD coverage such as improved cultivation technology including introduction of HYV varieties in the 70s.

6.2.2 Impact on Boro

Boro is the main dry season crop. Currently it contributes 37% of total rice production of Bangladesh. Since there is little rainfall during the dry season, therefore irrigation is essential for the Boro crop. Through the 1970s and 1980s, there has been rapid increase in irrigation coverage area. This rapid increase is mainly due to exploitation of groundwater through shallow and deep tubewells in private sector. The FCDI projects of BWDB contributed through gravity and pumped irrigation of surface water.

Figure 6.5(a) shows the growth of irrigation coverage during Boro season since 1973. It also shows the contribution of the FCDI projects in this regard. Currently total irrigation coverage stands at 5.74 Mha which is 63% of net cultivable area. Irrigation coverage through the FCDI projects stands at 0.6 Mha which is 10% of the total coverage. Figure 6.5(b) shows the Boro production during the same period. Growth in irrigation coverage and growth in Boro production are strongly correlated with a correlation coefficient of 0.98. Although FCDI coverage area is small compared to total irrigation coverage, the FCDI projects have been equally successful in increasing Boro production. Hunting (1992) notes that out of the 17 projects that it investigated, three highest cases of increase in crop production were obtained where there was substantial growth in Boro production due to the projects.

Partial flood control (submersible embankment) projects, however, have been less successful in protecting the Boro harvest from pre-monsoon flash floods . Shawinigan Lavalin et al (1992) found no impact of partial flood control projects on Boro production in Sunamganj district in the NE region.

6.2.3 Impact on crop diversification

Agro-climatic condition in the kharif season acts in favor of rice. Most non-rice crops are grown in the rabi season when hydrological regime is one of the major factors in the selection of crop type. Rice mono-cropping was in practice in perennially semi-aquatic area and became all the more prevalent with the expansion of irrigation facilities. Wherever irrigation facilities were created, farmers responded by growing rice in the winter season. Socio-economic considerations, specially the economics of irrigated high yielding varieties of Boro rice contributed to this development. This had a negative impact on crop diversification leading to reduction in area under non-rice crops. These crops were pushed out to marginal lands having no provision for irrigation. Negative impacts of such mono-cropping are already becoming apparent through soil degradation and reduced production of pulses, vegetables, oilseeds and fruits which were playing a very important role in providing nutrition to human diet (FPCO, 1995b).

6.2.4 Command area coverage

The single source planning concept generally adopted in Bangladesh is that there will be no groundwater development in major surface water irrigation schemes. But peak irrigation water demand occurs during February-April when surface water availability is at its lowest. As a result, lands with higher elevation and tail ends within project command areas frequently suffer from water shortage. An area of 290,000 ha is estimated to be outside the physical capacity of BWDB schemes to supply surface water (RDCL, 1992). In Meghna-Dhonagoda Irrigation Project during 1989-90, the target was set to cover an area of 10,500 ha but actual achievement was only 5,350 ha (IFCDR, 1992).

This warrants use of groundwater in conjunction with surface water for extending the irrigated area. There has been increasing realization of the appropriateness and imperativeness of conjunctive use as a strategy for water resources development in Bangladesh (for example, GOB, 1995). Although such a strategy has not been formally adopted for any project in Bangladesh, farmers themselves are using groundwater in conjunction with surface water in many surface water projects in order to increase the irrigated area and the reliability of their water supply. Such behavior of the farmers points out to the need of looking into conjunctive use formally and favorably.

RDCL (1992) reviewed the option of using groundwater in 4 major surface water projects of BWDB. RDCL found that these surface water schemes faced severe problems in supplying irrigation to their full irrigable area and/or at all times of the year. The study opined that the development of ground water can offer a solution to both problems. RDCL further opined that ground water development need not be limited only to those areas not served by surface water; there is a good case for conjunctive use of surface and groundwater resources. It needs to be mentioned here that flood control projects might interfere with the groundwater recharge during the wet season which may limit the scope of groundwater development or the conjunctive use of surface and groundwater (for details see Rahman and Chowdhury, 1996). A beneficial function of floodplain is that it recharges the shallow aquifer during monsoon (see Section 3.3.4).

6.3 Fisheries

As discussed in Section 3.5, Bangladesh is very rich in floodplain dependent fisheries resources. In the past, agriculture and fisheries were complementary in the floodplains. But with population pressure and intensive agriculture, the two are now in severe conflict. The FCDI projects were selected on the basis of engineering and economic criteria and no consideration was given to the potential harmful impacts on capture fisheries and the wetland environment.

Flood control infrastructure impinges in many ways on the life cycle of floodplain fisheries (for a full discussion see ODA, 1995; also see Mirza and Ericksen, 1996; Ali, 1990 & 1994). Principal among them are loss of floodplain habitat during the monsoon resulting in a loss of fish production and blockage to the movements of fish (adults, juveniles and hatchlings) between rivers and floodplains.

6.3.1 Impact on capture fisheries

ODA (1995) made an in-depth investigation on the impact of 8 flood control projects on openwater or capture fisheries. It reported a decline of 81% in catch per unit area in case of a full flood control project namely Brahmaputra Right Embankment Project. Shawanigan Lavalin (1994) determined a 90% decline inside full flood control projects and 50% decline inside partial flood control projects in the NE region. Mirza and Ericksen (1996) report a net loss of 5,343 tons/year of capture fisheries in case of Chandpur Irrigation Project in the SE region, a net loss of 83% compared to pre-project condition. ODA (1995) also noted a clear impact on fish bio-diversity due to flood control projects. Full flood control resulted in a reduction of 33% in the total number of species recorded annually. A reduction of 95% was found for migratory species in full flood control projects.

Such averse impact on capture fisheries has prompted decision makers to seriously think about undertaking mitigatory measures. The NE regional study (Shwanigan Lavalin, 1994) has made suggestions to make fish passes call 'fish ladders' through the embankment. It is a device by which the flow energy can be dissipated in such a manner as to provide smooth flow at sufficiently low velocity that the fish can overcome while moving upstream. Construction of fish ladders has already started in a few places.

6.3.2 Impact on culture fisheries

The FCD and FCDI projects while reducing and altering openwater fish habitat, in some instances create potentially more controllable and manageable aquatic habitat for fish production. The benefit that accrues to ponds and low lying areas in flood prone zones is that they are not overflooded every year. This condition facilitates year round use of the ponds for fish culture. Many FCDI projects have successfully raised the production of such culture fisheries. For example, in Chandpur Irrigation Project in the SE region, the production of culture fisheries has increased from 1,366 tons to 3,710 tons per year against an estimated loss of 5,343 tons/year of capture fisheries (Mirza and Ericksen, 1996). BWDB has started leasing out borrow pits within the project areas to Department of Fisheries for culture fisheries. As a whole, for Bangladesh culture fisheries production has increased two folds during the last few years.

Even if culture fisheries production is able to compensate the loss of capture fisheries, it will never be able to compensate the significant bio-diversity that is the characteristic of capture fisheries. ISPAN (1995) notes that the traditional mix of fish species is richer in nutrients and it is difficult to make up for the loss of these species in the diet through other food sources.

Another crucial factor for the rural poor who depend on floodplain catches for their protein intake, is the fact that while capture fisheries are common property and therefore accessible to the rural poor, culture fisheries are not. While the culture fish projects are intended to turn fish into profit, they are causing an underlying economic loss that will be borne by the poor (Minkin and Boyce, 1994).

6.4 Country Boat Transport

Country boat transport plays a particularly important role in Bangladesh (Section 3.8). The FCDI structures often cause hindrances to this traditional mode of transport. Hunting (1992) reports that in half of the 17 projects that it investigated, the FCDI infrastructure had seriously impeded boat transport. Shawinigan Lavalin (1993) studied 66 projects in NE region. It found that 19 have major and 14 have medium level negative impacts on boat transport. DHV (1989) reports deterioration of navigability in the SW and SC regions as a result of sedimentation and consequent river bed rise due to empoldering effects. It also observes that increased abstraction of surface and ground water in the low flow season resulted in reduced streamflows affecting waterways.

6.5 Wetland

As a consequence of modification in the water regime in the floodplain, as discussed in Section 6.1, many floodplain wetlands are shrinking. Brief description of wetlands has been given in Section 3.2.3. Flooding of Beels in the NW region has been prevented by flood control polders. Tidal flooding of swamps and tidal flats in the SW and SC regions has been prevented by flood control polders. Beels and Baors in the SC region and Haors in the NC and NE regions have been drained by drainage projects. Flooding of some Haors in the NE region has also been obstructed by flood control embankments. The flood protection embankments have considerably altered the hydraulic regime to the detriment of sustainable management of wetlands (Khan et al, 1994). The continual loss of wetlands threatens the very ability of the land to maintain life resulting in the reduction of wildlife habitat and displacing the wetland-based socio-economic activities. Although wetlands were traditionally equated with wasteland needing conversion into the so called productive agricultural land, there has, of late, been an increasing awareness of the importance of wetlands as storehouses for biodiversity.

6.6 Economics

There has yet to be an evaluation of the overall impact of the FCDI projects on Bangladesh economy. However economic evaluation of few projects has been carried out. Two studies are reported here.

Harza et al (1991a) conducted post-project evaluations of 6 FCDI projects. Of the six, four had very favorable B/C ratios and IRRs, one of them was marginal with an B/C ratio of 1.0 and an IRR of 12%, and one of them was not economically justified with an B/C ratio of 0.6 and an IRR of 7.3%. In general, Harza observed that the FCDI projects with short implementation periods have more favorable economic returns.

Hunting (1992) carried out economic evaluation of 17 projects. The projects showed an enormous range in their estimated economic returns, with 8 showing unacceptably low returns (an EIRR below 12%), while 7 had EIRRs of 30% or more. The two factors that were critical to project "success" appeared to be the net economic benefits (agricultural benefits minus fisheries losses) and the implementation time. All projects that had a net annual economic benefit per hectare of over 2,000 Taka and were completed in four years or less achieved EIRRs of 30% or more. The seven most successful projects were all small (9000 ha or less in gross area) and relatively simple in conception and design.

6.7 Construction Period

Construction of FCDI projects has often been delayed due to underestimation of the complexity of intervention in a floodplain environment and project cost. It is seen from analysis in Figure 5.5 that about half of the projects in Bangladesh have construction periods of at least 4 years. The Figure also indicates that projects having more than 5,000 and 10,000 ha of area required more than 3 and 6 years respectively to construct. Shawanigan Lavalin et al (1992) observed that construction of fully operational flood control, drainage or irrigation projects in the NE region cost more than the planners have acknowledged. Harza et al (1991) observed that it took 12 years to construct the Manu River Project in the NE region, and 11 years for the Muhuri Irrigation Project in the SE region, whereas the feasibility reports for both projects said the construction period would be 3 years. Such delay in construction often reduces the economic viability of a project. The delay in construction also causes unintended adverse affects. Dhaka City Flood Protection Project area suffered considerable drainage congestion due to delay in construction of appurtenant structures on the embankment (see Khondaker and Chowdhury, 1994 and Rasid & Mallik, 1995).

6.8 Social Impacts

6.8.1 Favourable response

The flood control projects have affected the society in a significant way. There are both positive and negative impacts. In many seminars and discussion meetings, the people who would be benefitted by project wanted construction of embankment to give protection against large floods. They also wanted prevention of drainage congestion due to rainfall inside the protected area. Most FCD projects do not provide pumped drainage facility which requires very high capital cost compared to the cost of earthen embankment and gravity flow type drainage regulators. In a flood response study in rural areas by ISPAN (1992b) under FAP14, it was observed that protection from floods, but not from normal inundation, was a common desire among study respondents. In a systematic sample survey among the residents of the Teesta right bank floodplain in the NW region and the Jamuna-Padma left bank floodplain in the NC region, an overwhelming 95% of the respondents preferred regulation of flood levels within a range of 0.3 to 2.0m (Rasid, 1993). Embankments are very important refuge sites for flood affected families who live outside protected areas (ISPAN, 1992b).

Dhaka city flood protection with pumped drainage facility has created a positive feeling among the residents in the protected land adjacent to the embankment. Despite conflicting view points on environmental aspects among different stakeholder groups, more than two-thirds of the respondents of a questionnaire survey agreed that the embankment had eliminated the threat of river flooding (Khondaker and Chowdhury, 1994). The people cut the embankment to get relief from drainage congestion and water- logging which occurred during the long construction period of more than 3 years. The undesirable consequences occurred because the regulators and link channels were constructed long after the construction of embankment. As a result of flood risk free environment in a FCDI project namely Dhaka-Narayanganj-Demra project with an area of approximately 84 sq.km which is on the outskirts of Dhaka city, the project area is now gradually turning into urban area. Thus the benefit of investing in FCDI project in agricultural land is being diverted to urbanization.

6.8.2 Social tension

There are reports of several social conflicts which arise mainly from two reasons: (1) increased flood risk in areas upstream, downstream and/or adjacent to the protected area, and (2) conflict of interests between farmers and fishermen and between high land and low land farmers within the protected area.

Generally protection from river flood in one area leads to increased flood depths or discharge elsewhere. As a result of increased flood risk, people of the unprotected area sometimes cut the flood protection embankment. Such public cutting is widespread throughout the NW region (Alam et al., 1990). In a FAP study, Hunting (1992) reports that 10 of the 17 FCDI projects had experienced public cuts. During the 1987 flood season, 39 public cuts were observed in the Chalan Beel Project in the NW region (BWDB, 1987).

Many shrimp farms have been established in the flood control polders in the coastal region. Allowing saline water into the farms, which is required for shrimp farming, causes damage to the agricultural land within the polders. This has given rise to social tension between farmers and shrimp producers. There are several instances of violent clashes between conflicting social groups. Due to change in water availability situation, conflicts also develop between highland and lowland farmers inside project area.

It was explained earlier that the Coastal Embankment Project has created severe waterlogging problem in several flood protected areas. The waterlogging has adversely affected the agriculture, socio-economy and ecology of the areas. The problem was so severe in Beel Dakatia that the enraged local people came out in thousands on the 17th August 1990 to protest against the continued waterlogging. An excellent documentation of socio-economic and environmental aspects of the development disaster in Beel Dakatia has been provided in a book by Rahman (1995).

6.8.3 Land acquisition and population displacement

Flood control projects require acquisition of substantial land for embankment causing economic hardship to displaced population. One km of embankment along major and medium rivers require about 35,000 and 25,000 sq. meter of land respectively as indicated by Figure 5.2. Since the floodplain is densely inhabited by population, land acquisition in Bangladesh frequently involves displacement of population. The land loss due to borrow pits can be in the order of 3% in the SW region, which taken over the entire project areas represents a considerable impact, unless this land can be returned to some future, productive use (Halcrow et al, 1993b). Land acquisition has always been viewed with concern in Bangladesh for three reasons. First, land is a scarce resource in Bangladesh and any acquisition of agricultural land in particular is seen as a further aggravation of the land use pattern. Second, the people of this country have a deep rooted emotional attachment to land, particularly when it is ancestral. Third, the process of land acquisition is full of hardships and harassment.

HIFAB and MARC (1992) under FAP-15 study have assessed the social and economic impacts of land acquisition by selecting 6 BWDB projects of which two in the NW region and one in each of the NC, NE, SW and SE regions. Household survey in the 6 projects shows that 38% households lost land and 4% lost homestead. According to the socio-economic survey, the consultation process on the selection of the alignment of embankments was poor. There was universal dissatisfaction with land valuation, affected households estimating an undervaluation of 73% on average. Even when compensation was fixed at above market prices, the initial satisfaction soon evaporated with galloping land price inflation. On average, 40% affected households sought arbitration which is a lengthy process and took over 4 years for final compensation.

6.9 Effects of Floodplain Characteristics

6.9.1 Retirement of embankment

Rivers in alluvial floodplain erode their banks and shift laterally every year during flood season (Section 2.11.3). Embankments are usually constructed by keeping a set-back distance from the river bank. But after a few years, part of the embankment is required to be retired to a safe distance when it is threatened by eroding river. This introduces substantial cost during the operating life of a project. Out of the 220 km of the Brahmaputra Right Bank Embankment, some 140 km had to be retired over the past 20 years (Halcrow et al, 1993a).

6.9.2 Failure of embankment

A crucial issue is the artificial hazard caused by floods due to failure of earthen embankments. Every year during flood season, this is a familiar news item in the newspapers. Damage due to flood control embankment failure is very high compared to that in the pre-project condition due to increased economic activities after the project. An earthen embankment may fail due to overtopping, breaching and/or erosion of the river bank. When an embankment fails, a disastrous flood like the dam-break flood wave causes extensive damage to the protected area. Sudden flooding due to breaching of embankments does much harm to the agricultural land by depositing coarse sand. On the other hand, natural flooding of floodplain by river bank overflow is considered to improve the fertility of the land by depositing silt (Section 3.4.1).

In Bangladesh, it is very difficult to guard against breaching of earthen embankments given the complex geomorphology of the floodplain. Data of a study by Bureau of Consulting Engineers and Halcrow (1988) shows that embankments of 12 projects breached at least in one year since completion of the projects, two-thirds of the projects breached in more than one year while one-third breached in more than two years. In one of the major FCDI project in the SE region, namely Meghna-Dhonagoda project which has a benefitted area of about 180 sq.km., embankment failed during 1987 flood just after construction and then again during 1988 flood within one km of the previous breach. The embankment failed due to piping through a lens of sand below the embankment. Such buried channel is a geomorphological feature of the deltaic floodplain. Rats dig holes in the earthen embankment which create piping and may cause failure of the embankment. Substantial settlement of earthen embankment is one of the cause of overtopping.

6.9.3 Sedimentation

It is observed that many of the flow regulating structures cannot function as intended due to erosion and siltation problems. Erosion and sedimentation are characteristics of rivers in the deltaic plain (Section 2.11). If entry or draining of water cannot be ensured in the protected agricultural land at the right time, crop production suffers from substantial yield reduction.

6.10 Flood Damage

The available flood damage information is not always complete and consistent. Flood damage assessments are generally prepared by various institutions, for example, crop damage by Ministry of Agriculture, damage to embankments and water control structures by BWDB, damage to roads by Roads and Highways Department, damage to rural infrastructure by the LGED etc. Damage assessments by various institutions are not systematic and consistent. There is a need for unified and consistent method of collecting damage data. The source of flood damage information for this study is the Ministry of Relief and Rehabilitation. The assessments by various institutions are compiled together into an overall flood damage assessment.

6.10.1 Crop damage

The main objective of completed flood control projects was to protect the crop land from flood damage. Figure 6.6(b) indicates that there were considerable crop damage even in years of moderate flood [Figure 6.6(a)] because the embankments were also damaged as seen in Figure 6.6(c). However, the crop loss due to flood damage does not seem to have substantial effect upon the total rice production of the country as evident from Figure 6.6(d). This is because the crops are replanted and a part or even the total amount of loss may be caught up during the later part of the season. It also happens that the crop damage by flood is largely compensated by substantially higher yields due to higher residual soil moisture available to the following crops.

It is observed in the NW regional study (FAP2) by Mott MacDonald and Others (1993b) that there is relatively small difference between crop damage avoided from protection upto a 20 year flood level, and damage avoided from lesser degrees of protection (10, 5-year return periods). Of course, the damage caused by a 20-year flood is considerably greater than that caused by a 5-year flood. But the infrequency of the major events means that major damages in one year do not translate into major changes in the value of expected annual damage. The results also suggested that crop damage in years of moderate flooding may also be quite widespread if less dramatic than in high flood years. These results raise the question of the desirable level of protection to aim for, from economic and other viewpoints.

6.10.2 Damage to flood control structure

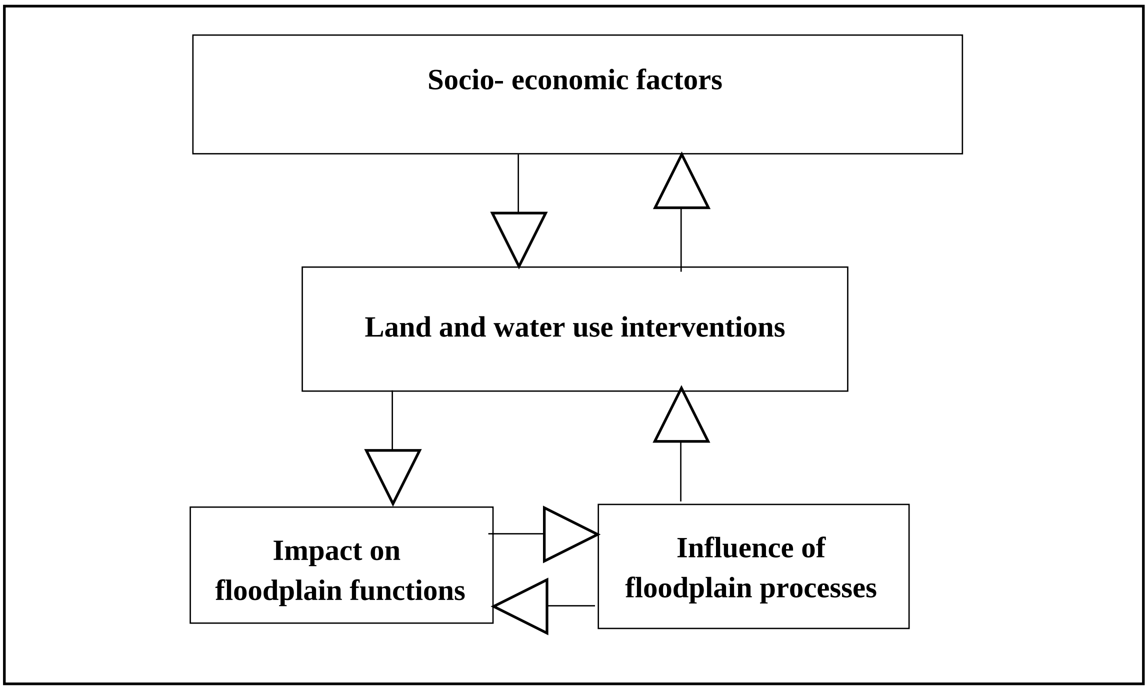
The flood control embankment itself suffers substantial damage as can be seen from Figure 6.6(c). Flood damage to embankments has a strong correlation with the magnitude of flood. It is seen that the earthen embankment was unable to give protection against severe floods in 1987 and 1988 and even against some medium floods in 1991, 1993 and 1995.

6.10.3 Damage to properties and infrastructure

The damage to dwellings, building, roads and bridges/culverts during the period 1985 to 1995 are plotted in Figure 6.7(a)-(d). These Figures display that the properties and infrastructure suffer substantial damage during large and medium floods. It is noted that in addition to damages shown in Figure 6.7, there are consequential effects such as reduced employment, industrial production loss, reduced consumer demand, reduced economic activities due to disruption to daily life of people etc.

6.11 Summary of Project Consequences

It has been seen that population do desire some form of protection especially from large floods. Consequent land and water use interventions create opportunities for social upliftment. However, while flood control interventions bring economic benefit to one section of the society, they cause economic hardships to another section, especially to those poorer sections who are dependent on many free resources of floodplain. The resultant conflict of interest in a densely populated country often compromises project performances. It has been observed that while projects affect the floodplain functions, the natural processes also affect the intended functioning of the projects. Such socio-economic and environmental interactions in the floodplain are illustrated schematically below.



Possible impacts of flood control interventions and the effects of floodplain characteristics upon the projects are listed below for convenience.

6.11.1 Benefits of flood control projects

- Increased agricultural production.
- Increased economic activity/opportunity in flood-free environment.
- Increased production of culture fisheries.
- Reduction of damage to infrastructure inside the protected area.
- Refuge to flood affected people provided by embankment.
- Expansion of road communication through embankment.
- Generation of employment.

6.11.2 Adverse impacts of flood control projects

Hydro-morphology:

- Drainage congestion and waterlogging inside protected area (especially in the tidal region).
- Increased flood risk due to rise in flood level in the river.
- Decrease in post-monsoon flow.
- Deterioration of river condition due to decrease in low water flow and rise in river bed.

Floodplain resources:

- Decrease in capture fisheries.
- Loss of agriculturally productive F1 land due to its conversion to F0 type land.
- Decline in soil fertility.
- Loss of crop diversity.
- Loss of wetlands and bio-diversity due to prevention of flooding and draining out water.

Socio-economic:

- Severe flood hazard due to failure of embankment.
- Social conflict (between farmer and fisherman, between high land and low land farmers inside protected area, between people inside and outside protected area, between localities upstream and downstream of flow regulating structure etc.).
- Displacement of population due to land acquisition.
- Disruption to water transport.
- Problem in drinking water supply due to non-operation of hand tubewell during dry season.

- Occasional hazards due to non operation of flow regulating structure.
- Hazards during long project construction period.
- Loss of land due to extensive construction of embankment.

6.11.3 Effects of floodplain characteristics upon project

- Failure of embankment due to floodplain soil characteristics.
- Failure of embankment due to breach by river bank erosion.
- Retirement of embankment due to shifting of river.
- Excessive length of embankment due to tortuosity of river and high density of rivers.
- Larger height of embankment because of higher and longer backwater effect due to small slope of river.
- Significant unprotected area left outside embankment due to necessity of large set-back distance from the river.
- Operational problem with flow regulating structure due to sedimentation.
- Attack on flow regulating structure by river erosion.
- Outfall problem with flow regulating structure when river shifts away.
- Requirement of several river closures and flow regulating structures due to presence of many channels and rivers.
- Requirement of several culverts and bridges due to presence of many channels inside project area.
- Costly foundation for flow regulating structures due to floodplain subsoil characteristics.

6.12 List of Hydro-morphological Hazards

Although flood management is the subject matter of present study, other hydro-morphological hazards require due attention in integrated floodplain management. These include natural hazards as well as artificial hazards due to project consequences. Some of them have been discussed earlier and how they affect the intended functioning of the projects has been explained. These hazards including floods are listed below for convenience.

Natural hazards:

- Abnormal river flood.
- High intensity and long duration rainfall flood.
- Storm surge flood from the Bay of Bengal.
- Drought due to long gap in rainfall during monsoon [about 5 million hectares of agricultural land are susceptible to droughts (Harza, 1991)].

- River bank erosion [on average nearly one million people are affected by river bank erosion every year (Mott Macdonald, 1993a).

- River course change [probable breakthrough of Jamuna into Bangali river in the NW region would seriously harm livelihood of some 3 million people (Halcrow, 1993a)].

- Sea level rise [Long term possibility; Relative sea level rise due to land subsidence has greater possibility compared to eustatic rise in terms of time span, but uncertainty in quantification is very large. Assessment of the implications of sea level rise for Bangladesh have been made by Milliman et al (1989), Kausher et al (1993) and Ahmad et al (1994)].

Man-made hazards:

- Sudden flood in the protected area due to failure of embankment.

- Damage to agricultural land due to deposition of coarse sand when embankment fails.

- Drainage congestion in the protected area due to embankment and roads.

- Waterlogging due to rise in river bed caused by empoldering effects.

- Non-operation of drinking water hand tubewells due to excessive lowering of groundwater level caused by irrigation tubewells.

Figure 6.1 : Time series of flooded area in Bangladesh. [Source of data: BWDB]

Figure 6.2 : Trends in annual time series of water level due to flood control project

Figure 6.3 : Siltation of tidal river in the SW region due to empoldering effects.

[Source : Halcrow et al, 1993]

Figure 6.4 : Relationship between growth in FCD area and Aman production

Figure 6.5 : Relationship between growth in FCDI area and Boro production

Figure 6.6 : Time series plots of flooded area, damaged crop, damaged embankment and total crop production. (Source of data in (a) : BWDB; Source of data in (b) & (c) : Ministry of Relief and Rehabilitation ; Source of data in (d) : BBS, 1996)

Figure 6.7 : Time series plots of damaged dwellings, damaged buildings, damaged roads and damaged bridges/culverts.

[Source of data : Ministry of Relief and Rehabilitation]

CHAPTER 7

LESSONS FOR FUTURE

Flood is the most dominant component in the hydrologic cycle of the floodplain. It plays an active role in shaping the landscape of the floodplain, nourishing its soil and sustaining its production system. Notwithstanding the occasional hazards of floods, this natural endowment induced people to inhabit the floodplain making long term adaptation to normal floods and short term adjustment to large floods. Large scale intervention in floodplain environment began when Government adopted a policy of protecting agricultural land from floods in order to increase agricultural production to meet increasing demand of foodgrain by rapidly growing population. Although this policy of grow-more-food has dictated activities in the water sector for long time, Bangladesh does not have a formal national water policy to guide long term water resource development and management.

The experiences of flood control interventions in a floodplain country have proved that it is difficult to attain stated objectives of intervention without giving due consideration to the hydro-morphologic features of the floodplain and the socio-economic condition and cultural heritage of its inhabitants. It has been observed that interventions in the floodplain have repercussions both within the protected areas and unprotected areas which are difficult to contain in the floodplain environment of Bangladesh. Such repercussions have compromised the project performances in many instances as have been discussed in Chapter 6.

As also discussed in Chapter 6, prevention of flood in floodplain has many negative environmental consequences. On the other hand, population in general do demand protection against flood damage. So the important issue is how to mitigate flood damage without causing degradation of floodplain environment. The logical approach is optimal risk taking under an overall context of environmentally sustainable floodplain development. This requires a shifting of policy from flood control to flood management even that under a broader framework of round-the-year water management. Experiences gained so far point to this direction.

It needs to be mentioned here that many previous studies highlighted many issues which are now being underscored again. Examples are, harmful effects of embanking tidal rivers in the SW region (Williams, 1919; Halcrow et al, 1993b); drainage problem for not giving consideration to flood factor in the construction of roads in the NW region (Mahalanobis, 1927; Ministry of Water Resources, 1995), and importance of involving local people in the planning and management of water development projects (Government of East Pakistan, 1964; FPCO, 1995a).

7.1 Performance of FCDI Projects

The main objective of the FCDI projects was to increase rice production by providing agricultural land with protection against flood and with supplemental irrigation when rainfall is not adequate. Data over the last thirty years indeed show a quite significant decreasing trend in the flooded area. There are also evidences that many projects have been highly successful in raising crop output in the project area. However, the impact of flood control projects on the monsoon crop production of the country as a whole is non-conclusive.

Although flood control projects with irrigation component have been more successful in raising dry season crop output, most of the FCDI projects could not provide irrigation water to the entire cultivable land within their command areas. The main reasons are shortage of surface water and variation in land level and inefficient water management. The greater amount of water requirement by the HYV rice which was not anticipated at the planning stage of several projects is also a factor. The highland areas and tail-end areas usually do not get water supply. As per planning and designs, the FCDI projects are solely dependent on surface water. RDCL (1992) observes that there is good case for the conjunctive use of surface and groundwater resources. In fact, farmers have installed private tubewells in the command area of many FCDI projects. It also results in considerable gain in water resources (Harza, 1986). The 15-year perspective plan (GOB, 1995) suggested the adoption of conjunctive use of water resources in planning further development.

7.2 Preservation of Floodplain Environment

The objective of increasing rice production by providing flood protection to agricultural land got so much priority that the consequential stress on the floodplain ecosystem received very little attention. We have seen in Chapter 6 that as a consequence of flood control projects, many floodplain wetlands are shrinking. This is causing harm to the bio-diversity and ecosystem and damaging indigenous production systems. We have seen in Chapter 3 that flood provides natural fertilization to the soil. The FCDI projects deprive soil within its command area from this natural rejuvenation. In Chapter 6, we have seen that FCDI projects have promoted rice mono-cropping. Such mono-cropping depletes soil nutrients. Flood control interventions are causing increase in flood risk elsewhere, reducing post-monsoon flow in the river, raising river bed and creating water-logging. The interventions often result in conflicts between different users of the floodplain resources, both within and outside the protected area, such as farmers, fishermen and boatmen.

Construction of large projects have often been delayed due to geo-morphologic and socio-economic conditions of the floodplain. Such delay erodes economic viability of the project and causes unwanted problems during construction period. Evidences show that small scale projects have been more successful than the larger ones due to the fact they can be quickly implemented and have least impact on floodplain environment. These experiences clearly show the need of maintaining harmony with the floodplain processes to the extent possible while taking advantage of beneficial functions of floodplain in order to keep the projects sustainable. This necessitates judicious selection of site and scale of intervention and construction of environment friendly water control structures.

Preservation of floodplain resources like soils, wetlands, capture fisheries, wildlife, flora and fauna and indigenous production systems should receive their due priority. Construction of fish-friendly structure under FAP-6 is a positive step in this direction. The traditional practice of cultivating mix of crops needs to be brought back for maintaining soil productivity and for better nutrition value of such crops. Floodplain zoning can be developed with the aim of preserving floodplain resources.

7.3 Consideration of Floodplain Processes

It has been seen that while physical interventions may affect the natural processes of a floodplain, natural processes themselves might influence intended functioning of interventions. We have seen in Chapter 6 that flood control infrastructures have often been overtopped, breached, eroded and silted up as a result of hydrological processes of the floodplain. These natural processes are difficult to contain in a floodplain environment. Therefore such natural processes should be taken into account in planning and design of intervention in a floodplain.

7.4 Equity Consideration

The nature of a water resources project is such that while it brings benefits to certain section of population, it brings disbenefits to another section of the population. While resolution of conflict arising out of inequitable distribution of project benefits and disbenefits is difficult in any country, it takes on special poignancy in Bangladesh where the majority of the population is overwhelmingly poor, holds small landholding and depends on many free resources of the floodplain. The level of tolerance to any actual or even perceived inequity on the part of affected population is therefore very low and often results in violent reaction often hampering project operation.

Calculation of economic return therefore cannot be the only guide in selecting a project. There should be equity in the distribution of social costs and benefits among the stakeholders. The concern of those who will be at greater risk due to project implementation should be addressed. The FAP studies followed a multi-criteria analysis which brought costs, benefits, and social and environmental impacts in a single framework (see FPCO, 1995b). Such multi-criteria approach is an improvement over the past practices.

7.5 Peoples Participation and Accountability

Peoples participation in planning and management of water development projects is now widely considered to be an essential input for both efficiency and equity. Through adaptation to the hydrologic cycle in an area over hundred of years, local people acquire detailed insights and knowledge of the hydrologic and ecologic system which is not found elsewhere. This wealth of information can be utilized by fostering peoples participation in planning decisions. Some of the FAP studies have set good examples by arranging public discussion meetings in project areas (see FPCO, 1995b).

Lack of understanding of local indigenous production system, and failure to take social relationship and the roles of culture into account as a result of lack of input from local people, many flood control, drainage and irrigation projects have failed to perform as intended in the project planning. The need for peoples participation in the planning of water development projects was stressed more than 30 years ago by a Committee of Parliament Members formed by the Government of East Pakistan (1964) to conduct a review on the working of the then EPWAPDA (presently BWDB and BPDB) and Works (Building and Road) Department. The report of the committee says, "..... we are sure that some very unhappy and untoward incidents could have been avoided, if the local people and the intelligentsia had been taken into confidence by the East Pakistan WAPDA before formulating the schemes". Shawinigan Lavalin et al (1992) observed that full flood control, partial flood control and other projects having had some construction activity on the part of local people or agencies other than BWDB seem to perform better, on average, than BWDB only projects.

Public discussion in the intended project area and obtaining consent from the elected Local Government must be a part of the feasibility study of a project. Involvement of the Local Government body in the planning decisions will facilitate the way of establishing transparency in the management and accountability of project managers as well as of project beneficiaries. Many social conflicts can be effectively resolved by involving the Local Government in the formulation of the project. When the Local Government body plays a role in the planning decisions, they would feel obliged to take responsibility of maintenance of embankments and management of water regulating structures. This will pave the way for participation of local people in the operation and maintenance of the water development projects which is so essential for successful performance of project.

7.6 Operation and Maintenance (O&M)

In most of the cases due to poor O&M practices, performances of costly projects often remain compromised. The cost of rehabilitation becomes of the order of a new project for negligence in maintenance over the years. It seems that the construction phase receives all attention and there is little concern about the operating life of the project. It is not prudent at all to invest huge amount of money in a project whose O&M fund is not guaranteed and proper O&M is not ensured. A transparent system of accountability is to be developed for proper O&M.

Lack of beneficiary participation at the identification, planning and design stage of a project has proved it to be difficult to involve beneficiaries at the O&M stage of the project. This lack of involvement in turn makes it difficult to realize O&M cost of the project from the beneficiaries. Therefore a project remains as a perpetual burden on the government treasury. These projects cannot be self sustaining if such costs are not recovered from the beneficiaries. The National Water Plan (Harza et al , 1991) recommends that water charges should be collected from project beneficiaries in an amount at least sufficient to cover annual operation and maintenance cost. Task Force Report (1991) also emphasizes on sharing of costs by the project beneficiaries.

7.7 Reduction of Vulnerability

Properties and infrastructures suffer substantial damage during major floods which in turn affect the national economy profoundly. It is seen in Chapter 6 that damage to infrastructures constitutes the significant part of total flood damage. Disruption of communication lines and essential utility services result in considerable suffering of the population. Vulnerability of the society to such hazard can be reduced by a programme of flood proofing and flood preparedness.

The national road network is to be flood proofed so that transport is not disrupted during emergencies. Vital installations and other infrastructures should be flood friendly. Foodstore houses, domestic water supply sources and capital assets should be secured by making them flood resistant. Daily economic and employment activities can be kept functioning by making industrial installations and business centers flood proofed. Recently prepared Bangladesh National Building Code (1993) has set the specifications for flood proofed buildings in the flood prone area. A floodplain land use regulation can be formulated so that flood factor is appropriately accounted for in the planning and construction of infrastructures, and preservation of floodplain resources and environment is ensured.

Agricultural damage is not usually significant in the total flood damage. The agricultural damage can be compensated by keeping emergency stock of seeds and other agricultural inputs ready during flood season so that they can be distributed immediately after flood water recedes. Development of effective flood preparedness programme and provision of basic services should be made for the inhabitants of charlands. Damaged rural drinking water supply sources should be immediately restored so that epidemic does not break out.

7.8 Coordinated Activities of Water Regime Affecting Agencies

Flood control embankments and other infrastructures (mainly road) affect the water regime in the floodplain. Construction of roads by LGED, NGOs and Roads and Highways Department is growing every year. The report of the committee on the devastating flood in September-October 1995 in the NW region (Ministry of Water Resources, 1995) observes that the development of roads and other infrastructure in the area prevented the spontaneous overland flow exacerbating the flooding condition. There should be coordinated planning and construction of rural roads, highways and flood control infrastructures with adequate provision for unimpeded drainage.

7.9 Risk-based Decision Making

In addition to the risk of exceedance of the design flood, there are also risks of major repair and rehabilitation costs during the design life of the project. One of the major costs is due to retirement of embankment necessitated by river bank erosion and shifting. Breaching of earthen embankment due to geotechnical problem associated with the complex geo-morphology of the floodplain results in another cost. Planning practices currently followed in the country do not take into account such costs.

For fair allocation of resources among competing needs, costs of all risks during the expected life of a project are to be accounted for in the economic feasibility study. Selection of the level of flood protection and the capacity of drainage structures should be based on the minimization of the sum of annualized capital cost, expected damage cost of risks and cost of operation and routine maintenance. The beneficiaries of flood control and drainage projects should not be given a sense of complete security and there should be transparency in the project management so that project beneficiaries remain aware of possible risks.

7.10 Integrated Water Management

Since water use during wet season has ramification on water use during dry season and vice-versa, therefore any water resources planning process should take water flow throughout the year into consideration. The FAP was so much driven by the immediate effects of the disasters of severe floods of 1987 and 1988 that it focused on flood season only. Ultimately FAP studies recognized the importance of round the year water management. It has also felt the need of integrating FAP with the National Water Plan so that comprehensive view of hydrologic cycle can be taken. The planning process should address the interactions between people, water, land and floodplain environment in a river basin, and take an integrated view of floods, droughts, river erosion, sedimentation, dry season flow, groundwater, agriculture, crop diversity, soil fertility, fish habitats, wetlands, charlands, salinity, water quality, non-point source of pollution etc.

7.11 Multi-objective Planning

The single objective of past flood control, drainage and irrigation projects was to expand the flood protected agricultural land to satisfy increasing national demand of food grain (mainly rice). No consideration was given to the potential harmful impacts on capture fisheries, navigation, public health and the wetland environment.

The document of Bangladesh Water and Flood Management Strategy (FPCO, 1995a) remarks that one of the shortfalls of National Water Plan was that programmes in other Ministries (fisheries, navigation, public health, industries, municipalities, etc.) were inadequately addressed, and their requirements were taken as constraints rather than incorporated within an overall water sector demand position. The Master Plan of Bangladesh Inland Water Transport (DHV, 1989) considers the coastal embankment project as the main cause of deterioration of waterways in SW and SC regions. Dredging of waterways is incurring huge cost on the navigation sector. The situation analysis report on water supply and sanitation (Ministry of LGRDC, 1994) observes that an increasing number of hand tubewells used for drinking and domestic purposes became inoperative for two to three months a year towards the end of the dry season due to expansion of mechanized shallow and deep tubewells for irrigation by groundwater. The National Environment Management Action Plan (Ministry of Environment and Forest, 1995) recommends that incorporation of environmental aspects into plans and project, and consideration of cross-sectoral environmental issues should be ensured. Benefits in one sector should not be at the expense of harmful effects on other sectors. There should be trade-off through mitigation measures so that harm to the environment is minimum.

Multi-objective water resource planning approach is required to optimize the water needs of agriculture, environment, public health, fisheries, navigation and industries. It is essential to take an integrated view of the hydrologic cycle and the interactions of human interferences. Development of comprehensive systems analysis model is required for this approach that would enable the identification of development priorities by accounting for the trade-offs between conflicting objectives.

7.12 Institutional Capability

Above discussion highlights that proper development of water resources sector requires multi-objective planning, integrated land and water resources management, risk-based decision making, fostering citizen's involvement in planning decisions, social equity and environmental preservation, feedback from beneficiaries and project evaluation and many other elements. This requires an institution capable of dealing with a job which is multi-dimensional and multi-disciplinary in nature. The component 26 in Table 4.1 of FAP studies was supposed to address the issue of institutional development. Unfortunately no significant output came out from this component during five year programme of FAP studies.

Water Resources Planning Organization (WARPO) is responsible for macro planning and was set up in 1983. Presently WARPO is staffed mostly by deputed engineers of BWDB and it needs to be balanced by the appointment of economists, social scientists and environmentalists (FPCO, 1995a). Multi-disciplinary structures of WARPO is essential, otherwise it will not be able to achieve the goal of producing an integrated national water management plan. It should have adequate resources so that monitoring and evaluations can be carried out for feedback to planning process.

7.13 Macro-economy

The traditional benefit cost analysis does not reflect the consequences of water sector investments upon other sectors. It is important to develop a planning methodology that relates water sector plans to macro-economic decisions which would help to guide the investment policies for the overall development of a country. A study was initiated under the FAP programme for assessing the potential macro-economic impacts of FAP including possible multiplier effects of the FAP investment on regional and national economics, and the implications of major water sector investment on the sectoral allocation of resources and overall investment planning in the economy. However, no significant output has been reported. It is overdue to evaluate the overall impacts of flood control, drainage and irrigation projects on Bangladesh economy. Rogers et al (1993) have built an economy-wide model for Bangladesh which incorporated a detailed water sector and its macro-economic linkage, and have illustrated how strategic and sector concerns can be accounted for in a simple and direct way.

7.14 Sustainable Development

The issues discussed so far are necessary conditions for sustainable development in floodplain environment but they alone are not sufficient conditions. Vulnerability to flood has increased due to economic marginalization and impoverishment of rural people who are overwhelmingly dependent on agricultural sector. Stimulating development in other sectors and ensuring equitable distribution of wealth are needed to ease pressure on agricultural sector, protection of which has been the major goal of flood control projects. This in turn will provide leeway in development in floodplain in an environmentally sustainable manner. Therefore flood management must be addressed from the context of overall development of the country. Such development approach can balance the need of present generation for a certain level of protection against flood damage and the right of future generations to the benefits of floodplain ecology.

7.15 Donor Support

Foreign donors have been a development partner in water resources sector for long. Most of the flood control, drainage and irrigation projects in Bangladesh are donor funded. Such external funding however has limitations which need to be overcome in order to make more effective utilization of these funds and to fit them into long-term development programme of the country.

Based on experiences from donor funded projects in many developing countries, Howe and Dixon (1993) observe that donor countries desire to sell their technology which means there is a bias toward technologies from the donor country whether or not they are appropriate for the host country, and such a bias is reinforced by the aid being tied to the use of donor country consultants and engineers. The situation in Bangladesh is not different from this.

The donor agencies generally have short budget periods that call for getting the budget spent and seeing quick results. But foreign consultants cannot understand the hydrological and ecological processes, social relationships and culture of the host country in such short period. Consequently many projects are weak in conceptualization, overestimated in design, difficult to operate and maintain, and ultimately not sustainable in the long run. The policy for donor funded projects needs to be formulated from the point of sustainability and national interest. Indigenous technology should get priority in the project concept. Maximum participation of local expertise and professionals is to be ensured at every stage of project planning, design and construction. The Task Force Report (1991) urged larger participation of the local experts to derive benefits of their rich experience of the local conditions.

7.16 Regional Cooperation

Bangladesh is lower riparian country and occupies only 8% of the combined total catchment areas of the Ganges-Brahmaputra-Meghna river system. So the management of its water resources will never be sustainable in the long run independent of water resources development in the upstream countries. Flood control, water diversion, drainage schemes and river training works, in addition to other development works, inevitably affect downstream countries. Chowdhury (1995) has shown that bed levels of many border rivers in Bangladesh are rising.

Water resources development is a vital issue in all the countries within the basins of the Ganges, the Brahmaputra and the Meghna. Huge hydro-electric, irrigation, flood control and water transport potential remains unused. It is in the best interest of all co-riparian countries to take a comprehensive approach to the water resources development within a basin. The opportunity cost of delay on the part of basin countries, both in terms of exhilarating potential benefits being forgone, and also in terms of the compounding environmental deterioration and the mounting costs of flood damages are well illustrated in Mehta (1992).

Cooperative effort is required to develop comprehensive system analysis model based on updated regional data base. Prompt exchange of hydrologic data as well as data on water resources development programmes and activities are essential for the success of integrated management of regional water resources.

7.17 Engineering Education and Society

Engineers play the major role in the planning, design, construction and management of water development projects. In fact engineering is concerned with the use of science for attaining social goals for the enrichment of human life. Engineers are therefore expected to be aware of the needs and concerns of the society. Therefore it is essential that our engineering students develop the capability of understanding the relationships between society and technology so that they become aware of the impacts of technology on the society and the environment. This requires introduction of adequate courses in humanities, social and environmental sciences in the curriculum for engineering education.

In Bangladesh, graduate degrees in Civil and other branches of engineering are offered by one Engineering University and four Institutes of Technologies. These are purely engineering institutions and do not give graduate degree on humanities and social sciences. Therefore, the students as well as the faculties have very little interaction with other disciplines of biological, social and political sciences. At present, the courses in social sciences are only around 5% of the total credit hours of the curriculum for the degree of B.Sc. Engineering (Civil). Such little exposure to social science cannot be expected to adequately prepare future engineers to fully comprehend and address the inter-connection between technology and the real world. The engineering institutions of the country should give due attention to this crucial issue. Water resources problems are likely to be better addressed if civil engineers can start their career with better understanding of social sciences.

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