RESEARCH REPORT

STATE OF BANGLADESH'S WATER

Hamidur Rahman Khan

With the support of the Nippon Foundation

2004

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RESEARCH REPORTS

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- Increasingly many of the emerging water problems and their solutions will come from outside the water sector and the water profession.
- Implementable solutions have to be case specific. For example, solutions that are feasible in France, Germany, UK or USA may not be applicable in China, India, Egypt or Mexico, because of differing climatic, physical, economic, social, environmental, legal and/or institutional conditions.
- A single paradigm may not be equally valid, or operationally applicable, for all countries of a non-homogenous world, which are at different stages of socio-economic development, irrespective of its conceptual attractiveness.

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ABBREVIATIONS AND GLOSSARY

BADC	Bangladesh Agriculture Development Corporation
BARC	Bangladesh Agricultural Research Council
BBS	Bangladesh Bureau of Statistics
BCAS	Bangladesh Center for Advanced Studies
BEMP	Bangladesh Environment Management Program
BIDS	Bangladesh Institute for Development Studies
BIWTA	Bangladesh Inland Water Transport Authority
BMD	Bangladesh Meteorological Department
BRAC	Bangladesh Rural Advancement Committee
BRE	Brahmaputra Right Embankment
BRRI	Bangladesh Rice Research Institute
BWDB	Bangladesh Water Development Board
DAE	Department of Agricultural Extension
DMB	Disaster Management Bureau
DoE	Department of Environment
DoF	Department of Fisheries
DoFo	Department of Forests
DPHE	Department of Public Health Engineering
DSSTW	Deep Set Shallow Tubewell
DSW	Dhaka Southwest Project
DTW	Deep Tubewell
EIA	Environmental Impact assessment
FAP	Flood Action Plan
FAO	Food and Agricultural Organization of the United Nations
FCD	Flood Control and Drainage
FCDI	Flood Control, Drainage and Irrigation
FMTW	Force Mode Tubewells
F0	Flood Free Land
F1	Shallow Flooded Land (Medium high land)
F2	Medium Flooded Land (Medium low land)
F3	Deep Flooded Land (Low land)
F4	Very Deep Flooded Land (Very low land)
FPCO	Flood Plan Coordination Office
GDA	Ganges Dependent Area
GDP	Gross Domestic Product
GIS	Geographical Information System.
GNP	Gross National Product
GoB	Government of Bangladesh
HTW	Hand Tubewell
HYV	High Yielding Variety
IPCC	International Panel on Climate Change
IEE	Initial Environmental Examination
ISPAN	Irrigation Support Project for Asia and Near East
JRC	Joint Rivers Commission
LLP	Low Lift Pump
LGD	Local Government Division under MLGRD&C
LGED	Local Government Engineering Department
LGIs	Local Government Institutions
M	Million
MLGRD&C	Ministry of Local Government, Rural development and Cooperatives

Mt	Million ton
MPO	Master Plan Organization (Presently WARPO)
NCA	Net Cultivable Area
NEMAP	National Environmental Management Action Plan
NGOs	Non-Government Organizations
NIPSOM	National Institute for Preventive and Social Medicine
NMIDP	National Minor Irrigation Development Project
NWMP P	National Water Management Plan Project
O&M	Operation and Maintenance
RRI	River Research Institute
SEMP	Sustainable Environmental Management Program
SRDI	Soil Resources Development Institute
STW	Shallow Tubewell
Taka (Tk)	Bangladeshi Currency (1 US$=Taka 57.8)
UNICEF	United Nations Children Emergency Fund
VDSSTW	Very Deep Set Shallow Tubewell
WARPO	Water Resources Planning Organization
WHO	World Health Organization

Measurement Conversions

Area
1 hectare (ha) = 10,000 square meters (m^2) = 2.47 acres

Volume
1 cubic meter (m^3) = 1,000 litres (l) = 35.31 cubic feet (ft^3)

Mass
1 ton = 1,000 kilograms (kg)
1 kilogram = approx 2.21 pounds (lb)

Salinity/Conductivity
1 ppt (of salt dissolved in water) = 3925 micromho/cm
(Note that the relationship between ppt and micromho/cm is not directly proportional.)

ACKNOWLEDGEMENTS

The materials for this book came from numerous publications, reports text books and personal experiences of the author. The contributions from these sources are gratefully acknowledged.

Special mentions must be made for the recent WARPO documents of National Water Management Plan Project, FAP documents and National Water Plan documents of 1986 and 1991.

Information provided in Chapter 6 (Water Related Environment), Chapter 8 (National Water Planning, Policy and Legislation), Chapter 12 (Water Quality) and Chapter 14 (Impacts of Climate Change) are based mainly on WARPO documents on National Water Management Plan (concerned volumes of Draft Development Strategy).

Professor K. B. S. Rasheed of Geography Department, Dhaka University has provided valuable suggestions for improvement of the book.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

Water is central to the way of life in Bangladesh and the single-most important resource for the well-being of its people. It sustains an extremely fragile natural environment and provides livelihood for millions of people (Ministry of Water Resources, Government of Bangladesh, National Water Policy, 1999).

The water ecosystem of Bangladesh comprises the tributaries and distributaries of three major river systems: the Ganges-Padma, the Brahmaputra-Jamuna, and the Meghna, and numerous perennial seasonal wetlands locally called haors, baors and beels. All the three major rivers systems originate outside the country. The three rivers systems drain a total catchment area of about 1.75 million square kilometers, of which 8% lies within Bangladesh. The remaining catchment areas of the Ganges, the Brahmaputra and the Meghna are located within India (62%), China (18%), Nepal (8%) and Bhutan (4%).

As the lower riparian of the Ganges, the Brahmaputra and the Meghna rivers, Bangladesh is located at the point of concentration for monsoon floods generated by runoff from the Himalayas.

Continued development of upstream basins will increase the disadvantages of being the lower riparian and floods are likely to increase because of deforestation of the Himalayas, confinement of rivers by diking, land degradation and erosion.

On the other hand, during the November-May lean period Bangladesh receives only the residual flow after diversion and upstream use. Reduction of dry season flows in Bangladesh due to increasing upstream withdrawal is causing severe water shortage across the country and in the south-west region in particular, reduced streamflow is also aggravating saline water intrusion in the coastal areas.

Efficient water and flood management and assured shares of the dry season flows of the trans-boundary rivers have, therefore, become imperative for the survival of Bangladesh.

As about 90% or more of the Bangladesh's annual runoff enters the country from outside its borders, there are uncertainties regarding the available flow both during the dry and wet seasons with serious planning implications for the management in the water and related sectors.

The most influential single natural phenomenon to have a deep impact on Bangladesh's culture, economy and politics is its river system. The country has the world's highest density of rivers per unit area; so it is called 'the gift of the rivers'. In spite of the reduced flow in the rivers during dry season, the system has significant role in country's agriculture and transportation. According to MPO (1986), the average annual flow of all the rivers is 37,590 cubic meters per second, which makes it the second largest hydrologic system next to the Amazon River of South America.

Much of Bangladesh is flooded every year, and agriculture and human settlements have adapted to normal floods caused by rainfall or overbank flow from rivers. But severe monsoon floods, like those of 1998, cause significant damage to crops and property. The normal sequence of floods starts with flash floods in the northeast, southeast and eastern hills regions caused by pre-monsoon storms in April and May, prior to the onset of the monsoon in June. The Meghna and the Jamuna Rivers normally reach their flood peaks during July and August, and the Ganges during August and September, but the peaks coincide, on average, every six years. When they do, as in 1988, they produce severe floods and may inundate about 60% of the country.

The amount of water which annually reaches Bangladesh would form a lake of the size of the country having a depth 10.3 meters. More than 85% of this water occurs during 5 months (June-Oct) and for the remaining period, rainfall is less than evapotranspiration.

Drought is also a major problem in Bangladesh during seven months of rabi, pre-monsoon and post monsoon season and agricultural production is heavily reliant on irrigation. Drought is not confined to the dry season only. Rainfed (monsoon) crops are normally grown without irrigation with the expectation that rainfall and soil moisture will be sufficient to meet the crop water needs. However, because rainfall is highly variable during the growing season and from year to year, there are periods in which rainfall and moisture available to the crops are less than required which results in water stress in the plant and reduced yield.

Major concerns have emerged relating to the natural environment and water related impacts on fisheries. While naturally occurring iron and boron each represent varying degrees of hazard to water users, the presence of arsenic in the shallow aquifer is an undeniably major threat to human health, as it is both toxic and carcinogenic. Current understanding is that about 25% of the population is exposed to contamination exceeding Bangladesh standards, with a further 21% with supplies that do not meet the more stringent WHO standards.

Bangladesh has been identified as being at risk if global climate change manifests itself in the form expected by the Intergovernmental Panel on Climate Change (IPCC). Among other changes, it is anticipated that floods may increase in volume and cyclone frequency is likely to rise as more cyclones make landfall. Coastal surge depths will increase and will spill over coastal embankments. A sea level rise of 0.5 m by 2050 would exacerbate drainage congestion, particularly in inland areas of the south-central and southwest areas where the tidal range is less.

Water resources management in Bangladesh faces immense challenge for resolving many diverse problems and issues. The most critical of these are alternating flood and water scarcity during the dry seasons, ever-expending water needs of a large population, growing economy, and massive river sedimentation and bank erosion (Ministry of Water Resources, Government of Bangladesh, National Water policy, Dhaka, 1999).

There is a growing need for providing total water quality management (dealing with surface water salinity in the coastal areas, deterioration of surface water and groundwater quality, and water pollution), and maintenance of the eco-system. There is also an urgency to satisfy multi-sector water needs with limited resources, promote efficient and socially responsible water use, delineate public and private responsibilities, and decentralize state activities where appropriate. All of these have to be accomplished under severe constraints, such as lack of control over rivers originating outside the country's borders, the difficulty of deltaic plain, and the virtual absence of unsettled land for building water structures (Ministry of Water Resources, Government of Bangladesh, 1999).

CHAPTER 1: THE PHYSICAL FRAMEWORK

LOCATION

Most of Bangladesh is located within the flood plains of three great rivers, the Ganges, the Brahmaputra and the Meghna rivers, their tributaries and distributaries. The three rivers drain a catchment area of about 1.75 million square kilometers of which 8% lies within Bangladesh.

It is located between 20^o 34' N and 26^o 33' N latitude and between 88^o 1' E and 92^o 41' E longitude. The country is bordered by India in the west, north and east except for a small portion in the south-east by Myanmar. The entire southern border is occupied by the Bay of Bengal (Figure 1.1). Although the country is predominantly a plain surface, it is criss-crossed by a very high density of river systems. This gives the country a riverine nature which is indeed present in the life style, custom, economy and history of the people of Bangladesh.

TOPOGRAPHY

Bangladesh is almost entirely an alluvial deltaic plain with hills on the northeast, east and southeast margins. Within the alluvial plain there are several slightly elevated areas of older alluvium referred to as terrace areas. Half of the country is below 12.5 m elevation above mean sea level (Figure 1.2).

The highest areas are in the Chittagong Hill Tract region consisting of a series of north-south trending synclinal valleys and anticlinal ridges varying in elevation between 70 and 1000 m. These ridges sweep northwards from the Chittagong area through the Indian state of Tripura and dip to the Sylhet plains. In the southern part of Sylhet area the highest elevations of these ridges reach about 60 m.

The alluvial plain falls southeastwards gradually over a distance of 400 km from an elevation of about 90 m in Tentulia in the far northwest to a coastal plain of less than 3 m elevation south of Khulna-Narayanganj-Chandpur-Noakhali. The Meghna valley, averaging less than 5 m in elevation, runs 200 km north-northeast from the coastal plain to the center of the Sylhet basin which is less than 10 km from the steeply elevated Shillong Plateau that forms the northern border of Bangladesh east of the Brahmaputra river.

Slightly elevated (10 to 30 m) tracts of land form terraces within the alluvium. The most significant of these are the Lalmai Hills of Comilla, the Madhupur Tract of Dhaka, Mymensingh and Tangail areas, and the Barind of the Rajshahi, Bogra, Dinajpur and Rangpur areas.

While the overall relief is fairly monotonous, there is considerable local diversity. Local relief differences can, for example, exceed 3 to 5 m between old levees and abandoned meander channels on the floodplains. In areas where such differences do not exist, farmers often terrace the land to mitigate effects of flood and drought. The local relief can adversely affect the efficiency of water development projects for irrigation and drainage. Villages are invariably placed on the highest land and are generally, except in the terrace areas, 2-5 m above the cultivated floodplains. This relief difference is of consequence for potable water supplies because it worsens the conflict arising from development of groundwater for irrigation.

GEOLOGY

The Bengal Basin of which Bangladesh is part, is bordered on the west by the outcropping Pre-Cambrian basement rocks of the Indian Shield and to the north by the Shillong Plateau, a large elevated area of Pre-Cambrian basement rocks with an area of Cretaceous and Tertiary shelf Sediments. The Dauki Fault Zone, which forms an active major W-E lineament, separates the Shillong Plateau from the adjacent deeply subsided Surma Basin. The eastern margin of the Bengal Basin is bordered by hills along the NNW-SSE and N-S trending frontal fold zones of the Neocene phase of the Indo-Burma Orogenic Belt (MPO, National Water Plan, 1986).

Most of the present-day Bangladesh comprises a gently sloping surface formed by the recent delta and alluvial plains of the Ganges, Brahmaputra and Meghna Rivers. This huge sub-aerial delta grades off-shore to the world's largest submarine fan complex that extends over 3,000 km south to 10^0 S latitude beneath the Indian Ocean (Currey, J. R. , and G. G. Moore, 1974).

The Bengal Basin can be divided into shelf, slope or hinge, and basin foredeep areas (Bakhtine 1966). The stable shelf in the north and northwest is characterized by comparative stability and reduced sedimentary sections. The geosynclinal Bengal Foredeep in the south and southeast has greater tectonic mobility and a very thick sedimentary infill. These two units are separated by a hinge zone running in a northeast-southwest direction through the middle of the basin. Both surface and subsurface data indicate that the geological histories of these units differ.

STRATIAGRAPHY AND DEPOSITIONAL HISTORY

Bangladesh is covered almost completely by Quarternary sediments deposited less than 2.4 million years, but early Tertiary sediments occur along the northern border and in the late Tertiary sequence in the eastern folded belt (MPO, National Water Plan, 1986, page 10-7).

The Bengal Basin occupies a remnant of the seaway that was closed some eight million years ago as the Indian Continental Plate reached Asia. During the infilling with sediments, the basin has generally deepened, and sea level has varied considerably from its present position. The modern Ganges-Brahmaputra delta complex was formed by erosion of the Himalayas and the deposition of those eroded materials in the deep basin as alluvial fans and riverine deposits.

Ganges sediments have high clay content because the Ganges basin is predominantly composed of highly weathered sedimentary volcanic rocks; the high sand and low clay content of the Brahmaputra river is from predominantly young and unweathered sediments. The difference between minerologies of the Gangetic and the Brahmaputra-Meghna alluvium cause quite different soils to develop on these parent materials. Ganges Floodplain soils are calcareous and strongly to extremely acid. Soils developed in the

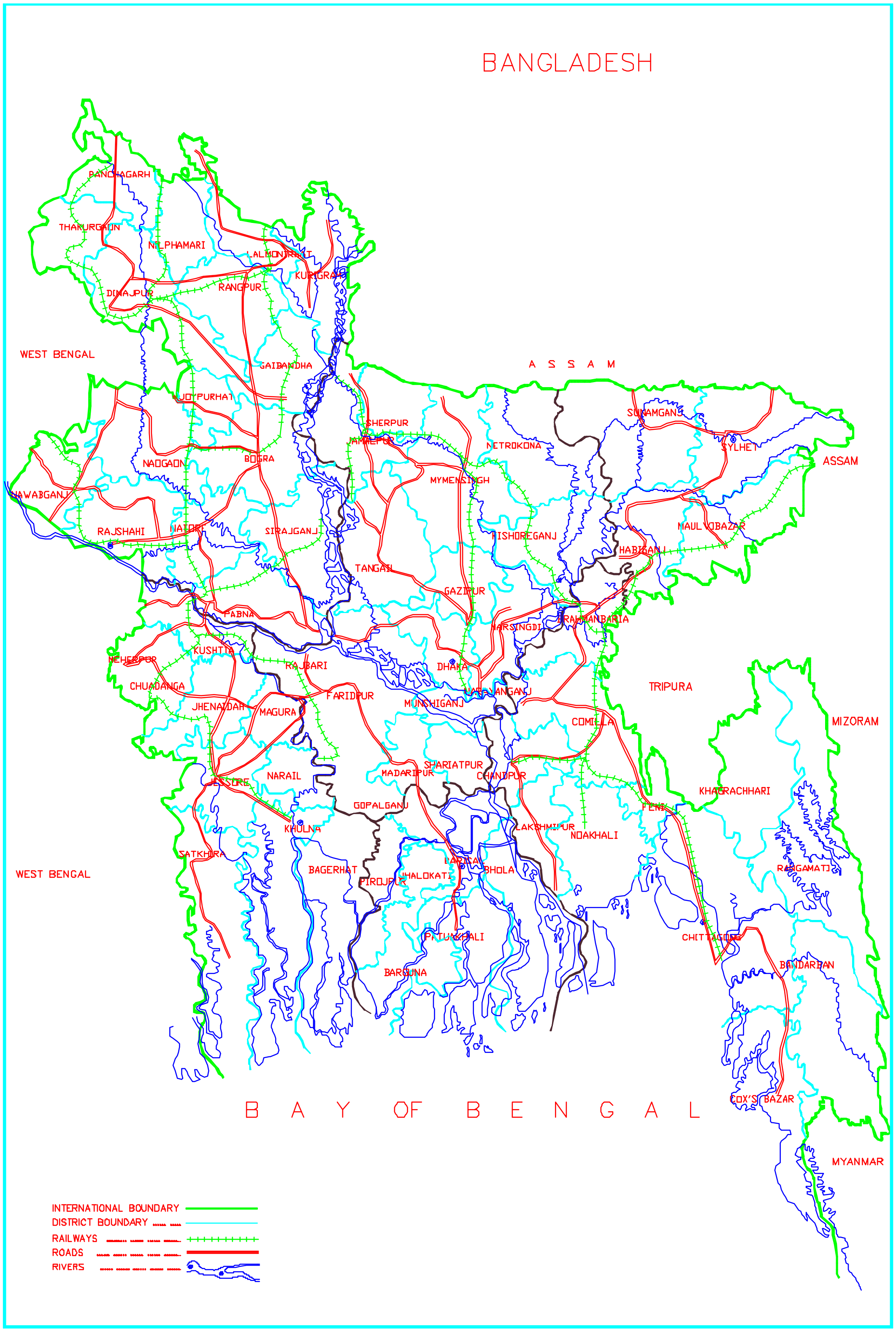


Figure 1.1: Map of Bangladesh

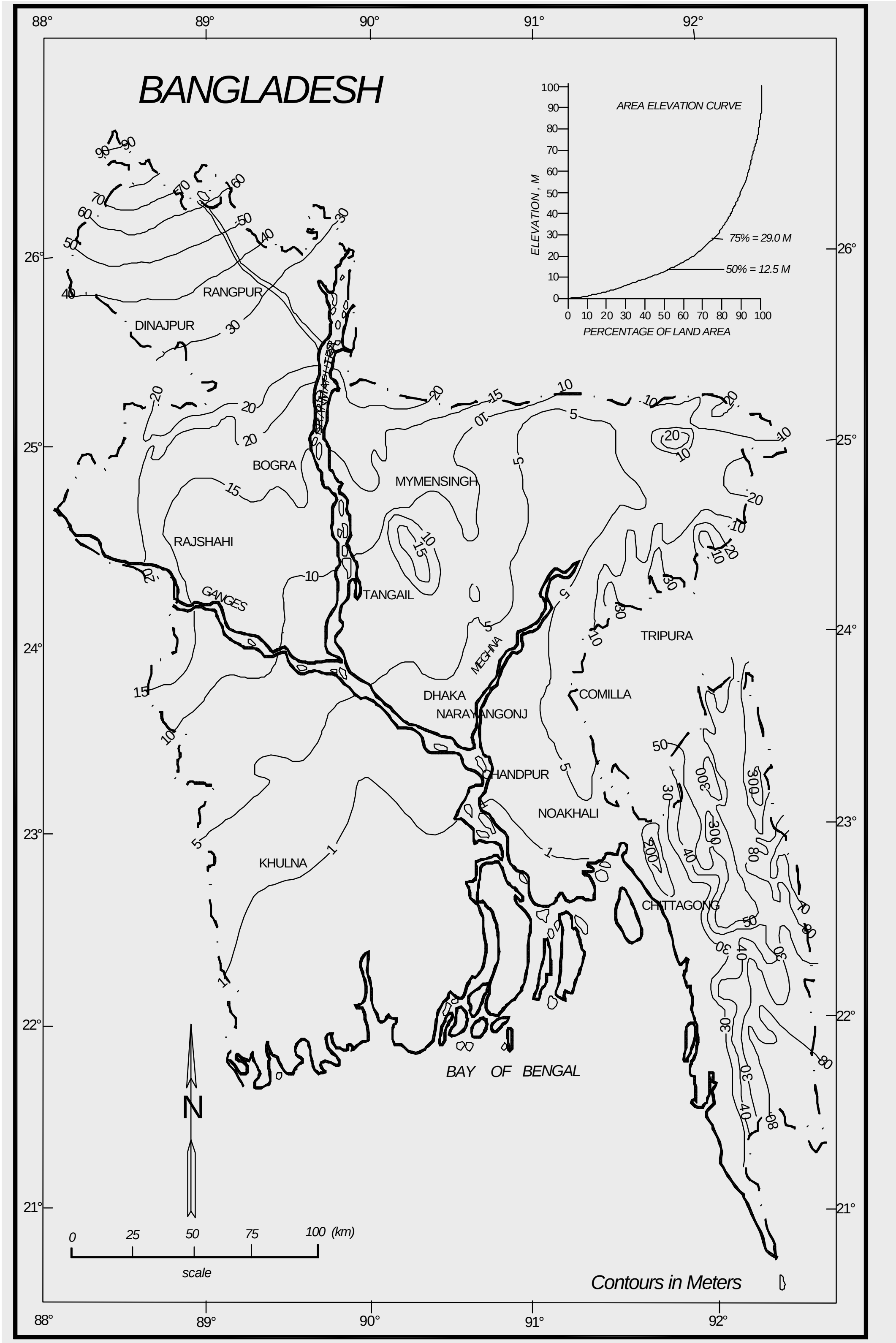


Figure 1.2: Generalized relief of Bangladesh

Old Brahmaputra, Meghna, Teesta, Karatoya-Bangali and Lower Atrai floodplains are non-calcareous and medium to strongly acid. The use of irrigation water with a markedly different chemical equilibrium could damage the calcareous Ganges soils. This should be considered in the overall appraisal of major surface water schemes.

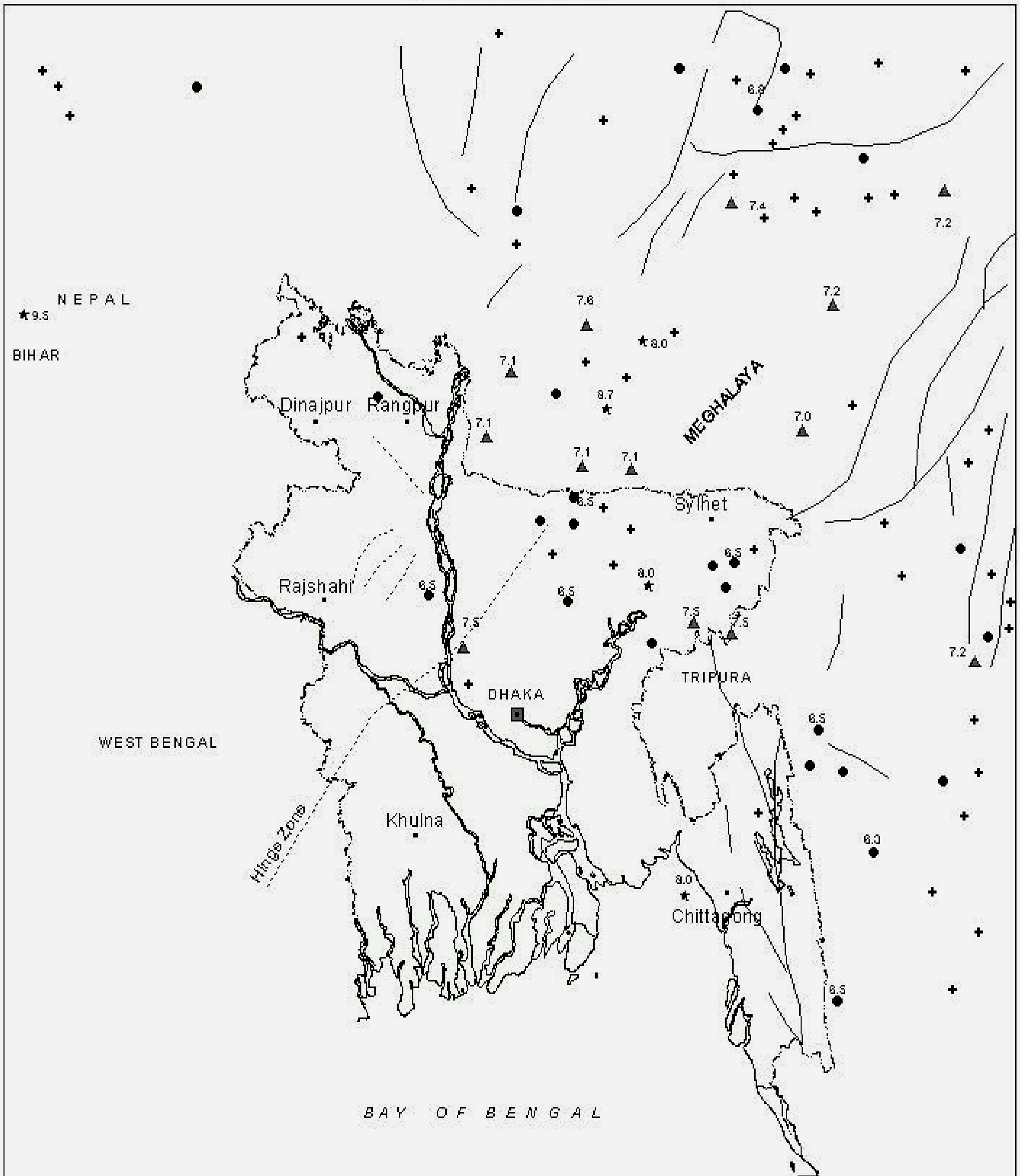
Using the microfossil data and geo-electric well logs from oil and gas exploration wells it has been hypothesized that the strata beneath the topmost lenses of alluvium form a series of six independent, regionally continuous stratigraphic sand units separated by continuous terrestial and marine clay beds varying in thickness from 20 to 150 m which outcrop in Sylhet and Tripura-Assam. The highest sand body, equivalent to the main aquifer used presently for groundwater supplies, is estimated to increase in thickness from less than 200 m to more than 600 m along the axis of the Lower Meghna River. The deepest sand body is postulated to be 100 to 150 m thick, varying in depth from 600 to 1,600 m. Stratigraphically, the huge Tertiary-Quaternary sedimentary infill is a complex intermixing of deltaic deposits where sedimentary facies characteristically lack horizontal continuity. The lateral continuity of the sediments is an important factor affecting groundwater development. While there are important differences in sediment type, mineralogy and distribution, the sands of the Quarternary alluvial complex effectively form one vast continuous aquifer with local clayey sediments. The geology and aquifer geometry down to 300 m can be predicted with some confidence; at depths in excess of 300 m very few data are available (Jones, P. H., 1985).

TECTONICS

The geological formations of Bangladesh are characterized by a series of E-W and N-S trending faults and basement and geomorphic lineaments. The E-W trending fault set is most prominent as it marks the southern edge of the Shillong Plateau. The N-S fault set appears to determine the course of the Jamuna River and may be responsible for the alignment of the Atrai and Little Jamuna Rivers in NW Bangladesh. Hydrologically the NW-SE fault set has the greater correlation with present day river channels, particularly the Teesta, Old Brahmaputra, the Ganges and the Atrai system. The NE-SW fault set is highly correlated with the alignment of the Meghna. These lineaments and faults provide boundary controls for the Madhupur Forest Tract of Pleistocene terraces (National Water Plan, 1986). Similar faulted boundaries are evident in the northwest, particularly north of Bogra, and in the Pleistocene High Barind north of Rajshahi.

Geophysical and systematic geological well log interpretations indicate that the thickness of recent sediments, their lithologies and their aquifer potential are possibly related to fault controlled troughs (grabens) and adjacent plateaus (horsts) in the NW. Both the High Barind of Rajshahi and the Bogra-Sherpur Barind represent uplifted blocks of older material, and the valleys to the west are infilled grabens. Hydrogeologically the Barind areas are very different from the adjacent alluvium-filled valleys.

The fact that major river channels are correlated with identifiable fault patterns also implies that these river alignments may be very ancient even if they are periodically disturbed by earthquakes as was the Old Brahmaputra in the earthquake of 1762.



+ Up to 6: Minimum damage
• 6.1-7: Moderate damage
σ 7.1-8-Great Damage
* More than 8-Catastrophic damage
Surface faults
Known or inferred subsurface faults
• Cities / Town
ν Capital / Dhaka

g = gravitational acceleration

Source: (a) The committee of Experts on Earthquake Hazard Minimization, GOB, Dhaka Nov 1976
(b) Kaila and Rao, 1979

Figure 1.3: Location of epicenters with magnitude in Richter Scale: Magnitude given where known

SUBSIDENCE

Subsidence is a common earth movement in Bangladesh, but there may also be some uplift. Major areas of subsidence are the Surma Basin, Faridpur Trough, Chalan Beel, Dhaka Depression and the Khulna-Sundarbans area. Calculated values of subsidence range from 0.6 mm/year to 5.5 mm/year but may exceed 20 mm/year in the central part of the Surma Basin (MPO Technical Report No 4, 1985). Evidence of recent uplift is difficult to find in Bangladesh, but geodetic levelling over the Shillong Plateau shows a rise of 2.5 cm over the period 1910-1977, equivalent to an annual rate of 0.37 mm/year.

Evidence of subsidence of geological strata should not be construed as a general lowering of the land surface. It is a natural process in areas of unconsolidated sediments because it reflects the gradual compaction of deeply buried sediments in response to overburden pressure. Generally equilibrium exists between sediment supplied to the surface and subsidence so that land levels do not significantly change. Activities by man, however, can create subsidence at the land surface by reducing the sediment supply or by accelerating compaction of the sediments. Large scale flood control and drainage schemes or river diversion can interrupt sediment supply while extensive groundwater withdrawals could significantly reduce subsurface groundwater pressure leading to increased vertical compaction of sediments. Well known cases of subsidence caused by groundwater withdrawals have occurred in Bangkok, Tokyo, Mexico City, Venice and in the San Joaquin Valley of California (Walton, W. C. , 1970). Large declines in groundwater levels have taken place beneath Dhaka City, but there is insufficient data to determine if significant subsidence has resulted.

The risk of subsidence and soil loss by winnowing is high in the Gopalganj-Khulna peat basins if groundwater levels are lowered. Consequently proposals for groundwater development will have to be limited in these areas.

EARTHQUAKES IN BANGLADESH

The region of Northeast India and Bangladesh has long been one of the more seismically active regions of the world, and it has experienced an average of one large earthquake every 30 years during the past 200 years. Figure 1.3 shows recorded earthquake epicenters affecting Bangladesh.

The catastrophic earthquakes of 1762 and 1782 are believed to have been partially responsible for the diversion of the Ganges from its main Arial Khan distributary to the present Padma channel. Similarly it may have assisted the change of the Teesta, which formerly flowed southwards down the Atrai-Punabhaba courses into the Atrai basin, to its present course.

The 1897 Earthquake.

The 1897 earthquake severely affected the northern area of Bangladesh from Rangpur and Natore to Moulavi Bazar and Sylhet (Khan, N. I, Rangpur Gazetter, Chapter I, page 30-32, 1977. Rizvi, S. N. H., Sylhet District Gazetter, Chapter I, page 1962. Anderson, F. P., 1900.). Elevation and subsidence of land severely affected the hydrology where beds of streams and rivers were raised and contracted by the slipping of their banks. Another effect was to raise the general level of the Rangpur area. Elsewhere arable areas were converted into uncultivable marshes and swamps.

The 1897 earthquake severely affected agriculture as “large tracts of cultivable land were covered with a thick layer of sand, causing major damage to standing crops and rendering many lands unculturable” (Rizvi, 1962). Water supplies were disrupted by the collapse of wells and, in Sylhet, by the seepage of black, sulphurous water from the ground.

Evaluation of Seismic Risk

The 1897 earthquake was an extreme event, and a review of the seismicity of the region suggests that major Himalayan ruptures will probably occur at about 180 to 240-year intervals. The repeat time for the large 1897 rupture may be longer.

Seismic events affecting Bangladesh were studied by a Bangladesh Committee of Experts on earthquake hazard minimization, and a seismic risk map was prepared (FIGURE 1.4).

Three seismic risk zones were identified as shown in the figure. While the apparent risk in Zone 1 is high, there are few cases of the failure of embankment dams, which are the nearest equivalent of the large flood control embankments and major river training works in Bangladesh. The 1897 earthquake displaced the railway embankment at Shaistaganj in the Khowai valley, Sylhet by 1.8 to 2.4 m over a length of 1.6 km and that the ground sank under the weight of embankment (this was the case almost every where that the line was in alluvium (Anderson, 1900). However, major hydraulic structures must be designed to withstand earthquake hazard. The earthquake zoning map, should be used to indicate the level of sub-soil investigation and remedial design measures required and the potential need for additional capital costs in major FCDI, FCD and groundwater development schemes, particularly those considered in Zone 1.

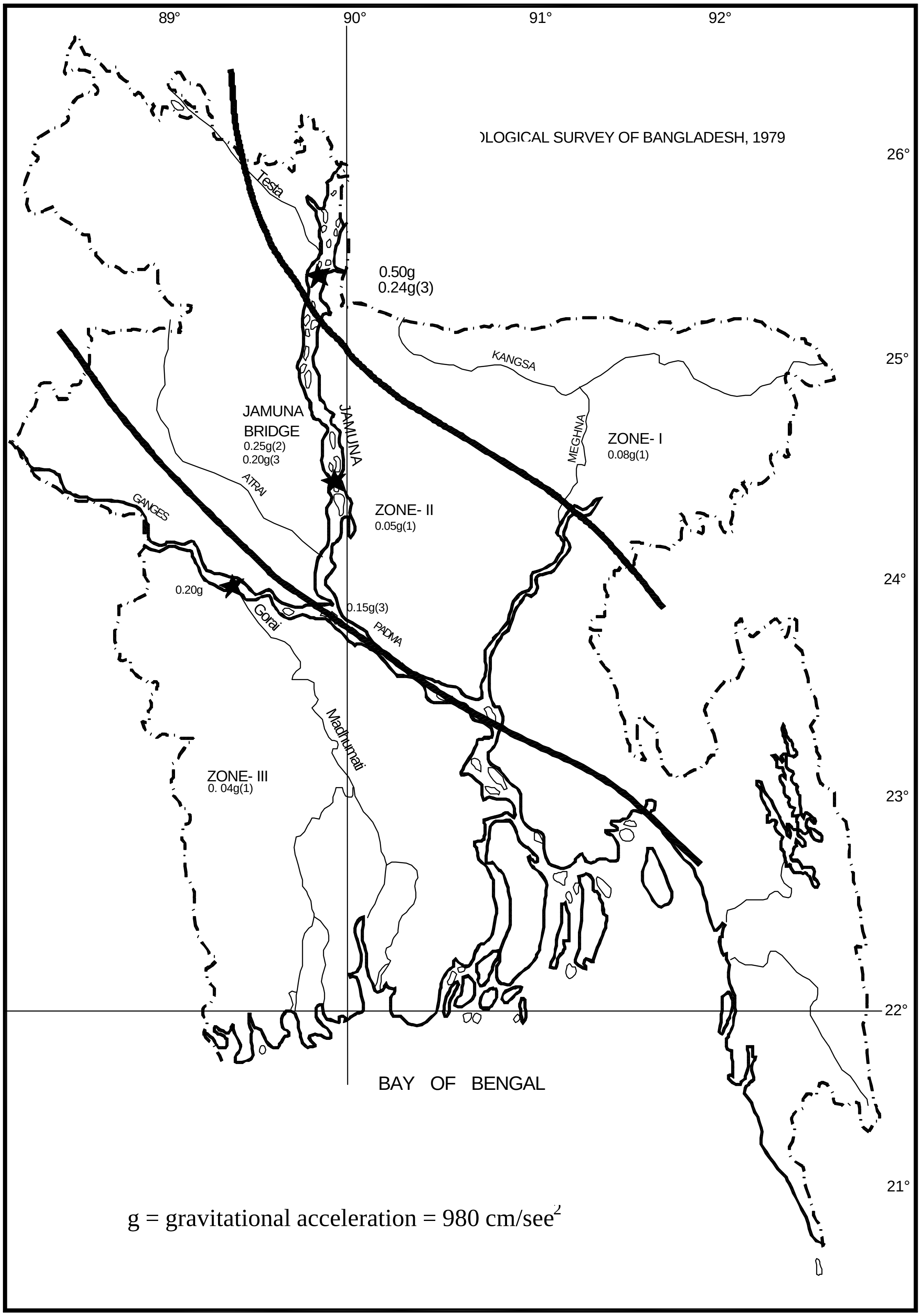


Figure 1.4: Seismic risk zoning

CHAPTER 2: SOCIAL SETTINGS

POPULATION

Bangladesh is a country of about 147,570 sq km including inland and estuarine water surfaces and has a population officially recorded at 112 million in the census of 1991 and estimated at about 131 million in 2001. With a population density of 890 people per square kilometer, Bangladesh is the most densely populated countries in the world excepting some city states.

In December 1971, the population was about 72 million and the rate of annual population growth was at least 2.5%. Since then, the country has achieved noted success in the field of population control. The number of children born per woman has declined from 6.3 in 1975 to 3.4 in 1995; the crude birth rate has declined from 49.9 persons per thousand to 25.5 persons, and the crude death rate from 19.4 persons per thousand to 8 persons.

The result of these changes has been a marked decline in the annual rate of population growth to about 2.2% between 1981 and 1991 and an estimated 1.7% in 1998. Given the widespread acceptance of family planning, the increasing adult literacy rate and the recognition by most Bangladeshis of the adverse effects of increasing population pressure, there is little doubt that this decline in population growth rate will continue in the future.

Various organizations have made population projections for Bangladesh, including the Bangladesh Planning Commission, the World Bank-BCAS Bangladesh 2020 Study and the Bangladesh Bureau of Statistics. The Medium Growth scenario population projections made by the Planning Commission and the World Bank for 2020 are almost the same, but the World Bank projections extend up to 2035 and include a breakdown into urban and rural populations. While calculating the projected population in 2040, 2045 and 2050 under the World Bank scenarios, a simplifying assumption was made by the NWMPP, the rate of population growth decline in the 2035 to 2050 period was assumed to be the average decline projected in the World Bank estimates for the 2020-25 to 2030-35 period (Table 2.1).

Table 2.1: Population Projections to Year 2050 (in million)

Year	Urban Population	Rural Population	Total	Growth Rate %	Urban as % of total
1998	25	101	126	-	20
2000	27	102	129		21
2010	43	107	150	1.46	29
2020	62	109	171	1.26	36
2025	73	108	181	1.15	40
2050	137	90	227	0.63	60

SOURCE: WARPO, Draft Development Strategy, Volume 8, Annex J: Economics, National Water Management Plan Project, Dhaka, 2000.

Currently about 80% of the population lives in rural areas having life expectancy at birth of 61 years for both males and females.

Total national population is expected to increase by more than 40% over the next 25 years, from 131 million in 2001 to 181 million in 2025 at an average growth rate of 1.36%. By 2050, a further increase of 25% may be expected, with the national total reaching 227 million.

The urban population of Bangladesh has increased rapidly in the last 25 years and is now about 27million, or 21% of the total population. Dhaka accounts for over 37% of the urban population, Chittagong 11%, and the other two cities of Khulna and Rajshahi about 7%. The remaining 45% is spread among the more than 500 other urban centers, all but 15 of which had populations under 100,000 in the 1991 Census. No indications of the likely direction of future urban growth are available till now. With the rapid growth of urban areas and industry, there is an urgent need for comprehensive land use planning for the country as a whole.

The projections set out above indicated that nearly all of the population growth over the next 25 years will be in urban areas, with numbers rising to 73 million in 2025 at a growth rate of 4.1% per year and accounting for 40% of the total. The urban population could nearly double again to 137 million by 2050, with rural in decline. Greater Dhaka could have a population of the order of 25 million by 2025 and 40 million by 2050.

This explosion of urbanization has profound implications for Bangladesh. Provision of essential water and sanitation services for such large urban populations will become, of necessity, a public health and development priority, if outbreaks of water-borne diseases are not to occur and quality of life for urban residents is not to suffer further.

THE ECONOMY

For most of the period from Independence in 1971 to the 1990s Bangladesh's economic growth was modest, at about 4% per year. Since the mid-1990s, however annual growth in Gross Domestic Product (GDP) has increased to an average rate of 5% to 6%, as a result of increased economic liberalization and other policy changes. GDP per capita has risen in dollar terms from about US$279 in the early 1990s to US$350 in 1998-99. For most of the period after 1972, the rate of economic growth has been greater than the rate of population growth but not sufficient to effect the radical economic transformation which is necessary to raise living standards to more acceptable levels. Reported agricultural growth rates have been substantially lower averaging only slightly over 2% per annum. However, rice output is considered to have increased by at least 3% per annum during the 1990s.

The agriculture's share of GDP has fallen from 50% in 1970s to 29% in 1998, whereas the service sector has grown from 38% to 54%. There has been a modest growth in the industrial sector's share, from 13% to nearly 18% of GDP.

Despite the recent acceleration in economic growth, per capita incomes and living standards are still low. Nevertheless, the improved economic performance is reflected in a recorded decline in poverty in the 1990s. Real wages are reported to have increased by about 7% per year in recent years.

A major success in the 1990s has been expansion of exports, mainly ready-made garments (although these have a high import content) and shrimps. Total merchandise exports increased from US$1.7 billion in 1991 to US$5.2 billion in 1998. A significant reduction in the debt service ratio, from 20.9% in 1991 to 9.5% in 1998, has also been achieved. On the other hand, the value of Taka has declined significantly, from Taka 35.7 to a US$ in 1991 to around Taka 54 to a US$ in August 2000 (the present value is Taka 57.8 to a US$).

The current Fifth Five Year Plan (1996-97 to 2001-02) set a target economic growth rate of 7% per year which has proved to be too optimistic. A more modest growth rate of 5.5% to 6% per year, similar to recent levels, has been assumed for National Water Management Plan planning purposes. This would yield a per capita GDP of US$480 by 2010 and US$910 by 2025.

The manufacturing sector, with increased industrial exports, is expected to be the main engine of economic growth. However, this will require continuing policies of economic liberalization, government reforms, encouragement of the private sector, and significant improvements in the provision and performance of infrastructure and utilities, all leading to a more favourable investment climate. Effective and efficient water resources management and service provision could make a significant contribution to this process of change and growth.

POVERTY

Bangladesh is amongst the poorer countries in the world, with a per capita income of US$350 (1998) and an average life expectancy of 61 years. The mortality rate of children under five years of age is one of the highest in the world, and about 38% of children suffer from moderate to severe malnutrition (BBS, 2001). The country also has a high incidence of water-borne and water-related diseases. Approximately 53% of the population above 7 years is illiterate, 59% among women and 49% among men (BBS, 2001). The, overwhelming problems of poverty, malnutrition, illiteracy, unemployment and under-employment, particularly in rural areas, are a constant and ever-present challenge to the people of Bangladesh, the Government and the development planners.

Poverty is the central socio-economic issue in Bangladesh. About 53% of the total population remains poor (classified by the upper poverty limit with an intake of less than 2,122 calories per person day), with a figure of 57% in rural areas and 35% in urban areas. Those living in absolute poverty (lower poverty line with an intake of less than 1,805 calories per person day) account for 36% of the population, with 40% in rural areas and only 14% in urban areas (Table 2.2). Comparisons with previous studies in 1988-89 and 1991-92 indicate that there has been a modest improvement in the incidence of poverty. However, these figures should not obscure the fact that the absolute numbers offer a more vivid picture of the scale of the problem - in 1993 about 6 million of the present population was classified as poor. Dhaka itself has about, three million poor people, or 30% of the city's population.

A recent World Bank Study (Bangladesh - From Counting the Poor to Making the Poor Count, September 1999) concludes that education and land ownership are the key determinants in the drive for poverty reduction and improved living standards. The Fifth Five Year Plan defined the root causes of poverty in Bangladesh as *"low economic growth, inequitable distribution of income; unequal distribution of productive assets,* *unemployment and underemployment; a high rate of population growth; a low level of human resource development; natural disaster; and limited access to public services".*

Table 2.2: Poverty Indices with the Cost of Basic Needs Method, 1983-84 to 1995-96 (Percent of population below poverty line)

	1983-84	1985-86	1988-89	1991-92	1995-96
1. Very Poor (Lower Poverty Line, Food intake of less than 1,805 calories/person/day)					
National	40.9	33.8	41.3	42.7	35.5
Rural	42.6	36.0	44.3	45.9	39.8
Urban	28	19.9	22.0	23.3	14.3
2. Poor (Upper Poverty Line, Food intake of less than 2,122 calories/person/day)					
National	58.3	51.7	57.1	58.8	53.1
Rural	59.6	53.1	59.2	61.2	56.6
Urban	50.1	42.9	43.9	44.9	35.0

SOURCE: World Bank staff estimates presented in Table 1.2 of "Bangladesh From Counting the Poor to Making the Poor Count" World Bank, April 1998.

Whilst the majority of households in rural Bangladesh live on an average income of between Taka 1,500 and 5,000 per month (with the greatest number of rural dwellers earning around Taka 3,000 per household), the hard-core and landless poor survive on much less. Rural poverty is greater among smaller individual land holdings, with the landless comprising the poorest of the poor. In demographic terms, widowed and divorced heads of households comprise 50-65% of the rural poor, and women- headed households 46-57% of the whole. A World Food Program (WFP) Impact Evaluation Study found the mean monthly income of women-headed households was less than Taka1,000 and, in some cases, as little as Taka 630 per month (WARPO, Draft Development Strategy, National Water Management Plan Project, Volume 6, Annex F: Social Analysis).

GENDER

In the household, the woman's role is to manage all aspects of domestic and family life. While men are responsible, in the main, for irrigation, women are responsible for providing water for a multiplicity of uses, such as drinking, cooking and washing, for themselves, their families and their livestock. Certain agricultural tasks within the perimeters of the homestead are specifically managed by women and require full access to water on a daily basis, namely, livestock watering, and animal husbandry (ducks, chickens, cows, etc)

Because the mobility of women and girls can often be constrained by conservative forces within the community and personal security, sanctioned access to water for women year-round is essential. Whatever effort or time constraints must be overcome, women know they are obliged by duty to provide water from any source, even though that means travelling long distances and seeking favours from neighbours.

The lack of water in the dry season is their foremost problem. Hand pumps dry up for as much as 5 months in the year and usual surface water sources like creeks and ponds tend to dry up. In that event, women must walk as far as two kilometers to fetch water and carry it home on their heads. In areas of the South West where salinity in the shallow aquifer is widespread, crises of supply are occurring regularly. Cattle are suffering and in many cases dying from the ingestion of saline water. Young children may be sent to bring potable water but mothers consider it a security risk for girls to travel so far from home unescorted. Tara pumps (Appendix A) and DTWs are few and far between and the transportation of sufficient drinking water over long distances is arduous if not impossible. Women have also increasingly expressed their frustration with the need to request permission from neighbors to have access to water during the dry season.

Poverty continues to plague women-headed households in rural areas. Of those families at the lower poverty line, 45% are headed by women, even though they constitute only 38% of the total.

In the urban environment, women are now emerging as a significant proportion of the labor force, not only on the urban informal sector but also in non-traditional labor intensive activities such as public works maintenance. According to the breakdown by gender, in 1999-2000, agricultural labor was undertaken by 54% of men and 77% of women (BBS, 2001). This startling figure may be attributed to a reassessment of women's contribution to household production and a belated recognition of the integral and economically important role women play in the rural economy. It would also appear to give tacit acknowledgement to the fact that many low-income women are engaged in informal as well as formal labor outside the household, for which they receive 'in kind' rather than cash payments and consequently, their work efforts are not recorded in conventional employment statistics.

MICRO-CREDIT

Rural poverty, as a whole, has declined in Bangladesh over the last two decades as a result of credit infusions and increased flow of remittances. However, these funds have not been sufficient to redress the gap in income levels between urban and rural populations. The rural people still lag behind the urban poor in terms of cash economy though in many ways they enjoy greater food security, bar natural disaster.

The availability of micro-credit, in particular, has spurred agricultural activity and entrepreneurial investment in small industry and contributed to a blossoming of the rural services sector. Since its inception, Grameen Bank alone has dispensed over Taka one billion in loans to the rural poor.

Micro-credit finance has prompted a boom in non-farm rural enterprise but has not necessarily created wealth. It has generated a flurry of income generating activities, however, and these are beginning to have a dramatic impact on rural livelihoods.Micro-credit programs have been criticized by some as not extending credit to the poorest of the poor and not providing large enough loans to reverse rural poverty; these criticisms are now accepted and are being more readily addressed. One of the major concerns is the issue of how low-income households will escape poverty when encumbered by borrowing rates of 20% per annum. Though this rate is lower than traditional moneylenders, evaluations show that it is still too high to permit longer-term accumulation of assets to take place.

Landless agricultural workers (ie those who own no agricultural land) and char dwellers constitute the bulk of the poorest households, and their access to credit has been a critical issue. People without secure and provable title to land in the past have seldom been eligible for formal bank loans or credit schemes. The category of those excluded includes widows and unmarried women. The absolutely landless (those without agricultural land) in the coastal and char areas are the most likely to have recourse to credit from local money lenders at the risk of losing their few and scarce main assets (including their homestead land) if they default.

EMPLOYMENT

In terms of national employment (BBS, 2001), 62.4% of the active labour force is employed in agriculture, forestry and fisheries, 7.4% in manufacturing, 12.1% in trade, hotels and restaurants, and 18.1% in the service sectors (construction, transport, trade, social, household and other services). Over the past 10 to 15 years, the proportion employed in agriculture has remained more or less unchanged, while employment in manufacturing has been unstable, and the service sectors have steadily increased. The Fifth Five-Year Plan reports that unemployment and underemployment remains stubbornly high at close to 30%, although official estimates indicate that there has been a modest downward trend in the 1990s.

In the rural sector, agriculture accounts for nearly 74% of recorded employment. According to the 1996 Agricultural Census, average farm size is only 0.68 ha. Farms less than 1 ha in size account for 41% of the total farm area and 80% of the owners. Farms between 1 and 3 ha account for 42% of the area and 18% of the owners. However, average farm size is unlikely to decline much further if the rural population begins to stabilize. Landlessness is high and rising, with about 37% of the rural population classed as functionally landless (owning less than 0.2ha). According to BBS Household Expenditure Surveys, about six million people (6% of the rural population) own no land at all and must purchase all the food they consume. Tenancy is widespread, although it has declined from 44% of the agricultural area in 1988 to about 38% at present. Most tenancies are operated on a sharecropping basis, although fixed rate tenancy has increased slightly.

In the urban areas, the service sectors predominate, accounting for 65% of employment, followed by manufacturing with 16% and agriculture with 19%. By the year 2025, urban dwellers are forecast to make up 40% of the total population, which implies significant rural-urban migration, increasing pressure on the main towns and cities, and potential for further increases in the slum population. In rural areas, the landless population will swell and look increasingly to industry and the service sector for employment opportunities.
The urban and rural poor in the future, as now, will remain the most vulnerable to loss of earnings and buying power in the event of natural disasters.

In the social context, safe potable water is a prime factor in safeguarding public health and enhancing general living standards. Considerable improvements in access were made in the 1990s, with coverage by tubewells and public water supply systems increasing in rural areas from 78% in 1991 to 96% at present. However, evidence of arsenic contamination in the shallow aquifers in 60 of the 64 Districts in the country is of great concern, particularly for poor and vulnerable communities in the rural and peri-urban areas. In terms of improved access to adequate sanitation facilities (public sewerage, septic tanks and water seal pit latrines), gains in service coverage have been disappointing. In rural areas adequate sanitation coverage has increased from 7% to about 25% at present, while urban coverage has risen little from 55% in 1991 because of the growth in poorly served areas surrounding Dhaka and other cities.

DEMAND FOR FOODGRAINS AND FISH

Demands for water arise from in-stream needs, which are more or less static, and abstraction for water supply and food production, which grow over time. The demand for the three primary food sources, rice, wheat and fish, grow as a function of income growth and elasticity of demand for the different urban and rural income groups. Projected demands for rice, wheat and fish are shown in Table 2.3 (Draft NWMP, 2000).

Table 2.3: Projected Demand for Milled Rice, Wheat and Fish
(million ton per year)

Year	Milled Rice		Wheat		Fish	
	Per Capita (kg)	Total (Mt)	Per Capita (kg)	Total (Mt)	Per Capita (kg)	Total (Mt)
2000	179	23.1	21	2.7	13.0	1.58
2010	190	28.5	24	3.6	17.5	2.62
2025	165	29.9	30	5.4	24.5	4.43

Source: Draft Development Strategy, Main Report, National Water Management Plan WARPO, 2000.

Total national rice requirements are predicted to increase by 29% between now and 2025, from about 23.1Mt to 29.9Mt. This is less than the growth in population. Consumption of rice per capita, after reaching a peak of 190kg in 2010, is expected to decline to 8% below current levels.

After 2025, total rice demand is expected to decline very gradually, due to the slow reduction in both per capita consumption and population growth rates. Wheat demand is predicted to rise steadily, with urbanization and increasing incomes, total demand doubling over the next 25 years.

Fish is a vital part of the national diet, providing over 60% of Bangladeshis' animal protein intake. Over the next 25 years, total demand for fish is predicted to rise by 164% to 4.43Mt. To meet this demand, fish production will have to increase at an average annual rate of about 4% over the next 25 years. Assuming little potential for increased inland or marine capture fisheries output and few imports, this growth in demand will have to be met by culture fisheries. Culture fisheries output therefore will need to grow by 6% to 8% per annum. Since the average annual growth rate since mid-1980s has been around 10% this is, in principle, achievable. There is abundant scope to raise aquaculture yields. Some conversion from cropland to fish ponds will take place since aquaculture is more profitable than field-scale crops like rice and wheat.

CHAPTER 3: LAND AND WATER RESOURCES

CLIMATE

The climate of Bangladesh is governed by the wet southwest monsoon that begins in June and continues to October, and the dry season that begins in November and continues through to May. The monsoon carries warm moist air that produces some of the highest rainfalls in the world over the catchments draining into Bangladesh from the Indian State of Meghalaya.

Major characteristics of the climate are provided below:

A hot spring or pre-monsoon season with moderate humidity from the end of March to May in which occur the highest temperature and evaporation rates; rainfall in this season consists occasional heavy thundershowers, sometimes with damaging hailstorms and cyclones. This season is characterized by thunderstorms and squalls, called Nor'westers, with heavy localized rainfall. Severe cyclones in the Bay of Bengal may affect the coastal areas during the pre- and post-monsoon seasons.

The hot monsoon season extends from May to September with high humidity and low solar radiation. More than 80% of the total annual rainfall of 2,320 mm occurs in this season. The monsoon, accompanied by strong winds and heavy squalls, moves in from the southwest in May or June, generally in association with tropical depressions in the Bay of Bengal and Indian Ocean. July tends to be wettest month except in the northeast where the highest rainfalls occur in June. August may experience a dry period particularly in the west, and a secondary monsoon rainfall peak may occur in September.

A cool, dry winter season from mid-October to early March, in which there is negligible rainfall, low humidity and high solar radiation. The post-monsoon transition season, October-November, is warm and humid with unstable atmospheric conditions which induce local thunderstorms and cyclones from the Bay of Bengal. The cool dry season, December-March, is sunny with infrequent, scattered rainfall that seldom exceeds five percent of the annual total. Seasons of Bangladesh are shown in Figure 3.1

The mean annual isohyetal map is provided in Figure 3.2. While the general pattern of the monsoon rainfall is well defined, the variability of monthly and annual rainfall is high. 80% dependable rainfall for the dry-season (November-May) is provided in Figure 3.3.

Five-year maximum two-day rainfall varies from more than 500 mm in northeast to less than 180 mm in northwest and about 160 mm in the southwest. Similarly, five-year maximum ten-day rainfall varies from about 1,250 mm in northeast to about 300 mm in northwest and southwest.

Ten-day minimum rainfall is a good index of drought conditions. Frequency analyses of rainfall records indicated that five-day minimum rainfall is practically zero for the seasons April-June, July-October, and November-March at all locations except for Sylhet (in Northeast) in April-June where it is only one mm (MPO, 1986). These analyses indicate that supplemental irrigation would be beneficial during the initial growth of Aus and the transplanting and flowering stage of Aman.

Cropping Season				**Months**	**Climate Season (BBS)**	**Climate Season (FAO)**	**Climate Season (NWMPP)**
Kharif I				Jun	Summer		Monsoon
	Kharif II			July	Monsoon	Monsoon	
				Aug			
				Sep			
				Oct		Post monsoon	
			Rabi dry	Nov	Winter		Early dry
		Rabi Boro		Dec		Dry season	
				Jan			
				Feb			Critical dry
Kharif I				Mar	Summer	Pre Monsoon	
				Apr			
				May			Late dry

Figure 3.1: Seasons of Bangladesh

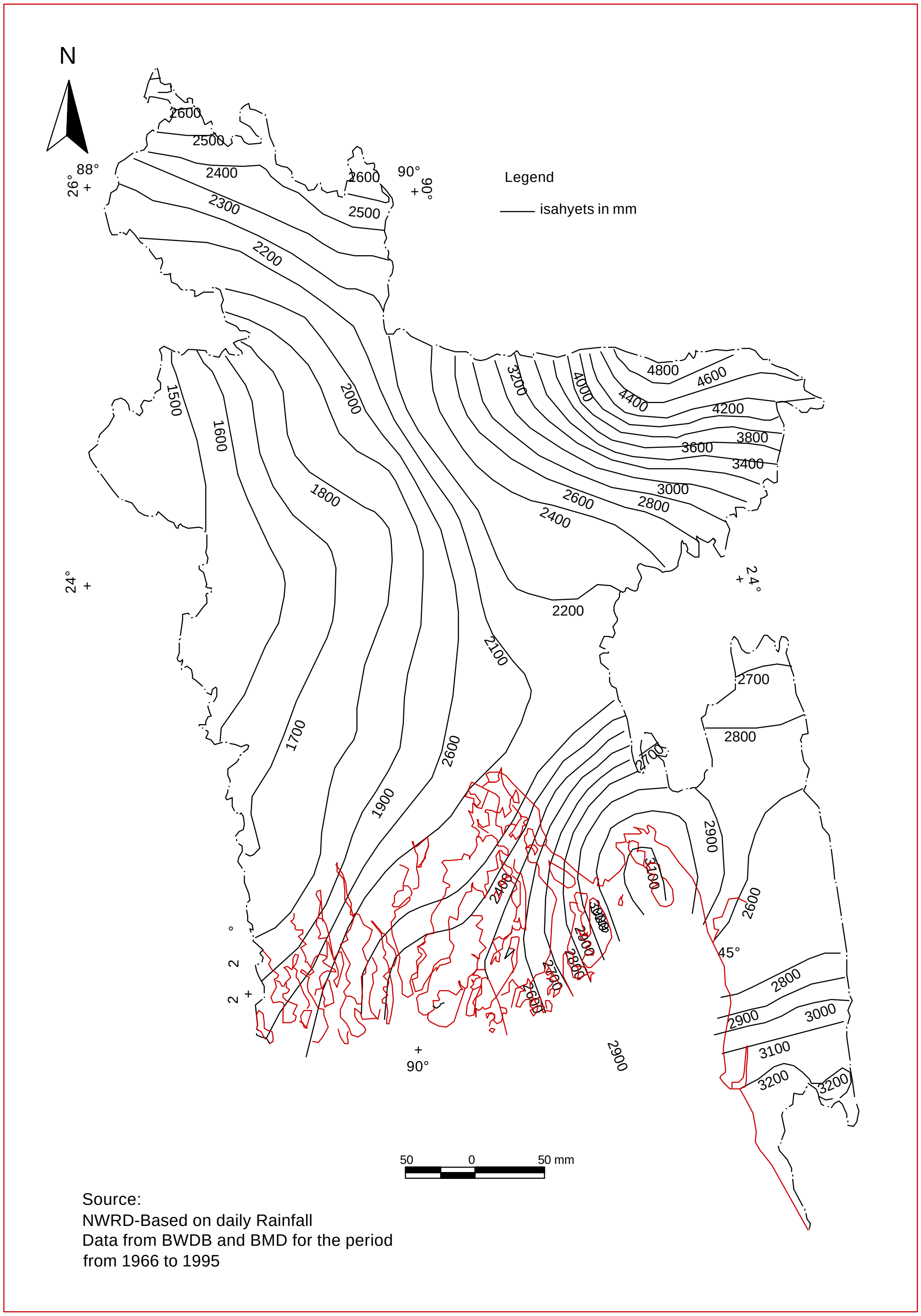
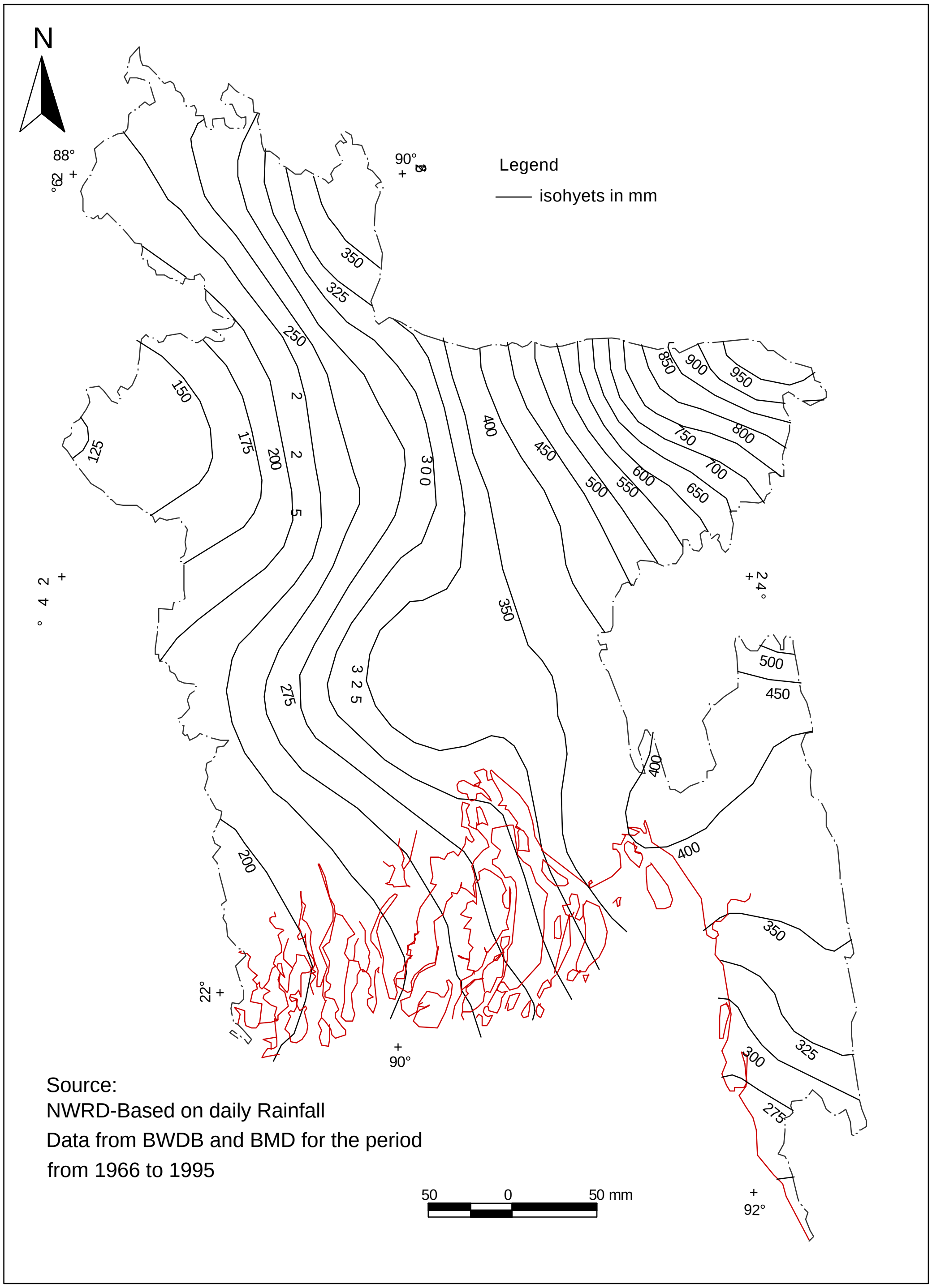


Figure 3.2: Average annual rainfall isohyets



Figufre 3.3 80% dependable dry season (Nov-May) rainfall isohyets.

Mean annual water loss by evaporation and evapotranspiration over Bangladesh is 142 billion cubic meters, equal to 43 percent of annual rainfall. Average pan evaporation rates, measured in modified US Weather Bureau Class A type pans, rise from 1.9 to 3.6 mm/day in December-February to 4.8 to 7.0 mm/day in April-May and fall to 3.7 to 4.4 mm/day in the monsoon season. Mean annual lake evaporation ranges from about 800 mm in Dhaka to more than 1,300 mm in the west central part of Bangladesh.

Temperatures in Bangladesh range from less than 5^{o} C to more than 43^{o} C. They peak in April-May but exceed 43^{o} C only in the western part of the northwest region. Extreme minimum temperatures in January-February reach about 2^{o} C in certain areas in northeast but remain around 5^{o}C or more elsewhere.

The critical aspects of climate in relation to crops and cropping pattern are:

- the occurrence and reliability of the pre-monsoon rains and
- the onset of the monsoon; the reliability, amount, and distribution of the end of monsoon rains;
- occurrence of storms and cyclones that damage standing crops; and
- the rise, duration and recession of floods associated with the monsoon rains.

LAND

Land Ownership

Bangladesh supports roughly 16 persons per hectare of arable land at the moment indicating an already intensive rate of cultivation and this will rise to approximately 22 persons per hectare (about 40% increase) as a result of increasing population in twenty years time.

Trends indicate that smallholder farmers are becoming increasingly productive as a result of enhanced access to irrigation. The proportion of land holdings below 1 acre (0.4 ha) rose from 24% of all farm holdings in 1960 to 40% in 1983-84, and 48% in 1996. In the 1983-84 Census, 86% of smallholders owned and operated their own holdings of 0.01 to 0.04 acres while 60% of holders owned and operated land between 0.5 and 0.99 of an acre (BBS, 1986). In 1983-84, roughly 70% of total farm households operated as small farming units covering only 24% of the total farm area, roughly one third of the total land cultivated. According to that Census data, fewer than one third of the farm households (medium and large farm holders) at that time operated more than two thirds of the farm area.

BBS classifies farm holdings sizes into three categories: small farm holdings (0.05 to 2.49 acres), medium farm holdings (2.54 to 7.49 acres) and large farm holdings (7.50 to 25 acres and above). For data presentation, BBS subdivided each of these categories into following sizes:

Small farm holdings:	0.05-0.49 acres

	0.05-0.99
	1.00-1.49
	1.50-2.49
Medium farm holdings	2.50-4.99
	5.00-7.49
Large farm holdings	7.50-9.99
	10.00-14.99
	15-24.99
	25.00 acres and above

According to 1996 Census, 76% of landowners holding 0.05 to 0.49 acres were "owner-operator' agricultural households, while the smallest category was no longer published and could not be compared. Medium sized landowners (those with 1.5 to 7.5 acres) control a higher proportion of the total operated area (60%) than any other group. Smallholders, (those own between 0.05 and 0.49 acre) own only 4.3% of the total operated area, though they constitute the majority of the farmers (BBS, 1998).

The discrepancy between small and large holders may point to the need for dual tier planning – one for small subsistence farmers who are notably highly efficient farmers, though under-capitalized, and the other for larger-scale surplus farm producers.

The 1996 Agricultural Census data showed that the number of landless families in rural areas is increasing. Since 1983-84, the proportion of completely landless families has risen from 8% to 12% and the number of functionally landless (those with less than 0.5 acres) has increased from 28% to 37% of the total, signifying a marked growth in the number of non-agricultural households in the rural areas. Women-headed households, usually regarded as amongst the most vulnerable and 'poorest of the poor' since they are compelled to bear the burden of poverty in the rural environment without the security of family networks or asset cushions, constitute 25% of this landless category. Unless rural employment creation programs are directed towards them, these women agriculturists will remain food insecure, asset poor, and entrenched in the lowest socio-economic category (BBS, 1998).

SHARECROPPING ARRANGEMENTS

Prior to the Land Reform Act of 1984, access to land through tenancy arrangements was very limited (FFYP 1998). Under that legislation, it became law that sharecroppers should receive two thirds of the crop, landlords one third, provided that the tenant provided all inputs. Unfortunately, this law is not widely observed.

An analysis of results obtained from the Agricultural Census of 1996 reveals the diverse nature of the tenancy and lease arrangements and gives a broad picture of the economies of share-cropping. Although the law indicates that sharecropping should he based on the above principle, the Census indicates that the number of farmers who pay one third of their total produce to landlords is relatively small in terms of both total holdings and total sharecropped acreage (4.38% and 4.11% respectively). The majority of sharecroppers divide production on an equal share basis (84.5% of total sharecropped holdings or 81.2% of total sharecropped acreage). 25.6% of the total area of operated land is leased, and 51.9% of this leased land is sharecropped.

An almost equivalent number of landholders share land 'on other terms' which, in the Agricultural Census, are undefined but allow land to be rented out without transfer of the right of security of tenure to the tenant. (Under the Land Reform Act, security of tenure for a tenant is achieved after five years of cultivations).

Of the total number of share-cropping farmers, roughly a quarter rent in land on 'fixed amount' cash contracts. Approximately double this number of holdings are mortgaged out to third parties (often mahajans or local money lenders) in return for cash loans usually during the lean season (ie during or after the flood season), or by absentee landlords. The contract taken in return for cash is the most precarious for a small landholder since his rights to the land may be forfeited if the cash borrowed is not repaid. For the absentee landlord, such contracts are convenient and short term, so as to avoid losing land to sharecroppers who acquire usufruct rights if they cultivate land over a longer period. The high number of holdings held on this basis indicates the number of financially vulnerable smallholders at risk of land loss under the mortgage/lending system.

Sharecropping and Tenancy Systems-

The degree to which agricultural production may be constrained by share-cropping systems has been increasingly noted in policy documents and reviews by donors. Recent research into land tenure systems in Bangladesh suggests that there may be a key relationship between lack of productivity and the prevalence of absentee landlords. In areas where absentee landlords predominate, sharecroppers are obliged to provide inputs. To do so, they must take risks to obtain credit (often mortgaging land for cash). At harvest, they must sell crops at a good price to make profits and in many cases, just to break even. In engaging in this venture, they risk losing their land if the crop is affected by floods, pest attack or drought. It would appear that the potential for not increasing cropping intensity and reaping the full benefits from the land are highest where sharecroppers are in the majority. Where landlords are in residence, evaluations show that there tends to be more sharing of the costs of inputs between sharecroppers and landlords, less risk for the share-cropper (in that there is less obligation for the poorer to take credit) and more equitable distribution of crop share.

The following types of tenancy systems have been identified to be followed throughout the country by WARPO (WARPO, Draft Development Strategy, NWMPP, 2000).

1. The sharecropper pays for all inputs. At harvest, he pays one sixth of the total crop to the block manager for irrigation water. The rest of the crop is shared equally between sharecropper and landowner, ie approx 41.5% of harvest to each.
2. The sharecropper pays the inputs. At harvest, he gives 25% of the crop to the LLP owner and the rest is equally divided between sharecropper and landowner, ie 37.5% to each.
3. The sharecropper provides all the inputs (seeds, fertiliser, power tiller or ox, irrigation facilities and pesticides). At harvest, the landowner receives one third of the crop.
4. The sharecropper provides all the inputs. At harvest, he gives one quarter of the crop to the pump owner for irrigation, one quarter to the landowner and one half is retained by the sharecropper.

5. The landowner provides some input (seedlings, fertiliser, water for irrigation or any other materials for cultivations At harvest, the sharecropper and the landowner share the harvest equally (50/50).
6. The landowner and the sharecropper share costs of specific inputs Cu-dgation and seeds) and at harvest, they share yields equally.
7. With non-irrigated crops (ie pulses) where no inputs are paid by the landowner, a system whereby a landlord is paid a flxed amount in kind (or paddy) of 500 kg/ha is in place in parts of the South West. This shows a rapprochement between in-kind systems and crop-sharing to the benefit of the sharecropper if productivity is increased.
8. The more general system for share-cropping of non-irrigated crops is shown to be 50/50 sharing between sharecropper and landowner. Increasingly, though, a sharecropper can also pay Taka 5000 to a landlord to rent in 100 decimals of land (1 acre or 0.4 ha) for the period of one year, as a purely cash-based tenancy contract. In this case, the landowner will not receive any portion of the crop.

Land Utilization

Bangladesh has an area of 14.8 million hectares of which 8.80 (59%) million hectares are cultivable and 8.14 million hectares (55%) are cultivated (BBS,2001). The difference between cultivable and cultivated lands is 0.35 million hectares of current fallow and 0.31 million hectares of culturable waste (BBS, 2001). Bangladesh's population of 131 million (2001) lives mainly on its floodplains. Rural population densities exceed 1,000 persons per sq km of cultivable land over wide areas.

At present almost all of the arable lands are cultivated, but only 2.99 million hectares (34%) is single cropped, 4.15 million hectares (47.0%) double cropped and 1.00 million hectares (11%) triple cropped, and the remaining 0.66 (8%) million hectares is cultivable waste and current fallow. Since 1986-87, there has been a gradual increase in the cropping intensity from 1.50 to currently 1.75 (BBS, 2001). This implies that there is potential for cultivating additional crops, particularly in the dry season (November to April), through the provision of irrigation. Irrigation presently covers about 43.0% of the cultivated area (BBS, 2001) but could be expanded to cover additional areas of the country by choosing proper technology.

Land use data, as given by BBS (2001), are provided in Figure 3.4.

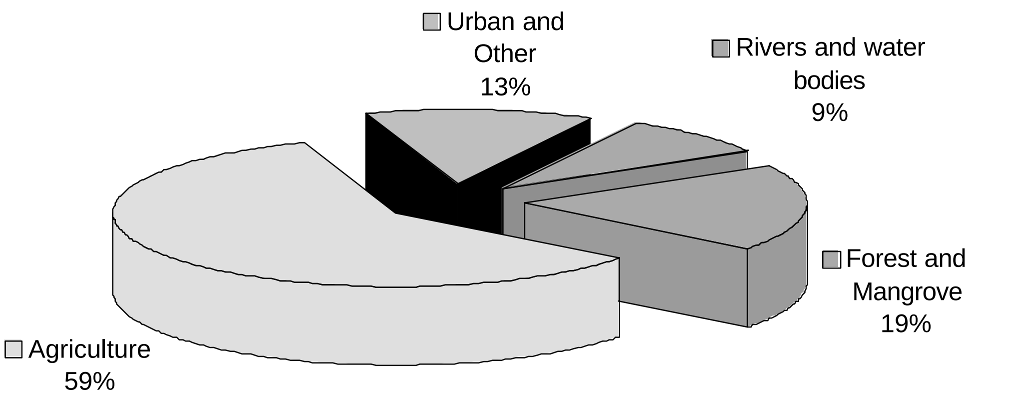


Figure 3.4 Land Utilization

Land Classification based on Flood Depth

The land resources of Bangladesh have been classified into five land types on the basis of flood depth (Table 3.1)

Table 3.1: Land Types Defined On The Basis Of Flood Depth

Land Types	Descriptions	Flood Depth	Nature of Flooding and Land Use in Wet Season
F0	High land	Not Flooded	Intermittent flooding up to 30 cm, land suitable for HYV Rice in wet season
F1	Medium high	30-90 cm	Seasonal, land suitable for local varieties of Aus and T Aman in monsoon
F2	Medium low	90-180 cm	Seasonal, land suitable for B Aman in wet season.
F3	Low	Over 180 cm	Seasonal (<9 months), land on which B Aman can be grown in wet season.
F4	Low/ very low	Over 180 cm	Seasonal (> 9 months) or perennial, flooding does not permit rice in wet season.

NOTE: Please refer to Figure 3.5 for annual cropping for cereals.

Charland

A char (bar, shoal) is defined as a large vegetated island (island char) or a large vegetated area within a river that is attached to the riverbank or flood plain. The chars are formed due to deposition of sediments. The source of the sediments is upper catchments and riverbank erosion. The braiding takes place in rivers which transport predominantly sand, such rivers are wide and relatively shallow and chars are common in such rivers.

More than 4.3 million people live in the chars of the principal rivers. The economic lives of char people are tied up with the nature and changing environment and depend on their ability to move constantly and yet survive. In the char areas, flooding of char lands including houses and erosion of the char itself make the dwellers vulnerable to floods, which often result in the shifting of population. According to FAP studies, flooding is an annual event in the Jamuna and Ganges char areas.

Further discussion on charland is provided in Appendix C

CROPS

Major Crops

With a climate favourable for the cultivation of a wide variety of crops, MPO (1986) identified 32 crops which cover 96 percent of the total cropped area and grouped them into 16 categories (8 rice and 8 others) based on their importance and similarity in terms of input requirements and water regime. The 16 crops are: Broadcast Aus and Aman rice (B. Aus, B. Aman), high yielding varieties of summer rice (HYV Aus, Aman), winter rice (HYV Boro), high yielding wheat (HYV wheat), local varieties of transplanted rice (L.T. Aman, L.T. Boro), potato, jute, sugarcane, pulses, oilseeds, spice, minor crops, and orchards.

Rice is the main crop grown in Bangladesh, covering about 73% of the cropped area. There are three rice growing seasons in a year – Aus (Kharif I, harvested in the monsoon), Aman (Kharif II, grown in the monsoon but harvested after) and Boro (Rabi, grown in the dry season).

Cereals crop calendar is provided in Figure 3.5. Areas under major crops and different varieties of rice are shown in Figure 3.6.

Wheat accounts for only 3 percent of the volume of annual foodgrain harvest at the present time, but its potential for growth is felt to be very large.

Jute is the most important commercial crop of the country. Jute is grown from late February to September. Bangladesh once had almost a monopoly on production of jute, but now its contribution to the total world jute production is much reduced.

Other important commercial crops are sugarcane, tobacco, tea and cotton.

Moisture Regime for Major Crops

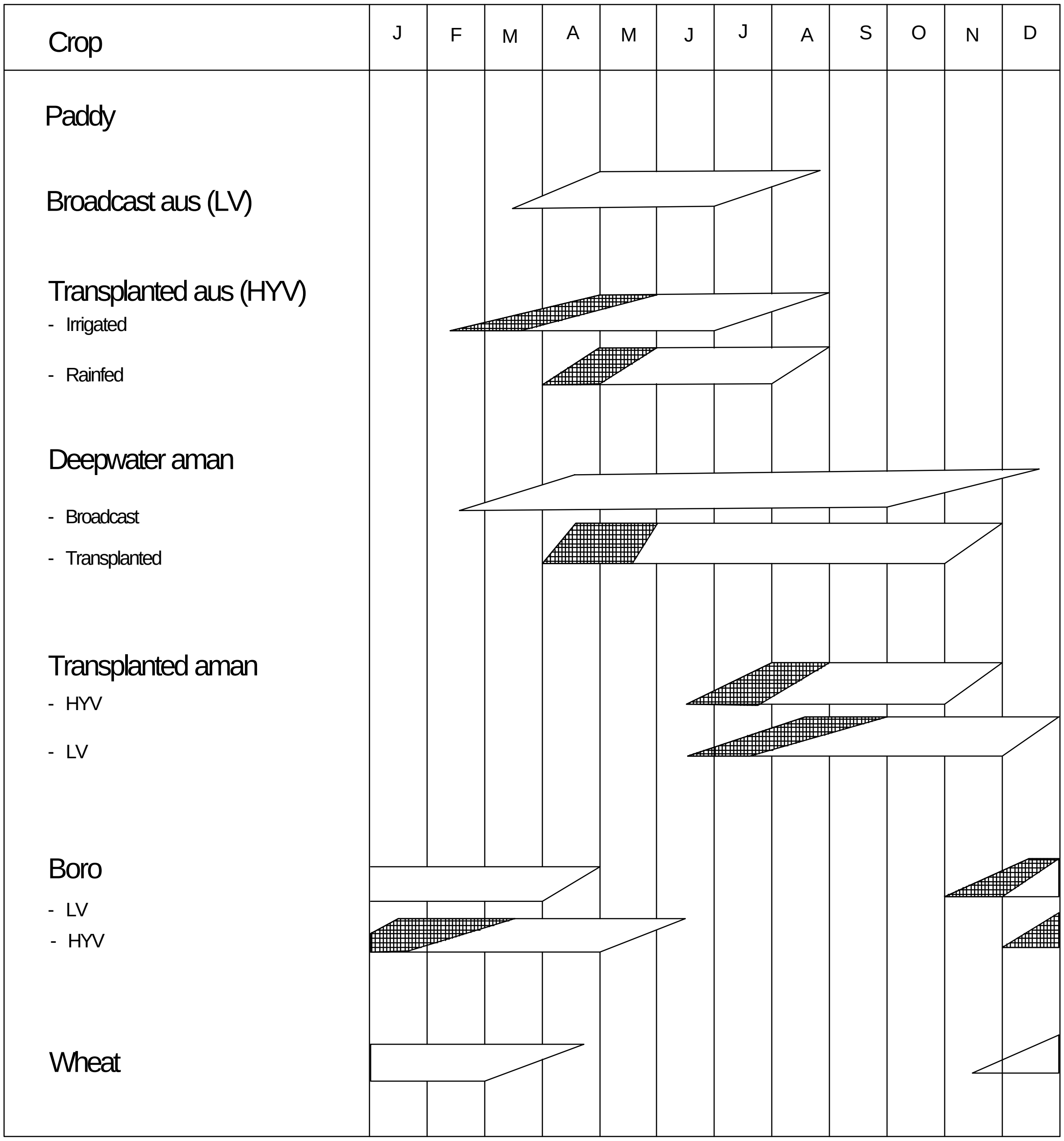
The main factors determining cropping patterns and crop yields on the floodplains of Bangladesh are the monsoon climate, soil properties, the depth, timing and duration of floods, salinity (in coastal areas), the presence or absence of irrigation, access to markets and farm management levels. Local variations in soils, in the timing and duration of seasonal flooding and in the provision of irrigation often lead to complex cropping patterns. Crop yields and production vary from year to year depending on the sufficiency of pre-monsoon and post-monsoon rainfall for non-irrigated crops, the incidence of untimely or high floods and, for dryland rabi crops, the time of recession of floodwater from the land and the incidence of rainfall during the dry season.

For Bangladesh agriculture, flooding is a very important element of the annual cycle. The Bengali language distinguishes between the normal beneficial floods of the rainy season, which are termed *Barsha*, and the harmful floods of abnormal depth and timing, which are termed *Bonna*. The *Barsha*, which occurs more frequently than

B*onna*, is not considered to be a hazard at all, but rather a necessity for survival. For Bangladesh's rice farmers, too little water is a greater threat than too much.

The relation between the cropping calendar and the seasonal flooding is documented in Figure 3.7. In different seasons of the year different varieties of rice dominate which are adapted to the hydrological conditions of the respective season. The cropping calendar is not only perfectly adapted to the different seasons but also to the different land levels.

The depth and nature of flooding determine the crops that can be grown in an area during the monsoon season. The permeability or internal drainage of the soil, the moisture available and soil moisture storage capacity largely determine which crops can be grown during the pre-monsoon and Rabi seasons. For instance, Broadcast Aus is mainly grown
in high to medium high land (F0 and Fl) that are not flooded deeper than 90 cm before harvesting in July/August.

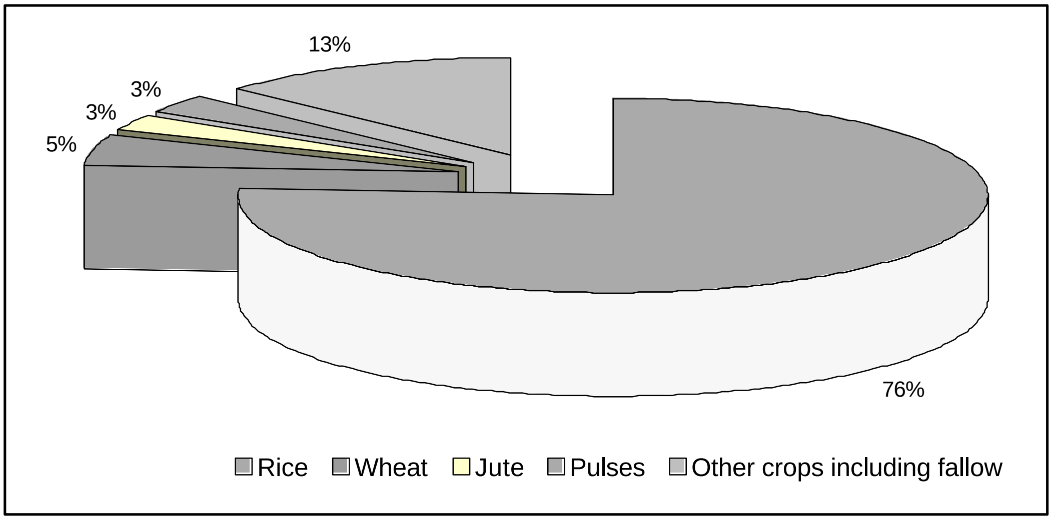


N.B. LV = local variety, HYV = high yielding variety.

Range of sowing dates   Seedbed period   Range of harvesting dates

Broadcast aus, deepwater aman and transplanted aman are mainly grown without irrigation
50 percent of wheat and over 90 percent of boro are grown with irrigation.

Figure 3.5: Cereals crop calendar



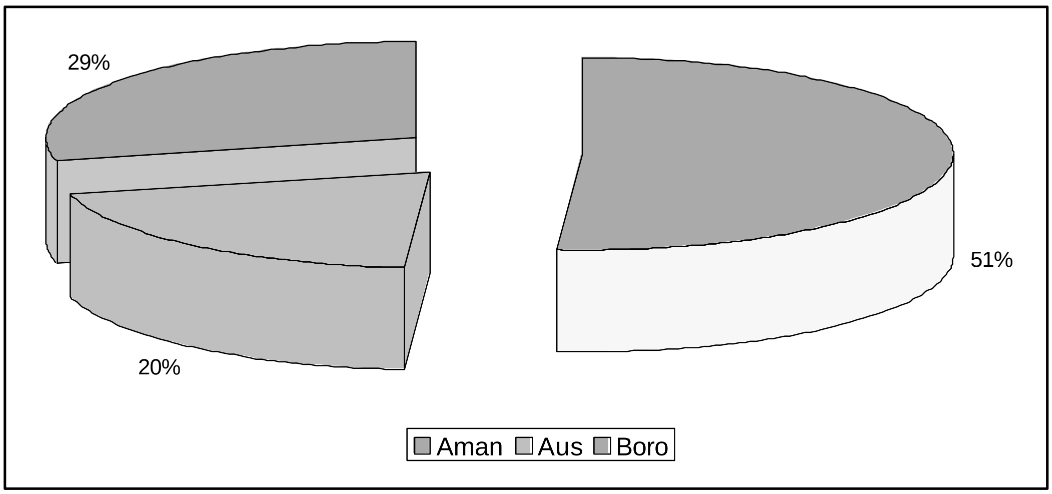


Figure 3.6: Areas under Major Crops (BBS, 2001)

Transplanted Aman is planted in poorly drained high to medium high lands (F0 and Fl) where flooding depth does not exceed 30 cm at the time of transplanting during July/August/September. Broadcast Aman is the main crop in medium low to low land (F2 and F3) where flooding is as high as 180 cm during the period of flood. Boro is planted in poorly drained soil or where irrigation can be provided and where no flooding will occur before harvesting of the crop.

Rabi crops are restricted to areas where either residual soil moisture is adequate or irrigation is available. The number of crops grown during the Rabi season is larger than in the Kharif. Prominent crops are Boro rice, wheat, mustard, groundnut, pulses, spices, sugarcane, vegetables, melons, potato, and millet.

Dry land Kharif crops and Rabi crops are planted in areas where soil moisture is adequate, drainage is good and flooding does not occur before the harvest of the crop. The perennial and annual crops, like orchards and sugarcane, are mainly grown on high lands (F0).

Rice, pulses, oilseed, spices and vegetable crops are commonly grown in all areas. These crops have their specific position in the annual cropping systems in the different land types. Of these crops, rice is grown in all three crop seasons though not necessarily in the same area. Jute is grown under conditions where broadcast Aus is grown and thus competes with broadcast Aus for land.

Soil salinity reduces the yields of transplanted aman in coastal areas such as Khulna and parts of Barisal, Patuakhali, Noakhali and Chittagong. It also limits the area planted to aus and dry land Rabi crops in these areas.

Table 3.2 shows the main cereal cropping patterns by depth of flooding and land types (under normal flooding) and the changes that can occur with irrigation. The impact of flood control and drainage is to reduce the flooding depth and to make it possible to grow higher yielding cropping patterns.

FUTURE RICE PRODUCTION

Introduction

The data for rice production show that the area and production of all local rice varieties (Aus, Aman and Boro) are decreasing but yields are increasing. However, area and production of all HYV rice varieties are increasing, but the yields are decreasing. Fibres and tobacco area and production are decreasing. Other cereals, sugarcane, potato, oilseeds, pulses, vegetables and fruits areas and production are increasing. The area and production of spices show few changes.

Future production will depend on the rate at which yields grow (WARPO, Draft Development Strategy, NWMP, 2000). Based on present rates, changes in yield within varieties over the next 25 years are likely to be small, as shown in Table 3.3.

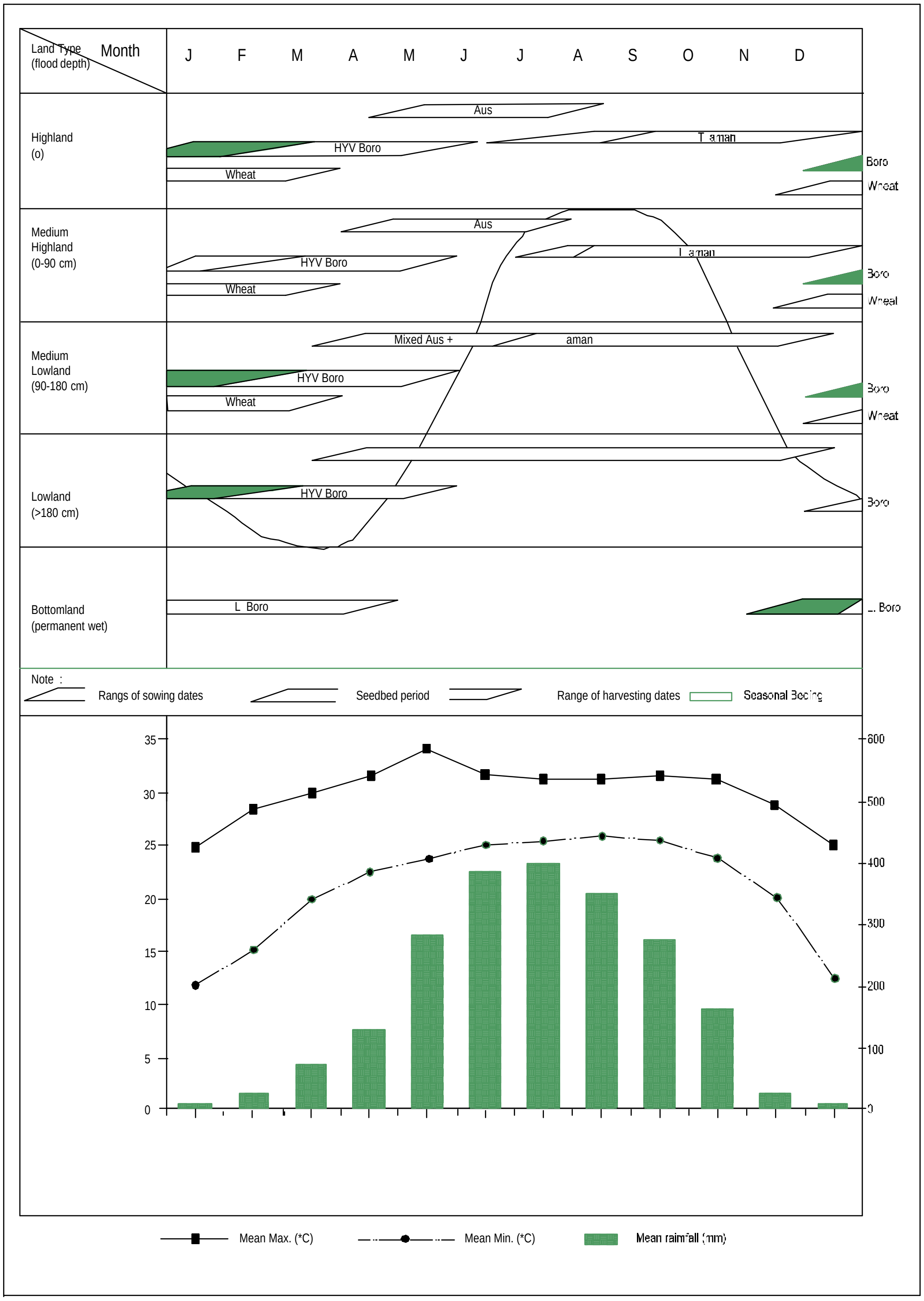


Figure 3.7 Rice and wheat crop calendar in relation to seasonal flooding, rainfall and temperature

Table 3.2 Main Cereal Cropping Patterns

Land Type	Kharif I	Kharif II	Rabi
NON IRRIGATED			
F0	B Aus	-	Wheat
	HYV Aus	LV T Aman	
F1	B Aus	LV T Aman	-
	HYV T Aus	LV T Aman	-
F2	B Aus	Mixed with B Aman	Wheat
	B Aus	Mixed with B Aman	-
F3	-	B. Aman	-
F4	-	-	LV Boro
IRRIGATED			
F0	-	HYV T Aman	Wheat
		HY T Aman	HYV Boro
F1	-	LV T Aman	Wheat
	-	LV T Aman	HYV Boo
F2	-	Transplanted Deep Water Aman	HYV Boro
F3	-	-	HYV Boro
F4	-	-	LV Boro

Abbreviations:
B: broadcast, T: transplanted, LV: local variety, HYV: high yielding variety,

Table 3.3 Yield Changes at Present Rates Over 25 Years

Yield (Tons/ha)	Yield in 2050/yield in 2000 (%)
Broadcast Aman	89
Local aman	94
HYV Aman	106
Local Aus	87
HYV Aus	87
Local boro	105
HYV Boro	107

Source: Draft Development Strategy, National Water Management Plan, WARPO,
Volume 4, Annex C, 2000.

The main opportunity for raising yields appears to be in HYV Boro, provided water for irrigation can be assured. Boro is a relatively risk-free crop, so farmers can afford to invest in more expensive seeds, fertilizers and other inputs.

Monsoon Rice Areas
Changes in the area of Aman varieties of rice are shown in Figure 3.8 and Table 3.4. Over the period of record, the total area of Aman rice first rose, then gradually declined. The total Aman rice area rose by 4% over the period 1975-85, and has declined by 7% since then, with an overall average rate of decline of 16,000 ha/yr. Within this area, local varieties have been replaced by HVY, which now is grown in 44% of the area, although the rate of substitution appears to have slowed in recent

years. This substitution can continue until all land suitable for HYV production is used up.

More such land could be created in principle by FCD works, although past experience showed the switch to HYV does not appear to be correlated with the increase in FCD. According to FAO, medium highlands, where it grows best, is about 60% of agricultural land, and this sets an upper limit to the area of HYV.

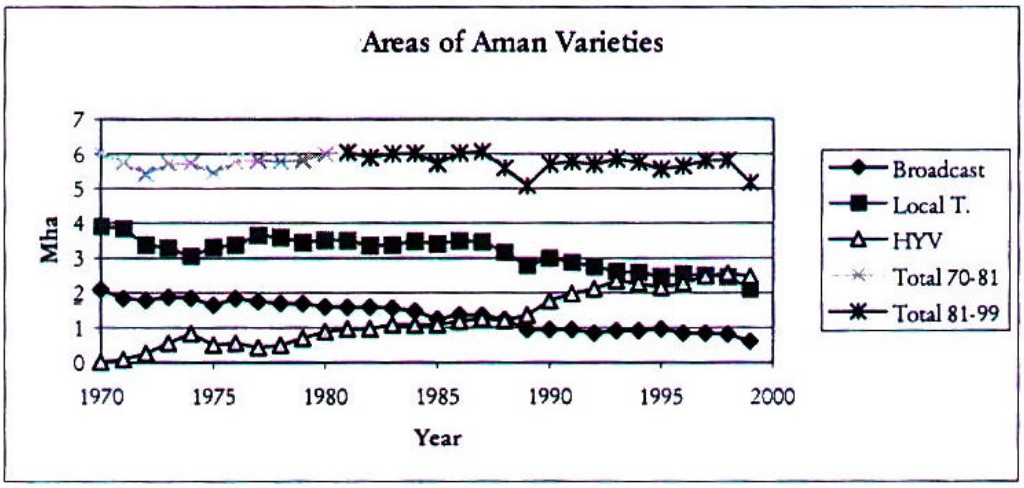


Figure 3.8: Trends in Areas under Aman (Source: WARPO, DDS, NWMPP, 2000

The actual limit may well be less than this. At present growth rate, HYV Aman would reach about 60% of total Aman area by 2005.

Table 3.4: Changes in Area of Monsoon Rice

Crop	Period	Average Rate of Change (ha/year)
Total Monsoon Rice	1970-81	+21,900
	1981-99	-24,000
Broadcast Aman	1970-99	-46,100
Local Transplanted Aman	1970-99	-45,500
HYV Aman	1970-99	+86,200

Source: WARPO, DDS, NWMPP, 2000

Dry Season Rice Areas

Changes in the area of Aus and Boro varieties of rice are shown in Figure 3.9 and Table 3.5. Boro has expanded rapidly over the last 20 years, but as its rate of growth has been almost exactly matched by the decline in local Aus, there has been little change in the combined area. It has been assumed that if Aus is produced followed by Boro, there will not be any Aman.

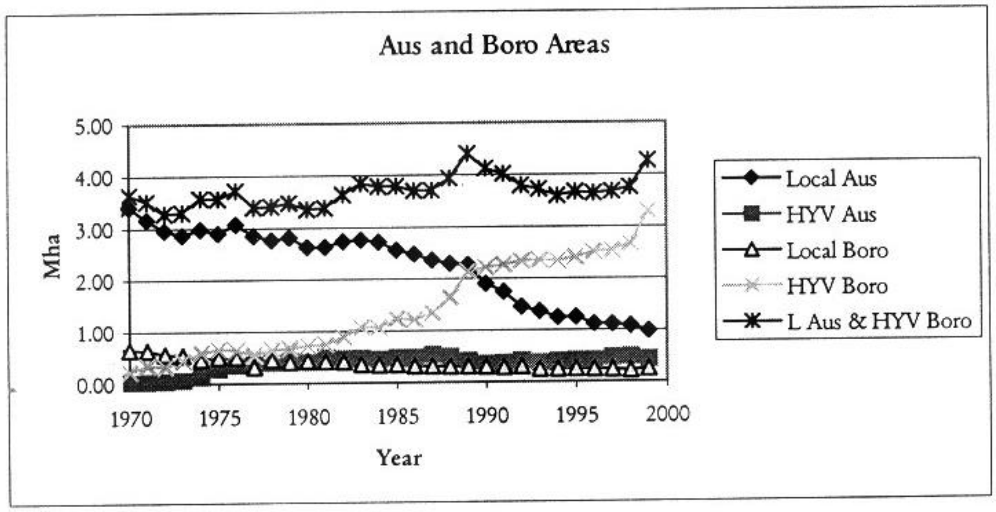


Figure 3.9: Trends in Areas under Aus and Boro

However, this substitution will not be possible for more than another six years, as by then the local Aus area will be very small. At this point, Boro will have to expand either at the expense of HYV Aus, or into new areas. There is little comparative advantage of HYV boro over HYV Aus, so the latter scenario is more likely happen. It has been observed that yields of HYV Boro have been gradually increasing, while those of HYV Aus have been declining, so ultimately Boro is likely to displace Aus except where the two can be grown in sequence.

By contrast, HYV Aus has shown little growth since the mid-70s probably due to the risk from tornado and flash floods at harvest time.

Table 3.5: Changes in Area of Dry Season Rice

Crop	Period	Average Rate of Change (ha/year)
Total dry season rice	1969-99	+17,800
Local Aus plus HYV Boro	1969-99	+18,500
Local Aus	1969-99	-77,800
HYV Aus	1969-99	+12,700
Local Boro	1969-99	-13,400
HYV Boro	1969-99	+96,300

Source: WARPO, DDS, NWMPP, 2000

Total Rice Areas

The combination of the two above trends have led to the pattern of growth of total rice areas as shown in figure 3.10.

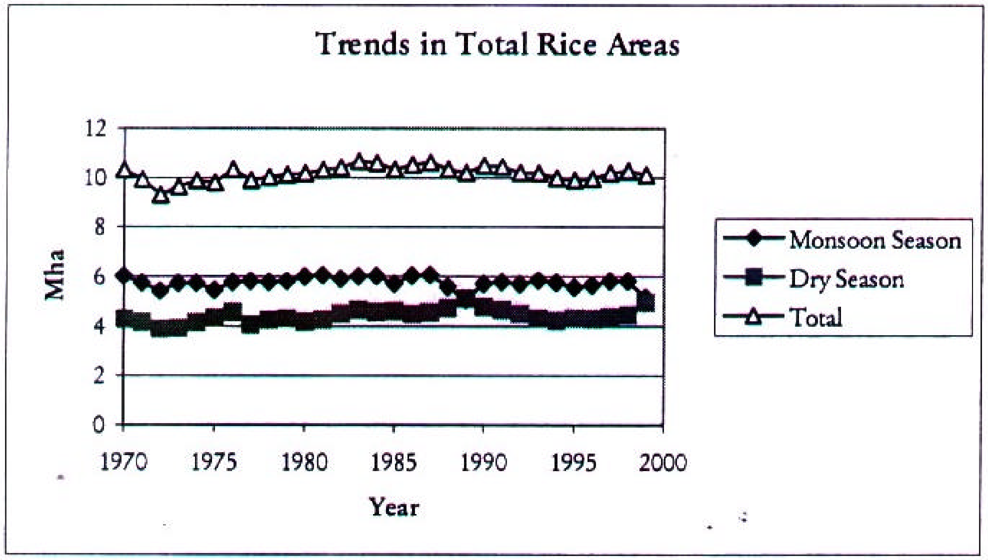


Figure 3.10: Trends in Total Rice Areas

From 1970 to 1983, the total area grew at the rate of 53,300 ha/yr. Since then it has been declining at the rate of 35,900 ha/yr. The area in the dry season is gradually overtaking that in the monsoon.

The difference in dry season and monsoon yields is such that, while Aman production is increasing at the rate of 0.105 Mt/yr, dry season production is increasing at twice this rate, or 0.211 Mt/yr. The fitted lines crossed over the 1992, see Figure 3.11.

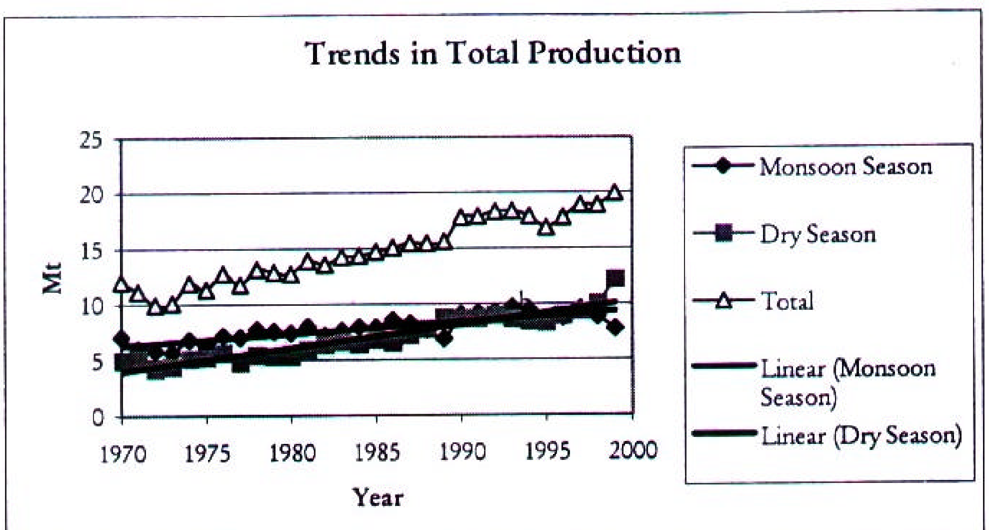


Figure 3.11: Comparison between Monsoon and Dry Season Rice Production

Wheat and Other Cereal Areas

Changes in the area of other cereals, the great majority of which is wheat, are shown in Figure 3.12. Areas of wheat expanded rapidly over 16 years from 1970, but from then up until 1998 its rate of expansion was very slow, at 0.011 Mha/yr. However, in 1998 and 1999 there were sudden increases.

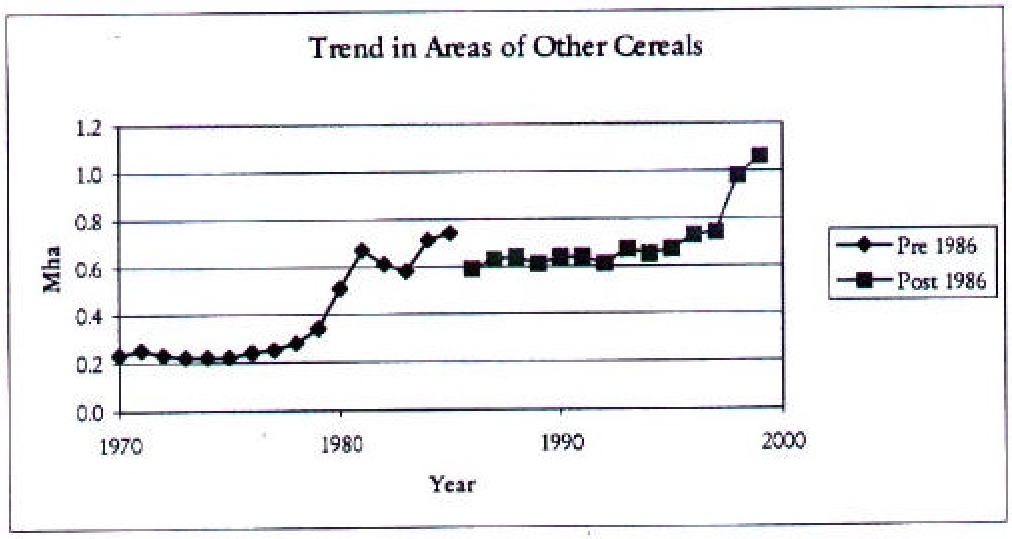


Figure 3.12: Trends Area of Other Cereals

Impact of 1998 Flood on Crop Production
The impact of the 1998 flood is clearly shown in the rice and other cereals production. As a result of these floods, production of Aman was 1.83 Mt less than might have been expected from trends up to the year before. However, dry season rice production was 2.43 Mt more, and other cereal production was up by 0.46 Mt, a net gain over the year of 1.06 Mt of foodgrains. This illustrates very clearly that, at least in the short term, monsoon production could be reduced substantially without jeopardizing total foodgrain production. Farmers appear to have the choice of reducing their exposure to risk in the monsoon, and produce fish rather than rice, where this is a viable alternative.

Projections on Rice Areas
Crops compete with each other for agricultural land, and this has to be taken into account when making projections of areas. The following assumptions have been made by WARPO (WARPO, Draft Development Strategy, Volume 4, NWMP, 2000) made about future crop areas.

- Maximum rice area: This area will continue to decline gradually at the present rate.
- HYV Aman: Expansion will continue at present rates until 50% of the maximum rice area is reached. Thereafter, it will continue to cover 50% of the declining maximum rice area.
- Local Transplanted Aman and Broadcast Aman: These will continue to decline at the present rate until the maximum HYV Aman area is reached, when 37% will be LT Aman and the balance Broadcast Aman. Thereafter they will cover the same proportion of the declining maximum rice area.
- Local Aus: The area will continue to decline until around 2006, by which time the area will be negligible.
- HYV Aus: The area will continue to decline slowly until squeezed out by HYV Boro sometime between 2015 and 2020.

- HYV Boro: The rapid expansion will continue until the maximum rice area is reached, and will then decline at the same rate as the maximum rice areas.
- Local Boro: The area will continue to decline slowly until squeezed out by HYV Boro and HYV Aus sometime between 2015 and 2020.
- By the year 2025, only HYV Boro will be grown in the dry season.

RETURNS FROM FCD INTERVENTIONS

Flood control and drainage can increase crop production in two ways. Inland FCD, by reducing flood depths and improving drainage, enables low-yielding deepwater Aman (B Aman) to be replaced by local transplanted Aman and HYV Transplanted Aman. It has also facilitated conversion of LT Aman to HYV Aman. Net benefits due FCD interventions may, however, be reduced by increased flooding in unprotected areas. In the coastal zone the exclusion of tidal flooding by the coastal embankments and the resulting reduction in salinity has resulted in both improved Aman yields and expansion of Rabi cropping (pulses and oilseeds) based on residual soil moisture, Reduced salinity has enabled local Aman varieties to be replaced by HYVs. Increased drainage congestion has, however, cancelled some of the benefits.

However, major uncertainties exist concerning the overall net effect of FCD (including the impact in adjacent areas) on Aman yields and production. Moreover within the FCD polders, low areas are never benefited (before and after development of facilities) because these remain submerged by the runoff generated during monsoon which could not be drained due to high water levels in rivers. Most of these FCD facilities, except very few large scale projects, are not provided with pump drainage. Pump drainage was found to be very expensive. The high lands which used to utilize the flood water on low and medium lands are adversely affected by the FCD development. Only the medium high lands are normally benefited by the FCD facilities. FCD projects were found to cause localized waterlogging due absence of drainage outlets. Large number of drainage outlets and flushing inlets are required for FCD embankments to be free from adverse impacts. Several years of project operation is necessary before locations of many these outlets/inlets could be identified. Once the development period of the project is over, it is difficult to find fund to add additional structures.

It is now generally accepted that the technical, environmental and social complexities of FCD projects have been underestimated and that the performance and benefits of many projects have fallen well below expectations. Economic performance has been highly variable, with significant adverse social effects. Environmental impacts have been generally negative, mainly because of disruption of fisheries, the degree of sustainability has been generally low, due to inadequate maintenance, and the positive impacts inside the protected areas have been at least partly cancelled out by negative external impacts. Technical problems include overtopped embankments, waterlogging in rivers and drains.

A 1998 study by the Bangladesh University of Engineering and Technology (Chowdhury, 1998) analyzed the effects of FCD on national Aman output. For each of the 20 Greater Districts a comparison was made of the percentage increase in FCD coverage and the percentage increase in Aman production between 1964 and 1993.

Logically, a reasonable correlation between the two variables would be expected, with FCD expansion causing Aman production to increase more in the better protected Districts. In fact, however, there was very little correlation, the correlation coefficient was only 0.07. Similarly low correlation was found between FCD coverage and Aman adoption. Whilst individual projects may have performed satisfactorily, the net overall effect appears to have been that adverse impacts (drainage disruption, greater flood levels in unprotected areas, erosion or public cuts) have reduced much of the positive impacts. In a floodplain environment, any FCD intervention inevitably has a hydrological impact elsewhere, even if the impact is not very obvious.

The evaluation of FCD projects by Flood Action Plan (FAP 12) found out that 13 of the 17 projects had resulted in higher water levels outside the project areas. The evaluation by Master Planning Organization (MPO) in 1990-91 reported that all eight projects had increased external flooding intensities. The modeling work carried out for the Compartmentalization Pilot Project (CPP) in Tangail by Danish Hydraulic Institute (DHI) in the FAP 25 Flood Modelling Management demonstrated the same point.

IRRIGATION FOR BORO

Irrigation in Bangladesh is divided into two categories, major and minor irrigation. Major irrigation, which accounts for only 10% of the total irrigated crop area comprises the BWDB schemes. Most of these are FCDI schemes, because they have FCD as well as irrigation component. Minor irrigation mainly comprises irrigation by tubewells, low lift pumps and traditional irrigation based on gravity supply and manual lifting devices. Minor irrigation is largely farmer-owned. Recently LGED has developed public sector irrigation for a very small area. At present tubewells and low lift pumps irrigate about 85% of the irrigated area., STWs alone irrigate about 65% of the irrigated area (Table 10.2).

Most of Bangladesh's agricultural land is irrigable. Water availability and the profitability of irrigation, rather than the quality of the land itself, are the key determinants for developing additions irrigated crops.

Since the accessible surface water resources (excluding the major rivers) are already more or less fully exploited, further growth of surface water irrigation is dependent on additional supplies being made available through development of major rivers (the Ganges, the Brahmaputra and the Meghna).

The scope for further expansion of tubewell irrigation will depend on the seasonal watertable lowering in the later part of dry season and the recharge during the monsoon.. Even with very deep setting, suction mode shallow tubewells (STWs) cannot draw from a static water level of below 9m. Below this level, force mode pumping is necessary, with much higher capital costs per hectare and is not affordable for most farmers.

Another major question is whether arsenic contamination in groundwater will significantly affect irrigated agriculture. If it does, a cutback in tubewell irrigation might become necessary. No definite answer is available now.

The Main environmental issue concerning groundwater irrigation is the effects on domestic rural water supplies and earlier drying of water bodies and small rivers and khals. Almost all of existing 10 million handpums used for rural water supplies are suction mode pumps. These pumps can pump water from watertable depth of about 6-7m. Most of these pumps are sunk near village homes located at higher elevations. In areas of intensive STW irrigation, watertables drop to the levels beyond the handpumps pumping limits resulting in disruption of rural domestic water supplies. Force mode handpumps (Tara Pumps) are being tried in some of the areas where suction mode hand pumps do not operate in later part of dry season. Tara pumps are expensive, not easy to operate and their numbers are limited.

SUPPLEMENTARY IRRIGATION

Due to erratic distribution of rainfall in late monsoon season, about 13% of Aman crop is lost due to water stress. This loss may be prevented by providing supplemental irrigation (National Water Plan, 1986). In most of the areas, Aman is grown under rainfed condition. Farmers are reluctant to use tubewells of low-lift pums for supplementary irrigation. This matter needs serious attention.

AGRO-ECOLOGICAL REGIONS

An understanding of the environmental context in which floods occur is essential for the identification of appropriate measures to mitigate their effects. A comprehensive account of the country's physical environment is given in the study reports of the FAO Agro-Ecological Zones.

The paddy production depends on number of climatic and ecological factors like rainfall, flood depth, temperature, length of sunshine hours, maximum temperatures. In order to facilitate the planning for water resources projects, agro-ecological maps have been developed which comprises the four major parameters – length of kharif growing period; length of pre-kharif transition period; length of cool winter period; and length of summer period with extremely high maximum temperatures – and also includes several other associated characteristics such as:

- Mean start and end dates of the pre-kharif, kharif and rabi growing seasons, together with standard deviations.
- Mean start and end dates of periods when temperatures lie above or below certain critical temperatures (minima 15^0C, 20^0C; maxima 40^0C), together with standard deviation.

On the agro-ecological map, 2 mm represents 1,500 m (scale is 1:750,000): in other words, the width of about 50 fields. A square with 2 mm sides on that map covers the land area of about three average villages in Bangladesh (average village area of about 1.4 square km). Such an area may have about 1,500 fields of various sizes: generally smaller on higher lands and bigger on lower lands. The diversity and complexity of soil conditions are typical of many floodplain areas in Bangladesh. This complexity needs to be kept well in mind in using the agro-ecological map.

The thirty agro-ecological regions have been described in the report using a common format. Each regional description contains the following sections:

1. Introduction (defining the region)

2. Location and extent
3. Sub-regions (including a list of included soil regions)
4. Physiography
5. Drainage (including the percentage proportions occupied by different flood depth and land types)
6. Climate (including tabulated data)
7. Soils (including descriptions of the included General Soil Types)
8. Water resources (for irrigation)
9. Present land use
10. Agricultural development possibilities
    - General
    - Rainfed agriculture
    - Small-scale irrigation/drainage
    - Large-scale irrigation/drainage
    - Infrastructure
11. Ecological hazards
12. Agricultural research needs

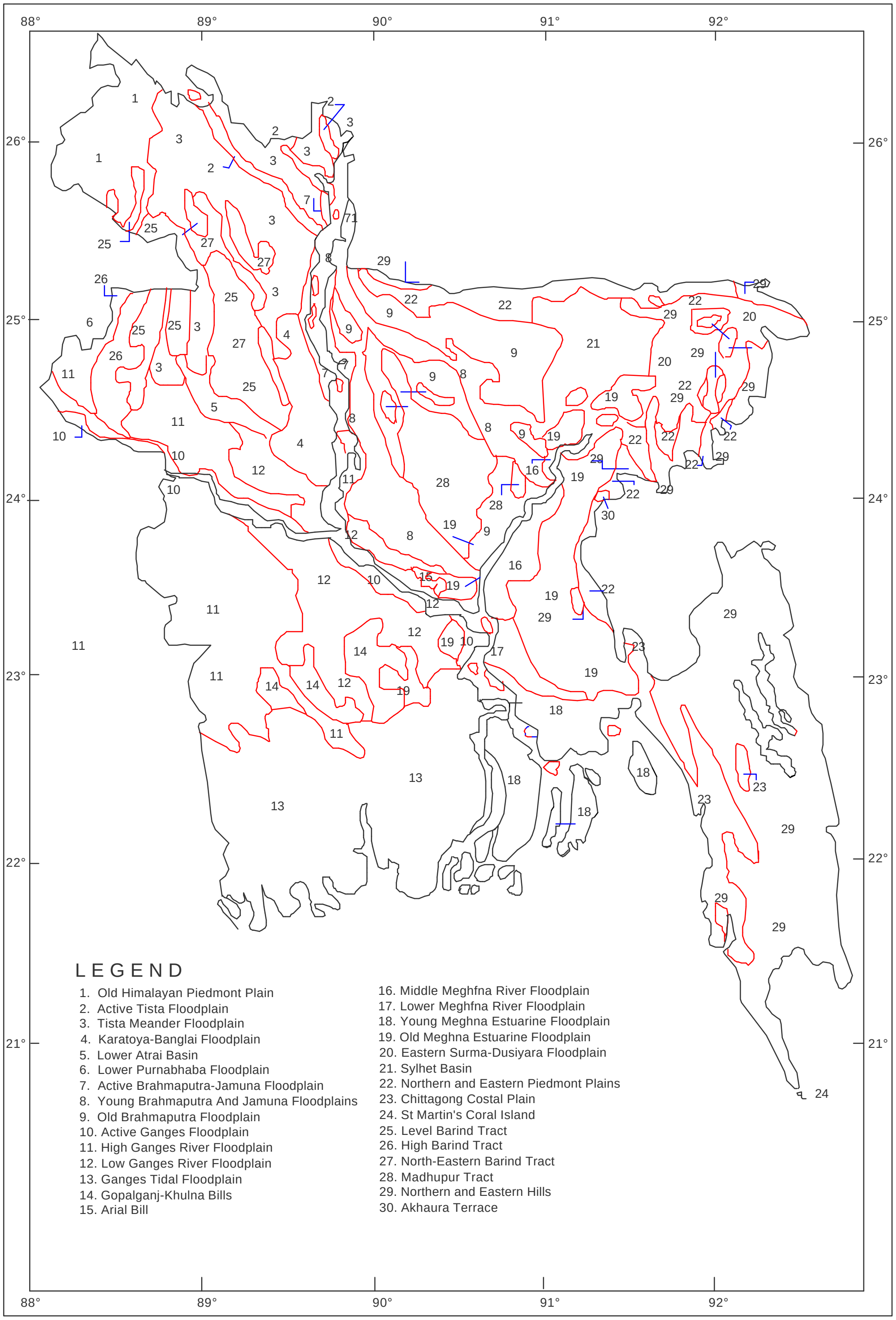
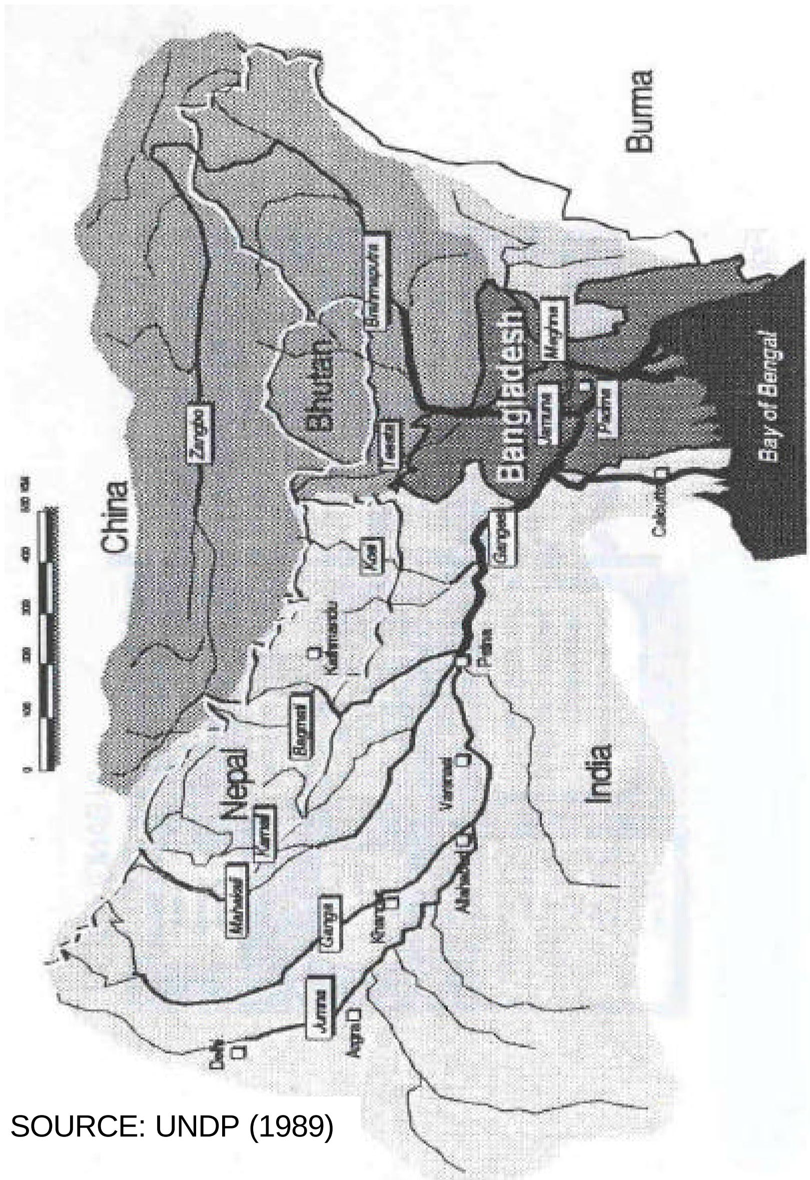


Figure 3.13: Agroecological regions

CHAPTER 4: RIVER SYSTEMS

RIVER SYSTEMS

Most of Bangladesh is located within the floodplains of the three great rivers (the Ganges, the Brahmaputra and the Meghna), their tributaries and distributaries. The three rivers drain a total catchment area of about 1.75 million square kilometers, of which 8% lies within Bangladesh (Figure 4.1). The remaining catchment areas of the Ganges, the Brahmaputra and the Meghna are located within India (62%), China (18%), Nepal (8%) and Bhutan (4%). Bangladesh, her neighbors and the river systems are given in Figure 4.2.



SOURCE: UNDP (1989)

Figure 4.1: Location of Bangladesh in the catchments of the Ganges, the Brahmaputra and the Meghna river systems

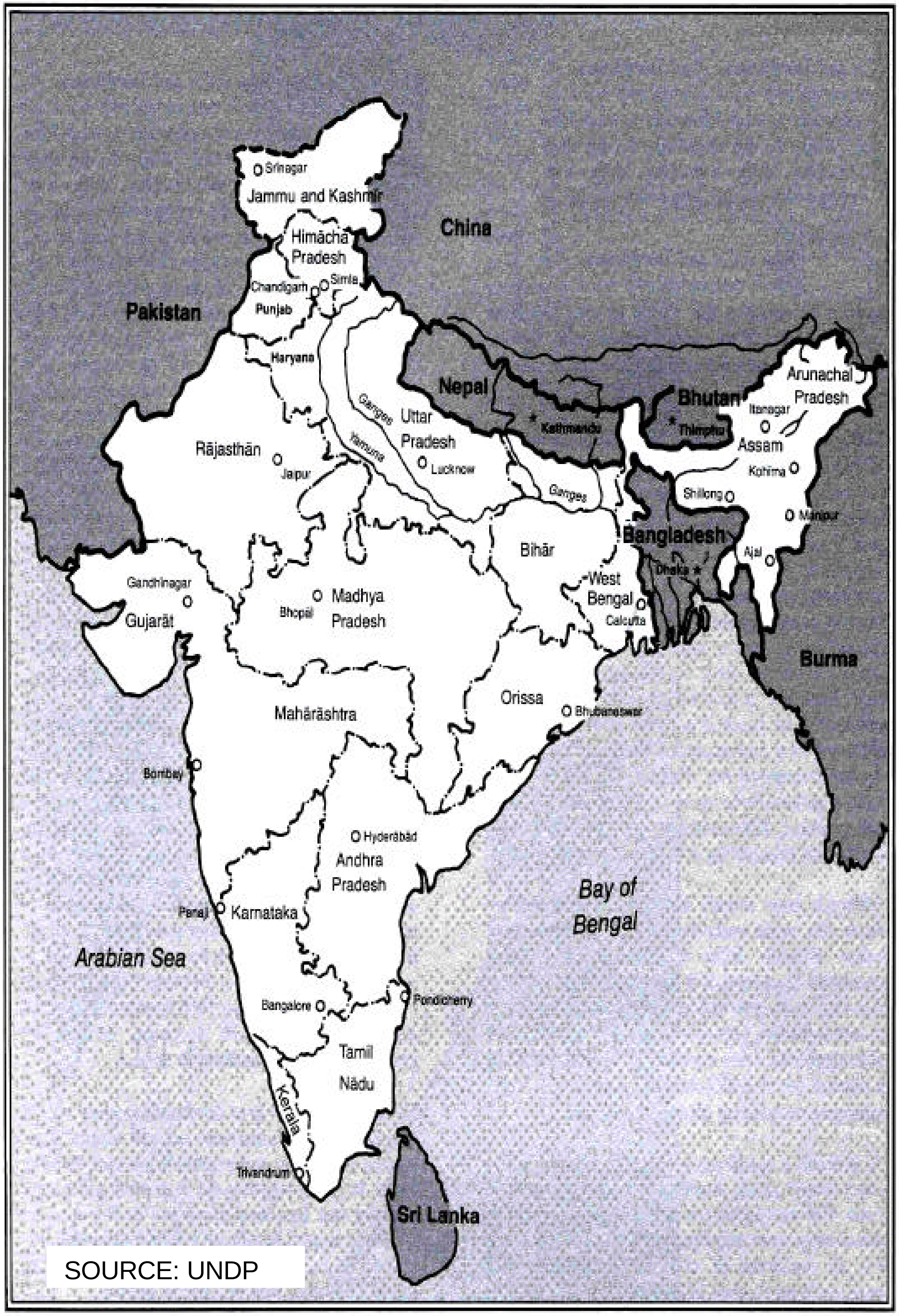


Figure 4.2: Bangladesh in South Asia and three major river systems.

The most influential single natural phenomena to have a deep impact on Bangladesh's culture, economy and politics is its river system. The country has the world's highest density of rivers per unit area; so it is called 'the gift of the rivers'. In spite of the reduced flow in the rivers during dry season, the system has significant role in country's agriculture and transportation. According to MPO (1986), the average annual flow of all the rivers is 37,590 cubic meters per second, which makes it the second largest hydrologic system next to the Amazon River of South America. Bangladesh's river system is given in Figure 4.3.

Streamflow is the largest component of the water resources in Bangladesh. Each day, on the average, approximately 3,400 million cubic meters of water are discharged into the Bay of Bengal. This is about 3.9 times the average daily rainfall over Bangladesh.

Three major river systems drain to the Bay of Bengal through Bangladesh. The Brahmaputra-Jamuna River, entering Bangladesh from the north, joins the Ganges Rives, flowing from the west, about 90 km west of Dhaka in cental Bangladesh. Downstream of their confluence the combined Jamuna-Ganges, known as Padma, flows southeasterly for 103 km to its confluence with the Meghna River. The latter river drains eastern Bangladesh including the hills of Assam, Tripura and Meghalaya in India. The combined channel known as Lower Meghna flows southward and discharges to the Bay of Bengal through a complex estuary.

The floodplains of the major rivers (the Brahmaputra, the Ganges and the Meghna), together with smaller rivers and streams, cover about 80% of the country. Therefore a flat, low-lying topography is the most characteristic geomorphic feature of Bangladesh; about half of the country is lower than 12.5 meters above sea level. Accordingly the average river gradient in the delta is very low, about 6 cm/km.

The Brahmaputra-Jamuna River, with a catchment area of 536,000 sq km upstream of Bahadurabad, rises in the Tibet province of China, flows eastwards on the north side of the Himalayas and then turns south and west through India to the border with Bangladesh. Three major right bank tributaries – the Dudhkumar, the Dharla, and the Teesta – join the Brahmaputra in Bangladesh while there are two major left bank spill channels, the Old Brahmaputra in the north and the Dhaleswari in the south, which join the Meghna River east of Dhaka. A former right bank spill channel, the Old Bangali River, has been closed-off by the Brahmaputra right bank flood embankment.

The Ganges-Padma River originates in the south slopes of the Himalayas and flows south-easterly through India to Bangladesh where it forms the international boundary with India for 140 km. Thereafter it continues east-southeast to become the Padma below its confluence with the Jamuna River near Goalando. The river drains 907,000 sq km upstream of the Hardinge Bridge.

The Mohananda River, west of Rajshahi, is the only northern tributary of the Ganges in Bangladesh. The Baral River at Charghat spills northwards into Chalan Beel and thence through the Atrai River to the Jamuna. The right bank distributary channels form the Ganges delta with an area of 51,000 sq km and coastal width of about 270 km from the Hooghly to the Meghna.

The course of the Ganges-Padma migrated steadily eastwards from the 16th century until it joined the Jamuna and Meghna Rivers. This easterly migration has left moribund formerly active right bank distributaries including the Ichamati, Bhadra, Bhairab, Chitra, Nabaganga, and Kumar rivers. At present the most active distributary to the west is the Gorai-Madhumati River while that to the east is the Arial Khan.

The Meghna River is formed by the confluence of the Surma and Kushiyara Rivers 140 km northeast of Dhaka. The drainage basin upstream of Bhairab Bazar, 60,700 sq km, is only 11 percent of the Brahmaputra-Jamuna Basin and 6.4 percent of the Ganges Basin.

SEDIMENTATION

All rivers in Bangladesh are alluvial and highly unstable. Alluvial channels consist primarily of deposited sediment that originated upstream. There is a constant interchange between the suspended sediment load of the flowing water and the bed material of the channel. The process of scouring and deposition is continuous and is responsible for significant changes in the channel geometry.

Although there are no accurate estimates of sediment discharge to the floodplain and delta of the Ganges-Brahmaputra rivers, it is obvious that Bangladesh receives an enormous sediment inflow from the upper catchments of the Ganges, Brahmaputra, and the Meghna rivers. Milliman and Meade (1983, Taken from World Bank, 1998) estimated that about 1.67 billion tons of suspended sediment is discharged annually through the Ganges-Brahmaputra rivers in Bangladesh. The Bangladesh Water Development Board estimated that 1.27 billion tons of suspended sediment per year is discharged through six major rivers (MPO 1986). This estimate does not include bed load sediments, which may account for as much as 50% of the total sediment load. According to other estimates annual sediment load is 735 million tons for the Brahmaputra and 450 million tons for the Ganges. The daily suspended sediment discharge of the Brahmaputra at Bahadurabad amounts to 2 - 3 million tons from July to August.

Sedimentation has positive and negative effects. Benefits include new land formation, particularly in the coastal areas. Fine-grained sediments deposited on floodplains and deltas increase the fertility of the soil and compensate for subsidence. However, coarse-grained sediments (sand and gravel) deposited on agricultural land after a flood may drastically reduce the productivity of the land. Because of rapid changes in stream flow immediately after a flood, bed load and suspended sediments are heavily deposited, causing river channels to silt up.

Updated sediment rating curves were developed by MPO for six locations using data through 1988 so as include the effects of major floods. In general, these curves indicated an increase in sediment load. The sediment rating curves developed during NWP II were used in conjunction with the flow duration curves developed during phase I to estimate annual suspended sediment discharge.

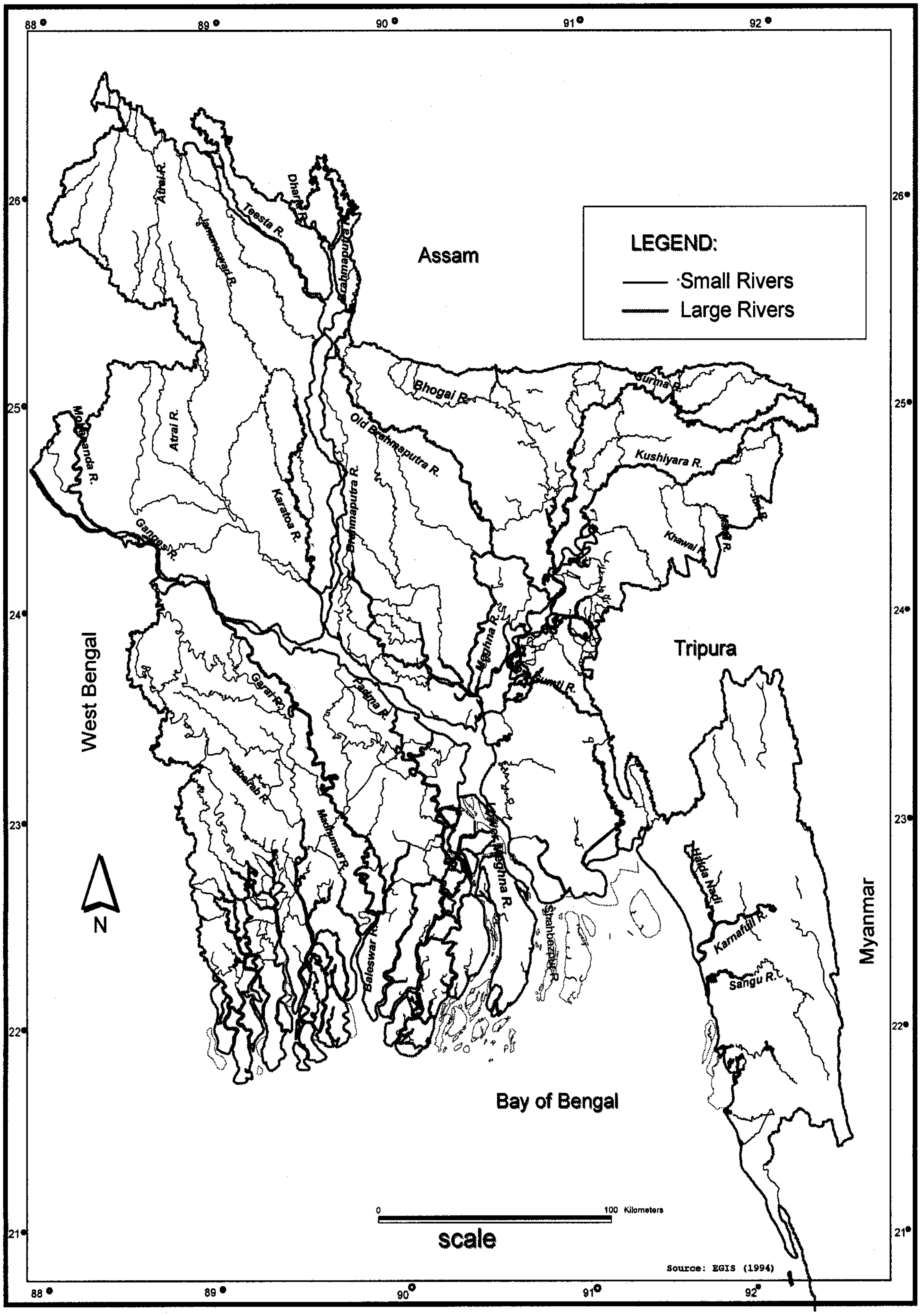


Figure 4.3: River Systems of Bangladesh

Table 4.1: Comparison of Phase I and II Suspended Sediment Discharge Calculations. (Million metric ton/year)

River/Location	Phase I	Phase II	Phase II suspended sediment discharge as percentage of Phase I
Brahmaputra River at Bahadurabad	387	450	116
Ganges River at Hardinge Bridge	212	310	146
Padma River at Baruria	536	506	94
Old Brahmaputra River at Mymensingh	2	12	600
Dhaleswari River at Jagir	40	Not Available	
Gorai River at Gorai Railway Bridge	30	29	97
Gorai River at Kamarkali	43	36	84

SOURCES:
Phase I, MPO Technical Report 11, Floods and Storms, October 1986.
Phase II: MPO Studies 1990.

A comparison of Phase I and II results is provided in Table 4.1 which shows the annual suspended sediment discharge for seven selected stations. There was a sediment discharge increase of 16% at Bahadurabad and 46% at Hardinge bridge while in river reaches at Baruria, the quantity dropped by 6%.

This suggests that although more sediment is flowing into the country, it is not passing through, some is being deposited along the reaches above Baruria. Both studies indicated net deposition between the three key stations of Bahadurabad, Hardinge Bridge and Baruria. The actual quantities of sediment scoured and deposited are many times larger than the figures indicated because the scouring and deposition are constantly occurring every few kilometers. The numbers in Table 4.1 only give the average quantity of suspended sediment past a given cross section in a year.

RIVERBANK EROSION

Most of the rivers of Bangladesh flow through unconsolidated sediments of the Ganges-Brahmaputra-Meghna floodplain and delta. The riverbanks are susceptible to erosion by river current and wave action. River erosion includes channel shifting, the creation of new channels during floods, bank slumping due to undercutting, and local scour from turbulence caused by obstruction. The Brahmaputra, Ganges, Meghna, Teesta, and Surma-Kushiyara rivers flow within well defined meander belts on extensive floodplain where erosion is heavy. Sudden changes are common during floods and cause rapid bank erosion. In lower deltaic areas, river erosion is accompanied by erosion from tidal currents and storm surges from the sea.

Life in Bangladesh revolves around its rivers and since time immemorial the most vulnerable and landless communities have dwelt on or near riverbanks. This has placed them at constant risk from erosion, which occurs on the banks of all the rivers of Bangladesh, but is most marked along the major rivers and their estuaries.

The Brahmaputra-Jamuna has changed course completely after 1762. This is a highly braided river, has steadily migrated westward in recent years, eroding the old floodplain and creating new sections of floodplain on its east bank. The Ganges, with larger areas of resistant clay on its older floodplain, is more stable than Brahmaputra. The Ganges and Padma rivers erode their banks locally, while the Lower Meghna is extremely active in Chandpur, and in the entire area of Bhola, Hatia and Sandwip islands.

The Bangladesh Water Development Board has estimated that about 1,200 kilometers of riverbank is actively eroding and more than 500 kilometers face severe problems related to erosion. Recent satellite-image studies of the Ganges-Brahmaputra-Middle Meghna rivers between 1982 and 1992 show that 106,300 hectares was lost to erosion, while only 19,300 hectares was accreted The net area of 87,000 hectares lost, most of it agricultural land, is equivalent to an annual erosion rate of 8,700 hectares. Erosion of border riverbanks is serious because it can cause loss of land to neighboring countries.

SALINITY IN COASTAL AREAS

Salinity is a factor of unusual importance in Bangladesh. The coastal zone directly affected by salinity is extensive and is inhabited by a large population. It includes major urban centers of Khulna and Chittagong. Figure 4.4 shows the increase in salinity levels in southwest due to reduction in the dry-season flows in the Ganges.

According to isosalinity maps developed by National Water Plan Phase I, streamflow salinity reached more than 2,000 micomhos/cm in the month of April in 40% of the area in southwest and south central regions (about 1.64 million hectares). In addition, about 0.38 million hectares within the polders of the Coastal Embankment Project in the southwest and south central regions are affected by similar levels of streamflow salinity (NWP, 1986). Analysis in National Water Plan Phase II suggested that the above described conditions will prevail in general unless there are major changes in flow conditions.

All the rivers of Bangladesh, except for those in Chittagong in the extreme southeast, combine to form a single broad and complex estuary. The greatly diminished flow in the dry season allows salinity to penetrate far inland through this estuarine river system. Salinity limits opportunities for supplemental irrigation of Aus crops in freshwater areas and damages the same crops by flooding during very high tides. The upland progression of saline water during the dry season eliminated surface water potentials for significant land areas in the southwest, south central and southeast regions.

Fresh groundwater for human and industrial consumption is also affected by the salinity. The shallow coastal aquifers have high salinity. Therefore, water supply wells must penetrate 250 meters or more to find water of acceptable quality. The recharge zones for these deep coastal aquifers are located away from coastal zones in Jessore, Kushtia, Faridpur and Comilla areas and perhaps further north. Activities which may decrease recharge in these upland areas, such as flood prevention, will affect the dynamic balance within these aquifers between the salt-water interface, withdrawals, and recharge.

Activities in the Ganges, Brahmaputra or Meghna river basins that decrease the freshwater flow into the estuary will allow further inland penetration of salinity front. This has been a major effect. Conversely, a policy aimed at limiting the inland penetration of salinity in the dry season would further limit surface water and groundwater withdrawals. In many parts of Bangladesh, particularly withdrawals from the main rivers (Ganges and Brahmaputra).

Plants differ in their ability to withstand salinity in the field. Rice can be grown without any yield reduction with EC of 2,000 micromhos/cm while yields of potato and most vegetables are affected when EC is more than 1,000 micromhos/cm. Cotton and barley are fairly salinity tolerant crops showing no yield reduction upto 5,000 micromhos/cm. Conversion between salinity measurements in ppt and micromhos/cm are provided in page ii.

DOWNSTREAM RIPARIANS IN RIVER BASINS

Due to the geographical location of Bangladesh as the downstream riparian state of two very large catchments (the Ganges and the Brahmaputra), there are specific major water issues. The major specific cross-border issues are water quantity and quality, increased flooding and sediment load.

As the lower riparian of the Ganges, Brahmaputra and Meghna rivers, Bangladesh occupies only about 8% of the total area of the three basins and is located at the point on concentration for monsoon floods generated by runoff from the Himalayas.

Continued development of upstream basins will increase the disadvantages of being the lower riparian and floods are likely to increase because of deforestation of the Himalayas, confinement of rivers by diking, land degradation and erosion.

On the other hand, during the October-May lean period Bangladesh receives only the residual flow after diversion and upstream use. The impacts of this action include reduction in flow to and increases in salinity in the Southwest region of Bangladesh, including the designated Ramsar site of the Sundarbans. The signing of the 1996 treaty with india on the sharing of the Ganges waters provides the opportunity to manage flows in the southwest part of the country, with environmental requirements as one of the criteria for allocation.

The amount of sediment in the Brahmaputra has increased over recent years. Studies of the sediments concluded that the sediment was getting coarser, with a high percentage of sandy material and less organic matter. The reasons for this change are thought to be environmental degradation in the upper catchments in India and China, with deforestation and deepening gully erosion.

The coarse sediment is detrimental to agriculture (ISPAN, 1995). The suspended sediment restricts sunlight penetration and hence reduces algal growth, making the river less biologically productive.

Efficient water and flood management and assured shares of the dry season flows of the trans-boundary rivers have, therefore, become imperative for the survival of Bangladesh.

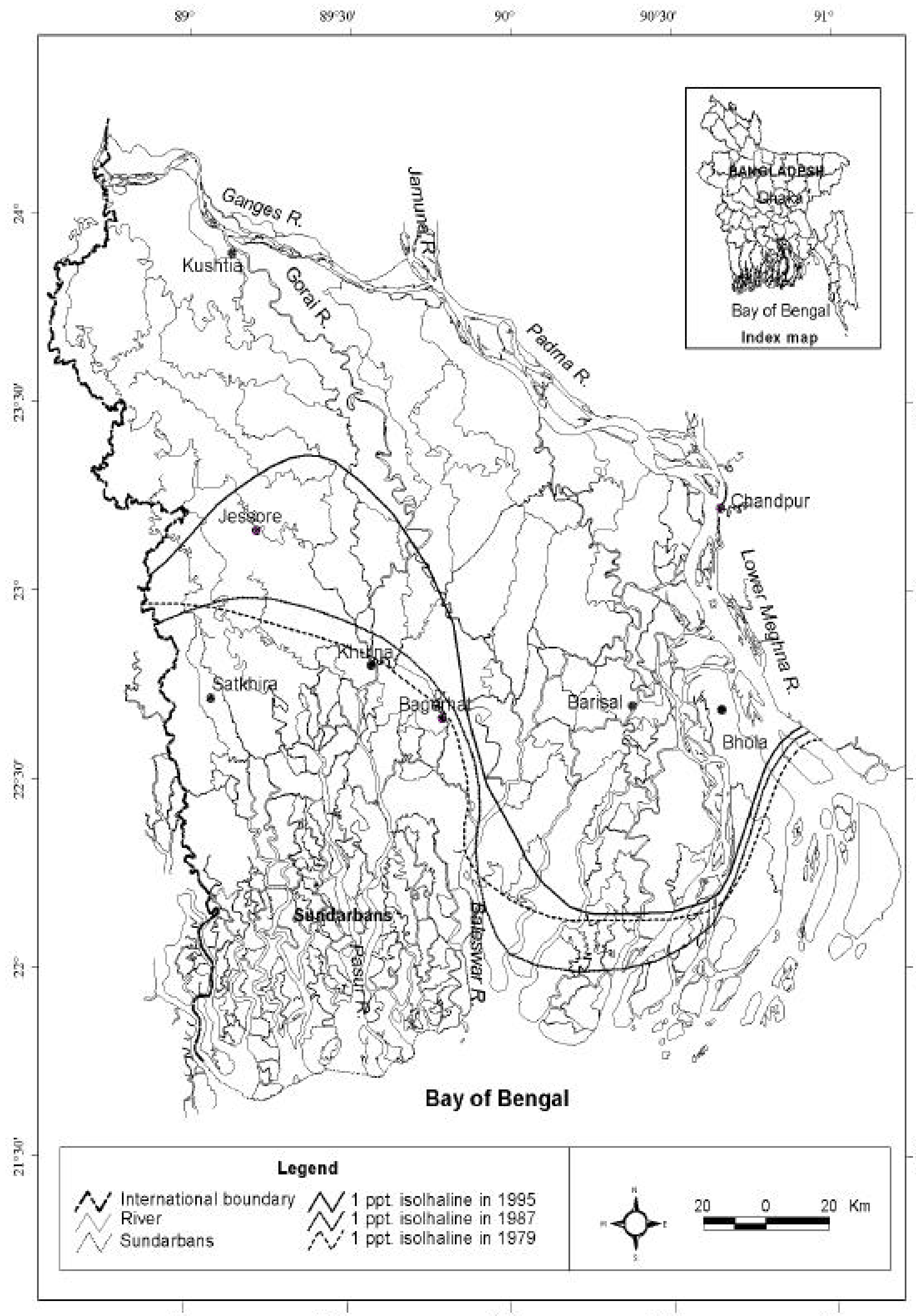


Figure 4.4: Salinity intrusion in the south-west Bangladesh due to reduction in the dry-season flows of the Ganges in India.

CHAPTER 5: FLOODS AND DROUGHTS

INTRODUCTION

Much of Bangladesh is flooded every year, and agriculture and human settlements have adapted to normal floods caused by rainfall or overbank flow from rivers. But severe monsoon floods, like those of 1998, cause significant damage to crops and property.

Floods are a recurring phenomenon in Bangladesh. Each year about 22% of the country is flooded (Figures 5.1 and 5.2). A flood of about 100-year return flood submerges 60% percent of the country (Table 5.1). The intensity and timing of floods vary from place to place and year to year. In general, poorest Bangladeshis live in areas frequently plagued by floods and river erosion.

Table 5.1: Areas affected by flooding

Return period (year)	Affected areas (percent of the country.
2	20
5	30
10	37
20	43
50	52
100	60
500	70
Mean	22

Source: World Bank, 1989 (Taken from World Bank, 1998)

CAUSES OF FLOODING

Flooding in Bangladesh is the result of a complex series of factors. These include a huge inflow of water from upstream catchment areas coinciding with heavy monsoon rainfall, a low floodplain gradient, congested drainage channels, the major rivers converging inside Bangladesh, tides and storm surges in coastal areas, and polders that increase the intensity of floodwater outside protected areas. These various factors give rise to different types of flooding.

Normally floods begin with flash floods in the hilly areas during the pre-monsoon months of April and May. The monsoon generally arrives in June. The Meghna and the Brahmaputra Rivers tend to reach their peaks during July and August; the Ganges River usually reaches its peak in August and September. Severe flooding occurs if the peaks of the Ganges and the Brahmaputra coincide.

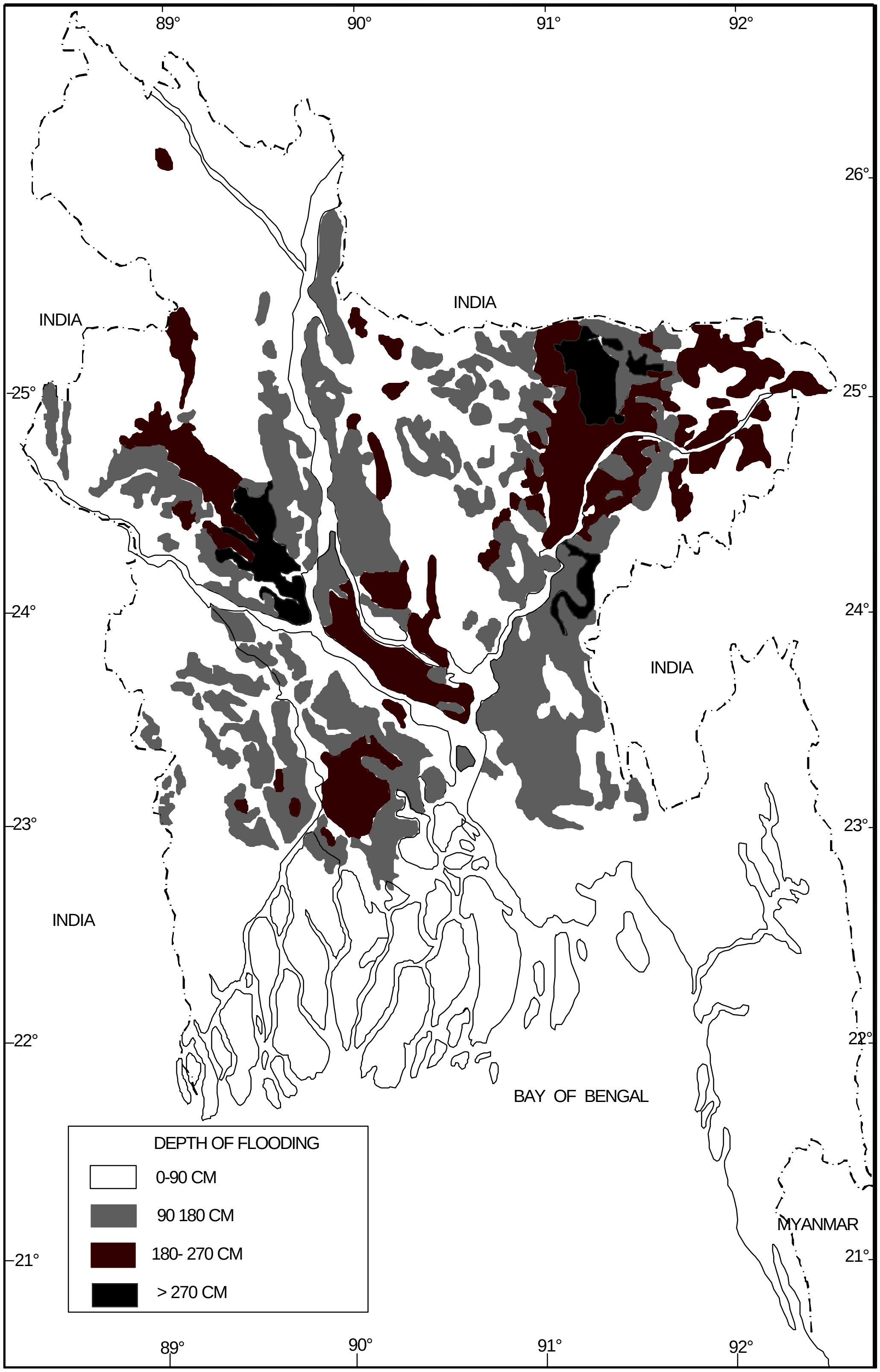


FIGURE 5.1: Average annual depths of inundation

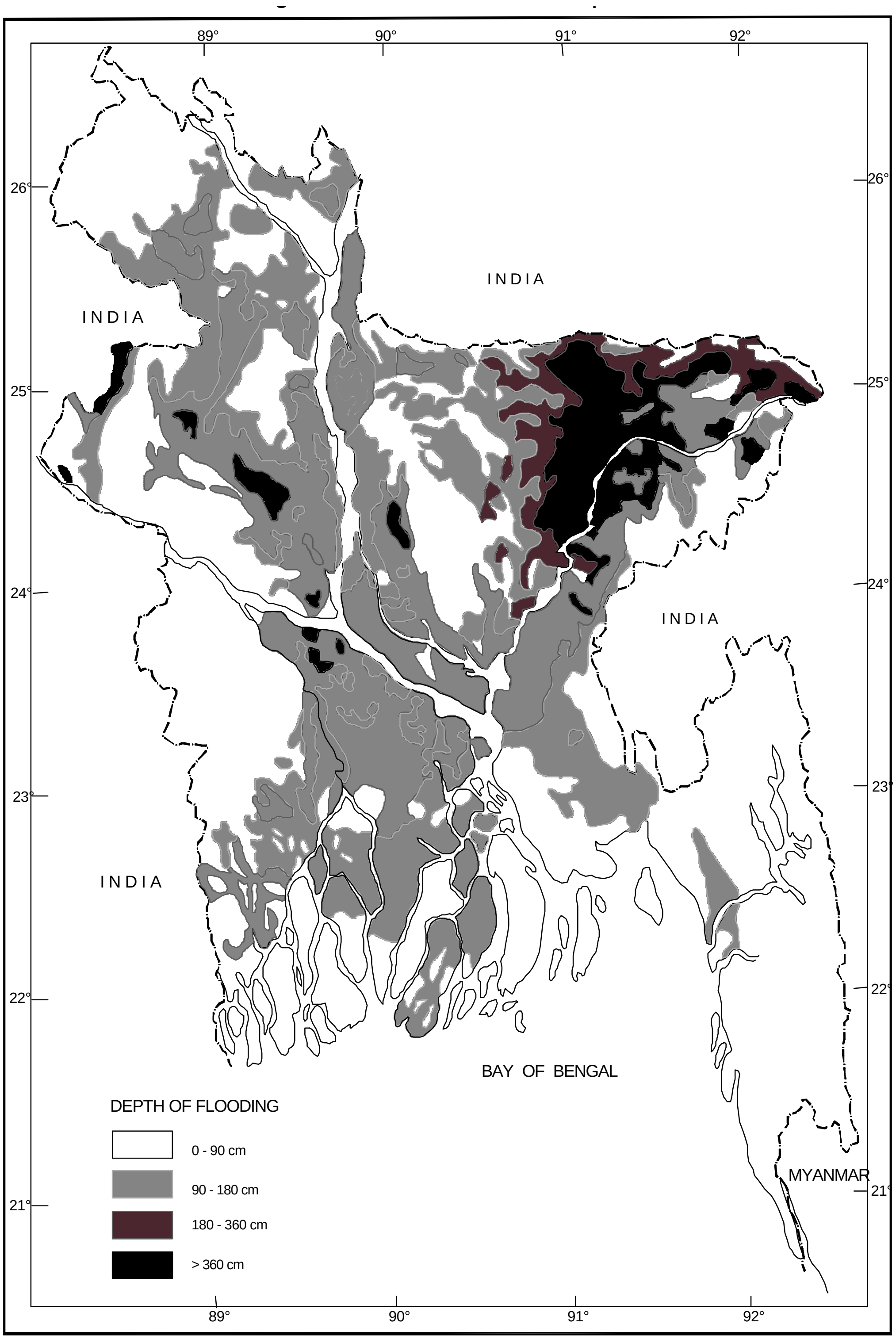


Figure 5.2: Depths of inundation due to 20-year flood

The following particular hydrological features result from the unique geographical situation of Bangladesh and explain the causes of flooding:

- About 8% of the catchment areas of the Ganges, the Brahmaputra and the Meghna Rivers are located within Bangladesh, 62% in India, 18% in China,, 8% in Nepal and 4% in Bhutan.
- The total annual flow of rivers through Bangladesh is about 1,511,000 million cubic meter of which 1,360,000 million cubic meter (90%) of discharge originates outside Bangladesh, 85% of which occur between June and October. Of the total annual flow, about 50% is contributed by the Brahmaputra, 40% by the Ganges and nearly 10% by the tributaries of the Meghna.
- The amount of water which annually reaches Bangladesh would form a lake of the size of the country having a depth 10.3 meters.
- Bangladesh has to drain water from an area which is 12 times its size.
- The estimated annual suspended sediment load is 735 million tons for the Brahmaputra and 450 million tons for the Ganges. The daily suspended sediment discharge of the Brahmaputra at Bahadurabad amounts to 2 -3 million tons from July to August.
- One third of the area of Bangladesh is influenced by the tides in the Bay of Bengal.

TYPES OF FLOODING

Natural Flooding

Four main types of natural floods occur in Bangladesh: flash flood; river flood; rainwater flood; and flood due to storm surge (Figure 5.3).

Flash floods rise and fall rapidly, usually within a few days. They may also flow rapidly along river channels and over the land. Water levels in some eastern rivers can rise by several meters within 24-48 hours. Flash floods are caused by run-off during exceptionally heavy rainfall occurring over neighboring upland areas. Flash floods in Bangladesh cause extensive damage to crops or property.

River floods result from snowmelt in the high Himalayas and heavy monsoon rainfall over the Himalayas, the Assam Hills, the Tripura Hills and the upper Brahmaputra and Ganges floodplains outside Bangladesh. In years when river levels rise earlier or higher than 'normal', river water also extends to varying distances over neighboring river meander floodplains that are normally flooded by rainwater.

Peak flood levels in the Brahmaputra-Jamuna River normally occur a month earlier than those in the Ganges, and floods may affect one river system without affecting the other. High floods in either of these rivers may cause damage downstream alongside the Padma and lower Meghna rivers. Overland flooding is particularly severe in years when high flood peaks in the two major rivers coincide, as they did in 1988 (Figure 5.4).

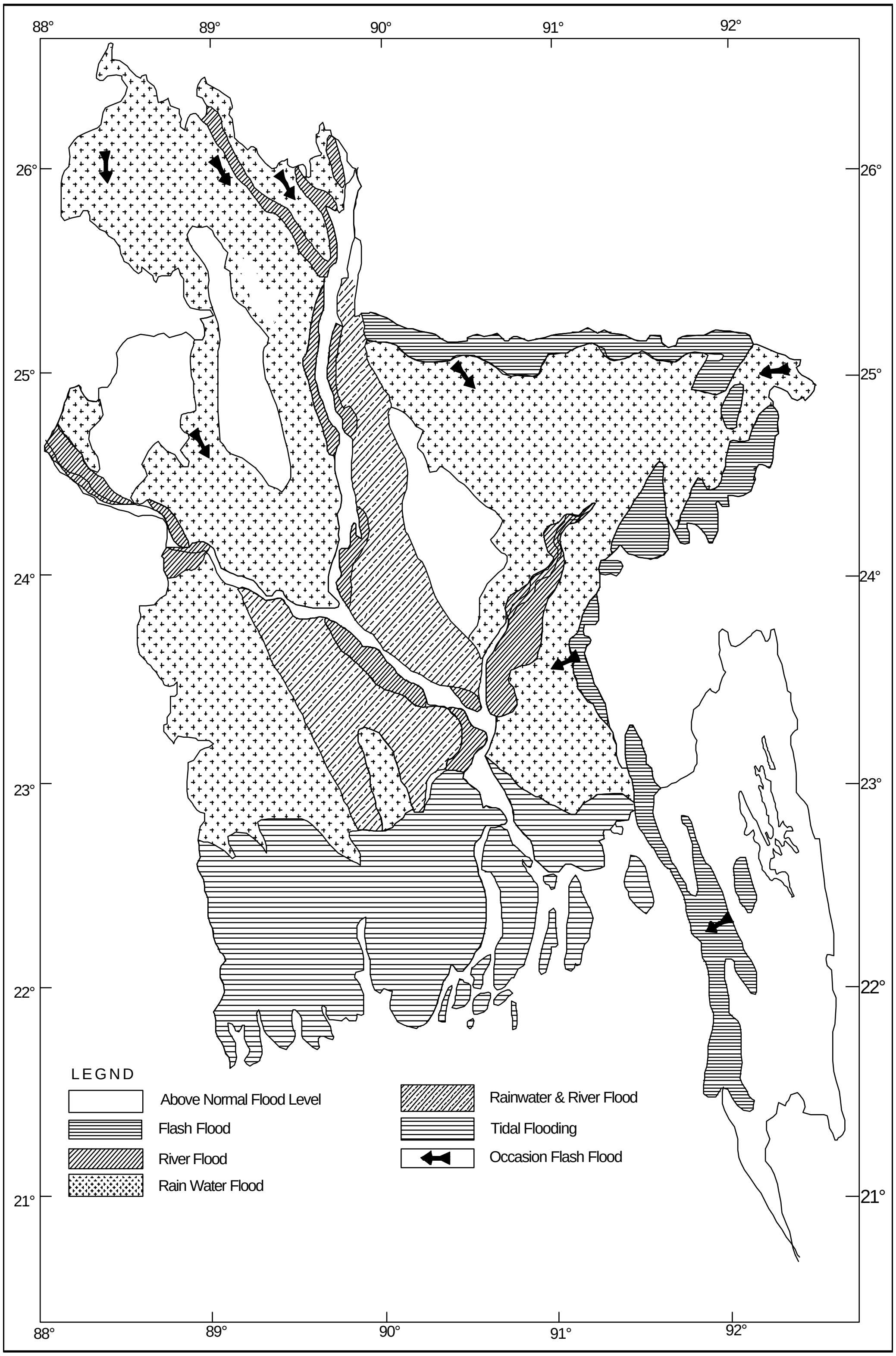


Figure 5.3: Flood types in Bangladesh

Rainwater floods are caused by heavy rainfall occurring over floodplain and terrace areas within Bangladesh. Heavy pre-monsoon rainfall (April - May) causes local run-off to accumulate in floodplain depressions and in the lower parts of valleys. Later (June-August), local rainwater is increasingly ponded on the land by the rising water levels in adjoining rivers. The extent and depth of rainwater flooding vary within the rainy season and from year to year, depending on the amount and intensity of local rainfall and on contemporary water levels in the major rivers which control drainage from the land.

As with river floods, the extent of any crop damage caused by rainwater floods depends mainly on abnormal depths of water on the land.

Damage to houses, roads and other property mainly occurs when, rainwater floods due to heavy local rainfall coincide with high river floods, causing relatively rapid flow of water over the land, over-topping of road embankments and inundation of towns and other settlements.

Storm surges are raised sea levels caused by a combination of low barometric pressure and strong onshore winds associated with tropical cyclones. They cause sudden, but temporary, flooding of coastal areas with seawater or brackish estuarine water for a few kilometers inland during the passage of cyclones, and are responsible for most of the casualties caused by cyclones. Cyclone and storm surge hazard areas are given in Figure 5.5.

Man-made floods.

There is little recorded information on man-made floods in Bangladesh. There are number of cases of this type of flooding.

Siltation of river beds due to water control projects (mainly embankments) caused major drainage problems in coastal areas and in some upland areas.

Floods in urban areas like Dhaka increased due to replacement of natural drainage systems by storm sewers which are not performing at the design capacity. Sudden breaching of an embankment at a time when there is a difference in elevation of several meters between the river level and the land inside the embankment can result in a catastrophic inflow of water into the protected area. A similar kind of disaster, but with a slower onset, can be envisaged in the case of the sustained failure of polder drainage pumps during the monsoon season, thus allowing ponding of rainwater within a polder.

Release of water from Kaptai dam at abnormally high rates occurred in several years when exceptionally heavy and prolonged rainfall over the reservoir catchment caused the lake level to rise rapidly, threatening to overtop the dam. This caused considerable flood damage to crops and property along the Karnaphuli River as far downstream as Chittagong port. Release of water was considered the lesser evil: failure of the dam would have caused even more catastrophic flooding and damage downstream, apart from the serious economic consequences of losing the dam and hydro-electric power station.

Ponding of water behind road, railway and flood embankments following heavy rainfall is a common occurrence. The scale of flooding and damage mainly to crops - varies with rainfall intensity and run-off, and with the nature of the embankment. Ponding behind

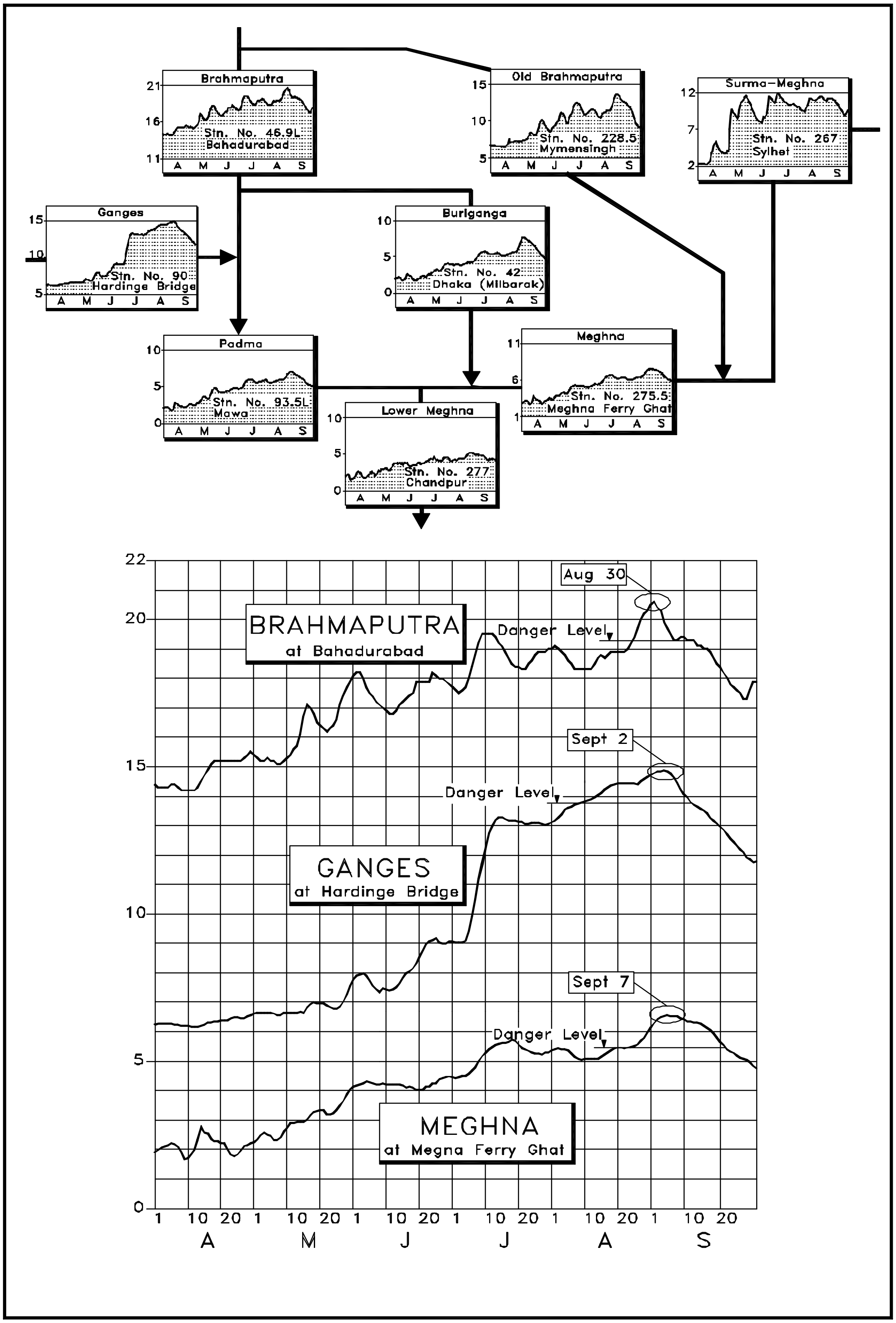


Figure 5.4: Peaks of major rivers coincided in

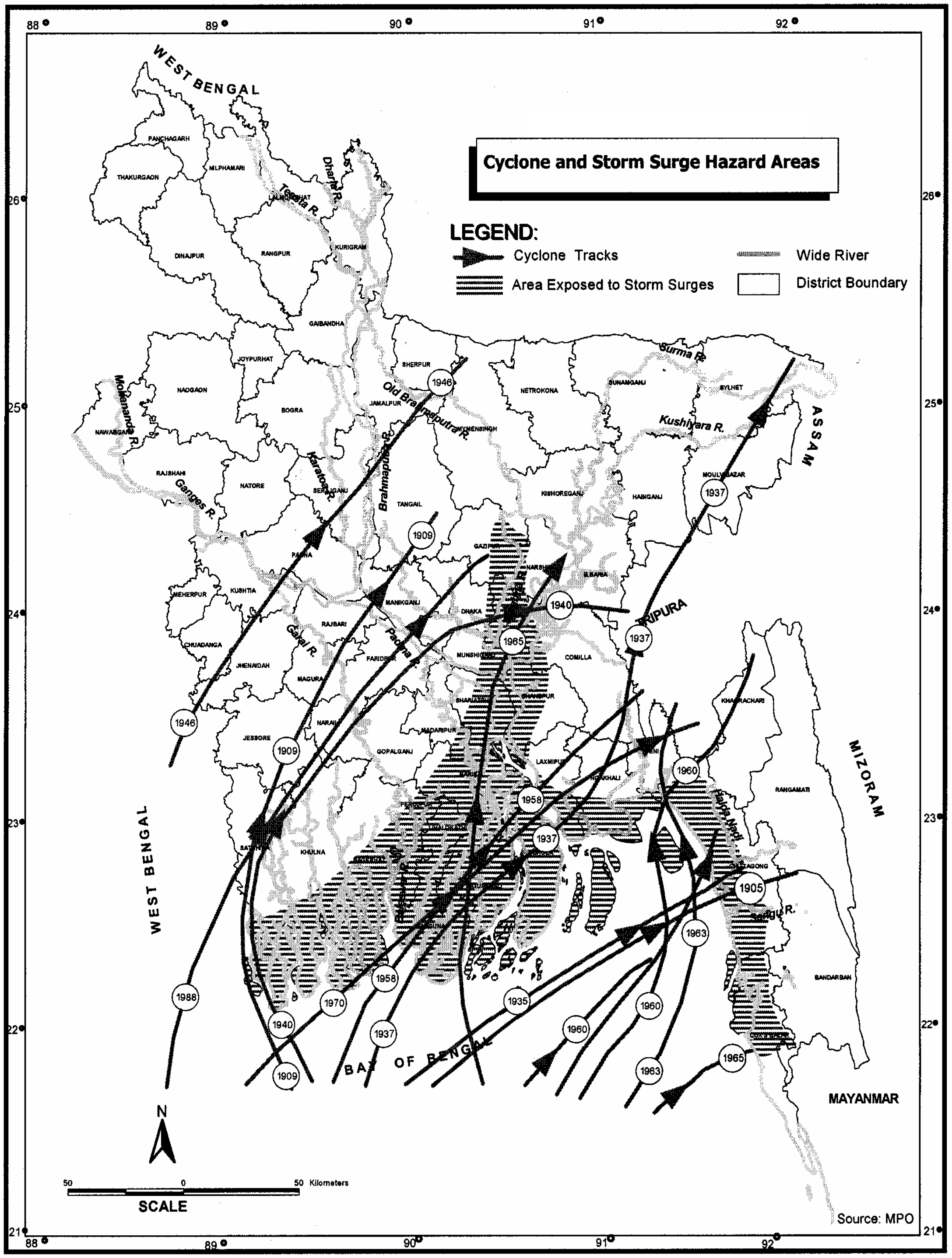


Figure 5.5: Cyclone and Storm Surge Areas

local council road embankments is common: rural roads often are built without an adequate number of bridges or culverts being provided. Ponding behind main road and railway embankments was a common cause of such structures being overtopped and breached in major floods. Ponding of rainwater on the land side of flood embankments has been a common cause of cuts being made by the public to relieve flooding on their land.

FLOOD DAMAGES

Though the people in Bangladesh have lived with flooding for a long time, the problem has become acute with the floodplains more heavily populated and the extent of flood damage increasing over the years.

Inland flooding (freshwater flooding has both negative and positive impacts. Coastal flooding has mainly negative impacts, because of the salinity of the floodwater. Most farmers consider normal inland flooding to be beneficial. Among the negative impacts are damage and loss to property, infrastructure and crops, and sometimes loss of life. Access to safe drinking water and sanitation is frequently lost, resulting in increased incidence of diseases There is disruption to transport, communications and economic activities, leading to temporary loss of employment opportunities. Among the positive impacts are the increase in soil fertility, the enhancement of capture fisheries and navigation access, and more groundwater recharge.

The extent of crop damage depends on the timing of a flood. Flash floods in March to May in North-East can cause heavy losses to HYV Boro rice. If flooding occurs before harvesting of Aus (mid June-mid July), the loss can also be serious and is made worse if planting of the Aman crop is delayed.

Structures built on flood plains, including roads and towns, obstruct floodwater recession and drainage. It is estimated that flood damage to roads and highways alone amounts to millions of dollars in flood years. The value of loss of crops and property is also very high.

The 1988 and 1998 floods have been very severe with widespread suffering and loss of life. A joint UN/Government of Bangladesh team has estimated the cost of a Reconstruction and Rehabilitation Program at US$ 1.14 billion for the 1988 flood. The damage assessment due to the 1998 flood was not as comprehensive as the 1988 flood. The 1988 flood caused over 3,000 deaths and damages variously estimated at about US$ 1,140 million. Loss of life in the 1998 flood, at about 1,500, was less and reflects the improvements in flood preparedness over the intervening period.

Extent of damage: the 1988 flood extended over parts or all of 53 of the 64 districts of Bangladesh and directly affected 45 million people out of a total population of 110 million. It was reported that crops on 2 million ha of land were damaged out of a cultivable area of 9.5 million ha in 1988. Severe damage occurred to roads, railways, and water control works. Social services were also seriously disrupted. Flooding reached unprecedented levels in Dhaka which added to the burden of Government organizations and officials in coping with a national emergency.

A summary of the assessment of the flood damage in 1988 is provided in Table 5.2.

DROUGHT

Drought during Monsoon

Drought is a major problem in Bangladesh, particularly in the North-Western regions during rabi and pre-monsoon where there are few surface water resources, and agricultural production is heavily reliant on groundwater resources.

In contrast to the high rainfall brought by the southwest monsoon from May to October, there are months without rain in the dry season. This can bring hardship to people living in areas with poor access to surface water and groundwater resources. There were severe droughts in Bangladesh in 1979, 1981, 1982 and 1989 and between November 1998 and April 1999; there can be periods of 150 days with almost no rain in Bangladesh.

A "Report of the Task Force on Droughts" (WARPO, NWMP, 2000) on what was seen as an impending drought in 1995 noted that the rainfall in the monsoon had been below average in the NW, SW, NE, SE and SC Regions by 35%, 20%, 25%, 30% and 15% respectively. Corresponding reduction in surface water availability was expected to be 20%, 20%, 5%, 10% and 5%. Overall, it was expected that the areas under LLP irrigation would reduce by 55,000 ha. They also expected that GW levels would fall by 0.5 to 3m, and that 90,000 STW's would be affected. The report stated that aman crop production in the 1994 season was reduced by 377,000 ton due to the effects of the drought. In fact, the total production on the year was little affected, partly because farmers respond to market forces and plant more rice if the preceding season prices are high.

Table 5.2: Estimates for Costs of Repair and Reconstruction by Sector, 1988 (in US$ million)

	Immediate (US$ million)	**Long-term (US$ million)**	**Total (US$million)**
Agriculture	**34.6**	**133.4**	**168.0**
Crops	24.4	91.2	115.6
Livestock	2.0	11.9	13.9
Fisheries	2.8	0.0	2.8
Forestry	0.7	3.1	3.8
Food	4.7	27.2	31.9
Flood control/irrigation	**53.8**	**72.8**	**126.6**
Roads and highways	**39.8**	**125.0**	**164.8**
Roads and Highways Department	25.5	97.6	123.1
Local government	11.8	22.7	34.5
Technical assistance	2.5	4.7	7.2
Railroads	**28.9**	**52.3**	**81.2**
Inland waterways and ports	**4.6**	**16.3**	**20.9**
Civil aviation	**7.0**	**36.0**	**43.0**
Posts and telecommunication	**23.2**	**78.2**	**101.2**
Power and electricity	**8.8**	**46.6**	**55.2**
Bangladesh Power Development Board	6.7	35.1	41.8
Rural Electrification Board	2.1	11.3	13.4
Industry	**124.4**	**100.8**	**225.2**
Public infrastructure	1.2	2.3	3.5
Small and cottage industries	75.5	70.7	146.2
Medium and large industries	47.7	27.8	75.5
Health	**16.7**	**21.0**	**37.7**
Education	**58.0**	**0.0**	**58.0**

Rural water and sanitation	**3.2**	**0.0**	**3.2**
Urban infrastructure	**21.5**	**30.4**	**51.9**
Local government	20.3	28.6	48.9
Technical assistance	1.2	1.8	3.0
GRAND TOTAL	**424.5**	**718.6**	**1,137.1**

Source: Report of the Task Force of the Government of the People's Republic of Bangladesh and United Nations and the 1988 Floods; February, 1989.

Rainfed (monsoon) crops are normally grown without irrigation with the expectation that rainfall and soil moisture will be sufficient to meet the crop water needs. However, because rainfall is highly variable during the growing season and from year to year, there are periods in which rainfall and moisture available to the crops are less than required. These water deficits induce stress in the plant and reduce yield. The amount of water required to off-set these deficits is called supplemental irrigation.

It was estimated by the NWP (1986) that about 1 to 35% (average of 13%) of monsoon crop is lost due to water stress during monsoon.

Since HYV monsoon crop (Aman) is restricted to lands with shallow inundation of less than 30 cm to 50 cm, early drought stress is less likely to be offset by flooding.

Drought During Dry Season

Following the monsoon, the availability of soil moisture declines and falls short of crop demand during the Rabi season. Potential soil moisture deficiencies over 6 to 7 months (November to May) seriously limit crop production in Bangladesh. It is not possible to grow rice during this season without irrigation.

The effect of drought is more marked now that irrigated boro (dry season) rice has become major rice crop. Streams and waterbodies used for LLPs dry up, and STWs reach their suction limit of 7m. Farmers using LLP start abstracting water reserved for environmental needs. STW can be lowered 2m in pits to reach more water, but deeper setting is difficult. When farmers draw the water down, there is a corresponding fall in the village hand pumps, which are also suction mode pumps, set generally on higher land and consequently more vulnerable. Women seek water from contaminated surface water sources as a result, with corresponding risks to public health and welfare. Thus water supplies, the environment, crops and navigation are all under threat during droughts. For integrated water resources management, the problem of too much of water (monsoon flood) and shortage of water (in post monsoon and dry season) should be addressed.

CHAPTER 6: WATER RELATED ENVIRONMENT

INTRODUCTION

The natural environment of Bangladesh is dominated by water, with over one fifth of the area flooded in the average monsoon and 9% of the area covered by rivers, estuaries, swamps and other wetlands. Quite apart from general environmental considerations, the aquatic environment forms the basis for the highly productive inland fisheries on which so many people, especially the very poor, depend.

In the context of the water sector, there are two ecologically sensitive areas of outstanding importance; the Sundarban mangrove forest area in the southwest and the Hakaluki Haor, part of the Haor Basin wetlands in the northeast; the former as a World Heritage Site and both as Ramsar Sites. The Sundarbans is a coastal mangrove forest unique in height of its forest and the diversity of its wildlife, particularly large mammals. The parts of Haor Basin in the northeast has extensive open wetlands and abundant fish and bird life and is also especially important because of its great biodiversity with many rare species and waterfowl habitats.

NATURAL AQUATIC ENVIRONMENT

With the exception of the northern hillslopes and the Chittagong Hill Tracts in the south east, the whole country has formed as vast, coalescing alluvial fans of the three major rivers, the Ganges (or Padma), the Brahmaputra and the Meghna. The continued re-working of these alluvial sediments over the millennia has left a highly complex pattern of about 700 active rivers, tributaries and distributaries-mostly in highly dynamic states of formation or decay. Apart from the rivers, there are many open water bodies comprising features such as water-filled depressions, river backswamps and ox-bow lakes, the individual areas ranging from a few hectares in size to over 1,000 ha, with large expanses of water extending over many square kilometers in the northeast. Overall, water bodies with an area of 30 ha or more total at least 13,000. They cover an area of about 1,700 km^2, or just over 1% of the total surface area of the country. The majority are termed *haors, baors or beels*:

Haors, most of which retain some water over the dry season, are seasonally flooded shallow depressions between river levees. Their main concentration is in the Haor Basin in the northeast of the country in eastern Mymensingh and Sylhet Districts;

Baors are mainly perennial wetlands formed from oxbow lakes or other isolated stretches of former rivers. They occur particularly in the southwest parts of the country in the Kushtia, Jessore and Faridpur Districts;

Beels are depressions occurring throughout the country except in the hilly areas; most retain at least some water throughout the dry season. The greatest density occurs in the main delta regions, notably in the Districts of Rajshahi, Pabna, Kushtia, Jessore, Faridpur, Camilla and Noakhali, as well as in the Haor Basin.

The Eastern Hills Region (EH) is characterised by extensive marshes along many of its rivers and is the location of Lake Bogakine and the 766 km^2 Kaptai Reservoir on the Karnafuli River. Other artificial water bodies culture fishponds, including the extensive salt-water prawn *bagda*, (*Penaeus monodon*). The 480 km-long coastal region, from the western border to the Burmese border in the far South East, includes the Sundarbans, which also extend westwards into India, and the smaller Chokoria Sundarbans on the Chittagong coast. There are numerous islands in the region, many of them newly-emerged *char* lands formed by deposition of the large volumes of river-borne sediments transported to the Bay of Bengal.

The monsoon rains and associated cross-border flows flood about half the country for two to five months in normal years. This seasonal flooding, to a depth of a meter or more, is essential to the life-cycle of migratory fish and other aquatic species, which are able to spread into the floodplains -where they later remain in temporary and permanent pools as the flood waters recede.

FLORA AND FAUNA

With such extensive and varied aquatic environments, the country contains a rich variety of wildlife, representing considerable biodiversity. Among many others, the commercially important river and floodplain fish include *Channa, Hilsa, Puntius* and *Labeo spp,* whilst shrimps and prawns in the estuaries include *Macrobracchium, Penaeus* and *Metapenaeus*. The freshwater prawn, *Golda (Macrobrachium rosenbergu),*is also increasingly cultivated. Reptiles include some 25 species of turtles and tortoises, many snakes and several important rare or endangered species, such as the Ganges River Dolphin (Platanista gangeticus), crocodiles and Felis verrina, the Fishing Cat.

Water fowl once represented by over 150 recorded species, now number some 80 species of birds, including herons, egrets, ducks and many coastal birds like gulls and terns. The inland species occur in large numbers in the Haor Basin, which lies on the Asian Flyway.

The Sundarbans mangroves consist of an association of *gewa (excoecaria agallocha)* and *goran (Ceriops roxburghiana)*, which predominate in the more saline west, and *sundri (Heritiera minor)* in the less saline central and eastern parts. Timber, pulp wood and firewood are all extracted as valuable forest products, and palm leaves are used for thatching and house walls. These mangrove swamps are highly biodiverse and are home to deer and other rare species as well as forming one of the last remaining refuges of the Royal Bengal Tiger (*Panthera tigris*).

The Sundarbans is already a destination for eco-tourism, although it is not yet well-developed, and the Haor Basin has the potential to become one too. These and several other wetlands could also be useful sites for scientific research and environmental education.

ECONOMIC IMPORTANCE OF INLAND WATER RESOURCES

The wetlands and floodplains are important for both lives and livelihoods. The World Bank (World Bank, 1997) estimates that "about 8% of the population and 1.2 million commercial fishermen depend on fisheries for their livelihood, and over 70% of households are involved in subsistence fishing". Large numbers of subsistence fishermen are poor and socially-vu1nerable, who depend on subsistence capture fisheries as their only source of protein. These disadvantaged members of society do not have an effective 'voice' in development planning and implementation, but their needs are a major reason for protection of capture fisheries.

Preservation of the essential features of the aquatic habitat is therefore not merely a matter of ecological significance but a major socio-economic necessity to protect the lives, well-being and livelihoods of many thousands of the country's inhabitants.

POLICY, LEGAL AND INSTITUTIONAL ASPECTS

Environmental aspects of water resources are now well served by National Policy. Both the 1995 Environment Policy and, especially, the Fisheries and Livestock and the Water Policies (1998 and 1999, respectively) contain provisions for the preservation and/or ecologically-sensitive development of the aquatic environment. Environmental concerns appear to be firmly on the development agendas in other sectors too, many other key policies including specific reference to the environment-among them the policies on industry, agriculture and land resources.

There are three major laws/rules relating to the environment:

1. The 1995 Environment Conservation Act. This is a comprehensive legislative framework for protecting the environment through responsible behavior by industry, government agencies, city corporations, municipalities, local authorities and individuals;
2. The 1997 Environmental Conservation Rules, which contain wastewater effluent standards for industries and selected surface water uses; and
3. The 1999 Environmental Court Act.

The 1997 Department of the Environment (DoE) publication "EIA Guidelines for Industry" gives more specific mandatory regulations and procedures for environmental impact assessments (EIAs) - not only of industrial projects, but also of many water resource developments. Further Guidelines are under preparation by DoE, and WARPO is contributing to those covering flood protection and drainage.

For the water environment, the issue now is not so much the formulation of new, laws and regulations, but implementation of the existing ones. It is widely acknowledged that the established planning controls and procedures are seldom followed, and there is - as yet - no effective policing of the regulations, either for existing or new enterprises. In practice, there may often be no notification to the key authorities of developments which have major impacts on water resources, let alone implementation of proper IEE or EIA studies, with subsequent environmental management and monitoring.

The situation is, in part, a reflection of institutional weaknesses. The DoE has for years been under-resourced and has consequently been unable to carry out its full mandate. The current Bangladesh Environmental Management Program (BEMP) is, however, addressing some of the deficiencies. In the water resources sector, WARPO has had an Environment Section for about five years. The DoF's involvement with the aquatic environment, although long-standing, has tended to be on fish production, rather than on the aquatic environment as a whole. As in many countries, one of the key difficulties is attempting to ensure co-ordination of the measures being undertaken and ensuring inter-organisational and inter-sectoral cooperation.

INSTITUTIONS

The primary institution for environmental management is the Department of Environment (DoE) under the Ministry of Environment and Forest (MoEF). The DoE is the authority with the mandate to regulate and enforce environmental management, including control of pollution of water resources. The DoE has the task of ensuring that adequate EIAs are undertaken; it is the primary institution for environmental management and setting and enforcement of environmental regulations. Its key duties related to the water sector include:

- pollution control, including: monitoring effluent sources, ensuring mitigation of environmental pollution;
- setting Water Quality Standards (WQS) for particular uses of water and for discharges to water bodies;
- defining Environmental Impact Assessments (EIA) procedures and issuing environmental clearance permits - the latter being legal requirements before proposed projects can proceed to implementation;
- providing advice or taking direct action to prevent degradation of the environment;
- declaring Environmentally Critical Areas (ECAs) where the ecosystem has been degraded to a critical state. ECA status confers protection on land and water resources through a series of environmental regulations.

  (The Forestry Department (FD) is responsible for Sensitive Area protection in the following four types of legally protected areas: wildlife sanctuaries, game reserves, reserve forests and natural reserve forests).

However, the DoE has consistently been under-resourced and needs institutional strengthening. The Sustainable Environment Management Programme (SEMP) has recently commenced this with the help of the UNDP. SEMP includes a Policy and Institutions sub-programme, which has a component on "Capacity Building for Environmental Legislation and Policy Analysis". Linked with this is the Bangladesh Environmental Management Project (BEMP) supported by the Canadian Government which over a five year period also seeks to strengthen the DoE.

The 1995 National Environmental Management Action Plan (NEMAP) was based on a national consultative process to identify the main environmental issues in the country, including those that relate to the water sector. NEMAP calls for the Ministry of Water Resources (MoWR) and other organizations to undertake actions in the following environmentally-related fields:

- develop flood protection measures with people's participation and EIA;
- together with the universities, research organizations and the DoE, develop guidelines for the environmental review of water sector projects;
- carry out mitigation and restoration activities to alleviate problems with drainage in wetlands, waterlogging, flooding, siltation, salinity and biodiversity;
- together with the universities, research organizations and the DoE, develop guidelines for the environmental review of water sector projects;
- develop a comprehensive plan for the development and management of the water sector database (an activity for WARPO with the DoE and Ministry of Fisheries and Livestock);

- together with the LGED (for small-scale irrigation projects), prepare guidelines to address unplanned abstraction of groundwater that would otherwise lead to the drawing down of the water table and failure of both shallow and deep tubewells;
- together with the MoEF, the Ministry of Law, Community Organisations. NGOs and the people of Bangladesh, formulate a strategy at both national and international level to address the problem of reduced availability of water during the dry season in the Ganges.

INSTITUTIONAL ISSUES

WARPO identified the following institutional issues (WARPO, 2000):

- large number of rules and regulations have been framed and developed over a period of time, but there is a lack of capacity to enforce them;
- though much progress has been made, particularly over the last decade, in identifying environmental issues and potential solutions, there is a lack of skills in taking appropriate action during project design and implementation to ensure that environmental concerns are properly addressed; and
- there are apparent overlaps in the mandates of MoEF, WARPO, and NWRC in developing policies for, and management of, water resources development. This could be a strength or a weakness, depending on the degree of coordination and cooperation achieved in practice. The danger is that the different bodies might set differing agendas and follow different-even somewhat conflicting-paths and hence weaken the efforts being made to improve the environment.

MoEF and DoE are tasked with (a) setting standards, (b) evaluating and giving clearance to impact assessments and (c) enforcing environmental regulations and rules. These are major tasks, and although institutional strengthening of DoE is under way to help develop its capacity to fulfil its mandate, the process is likely to take many years before the goal can be achieved.

Whilst major agencies with activities in the water sector, such as BWDB, LGED and DWASA, have environmental guidelines for developing and implementing their projects, there is a lack of relevant skills in these organizations. Whereas LGED has established an environmental cell, BWDB has not, usually outsourcing EIA work for larger project. Current legal frameworks require all implementing agencies to conform to environmental rules and standards, but without a strong DoE and proper resources, the quality of the EIAs undertaken cannot be assured.

CHAPTER 7: INSTITUTIONS FOR WATER RESOURCES DEVELOPMENT

INTRODUCTION

The institutions for water resources development may be classifies into four categories: institutions for administration and planning, major implementing agencies, water related agencies and water related service providers. These are described below.

INSTITUTIONS FOR ADMINISTRATION AND PLANNING

National Water Resources Council

The National Water Resources Council (NWRC) is the highest body for formulation of water policy including inter-agency coordination, and is charged with making recommendations to the Cabinet on all water policy issues. The council consists of ministers from respective ministries and is chaired by the Prime Minister. This high-powered council has not functioned well in the past because of the absence of a supporting organization. There is no effective organization for examining water issues in a comprehensive manner and presenting them to the council. This task has been partially performed by the Ministry of Water Resources, which lacks appropriate resources to do this job efficiently (WARPO, DDS, NWMPP, 2000).

Ministry of Water Resources

The Ministry of Water Resources (MoWR) is responsible for all aspects of water resources including expansion of irrigated areas, water conservation, surface and groundwater use and river management. In addition to the Minister, State Minister, the MoWR consists of the Secretary, an administrative group of 16 Class I officers and a small Planning Cell.

The Executive Committee of the NWRC

To support the NWRC, an Executive Committee of the NWRC (ECNWRC) was constituted in 1997 by an order of the Government. ECNWRC is chaired by the Minister of Water Resources. ECNWRC with the support from the WARPO ensures that routine matters are addressed without delay and that issues requiring the attention of the full Council are properly presented, recorded and executed.

Water Resources Planning Organization (WARPO)

Water Resources Planning Organization (WARPO) was established to undertake integrated water resources planning. WARPO is also responsible for national, regional and basin planning with overall assessment of water supply and demand in the country. This task requires close coordination with all sub-sectoral agencies and with people who are affected by the plans and programs of all these agencies. WARPO has developed National Water Resources Data Base and periodically updates it. In future WARPO will be given responsibility of "clearing house" for all water sector projects identified by different agencies and reporting to the ECNWRC on their conformity to the National Water Management Plan.

MAJOR IMPLEMENTING AGENCIES

Bangladesh Water Development Board (BWDB)

Originally established in 1959 as the Water Wing of the East Pakistan Water and Power Development Authority, the organization was restructured in 1972 as BWDB and its mandate was limited to water resource development. BWDB has been reconstituted in July 2000 under a new act that repositions the organization and aligns its responsibilities to those set out in the National Water Policy.

Under the BWDB Act, the Board is empowered, inter alia, to exercise the right to control the flow in all channels and rivers, underground aquifers, develop standards and guidelines for water management structures, levy and collect charges in schemes, undertake projects and sign contracts.

The functions of the Board include construction of water management structures, dredging and excavation of channels, land reclamation works, river training and erosion control, construction and maintenance of coastal embankments, and rain water harvesting. It is responsible for flood and drought forecasting, hydrological survey and investigations, research, establishment and training of water user associations and other stakeholder organizations.

Local Government Engineering Department (LGED)

LGED grew from a rural works program started in the early 1960s and a Works Program Wing was created in 1982 under the Local Government Division of the MLGRD&C. Thereafter it expanded rapidly to become the Local Government Engineering Bureau in 1982 and a Department in 1992.

In regard to water sector projects LGED was given the responsibility of implementing small-scale water resources project (less than 1,000 ha).

Bangladesh Agricultural Development Corporation (BADC)

BADC was established in 1961 to bring about a technical transformation of agriculture through the distribution of inputs and related technical support services.

BADC pioneered the introduction of mechanized minor irrigation (LLPs, STWs, and DTWs) from the 1960s, and laid the foundation for the rapid expansion that has since occurred. Activities have been progressively privatized and in 1993 Cabinet decided that all their remaining operative functions related to irrigation, distribution of pumps, and most of their repair and maintenance functions should cease.

WATER RELATED AGENCIES

Bangladesh Inland Water Transport Authority (BIWTA)

BIWTA was established in 1958. The total length of significant waterways in the country is 24,000 km of which BIWTA is responsible for maintaining 5,968 km in the monsoon and 3,865 km in the dry season. BIWTA undertakes hydrographic surveys and investigations and publishes charts and tide tables to facilitate dredging, conservancy and channel marking systems. The Department operates 50 water level recorders from which water level data is collected, compiled, analyzed, processed and published. BIWTA is also required to de-silt watercourses to maintain navigation channels and ensure proper drainage. BWDB also has a responsibility to de-silt for improvement of drainage.

Department of Fisheries (DOF)
Department of Fisheries is responsible for development of fisheries. National Water Policy implies that all agencies have an obligation to ensure that fisheries and wildlife receive due emphasis in water resource planning in areas where their social impact is high. Natural water bodies will be preserved for maintaining the aquatic environment and only those water-related projects will be taken up for execution that will not interfere with the aquatic characteristics of water bodies; and integrated projects in water bodies will be developed for increased fish production. No further reduction in dry-season water bodies will be permitted. DoF is supposed to ensure that the above guidelines are not violated.

Forest Department (FD):
Forest department is responsible for forest management programs including the issue of the logging permits, national parks and game sanctuaries and government forest lands. The Forest Department often finds itself in conflict with Roads and Highways Department and Bangladesh Water Development Board regarding road and flood embankment plantings, with agriculture in forested areas and with fisheries in coastal areas.

Department of Agricultural Extension (DAE):
DAE is responsible for agricultural extension and has five directorates: Food Crops, Field Services, Plant Protection, Cash Crops and Training. The Additional Directorate of Water Management (within Field Services Directorate) has recently been established to support minor irrigation development through a variety of programs.

Disaster Management Bureau (DMB):
DMB is required to develop early warning (using the flood forecasting by BWDB) and flood proofing systems to manage flood, drought, and other natural disasters and designate flood-risk zones and take appropriate measures to provide the desired levels of protection for life, property, vital infrastructure, agriculture and wetlands.

WATER RELATED SERVICES PROVIDERS
There are several water related service providers in Bangladesh:

River Research Institute (RRI):
Established in 1977 the RRI grew out of the BWDB's Hydraulic Research Laboratory (established in 1948) and received UNDP assistance until 1982. RRI moved to Faridpur in July 1989 to occupy purpose-built facilities on a 35 ha site with financial assistance from world Bank and UNDP.

Institute of Water Modelling (Former Surface Water Modelling Center) (IWM):
Surface water modeling activities started in 1986 under National Water Plan I. SWMC was established in 1990 as a part of National Water Plan II and became a part of RRI in 1992. After a thorough review of development options, SWMC was established as a Government-owned Trust in January 1997, with strong support from DANIDA and Danish Hydraulic Institute. SWMC has been a pioneer of numerical modelling of the nations's rivers and environmental modelling, GIS, groundwater modelling, etc. It has been named as Institute of Water Modelling (IWM) in 2002.

Bangladesh Agricultural Research Council (BARC):
BARC is the umbrella organization for ten research institutes It also carries out research in its own right.

Bangladesh Agricultural Research Institute (BARI):
BARI mainly deals with research and development of non-rice crops.

Bangladesh Rice Research Institute (BRRI):
BRRI was established as autonomous national institute in 1973. Besides developing new rice varieties, the institute is involved in irrigation and water management directed at efficient and optimal utilization of water.

Soil Resources Development Institute (SRDI):
From 1984 to present, SRDI has been working on Land and Resource Utilization Guides and has completed soil surveys and reports on all Upazilas at 1:50,000 scale.

CHAPTER 8: NATIONAL WATER PLANNING, POLICY AND LEGISLATION.

NATIONAL WATER PLANNING AND POLICY

Introduction

National Water Planning in Bangladesh dates from the 1960s. The predecessor of the present Bangladesh Water Development Board (BWDB) prepared in 1964 a Master Plan comprising 58 large-scale projects for flood control, drainage and/or irrigation.
Disastrous floods in 1954 and 1955, just seven years after the creation of Pakistan focused world attention on the importance and need for water management in East Pakistan. UNDP assistance was sought, and in 1957 the Krug Mission reviewed the situation and concluded that water resources development was essential for higher agricultural production in East Pakistan and that the control of floods was the central issue. The mission recognized that the implementation of the schemes needed would be a massive undertaking in view of the complexity of the hydrologic system, the land area to be developed and the possible need to control and train the extraordinarily large Ganges and Brahmaputra rivers, whose combined flows can exceed 140,000 m^3/s.

The responsibilities for water resources development were assigned to the East Pakistan Water and Power Development Authority (EPWAPDA), an autonomous agency created in 1959 to plan design, construct, operate and maintain comprehensive development schemes. In 1961, the East Pakistan Agricultural Development Corporation (EPADC) was created to supply seed, fertilizers, pesticides, power pumps (low-lift pumps) and other production inputs to farmers.

The decade of 1960s was one of rising pressure to accelerate water resources development. The EPADC program to distribute improved seeds and fertilizers met with immediate success as did the rental of low-lift pumps for irrigation. EPWAPDA completed a Master Plan for water resources development in 1964, undertook feasibility studies of a large number of schemes from the 1964 master plan, and initiated follow-up studies and investigations of others.

1964 Master Plan

The 1964 EPWAPDA Master Plan envisaged flood protection for 5.8 Mha of land, mainly by construction of polders. Three types of projects were envisaged: flood embankments with gravity drainage, flood embankments with tidal sluice drainage, and flood embankments with pump drainage. Irrigation within these flood protected areas were also envisaged, but flood control was given a priority in the first stage partly because of limited knowledge of surface water and groundwater resources at that time. The principle that flood control and improved drainage creates the opportunity for further development, including irrigation, became a basic tenet for water resources planning.

The EPWAPDA Master Plan included about 58 projects covering nearly the entire country. The initial and most important question was which of these should be undertaken in view of the inadequate knowledge of the hydrologic system. At the request of EPWAPDA, Prof J. Thijsse reviewed the Master Plan proposals and the entire hydrology of the country. He classified the Master Plan projects into three categories: a harmless group that could go forward immediately; a second group that would have to wait for the conclusion of extensive studies; and a third group (consisting only of the Old

Brahmaputra River Projects) which should be changed or abandoned. Thijsse proposed that development be based on a free flowing river system.

Many of these projects were implemented between the mid-1960s and late 1980s. These projects were mostly justified in terms of increased crop production and did not fully take account of the potential impacts on fisheries, navigation, forests, domestic and industrial water supply, biodiversity and salinity management.

In reviewing the 1964 EPWAPDA Master Plan in February 1966, the World Bank observed that the plan represented a useful beginning and a unique attempt to collect and bring together all the necessary data on a scale sufficient to formulate an integrated plan for development of land and water resources. While appreciating the attempt and agreeing with the generalized principles regarding the importance of flood control, drainage and irrigation, the Bank expressed serious reservations to the suggested strategy and specific proposals of the Plan. The reservations were:

- The plan overestimated the foodgrain requirements and underestimated the production potential without major projects;
- Data were insufficient to embark on massive investment projects along big rivers;
- The pace of implementation exceeded EPWAPDA's capability and resources;
- The plan did not consider changes in river regimes due to probable works in India.

IBRD Land and Water Sector Study

The struggle for independence in 1970 and 1971 greatly disrupted the functioning of Government institutions and all national life. The water development program suffered accordingly. During this period the World Bank completed a nine volume sector study to provide a basis for post-liberation development programs in water and agriculture. The Government steadfastly refused to accept the World Bank Study. Despite this, the water development program of the Government since 1973 has gradually evolved into one consistent with the strategy proposed in the study. This strategy emphasized the need for quick results from water development efforts in order to achieve foodgrain self-sufficiency in the face of rapidly increasing population and declining financial resources. It attached high priority to small and medium-sized, simple, low cost, labour intensive projects in shallow flooded areas. Such schemes would involve low embankments and gravity drainage based on simple and less sophisticated technology and would not require complex construction management. Benefits would accrue from higher intensities and yields. The main tasks of the development program were to spread HYV-fertilizer technology through water control in the monsoon season and water supply for expanded irrigation in the dry season. The water supply for dry season irrigation would be provided by minor irrigation equipment (manual, low lift pumps, shallow and deep tubewells). The strategy essentially directed investments from deeply flooded areas and the main rivers to the shallow flooded lands.

National Water Plan 1, 1986 and 2, 1991

By the early-1980s, however, the need for a long term water resources development plan became apparent and the Master Planning Organization (MPO) was established in the Ministry of Irrigation, Water Development and Flood Control. The MPO produced the National Water Plan (NWP) - Phase 1 in 1986, focusing on the assessment of water resources and future demand by future users. Phase 2 of the plan was completed in 1991. The NWP assembled a substantial amount of information, developed a range of planning models and analytical tools, and recommended strategies and programs, many of which were adopted by the government and endorsed by donors.

Despite these achievements, the MPO reports fell short of a comprehensive national water plan. First, its perspective to the year 2010 was inadequate for evaluating large-scale programs, impacts and requirements. Second, it failed to evaluate properly and integrate a number of major projects and programs within the sector. Third, programs in fisheries, navigation, public health, industries, municipalities, etc. were inadequately addressed, and their requirements taken as constraints rather than incorporated within an overall water sector demand position. Fourth, in the absence of agreements on international rivers, the plan dealt only tangentially with the different water supply scenarios.

The main focus of NWP 1 (National Water Plan Phase I) was the detailed assessment of the country's land and water resources and the water sector's development potential and the formulation of an appropriate sector strategy rather than detailed plan. It was directed more towards irrigation than FCD, partly due to concerns about FCD schemes' performance and impact. The proposed strategy comprised a mixture of small-scale private sector development and large-scale public sector development. It was not accepted by GoB because of concerns regarding the possible over-estimation of groundwater resources and insufficient priority being given to development of major river surface water resources through appropriate interventions. Like its predecessor, NWP 1 was essentially a foodgrain self-sufficiency plan, not a broad-based water development plan. Non-agricultural water-using sectors did receive mention but were not included explicitly in the Plan.

National Water Plan Phase 2 (NWP 1991) was essentially an update of NWP 1, but with a detailed investment program and list of projects. It was never accepted by GoB, for the same reasons as before, and also because it did not adequately address non-agricultural water demands and was overtaken by the launching of the Flood Action Plan (FAP) in 1989. Particular points in the NWP 2 were:

- The 20-year (1991-2010) public investment program gave more emphasis to FCD than NWP 1, with proposed development of 2.54Mha of FCD, 0.64Mha of large-scale surface irrigation, all based on pumping, and 0.97Mha of DTW irrigation. The STW irrigated area was predicted to increase by 0.59Mha over the 20 years, to 1.48Mha by 2010. The fact that this target was reached by 1992-93 illustrates the degree of underestimation of potential irrigation coverage by groundwater.
- NWP 2 acknowledged the realities of water sector development in Bangladesh (eg the O&M and cost recovery problems and the need for more local participation), even though these do not seem to have much influenced the proposed plan. It was over-ambitious with regard to public sector development capacity. Little attention was given to the institutional and other supporting measures required for success.
- Insufficient emphasis was given to rehabilitation rather than new development and urban FCD was hardly mentioned. Social and environmental impacts and aspects received little attention and the planning process was no more participatory than NWP 1.

- The opportunity to ensure the future accessibility of the large volume of data collected by NWP was missed, because the planned Oracle-based database was never successfully brought into operation.

Despite the above, both phases of the NWP made vital contributions to the knowledge and understanding of the water resources of Bangladesh. NWP data have provided the basis for much subsequent water planning. The NWP groundwater model, with updating and calibration, continues to be the principal tool used for groundwater resources assessment.

Flood Action Plan (FAP), 1989-95

The severe floods of 1987 and 1988 created a major response from the international community which resulted in regional studies and supporting studies for the preparation of a Flood Action Plan (FAP) by the Flood Plan Coordination Organization (FPCO).

FAP comprised regional planning studies, project preparation studies, data collection and analysis, pilot projects and a single institutional component (FAP 26). The different activities of FAP are presented in Appendix D. Although FCD rather than integrated water management was the dominant theme, its scope was more comprehensive than its national planning predecessors and the emphasis on FCD alone lessened as work proceeded. Noteworthy features of FAP are the following (WARPO, 2000):

- Attention was paid to urban FCD and non-structural flood proofing, although agriculture remained the main focus of regional plans.
- A thorough evaluation was undertaken of the performance and impacts of rural FCD/FCDI projects (through FAP 12) and of O&M (FAP 13), so development proposals could take due account of the experience gained.
- Social, environmental and fisheries impacts and people's participation were given particular emphasis.
- FAP's five regional planning studies differed significantly in their scope. They range from the North West Regional Study (FAP 2), which produced a full water resources development plan. These plans cannot be regarded as a suite of five similar plans to be integrated without modification into an overall national plan – their diversity is too great for that to be feasible.
- A sixth regional planning study, the Meghna Estuary Study, was undertaken later, with emphasis on data collection and the establishment of a baseline scenario. Its Draft Master Plan (November 1998) is essentially a strategy rather than a plan, reflecting the still inadequate database. It does, however, include a 10 year Draft Development Plan (March 1999) which comprises four projects proposed for implementation before 2004 and four other projects proposed for feasibility study and then implementation between 2004 and 2009.

The rehabilitation and improvement of existing schemes, rather than new development, was given little explicit attention in FAP. The FCD approach was directed towards achieving controlled flooding rather than no flooding. The concept of compartmentalization was introduced and was tested in Tangail.

The FAP Summary Report, published in December 1995, presented a proposed framework and short-term (1995-2000) program for future development. This included a modest implementation program centred on completion of FAP activities, flood proofing, river management and coastal protection, urban FCD and water and flood management. Its overall approach is consistent with the strategy proposed in the Bangladesh Water and Flood Management Strategy (BWFMS) prepared earlier in 1995.

The Bangladesh Water and Flood Management Strategy (BWFMS)
The FAP regional and supporting studies culminated in the preparation by FPCO of the Bangladesh Water and Flood Management Strategy (BWFMS) Report. The formulated strategy has been approved by GoB and endorsed by the associated donor agency.

A widespread criticism of earlier plans was that the social and environmental impacts of water resource development were not being addressed. Responding to this, BWFMS recommended that the Government should formulate a National Water Policy (NWPo) that addressed these issues and that a comprehensive National Water Management Plan (NWMP) should be prepared within this framework.

The Government acted promptly to implement these recommendations. WARPO, which was formed in 1992, took over the functions of FPCO in January 1996. The National Water Council (NWC), in a meeting on November 2, 1998 approved the National Water Policy and this was approved by the Parliament in 1999.

The BWFMS was the major strategy follow-up to FAP and became the working policy document for the water sector. Many of the BWFMS concepts were carried forward into the National Water policy, which was adopted in December 1998. They involved substantial changes from the ideas that had dominated water sector thinking until the early days of FAP. The first version was published in 1995, with subsequent versions being published in March 1997, after the signing of the Ganges Water Sharing Treaty in December 1996, and in September 1998.

The 1995 BWFMS drew together the lessons and other outputs from previous planning work into a comprehensive and practicable strategy and short-term action programme. It identified the key problems and constraints, endorsed the continuing role of the private-sector, and proposed a deliberately modest public-sector investment programme in the short term. The strong emphasis on flood proofing was a new feature. No mention was made of the huge stock of existing BWDB FCD and FCDI schemes, although the need for their rehabilitation and improved O&M was fully recognized.

Although its proposed short-term strategy differed little from the 1995 version, the March 1997 BWFMS Update proposals for the longer term reverted to the NWP approach. The emphasis was on raising rice production by means of large public-sector project. Little mention was made of O&M and institutional constraints, affordability or flood proofing.

The September 1998 BWFMS Update provided direction for the sector in the light of the 1996 Ganges Water Treaty and guidelines “for continuing the momentum of the new initiatives by undertaking essential investment program as early as possible”. It projected a probable development program for all the major water-related sectors till the year 2010, using potential projects taken from the 1995-2010 National Perspective Plan Project Portfolio, although the Perspective Plan was never accepted by GoB.

The successive versions of the BWFMS have served their purpose in helping to shape policy, but a new strategy is required now that the NWPo has been issued. A major revision of potential projects taking account of the NWPo is now in progress, through the NWMPP, with the participation of the agencies concerned. The BWFMS will have a continuing role as a source of ideas for the new strategy.

National Water Policy (NWPo)
The Ministry of Water Resources framed the National Water Policy in 1999 with the intention of guiding both public and private actions in the future for ensuring optimal development and management of water resources that benefits both individuals and the society at large.

The goal of the Policy is to ensure progress towards fulfilling national goals of economic development, poverty alleviation, food security, public health and safety, a decent standard of living for the people and protection of the natural environment.

As water is essential for human survival, socio-economic development of the country and preservation of its natural environment, it is the policy of the Government of Bangladesh that all necessary means and measures will be taken to manage the water resources of the country in a comprehensive, integrated and equitable manner.

The National Water Policy (NWPo) will guide management of the country's water resources by all the concerned ministries, agencies, departments, and local bodies that are assigned responsibilities for the development, maintenance, and delivery of water and water related services as well as the private users and developers of water resources. The objectives of the policy are broadly:

- To address issues related to the harnessing and development of all forms of surface water and groundwater and management of these resources in an efficient and equitable manner.
- To ensure the availability of water to all elements of the society including the poor and the underprivileged, and to take into account the particular needs of women and children.
- To accelerate the development of sustainable public and private water delivery systems with appropriate legal and financial measures and incentives, including delineation of water rights and water pricing.
- To bring institutional changes that will help decentralize the management of water resources and enhance the role of women in water management.
- To develop a legal and regulatory environment that will help the process of decentralization, sound environmental management, and improve the investment climate for the private sector in water development and management.
- To develop a state of knowledge and capability that will enable the country to design future water resources management plans by itself with economic efficiency, gender equity, social justice and environmental awareness to facilitate

achievement of the water management objectives through broad public participation.

The National Water Policy (NWPo), published in January, 1999, recognizes the problem of supplying safe drinking water and the need for better sanitation and drainage. One of the policy objectives of the NWPo is to *Ensure the availability of water to all elements of the society including the poor and underprivileged and to take into account, the particular needs of women.* Also one of the specific aims of the NWPo is to *Facilitate availability of safe and affordable drinking water supplies through various means, including rainwater harvesting and conservation.*

The potential conflict of priorities between water supplies and agriculture was also addressed in the NWPo through the following guidelines.

In general, the priority for allocating water during critical periods in water shortage zones will be in the following order: domestic and municipal uses, non-consumptive uses (e.g. navigation, fisheries, and wild life), sustenance of the rivers regime, and other consumptive and non-consumptive uses such as irrigation, industry, environment, salinity management, and recreation. The above order of priority could however be changed on specific socio-economic criteria of an area by local bodies through local concensus.

Decisions on water resources management in Bangladesh can affect nearly every sector of the economy and the public and therefore the NWPo stresses the importance of public participation in the decision making.

The NWPo recognizes that women have a particular stake in water management because they are principal providers and carriers of water, the main caretakers of family health, and participants in any pre- and post-harvest activities. Therefore an enabling environment will be created for women to play a key role in local community organizations for management of water resources, while the interests of women and other low-income water users are adequately protected in water resources management.

The NWPo will be reviewed periodically and revised as necessary.

In addition to NWPo, the National Policy for Safe Water Supply and Sanitation, published in 1998, states the aim to facilitate access of all citizens to a basic level of services in water supply and sanitation.

National Water Management Plan (NWMP), 1998-2002

Ministry of Water Resources started preparation of the National Water Management Plan in March 1998 with the intention of operationalizing the directives given by the Policy.

The National Water Management Plan provides a framework within which all concerned with the development, management and use of water resources and water services in Bangladesh can plan and implement their own activities in a coordinated and integrated manner, confident that in doing so they are contributing to achievement of the national goals.

The plan's conceptual framework is founded on an assessment of needs, opportunities and constraints throughout the sector. The assessments made during plan preparation have highlighted the spatial and sub-sectoral diversity of the water sector. To facilitate a fully integrated approach, both the analyses undertaken and the presentation of the plan are based on eight distinct and defined hydrological regions.

The planned activity programs have been presented in the following eight sub-sectoral clusters:

- Institutional Development
- Enabling Environment
- Main Rivers
- Towns and Rural Areas
- Major Cities
- Disaster Management
- Agriculture and Water Management
- Environment and Aquatic Resources

Each cluster comprises of a number of individual programs, with overall a total of 84 sub-sectoral programs identified and presented in the Investment Portfolio.

A pyramid of nested objectives at different levels, from cluster up to the Plan and national levels, are summarized in Appendix E. The individual program development objectives that contribute to the cluster objectives are set out in the Investment Portfolio.

The sub-sectoral programs under the clusters can be summarized in the following three broad categories.

Cross-Cutting Programs: These programs related to the actions necessary to evolve and strengthen the institutional framework and to create an enabling environment conducive to efficient and effective management of the sector. They are central to the plan as a whole and have bearing on all sub-sectoral activities and through the regions. They fully embody the key tenets of the National Water Policy and are considered priority actions.

National-level Programs: In addition to the cross-cutting issues, certain issues need to be dealt with at a national level in order to fully address the problems. These mainly related to long-term strategic security of water supplies to Bangladesh, pollution control, restoration of flood-plain and river fisheries, and other environmental management issues.

Regional Programs: These fall into two sub-categories. Firstly these are those that are generic in nature and applicable to all or most regions (eg., rural water supplies and arsenic mitigation). The second sub-category is made up of those programs which are specific to one or two regions only (eg., cyclone protection).

The draft plan was submitted to the Ministry in December 2001. The Ministry is currently examining the draft plan, it seems that additional works are required to take care of the shortcomings in the plan before it is accepted by the GoB.

Comments
Almost all of the above studies were done by foreign consultants. There were supposed to transfer of knowledge to the Bangladeshi counterpart professionals on various aspects of water planning but it did not happen. The 1964 Master Plan, 1972 IBRD studies, National Water Plan Phase 1 and 2 (1986 and 1991) did not receive approval from the Government. The draft National Water Management (1991) has not yet been approved.

In future, the main responsibility for such studies should be given to the Bangladeshi professionals, expatriate consultants may be brought in to assist and train the professionals for doing these works.

LEGISLATION

Introduction:
The section on Water Rights and Allocation (Item 4.3) in the National Water Policy provided requirement for legislation for water resources management in Bangladesh and is quoted below.

The ownership of water does not vest in an individual but in the state. The Government reserves the right to allocate water to ensure equitable distribution, efficient development and use and to address poverty. The Government can redirect its use during periods of droughts, floods, cyclones, and other natural and man-made disasters, such as contamination of groundwater aquifers that threaten public health and the ecological integrity. Allocation rules will be the formal mechanism for deciding who gets water for what purpose(s), for how much, at what time, for how long, and under what circumstances water use may be curtailed. Rules for water allocation will be developed for in-stream needs (ecological, water quality, salinity control, fisheries and navigation) during low-flow periods: for off-stream withdrawal (irrigation, municipal and industrial power), and for groundwater recharge and abstraction. Allocation for non-consumptive use (eg navigation) would imply ensuring minimum levels in water bodies used for that purpose.

Henceforth, the policy of the Government to regulate the use of water, where required, will be exercised in the following manner.

(a) The Government will exercise its water allocation power in identified scarcity zones on the basis of specified priorities.

(b) In general, the priority for allocating water during critical periods in the water shortage zones will be in the following order: domestic and municipal uses, non-consumptive uses (eg navigation, fisheries and wildlife), sustenance of river regime, and other consumptive and non-consumptive uses uses such as irrigation, industry, environment, salinity management, and recreation. The order of priority could however be changed on specific socio-economic criteria of an area by local bodies through local consensus.

(c) *For sustaining rechargeable shallow groundwater aquifers, the Government will regulate the extraction of water in identified scarcity zones with full public knowledge.*

(d) *Specific drought monitoring and contingency plans will be prepared for each region experiencing recurrent seasonal shortages of water with due consideration to conjunctive use of rainwater, surface water and groundwater and alternative ways of satisfying demand. The contingency plan will include action to limit the use of groundwater according to priorities. Appropriate provisions of law should be made to protect specific users' right in these extreme cases.*

(e) *The Government may empower the local government or any local body it deems fit, to exercise its right to allocate water in scarcity zones during periods of severe drought, and it will monitor the water regime and enforcement of the regulations through specifically designed mechanisms.*

(f) *The Government may confer water rights on private and community bodies to provide secure, defensible and enforceable ownership/usufructuary rights to ground water and surface water for attracting private investment.*

(g) *In specifying surface water rights, the minimum requirement of stream-flow for maintaining the conveyance channel will be ensured.*

Existing Water Regulations

The Table 8.1 lists existing Bangladesh legislation of relevance to water use and regulation.

Table 8.1: Summary of Existing Legislation Related to Regulation of Water.

Year	Name of Act/Ordinance	Main Agency	Main issues/items/features
1876	The Irrigation Act	BWDB	Concerns various aspects of irrigation development
1952	Embankment and Drainage Act	BWDB	Construction, maintenance and management of embankments and water courses; no provision for regulation of the use of those watercourses.
1972	Bangladesh Water and Power Development Boards Order	BWDB	Assigns control of surface and groundwater resources to BWDB
1983	Irrigation Water Rate Ordinance	BWDB and BADC	Imposition of water rates for irrigation and drainage.
1985	Groundwater Management Ordinance	MLGRD&C (LGD)	Assigns power to control irrigation tubewell installation to the Thana Irrigation Committees.
1992	Water Resources Planning Act	WARPO	Establishment of Water Resources Planning Organization (WARPO)

The most conspicuous omission from the list is any specific overall Water Law or Water Resources Act of the kind found in most countries (WARPO, Draft Development Strategy, Volume 7, Annex I, 2000). Under the concepts inherited from British Colonial rule, the right of the State to control water use is established as a general principle, but there is no detailed legislation for the implementation of this principle. Regulation of water abstractions is not possible without the legal basis that such laws provide. The Groundwater Management Ordinance of 1985 was rescinded in the late 1980s, having not been successful. A licensing system for deep tubewells (DTWs) is in operation in Dhaka and Chittagong cities, under the Water Supply and Sewerage Act of 1996. It is, however, confined to just these two cities.

In the absence of comprehensive Water Law, some existing regulatory practices run contrary to NWPo objectives. An example is shallow tubewell development in the private sector has been discouraged within BWDB surface irrigation schemes by the Board, the effect being to discourage conjunctive use, the promotion of which is an NWPo objective.

Even customary rights to the use of water and water bodies are less developed than in many countries. A major reason is that the mechanized minor irrigation sector which is by far the largest water user has developed in recent years. Private pump irrigation began on a substantial scale only about 30 years ago and many units especially shallow tubewells (STWs) have been installed in the past decade. Thus there has been not enough time for customary water rights to have evolved, unlike many countries where such rights have been in existence for centuries. Development of water rights through regulation and licensing system would therefore be starting from scratch rather than building on an existing informal (customary) system.

CHAPTER 9: WATER DEMAND AND AVAILABILITY

INTRODUCTION

The demand for water in Bangladesh in the wet season in only a small fraction of supply. Potential evapotranspiration over the five-month wet period averages about 0.56 m, compared with rainfall of 1.8 m and inflows for the period in excess of 10 m (if spread over the whole area of the country). The imbalance is so great that issues of supply and demand in the monsoon season do not arise. In Bangladesh water cannot be stored for future use as storage areas are not available and the country has a huge surplus of water during wet season that it must dispose off and a shortage of water in dry season. Demands for the seven-month dry season would be discussed.

WATER DEMANDS

Water use in Bangladesh falls within two broad categories: withdrawal uses (surface and ground water) and in-stream uses. The former includes agricultural use, potable and domestic use, and industrial use; the later is composed of fisheries (flowing and static surface water), inland navigation and management of environment including management of salinity in coastal areas.

In the past, investment in water control structures in Bangladesh provided fairly adequate access to fresh water for all users. Demand for water, however, particularly for agriculture, has been growing, creating potential for conflict among water users. The competing demands for water for agriculture, fisheries, and navigation require serious attention. Upstream developments in India have reduced the availability of surface water during dry season. With supply diminishing and demand intensifying, it has become ever more critical to develop a clear management policy.

To establish priorities for water use, the needs of various classes of users have to be examined in light of broad national objectives.

Agriculture creates the most prominent and visible demand for water in Bangladesh. It is argued that demands for increased production will increase pressure on farmers to obtain the maximum value from their land by introducing innovations in cropping and irrigation technologies and that this will ultimately lead to continuous cropping in the dry season. There is much evidence for this and cropping intensity has steadily risen over the last two decades. Water planning must anticipate this and cater for the trends by ensuring that, to the maximum extent possible, the availability of water is not a constraint to agricultural production, provided that the costs of providing water is less than its value in agriculture. In estimating potential future demand, it is therefore assumed that all land that could be irrigated is irrigated.

Domestic, commercial and industrial needs have low consumptive demands but are given highest priority under the National Water Policy. Water for domestic use is a basic human need, while commerce and industry are so important that they should not be constrained unnecessarily by water availability.

The demand for *fisheries* includes the demand for fish production in water bodies and pond, and the demand for flowing water fisheries. The minimum dry season water requirements for fisheries in rivers are in the form of pools of water for refuges. However, from April onwards through the monsoon there is a need for flowing water along the migratory routes with a depth of over 1 m. The primary fish migration routes where the minimum depth of flow should be maintained is given in Figure 9.1. The minimum flows necessary to maintain the target depths in individual rivers will depend on the river widths. These routes are of two types: those to upstream spawning areas; and those connecting rivers to water bodies and floodplains. The former tend to be along the rivers which have historically had adequate flows, while the main issue concerning the linkage between rivers and water bodies has been obstructed by embankments and water control structures constructed for FCD projects. The impact of FCD projects on fisheries has been discussed in the Chapter 13 on Conflicts in Management and Impacts of Water Resources Projects.

River transport is an important mode of communication and shipment in Bangladesh, and a network of routes as shown in Figure 9.2 has been developed by Bangladesh Inland Water Transport Authority (BIWTA) with specified depths according to the class of route as given in Table 9.2.

Table 9.1: Navigation Route Classes

Class	Depth (metres)	Length (km)	Width (metres)
I	4	683	70
II	2	1,000	30
III	1	1,905	20
IV	<1	2.380	10

The BIWTA (1989), and National Water Plan I (1986) estimated the minimum flows with existing channel conditions required for satisfactory navigation. Based on these sources, NWMPP (2000) estimated the minimum flows in each region to maintain navigability in the rivers identified on Figure 9.1. The results are given in Table 9.2.

An analysis on economic returns from various uses of water is provided in Appendix F (WARPO, DDS, NWMPP, 2001).

Table 9.2: Estimated Minimum Flows for Unimproved Navigation

Region	Flow (m^3/s)	Million m^3/s / month
Northeast	92	238
Northcentral	250	648
Northwest	90	233
Souhwest	180	467
Southcentral	500	1,296
Southeast	50	130
Eastern hills	100	259
Rivers and estuaries	600	15,552
Total	**1,862**	**18,823**

Any withdrawal from the major rivers would reduce main river flows in the Lower Meghna and alter the position of the *saline front,* drawing it further inland. The residual flow in the Lower Meghna needed to maintain salinity control at Ilshaghat has been estimated by Chowdhury (1990) to be 3,000 m^3/s.

In the South-west Region the reduction of dry season flows following the diversion of Ganges flow at Farakka in India led to an increase in intrusion of the *saline front* in the dry season. A major objective of planners ever since has been to restore the front to the pre-Farakka position. The FAP 4 study of the SW area estimated that a flow (net of any abstractions) of about 250 m^3/s down the Gorai would be needed to restore the pre-Farakka situation.

To maintain reasonable level of *environment,* some flows are normally allocated to ensure minimum flows in the rivers. These are needed to provide dilution of effluents from sewage treatment works or untreated sewage, untreated effluents and for the maintenance of aquatic life. Under MPO (NWP 1991), 40% of the flow in rivers were set aside for navigation and fisheries. In their negotiations, India and Bangladesh have recognized the need to maintain up to 40% of flows in-stream to meet environmental needs. NWMPP followed this approach.

It may be mentioned here that requirements for environment including salinity management, fisheries and navigation are not additive, maintenance of flows for the largest component will satisfy other requirements.

WATER AVAILABILITY

Surface Water

Surface water resources include the static water volume (stored surface water and residual moisture) and river flows (transboundary inflows and flow generated within the country) and computation of it is relatively simple. The volume of available surface water has been computed both by National Water plan and the NWMPP. The major uncertainty in these calculations is the upstream diversion in India. The Ganges Water Treaty of 1996 assured flows in the river between January and May. There are 53 other common rivers with India and 3 with Burma, no sharing arrangements have been worked out for these rivers.

The National Water Plan (1991) estimated the available surface water after existing uses in 1989-90 for the five regions (Table 9.3). Water availability during the minimum dry period was 3,710 million cubic meters in February 1990, during the maximum wet period, 111,250 million cubic meters in August 1990.

Table 9.3: Regional Surface Water Available For Development, 1989-90
(million cable meters)

	Dry months							Wet months				
Region	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct
NW	2,970	1,840	1,160	780	780	920	2,210	5,360	13,950	13,520	13,540	6,470
NE	5,090	1,710	710	130	230	2,480	9,680	22,290	40,840	39,800	28,860	16,350
SE	820	950	750	640	650	630	1,090	3,170	6,450	5,480	3,190	19,800
SC	8,250	4,400	3,050	2,020	2,320	3,760	7,680	14,300	35,370	44,230	40,050	20,960
SW	1,180	580	270	140	120	100	230	1,080	4,440	8,220	7,280	3,050
Total	18,310	9,520	5,940	3,710	4,100	7,890	20,890	46,200	101,050	111,250	92,920	48,810

Source: MPO 1991.

The NWMPP (2001) also computed the available surface water resources; because of the manner of presentation it is very difficult to compare this data with 1991 computations. It seems that the difference between these estimates will not be great.

Groundwater

MPO (NWP, 1991) estimated that the available groundwater in the five regions was 21,008 million cubic meters. It was also estimated that the agriculture sector was using 8,406 million cubic meters (Table 9.4). It estimated the groundwater-resource potential for agricultural use beyond 1991 was 9,447 million cubic meters, of which about 8,501 million cubic meters was likely to be exploited by 2010. The balance of 946 million cubic meters was not economically exploitable by available technology (suction mode STW) but remained a potential for the future which could be exploited by DTWs.

Table 9.4: The Groundwater Balance Derived by National Water Plan Phase 2, 1991 (million cubic meters)

Resource potential	NW	NE	SE	SC	SW	Total
Available recharge[a]	9,786	6,594	1,498	1,249	1961	21,088
Present Agricultural use[b]	3,943	2,831	630	165	1287	8,406
Domestic and industrial reserve up 2010	5,54	12,76	638	257	466	3,191
Surplus to agriculture[c]	1,026	-	-	-	-	1,026
Future agriculture development potential[d]	4,313	2,853	626	977	678	9,447
Net surplus	0	366	396	150	470	1,382
Future agricultural use up to 2010[e]						
Deep-set shallow tubewells	2,160	0	0	0	270	2,430
Deep tubewells	1,575	2,757	373	965	401	6,070
Total	3,725	2,757	373	965	671	8,501
Balance beyond 2010	588	96	253	12	7	946

NOTE:

(a) Including all planning areas except the active floodplain and the Sunderbans.

(b) Based on existing cropping patterns and 40 percent recycling of irrigation water losses.

(c) Surplus to agriculture is the difference between available groundwater and the maximum crop demand for water and land resources available under present cropping patterns.

(d) Future development potential does not balance by the volume given because for some planning areas present use is associated with domestic and industrial reserves greater than the available recharge.

(e) Based on recommended plan.

(f) Excluding surplus to agriculture of 1,026 millions of cubic meters.

Source: MPO 1991

The above estimate of the available groundwater was very conservative and the current withdrawal of groundwater is far greater than the above estimate. Please refer to Chapter 10: Water Management Interventions for the number of irrigation tubewells currently in use.

Under NWMPP (2001), 76 key Thanas (named as Groundwater Irrigation Thanas, GIT) were selected and subjected to detailed analysis of groundwater levels and historical irrigation development to determine the proportion of the Net Cultivable Area (NCA) in each Thana which can be irrigated from groundwater and residual soil moisture. Several parameters were defined in these key Thanas and were extrapolated to other Thans with similar physiography, aquifer characteristics and development trends. In these analyses, no data could be found on the total amount of available groundwater. From the suggested use it seems that NWMPP estimate on the available groundwater is significantly greater than the NWP estimate of 1991.

Groundwater is a very important resource. Its use has increased much more than ever foreseen under previous plans. Despite different assessments made in national water plans, there is no consensus on an estimate of the availability of groundwater. An effort should be made to improve the estimates. The groundwater availability and the resulting water balances may be presented as a range of values and the possible consequences of accepting the lower or upper values of the range on the need to select certain options may be pointed out. Well devised and controlled monitoring program may be set up to calibrate the groundwater models in order to come to generally accepted values of groundwater availability.

Moreover the assessment of usable groundwater should consider the arsenic contamination and other pollutants. Arsenic contamination has been found in varying degrees in groundwater in 60 of 64 Districts of Bangladesh. In the cluster surveys undertaken by UNICEF/BBS in 1998-99, previous estimates of access to safe water have now had to be revised downwards to 80% to take into account the number of wells which are contaminated by arsenic, though a more likely estimate may be 60%. The figure is constantly being revised downward as number of agencies continues to conduct arsenic testing of existing HTWs. Most recent assessments of the degree and extent of arsenic contamination across Bangladesh indicate that the problem is most acute in the northeast and southeast with significant hotspots in the southwest and northwest regions. The need to prevent very serious problems in these stricken rural areas is urgent, before illness and a new wave of underdevelopment are allowed to take root.

Arsenic contamination in groundwater is discussed in details in Appendix G.

WATER BALANCE
In the absence of significant storage for water in Bangladesh, water balance calculations were made on a monthly basis by MPO (NWP, 1991). The Table 9.5 provides the water balance for the month of March, when demands are at their greatest relative to supply. Since navigation, environment and fisheries are all in-stream uses, the problem will be to meet the demands for abstraction of the other uses, totaling approximately 15,000 Mm^3 from either groundwater or the main rivers.

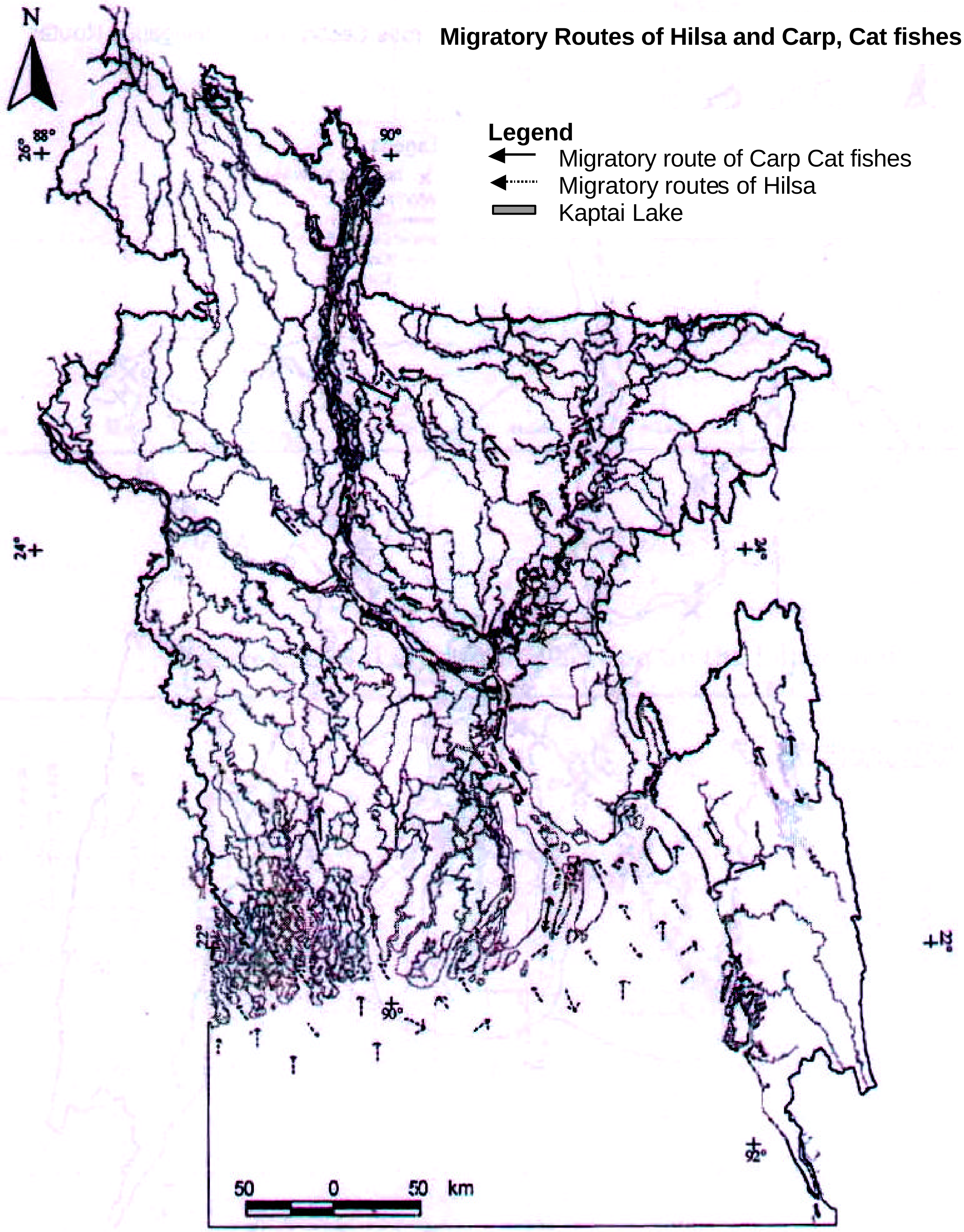


Figure 9.1 Fish Migration Routes

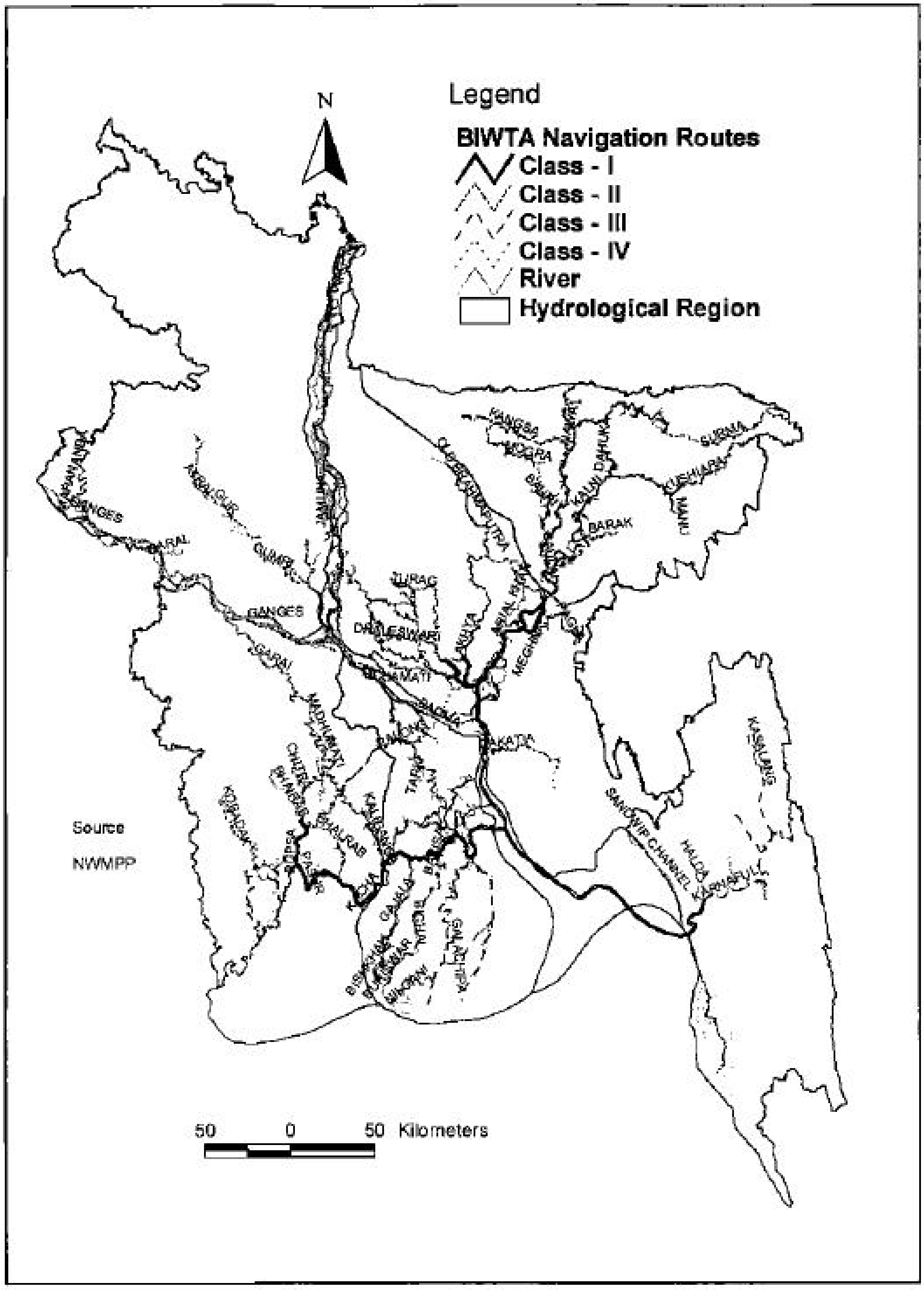


Figure 9.2: Inland river transport routes

TABLE 9.5: Projected Water Supply and Demand, March, 2018

Water Requirements	Amount (Million m^3)	%	Water Supplies	Amount (Million m^3)	%
Agriculture	14,290	58.6	Main rivers	11,740	50
Navigation, Environment and Fisheries	9,910	40.7	Regional rivers	6,390	27
Domestic uses and industry	170	0.7	Groundwater	5,360	23
Total	24,370	100	Total	23,490	100

Source: MPO 1991, Quoted by World Bank, 1998.

The above calculations showed that there would be deficit in supply in March, 2018 to meet the demands.

The NWMPP (2001) also assessed annual water supply and demand. Instead of providing the water balance in a table (as done by NWP, 1991) their results are summarized in Figures 9.3, 9.4 and 9.5 and Table 9.6. The assumption was that water requirements in GIT areas would mainly be supplied from groundwater, some surface water diversions might be necessary in GIT areas. Irrigation needs in other Thanas will have to be provided from stored surface resources or abstraction from rivers. GIT areas cover about 56% of the country.

The main criticisms about their procedure is lack of clarity in computations, excessive amount of assessed groundwater volume, no monthly breakdown of availability and demand figures and assumptions about navigation requirements which may not be acceptable to the concerned authorities.

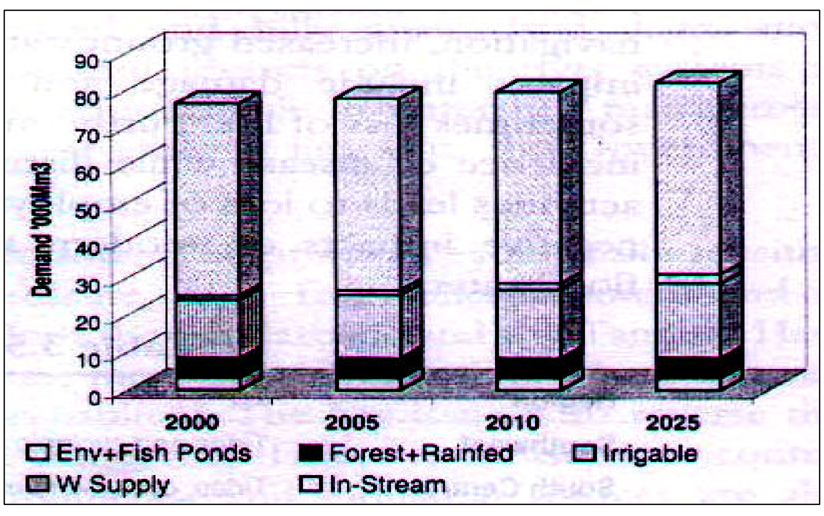


Figure 9.3: Projected water demands (NWMPP, 2001)

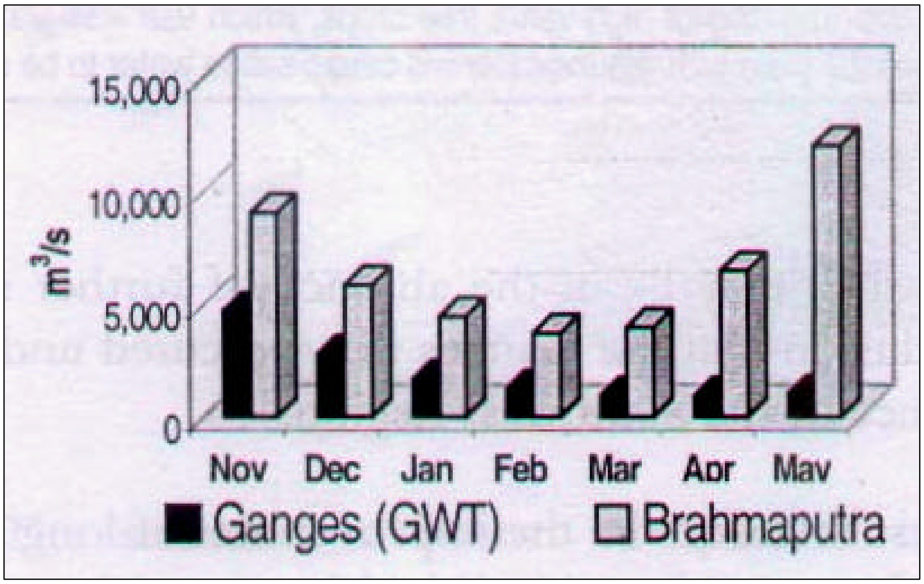


Figure 9.4: Major river inflows (NWMPP, 2001)

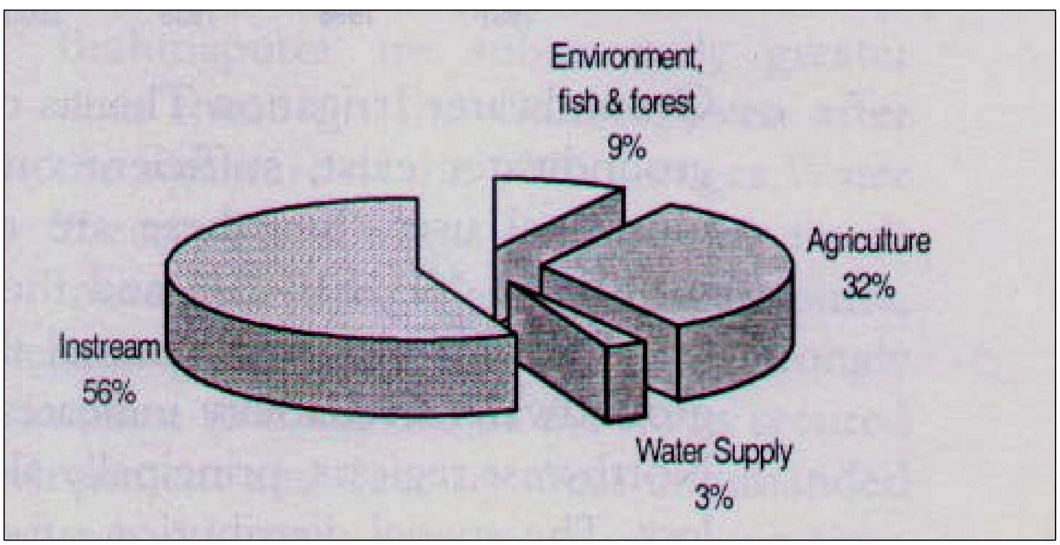


Figure 9.5: Water demands by different sectors (NWMPP, 2001)

Table 9.6: Regional Water Balances by NWMPP, 2001

Region	Assessment by NWMP
South West Region	This region is clearly the region with greatest need of augmentation, due to multiple demands and the low flows entering the region when the Gorai River is cut off in the dry season. The deficit could be made up by diversion from the Ganges, and options to do this are being reviewed in the GRRP and GDA studies. The region has a significant extent of arsenic contamination.
North East Region	There is relatively little exploitable groundwater in the area, there are large quantities of static surface water resources that could meet the demands outside the groundwater areas. However, the haor basins that contain this static water are of considerable environmental importance, and therefore water resource development of this region needs to be handled with particular sensitivity. The area is relatively highly contaminated with arsenic in the groundwater areas.
North Central Region	This region is in overall deficit and available groundwater is not enough to meet evaporative demands, and net irrigation requirements. The shortage arises because regional inflows from the Old Brahmaputra and Dhaleswari are small compared with the flows needed for navigation in the busy waterways around Dhaka. Parts of the region are contaminated with arsenic adjacent to the main river courses.
North West Region	Groundwater is generally in good supply, there are nonetheless significant parts, mainly along the border with India (notably the western part of the High Barind) that are in deficit due to low recharge. In the four northernmost thanas, although groundwater is plentiful, there is a high incidence of boulders, making drilling of tubewells difficult. The region is relatively free of high arsenic contamination, although low levels appear to occur throughout the Region.
South Central Region	There are inflows through the Arial Khan and the three Telulia channels. These natural inflows can be used to meet the potential consumptive and in-stream demands in the region
South East Region	The region experiences a deficit in the peak month of January. In the northern part, within the groundwater area, groundwater is available but is difficult to extract with suction mode pumps, as it often has a high content of gas. The area has the highest concentration of arsenic in the country, and is therefore the one where additional surface water would first be required if arsenic became a problem for agriculture.
Eastern Hills Region	This region may be viewed in two parts: the hills, where surface run-off and irrigation returns feed the plains, and the coastal plain, where they contribute to salinity control. The region as a whole is in deficit, and therefore will require a different approach to the rest of the country. In the hills for instance, there are opportunities for drip irrigation of high value tree crops, which use less water. A concern is that over-irrigation on the coastal plain with groundwater will cause saline water to be drawn in.
SOURCE:	WARPO, Ministry of Water Resources, Government of the Peoples Republic of Bangladesh, *National Water Management Plan, Main Report,* December, 2001.

The assessments in Table 9.6 confirms that diversions from major rivers are essential for supplying the required water demand. Accordingly the NWMPP recommended that *A key feature of the Plan must therefore be the improvement of long range resource and agricultural demand assessment, coupled with preparation of a strategy for maintaining water balances beyond the plan period and beyond the 2026 end-date for the Ganges Water Treaty. At the same time, treaties securing Bangladesh's share of the flows of the other 53 transboundary rivers should be ideally be brought into place. Though many of these contribute only a small proportion of the overall balance, locally they are important.*

OPTIONS TO INCREASE WATER AVAILABILITY

There are two basic options to increase availability in the critical period. One is to store monsoon excess for use in the dry season, and the other is to harness the resources of the main rivers.

In the absence of major surface storage sites, the only place to store water is in the ground, by drawing down the aquifer water table further at the end of the dry season to allow increased storage. The major issue here is whether this can be done at a cost which allows a reasonable profit margin on crops grown. NMIDP studies indicated that any water below the depth that can be tapped by VDSSTW will be uneconomic to exploit. Further lowering of groundwater tables, even if it is only on a seasonal basis, may also exacerbate the arsenic problem described earlier (Taken from WARPO,DDS, NWMPP, 2000).

Water harvesting is often cited as a possible solution, but this requires considerable investment in storage. The cost may be affordable as an alternative for drinking water where groundwater is contaminated by arsenic, but even for other domestic and livestock uses it is liable to be prohibitive (WARPO, 1998 Inception Report).

Harnessing of the major rivers using barrages to divert the flow will be expensive, but it is a solution that has been practiced widely in many countries and found to be economic. The construction of the Farakka Barrage in India in 1974 (a short distance from Bangladesh border) has demonstrated the technical feasibility of a barrage on the lower Ganges. On the Brahmaputra, the Jamuna Bridge provides a strong preliminary indication that such works, which have been given a high priority on the national agenda, are technically feasible. The issue to be addressed is whether such works can be built at a cost that is within reach of users.

CHAPTER 10: WATER MANAGEMENT INTERVENTIONS

INTRODUCTION

Flood control and drainage (FCD) systems are located in the floodplains of the rivers of Bangladesh or along the coast. Embankments along the periphery of the project area provide protection against river floods or intrusion of saline water. Regulators are constructed in these embankments to drain natural khals and to prevent backflow from high river levels into low-lying areas. Many FCD systems have field depressions in the interior, called *beels*, that contains water during most or all of the year. These are often connected to rivers through a network of khals and can only be drained when river levels permit.

The term *FCD* can be misleading, as it suggests that a certain type of water control infrastructure is used only for flood control and drainage. However, in practice it is not possible to provide full flood control within FCD systems because the rainfall runoff cannot be drained during monsoon due to high river stage. There are always flooding of low to medium low lands within the FCD areas.

To comprehend the complex nature of water management in FCD systems, it is important to understand their development.

The starting point for the development of FCD systems are the wetlands of Bangladesh. These wetlands encompass the vast floodplains of the Ganges, the Brahmaputra and the Meghna Rivers, covering some 6.3 million ha which is 42% of the area of Bangladesh. The floodplain area is a complex and diverse sub-system of the main rivers that enable the temporary storage of excess water during floods. They tend to increase enormously the fishery productivity of the river system. Two types of floodplains can be distinguished in Bangladesh, namely the internal floodplains and the deltaic floodplains.

The internal floodplains are subject to seasonal flooding during the monsoon. These floods are fairly predictable and the cropping patterns are adapted to them, although they result in low cropping intensities and crop yields. More damaging are the much less predictable flash floods (mainly in the Chittagong and Sylhet regions) during the pre-monsoon period. The situation in the deltaic plains is not much different. The area suffers from flooding during spring tides and from saline water intrusion during the dry season. Consequently the crop yields are rather low.

TYPES OF INTERVENTIONS

The different types of water management activities in Bangladesh are described below:

Flood Control and Drainage:

Flood depth, duration and timing determine cropping pattern, crop selection and yields. Since Bangladesh lacks the usual means to store flood waters except in the Chittagong Hill Tracts and the Sylhet basin, development for flood control and drainage have consisted of embankments, river closures, drainage control structures and drainage pumps where river levels prevent interior drainage by gravity. In freshwater tidal areas sluice gates are used to take advantage of tidal river level fluctuations to facilitate gravity drainage. Since the flat delta landscape provided little or no high ground, embankments are usually designed to form polders or ring dikes with road and railway embankments system. The natural river levees are usually the highest lands and embankments are constructed there to minimize height and cost but these results in narrow, confining floodways.

Gravity Drainage:
Systems based on gravity drainage provide limited water control since drainage of the accumulated rainfall within the polder is limited to periods when outside river levels are lower than those inside. Inundation of the land by overbank flooding from rivers is prevented by the embankments, and the control structures prevent backflow from river levels into low-lying areas. However, concentration of runoff inside low-lying areas of the polder restricts the benefited area. The reduced flood depths generally benefit high land and medium high land areas. Therefore, such schemes are generally more favorable where large variations in land levels do not occur. An additional benefit of these schemes is the protection of late harvested irrigated Boro rice or the newly planted Aus from damage by sudden inundation by floodwaters originating from intense pre-monsoon rainstorms. On the other hand, where access of river fish to the interior flood plains and beels is completely eliminated there is a significant negative impact on the open channel capture fishery, and this impact is rarely considered adequately in the evaluation of schemes.

Gravity drainage controls have significant impacts on the entire cropping calendar. Gated hydraulic structures are used effectively to restrict pre-monsoon backflows into low-lying areas preventing damage to the harvest of the irrigated Boro. They lower maximum flood levels in polders by preventing inundation from high river levels; and they control outflow when river levels are low thereby conserving water for supplemental irrigation of late monsoon crops and early winter upland crops. Thus the need for drainage control derives from the need to manage water levels and water supply of an area during important periods of transition between seasons and crops.

Submersible Embankments:
Submersible embankments are low embankments built around floodplain basins to prevent early flash floods (and sometimes local rainwater floods) from damaging HYV Boro rice and sometimes young Aus and deepwater Aman crops. They are especially used in the haor areas in the northeast where very deep flooding of basins prevents any crop from being grown in the monsoon season. Regulators and spillways are provided in some embankments, and internal low bunds are sometimes added to retain water and provide protection to lower-lying land in case of the main embankment breaching. The embankments and structures are submerged during the monsoon flood season.

Submersible embankments are vulnerable to breaching by early flash floods. Damage is particularly liable to occur when embankments are overtopped at a time when there is a big difference in levels between floodwater outside the embankment and land on the inside. Such floods may also damage regulator structures when flows exceed their design capacity. Maintenance of these embankments in remote areas provides a problem, and inadequate maintenance often is a contributory factor to embankment and regulator failures.

IRRIGATION SYSTEMS

Major Irrigation Systems:

Expansion of irrigated area is essential to increasing the total cropped area and cropping intensity. Because of the good water control normally available with irrigation, a high percentage of this increased cropped area is planted with hyvs. For historical and institutional reasons, non-traditional irrigation is classified into major and minor systems. The former consists of primary pumping plants and gravity diversion schemes often with canal distribution systems but also including a second lift by low-lift pumps (LLPs).

This type of projects may have several versions;
Primary Pump/ Gravity Distribution System (Single Lift): This mode, consisting of a primary pump station with gravity distribution system, is especially suited to highland areas that are not flooded. Water is delivered by single lift primary pumps into a built-up distribution system which supplies water by gravity to the fields. A separate channel network drains excess rainfall by gravity.

Primary Pump/Low-lift Pump Distribution System (Double Lift): The double lift systems uses primary pumps followed by low lift pumps. Double pumping is particularly suitable where either topography or the scarcity of land prevents construction of a built-up distribution system and where existing channels provide an adequate distribution system.

Floating Pump/LLP Distribution System (Double Lift): Pontoon mounted floating pump stations are suitable for river reaches where unstable banks, sedimentation and shifting low flow channels prohibit construction of permanent pump stations or otherwise limit abstraction by LLPs.

Barrage/Gravity Distribution System: A barrage is a gated structure spanning a river for the purpose of diverting water at a constant head to a water distribution system. A major structure, the Teesta Barrage has been designed and constructed by Bangladeshi engineers and contractors. The Teesta Barrage has been designed for a maximum discharge of 9,915 m^3/s (350,000 ft^3/s). A number of smaller barrages have also been constructed in Bangladesh. The Magura Barrage was constructed in mid sixties with a discharge capacity of 140 m^3/s (5,000 ft^3/s), and the Manu Barrage was completed in 1983 with a discharge capacity of 1,275 m^3/s (45,000 ft^3/s).

Minor Irrigation:
Traditional Irrigation: For centuries farmers have used indigenous techniques for irrigating dry season crops near low lying areas with water from beels, haors, canals, borrow pits, or perennial streams. These traditional devices are strictly manual and have low lifts. Although the dhoon and swing basket can only be operated at lifts upto 1.5 to 2 meters, they accounted for about one-fourth of the irrigated area in mid-eighties. The proportion of their contribution reduced recently due to expansion of irrigation by mechanized devices.

Low Lift Pumps (LLPs): These are centrifugal pumps used for lifting water from surface water sources. A diesel driven pump with a rated capacity of 60 litres per second typically irrigates about 16 ha.

Shallow Tubewells (STW): A shallow tubewell uses a centrifugal pump to lift groundwater by suction. The limited suction head of about 7 meters restricts use of this mode to areas where the groundwater table does not drop below 7 meters during the peak demand period. The delivery capacity of these diesel driven units averages about 14 litres/second with a typical command area of about 5 ha.

Deepset Shallow Tubewells (DSSTW): Modifications to the standard STW design are possible to increase lift limit. The most commonly practiced modification is placing the centrifugal pump set in a dug well or pit 2 to 4 meters deep, thus increasing the effective lift limit to about 10 meters. Deep set shallow tubewells are found in the high areas of Rajshahi and Bogra Barind and in Madhupur forest tract and Comilla areas.

Deep Tubewells: A deep tubewell is a cased well, with the screen usually set at about 25 to 40 metres below surface, in which a turbine pump is set. DTWs generally operate with a maximum pumping lift of 20 m. A well with a rated capacity of 60 litres per second typically irrigates about 24 ha.

Development of irrigated area in Bangladesh is provided in Figure 10.1. Details of groundwater abstraction technologies for minor irrigation are provided in Table 10.1 and Appendix A. Data of irrigated areas by minor irrigation are given in Table 10.2. Minor irrigation sector provides irrigation supplies to about 85% of irrigated area. BWDB's large scale systems irrigate the rest of the area.

Table 10.1: Groundwater Abstraction Technologies

Abstraction Technology	Abstraction Mode	Depth to Groundwater
Shallow Tubewell (STW)	Suction Mode	Less than 5 m below surface.
Deep Set Shallow Tubewell (DSSTW)	Suction Mode	5 to 7 m below surface
Very Deep Set Shallow Tubewell (VDSSTW)	Suction Mode	7 to 10 m
Forced Mode Tubewells	Forced Mode	Upto 40 m

Table 10.2: Areas under Minor Irrigation

Mode of Irrigation	Year 2002			Year 2001		
	Numbers	Irrigated Area (ha)	% of Irrigated Area	Numbers	Irrigated Area (ha)	% of Irrigated Area
Deep Tubewell	23,001	530,291	13.77	23,182	538,263	14.29
Shallow Tubewell	893,359	2,355,032	61.17	865,213	2,295,066	60.94
LLP and Floating Pumps	77,007	628,748	16.33	71,328	611,826	16.24
Manually Operated Pumps	20,169	7,460	0.19	22,919	6,536	0.17
Artisan Wells	4,785	5,324	0.14	5,321	34,487	0.92
Dug Well	5,975	286,008	7.43	-	208,331	5.53
Traditional Irrigation (Manual)	88,242	36,901	0.96	130,719	71,735	1.90
Total		**3,849,767**	**100**		**3,766,247**	**100**

SOURCE: Bangladesh Agricultural Development Corporation (BADC), *Survey Report on Irrigation Equipment and Irrigated Area in Boro/2002 Season,* Survey and Monitoring Project for Development of Minor Irrigation, December 2002

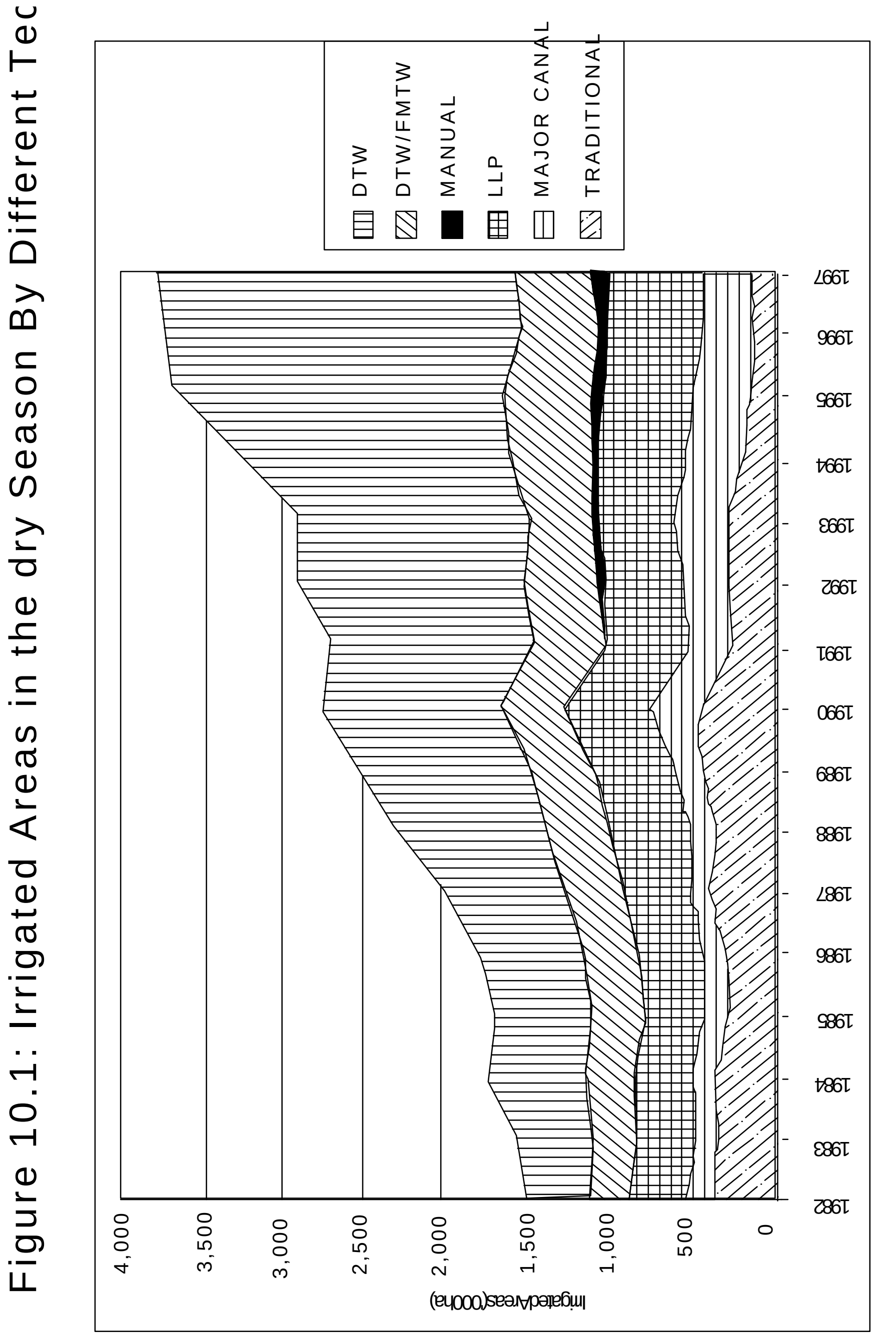


Figure 10.1: Irrigation development

Experiences with Flood Control Embankments

Benefits from flood control embankments were much less than expected. This is due to number of factors. The following factors, alone or in combination, are responsible for the structural failure of the embankments:

- river-bank erosion;
- public cuts;

- Inadequate design;
- poor construction;
- poor materials; and
- poor operation and maintenance.

River-bank erosion provides the main threat to embankments; it also provides a major hazard for towns situated along the major rivers, such as Serajganj and Chandpur. The Brahmaputra right-bank embankment (BRE) and embankments along most of the eastern rivers have been breached several times, allowing serious flooding to occur periodically on adjoining 'protected' land. More than half the 217 km length of the BRE has been retired since it was completed in 1968, some sections several times. Some retired sections are now located about 2 km inland from the alignment of the original embankment, which was built at a distance of 1.6-2.4 km from the 1968 river bank. Retirements have also been needed along sections of the Chandpur Irrigation Project embankment and embankments along some of the eastern rivers.

The Brahmaputra-Jamuna River has a marked tendency to erode its right bank, but some sections on the left bank have also been seriously eroded in recent years. Attempts to stabilize the channel near Serajganj by means of revetment and groynes have been very costly and not totally successful. The Brahmaputra has a braided channel in which unpredictable changes in flow and direction can take place, sometimes rapidly. Coleman (1969) measured lateral changes in bank configuration of up to 850 m within a single year. The lower Meghna adjoining Chandpur town and the Chandpur Irrigation Project also has experienced serious erosion problems. Erosion here and in the southwest of the neighboring Meghna-Dhonagoda project is aggravated by exposure to waves generated in the 4-5 km wide Meghna channel during the monsoon season. Along the eastern rivers, bank erosion takes place mainly at meander bends, which is more easily predictable. The Ganges and Padma rivers also have mainly meandering courses where prediction of bank erosion is simpler (though not necessarily less costly to prevent).

Public cuts in embankments occur in two situations: where people living on the river side of an embankment seek to relieve high flood levels threatening their homes or land by releasing water into adjoining protected land; and where run-off from heavy rainfall accumulates on the inside of an embankment and submerges farmers' crops. This problem has been most serious in the Chalan Beel project; public cuts have also occurred occasionally in the BRE and in embankments along some of the eastern rivers. It is a problem which could become more serious in future as population pressure grows on land lying outside major embankments and especially if confinement of such rivers by embankments along both their banks increases river flood levels.

Inadequate design has generally not been a reason for failure of major embankments. The major embankments along the Brahmaputra-Jamuna and Ganges Rivers were designed to withstand a 1 in 100 year flood, and none was overtopped during the exceptionally high 1987, 1988 and 1998 floods. Failures occurred in embankments built to lower design standards, including inadequate crest width, side slopes and berm width between embankment and borrow pit.

Two other design problems exist, mainly relating to small-scale projects. One is the lack of up-to-date topographic maps. The existing 1:15,850 and 1:7,920 irrigation planning maps with 1-foot contours were made more than 30 years ago, since when there have been significant changes in some places in settlements, roads, river courses and even in land levels (due to sedimentation and possibly to tectonic subsidence or uplift). Incorrect topographic detail can produce incorrect designs for structures which may lead to ponding of water and then public cuts or breaching. Also, different run-off criteria are used for designing structures on different projects, even within BWDB; and the maximum allowable flood depth within protected areas varies between 50 cm and 150 cm in the pre-monsoon season and between 150 cm and 400 cm in the monsoon season, both rates calculated for 72 hours duration. Whilst, to some extent, these differences reflect regional differences in physiography, rainfall and cropping patterns, there would seem to be scope for closer standardization.

Poor construction and poor materials are often related. The alluvial sediments alongside the main rivers are far from uniform. Floodplain alluvium is generally permanently saturated and unripened below a depth of 1-2 meters. Clayey and silty material taken from such layers is difficult to compact satisfactorily by the manual construction techniques generally used. Heterogeneous sands and silts also provide compaction problems. This problem is aggravated where an embankment section is underlain by sandy layers: the difference in water pressure between the river side and the land side of an embankment may then lead to piping and embankment failure unless appropriate design or construction techniques are used.

Other construction faults include: excavation of continuous borrow pits on the river side of embankments which can turn into erosive channels during floods and damage the embankment; and building embankments across old river channels without excavating the stratified, usually sandy, river-bed material and back-filling with less pervious material.

There are only a few sources of rock or hard aggregate material in Bangladesh, mainly remote from densely-populated floodplain areas. Boulders are transported from a river-bed on the northeastern border. Otherwise, bricks or concrete blocks are made for protective aprons, gabions and revetments, and broken bricks are commonly used for concrete aggregate. The products are often of low quality. Geotextiles are being used recently only in major bank protection works.

Poor operation and maintenance represents an important threat to embankment projects. Generally, the problem arises from inadequate fund allocations rather than from lack of skills or diligence on the part of staff responsible for operating projects. This can result in: lack of embankment inspections to identify potential problems; inadequate attention to routine maintenance and repairs; inability to prevent encroachment of settlers on the embankment; inability to acquire land for constructing new embankment sections when existing embankments are threatened by advancing river erosion; inadequate patrolling during floods; and inability to take emergency actions during floods.

In some polders, design assumptions are not followed during project operation: e.g., that no flow will enter from outside; that all regulators/sluices will operate simultaneously. Unplanned developments (such as new roads, drains, urban development) can also upset hydraulic design assumptions. These changes can subject structures to flows or pressures greater than they were designed to withstand, leading to risk of failure.

CHAPTER 11: WATER SUPPLY AND SANITATION

URBANIZATION

Bangladesh faces massive urban population growth challenges due to rural to urban migration, resulting from increased rural landlessness, lack of opportunities in rural areas and the effect of natural disasters in rural areas. It is estimated that between 1974 to 1981, the urban population growth rate was 10.6% per annum, declining to 5.4% recently, compared to a total population growth rate of about 2.2% in eighties. The urban population of Bangladesh has increased rapidly in the last 25 years and is now about 27million, or 21% of the total population. Dhaka accounts for over 37% of the urban population, Chittagong 11%, and the other two cities of Khulna and Rajshahi about 7%. The remaining 45% is spread among the more than 500 other urban centres, all but 15 of which had populations under 100,000 in the 1991 Census. The disproportionate rise in the urban population has created severe pressure on existing infrastructure and services including water supply, sanitation, solid waste collection and drainage services. The environmental conditions throughout most of the urban areas of Bangladesh are poor, with discharges of human and industrial wastes into river systems, possible contamination of groundwater from lack of adequate sewerage, and inadequate management of solid waste disposal. The size of the urban population, combined with limited financial resources, puts constraints on the development of adequate urban infrastructure, particularly water supply and sanitation.

SOURCES OF WATER SUPPLIES

The hydrology of Bangladesh is characterized by three major rivers, the Brahmaputra, the Ganges and the Meghna. The country experiences heavy rainfall during the monsoon, generally varying between 1,500 and 5,000 mm annually. This results in abundant surface water, which is usually polluted and requires full treatment involving clarification, rapid sand filtration and disinfection. A very high incidence of diarrhoeal and other waterborne diseases reflects the extent of contamination in the surface water and extensive use of untreated water from streams, rivers and shallow tubewells. Bangladesh is underlain by sedimentary deposits containing aquifers, which are the good source of groundwater. The groundwater requires little treatment and is used by public water utilities and private institutions as a major source of supply. About 95% of the domestic and industrial water supplies including major urban areas like Dhaka are drawn from groundwater. However, over-abstraction in places such as Dhaka is causing groundwater levels to decline rapidly, resulting in increased abstraction costs, limited water availability in the dry season in some areas, and widespread failure of shallow tubewells. As a result, there is an increasing need to supplement groundwater sources with treated surface water sources.

It is estimated that in the urban areas, about 42% of the population have access to reasonably safe water, but the remaining 58% depend on the contaminated traditional sources (World Bank, 1997).

SANITATION FACILITIES

With regard to sanitation, waterborne sewerage has been introduced only in parts of Dhaka, but elsewhere, there is general use of unsanitary latrines, direct disposal of sewage in open fields and to a limited extent, pit latrines and septic tanks. In urban areas, it is estimated that about 40% of the population have access to sanitary waste disposal facilities. Because of the limited sewerage systems and the inefficient sanitary waste disposal facilities, untreated or poorly treated domestic sewage is a major source of water pollution, and the morbidity/mortality rate due to waterborne diseases in Bangladesh is among the highest in the world.

SECTOR ORGANIZATIONS

The statutory responsibility for the water supply and sanitation sector is under the Ministry of Local Government, Rural Development and Cooperatives (MLGRDC). The Ministry, together with the Planning Commission shares the tasks of sectoral resource allocation, funding and policy decisions, as well as project appraisal, approval, monitoring and evaluation. All projects in the sector are processed through the Ministry. The Ministry's Department of Public Health Engineering (DPHE) is responsible for planning, construction and operating water supply and sanitation facilities in smaller towns and rural areas. In Dhaka and Chittagong (major cities), the Government established Water Supply and Sewerage Authorities (DWASA and CWASA) as autonomous agencies responsible for provision of water supply and sewerage services. These authorities also come under MLGRDC as public utilities. DWASA is also responsible for stormwater drainage in Dhaka. In the two cities, the Dhaka and Chittagong City Corporations (DCC, CCC) are responsible for all other sanitation activities other than waterborne sewerage. Additionally, the Local Government Engineering Department (LGED), also under the Ministry, is responsible for providing technical assistance to sanitation and other municipal services to district towns that do not have municipal corporation status.

SECTOR ISSUES

Unaccounted for Water

During a pilot leak detection and waste prevention program, it was estimated that, of the total water produced by DWASA only 44% was billed (World Bank, 1997). The reminder was attributed to administrative losses (31%) and technical losses (25%). The major losses contributing to administrative losses were: (i) incomplete customer data base; (ii) unmetered service connections; (iii) illegal and illegally reconnected service connections; (iv) inaccurate and tampered connections; and (v) wrong meter reading, faulty invoicing and rent seeking behavior by revenue inspectors. Leaking pipes, service connections, in-operational fittings, and overflow mainly caused technical losses from tanks and pump stations. Although reliable information is not available, DWASA's systems losses are between 45 to 50% (World Bank).

Lack of Commercial Orientation

DWASA and CWASA also suffer from a lack of commercial orientation and accountability, poor management systems, and shortage of trained and motivated staff (World Bank, 1997). Poor billing and collection practices, a high level of unaccounted-for-water, and high accounts receivable arrears are typical examples of the lack of accountability.

Management also lacks the necessary skills and experience to manage and operate the institution, and there are no clear institutional performance objectives and targets(World Bank, 1997). DWASA's staff is generally engineering oriented and the technical staffs are of reasonable quality. There is, however, a general lack of capability and weakness in commercial and accounting section staffs, in particular, revenue and meter inspectors. In addition, DWASA is responsible for the operation and maintenance of the Dhaka stormwater drainage system for which it has no technical staff.

As of January 1996, DWASA had a staffing ratio of 20 employees per 1,000 connections, which is considered high by most standards. On the other hand, a more representative indicator of staff efficiency would be the ratio of personnel costs to operating costs. This has been around 15% in DWASA, considerably lower than other developing or developed countries.

Resource Mobilization
The availability of local funds to support investments in the sector is generally inadequate. Government counterpart funds, even when budgeted for, are not always made available when required, due to competing demands, thus delaying project execution. Inadequate tariffs, poor revenue collection and a high level of system losses in the sector institutions (DWASA and CWASA) hamper the mobilization of adequate internal resources to finance capital expenditures for water supply and sanitation. In the municipalities, revenues are totally inadequate to finance development and operating expenditures. A 1986 analysis of 42 district towns shows that revenues on average covered only 29% of current expenditures. Foreign assistance through multilateral sources accounts for about 80% of investments in the sector.

Sector Management
Overall sector management is characterized by Government control and interference in the planning and operation of the sector entities. While DWASA and CWASA are supposed to be autonomous, most management decisions, including tariff reviews and adjustments, staffing and investment decisions have been controlled by the Government through the Ministry of Local Government, Rural Development and Cooperatives (MLGRDC). As a result, the WASAs have never had real commercial or management autonomy, which has significantly hampered their performance.

Inadequate Planning Capacity
Development in the sector tends to be adversely affected by optimistic and ambitious goals that do not take into account the physical and financial capacity of the sector institutions to carry out investment programs. Sector development activities are planned on a project by project basis, without a guiding framework. In addition, lack of clear operation and maintenance programs and funding makes planned investments unsustainable.

Water and Sewerage Tariffs
DWASA has separate tariffs for metered and non-metered customers. The metered charge (which applies to about 76% of its customers) is Taka 4.75 (US$ 0.08) per cubic meter for domestic consumers and Taka 15.75 (US$ 0.27) per cubic meter for commercial and industrial users. The remaining unmetered connections are billed on the basis of the valuation of the property supplied by the connection, regardless of the amount of water consumed. It is believed that the amount of actual consumption from non-metered connections is significantly much higher than DWASA's estimates.

The sewerage charge is 100% of the water tariffs for all water and sewer connected buildings.

DWASA’s tariffs, which are currently regulated by the Government, do not reflect DWASA’s cost structures and are not designed to respond to changes in DWASA’s financial requirements. Tariff increases have been irregular in the past. Even with recent increases, which makes the DWASA’s tariffs high by South Asia standards, DWASA is unable to fully meet its total costs. Tariffs do not properly reflect the cost of services provided to consumers because: (a) they convey the wrong economic signals, since inefficiencies and distortions (e.g., systems losses) are passed on to consumers; (b) they do not give adequate guidance on whether there should be cross-subsidies or the degree of such subsidies; (c) they do not provide enough justification on the charges being applied to small, large, domestic or commercial consumers; (d) they do not reflect externalities, (e.g., the cost of treating pollution to the water supply and how these would be reflected in the charges); and (e) being non-progressive, they encourage wasteful water consumption practices, particularly among upper income and unmetered consumers.

Unenforced Regulations
Pollution of water resources, especially of drinking water, comes in many forms, from the recently detected and only partially understood phenomenon of arsenic contamination to industrial discharges from tanneries, distilleries, pulp and paper mills, textile dyeing and other chemical industries. The other points of industrial pollution are in the Karnaphulli River in Chittagong, and Pussur River in Khulna.

With the explosive rise in urbanization over the next decades, untreated sewage could easily become the most serious source of water pollution and the gravest hazard to human health. In Dhaka, the DWASA sewage system covers only one-third of the metropolitan area, and the city’s lone sewage system is completely inadequate. About 70% of the Dhaka household that are not connected to sewers have sanitary latrines hooked into septic tanks, but the rest use either open latrines or none at all. Although Department of Environment (DOE) has promulgated standards for sewage effluents, these regulations go largely unenforced.

The passage of Environment Conservation Act of 1995 has given greater power to the Department of Environment to enforce anti-pollution laws but enforcement of those are not noticeable till now. The DOE should be strengthened to prevent the deterioration of environments in congested urban areas.

CHAPTER 12: WATER QUALITY

SURFACE WATER QUALITY

Introduction

The main quality problem with surface water is pollution from human and industrial sources. There are some particularly acute hot-spots. The worst problem is the Buriganga river in Dhaka but other rivers around Dhaka and Chittagong are seriously polluted. Power stations also did cause thermal pollution through their cooling water.

Pollution makes water unfit for uses without treatment, and has adverse effects on natural resources, in particular, fisheries.

Sediment load also constitutes a quality problem where it renders water unsuitable for certain uses without treatment, and causes bed levels in rivers to rise. This is problem over which Bangladesh has no control as the sources of sediments are outside its borders and it is expected that good catchment management practices would mitigate the problem to some extent.

Salinity

Salinity in the coastal areas is a normal hazard, but in the southwest it has been accentuated by the reduction in dry-season flows entering the Gorai distributary, following the diversion of the Ganges flow upstream of the border. Salinity now reaches as far as Khulna, and affects the supply of clean water for industrial use, particularly for cooling water use (Figure 4.4).

Salinity is also a problem for Chittagong when there are no releases from Kaptai Lake, as the saline front approaches the abstraction point for the city supply. This is a normal hazard which appears to have been overlooked by the designers of the system, and may require relocation of the intake, especially in view of the major expansion likely for the population living there.

The presence of salt water in the rivers upstream of the estuaries makes the use of groundwater near the river not usable, as there is a risk that salt water will be drawn into the aquifer. Regulations concerning groundwater use are required in these zones.

Surface Water Quality around Dhaka

The Dhaka Metropolitan Development Plan (DMDP) identified the Lakhya River as a relatively unpolluted and suitable source of water rather than the Buriganga, and suggested measures to protect it and the Balu, but none of these measures have been implemented. The 4th Dhaka Water Supply Project, dated November 1998, summarises the results of sampling made in the rivers around Dhaka. Measurements by SWMC (presently named as IWM) on coliform counts in 1997-98 produced results of 3,000-910,000 for the Buriganga, 29,000-80,000 for the Tongi/Turag, 8,500-203,000 for the Balu and 600-5,000 for the Lakhya. All four rivers show the signs of discharge of untreated sewage of human origin, and have high biological oxygen demand (BOD) values. All four rivers also have concentrations of orthophosphates, aluminium, cadmium and mercury well above acceptable standards. The Lakhya is generally of a better quality than the other rivers, but fails to meet acceptable standards, and the quality is showing a rapidly declining trend.

It would appear that relying on the Lakhya for future supplies on the assumption that unsatisfactory and declining water quality standards can be improved by effective legislation is unwise, and an alternative source needs to he found.

GROUNDWATER QUALITY

Dissolved Minerals

Except in the coastal zones, Bangladesh does not suffer problems with saline groundwater. Groundwater in the coastal zones is vulnerable to saline intrusion and abstraction will need to be monitored. Heavy abstraction of water for agricultural or industrial purposes could cause saline intrusion and render groundwater unsuitable for domestic use.

Iron in groundwater makes it unpopular for use for drinking (taste), washing (staining clothes) and irrigation (progressive deterioration of soil conditions). This problem occurs in some areas including Pabna, Atghoria, Thakurgaon and Ashuganj and can usually he overcome by sinking deeper horeholes.

In some areas the groundwater from deeper boreholes contains modest amounts of other dissolved minerals thus making the water less attractive for domestic uses.

Groundwater Table Lowering under Dhaka

Groundwater supplies about 83%f Dhaka's water supply needs, but levels are falling fast and do not fully recover in the monsoon season, indicating that mining has already started.

The drawdown is already drawing water in from the surrounding rivers and, in the case of the Buriganga, from the aquifer on the other (south) side of the river. Since these rivers are heavily contaminated, and the aquifer south of the Buriganga is contaminated with arsenic, the quality of the aquifer is at risk. Metals will tend to be absorbed on clay particles in the upper strata, but as water is drawn from relatively shallow depths, this protection cannot be expected to last for long.

Fertilizers and Pesticides Residues

National Minor Irrigation Development Project (NMIDP) indicated that average annual application rates of fertilisers were in the order of 100 kg/ha of nitrogen, which was considered low when taking into account the fact that cropping intensities in the country are high. However the rates in Bogra, Comilla and Chittagong are higher than this, especially at Bogra, where cropping intensity is the highest in the country. There is cause for concern for the future, as application rates will need to he increased in some parts of the country and at certain times of the year if the yields of HYV varieties are to be sustained or improved, especially in areas which are under rice monoculture. Such levels of use create problem for the aquatic environment from high nitrogen and phosphate residues, which might contribute to eutrophication processes in open shallow standing water, and possibly the development of toxic algae, especially in times of high sunlight levels.

Recently published results of detailed sampling and analyses of pesticide residues as part of the FAP regional studies found only one sample site which gave cause for concern, and even in this most extreme case the results were still within international limits. Earlier references by NMIDP and the World Bank indicated that, in overall national terms, application rates of pesticides and herbicides were very low by international standards, so for the time-being they were not considered a major problem in Bangladesh. If agricultural productivity increases, there might well be increased problems in the future. However, there is already concern at the level of pesticide use on vegetables.

FAP 17 and FAP 3.1 projects carried out testing to determine agro-chemical residues in fish tissue. The results indicated that there were low levels of pesticide residuals in fish tissue but they were not considered harmful to humans.

Worldwide, however, there is a trend towards making agro-chemicals more environmentally friendly and using integrated pest management (IPM) techniques. Given the sensitivity of the Bangladesh environment, with its extensive wetlands and dependence on aquatic systems, it is essential that such efforts being made in other places be replicated countrywide. At present, there appears to be a low level of awareness among farmers of the benefits of appropriate fertiliser use, and inadequate affordable crop credit to allow them to follow good practice.

Arsenic Contamination

Arsenic in groundwater was identified in Bangladesh in 1993. The full extent of this problem has yet to be defined but the problem is most strongly concentrated in the South West, South East and North East regions of the country. Some 20 million people are now considered at risk from arsenic in their drinking water.

Preliminary findings indicated that the distribution is far from uniform. In some hot spots all tubewells are contaminated while in other places both positive and negative results are obtained for different tubewells in close proximity. Some tubewells, which were initially not contaminated, are now affected.

At present, arsenic contamination has been found in shallow tubewells. Wells over 250 m deep are very rarely contaminated. There are suggestions that further lowering of ground water table by deep tubewells may contaminate deeper aquifers.

Further testing increased the known number of arsenic-infected wells, particularly since a new low-cost field test kit has been developed in Bangladesh. Few kits can detect concentrations below 20 ppb.

Opinion was divided as to whether increased abstraction of water for irrigation has caused an increase in the concentration of arsenic in groundwater. One group suggested that there is no evidence to prove any linkage apart from the fact that the recorded increase in the incidence in arsenic in groundwater has coincided with the general increase in the use of groundwater for irrigation. At the same time, the number of tubewells for domestic water, and the number of people using this source of water, has substantially increased over the same period. The weight of opinion at present is that there is no connection. Other groups claimed that the greater incidence of arsenic in groundwater is due to increased abstraction and lowering of ground water table.

Recent research indicates that arsenic does not accumulate in the rice grains, but is concentrated in the roots. It has been shown in studies that some green leafy vegetables accumulate arsenic.

The issue of arsenic and the potable water supply is discussed further in Appendix G. However, research is urgently needed to improve understanding of the mechanisms involved and the risks, particularly in the context of irritated agriculture

Farmers are likely to continue to use groundwater for irrigation unless an equally reliable and cheaper alternative becomes available. Should some crops be found to accumulate arsenic then controls on their production will have to he considered. However, this may be difficult to implement in a situation where the arsenic contamination of the water is unevenly distributed.

SUMMARY ON WATER QUALITY

Surface water in ponds is already contaminated throughout Bangladesh from faecal matter, and many smaller rivers with low flows are likely to be similarly contaminated in the dry season. Around Dhaka, the problems with industrial effluents are already serious, and the situation is probably similar in the other cities, except that large main river or tidal flows dilute their effluents. The result is merely to transfer the problem to the Bay of Bengal, the place where much of Bangladesh's fish and crustaceans spawn or pass through their juvenile phases. The long-term damage that is likely to result risks destroying the source of much of the protein on which people depend. Dilution is not the answer and environmental clean-up programmes are essential. This may be accomplished by encouraging the industry to install recycling systems.

Groundwater problems, apart from arsenic and faecal contamination, have yet to develop seriously, due mainly to low levels of agro-chemical use. There is a major risk that the search for higher yields and more intensive cultivation will lead to uncontrolled use of chemicals, and this must be safeguarded against.

CHAPTER 13: CONFLICTS IN MANAGEMENT AND IMPACTS OF WATER RESOURCES PROJECTS

WATER MANAGEMENT CONFLICTS WITHIN FCD SYSTEMS

The design of FCD systems primarily aims at establishing conditions for the adoption of HYV rice by reducing the annual depth, timing and duration of flooding. The expected increase in agricultural production, and to some extent the protection of homesteads against floods, has always been the primary economical justification for their construction. From an agricultural perspective the objectives of FCD systems are to:

- Protect standing Boro/Aus against early river floods (flash floods);
- Reduce salt Intrusion **(**in the coastal belt);
- Expand the area under HYV Aman by either excluding or reducing flood depth within the system during the monsoon; and ;
- Retain water in the system during the post-monsoon period.

Although FCD systems serve to boost agricultural production, agriculture is not the only activity in FCD systems that depend on water. The objectives mentioned above often conflict with water management demands from other stakeholders, such as:

- Fisheries: fish production demands flooding of the floodplain during specific periods;
- Transport: water transport is an important means of communication;
- Domestic: surface water is important for domestic purposes, such as drinking water and sanitation;
- Salt production: demands the entry of salt water into the system;
- Shrimp production: also demands the entry of salt water into the system; and
- Livestock: surface water is important for the watering and washing of livestock.

Not only are there conflicting interests between different sectors in FCD systems, also within the agricultural sector there are diverging water management demands:

- Low land farmers demand early drainage at the end of the monsoon;
- High land farmers demand the retention of water in the low lying areas of the system;
- Low land farmers demand the retention of rain water and overland flow on the high lands during the monsoon, as the release of this water floods their land; and
- High land farmers demand drainage of excess rainwater and overland flow from their lands.

Moreover, certain stakeholders have their own specific requirements. Owners of irrigation pump owners who sell water, for example, want to secure their share of surface water and construct cross dams in *khals* to do so and may obstruct drainage. Shrimp farmers need high water levels of salt water inside a system, while salt producers demand low water levels. Often this does not conflict, because shrimp are cultivated in the monsoon and salt is produced in the dry season. More and more, however, shrimp cultivation is also taking place in the dry season, leading to conflicts with salt producers. Lastly, a special category of stakeholders, namely those living outside a FCD system but affected by it, place another type of demand on FCD systems. Often "outside" stakeholders cut embankments to get relief from flooding or they demand that their land is also included in the system.

This multitude of water management demands within one FCD system lead to many different water management options and critical moments in water management. They also lead to the following conflicts between stakeholders, because the demands are often characterized by mutual exclusivity. These demands have a strong time aspect, which defines the critical moments in water management (BWDB, SRP):

- **fisheries vs. agriculture:** fishermen require high water levels right from the start of the monsoon, while farmers require low water levels to harvest their Boro/Aus crop and to grow an Aman crop;
- **high land vs. low land in beels:** high land farmers want to retain water in the beel during the dry season for low-lift pump irrigation while farmers with land in the beel (low land) want to drain the beel so that they can cultivate;
- **high land vs. low land in general:** a common feature of FCD systems is that draining the high land leads to drowning the low land. In the wet season high land farmers drain their land thereby flooding the low land. During the dry season they demand water retention in low-lying areas. Low land farmers aim at drainage during the wet season and want water retention on high lands;
- **drainage vs. water retention:** at some point in time the choice for water retention needs to be made. This generally entails the construction of a cross dam or the closing of a gate. Intervening too early may cause flood damage by the last storms of the season, too late will limit reduce the volume of water retained;
- **flood protection vs. drainage:** the construction of embankments leads to higher flood levels outside the FCD system. "Outside" stakeholders often try to cut the embankment to pass floods through the system, while "inside" stakeholders try to protect the embankment to avoid flooding;
- **navigation vs. agriculture:** access to water ways is blocked by structures, navigation always requires high water levels, while agriculture requires varying water levels;
- **salt and shrimp vs. paddy:** the need for saline water for salt production and shrimp farming hampers agriculture. In several cases precautions are taken to limit this conflict (partition dykes) but in many cases the operation of the infrastructure leads to conflicts among different interest groups;
- **agriculture vs. domestic:** the use of surface water for agricultural production during the dry season makes water scarce, to the detriment of domestic water use;
- **drainage vs. road transport:** embankments are cut to alleviate drainage problems. This severely impedes transport on the embankments;
- **security vs. social:** flood and river erosion result in people encroaching on the embankments and building houses and gardens on them. This weakens the embankment, increasing the risk of flooding.

It can be concluded that the most important characteristic of water management in FCD systems is that there are many different water management stakeholders, each with different, often conflicting water management demands. An important question in this regard was the extent to which a stakeholders occupation or location determined his level of interest in water control. A list of stakeholders is given in Table 13.1 (BWDB, SRP). Thinking in terms of different categories of stakeholders is important because it sensitizes one to the fact that the users of FCD systems are not a homogeneous group of "beneficiaries", but rather individuals with differing water management interests. The above facts explain why performances of FCD projects are short of expectations.

Table 13.1: Water Management Stakeholders in FCD Systems

Type of Stakeholder	Demand in Dry Season	Demand in Wet Season
Low land Farmers in beels	Drainage of beel	Flood protection
High land farmers in beels	Water retention in beel	Flood protection
Fishermen in beels	Water retention	No gated structure to interfere with fish migration from rivers
Low land farmers	Drainage	Flood protection, water retention on high land
High land farmers	Water retention	Drainage
Professional fishermen	Almost full drainage	Maximize fish production through flooding
Shrimp farmers		High levels of saline water entry into the system
Salt producers	Low levels of saline water entry into the system	
Pump owners (LLPs)	Water retention	
Boatmen	High water levels throughout the year	
Households	Water retention	
Agricultural laborers	A well managed WM-System leading to improved employment opportunities in agriculture	
Transporters/traders	Well maintained embankments	

SOURCE: BWDB, Systems Rehabilitation Project

IMPACTS OF WATER RESOURCES PROJECTS

As described in previous section, water resources development for agriculture may have unfavorable impacts upon others users of the resource. The major impacts are described below.

Fisheries
Embankments for flood control, drainage and irrigation have a negative impact on fisheries because they reduce floodplains and obstruct fish movement from rivers to the remaining flood plains for breeding and feeding. Typical pre- and post FCD/FCDI conditions in Bangladesh are shown in Figure 13.1.

Impacts of FCDI project on fisheries are well illustrated by the effects on the Chandpur Flood Control and Irrigation Project. Construction of an embankment around the project area (555.5 square km) and blockage of the South Dakatia River were found to produce the following impact:

- Overall fish production from the open water resources within the project area declined by 35% over the first two years of the project.
- The regulators (water control structure) on the rivers prevented recruitment of major Carps (popular and expensive fish in Bangladesh) into the South Dakatia River. As a result, the major Carp fishery inside the project area disappeared.
- High valued commercial giant freshwater prawns in the project area were replaced by less valuable small species.
- Since the embankment, 18 species of tidal or estuaries origin fish were obstructed from entering the project area by regulators and embankments. Hilsa, previously a good commercial fishery in the South Dakatia River, disappeared.

Although FCD and FCDI projects reduce the open water fishery, they may create a potentially more controllable and manageable habitat for closed water culture fish production. However, lack of natural recruitment into the water bodies would require that populations be maintained through artificial stocking. Taking the Chandpur FCDI Project as the example, the ponds were no longer inundated and restocked naturally with fish on a yearly yearly basis after closure of the embankments. Therefore, a fish hatchery was established by the Directorate of Fisheries (DOF) to provide fish seed and aquaculture support services for the open and closed water bodies of the project. The impact of the hatchery has been very significant to the pond culture within the project area, but the open water fishery has not received the support in fish seed and management envisioned.
Construction of the coastal embankments has reduced the coastal tidal plain habitat available for marine shrimp and fish. The extent of fishery losses has not been quantified. The embankments have provided a more stable environment for the development of brackish water aquaculture in areas where introduction of brackish water is permitted.

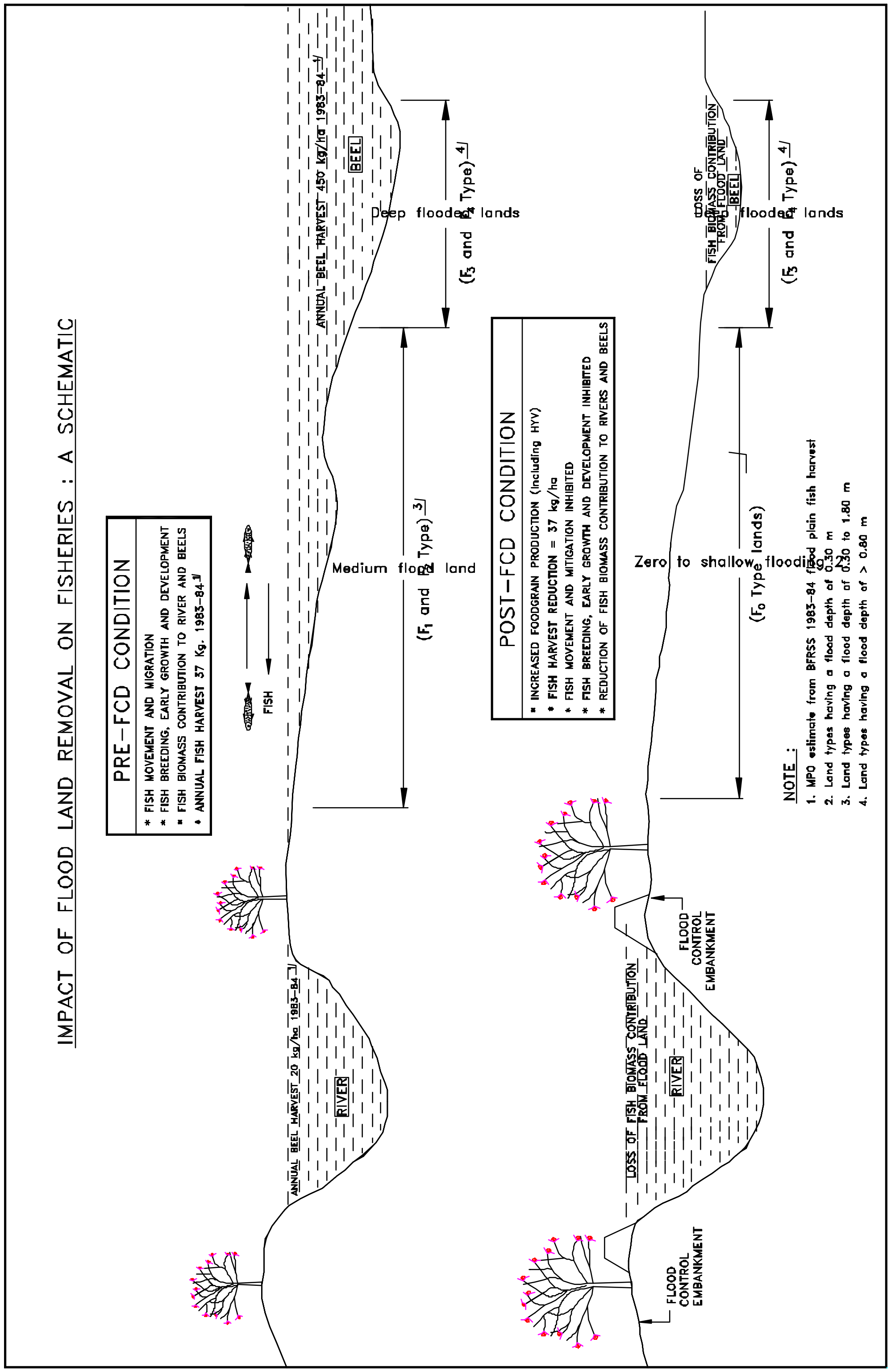


Figure 13.1: Impact on flood land removal on fisheries

Increased Flood Stage in Embanked Reach

Embankments restrict the channel width by preventing flow on the flood plain, and this results in increased stages in the embanked reach. Channel improvements, which usually accompany embankment construction, increase velocity and may offset some or all of this increase. If stages in the embanked reach are increased, stages will also be higher upstream from the embanked reach. Downstream from the embanked area peak flows will be increased because of lessened channel storage as a result of the increase in the flow velocity. The net result of dike construction depends very much on the physical characteristics of the situation. Usually, however, embankment construction for flood-mitigation works resulted in a general increase in flood stages along a river unless extensive channel improvements are provided.

The increase in stage following dike construction has sometimes led to unfortunate consequences. An area protected by embankment may find itself endangered and perhaps flooded because of new embankments constructed in the vicinity. Excessive encroachment on the floodplain initiates a cycle of higher stage which leads to failure of embankments and extensive flood fighting which may offset the economic advantage of protecting more floodplain land from flooding. Table 13.2 shows the effects of some FCD projects on the embanked rivers.

TABLE 13.2: Backwater Effect of Confinement of Rivers by FCD Projects

River	**Discharge m^3/s**	**Project**	**Length of Confinement (km)**	**Rise of Water Level (m)**			**Flood Frequency**
				U/S End	Maximum	D/S End	
Dhaleswari	1,700	DSW	159	0.3	0.61	0.15	100
Kaligonga	4,530	DSW	63	0.61	0.61	0.15	100
Buriganga		DSW	35	0.15	0.15	0.15	100
Atrai-Gur-Gumani	1,190	CBP	157	2.61	0.90	0.90	100
Barnai	790	CBP	87	3.75	4.12	3.41	100
Barnai	490	CBP+BP	53	2.30	N.A.	2.30	20
Nandakuja	255	CBP+BP	35	2.56	2.74	2.68	100

SOURCE: National Water Plan, Master Plan Organization 1986

Data covered only the medium-sized rivers.
DSW: Dhaka South West Project, CBP: Chalan Beel Project, BP: Bogra Project

Public Cuts of Flood Embankments

Public cuts in embankments occur in two situations: where people living on the river side of an embankment seek to relieve high flood levels (as explained in previous section) releasing water into adjoining protected land; and where run-off from heavy rainfall accumulates on the inside of an embankment and submerges farmers' crops.

Public cutting of embankments is often as much an institutional problem as a technical one. It generally reflects inadequate consultation between project management and the local public during project design or operation. Various ways to increase or improve public involvement in project identification, design, management and operation have been suggested: prior consultation; public relations activities; formation of embankment committees; involvement of local government in management; local ownership. Some of these methods are currently being experimented in Bangladesh; most are more appropriate for small-scale projects than for major ones.

Technical modification of project design or operation may also make it possible to eliminate the problem or problems which induce the public to cut embankments. Consultation with local residents will identify the difficulties. It then needs to be determined what might he the most appropriate local solution to the problem.

(a) provision of a drain, regulator or pumps to relieve ponding of rainwater behind an embankment;

(b) modification of the rules for operating a regulator or regulators;

(c) resettlement of people adversely affected by the project;

(d) a change in project design to reduce the command area or the kind or level of flood protection provided; and

(e) possibly, if conflicts cannot be resolved, abandonment of the project (but possibly with the substitution of another kind of project to cater for local development needs).

Siltation Of Waterways

Siltation of waterways is a major problem in Bangladesh. The problem is acute in the Coastal Embankment Project (CEP), where drainage channels have been choked up and sluice gates have been clogged. Construction of CEP was started in 1961-62. By 1984, about 626 km of channels had been silted up in the southwest region alone. Siltation in some of the channels is very high (0.5-1.0 m per year). Possible causes of siltation of waterways are the following:

- Decrease of tidal prism,
- Decrease of upland flow, and
- Confinement of channels.

Analyses of data from Polder 1 of Coastal Embankment Project showed that the volume of the tidal prism was about 92.9 million m^3 prior to construction of dikes in 1962, but after the project in 1970 it was only 7.90 million m^3. Subsequently the volume has been further reduced.

Maximum siltation occurred during the dry season when there is no upland flow. Upland flows of all the rivers in the southwestern region hve been greatly reduced due to large withdrawals of waters for irrigation from the Ganges outside Bangladesh. Confinement of rivers also increased siltation because silt that used to be deposited in the floodplains was deposited in the channels.

Morphological Changes in River Systems

Effect of confinement of smaller channel by FCD projects on both sides is similar to the effect of narrowing a channel during the high flood stage when the banks are submerged.

At the upstream of the narrowing section where the hydraulic slope flattens, there will be deposition, with degradation occurring downstream. When the banks are not submerged the river may still have the narrowing effect if some water that had flowed out through distributaries were blocked by a FCD project.

For major channels, such as the Ganges, the Brahmaputra, the effect of flood control is difficult to predict. Complete control of a river of the size of the Jamuna-Padma-Lower Meghna has not been attempted anywhere in the world.

Frequent breaching of an embankment and vegetation growth within a confined channel may seriously affect the channel section. There may be heavy deposition below the breach as water will flow through the breach and decrease velocity downstream. Vegetation in the channels increases friction and causes silt deposition.
Another interesting phenomenon is observed in the Dhaleswari-Turag-Buriganga complex near Dhaka. This area is deeply flooded. During the flood season the northern end of Buriganga becomes a large lake with high depth of water filled by overflow from the Turag, Dhaleswari and Bangshi Rivers. Most silt in suspension is deposited here. This is probably the reason why the navigation route from Dhaka to Manikganj is heavily silted up. After confinement of the channels by FCD projects the flow may be concentrated in the channels increasing their carrying capacity and reducing siltation. From the above it is apparent that the effect of FD projects is a complex subject which needs a thorough study with collected data and models.

Rural Domestic Water Supply
There is a substantial conflict between expanding irrigation abstractions by mechanized shallow tubewells and the viability of potable water supplies obtained through suction lift hand tubewells (HTWs). The Department of Public Health Engineering was very successful in implementing rural water supply program based on groundwater withdrawals from shallow aquifers using HTWs. The large scale of groundwater-based irrigation has resulted in declining groundwater levels characterized by increased depths to the water table before the monsoon season. By the early 1980`s, a growing number of suction pumps were found to be going out of action during the dry season, as the water table fell below the suction limit (approximately 7.5 meters). The problem is aggravated by the fact that many handpumps are located on village mounds, the higher habitation areas built to protect the people from the annual flood waters, increasing the pumping lift by about 2.5 to 3 meters above the land level. It is estimated that substantial part of rural areas may be unsuitable for HTWs during dry months. .

CHAPTER 14: IMPACTS OF CLIMATE CHANGE

EFFECTS OF CLIMATE CHANGE

The probable effects of global climate change have been examined in general by the Intergovernmental Panel for Climate Change (IPCC) and are regularly reviewed. The findings for Bangladesh have been studied in detail by BCAS (1994), Warrick (1996), Stratus (1998) and Huq (1999) amongst others. The most recent projections set out the changes anticipated in Bangladesh, which are:

(i) A rise in sea level in the order of 300 mm by the year 2030 and 700 mm 2075. This suggests a rise of 250 mm by 2025, at the rate of 10mni/year.

(ii) A rise in monsoon season temperature of 0.7 C by 2030 and 1.1 C by 2050. Dry season temperatures would rise by 1.3 C by 2030 and 1.8 C by 2050.

(iii) An increase in monsoon rainfall of about 10% by the year 2030 and 25% by 2050. Dry season rainfall is projected to reduce in the long term.

Climate change will also affect flows in trans-boundary rivers. Temperature changes would affect the timing and rate of snow melt in the Upper Himalayan reaches, which would alter the flow regime in the rivers which originated in the Himalayas. Lower dry season rainfall and increased water demands due to higher temperatures would increase abstractions from rivers upstream and reduce the flow reaching Bangladesh.

Results of the above studies indicated that the possible impacts of climate change for Bangladesh would be the following:

During wet season (monsoon)

- there will be increased flooding due to increased monsoon season rainfall.
- There will be deterioration of drainage congestion, waterlogging and flooding due to higher sea levels and a consequential rise in river bed levels. Higher sea levels will increase the tide-locked period for tidal drainage sluices and reduce their drainage capacity.
- coastal erosion may increase marginally due to greater foreshore depths and corresponding wave depths.

During the dry season

- There could be changes in the balance of recharge and demand on aquifers due to changes in climate parameters. Further studies would be required to assess the changes more accurately.
- Reduced transboundary surface water inflows into Bangladesh due to increased demand in upper riparians experiencing lower rainfall and higher temperatures and more abstraction upstream of Bangladesh.
- Disturbance of existing morphological processes by the changed balance between wet and dry season flows and changes in sediment transport and deposition caused

by changes in flows and water levels. This will affect bank erosion and channel sedimentation.

- Increased incidence of cyclones making landfall due to reduced energy losses aver warmer areas in the Bay of Bengal

Calculations have been made for the key meteorological stations in Bangladesh of the changes in rainfall and potential evapotranspiration. The average for the country are shown in Figures 14.1 and 14.2.

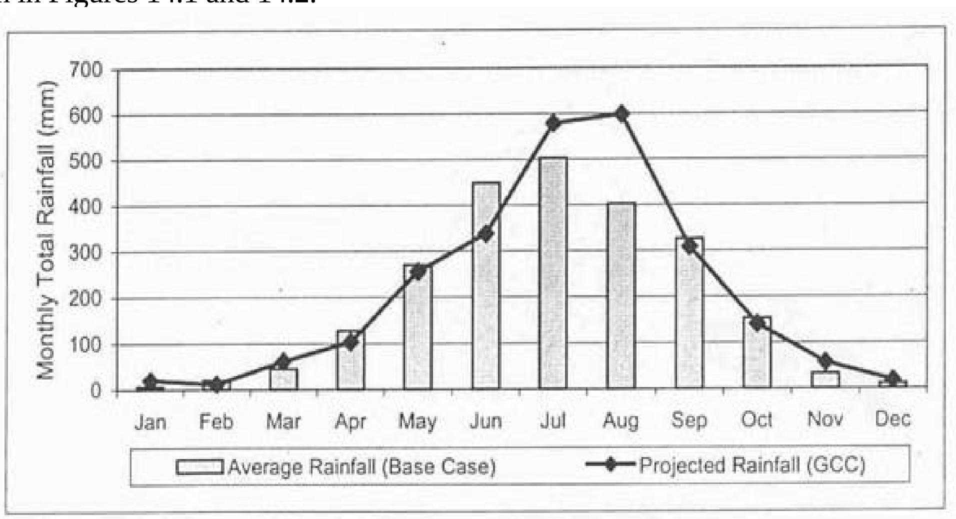


Figure 14.1: Changes in rainfall in Bangladesh due to global climate

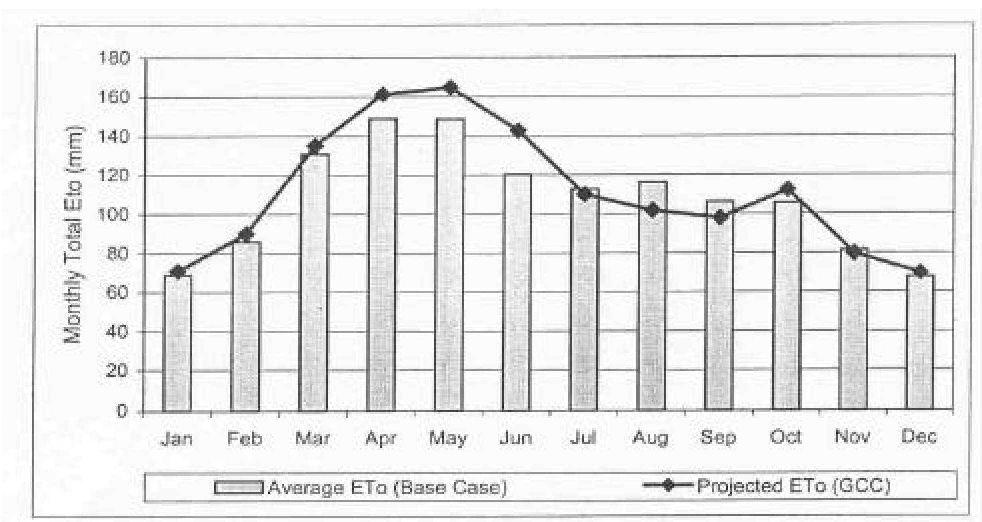


Figure 14.2: Changes in potential evapotranspiration in Bangladesh due to global climate change (SOURCE: WARPO, 2000)

In general, the combination of increased rainfall and unchanged evapotranspiration in the monsoon results in increased recharge. By contrast, the combination of unchanged rainfall and increased evapotranspiration in the dry season results in increased demands.

For thanas having major areas under groundwater irrigation, the results are almost the same as the present situation, and no additional surface water would be needed to allow irrigation. However, in a drought year with climate change, the imbalance of supply and demand would rise by almost 50%, underlining the importance of using FMTW to allow such variations to be accommodated.

ADAPTATIONS TO CLIMATE CHANGE

Studies (references mentioned above) have been undertaken regarding adaptation to climate change in Bangladesh and there appears to be consensus that the country is too vulnerable to be able to ignore the anticipated effects in current and future planning.

Many of the proposed strategies which are those needed even without climate change effects in order to accommodate the needs of the rising population.

The basic strategies identified for accommodating the effects of climate change are:

- Physical measures to reduce drainage congestion (or at least avoid worsening of the present situation). Existing and proposed infrastructure must be examined to determine whether changes that enhance natural drainage processes are appropriate. Many man-made interventions not only impede flows but also promote channel siltation. One of the major causes of drainage congestion is the deposition of fine sediments brought in the dry season during tide in the SW and SC Regions. Measures such as providing increased freshwater flow in the SW would be very useful.
- Pumped drainage may be required.
- Land filling using natural or artificial methods to prevent, or at least reduce, inundation and promote drainage.
- Increased tree and mangrove planting on accreted lands and in coastal belts.
- Encourage more efficient use of water resources.

The planning and design of future projects will need to take account of climate change effects.

Capturing part of the sediment load of the major rivers to build up low-lying land could be one strategy to combat sea level rise and effectively builds on the natural delta-building processes. A rate of deposition that would match the rate of sea level rise may be feasible.

CHAPTER 15: REGIONAL COOPERATION FOR WATER RESOURCES DEVELOPMENT

MAJOR ISSUES IN WATER RESOURCES PLANNING

The Critical issues that the water planning in Bangladesh will have to address include:

Floods:
Much of Bangladesh is flooded every year, and agriculture and human settlements have adapted to normal floods caused by rainfall or overbank flow from rivers. But severe monsoon floods, like those of 1987, 1988 and 1998, cause significant damage to crops and property. The impact of recurrent floods on this small, densely populated nation, and particularly on its agriculture, becomes more serious with each successive event. Population pressure is compelling more and more people to live in flood-prone areas. The impact of recurrent flooding across the economy imposed an unacceptable toll on the quality of life and the country's economic prospects. The flood mitigation measures by works (mainly flood embankments) within the country did not produce desirable results.

Increase in dry-season flow to manage drought:
Following the monsoon, the availability of soil moisture declines and falls short of crop demand during dry season. The dependable rainfall between November and May is almost zero. Potential soil moisture deficiencies over 6 to 7 months (November to May) seriously limit crop production. It is not possible to grow paddy without irrigation during this season. Drought during pre- and post-monsoon also causes significant crop losses. Increase in dry-season flow to meet the water requirements for domestic and industrial water supply, irrigation, salinity control, fisheries and navigation is essential.

Control of sedimentation in major rivers:
Bangladesh is the outlet for all the major upstream rivers and the average annual sediment load that passes through the country to the Bay of Bengal ranges from 0.5 billion to 1.8 billion tons. A part of this sediment load is deposited on the flood plain, gradually changing its topography and seriously reducing the water conveyance capacity and navigability of the drainage channels. Major source of this sedimentation is outside the borders of Bangladesh.

River bank erosion:
High water velocities during flood season, large seasonal variations in river flows and the gradual shallowing of river beds cause river-bank erosion and migration of channels. During 1982-1992, a net area of 87,000 ha was lost to erosion and thousands of people lost their homes and agricultural land (WARPO, 2000).

Salinity control in coastal areas:
Salinity intrusion is a major problem in the southwestern region. The process has been exacerbated by the reduction of the Ganges flow during the dry season. The reduced flow has enabled the northward movement of the salinity front and tidal limits, threatening important urban and industrial areas like Khulna and the economic viability of over 25,000 square kilometers of the Ganges dependent areas. Control of salinity would require greater dry-season flows in the Ganges.

Pollution of surface and groundwater:
Unchecked dumping of industrial and municipal wastes in rivers and streams, and contamination of both surface and groundwater from agricultural chemicals are fast becoming serious problems for both human and aquatic life in the country. Another major pollutant is the arsenic in groundwater.

Regional cooperation for mitigation of water related problems in Bangladesh
Most of the above problems in Bangladesh could be solved through regional cooperation among the countries in the basins of the Ganges, the Brahmaputra and the Meghna Rivers.

Problems of floods, increased dry season flows and salinity control in coastal areas may be taken care of by constructing storage reservoirs in the upper catchments of the Ganges, the Brahmaputra and the Meghna Rivers. Due to its flat topography, suitable sites for reservoir construction are not available within Bangladesh. It is expected such reservoirs would have positive impacts on river erosion, siltation and water quality. These storages would minimize the flood peaks and would reduce erosion and siltation. The increased dry season flow would reduce the dependency on groundwater.

A major option for significant flood reduction and augmentation in the Ganges river system - which can benefit Nepal, India and Bangladesh - would be to construct large storages on the tributaries originating in Nepal. The terrain of the northern and middle belts of Nepal offer excellent sites for storage reservoirs.
Studies in Nepal have identified 28 potential reservoir sites - nine of which are classified as large, each having live storage capacity of over three billion cubic metres. From the Bangladesh perspective, the storage project in Nepal which has the maximum potential for augmenting the flows at Farakka is the Sapta Kosi High Dam Project. This reservoir envisages a live storage of about nine billion cubic metres, and the stored water behind the High Dam could augment the Ganges flow and benefit both Bangladesh and India. It must be repeated here that storage reservoirs in the Himalayas would have to be multipurpose in nature in order to be economically justifiable.

The issues of population displacement and seismic hazard have often been raised against the schemes for large reservoirs in the Himalayas. These socio-environmental issues are very important and cannot be ignored and can be constructively and equitably addressed during project planning and implementation, and need not hold back pursuit of long-term visionary goals.

Sharing of Transboundary River Flows
Three large interacting river systems stretching over several countries would necessarily generate issues or problems of sharing transboundry water flows in dry season among the upper, middle and lower riparians. In the Ganges, the Brahmaputra and the Meghna rivers basins, Bangladesh is the lowest riparian with 54 rivers entering the country from India. Since Bangladesh receives the residual flow after upstream utilization, shortage of flow in the dry season has always been an issue during water sharing negotiations with India. Of the 54 common rivers, sharing arrangement has been agreed upon only in the case of the Ganges. The Governments of Bangladesh and India signed a Treaty on the dry season sharing of the Ganges Waters in December, 1996 (Appendix H). The Treaty is for duration of 30 years, renewable on the basis of mutual consent. Under the Treaty,

specified quantities of water are to be released at Farakka for downstream flow into Bangladesh between January 1 and May 31.The Ganges Water Treaty has provided Bangladesh with an opportunity for environmental restoration of the Ganges Dependent Area (GDA), *i.e.* southwestern Bangladesh.

The Ganges Water Treaty of 1996 recognized the need for augmenting the dry season flows of the Ganges, urging the two governments "to cooperate with each other in finding a solution to the long-term problem of augmenting the flows of the Ganges during the dry season."

Assured in-stream flows in the Ganges, resulting from Ganges Treaty, has offered Bangladesh the potential for surface water augmentation in the GDA through the construction of a barrage on the Ganges between Hardinge Bridge and the Ganges-Brahmaputra confluence. Although barrage construction has a long gestation period, this would be the most potential means for effective utilization of the Ganges through maintaining the dry season water level in the barrage pond at a controlled height at or near bank-full level and resuscitate the shrinking distributaries in the GDA, and this project should be an integral part of the long-term vision for Bangladesh.

The Ganges Water Treaty of 1996 states in Article IX that both Bangladesh and India should endeavour to "agree to conclude water sharing Treaties/Agreements with regard to other common rivers".

Following the 1996 Treaty, the Indo-Bangladesh Joint Rivers Commission (JRC) agreed to set up a Joint Committee of Experts (JCE) to work out arrangements for long-term/permanent sharing of the waters of common rivers between the two countries in phases. The climate, therefore, is favourable for negotiating arrangements in sharing of all common or transboundary rivers between Bangladesh and India.

It was agreed by the JCE to examine and negotiate the sharing issues in phases. In the first phase, seven medium sized rivers are being considered, viz, Teesta, Dharla and Dudhkumar in the north west, and Manu, Khowai, Gumti and Muhuri in the east. However, the JCE accorded priority to the sharing of the Teesta river - especially because both countries have constructed barrages on the Teesta, and since both of them are based on the natural flows of the river, and the low season flows are inadequate for the combined needs of the two countries. Some progress on the sharing issue has been achieved. Meanwhile, the tying up of the embankment along the Teesta right bank at the border has been completed.

Although the sharing negotiations in the past had been very lengthy and difficult, the expectation now - following the 1996 Treaty - is that there will be equitable sharing of the lean season flows of not only the Teesta, but also for all other common rivers. Since the Teesta, by itself, has insufficient flows to meet the requirements of two projects (one on each side of the border), it may be useful to examine seriously the option for Teesta augmentation as well as coordination in operation of the two barrages. Parallel with the sharing issue, the co-riparians should also agree on an arrangement whereby all countries are kept informed of any intervention in the international rivers so that there is a transparent and trusted partnership among all countries in the GBM region (Ahmad and

Rasheed, 1994). This will, also facilitate a continuous assessment of trade-offs towards ensuring a balanced future for all.

Hydropower

The hydropower potential of the GBM Basins is vast. Yet, ironically, the per capita energy consumption in the region is among the lowest in the world. The energy economy of the countries in the GBM Basins is highly dependent on non-commercial sources, mainly derived from biomass. In the past, efforts have been made by each of the regional countries to develop hydropower within its own territories to meet domestic needs. But cooperative efforts to produce and share hydropower have not been pursued.

Nepal is the leading country in the GBM Basins in terms of hydropower potential (Ahmad and Rasheed, 1994). It has a theoretical potential of 83,000 MW, and an economic potential of about 42,000 MW. In India, the GBM Basins region has an identified potential of over 45,000 MW, while Bhutan's hydropower potential is put at over 20,000 MW. Bangladesh does not have topographic conditions favourable for hydroelectricity generation. The country's lone hydel plant in southeastern hills has an installed capacity of only 230 MW.

The energy demand in each of the countries in the GBM Basins is steadily rising. Against this backdrop, it is essential that the region formulate a vision and develop an integrated plan of action for hydropower development and sharing on a mutually beneficial basis. The hydrocarbon fuels are non-renewable resources, and their continued use would bring adverse effects on the environment. Hence, the use of environment-friendly, clean and renewable energy like hydropower should be part of a vision for sustainable development in the countries in the region.

The economic justification of reservoirs in the Himalayas for flood moderation and flow augmentation is increased manifold when they also produce electricity for the region. Such projects will not only cater to the needs of Nepal or Bhutan, but may focus on the vast and growing energy market in northern India as well as in Bangladesh. As a matter of fact, the countries in the region can share the costs and benefits of such multipurpose reservoir projects on agreed terms. It is necessary, therefore, to visualize and plan for the establishment of an inter-country energy grid stretching across these countries. This interconnected grid would facilitate the integration of different power systems across the region and allow Nepal and Bhutan to export excess hydropower to India and Bangladesh.

Regional Cooperation for Water Resources Development

The countries in the GBM Basins is characterized by endemic poverty and progressive environmental degradation (Ahmad and Rasheed, 1994). Yet, there are enormous possibilities for the region's development - pivoted around its huge water resources. Water indeed could be the principal vector of development towards shaping the future of millions of people in this region. What is needed is a visionary perspective to develop a macro framework for a cooperative development of the countries of the GBM Basins (Ahmad and Rasheed, 1994).

Nearly five decades of national development efforts have been unsuccessful in evolving a long-term vision of a concerted effort in a holistic regional development framework. In the absence of a vision for regional development, national efforts for poverty reduction and infrastructure development did not succeed in producing the results that an appropriate regional approach would have. Investments in infrastructure and sharing of transboundary resources under mutually beneficial arrangements have remained minimal and largely unexplored.

Water based integrated development and management would be the major option with great potential for future development in the GBM Basins region (Ahmad and Rasheed, 1994). A long-term regional water vision, involving the GBM Basins countries, should be built on the premise that the supply side is likely to remain largely finite, while the demand will continue to rise in the next century at a rapid pace. In order to meet the challenges of water utilization as a transboundary resource in the region, it is imperative for the countries in the GBM Basins to identify sectors and issues where cooperative strategies and action plans can be formulated for the benefit of all, using water as the focal take-off point. A number of options and opportunities exist for collaborative efforts in such sectors as flood management, equitable apportionment of water, dry season flow augmentation, hydroelectricity trade, water quality improvement, and inland navigation. Mutual of mistrust, lack of effective dialogues and differences in perception had so long impeded the development of a long-term regional water vision. Policy environment in the region has undergone changes in recent years, and the opening of a "window of opportunity" has produced a favourable climate for mutual cooperation towards regionally integrated development. The 1996 signing of two landmark water treaties: the Ganges Water Sharing Treaty between Bangladesh and India (Appendix F) and the Mahakali Treaty between India and Nepal have ushered in changes in favour of cooperation in the countries in the GBM Basins. It is, therefore, possible now to envision a progressive journey toward further cooperation in water-based integrated regional development.

CHAPTER 16: CONCLUDING REMARKS

INTRODUCTION

The river systems, many of which originate outside the country, have shaped much of the history, economy, literature and rich culture of the people.

With a current population of 130 million expected to rise to 181 million by 2025 and to 224 million by 2050, Bangladesh faces many challenges ahead in an era of increasing globalization. Rapid urbanization is expected with 40% of people living in towns and major cities by 2025, and 60% by 2050 (Chapter 2). Poverty is still endemic with over half the population classified as poor (Chapter 2). The recent discovery of arsenic contamination of the shallow aquifer has set back past successes in bringing safe water supply to the rural population in particular (Appendix G). Pressures remain on agriculture to intensify production and to achieve self-sufficiency in food-grains. Aquatic resources and the natural environment are under severe threat from changes in flood-plain management over the last three decades and, more recently, from an alarming rise in pollution due mainly to industrial growth and poor sanitation.

Flooding occurs regularly each year to 20% of the country, extending to more than 60% in peak floods (Chapter 5). Flooding enriches the fertile soils of Bangladesh, but exceptional floods can also bring severe hardship. The generally low-lying and flat topography presents special challenges to drain the land and control erosion in the main and regional rivers.

After the monsoon season, the availability of soil-moisture declines and falls short of crop demand during the dry-season (Rabi) season. Then during the pre-monsoon and post-monsoon seasons, erratic distribution of rainfall also causes soil-moisture deficits for crops. Potential soil moisture deficiencies over 7 months seriously limit crop production in Bangladesh.

Climatic changes are expected to increase flooding, reduce drainage flows and increase water demands in the dry season. These changes will also exacerbate the frequently occurring natural disasters such as cyclonic storms that sweep each year over the coastal areas from the Bay of Bengal (Chapter 14).

There is a growing need for providing total water quality management (dealing with surface water salinity in the coastal areas, deterioration of surface water and groundwater quality, and water pollution), and maintenance of the eco-system. There is also an urgency to satisfy multi-sector water needs with limited resources, promote efficient and socially responsible water use, delineate public and private responsibilities, and decentralize state activities where appropriate. All of these have to be accomplished under severe constraints, such as lack of control over rivers originating outside the country's borders, the difficulty of deltaic plain, and the virtual absence of unsettled land for building water structures (National Water Policy, Ministry of Water Resources, Government of Bangladesh, 1999).

GoB's overall policy aim for the agricultural sector is to increase production so as to ensure food security and improve the incomes and living standards of the people. Of Bangladesh's total area of 14.8 Mha, the net cultivable area (NCA) is 8.80 Mha. NWMPP projections predict that this will drop by about 7% by 2025, to 8.18 Mha, mainly as a result of growth in urban areas. Pressure on land is severe, with the rural population density being the highest in the world. At present all of the arable lands are cultivated. In future the increase in crop production would come from either increase in yield or in cropping intensity. The need for intensification of agricultural land use and production is acute. The water sector has a crucial role to play in this process through irrigation and reduction of flooding.

Land availability is more of a constraint on crop production than is land suitability and soils. The only substantial soil constraints are salinity in parts of the coastal areas and the light textures of some soils, mainly on the higher alluvial lands.

Major rice crops are Aman in wet season which is mainly rainfed and HYV Boro in dry season which is dependent fully on irrigation. In order to increase production, Aman would require controlled flooding so that high yielding varieties can be grown supported supplementary irrigation. Boro would require irrigation.

Effective FCD

Increased crop production, in future, would be possible through effective flood control in monsoon and provision of irrigation during dry season.

The success of a national flood control plan for Bangladesh hinges on a viable solution being found to the problem of river bank erosion along the Brahmaputra-Jamuna river. Control of flooding from this river is the linchpin in the national flood control strategy. Without control of flooding along this river, it will be impractical to control flooding in the densely-populated central parts of Bangladesh and in areas downstream along the Padma and the lower Meghna.

A solution to this problem is not yet in sight. The history of the Brahmaputra Right-bank Embankment (BRE) project has been one of continuous retreat. This has been expensive not only in terms of the costs incurred in repeatedly retiring eroded or threatened sections of embankment and in attempting to defend Serajganj town, but also in terms of the land, crops and property that have been lost or damaged due to river erosion or breaches of embankment.

The technical methods for stabilizing river channels are well known and these are all in use in Bangladesh. The major problem is with applying these techniques on a braided river of the size of the Brahmaputra and the huge costs involved in constructing and maintaining structures on the scale required. A French study team (French Engineering Consortium, 1989) estimated that river training works to protect embankments built along the whole length of Bangladesh's major rivers could cost US$ 5-10 billion, with annual operation and maintenance costs between US$ 165 million and 418 million. Among the technical difficulties contributing to these high costs are: (a) lateral bank erosion rates of up to 800m/year on the Jamuna river; (b) water velocities during floods up to 4.5 m/second in the Jamuna and Lower Meghna; (c) local scour depths of 30-50 m near river banks; (d) the enormous sediment load of the Brahmaputra and the Ganges, which make dredging impractical for channel deepening; (e) the incoherent nature of many floodplain sediments; (f) the scarcity of suitable rock in the country for constructing river training works; and (g) the high cost of land acquisition for making new structures and channels.

A Chinese-Bangladesh Joint Expert Team carried out a study on total confinement of the Jamuna River in 1991. This study proposed confining the river channel within an average width of 4.5 km (5.0 km for braided section), using the concept of node control developed on the Yangze and Yellow Rivers in China. The cost of the project was estimated at US$ 1,650 million between the confluence with the Dudkumar and the Ganges Rivers, a distance of 250 km. However, the study did not appear to have received much attention, possibly because of the high cost involved.

Ubtil now, the FCD interventions were solely by embankments within the country and were not very effective for containing floods in major rivers (Chapter 10).

Dry season Irrigation

Irrigation in Bangladesh is divided into two categories, major and minor irrigation. Major irrigation, which accounts for only 10% of the total irrigated crop area, comprises the BWDB schemes. Most of these are FCDI schemes, because they have FCD as well as irrigation component. Minor irrigation mainly comprises irrigation by tubewells, low lift pumps and traditional irrigation based on gravity supply and manual lifting devices. Minor irrigation is largely farmer-owned. Recently LGED has developed public sector irrigation for a very small area. At present minor irrigation facilities (tubewells, low lift pumps and traditional methods) irrigate about 85% of the irrigated area., STWs alone irrigate about 65% of the irrigated area (Table 10.2).

Most of Bangladesh's agricultural land is irrigable. Water availability and the profitability of irrigation, rather than the quality of the land itself, are the key determinants for developing additions irrigated crops.

Since the accessible surface water resources (excluding the major rivers) are already more or less fully exploited, further growth of surface water irrigation is dependent on additional supplies being made available through development of major rivers (the Ganges, the Brahmaputra and the Meghna).

The scope for further expansion of tubewell irrigation will depend on the seasonal watertable lowering in the later part of dry season and the recharge during the monsoon.. Even with very deep setting, suction mode shallow tubewells (STWs) cannot draw from a static water level of below 9m. Below this level, force mode pumping is necessary, with much higher capital costs per hectare and is not affordable for most farmers.

Will arsenic contamination in groundwater significantly affect irrigated agriculture? If it does, a cutback in tubewell irrigation might become necessary. No definite answer is available now.

The Main environmental issue concerning groundwater irrigation is the effects on domestic rural water supplies and earlier drying of water bodies and small rivers and khals. Almost all of existing 10 million handpums used for rural water supplies are suction mode pumps. These pumps can pump water from watertable depth of about 6-7m. Most of these pumps are sunk near village homes located at higher elevations. In areas of intensive STW irrigation, watertables drop to the levels beyond the handpumps pumping limits resulting in disruption of rural domestic water supplies. Force mode handpumps

(Tara Pumps) are being tried in some of the areas where suction mode hand pumps do not operate in later part of dry season. Tara pumps are expensive, not easy to operate and their numbers are limited.

Major Rivers Development

The Aman production did not increase greatly during the last few decades despite substantial investments on FCD projects. Increase in Aman production would depend on regulation of monsoon flood levels in major rivers, development of viable FCD projects (Chapter 3) and provision of supplementary irrigation.

For increase in Boro production, it is necessary to develop additional irrigation facilities. During the last decade, most of the additional irrigated areas were provided with supplies from groundwater. Considering uncertainties regarding availability, quality and impacts on other sectors by grater groundwater withdrawals, attention should be given to the development of major rivers on an urgent basis.

Development of major rivers (the Ganges, the Brahmaputra and the Meghna) would require cooperation from countries in the region; India, Nepal and possibly China.

Development of major rivers may include (a) construction of storages in upper catchments in Nepal and India for hydropower generation, augmentation of dry-season flows and flood moderation; and (b) construction of barrages within Bangladesh for irrigation in dry-season and supplementary irrigation in late monsoon, control of salinity in coastal areas and fisheries.

Major dams have been suggested as a means to reduce monsoon flooding. However, there are arguments that if major storages are constructed in Nepal, the impact on flooding in Bangladesh would be small, as the flood volume is huge and the stage-discharge curves are extremely flat.

Analyses demonstrated that proposals for augmenting flows by dams in the Himalayas are technically feasible provided the conditions exist for building the dams. These conditions concern political relationships, investment conditions for development agencies or direct foreign investment, and socio-cultural attitudes towards major infrastructure development, particularly in relation to environmental conservation.

The political climate has improved to the point where the Mahakali treaty between India and Nepal (creating the necessary conditions for the Pancheswar dam), and the Ganges Water Treaty between India and Bangladesh (creating the conditions necessary for use of the Ganges water in Bangladesh) have both been signed. This has been a favorable development.

Trade relations are developing fast in the region, and liberalization of trade, removal of tariff barriers and obstacles to transit and cross-border activity are improving economic growth. However, neither India nor Bangladesh has resolved the issues in the power sector sufficiently to create a climate suitable for attracting the private sector to show interest in long-term projects such as dam construction.

Attitudes towards environmental conservation have hardened in recent years and international funding agencies are showing extreme reluctance to participate in large dam construction projects. The withdrawal of funding in Ataturk dam in Turkey, Sun Kosi dam in Nepal, Sardar Sarovar dam in India and the Three Gorges dam in China have meant that only countries with large economic resources are able to proceed with dam construction.

Construction of barrages is possible within Bangladesh. In addition to the already constructed Teesta Barrage, there are proposals for constructing barrages on the Ganges between the Hardinge Bridge and Pangsha, on the Brahmaputra between Bahadurabad and Jamuna Bridge and on the Meghna at Bhairab Bazar. The barrages would make surface water available for multiple uses including irrigation during dry-season and supplementary irrigation.

The Ganges Barrage deserves much closer study at present, as there are unsatisfied demands for irrigation in the south of the service area, arsenic contamination is widespread, salinity poses an important constraint to use of both surface and groundwater, and sedimentation due to saline tidal flooding is a major problem. The social and environmental benefits appear high, but the economic viability is yet to be confirmed following reduction of multi-purpose benefits for the barrage by construction of the separate Paksey Bridge.

Extensive information are available on the benefits of storages in upper catchment in studies by Ahmad (1994), Ahmad and Rasheed (1994) and their colleagues in India and Nepal.

MITIGATION OF FISHERIES IMPACTS

The most serious environmental and social impact of FCD has been its adverse effects on capture fisheries. Construction of embankments have cut fish migration routes between the rivers and floodplains and, together with the reduction in surface water areas of beels and floodplains, has drastically reduced capture fisheries. Installation of fish passes and fish friendly structures may be able to reverse the capture fisheries losses to some extent. The Pilot Fishpass Project connecting the Manu River and Kawadighi Haor in NorthEast Region is an example of successful fishpass. The need to restore fish migration on FCD schemes, through fish passes and fish friendly structures and other measures, is now widely recognized. What is needed is development of appropriate designs for such structures for different situations.

DREDGING

Due to the very heavy sediment load, dredging was found to be not feasible in the past except at local situations. A three-year dredging program on the Gorai river was taken up by BWDB. In the first year (1998-99), capital dredging work amounting to 7.70 Mm^3 was undertaken over the first 20km reach, and the diverted flow was enough to scour out the 20 km for another 10km. However, according to surveys carried out in September 1999, 60% of the channel was refilled by the monsoon flow. The maintenance dredging was found to be much higher than expected.

OTHER CONSIDERATIONS

Considerable sums of money have already been invested in construction, rehabilitation and improvement of coastal embankments. The early gains in agricultural benefits have been largely lost due to increased *drainage* problems. Increased efforts are required to alleviate the drainage problem that affects so many polders. Up to now, coastal FCD rehabilitation has tended to concentrate more on the polder embankments than on drainage systems. The same has happened to upland FCD. Always there is emphasis on FC (embankments) but not on drainage (maintenance of adequate size for drainage channels). This is mainly due to land acquisition problems.

Inadequate stakeholder consultation and participation has been a major shortcoming. It has affected all stages of the project cycle, from initial planning through to O&M. However, the problem has been recognized by GoB and strong efforts are being made to rectify the situation. Guidelines for people's participation in public sector projects have been developed

Inadequate O&M has been a major problem on virtually all public sector schemes. Its causes include inadequate GoB funding, poor cost recovery, lack of beneficiary participation and the technical difficulties associated with FCD and irrigation development under Bangladesh conditions. High siltation and erosion rates are the most serious problems. As a result of the generally poor maintenance, long-term sustainability is lacking and the GoB schemes are now in an unsatisfactory state of repair and in need of rehabilitation. Definition of an appropriate policy on the future of the existing BWDB rural FCD and irrigation schemes is one of the greatest challenges..

Poor cost recovery and inadequate cost sharing has been another widely recognized problem. For practical reasons GoB does not introduce cost recovery for FCD schemes. Irrigation water charges are applied in only few BWDB schemes and are set at too low a level. Collection rates are minimal. The poor collection rates is partly a reflection of the poor quality of the irrigation services provided, due to O&M deficiencies. On small-scale developments, the beneficiaries are now required to meet all O&M costs, but capital cost sharing arrangements vary considerably. For example, a 30% contribution is required for NMIDP khal re-excavation but only 1.5-3% (plus 30% of the land cost) for LGED's SSWRDSP schemes which also include khal re-excavation.

Most projects initially achieve their technical objectives until poor O&M reduces performance. Project design has often been satisfactory, except for drainage within FCD schemes, but inadequate design has still been a common problem, due specially to shortage of funds and the resultant emphasis on least-cost solution (WARPO, DDS, 2000). Construction standards have been generally adequate, apart from the widespread problem of insufficient earthworks compaction. Drainage congestion has been by far the most serious technical problem with FCD schemes. A common shortcoming has been the lack of consideration given to external impacts (higher flood levels outside polders, reduction of river flows downstream of rubber dams) and adverse internal impacts (such as siltation), and to the inclusion of mitigation measures (structural flood proofing to mitigate higher external flood levels). Inaccurate maps and other data deficiencies have also caused difficulties.

Inadequate monitoring of project performance, linked with corrective action to rectify the problems thus identified, is a major shortcoming. If, for example, the performance of the Coastal Embankment Project initiated in the 1960's had been better monitored, the importance of the increasing drainage congestion would have been better recognized earlier. It might then have been possible to mitigate drainage difficulties on existing projects and also to modify the design of new projects in order to minimize such problems in the future.

Public sector institutional weaknesses have been a major constraint on project effectiveness. They have resulted in widespread delays in implementation, often leading to cost overruns, and inadequate O&M of completed projects. Procurement (mainly contract awards) and slow disbursement of funds have been particular problem areas.

There has been a general lack of integrated water management planning. Such planning would have enabled better account to be taken of the characteristics of the overall regional/ sub-regional hydrologic system, its implications for a project's design and operation and the external impacts which a project is likely to have.

Gender impacts have been mixed except in projects like Barind Multipurpose Development Authority (BMDA) where women were chosen specifically to work as operators of electrified DTWs or in Embankment Maintenance Groups (EMGs). In these projects, women were given specific opportunity to work in manual gangs or to supervise khal excavation.

Smaller-scale projects have generally performed better than larger-scale projects. Management of smaller units is less complex, simply because of the smaller area and numbers of beneficiaries involved.

Benefits from FCD and irrigation units are generally higher in the coastal regions than inland. This is because saline flooding is far more damaging than freshwater flooding, especially for agriculture, and because the scope for private irrigation in the coastal region is limited by its lack of STW potential.

Land acquisition is a major constraint and causes long implementation delays. The problem can, however be mitigated or avoided in small-scale highly participatory developments where provision of land for project works is made a pre-condition for project funding and execution. The poor state of the Public Land Records hampers efficient land acquisition.

River training and bank protection works have been found to be very costly, but they are the only effective means of combating river erosion. Experience has shown that the maintenance costs are also very high. There is need for contingency planning to cope with failures, especially as these can have very severe consequences. They need to be assessed in relation to setback and densification policies.

Bangladesh currently faces severe water quality problems arising from faecal and industrial pollution. Industrial wastewater with high loads of heavy metals are leading to localized severe surface water pollution. The impacts of these pollutants on groundwater resources have not yet been studied but are likely to affect this main source of potable water.

Systematic monitoring of water quality of groundwater and surface water or drains has seldom taken place. Within embankments where rainwater and domestic wastewater remain trapped, public health impacts have often been severe. Arsenic pollution of groundwater resources has created an environmental crisis of potable water in large parts of the country. Arsenic problem should be addressed very urgently.

As in the 1998 flood indicated, *capture fisheries on the floodplain* are still an enormously valuable nutritional and economic resource to the farmers who fish during the monsoon and to full-time professional fishermen. Bangladesh possesses an unrivalled diversity of inland water bodies for fish production and the poor in particular rely on freshwater fish for the regular supply of animal protein and micro-nutrients. The collapse of capture fisheries has only been partially redressed through intensified investment in culture fisheries. Capture fisheries are clearly an area in which Bangladesh could still claim competitive advantage in the future.

Salt-water shrimp production is known to be deleterious to the environment if conducted in an unplanned manner, which has frequently been the case. The intrusion of salt water for shrimp cultivation or salt production has widespread impacts on the quality of life of communities as well as the environment. Saline groundwater conditions prevent irrigation of vital vegetable crops in homestead gardens (foods which are critical to family nutrition) and crop yields are lowered. When dry-season paddy is replaced by shrimp culture, grazing land for cattle and goats is reduced (with a resultant loss in manure for fuel and fertilizer) and groundwater initially sweet, becomes saline. Bathing in such water results in skin diseases. Residents in shrimp producing areas complained that these impacts were harmful to health. On the other hand, the economic benefits to Bangladesh from shrimp culture are high.

APPENDICES

APPENDIX A: Definitions of Irrigation Technologies

Definitions of Mechanized Irrigation Technology

Suction Mode Technologies	Use centrifugal pumps placed above the water and outside the well. The pumping lift cannot exceed the suction limit (about 7m below the pump).
Shallow Tubewells (STWs)	Pump is placed at the surface and driven by either a diesel engine or electric motor. The pump can lift water from the well up to a depth of 7-8m (20-25 feet). Actual suction limit depends on the design and operating condition of the pump and capacity of the well.
Deep Set Shallow Tubewells (DSSTWs)	DSSTW use the same pump driven by diesel engine or electric motor as for STWs. The pump set is placed in a pit of up to 2m deep to lift groundwater from lower levels. The pits are usually unlined but in some areas farmers build brick lined pit, especially for electric driven pump sets.
Very Deep Set Shallow Tubewells (VDSSTW):	For very deep set STW the pump set is placed in a pit of more than 2m deep. In few areas with very low water tables farmers have dug pits up to 6m deep to reach the water. The pit may be lined but this depends on the actual soil conditions and the farmer's preferences. VDSSTW use basically the same type of pump driven by diesel engine or electric motor as for STW. Because of the greater depths as compared to DSSTW more attention has to be given to the choice of pump (large impeller diameter to provide more head) and the engine/motor to give more horsepower than for STW.
Low Lift Pumps (LLPs)	The equivalent unit is basically the same as for STW. Water is lifted from surface water sources (rivers or khals) and therefore, no well is required. The pumps are equipped with a suction pipe and foot-valve to simplify priming. Because of lower heads, the centrifugal pump casing and impeller may be different from STW.
Force Mode Technology	Use pumps installed under the water level and inside the well. It forces water to the surface. These pumps can lift water from beyond the suction limit but are more expensive and complex.
Force Mode Tube Wells with electric submersible pumps (FMTW submersibles):	These wells equipped with electric driven submersible pumps can lift water from any depth as the pump is under the water level. For irrigation the static water level is usually between 10 and 17 m. The submersible pumps are available on the different sizes and discharge capacities ranging from 4 inch (10cm) diameter pumps producing 3-5 l/s to 8 inch (20 cm) pumps with 20-28 l/s capacity.
Force Mode Tube Wells (FMTW with vertical turbine pumps):	These FMTW are equipped with vertical turbine pumps, located below the water table, and driven from the top by diesel engine or electric motor through a vertical shaft. These pumps vary in diameter from 6.5 to 7.5 inch (15-20 cm) and have a discharge from 14 to 28 l/s. The casing of the well has to be bigger than the pump diameter to allow for verticality corrections.
Deep Tube Well (DTW with vertical turbine pumps):	These large diameter wells (usually 14 inch) and pumps are of the same principle as the FMTW with turbine pump. DTW have a pump of 10-11 inch diameter with a discharge of 56 l/s (2 cfs) DTWs are driven by either a diesel engine or an electric motor. DTWs have been installed through public sector programs.

Definitions for Manual Water Lifting for Irrigation :

HTW	Hand tubewells; water well equipped with handpump.
No 6 handpump	A popular and cheap form of suction mode handpump. Mainly used for rural water supply.
Tara handpump	A direct action manually operated tubewell for potable supply. Developed in Bangladesh for use in areas where water levels exceed the suction limit of conventional hand tubewells, up to an operating limit of 15m.
MOSTI	Manually operated shallow tubewell for irrigation. A classification which includes hand tubewells, treadle pumps and rower pumps.
Treadle pump	A low cost, low discharge suction mode tubewell operated by foot using bamboo treadles.
Rower pump	A low cost, low discharge suction mode tubewell operated using a reciprocating piston hand pump.
Traditional Irrigation	Form of irrigation using traditional manual devices such as swing basket or dhoon to lift water from surface water bodies.
Swing basket	A traditional form of irrigation using swing basket or scoop held by two men to lift water.
Dhoon	A traditional form of irrigation using a hinged boat-shaped scoop.

APPENDIX B

AGRICULTURAL TERMS

B Aman:	Broadcast Aman; a rice crop usually planted in March/April under dry land conditions, but in areas liable to deep flooding. Also known as deepwater rice. Harvested October to December. All varieties highly sensitive to day length.
T Aman	Transplanted Aman; a rice crop planted usually July/August, during the monsoon in areas liable to a maximum flood depth of about 0.5 m. Harvested in November/December. Local varieties are sensitive to day length whereas modern varieties are insensitive or slightly sensitive.
Boro	A rice crop planted under irrigation during the dry season from December to March and harvested April to June. Local Boro varieties are more tolerant to cool temperatures and are usually planted in areas which are subject to early flooding due to rise in river levels. Improved varieties, less tolerant of cool conditions, are usually transplanted from January onwards. All varieties are insensitive to day length.
B Aus	Broadcast Aus; a rice crop planted March/April under dry land conditions. Matures on pre-monsoon showers to be harvested in June/July and is insensitive to day length.
T Aus	Transplanted Aus; a rice crop. Transplanted March/April usually under irrigated conditions and harvested June/July. The distinction between a late planted Boro and early Aus is academic, since the same varieties may be used. Varieties are insensitive to day length.
Kharif	The wet season (typically March to October), characterized by monsoon rain and high temperatures.
Kharif 1	The first part of the kharif season (March to June). Rainfall is variable and temperatures are high. The main crops grown are Aus, summer vegetables and pulses. Broadcast Aman and Jute are planted.
Kharif 2	The second part of the kharif season (July to October), characterized by heavy rain and floods. T Aman is the major crop grown during this season. Harvesting of Jute takes place. Fruit and summer vegetables are crown in high land.
Rabi	The dry season (typically November to February) with low or minimal rainfall, high evapotranspiration rates, low temperatures, and clear skies with bright sunshine. Crops grown are Boro, wheat, potato, pulses, oilseeds and vegetables.

HYV	High yielding varieties of rice; introduced varieties developed through formal breeding programs. HYVs have a higher yield potential than local varieties but require correspondingly high inputs of fertilizer and soil moisture to reach full yield potential.
Local Varieties	Varieties of rice developed and used by farmers. Sometimes referred to as local improved varieties (LIVs).
Fallow land	Agriculturally productive land which is temporarily not being cropped due to a crop rotation limitation or due to a seasonal shortage of water.
B	When preceding a rice variety means broadcast.
T	When preceding a rice variety means transplanted.

BANGLA TERMS

Baor	Oxbow lake – a crescent-shaped lake formed from an old section of river channel.
Beel	Natural depression, normally a permanent or temporary water body or swamp.
Char	Land newly formed by accretion of rivers
Haor	Bowl-shaped natural depression between river levees, common in the north-east.
Khal	Channel
Khas	Government owned land
Kharif	Summer and monsoon cropping season
Rabi	Winter (dry) cropping season
Thana	Sub-district administrative area (There are 465 Thanas outside 4 City Corporations)
Union	Sub-thana administrative area (There are 4,484 Unions in the country)
Upazila	Alternative term for Thana
Zila	Administrative district

APPENDIX C

CHARLAND

Introduction
A char is defined as a large vegetated island (island char) or a large vegetated area within a river that is attached to the riverbank or flood plain. The chars are formed due to deposition of sediments. The source of the sediments is upper catchments and riverbank erosion. The braiding takes place in rivers which transport predominantly sand, such rivers are wide and relatively shallow and chars are common in such rivers.

Large number of chars have formed in the Jamuna River. The average width of the river has increased about 130 m per year since 1973. Widening of the river in recent years caused retreat of both left and right banks. The average width of the river has increased from about 8 km to 11 km since 1973, an increase of 3 km or nearly 40%. On average, bank erosion has occurred in two out of three years for most reaches and the rate and extent of erosion may be very severe, with about a one in ten chance annually that more than 400 meters of retreat will occur.

The total area between the banklines is 3.4% of the area of Bangladesh. Of this area, 30% is land, most of it being used for agriculture os habitations. The area of land is 43% in the Brahmaputra, 18% in the Ganges and 25% in the Meghna, mostly in Lower Meghna (Figure AC 1).

More than 4.3 million people live in the chars of the principal rivers. The economic lives of char people are tied up with the nature and changing environment and depend on their ability to move constantly and yet survive.

Much of the materials from the eroded floodplains are deposited to form new chars. Since 1973, on an average, 2,000 ha of charland has formed in the braided course of the Jamuna River each year. With the exception of the 10% of stable char land (more than 20 years old), chars are frequently eroded from one location and formed at another location. The average age of a charland is only 4 years old which means that homesteads, lands and infrastructure of most char dwellers are destroyed by erosion every few years (JICA, August 2002, page A-114).

The chars are highly dynamic due to erosion and deposition of sediments. Many of the Brahmaputra-Jamuna chars experience yearly submergence of different magnitudes during the wet season. The chars are almost completely inundated by the floods that have been estimated to have a return period of 25 years at Chilmari and 12 years in Sirajganj. These flood-and-erosion chars are homes of substantial number of people who fall victims to floods.

Vulnerability of Chars
In the char areas, both inundation of the households and the erosion of the char itself make the dwellers more vulnerable to floods, which often result in the shifting of households. According to FAP studies, flooding is an annual event in the Brahmaputra and Ganges char areas and an estimated 96% of homesteads in the lower reach, 86% in the middle reach and 71% in the higher reach are affected by flooding. Permanent out-

migration of residents from chars is higher in the middle reach while seasonal out-migration is the preferred practice in the upper reach. Cultivation of Boro (HYV and LV) and dryland crops are cultivated mainly in middle chars during Rabi season. They move to a nearby flood-free place till the flood recedes. In case of erosion of their home, they may settle in a nearby location waiting indefinitely for the eroded char to re-emerge. Such materials that can be moved easily build the houses in the char. The mitigation measures for char dwellers include flood warning, assistance for evacuation to temporary shelters and other support services.

Sample surveys were conducted in 99 mouzas located in the chars of Jamuna by JICA (JICA 2002). The survey areas are located in the districts of Gaibandha, Jamalpur, Kurigram and Sirajganj. None of the mouzas is protected from flooding of any degree nor are from river erosion of the chars. Some of the households have vegetated areas, which provided very limited protection against river erosion. Source of flooding is the main river. It was found that the river erosion of chars is as great a hazard as flooding (JICA 2002, page B-43). The Table AC 1 provides results of the JICA survey on depth and duration of flooding.

Table AC 1: Depth and duration of flooding in surveyed chars during 1998-2000.

Year	**Number of villages with depth of flooding (m).**				**Number of villages with duration of flooding (month).**			
	<1.5	**1.5-3.0**	**3.0-4.5**	**>4.5**	**<2**	**2-3**	**4-5**	**>5**
1998	15	96	4	0	1	107	7	0
1999	93	22	0	0	40	74	1	0
2000	100	15	0	0	47	66	1	1

Source: The Study for Rural Development Focusing on Flood Proofing in Bangladesh. The People's Republic of Bangladesh, Japan International Cooperation Agency (JICA) and Ministry of Local Government, Rural Development and Cooperatives, The Peoples Republic of Bangladesh (August 2002. page B43).

Land use in chars is largely determined by elevation and stability (against erosion) of land. In higher and stable lands including artificially raised land, people enjoy ordinary life. Homesteads with useful trees and garden, road, school, hat/bazaar (markets) are usually seen on highland. Medium high lands are used for homesteads and agricultural lands. Lowlands are used for temporary settlement, seasonal crop field, seasonal fish farming/rice-cum-fish farming, fishing etc. Water bodies are used for pisciculture.
Major crops grown are rice, wheat, jute, groundnut, chili, sweet potato, potato, garlic, onion, pulses vegetables and spices. Fruit trees grown include mango, banana, coconut, jackfruit papaya etc.

JICA survey results showed that 33% of the total households are absolute landless. A broad category of landless (combining absolute landless, functional landless and landless) accounts for 68% of the households. Only 1.8% of the households are large farmers who owns 7.5 ha or more. More than 90% of female-headed households fall under the broad category of landless. Many of the landless and marginal farmers lease land from large landowners for agricultural and residential purposes.

Occupation

Most of the male members have more than two occupations. All females do not have occupation; those who are involved in economic activities also have more than two occupations

Agriculture related activities are by far the dominant occupation in chars. Other occupations include business, fishing, tailoring for men and tailoring and handicrafts for women.

In the dry season (Rabi), agriculture is the main profession, but it is not possible to employ all local labours. Some people go out of the village in search of jobs. In the wet season, employment opportunities are reduced due to flooding of low and medium high agricultural lands.

Cropping

The gross area of the chars, in the survey area, is 47,207 ha of which the cultivable land is 21,473 ha (45%). The average density of population in the char lands of the study areas is 525 persons per square kilometer. According to JICA survey the cropping intensity was found to be 1.72 percent, details are given in Table AC 2.

Table AC 2: Cropping intensity in JICA survey area (2002).

Districts	Gross area (ha)	Uncultivated Area (ha)	Cultivated Area (ha)	Single crop (ha)	Double crop (ha)	Crop Intensity
Gaibandha	9,982	5,335	4,642 (47%)	1,498	7,019	1.85
Jamalpur	1,219	6,248	5,936 (49%)	2,829	6,577	1.58
Kurigram	16,931	10,513	6,419 (38%)	2,385	9,054	1.78
Sirajganj	8,110	3,637	4,473 (55%)	1,690	5,710	1.65

The Table AC 3 shows that crop yield in char are very good. The yield has been possible due to irrigation and fertilizer and other agricultural inputs. Mainly shallow tube wells and some low-lift pumps provide the irrigation. The pumping lift does exceed the suction limit (about 7m below the pump).

Table AC 3: Average yields of cereal crops in char area, t/ha (JICA survey area).

Crop	Gaibandha	Jamalpur	Kurigram	Sirajganj	Average
Boro (HYV)	4.23	3.96	4.62	5.13	4.49
Boro (LV)	2.09	3.15	2.28	2.17	2.42
Aus (HYV)	3.44	5.03	3.12	2.01	3.40
Aman (HYV)	3.61	3.95	3.11	-	3.56
Aman (LV)	2.55	2.95	2.36	2.14	2.50
Wheat	2.67	2.62	2.40	2.16	2.46
Pulses (Lentils)	1.31	1.05	1.46	1.33	1.29

Chemical fertilizers and pesticides are used for HYV boro. Nitrogen is the most widely used fertilizer followed by Phosphate and Potash. Fertilizer dosages are lower than optimum.

Migration in and out of chars

Information on in- and out-migration of households in JICA surveyed char are provided in Table AC 4.

Table AC 4: Number of migrations in and out of chars surveyed by JICA

District (No of surveyed villages)	Number of villages without		Number of villages		Number of villages	
	Out-migration	In-migration	In-migration> Out-migration	Out-migration > In-migration	In-migrated	Out-migrated
Gaibandha (25)	5	2	16	9	1,778	794
Jamalpur (25)	10	2	18	7	1,222	1,287
Kurigram (34)	18	6	21	13	1,170	1,054
Sirajganj (31)	11	6	22	9	3,094	1,490
Total	44	16	77	38	7,264	4,625

Source: JICA (2002)

The survey results showed that 7,264 household in-migrated while 4,625 out-migrated during the 5 years preceding 2001. The survey period included a catastrophic flood in 1998. Although the number of in-migrated households surpassed out-migrated in two-thirds of surveyed villages, the total number of in-migrated households is almost same as out-migrated in Jamalpur and Kurigram. Both of these two districts were very badly affected by 1998 flood. About 40% of surveyed villages did not experience out-migration while 14% villages did not have in-migration. The above information indicates that population in char areas would continue to grow in future.

Mitigation Measures

At present, number of NGOs are working in some of the char areas for providing assistance to the dwellers. There are no well planned programs for addressing the problems faced by the inhabitants.

Programs for char development should include the following:
(a) improvement of the economic and social condition of people in the chars in a sustainable way through community-based programs, (b) develop a sustainable institutional system for improving the productivity and safety of char dwellers. (c) resettle the landless and people displaced by river erosion in char lands, (d) gather data and information for sustainable development of chars, (e) study the impact of char development on river morphology including river erosion, and project activities and (f) study the effects of proposed riverbank protection works on the char areas.

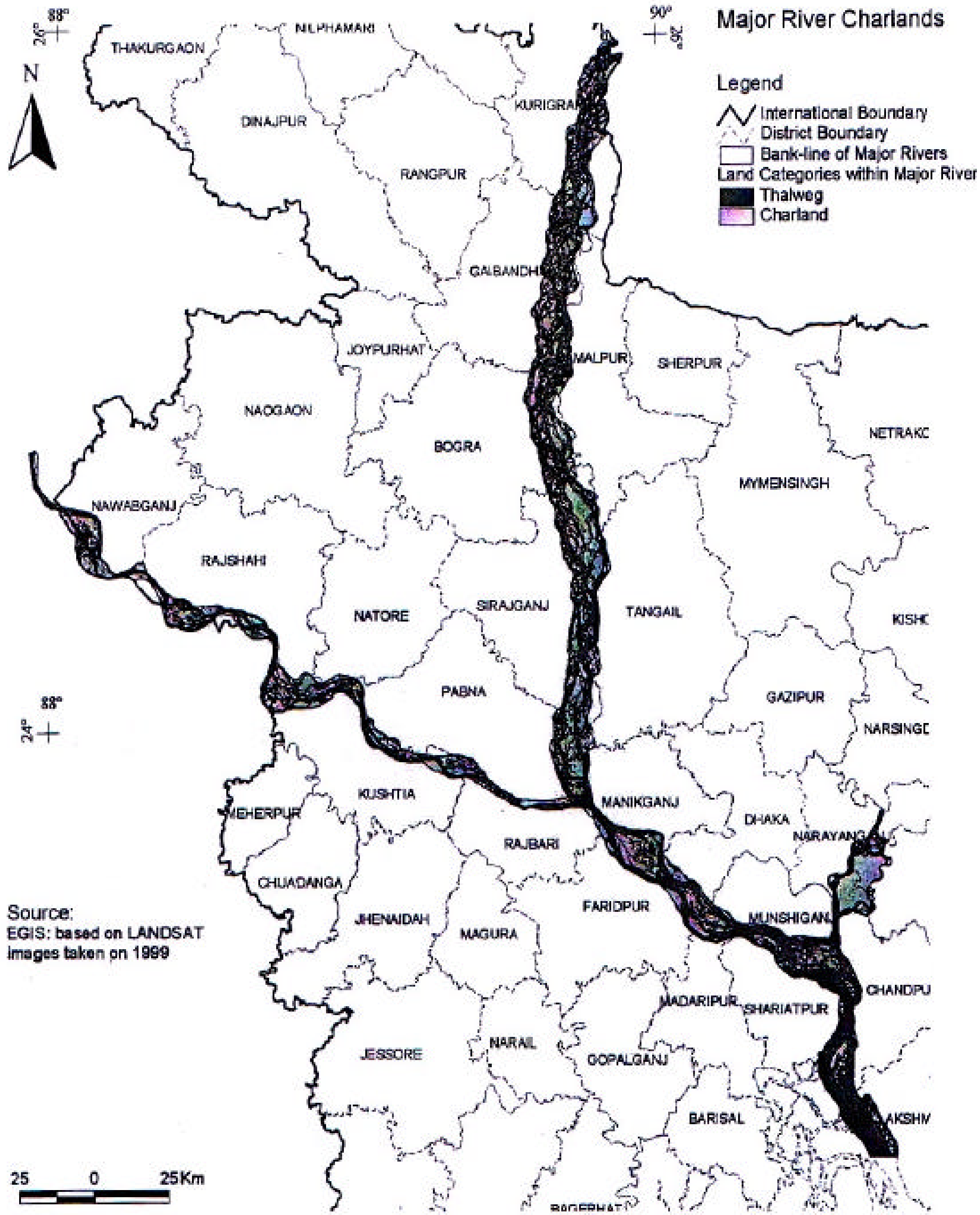


Figure AC 1 Charland areas

APPENDIX D

Table: Flood Action Plan (FAP) Components

FAP Component		Donors	Study Completion
1:	Brahmaputra Right Embankment Strengthening	IDA	1993
2:	North West Regional Study	UK, Japan	1993
3:	North Central Regional Study	EU, France	1993
4:	South West Area Water Management	ADB, UNDP	1993
5:	South East Regional Study	IDA, UNDP	1993
6:	North East Regional Study	Canada	1994
7:	Cyclone Protection Project	EU, IDA	1992
8A:	Greater Dhaka Protection Project	Japan	1992
8B:	Dhaka Integrated Town Protection Project	ADB	1993
9A:	Secondary Towns Integrated Flood Protection Project	ADB	1992
9B:	Meghna River Bank Protection short-term Study	IDA	1992
10:	Flood Forecasting and Warning Project	UNDP, Japan, Denmark	1992
11:	Disaster Preparedness Project	UNDP	1994
12:	FCDI Agricultural Review	UK, Japan	1992
13:	Operation and Maintenance Study	UK, Japan	1992
14:	Flood Response Study	USA	1992
15:	Land Acquisition and Resettlement	Sweden	1993
16:	Environmental Study	USA	1995
17:	Fisheries Study and Pilot Project	UK	1995
18:	Topographic Mapping	France, Switzerland, Finland, Germany	1994
19:	Geographic Information System (GIS)	USA	1995
20:	Compartmentalization Pilot Project	Netherlands, Germany	-
21:	Bank Protection /Training	Germany, France	-
22:	Floodplain Management Pilot Project		
23:	Flood Proofing Study and Pilot Project	USA	1993
24:	River Surveys and Studies	EU	1995
25:	Flood Modelling/Management Project	UK, Denmark, France, Netherlands	1994
26:	Institutional Development Programme	UNDP, France	1995
	Macro-Economic Study.	France	Not completed

SOURCE: Bangladesh Water and Flood Management Strategy, FPCO, Ministry of Water Resources, Dhaka, 1995.

APPENDIX E

NATIONAL WATER MANAGEMENT PLAN (DRAFT), DECEMBER 2001 IMMEDIATE OBJECTIVES OF THE SUB-SECTORAL CLUSTERS.

Sub-sectoral Cluster	Programmes involved	Immediate Objectives of the Sub-sectoral Clusters	Immediate Objectives of the NWMP	Development Objective of the NWMP
Institutional Development	ID 001-004	Bangladesh's institutional framework for the water sector regulated, decentralized and devolved according to subsidiarity principles	Rational management and wise use of Bangladesh's water resources	BALANCED ACHIEVEMENT OF THE NATIONAL GOALS
	ID 005-010	Capacities of Bangladesh's restructured water sector institutions strengthened in line with future demands on them		
Enabling Environment	EE 001-006	Rights, obligations and rules of business as they apply to all water sector stakeholders promulgated via a coherent and comprehensive set of documents		
	EE 007-009	Development and management of water sector resources, institutions and infrastructure characterized by the use of reliable, well organized data and targeted, adaptive research		
	EE 010	User commitment to the sustainable and wise use of Bangladesh's water resources		
	EE 011-013	Bangladesh's water sector costs shared between Public, private and grass roots entities according to comparative advantage		
Main Rivers	MR 001012	Bangladesh's main and regional rivers comprehensively developed for sustainable multipurpose use	People's quality of life improved by the equitable, safe and reliable access to water for production, health and hygiene	
Towns and Rural Areas	TR 001-004	Demand for safe and reliable drinking water supplies and services satisfied in towns and rural areas		
	TR 005-006	Demand for sanitation facilities and services created and satisfied in towns and rural areas		
	TR 007-008	Large and small towns protected from flooding and stormwater run-off		
Major Cities	MC 001-005	Demand for safe and reliable drinking water supplies and services satisfied in the Statistical Metropolitan Areas		
	MC 006-009	Demand for sanitation facilities and services created and satisfied in the Statistical Metropolitan Are as		
	MC 010-017	Statistical Metropolitan Areas protected from flooding and stormwater run-off		
Disaster Management	DM 001-005	Lives and national infrastructure protected against inundation damage		
	DM 006	Climatic threats to life and livelihood mitigated by structural and non-structural measures		
Agriculture & Water Management	AW 001-008	Water related constraints in agricultural production minimized		
Environment and Aquatic Resources	EA 001-003	Sufficient clean water for multi-purpose use	Clean water in sufficient and timely quantities for multi-purpose use and preservation of the aquatic and water dependent ecosystems	
	EA 004-009	Quality, size and connectively of water bodies adequate for the restoration and preservation of the aquatic biomes		
	EA 010	Public sensitized and empowered to demand environmental restoration and stewardship		

SOURCE: WARPO, Ministry of Water Resources, National water Management Plan (Draft), Volume 1, Summary, Page 11, Dhaka, December, 2001.

APPENDIX F

Economic Returns to Water

The monetary value of water is a useful economic indicator of the comparative benefits in alternative uses. The estimated net economic returns to water and land from alternative uses of water were calculated by the Draft Development Strategy of the NWMPP (2001) and are summarized below (Table AF 1).

Observations from these analyses are as follows:

Surface water irrigation (LLP) and capture fisheries in beels yield net economic returns of about Taka 2/ m^3 of net water use, but irrigation gives lower returns to land because the net value of dry land cropping is deducted. However, draining perennial beels for dry season cropping is generally not justifiable and contrary to the NWPo because capture fisheries generate important social and environmental benefits, particularly for the rural poor.

Groundwater irrigation is less profitable than LLP surface water irrigation with net economic returns to water of Taka 1.2-1.7/ m^3 of net water use.

Culture fisheries offer the highest returns to water at Taka 8.1-16.8/ m^3.

Bagda (Tiger Shrimp) culture in the coastal region, which uses brackish rather than fresh water, gives high economic returns to land of Taka 47,000-54,800/ha (depending on salinity levels), even after allowing for the reduction in Aman output and non-crop agricultural production which it causes.

Urban water supply estimates indicate values for water in the range of Taka 5-10/ m^3. This is a gross rather than net water use figure, before allowing for return flows to the water resources system, which may be polluted.

Capture fisheries in rivers and inland water transport offer very low returns to water use of only Taka 0.01-0.28/ m^3. The implication of these estimates is that reserving dry season flows for in-stream uses such as river fisheries and navigation would not be worthwhile in economic terms.

Table AF 1: Estimated Net Economic Returns to Water and Land from Alternative Uses

(Taka at 1998-99 prices)

Category	**Returns to water** (Taka/m^3 of net water use)	**Returns to land** (Taka/ha)
Irrigated agriculture:		
- Groundwater use (Tubewells)	1.2-1.7	6,400-9,500 (1)
- Surface water use (LLPs)	2.0	11,500 (1)
Capture fisheries in perennial beels	2.0	15,000
Capture fisheries in rivers	0.28	10,050 (2)
Culture fisheries:		
- Unimproved, from existing ponds	8.3	41,300
- Improved, from existing ponds	16.8	84,100
- Improved, from new ponds	8.1	40,700 (3)
Bagda shrimp culture (including Aman rice production):		
- Low salinity condition	-	49,000
- Medium salinity condition	-	54,800
- High salinity condition	-	47,000
Urban water supply	5.0-10.0 (4)	-
Inland water transport	0.01	-

Source: Draft Development Strategy, National Water Management Plan, Annex J, Economics (2001)

(1) Net of the value of dryland cropping lost through the conversion to irrigation per hectare of river water area

(2) After deducting the cost of pond excavation and development.
This value is in terms of gross water use, without allowance for return flows. The value per m^3 of net water use would be much higher.

(3) This value is in terms of gross water use, without allowance for return flows. The value per m^3 of net water use would be much higher.

APPENDIX G: ARSENIC CONTAMINATION IN GROUNDWATER

CONTENTS

INTRODUCTION

In the last few years it has been recognized that Bangladesh is affected by one of the worst cases of groundwater contamination in the world. With exception of diarrhoeal diseases and coastal salinity in rivers, until recently water quality was not perceived as a problem in Bangladesh, as may be recognized by reference to the earlier National Water Plan projects (MPO, 1986 and 1991).

Until recently, Bangladesh had made great strides in providing safe water supply to rural dwellers, but this success has been badly affected by the discovery of arsenic in the shallow aquifer. Arsenic contamination has been found in varying degrees in tubewell water in 60 of 64 Districts of Bangladesh. In the cluster surveys undertaken by UNICEF/BBS in 1998-99, previous estimates of access to safe water have now had to be revised downwards to 80% to take into account the number of wells which are contaminated by arsenic, though a more likely estimate may be 60%. The figure is constantly being revised downward as number of agencies continues to conduct arsenic testing of existing HTWs. Most recent assessments of the degree and extent of arsenic contamination across Bangladesh indicate that the problem is most acute in the northeast and southeast with significant hotspots in the southwest and northwest regions. The need to prevent very serious problems in these stricken rural areas is urgent, before illness and a new wave of underdevelopment are allowed to take root.

Arsenic contamination has affected the access of consumers to safe potable supply and created a demand for more sophisticated and improved service technologies to be installed in both rural and urban communities For a variety of technical and economic factors, access for consumers to potable water sources has been particularly constrained in four geophysical regions, the low water table areas, the coastal belt areas, high water table areas and the hilly areas (eastern hills).

Medical evidence of arsenic poisoning was first discovered in West Bengal, India in 1978, although the connection with groundwater contamination was not recognized until some years later. Further surveys were carried out during the 1980s (Chakraborty and others, 1987; Mazumder and others, 1988), culminating in a national report by Public Health Engineering Department (PHED), India, in 1991. In, 1993, Department of Public Health Engineering (DPHE), Bangladesh, tested for and identified arsenic at Chapai Nawabganj, near the border with West Bengal, but it was not until 1995 that the existence of arsenic in Bangladesh became widely known. It was not appreciated until early 1997 that arsenic contamination extended over large parts of the country. By the end of 1998, a national assessment of the extent of contamination across the country had been made (Department of Public Health Engineering, 1999). At around the same time, projects of both the Ministry of Heath and the Department of Public Health Engineering (DPHE) as well as various NGO's began work on extensive testing, awareness raising and providing small-scale arsenic removal systems.

STUDIES ON THE DISTRIBUTION AND ORIGIN OF ARSENIC IN GROUNDWATER

The studies of arsenic occurrence in Bangladesh and West Bengal may be divided into two groups, those with a medical bias aimed at confirming diagnoses of arsenicosis and those with a hydrogeological bias aimed at estimating exposure and the causes of contamination. The following discussion concerns the theories about the origin of arsenic, which have important implications for water management policy. The principal competing explanations all point to a geological source. These ideas have been presented both in reports and scientific literature, and are given a detailed discussion below. Other, anthropogenic, sources have been proposed, but have generally been made in the popular press rather than in reports or in scientific journals.

Geological Source Hypotheses

The first major investigation of arsenic contamination in West Bengal by PHED (1991) contained much analytical and descriptive detail but did not suggest an origin for the contamination other than ruling out anthropogenic sources. In the absence of any formal explanation, a number of (non-hydrogeological) studies (Das and others,1994 and 1996; Chatterjee and others, 1995) went on to suggest that extensive seasonal pumping of groundwater for irrigation is responsible. This idea came to be known as the 'pyrite oxidation' hypothesis and was formally described by Mal1ick and Rajagopal (1996). The idea is based on the assumption that arsenic is present in the sulphide minerals pyrite and arsenopyrite. According to the theory, lowering of the water table due to pumping introduces oxygen which causes the breakdown of pyrite and releases arsenic, iron and sulphate into the water. Recharge during the subsequent monsoon then flushes the arsenic into the underlying aquifers. This explanation, whereby the arsenic pollution is caused by man's over-exploitation of groundwater, became well known and led to calls for the banning of tubewell irrigation.

In 1997, an alternative explanation was independently put forward by an Indo-Swedish group (Bhattacharya and others, 1997) and an Anglo-Bangladeshi group (Nickson, 1997; Nickson and others, 1998 and 2000) and has become known as the 'oxyhydroxide reduction' hypothesis. Both these groups presented their ideas in international scientific journals where the origin of arsenic was the main subject of the papers. According to the theory, arsenic weathered from the hard rock areas of India is carried in the suspended load of the rivers adsorbed on to iron oxides or hydroxides. Following deposition of this fine sediment, decomposition of organic matter leads to strongly reducing groundwater conditions which causes dissolution of the iron oxyhydroxides and consequent release of arsenic into solution. This hypothesis also accounts for the pervasive occurrence of iron in wells beneath the floodplains.

The debate between these views hinges on a number of issues. First, the chemistry of the affected water points towards strongly reducing conditions and hence that release by oxidation is very unlikely. Evidence for reducing conditions includes direct measurement of redox potential, low-to-negligible concentrations of dissolved oxygen, nitrate and sulphate combined with high concentrations of iron, manganese and bicarbonate plus the occurrence of dissolved gases such as carbon dioxide and methane (Ahmed and others, 1998). Only limited evidence has been presented for the occurrence of arsenopyrite or arsenic-rich pyrite, while Nickson and others (1998) showed that pyrite is present in a stable diagenetic ('framboidal ') form. This indicates that it has grown after deposition and is a sink rather than a source for arsenic. Imam (1998) identified the ubiquitous presence of iron-rich coatings on sands from the affected aquifers. Further, PHED (1991) showed very high arsenic concentrations (2000mg/kg) in the ferruginous coatings of aquifer sands. Chemical analyses of sediments from the arsenic affected aquifers show a good correlation between iron and arsenic but no correlation between sulphur and arsenic. In addition, arsenic concentrations are low at or immediately below the zone of water table fluctuation. The combination of reducing conditions, the problem of accounting for the absence of sulphur, and the near-neutral pH all point strongly towards the oxyhydroxide reduction hypothesis as being the predominant mechanism of arsenic release in the Bengal Basin (WARPO, 2000).

Subsequent field and laboratory investigations have all confirmed the ‘oxyhydroxide reduction’ hypothesis. These studies include investigations in Meherpur by Burren (1998) and Perrin (1998), in Jessore by Asian Arsenic Network (AAN) (1999) and in Noakhali by Mather (1999), as well as the major national investigation by DPHE (1999). In addition, there have been two published discussion on the 'oxyhydroxide reduction' explanation in the journal ‘Nature’. Acharyya et al (1999) of the Geological Survey of India agree with their main conclusion that “arsenic is released through the reductive dissolution of iron oxyhydroxides”. Further they add that “arsenic-rich pyrite and other arsenic minerals, which were cited in previous models, are rare or even absent in sediments of the Ganges Delta". Chowdhury etal (1999) of the Jadavpur University group also “agree with Nickson *et al* that arsenic associated with iron oxyhydroxides, may be leached from the sediments under reducing conditions” but qualify their support by adding that “this could be one of several ways that arsenic is leached from the aquifer sediments”.

Public interest in the origin of arsenic contamination has important practical implications if there is a relationship between tubewell irrigation and arsenic. From the process perspective, the oxyhydroxide reduction hypotheses is totally inconsistent with the idea that arsenic pollution is caused by water table lowering due to irrigation pumping. In fact, that idea suggests that lowering the water table will have the effect of removing arsenic from shallow groundwater, an idea that is supported by evidence from dug wells (see below). DPHE (1999) carried out statistical tests for an association between the intensity of arsenic contamination and both groundwater abstraction for irrigation and the seasonal depth to the water table. They found significant negative correlations with both parameters. This finding is consistent with the simple observation that arsenic is absent in the intensively-irrigated Bogra region and the pervasive contamination in the modestly-irrigated (by groundwater) Chandpur-Noakhali region. While it would be unjustified to suggest that pumping has no effect on arsenic, it can be stated confidendy that there is no evidence pointing to a causal relationship between tubewell irrigation and the occurrence of arsenic in groundwater (WARPO, 2000).

As a minor modification to the above explanation, Acharyya *et al* (1999), while accepting oxyhydroxide reduction as the dominant mechanism, have suggested that phosphatic fertilisers might enhance mobilisation of arsenic in the soil zone by displacing arsenic from adsorption sites. However, they have presented no evidence to support this, and it is clear that even if correct, the effect would be minute compared to the quantity of arsenic released by natural processes.

Anthropogenic hypotheses

Newspaper and magazine articles have suggested various man-made sources of arsenic such as fertilisers, pesticides, wood preservatives and even acid-mine drainage or interventions such as the construction of barrages on regional rivers. None of these ideas have been presented in reports or journals where a process of peer-review is possible, and none has gained support amongst the scientific community. Virtually all have been presented without verifiable supporting evidence and hence should be classified as unsubstantiated speculations. Nevertheless some have gained attention in the popular media and therefore cannot be ignored. The wood-preservative suggestion was .formally investigated by NRECA (1997) who concluded that there was no connection.

As noted above, the chemistry of arsenic and phosphate are related. The geographical distribution of phosphate and arsenic are similar. However, it is more likely that phosphate and arsenic share a common or closely related origin than that one causes the other. The hypothesis of a causal relationship with fertiliser use is strongly opposed by the virtual absence of phosphate in the intensively irrigated Bogra- Dinajpur and Gazipur-Mymensingh regions. The similar rare occurrence of nitrate in groundwater, especially in arsenic-affected areas, also argues against widespread fertiliser pollution.

Claims for connection between barrage building and arsenic contamination are highly tenuous, requiring pyrite oxidation as a mechanism, which as discussed above is rejected by most workers. It is claim

SAFE LEVELS OF ARSENIC IN DRINKING WATER

Arsenic in the environment may exist in a number of organic and inorganic forms. The most toxic form of arsenic is arsine gas, followed by arsenite and arsenate which are the *forms* of arsenic normally found in groundwater. Organic forms of arsenic such as found in many foodstuffs are much less toxic (Morton and Dunnette, 1994;) than the inorganic *forms* in drinking water.

Arsenic is both toxic and carcinogenic (Morton and Dunnette, 1994). The clinical effects of chronic arsenic poisoning range from skin ailments (keratosis and melanosis), through damage to internal organs to gangrene and various forms of cancer. The clinical effects of arsenic in drinking water in Bangladesh have been extensively demonstrated by Dhaka Community Hospital and NIPSOM amongst others.

The present drinking water standard adopted in Bangladesh and India is 0.05mg/l (50ppb) of (total) arsenic, which followed WHO advice at the time the standards were set. In 1993, the WHO proposed a new provisional guideline value for arsenic of 0.01mg/l (10ppb). This limit is based on practical limits of detection of arsenic and not on the normal health risk criteria. Conventionally, limits for carcinogens are set at the level of one excess lifetime cancer per 10,000 of population exposed. The provisional value of 0.01mg/l corresponds to an estimated risk of six additional skin cancers per 10,000 exposed persons.

The European Union has adopted the guideline value of 0.01mg/l, while Heath Canada has adopted an interim maximum acceptable concentration of 0.025mg/l (25ppb). The USA has recently reduced the allowable limit from 0.05 mg/l to 0.005 mg/l (5 ppb).

It is anticipated that there will be demands to lower the standard for acceptable concentrations of arsenic in drinking water in Bangladesh. However, in considering the implications of the arsenic drinking water standard, it is important that the intervention strategies consider the dose-response relationships. Published dose-response curves from China (Lianfang and]ianzhong, 1994 reported in WARPO, 2000)) suggests that the prevalence rate of arsenicosis rises to 10% at about 0.4mg/l, and to the order of 40% of the exposed population at concentrations of around 0.6mg/l. As discussed below, such concentrations are not rare in Bangladesh.

In summary, epidemiological evidence from around the world indicates that the present Bangladesh Drinking Water Standard does not correspond to a safe level according to the standard criteria of WHO and others. On the other hand, the dose - response function makes it imperative that interventions are prioritized according to the concentrations to which people are exposed.

REGIONAL DISTRIBUTION OF ARSENIC IN GROUNDWATER

Figure AG-1 shows the occurrence of arsenic in Bangladesh.

The Figure AG-2 shows the probability of exceeding the four threshold concentrations of 0.01 mg/l (the WHO guideline values), 0.05 mg/l (the current drinking water standard in Bangladesh), 0.2 mg/l and 0.04 mg/l. If a lower drinking water standard (e.g. 0.01 mg/l) is adopted, the affected area will expand considerably.

Figure AD-G shows that arsenic-contaminated groundwater may be found in most parts of the country, but is strongly concentrated in the South West, South East and North East. In large parts of the South East, more than 70% of the wells are contaminated. In the case of Hajiganj upazila of Chandpur District, Jakatyia et al (1998) tested all 12,000 wells and found that 93% were contaminated. There is currently very little data on the occurrence of arsenic in the Chittagong Hill Tracts, which are geologically very different from the areas tested.

In Figure AG-3, which shows the occurrence of arsenic in wells deeper than 200m, is very different. Although far fewer deep tubewells have been tested, it is clear that the risk of contamination at this depth is much lower.

The regional pattern of arsenic distribution is closely related to its origin by reduction of iron oxyhydroxides and has been described in detail by DPHE (1999), and the key features are described only in summary here:

Arsenic occurs in the catchments of all major rivers of Bangladesh. This demonstrates the existence of multiple source areas.

Aquifers beneath the hills of Greater Sylhet and terrace areas (Barind and Madupur tracts) are virtually free of arsenic contamination. These aquifers are formed of older sediments from which arsenic has either been flushed out or has been immobilized.

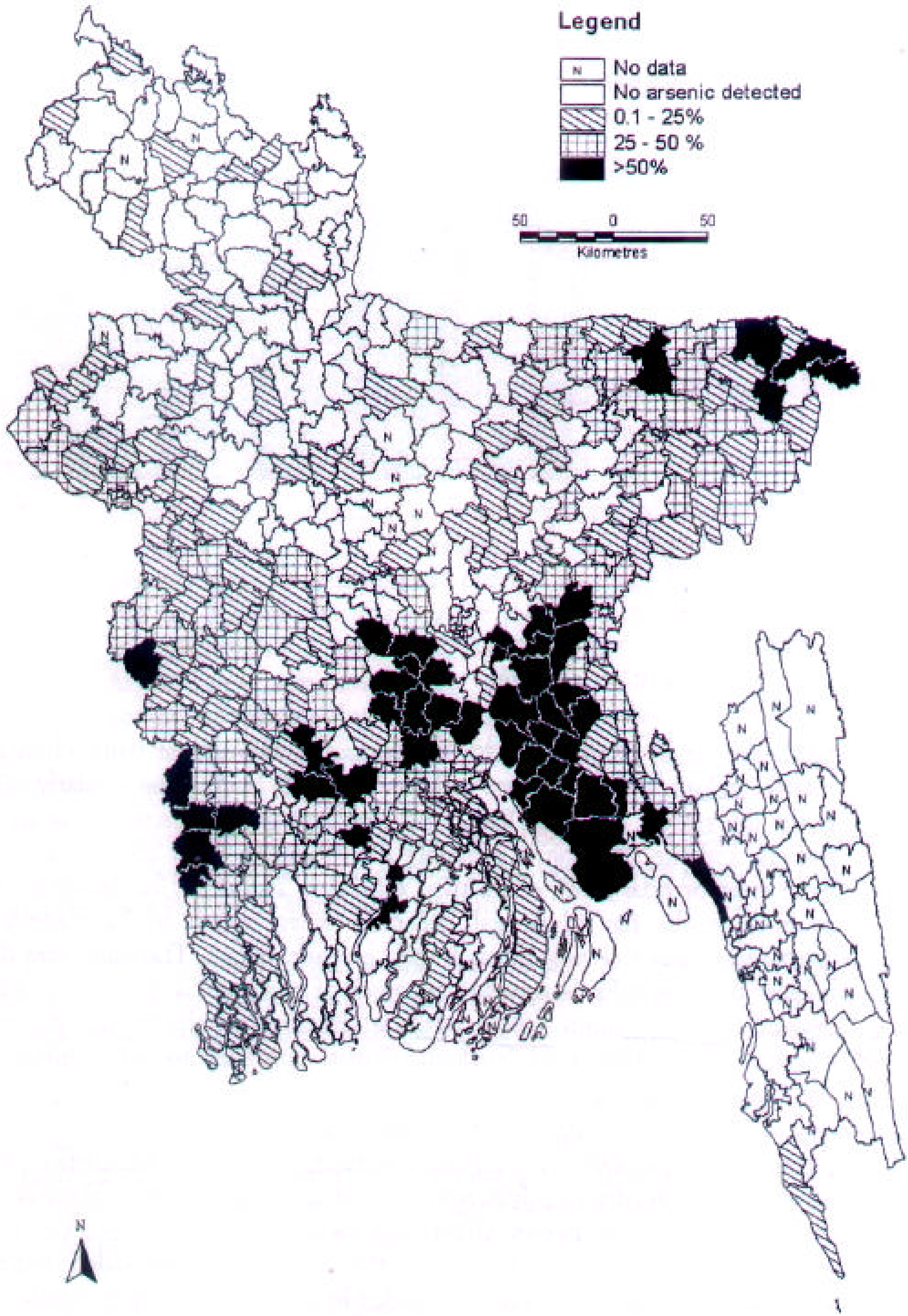
Of the major river systems, the Brahmaputra and Teesta floodplains are least affected, while the Meghna floodplains are worst affected-

Over large parts of North West and North Central Bangladesh and the Chittagong coastal plain the probability of wells being affected by arsenic is less than 5%.

Arsenic is far less likely to occur in aquifers deeper than 200m.

Arsenic in Surface Water

Arsenic contamination in Bangladesh is principally a problem in groundwater and it is often stated that surface water is safe from arsenic. However, concentrations up to 0.5mg/l (500ppb) have been reported from a partially dried up river in Meherpur (Burren, 1998). While this is believed to be an exceptional case, it demonstrates that surface water cannot be assumed to be safe from arsenic. It is anticipated that arsenic contamination of surface water is most likely in ponds or in relatively stagnant water bodies that are fed by groundwater. This is likely to be a seasonal phenomenon, occurring in the dry season. The occurrence of arsenic in some surface waters raises the possibility of arsenic uptake by fish.



Source: Vol: S5. Groundwater studies for Arsenic Contaminati on in Bangladesh, British Geological Survey, April 1999. (Data upto mid 1998)

Figure AG-1: Occurrence of Arsenic in Groundwater in Bangladesh

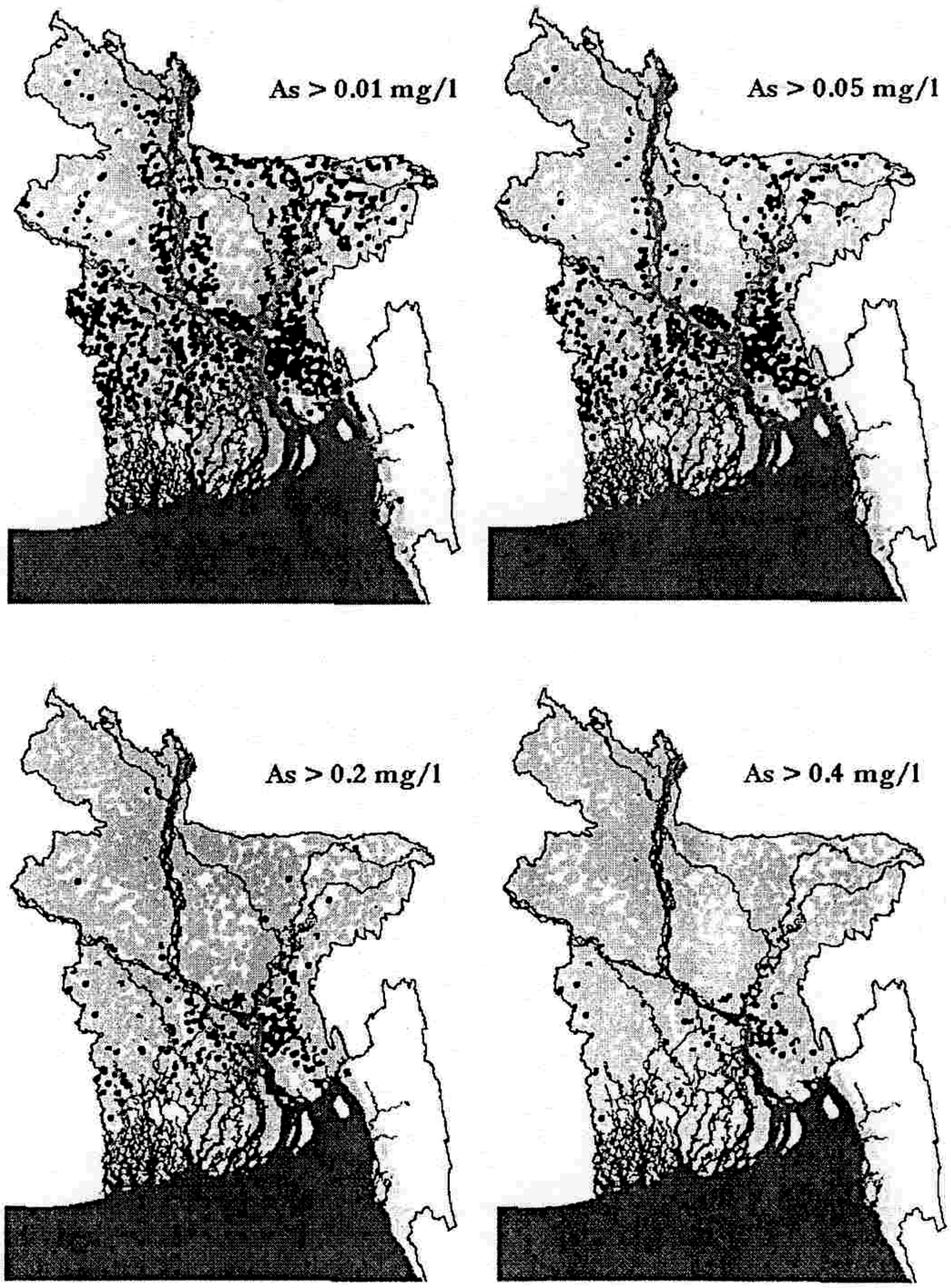


Figure AG-2: Probability of Arsenic Exceeding Threshold Values

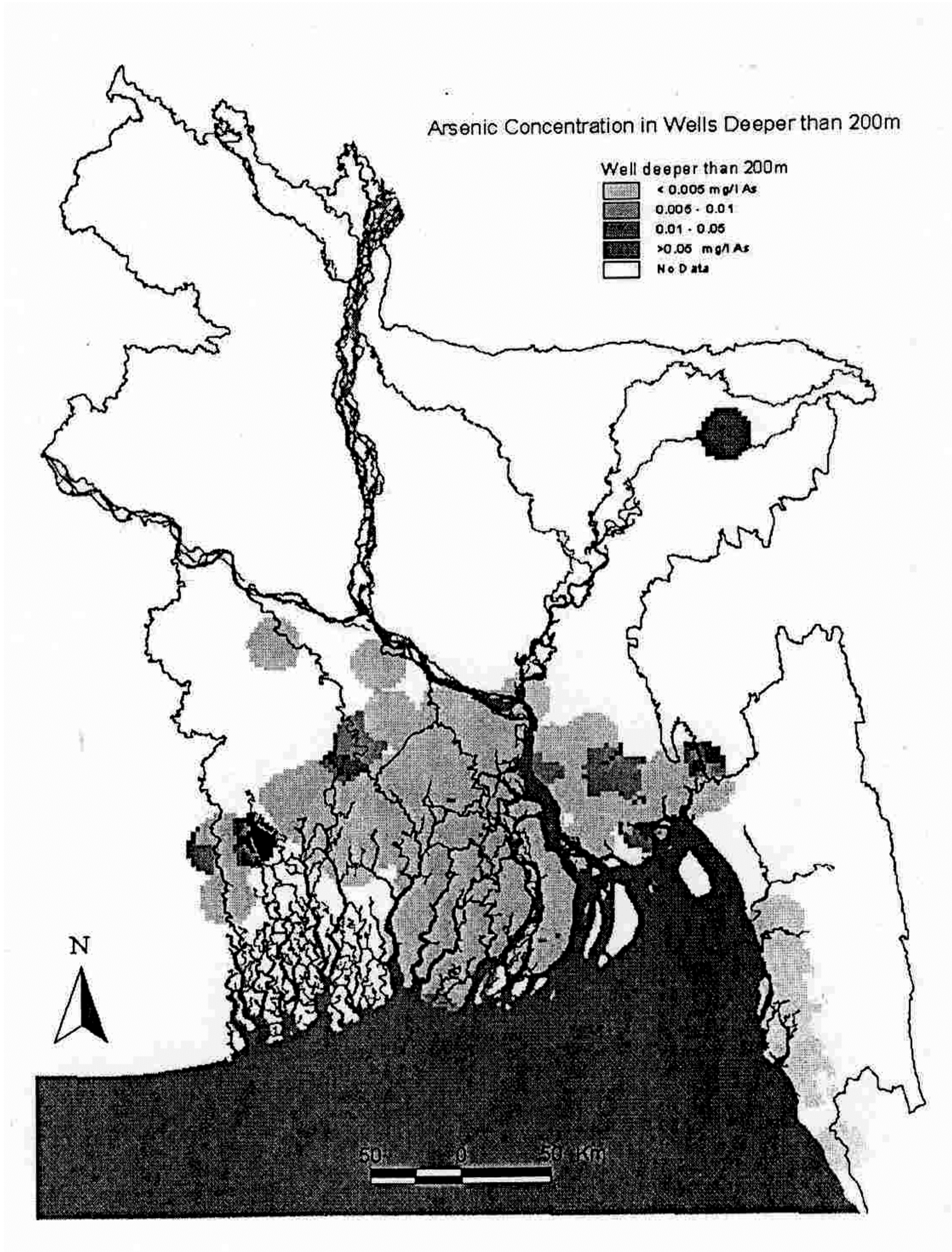


Figure AG-3: Arsenic in Wells with Depth Greater than 200m

Arsenic in Dug Wells

It was noted earlier that the risk of arsenic contamination is low in very shallow groundwater. It has been widely reported that dug wells are safe from arsenic. Dr. Dipanker Chakraborty reports analyzed more than 100 dug wells from West Bengal and Bangladesh and that none exceeded 0.05mg/l. The problem with dug wells is not arsenic, but the risk of diarrhoeal disease.

Arsenic in Hand Pumps (Tubewells)

The majority of private water supplies are obtained from drilled hand pumps (tubewells) between 10 and 100 meters deep. There are no reliable figures, but there may be between eight - and eleven million such wells in the country. These sources pose the principal threat to public health from arsenic. Nevertheless, the majority (> 70%) of such wells have arsenic contamination levels of less than 0.05mg/l and they also pose a low risk of diarrhoeal disease (WARPO, 2000). As noted above, arsenic concentrations may increase over time (most probably in wells screened very close to aquitard layers). The continued safety of presently uncontaminated wells is an important water management issue.

Arsenic in Deep Tubewells

Because of the differing nomenclature in irrigation and water supply circles, the term "deep tubewells" regularly causes major confusion. Reports from BADC that arsenic occurs in deep tubewells can cause confusion because BADC refer to wells with depths in the range 150 to 350 feet (50 to 110m). In addition, BADC set screens at depths of 50-80m, thus drawing water from the shallow aquifer, which is known to be contaminated. Here, the term is used to refer to wells screened in aquifers deeper than 200m. However, it is strongly recommended that depths are always quoted when this subject is discussed. Most wells screened below 200m have arsenic concentrations below detection limits and less than 2% exceed the Drinking Water Standard, and even then only by a small amount. The distribution of arsenic in wells deeper than 2OOm is shown in Figure AG-3, from which it is clear that the majority conforms to WHO standard.

Changes over Time

The question is often asked if the 'arsenic map' will change in a few years' time. Of course, some change will occur as more data are collected and uncertainty is reduced. It is possible that there will be an increase in the percentage of wells contaminated in the badly affected areas, however, it seems unlikely that new areas of contamination will emerge.

Population Exposed

A simple assessment of the population exposed to hazardous levels of arsenic was made using the 1991 census and the National Arsenic Survey of the Groundwater Studies for Arsenic Contamination Project carried out in 1998 and 1999. That survey is the only one that has a large, evenly spaced and reliable arsenic concentration data over the whole country excepting the Chittagong Hill Tracts. The estimates are made for the year 2000 assuming a population growth rate of 2.2% pet year and that 95% of the population draw their water from groundwater supplies. No explicit account has been taken of the difference in arsenic between the deep and shallow aquifers, however, the survey design was stratified to reflect the importance of deep and sallow aquifers in each Thana. The results of the assessment are given in Table AG 1 (WARPO, NWMPP, 2000).

Table AG-1: Estimated Population Exposed to Arsenic in Drinking Water

Arsenic Concentration	Exposed Population in 2000 (million)
> 10 ppb	47.5
> 50 ppb	29.0
> 200 ppb	10.3
> 400 ppb	2.90
Total population	125

Note: Table excludes the three Chittagong Hill Tracts Districts due to lack of arsenic data

The distribution of population exposed is somewhat different to the arsenic distribution itself because the most affected areas of the south east of the country also correspond to the areas of highest population density.

Options for Avoidance or Treatment

Preventing exposure to arsenic in drinking water by providing arsenic-free water supplies is the essential requirement for the improvement of health in the affected areas. There are three basic approaches:

- treatment of arsenic-contaminated groundwater;
- develop arsenic-free groundwater sources; or
- develop surface water sources such as rivers, ponds and rainwater.

All three approaches have relevance in different settings, and all have some difficulties. Hydrological and climatic factors obviously constrain the technical selection of methods, while the scale (e.g., household, community, municipal) of the operation will determine their social and economic suitability. The choice of method must also be considered in relationship to different drinking water standards. It is known that common methods such as aeration and coagulation-filtration will effectively reduce arsenic to around 0.05mg/l but not to 0.01mg/l.

Arsenic, Irrigation and Agriculture

Discussion of the inter-relation of arsenic and irrigated agriculture must be extended to ask whether arsenic in irrigation water affects the growth of crops, and whether and how arsenic in irrigation water or soil might accumulate in the food chain?

There are few analyses on arsenic in food grain in Bangladesh. However, no reports are available of analyses of rice or wheat containing arsenic at levels of health significance. Most analyses show arsenic below detection limits. Of the food grains, rice has the most potential to take up arsenic due to the anaerobic root zone (Chappell, 2000). No comprehensive study has been carried out, although a study is underway at CSIRO in Australia and results are expected soon. The CSIRO study will make a survey of arsenic in vegetables and crops, plus their associated soils and water sources across Bangladesh and West Bengal. The long-term objective is to integrate the arsenic-crop-soil-water-medical relations to develop a landscape risk assessment model.
Any serious uncertainty regarding irrigation of rice by water contaminated with arsenic must be explicitly addressed.

Professor Imamul Huq of Dhaka University has shown that arsenic may accumulate in the edible parts of leafy vegetables. Although these are not specifically water management issues, they are extremely important and require urgent investigation.

FAO Irrigation and Drainage Paper 29 (Water Quality for Agriculture) reports that-arsenic is toxic to rice, and causes a reduction of yield, at the same levels as it is toxic to humans in drinking water (0.05mg/l). Based on studies in Japan, Huang (1994) notes that although there is a weak correlation with total arsenic content there is a strong correlation with soluble arsenic in the soils. The factors controlling crop yield are many and complex, and single factors rarely dominate yields under normal conditions. The effect of arsenic on rice yield remains an area of uncertainty for water management, and it is believed (Chappell, 2000) that yield reduction in rice occurs at concentrations below those resulting in visible symptoms of phytotoxicity.

APPENDIX H

The Ganges Water Treaty:

Conflict and Agreement

The Indian sub-continent has several great rivers, the Ganges, the Brahmaputra-Jamuna and the Meghna Rivers. The Ganges and Brahmaputra basins together contain an estimated 400 million people living at a standard of living as low as anywhere on Earth (Rogers et al. 1994). There has been little regional cooperation over these waters, particularly over how to allocate flows, address the disastrous flooding that occurs, or tap the hydropower potential of the upstream riparians. In the 1980s, the South Asian Association for Regional Cooperation (SAARC) was formed, but it expressly excluded water as a topic for discussion, leaving that issue for bilateral or multilateral political talks. Over the years, various interim agreements have been signed; these were followed by renewed disputes and chronic lack of agreement, and international discussions repeatedly failed to resolve the conflicts. Moreover, while the riparians include Nepal, China, India, Bhutan, and Bangladesh, most discussions have excluded China, Bhutan, and Nepal. Yet at the very end of 1996, India and Bangladesh signed a water-sharing agreement that may have finally put to rest the most contentious water issues between the two countries - the allocation of flows of the Ganges between India and Bangladesh, and the operation of the Farakka Barrage.

The Farakka Barrage was built by India during the late 1960s and early 1970s across the Ganges River just upstream of the Bangladeshi border to divert water into the Hooghly River for irrigation use and to improve navigation. This dam was built without international agreement and it seriously affects dry-season flows to Bangladesh. In the early 1990s, dry-season flow in the Ganges reaching Bangladesh fell to 10 percent of mean dry-season flow, causing serious problems for agriculture and food production.

When Bangladesh became independent in 1971, the Farakka Barrage was still under construction. Because of the good relations between India and Bangladesh at the time, an interim agreement for operating Farakka was signed in 1974. These good relations, however, soon soured after changes in government, and Bangladesh brought the issue to the UN General Assembly in 1976, asking for help in resolving their concerns. A change in government in India in 1977 led to another agreement (The 1977 Ganges Waters Agreement), which guaranteed a minimum flow to Bangladesh and committed both governments to find a way to increase flows in the dry season. The agreement over water sharing held for five years without conflict, but ultimately expired (Crow et al. 1995).

Other attempts at agreement were made during the 1980s, with a "memorandum of understanding" signed in 1982. This memorandum itself expired in 1984 and a subsequent 1988 agreement on flows from India to Bangladesh was negotiated and quickly lapsed without a renewal. Finally, in December 1996, India and Bangladesh signed a water-sharing accord. What had seemed intractable over nearly three decades was suddenly possible due to changes in government and political will on both sides, pushed along by unofficial dialogues between the two countries (Gleick, 1998). In addition to specifying water allocations in normal and dry periods, both governments agreed to conclude water-sharing treaties and agreements over more than 50 other shared rivers and to find solutions to augmenting the flow of the Ganges in the dry season. The full text of the Treaty is provided below.

The treaty certainly doesn't mark the end of problems in the region over water - much depends on the future implementation of the accord. Yet it offers a promising beginning to a final resolution and a framework in which future disputes can be addressed. In the spirit of cooperation that followed this agreement, new avenues for resolving other outstanding issues between India and Bangladesh have opened up, showing that cooperative agreements over resource disputes can play a broader role in peace and security arrangements in South Asia.

The Treaty Between the Government of the Republic of India and the Government of the People's Republic of Bangladesh on Sharing of the Ganga/ Ganges Waters at Farakka

On December 12, 1996, India and Bangladesh signed a formal treaty that moves toward resolving their long-standing dispute over the Farakka Barrage and water flows in the Ganges River. This agreement covers the sharing of Ganges river flows between January I and May 31, when water flows are low and demands are high. In addition to specifying water allocations in normal and dry periods, both governments agreed to work out water-sharing treaties and agreements over more than 50 other shared rivers and to find solutions to augmenting the flow of the Ganges in the dry season.

The Farakka Barrage was built by India across the Ganges River in the late 1960s and early 1970s just upstream of the Bangladeshi border to divert water into the Hooghly River for irrigation and navigation. The dam was built without international agreement and particularly affected dry-season flows to Bangladesh, leading to serious political disputes between the two nations. Several interim agreements over the operation of the Farakka Barrage were signed, ignored, and voided over the years after construction of the dam. In the early 1990s, dry-season flow in the Ganges reaching Bangladesh fell to one-tenth of average dry-season flows, causing serious problems for downstream agriculture and leading to new regional interest in negotiating a solution, and ultimately, to the new agreement. There is widespread hope that the new treaty will help to permanently resolve problems between the two nations over the shared water resources. In particular, there is hope that the Joint Rivers Commission specified in the treaty will work to resolve disputes and to set an example for other international water sharing agreements.

The full text of the treaty is presented below.

Signed on December 12, 1996.

The Government of the Republic of India and the Government of the People's Republic of Bangladesh,

Determined to promote and strengthen their relations of friendship and good neighbourliness,

Inspired by the common desire of promoting the well- being of their people, Being desirous of sharing by mutual agreement the waters of the international rivers flowing through the territories of the two countries and of making the optimum utilisation of the water resources of their region in the fields of flood management, irrigation, river basin development and generation of hydro-power for the mutual benefit of the peoples of the two countries,

Recognizing that the need for making an arrangement for sharing of the Ganga/Ganges waters at Farakka in a spirit of mutual accommodation and the need for a solution to the long-term problem of augmenting the flows of the Ganga/Ganges are in the mutual interests of the peoples of the two countries,

Being desirous of finding a fair and just solution without affecting the rights and entitlements of either country other than those covered by this Treaty, or establishing any general principles of law or precedent,

Have agreed as Follows:

Article -I
The quantum of waters agreed to be released by India to Bangladesh will be at Farakka.

Article -II:

(i) The sharing between India and Bangladesh of the Ganga/Ganges waters at Farakka by ten day periods from the 1st January to the 31st May every year will be with reference to the formula at Annexure I and an indicative schedule giving the implications of the sharing arrangement under Annexure I is at Annexure II.

(ii) The indicative schedule at Annexure II, as referred to in sub para (i) above, is based on 40 years (1949-1988) 10-day period average availability of water at Farakka. Every effort would be made by the upper riparian to protect flows of water at Farakka as in the 40-years average availability as mentioned above.

(iii) In the event flow at Farakka falls below 50,000 cusecs in any 10-day period, the two governments will enter into immediate consultations to make adjustments on an emergency basis, in accordance with the principles of equity, fair play and no harm to either party.

Article -III
The waters released to Bangladesh at Farakka under Article -I shall not be reduced below Farakka, except for reasonable uses of waters, not exceeding 200 cusecs, by India between Farakka and the point on the Ganga/Ganges where both its banks are in Bangladesh.

Article -IV
A Committee consisting of representatives appointed by the two Governments in equal numbers (hereinafter called the Joint Committee) shall be constituted following the signing of the Treaty. The Joint.Committee shall set up suitable teams at Farakka and Hardinge Bridge to observe and record at Farakka the daily flow below Farakka barrage, in the Feeder canal, at the Navigation Lock, as well as at the Hardinge Bridge.

Article -V
The Joint Committee shall decide its own procedure and method of functioning.

Article -VI
The Joint Committee shall submit to the two Governments all data collected by it and shall also submit a yearly report to both the governments. Following submission of the reports the two Governments will meet at appropriate levels to decide upon such further actions as may be needed.

Article -VII
The Joint Committee shall be responsible for implementing the arrangements contained in this Treaty and examining any difficulty arising out of the implementation of the above arrangements and of the operation of the Farakka Barrage. Any difference or dispute arising in this regard, if not resolved by the Joint Committee, shall be referred to the Indo-Bangladesh Joint Rivers Commission. If the difference or dispute still remains unresolved, it shall be referred to the two governments which shall meet urgently at the appropriate level to resolve it by mutual discussion.

Article -VIII
The two Governments recognise the need to cooperate with each other in finding a solution to the long term problem of augmenting the flows of the Ganga/ Ganges during the dry season.

Article -IX
Guided by the principles of equity, fairness and no harm to either party, both the Governments agree to conclude water sharing Treaties/Agreements with regard to other common rivers.

Article -X
The sharing arrangements under this Treaty shall be reviewed by the two Governments at five year intervals or earlier, as required by either party and needed adjustments, based on principles of equity, fairness and no harm to either party made thereto, if necessary. It would be open to either party to seek the first review after two years to assess the impact and working of the sharing arrangements as contained in this Treaty.

Article -XI
For the period of this Treaty, in the absence of mutual agreement on adjustments following review as mentioned in Article X, India shall release downstream of Farakka Barrage, water at a rate not less than 90% (ninety percent) of Bangladesh's share according to the formula referred to in Article II, until such time as mutually agreed flows are decided upon.

Article -XII
This Treaty shall enter into force upon signatures and shall remain in force for a period of thirty years and it shall be renewable on the basis of mutual consent.

In witness whereof the undersigned, being duly authorised thereto by the respective Governnients, have signed this Treaty.

Done at New Delhi, 12th December, 1996, in Hindi, Bangla and English languages. In the event of any conflict between the texts, the English text shall prevail.

Signed: the Prime Minister of the Republic of India; the Prime Minister of the People's Republic of Bangladesh.

ANNEXURE – I

Availability at Farakka	Share of India	Share of Bangladesh
70,000 cusecs or less	50%	50%
70,000 – 75,000 cusecs	Balance of flow	35,000
75,000 cusecs or more	40,000 cusecs	Balance of flow

Subject to the condition that India and Bangladesh each shall receive guaranteed 35,000 cusecs of water in alternative three 10-day periods during the period March 1 to May 10.

ANNEXURE – II

(Indicative schedule giving the implications of the sharing arrangements under Annexure-I for the period 1st January to 31May). Figures in cusecs.

Period	Average of Actual Flow (1949-1988)	India's share	Bangladesh's share
January			
1-10	107,516	40,000	67,516
11-20	97,673	40,000	57,673
21-31	90,154	40,000	50,154
February			
1-10	86,323	40,000	46,323
11-20	82,839	40,000	42,839
21-28	79,106	40,000	39,106
March			
1-10	74,419	39,419	35,000
11-20	68,931	33,931	35,000
21-31	63,688	35,000	29,688
April			
1-10	63,180	28,180	35,000
11-20	62,633	35,000	27,633
21-30	60,992	25,992	35,000
May			
1-10	67,251	35,000	32,351
11-20	73,590	38,590	35,000
21-31	81,834	40,000	41,854

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