PN-ABF-528
67045

EASTERN WATERS STUDY

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EASTERN WATERS STUDY:

Strategies to Manage Flood and Drought in the Ganges-Brahmaputra Basin

Peter Rogers, Peter Lydon, and David Seckler

April 1989

Prepared for the Office of Technical Resources,
Agriculture and Rural Development Division,
Bureau for Asia and Near East
U.S. Agency for International Development

by the Irrigation Support Project for Asia and the Near East

PREFACE

On October 30, 1988, President Reagan signed into law H.R. 5389, the "Bangladesh Disaster Assistance Act of 1988." In addition to authorizing short-term relief efforts, this act also requested that no later than six months after enactment the President should report back to Congress "on efforts by the international community and the governments of the region to develop regional programs for the Ganges basin and the Brahmaputra basin that are designed (1) to ensure an equitable and predictable supply of water in the dry season, and (2) to promote better flood control mechanisms to mitigate in the mid-term, and prevent in the long-term, floods as severe as the 1988 floods in Bangladesh."

In preparation for the President's report to Congress, the Agency for International Development (A.I.D.) commissioned the Eastern Waters Study. The ISPAN Project of A.I.D.'s Bureau for Asia and Near East recruited the study team, arranged team support, and managed the study. The study was carried out by a team of three experts: Peter Rogers, Peter Lydon and David Seckler.

Peter Rogers, the team leader, is Gordon McKay Professor of Environmental Engineering and Professor of City and Regional Planning at Harvard University and has had over 20 years of experience researching issues of land, water, and energy planning in India, Bangladesh, Nepal, and Pakistan. His first technical publication, in 1966, was a game theory analysis of the development of the Ganges-Brahmaputra basin. During 1978 he was a consultant to the Ford Foundation in New Delhi; in 1981 he was a Visiting Professor at the Indian Institute of Technology in New Delhi; in 1984 and 1985 he was a senior consultant to the Master Planning Organization of the Ministry of Irrigation, Water Development and Flood Control, Government of Bangladesh; and in 1984 he reviewed water resources planning capabilities and needs for the Minister of Water Resources of the Royal Nepalese Government.

Peter Lydon, who is trained in political science, is a former State Department official and has worked in the U.S. missions in India and Bangladesh. He is also author of a monograph on aspects of water resource development in the Ganges-Brahmaputra basin.

The third member of the team, David Seckler, is Director of Agricultural Policy and Resource Development at Winrock International and Professor of Agricultural and Resource Economics at Colorado State University. Seckler has extensive experience in India, where he served from 1978 until 1983 as a Ford Foundation program officer in New Delhi. His special areas of concern have been agricultural policy and the economics of natural resources, environment, and irrigation.

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ACKNOWLEDGMENTS

The team would like to thank all those who helped with the preparation of this report. First, we wish to thank John Pielemeier, Mike Korin, and Dr. Stan Peabody of A.I.D./Washington for inviting us to participate in this venture and for being very supportive throughout the study. Second, we wish to express our gratitude to Dr. Tony Garvey of ISPAN for devoting so much time to facilitating our work and, more important, for provoking us to go deeper into some of the particularly thorny issues. Third, we wish to thank all of the members of the State Department's Eastern Waters study group. They were extremely helpful in sharing their impressions with us and helping us get a running start on the report. Fourth, we wish to thank all of the dozens of USAID and State Department field staff who helped us on our visits to Bangladesh, India, and Nepal and made our trips so productive and enjoyable. In particular, we would like to thank Glen Anders in New Delhi, Dr. Jon Breslar in Kathmandu, and Drs. Renfro, Hurdus, and Purvis in Dhaka. Also, Dr. Bruce Currey of Winrock International provided valuable advice and assistance in Bangladesh. Fifth, we wish to express our gratitude for the free and open discussions that we were able to have with very busy government, World Bank, United Nations Development Program, and Asian Development Bank officers in the three countries we visited, as well as in Washington, D.C. The opportunity to exchange views with these people helped us to ensure that the report was not a one-sided affair. Sixth, we were allowed to engage a very talented and interesting set of consultants to help us with some of the arcane areas of sedimentology, geomorphology, and meteorology. These consultants were Dr. Jack Ives of the University of Colorado; Dr. Daryl Simons of Simons and Associates; Dr. J. Shukla of the University of Maryland; Dr. Paul Jones of Paul Jones Associates; Mr. Mike Barber, a World Bank groundwater consultant; Mr. Steve Brichieri-Colombi of SNC in Montreal; and Dr. David Molden and Dr. Timothy C. Martin of Computer Assisted Development, Inc.

We wish also to thank our research assistants. The report would never have been completed without their help. We have been consistently amazed at the talent, enthusiasm, and just plain staying power of these young people. In alphabetical order they are: Deo Dhakal of the Kennedy School at Harvard University, Fred Euphrat of the University of California at Berkeley, John Quinn of Applied Sciences at Harvard, Linda Raymond-Dougher of the Fletcher School at Tufts University, and Ralph Stengren of the Kennedy School at Harvard. In addition, we had volunteer help to get us through some crises from George Christakos of Applied Sciences and George Wu of Decision Sciences at Harvard.

Finally, our thanks go to the ISPAN staff for production of the final report—Betsy Andrews, who coordinated the effort, and Carol Tilton, who produced the camera-ready pages—and to Jean Shirhall, the editor of the report.

CONVERSION TABLES

Length

1 meter (m)	= 3.28 feet (ft)
1 foot	= 30.48 centimeters (cm)
1 mile	= 1.609 kilometers (km)

Area

1 acre	= 0.405 hectare (ha)
1 hectare	= 2.47 acres
1 sq. km	= 100 ha
1 sq. mile	= 259 ha = 640 acres

Volume

1 million acre feet	= 1233.48 million cubic meters
1 cubic foot	= 6.23 gallons
1 cubic meter	= 219.97 gallons
	= 35.32 cubic feet
1 BCM = 1,000 million cubic meters	= 0.81 million acre feet
1 million gallons	= 160.544 cu. ft.
	= 4546.09 cubic meters

Volume and time

1 cubic meter per second (cumec)	= 35.3 cubic feet per second (cusec)

Weight

1 long ton (USA)	= 2240 pounds
1 ton (metric)	= 0.984 long ton
1 short ton	= 2000 pounds
	= 0.454 kilograms
1 pound	= 0.454 kilograms

Currency

Bangladesh Taka (Tk) 32	= US $1
Indian Rupees (Rs) 15.1	= US $1
Nepal Rupees (Rs) 25	= US $1

GLOSSARY

aman	Rice planted in the late *kharif* season during the monsoon (which begins in June) and harvested November-December (*B. Aman*—broadcast *aman*; *T. Aman*—transplanted *aman*).
aus	Rice planted during the pre-monsoon period, March and April, and harvested during July and August (*B. Aus*—broadcast *aus*; *T. Aus*—transplanted *aus*).
boro	Rice planted in the *rabi* season, December-January, and harvested in March-April (local varieties) or April-May (High Yielding Varieties - HYV).
kharif	wet season (mid-April to mid-October).
rabi	dry season (mid-October to mid-April).
Upazilla	smallest administrative unit in Bangladesh, formerly called a *thana*. A *Zilla* comprises several *upazillas*; *Zillas* have recently replaced the former and larger Districts.

EXECUTIVE SUMMARY

The Eastern Waters basin, where about a tenth of the world's population lives, presents the challenge of a densely settled, rapidly growing, and impoverished population facing alternating seasons of water surplus and deficiency. Water, energy, population, and poverty in a complex geographic interrelationship frame this study, which has worked to fit flood management into a broader context of human and social purposes.

Population, Resources, and Poverty

The Eastern Waters basin is the watershed of three great rivers of South Asia, the Ganges, the Brahmaputra, and the Meghna, which join in Bangladesh before entering the Bay of Bengal. Of its 1,758,000 square kilometers, 8 percent lie within Bangladesh, 8 percent in Nepal, 4 percent in Bhutan, 18 percent in the Autonomous Region of Tibet (China), and 62 percent in the Gangetic and northeastern states of India. Most of the area in Bangladesh is flat, rich farmland, 70 percent in India is arable plains, while the bulk of Nepal, Bhutan, and China's part of the basin is steep hills or arid plateaus. Most of the total population of half a billion people is in India (over 350 million) and Bangladesh (over 110 million).

The population of the basin is growing at a rate of about 2.2 percent per annum. Approximately half, or 250 million people, are below the poverty line. These people, numbering more than the total population of the United States, cannot afford an adequate diet. The number of people below the poverty line has progressively increased, with the growth of population, from the early part of this century to the present.

It is estimated that when the population of the basin reaches a stationary level in about 100 years, it will have tripled, to about 1.5 billion people. It is difficult to imagine life then, but a brief glance at Bangladesh is indicative. Bangladesh has 11.6 people per hectare of arable land, compared with 1.3 in the United States. At currently estimated stationary populations, Bangladesh will have increased to 38.5, while the United States will have 1.5 people per hectare of arable land. The average per capita income of Bangladesh is only 1 percent that of the United States, and the gap is widening every year.

From these and related facts, it is clear that the central problem of the basin is population and that the problem is worsening with time. Unless the rate of growth of population is drastically slowed, it is likely that there will be no solution to poverty and vulnerability to disaster in the region.

Flood Ecosystem

The delta of this region, where the dramatic flood of 1988 was experienced, is the outlet for three of the largest rivers in the world. Dozens of other smaller but substantial rivers are tributaries or distributaries of the main ones. The delta and adjoining areas are subject to intense rainfall and periodic cyclones. People can crowd into the floodplains of this gigantic hydrologic system only at their peril. There are narrow limits to what technology can do to control the risks of living in the major floodplains.

An idea of the size and power of these floodwaters can be obtained by noting the vast changes in channel depth and configuration that occur rapidly on these rivers. For example, during the flood season of 1966, just downstream of Faridpur on the combined Ganges and Brahmaputra, the river moved laterally in a northward direction 1,500 meters, eroding the bank and digging a new channel 30 m deep. This amounts to about 100 million tons of sediment moved per river mile. During the 1988 flood, the outlet of the river system swung about 550 m eastward toward the protective embankment of the Chandpur flood control and irrigation project, where it dug a new channel 45 m deep. This embankment will now have to be abandoned and a new one built behind it. In few other situations does mankind have to deal directly with the raw power of nature as it does in Bangladesh.

It is tempting to view the floods as a disaster that has to be stopped. The paradox, however, is that the floods are a necessary part of the ecosystem in this part of the world. Without the annual flood, Bangladesh would find itself in very serious economic and environmental straits. The floods are essential to maintain the fertility of the soils, to replenish the groundwater and soil moisture for the winter season, to help maintain the extensive fisheries (both in the flooded areas and in the rivers and estuaries), and to provide plentiful water to the monsoon crops. In a normal year, floods do all of these things without causing havoc. Even large floods like the one in 1988 have many beneficial effects as well as many damaging ones. Deciding just what level of flood to protect against is a question as yet unanswered in Bangladesh. One flood control expert said, "instead of attempting to stop the flood all the way from the bottom up, if we could have embankments that only took the top one half meter off the flood we would have the problem licked."

Geographical Interrelationships

The actual physical layout of the basin adds its own series of complications to the problem. Nepal, which is mostly mountains, is everywhere upstream of India. Nepal can, however, only divert and use for its own purposes very small amounts of water, and it cannot affect the bulk, which flows unhindered into India. Nepal sees the need to extract as much energy as possible from the water before it leaves its territory forever. But, also because of geography, Nepal can realistically only sell this same extracted energy to one customer—India.

India is everywhere upstream of Bangladesh. India, however, can divert large amounts of water from the rivers before they enter Bangladesh, causing potential water shortages there. China is upstream of India, but it has little chance of diverting water from the Brahmaputra before it enters India because of the nature of its mountainous terrain and low population densities in the area. Its power load centers may also be too far away to make power exploitation realistic—unless again electricity is sold to India.

Because of geography, the central part of India has a major problem in accessing and using one of the country's largest rivers, the Brahmaputra in Assam. It is the perception of many Indians that fully one-third of India's surface waters remain unutilized in this river.

For floods, it is customary to place great emphasis on the Brahmaputra. Even in Bangladesh it is little understood that the areas vulnerable to flood from the Ganges and those vulnerable from the Brahmaputra are very similar in size. This fact is of great importance in assessing flood mitigation programs because even though there appears to be little that can be done about the floods in the Brahmaputra basin, the outlook is much better on the Ganges.

After reviewing the resource base of the region, this report examines the social and political patterns of water resource use. It concludes that it is not necessary or helpful now to look for some overarching regional cooperation on water resources development in the basin. At some point in the future a cooperative structure could be desirable, but currently the pressing issues can be dealt with by each country within its borders or on a bilateral basis.

Causes of the Flood

The causes of the 1988 flood were examined for evidence of discontinuities or long-term environmental changes, such as a trend to larger floods. First, there is no statistically reliable evidence that the physical extent and severity of flooding have increased over the 100 years for which data are available.

Second, deforestation of the Himalayas is not likely to have a significant effect on the extent of the floods in the plains and the delta below. Growing human population is increasing pressure on the mountain and hill forests, and the scarcity of firewood and local soil erosion related to this are serious problems calling for remedies to maintain the wood and agricultural productivity of the hill lands and the quality of life in hill environments. But generalizations that changes in mountain tree cover are responsible for siltation and floods in the densely populated plains below are not justified. Apart from the finding that physical floods are not in fact increasing in severity in this period, natural causes are fully adequate to explain the flow and siltation levels of the region's rivers without reference to the effects of man. The high monsoon rains in the mountains, combined with steep slopes and seismically unstable terrain, ensure that this zone will have rapid run-off and high sedimentation whatever the land cover may be, as was true before human settlement in the region.

Another cause for alarm in the region is the apprehension that the global climate may be warming, causing the seas to rise, snows in the Himalayan watershed to melt more rapidly, and perhaps rainfall to become more severe in this region. Although this is a matter of wide scientific debate, no evidence of these effects is found in the Eastern Waters basin. Even the 0.5 degree Celsius rise, which is asserted to have already happened during this century, is very hard to distinguish from statistical noise (non-trend variations) in the voluminous temperature data. It is extremely unlikely that these effects have had any impact so far on the magnitude of the recent floods in Bangladesh. Water planners in Bangladesh, and elsewhere, should take careful note of developments in this regard, but immediate alarm in Bangladesh about the greenhouse effect appears to be very much premature.

Flood Control

The conventional flood mitigation approaches of upstream storage in mountain zones and embankments on the main rivers raise basic questions regarding technical and economic feasibility. These are also the approaches that lead to the largest environmental disruptions. For example, upstream storage would require the inundation of large areas of the best agricultural lands in the hills, which would displace many thousands of inhabitants and disrupt wildlife and other ecosystems. Reservoirs act as sediment traps; they soon lose their own capacity to withdraw flood water and cause downstream erosion and upstream aggradation. Dams in the Himalayas are exposed to earthquakes and the risk of catastrophic breaching, and at the same time may contribute to seismic destabilization through both the weight and fault-lubricating effect of collected water. To store sufficient water in the hills to affect the floods on the plains, as much as $60 billion would have to be expended and the time taken to complete the storages could be as long as 60 years—at the end of which the original storages could well be fully silted, and it would be necessary to renew the process of dam building.

Flood control by embankments along both sides of the main rivers, unlike reservoirs, makes no contribution to irrigation or hydropower. A major river-embanking program is now under consideration by the Government of Bangladesh, but the drawbacks of such an investment are extremely large. As mentioned above, embankments will cut the country off from many of the beneficial effects of the monsoon, which are critical not only to agriculture, but to the fish on which Bangladeshis rely for over 70 percent of their animal protein intake, and which are their second largest export earning product after jute, itself a highly flood-dependent crop. Every year, embankments will damage historic environmental balances critical to human life in the delta, but they will pay back their massive investments by providing flood protection benefits only in relatively rare years of high floods. If they are placed close to the river banks, the earthworks must confront the immense cutting forces of dynamic and unstable rivers in flood; if they are conservatively placed farther back from the river courses, in a country as densely populated as Bangladesh, many people will be living between the riverbanks and the embankments and for them the flood danger will be increased rather than reduced. Those outside the embankment will suffer from the often persistent and hard-to-manage flooding that arises when local rainwater is blocked by the embankment and cannot drain normally into the river course. Embankments, moreover, do not reduce floodwater, but merely move it; excess water that is confined in the streambed in the districts higher on the river will increase the volume and velocity, and perhaps the depth, of the flow that has to be managed in districts closer to the sea. Rivers that carry very heavy sediment loads, as do those coming from the Himalayas, will tend to build up their beds if confined. After a period of years of such buildup, a river could run at a level higher than the surrounding countryside, an extremely dangerous situation for the inhabitants.

Embankment of the major rivers in Bangladesh as now envisioned would cost about $6 billion and have annual maintenance costs on the order of $600 million. It seems extremely unlikely that this is a justifiable investment, and even less likely that it is the best development investment available for Bangladesh's extremely limited domestic or even foreign-donated resources.

Other approaches to physical flood mitigation, such as drainage improvements, are less disruptive ecologically and more technically and economically feasible than dams and embankments, but the two billion tons of sediment carried by the rivers of the basin, far more than is normally encountered in Europe and the United States, make dredging a permanent and usually uneconomic proposition.

A series of underground storage options based on purposeful raising and lowering of the water table have been put forward since the early 1970s.

Although they appear to have little or no environmental impact, their large-scale technical and economic feasibility still has to be established. Other concepts, such as storing substantial amounts of water on the plains themselves, have not been seriously explored in the region. Major social and environmental problems can be anticipated if such storages were to be implemented, but the concepts merit further exploration.

Large flood control projects involving upstream storage or embankments in or near the main channels of these rivers are probably not feasible means of dealing with the flood problem in the near future. In the meantime, the people of this region have adopted many ingenious ways of living through the floods. Resources should be allocated to helping them do this more effectively by establishing refuge areas, providing better emergency food and medical services, protecting some agricultural areas from shallow-flood damage, increasing surface drainage capacities, and the like. These approaches have been grouped in the report under the heading "flood proofing." Most of them appear to be technically sound, economically attractive, and environmentally benign. It is strongly recommended that international assistance be provided to support actions that will help people "live with the floods."

Low-flow Augmentation and Agriculture

Three methods were considered to make more water available in the dry season, in addition to upstream storage, underground storage, and storage on the plains (discussed above), all of which can serve both flood mitigation and low-flow augmentation goals. The most widely discussed (although with perhaps more vehemence than actual understanding on all sides) is the interbasin transfer of water from the Brahmaputra to the Ganges. Several different versions of this approach are current, but they all suffer from serious technical feasibility questions involving the necessary cross-drainage works, prospectively enormous costs (particularly the maintenance costs), social conflicts because of the land-taking requirements in both India and Bangladesh, and serious environmental conflicts with sediment control and fisheries in the cross-drainage lines. If ultimately shown to be feasible and economical, this approach, in combination with large dams on the upper Brahmaputra as outlined by India, could offer Bangladesh both flood storage and low-flow augmentation. Bangladesh, nonetheless, is committedly opposed to this use of its land for the transfer of water between two parts of India.

In relation to the basic problem of growing enough food for the increasing population, overcoming the lack of winter rain is far more important than managing periodic flood disasters, which on analysis, cost surprisingly little in annual national grain production. In the basin's deep alluvial soil, water is abundantly available. In the subcontinent, a drilled water well is called a tubewell. The technology of the tubewell, pumped by diesel or electric power, permits all-year cultivation by tapping underground water efficiently, and it has spread widely in the past 40 years. Growth in grain production is directly related to the availability of dry season irrigation, the indispensable "platform" supporting all other green revolution inputs. To end the long relative agricultural stagnation of eastern India, and to emerge from a three-year slowdown in growth of grain production in Bangladesh, no policy available to governments is more important than active support for groundwater capture by tubewells.

Recommendations

Although the report sees great expense, possibly serious environmental risk, and little prospect of effectiveness from quick application of the heaviest engineering solutions—large storage dams and river embanking—it does not say that nothing can or should be done about the floods and water shortages in the immediate future.

On the contrary, a great deal should be done in a variety of directions to reduce flood vulnerability, from better emergency preparation and relief services, through international cooperation for flood warning and analysis, modest embankments to protect high-intensity land uses or to alleviate low-flood damage, to a range of flood-proofing measures.

To make water available in the eight months with virtually no rain, electrification from the vast hydropower potential of the region should go forward with more firmness of purpose, and the governments and technical establishments should much more thoughtfully and actively support the spread and efficient use of tubewells. It is also important that several research agendas be actively pursued, and very desirable that they be supported by greater liberality in the exchange of data.

The recommendations of the report are divided into the following categories: general recommendations, action recommendations, and recommended technical and scientific research.

General Recommendations

1. **Necessary Awareness of Being Outsiders.** The United States is well equipped to make a contribution to harnessing the basin's water by virtue of long and successful involvement in past water developments at home and in the region. However, the United States and all nonregional countries, although they have important experience and knowledge to contribute, must understand the limits on their roles and show the discretion legitimately expected of outsiders. This is particularly important with regard to India, by far the central and largest country of the region, which has been deeply committed since its independence to developmental self-reliance.

2. **No Overall Regional Water Development Program Necessary.** In the longer term it will be desirable for the riparian countries to coordinate their water development programs. Currently, however, the quest for a broad cooperative regional approach to water development is likely to delay rather than hasten the specific water arrangements that will benefit the basin population. With few exceptions—building hydropower capacity in Nepal based on Indian purchase commitments being the principal one—the most important practical measures to be taken are in-country ones.

3. **Intensify Study and Institutionalization of Groundwater Use.** The rapid spread of tubewells to exploit renewable groundwater, which stores the abundant monsoon flows for dry season irrigation, continues in this area of extraordinarily rich aquifers. Farmers know that electric or diesel tubewells are a good investment, but regional governments need to speed up their full acceptance, study, and legitimization of this "new technology."

4. **Exercise Caution against "Single Solution" Approaches.** A broad and integrative approach must be taken to the complex challenge of water management in this highly water-dependent environment. On a scale of decades, only tested combinations of interventions and adaptations will, for example, mitigate the threat of floods in Bangladesh without negative side effects on extremely important concerns, such as fish production. The search for single, conclusive solutions, for example, flood protection by embankment in the great delta, is likely to be wasteful and ineffective.

5. **Indian and Bangladeshi Hydrological and Meteorological Data Should Be Shared Internationally.** A freer flow of technical and scientific information, following predominant world reporting and sharing practices, could improve policymaking within the countries and be a confidence-building step in all water dealings among regional countries.

6. **Broadened Analysis of Engineering Projects.** Bringing in economists and physical, biological, and social scientists to develop estimates of the costs and benefits and the environmental and social impact of water engineering projects would improve decision making and increase the return from what are often very large investments.

Action Recommendations

1. **Immediate Pursuit of Elements of the Government of Bangladesh's Guiding Principles.** Of 11 "Guiding Principles" set out by the Government of Bangladesh in 1988 as part of the nation's response to two years of disastrous flood, 7 suggest actions that can immediately help the population deal with future floods. They set forth the important "soft" program of flood proofing discussed throughout this report. The donor countries should endorse these principles, and Bangladesh should proceed with their implementation. However, the four remaining principles imply massive investments in embankments and river training. This is a confrontational approach to the floods that is certain to be costly and unlikely to be successful.

2. **Execution of Bangladesh's National Water Plan.** The Government of Bangladesh has in its National Water Plan an excellent approach to its water resources. Endorsed by the National Water Council under President Ershad's chairmanship and by the main international donors, the plan will invest $6 billion over 20 years on flood control, drainage, and tubewell irrigation projects prioritized to meet Bangladesh's food production needs until 2005. Unfortunately, delays in implementing the National Water Plan have already led to foregone benefits in the billions of dollars. There is an urgent need for the World Bank,

as coordinator of the Aid to Bangladesh Consortium, to take a lead in mobilizing donor support for this plan.

3. **Intensify Efforts to Achieve Interregional Power Development and Use.** Building hydropower facilities in Nepal, either run-of-the-river or with storage, to provide electricity to north India would benefit both countries. It is to be hoped that the necessary discussions can proceed with vigor and will be supported by international financial institutions. In the long run, the large-scale use of pumped tubewells in the plains may be contingent on capturing Himalayan hydropower. Similarly, Bangladesh should be encouraged to develop its considerable natural gas resources for electricity generation for the region.

4. **Research Coordination.** Certain priority lines of research needed for effective water management should be discussed at a conference in the region in the second half of 1989 or early 1990. It should have participation by technical people based in government departments, planning bodies, universities, and institutes of the region. The conference, and probably some of the research it proposes, could be effective projects for USAI[illegible] international financial institutions, or priva[illegible] [illegible]undation development assistance to the region.

Recommended Scientific and Technical Research

1. **Monsoon Hydrology.** Great recent achievements in monsoon meteorology make it possible to go beyond weather analysis and to improve "monsoon hydrology." Advancing from the analysis of rainfall to a much better understanding of run-off in the streams and infiltration into the ground should be the goal. This step is critical to understanding sediment transport and floods in the Himalayan region.

2. **Water Balances on the River Basins.** Through a series of measurements, a water balance follows water from its descent as rain, through its flow either underground or on the surface, until it evaporates or reenters the sea. A detailed water balance should be calculated for the Ganges River basin. Similar work is desirable but less pressing for the Brahmaputra and Meghna basins.

3. **Sediment Balances.** To put certain tensions among the riparians to rest and also to aid in the technical appraisal of embankment and river training works, sediment balances should also be carried out in the three major land forms of the region—the mountains, the plains, and the coastal deltas.

4. **Geology and Seismology of the Himalayas.** Specification of the earthquake risk is critical to correct decisions on whether high dams and large storage reservoirs can be built at many otherwise excellent sites in the Himalayas. Both the rewards and the risks of such projects are very high; fundamental geological and seismological understanding is of the essence to their basic safety.

5. **Potential for Underground Storage of Flood Waters.** A careful study combining detailed empirical field work and modeling should be made of how pumping out groundwater on the Ganges plains creates space to store monsoon water, in principle moderating floods and almost certainly reducing early season floods. Better understanding should lead to more conscious and effective exploitation of an important side benefit of tubewell irrigation.

6. **Rural Electrification for Tubewells and Other Uses.** The strategy for agricultural development outlined in this report depends heavily on tubewell capture of groundwater, which depends in turn on energy availability at dispersed rural well sites. Broad study of how the large and rather seasonal energy needs of large numbers of additional tubewells of different sizes can be met on a national and regional basis would be extremely useful.

7. **River Mechanics.** Following up on the durably useful work of Coleman (1969) on the Brahmaputra, detailed hydrographic analysis of the dynamic and shifting regional rivers is needed. It is a fundamental basis for engineering pre-feasibility studies of projects such as bridges and embankments.

8. **Interbasin Transfer of Water.** To help resolve the issue of Ganges low-flow augmentation, which is a conflict of a decades's standing between India and Bangladesh, there is need for studies of the technical feasibility of the diversion of water from the Brahmaputra to the Ganges. Creative thinking should assess other interbasin options, including transfers of water

from Assam to West Bengal via a series of diversions that would open a navigation link for Nepal to the sea and trans-Himalayan prospects using the Gandak or the Kosi for diversions from the Tsangpo.

9. **Research in Support of Flood Proofing.** Social scientists, crop systems specialists, and others should study how people in the rural areas live with the floods. What kinds of safety measures do they undertake at the family and community level before and during a flood? How are crop systems adjusted to flood expectations? More effective national flood management can result from understanding and disseminating successful strategies.

1

INTRODUCTION

These rivers have played a vital role in the history and economy of Dacca district ... Along them, since time immemorial, have travelled both warriors and traders: witness, for example, the histories of Vikrampur, Sonargaon and Dacca itself located along their courses ... Still today, they are bustling with activity, their channels thronged with busy motor launches, stately steamers, and the eternal slow procession of sail boats, big and small. Fish they provide and domestic water supplies, too ... their annual floods water the land and determine the harvests that will be reaped.

If rich blessings they bring, then tragedies also they bring; calamitous high floods which wash away dwellings, livestock and crops; changes in course which erode settlements and fertile cropland, or close old arteries of trade; and sudden storms which overtake boatmen, puny against the rivers' might. So, into all parts of the people's lives—their history, their culture, the economy, their very way of life—have the rivers entered and enter still....

—Excerpt from *East Pakistan District Gazetteers* (rev. ed., Rizvi, 1969:17)

In the large Ganges-Brahmaputra-Meghna basin of Asia, a rapidly growing population, already close to 500 million people, and a monsoon climate of heavy summer rains and a long winter dry season, make water management a central element in economic development.

This review of current and prospective water issues in the Eastern Waters basin draws on documentation from various sources, on consultation with experts and officials of the region's countries, and on the experience in the region of many experts from the United States and other countries. It treats the large watershed as a whole, but stresses the problem of flooding in deltaic Bangladesh, because the 1988 floods there prompted the request by the Foreign Affairs Committee of the U.S. House of Representatives for hearings and for this report. In its focus on irrigation, flood control, and hydroelectricity, the report does not attempt to cover other important topics, for example, water quality and public health, fisheries, water transportation, and the differential effects on various economic groups of developments in irrigation and agricultural productivity. This is not to imply that such matters are not active or significant in this region.

1.1 The Basin

The Ganges-Brahmaputra-Meghna basin extends over Bhutan, Nepal, India, Bangladesh, and China (Autonomous Region of Tibet). Its total area is 1,758,000 square kilometers, roughly 2,400 km east to west and 800 km north to south. Sixty-two percent of the basin's surface is within India, 18 percent in China, 8 percent in Bangladesh and in Nepal, and 4 percent in Bhutan (see Figure 1).

The northern rim of the Ganges-Brahmaputra watershed lies on the Tibetan plateau, well beyond the Himalaya Mountains, but this report concerns itself mainly with India, Nepal, and Bangladesh and often speaks of them as the "basin countries." Bhutan is a country of very small population, has close ties to India, and has a mountainous geography similar to that of Nepal. China is not prominent in the discussion because of the thinness of population in Tibet and because north of the Himalayas the basin rivers do not receive heavy monsoon rains and have much less water in their reaches than farther downstream. This means that, in general, the floods and droughts affecting millions of South Asians lower in the basin are not significantly controllable by measures on the high plateau.

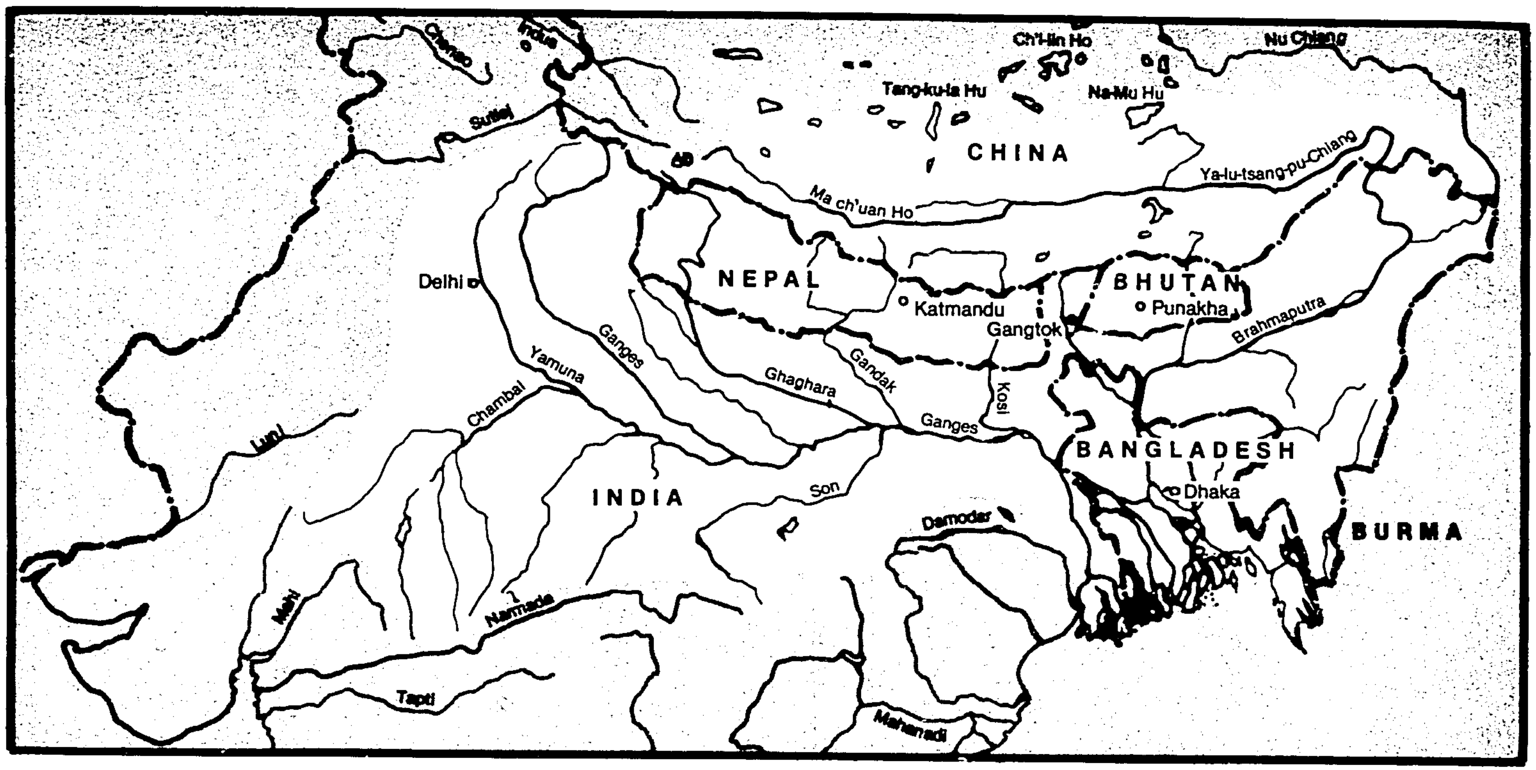


Figure 1

Map of Ganges-Brahmaputra Basin

1.2 Cultural and Religious Importance of Water

No one in South Asia thinks that water is unimportant. It is well known in the world at large that the Ganges is a great religious river. But in South Asia, beyond that and beyond water's material uses, which are critical to life and to development, all water is associated with fertility, purity, and spiritual nourishment. Its great value is a deep and central element of the millennial culture. There should be no surprise at the strength of feeling that surrounds water issues, nor at the vehemence and deep-rooted emotions that can emerge in conflicts about water.

1.3 Immensity of Water System and Its Forces

Those who consider how this natural water system can be managed for the safety and benefit of increasing numbers of human beings must not lose sight of its scale. The energies at work each year, starting with the sun's evaporation of trillions of tons of sea water and the wind's carrying it up over land and against the Himalaya Mountains, dwarf all the energy produced here in the basin by man through all his history.

The combined Ganges, Brahmaputra, and Meghna rivers in the last hundred kilometers of their run to the sea form a river two and a half times the size of the Mississippi. Although the total area of the South Asian watershed is slightly less than one-half the area of the central basin of the United States, it receives four times the Mississippi basin's total annual rainfall, 85 percent of it in one-third of the year. From the highest mountains in the world and from earthquake-prone foothill jungles that include sites that receive the highest annual rainfall in the world, the descending water carries more than two billion tons of silt each year; no work of clearing or channelling can be considered stable or permanent.

The Ganges and its major tributaries have often brought flood disaster to the plains of India. The larger Brahmaputra is one of the world's most turbulent and dynamic rivers. In known history the Brahmaputra has shifted its course on a geographic scale, and in northern Bangladesh it is now perched on a fan of its own silt deposits, perhaps ready for a further major shift, which must not be provoked by ill-judged works on the river. In a recent "normal" small shift of a lower combined section of the Ganges-Brahmaputra, the river moved its course east in a matter of days by half a mile in front of the port city of Chandpur in Bangladesh. It cut a new east bank channel about 45 meters deep, joining that land to its sediment load and carrying it out toward the sea. No embankments or river-training works in the world can control these forces if they are taken head on.

Although cumulatively their effects can be great, human beings are an infinitesimally small part of the immensity of this natural picture; they will manage its forces better in awareness of that scale and with a goal of reconciliation with a powerful nature rather than confrontation. Respect for the rivers, painstaking and repeated scientific analysis, and human adaptation must play large roles. Technological or engineering hubris is likely to lead to massive waste of the scarce resources of currently very poor societies, and even to sudden catastrophe if a storage dam should be overwhelmed. Fundamental geological and meteorological knowledge of this environment must continue to be sought, and wisdom, not haste, must be the keynote of the central decisions of coming decades on this very large canvas.

1.4 Population, Food, and Poverty

The relationship between population growth and economic development is much disputed, but two issues are of major importance to the Ganges-Brahmaputra countries:

1. Given their population growth, will they be able to maintain a reasonable degree of food self-sufficiency, or will they become increasingly dependent on food imports?

2. What is the relationship here between population growth and poverty? If the growth of the economy is not sufficient to absorb a rapidly expanding labor force at rising wages, poverty will not be reduced—even if average per capita GNP rises.

Table 1 presents some basic statistics on these issues for Bangladesh, Nepal, and India, compared with the United States for illustrative purposes. By the time the stationary population is expected to be reached (about 100 years), the current population of Bangladesh will have more than tripled, Nepal's will have almost quadrupled, and India's will have doubled. The number of people per hectare of arable land in Bangladesh will have increased from the current level of 12, compared with only 1.3 in the United States, to 38. At stationary population, Nepal will have 27 and India 10 people per ha of arable land. Because Bangladesh has only utilized about 25 percent of its irrigation potential, however, compared

Table 1

Social and Economic Indicators by Country

	Bangladesh	Nepal	India	USA
POPULATION				
Population (1986, Millions)	103.2	17	781.4	241.6
Growth (%)				
1965-80	2.7	2.4	2.3	1.0
1980-86	2.6	2.6	2.2	1.0
1986-2000	2.5	2.5	1.8	0.6
Size of Stationary Population (Millions)[a]	342	63	1,698	279
Urban Pop (% Total 1985)	18	7	25	74
AREA AND DENSITY				
Total Area (1000 sq km)	144	141	3,288	9,363
Arable Land (1000 ha)	8,891	2,290	164,850	187,881
Pop per sq km Total Area	717	121	238	26
Pop per ha Arable Land				
1986	11.6	7.4	4.7	1.3
Stationary Population	38.5	27.5	10.3	1.5
ECONOMIC AND SOCIAL INDICATORS				
GNP Per Capita (US$)	160	150	290	17,480
Growth PC GNP (1965-85)	0.4	1.9	1.8	1.6
Life Expectancy at Birth (yrs)	50	47	57	75
Daily Calories Per Capita (1985)	1,804	1,997	2,126	3,682
Infant Mortality (Per 1000 Live Births)				
1965	153	184	151	25
1985	121	130	86	10

[a] Stationary populations are expected by the end of the next century.

Sources: World Bank (1988), World Development Report 1988; Food and Agricultural Organization, Production Yearbook 1985.

with about 60 percent in India and Nepal, it probably has the best chance among the countries of feeding its people, notwithstanding its higher population density.

As a rough estimate, about two-thirds of a kilogram of rice equivalent per capita per day is required to meet caloric requirements, or 240 kg per capita per annum. Thus, at Bangladesh's stationary population, each hectare will have to produce about 9 metric tons of foodgrain per year. It is doubtful whether average cropping intensity can exceed 250 percent on a countrywide basis. Thus, average yields will have to be 3.6 mt/ha/crop. This is a very difficult, although not impossible, goal to attain. Japan attains slightly greater yields on a single-crop system. Attaining the goal would require very high levels of fertilizer, energy for pumping water, and other inputs and would probably require food prices to increase threefold in real terms, as in Japan. Thus, the question is not whether Bangladesh can physically meet food requirements but whether people will be able to purchase the food produced.

In India, the percentage of the people below the poverty, or basic subsistence, line has remained constant at 40 percent since the early 1950s, when the data were first collected (Mellor and Desai, 1985). In eastern India, the percentage is probably close to 50 percent and may be increasing. The same is probably true of Bangladesh and Nepal, although the data are not so systematically collected. One of the explanations is that, despite the green revolution, in the face of population growth, per capita food production has remained roughly constant over the entire period. Another reason is that the nonagricultural economy has not grown fast enough to create large demands for labor and rising real wages. It has been estimated (Seckler and Sampath, 1985) that the required rate of economic growth in India to reach full employment is about 9 percent per annum, compared with about 5.6 percent per annum over the 1976-1986 period. The required growth is probably higher in Bangladesh and Nepal, because of higher population growth. Again, this is a very difficult, although not impossible, goal to attain.

Considering both these issues, reduced population growth would greatly ease the pressure on all resources, including water. There is no doubt that restraint of population growth is one of the most essential elements in any long-run strategy for development in this part of the world.

1.5 Overview of Floods of 1988 in Bangladesh

This report's point of departure is the flooding of 1988 in Bangladesh, which was one of the most prolonged, extensive, and damaging inundations in living memory, made more traumatic for the leaders and the people of the country because there had also been heavy flooding in 1987. The flooding of 1988 was widely perceived abroad as a massive and devastating ecological catastrophe.

Flooding is dramatic and totally disruptive when it is taking place, but the aftereffects of a flood in Bangladesh are less severe than is often imagined. In historical and physical context, river and rainstorm flooding in this region is unmistakably less devastating than drought, and historically less lethal to human beings than more sudden and localized water disasters, such as cyclonic tidal waves in the coastal districts of Bangladesh. Some salient points about the 1988 flood follow:

- Bangladesh is a virtually flat, deltaic country traditionally adapted over hundreds of years to annual flooding that reaches an estimated 20 percent of the total land, and to periodically very high floods reaching 50 percent of its area. The 1988 flood was estimated to cover 46 percent of the area (66,360 km^2) (Caritas, 1988).

- Donor missions in Bangladesh estimated that for the crop year 1988-1989 about 14 percent of the main summer (*kharif*) rice crop (compared with the last five-year average) was lost to the flood. It now appears likely that despite the direct flood loss, Bangladesh's all-season foodgrain production in 1988-1989 will be at record high levels, in part because of abundant residual moisture left by the flood for intensified cultivation in the winter dry (*rabi*) season (Hash, 1989, which is an update of Hurdus, 1988).

- The 1,500 fatalities reported (Caritas, 1988) at the time of the flood should be related to the loss of over 200,000 lives in the cyclone-driven tidal wave of 1970, to the heavy fatalities of a tidal wave on October 19, 1988, and to the more than a thousand deaths caused by a cyclone on November 29, 1988.

- There are no grounds for considering deforestation in the Himalayas as a significant cause of the flooding in the delta of the river system. At present, there is no indication of a major cause for the 1988 flood that was realistically within the control of an upstream country.

- There is no evidence of long-term changes in rainfall in the Ganges-Brahmaputra basin or any trend of increased flood depth or frequency in recent years. Modern floods are not physically different or worse than historical ones, although the economic losses of recent floods are higher due to the growth of the population and the building of cities, roads, and factories. However, it is probably true that an unmanaged flood vulnerability and the consequent risks of flood damage take a significant silent toll by inhibiting investments in development.

- The hypothesized warming of the globe, the "greenhouse effect," has been suggested as a cause for the recent floods in Bangladesh. No evidence has been found for any temperature-induced changes in the hydrology of the Eastern Waters basin.

2

NATURAL RESOURCES AND STRATEGIC ISSUES FOR DEVELOPMENT

2.1 Development Needs and Aspirations in the Basin

By the year 2020, the population of the basin, now 500 million, can be expected to have grown to 1 billion (about 750 million in India, 30 million in Nepal, and 220 million in Bangladesh). The first developmental imperative is to be able to grow food for those numbers of people, and each country takes this as a primary goal, usually in terms of "food self-reliance."

In India, Bangladesh, and Nepal there are also severe employment or purchasing power problems: Even with adequate food being produced within their borders, about half the people do not have enough income from the land or sustained and remunerative employment to be able to purchase adequate diets. All three countries seek a major intensification of agricultural and general economic activity to offer productive employment.

To build industrial, communications, and service sectors, the overall economy of each country requires increased quantities, absolute and per capita, of low-cost food with which to feed the work force. This requires an efficient, high-input agriculture making intensive and effective use of land and human resources. This, in turn, implies investments in fertilizer, high-yielding seeds, pesticides, rural energy supply, and the lead input, irrigation.

At the national political level, each basin country aspires to affirm and intensify its sovereignty and autonomy. This is an aspiration that conflicts, especially for Bangladesh and Nepal, with increasing regional economic integration, and therefore, it may be in some conflict with the goal of general economic advance. Within this goal of autonomy, therefore, there is a dilemma:

- Poverty means dependency and a loss of autonomy; it means greater vulnerability to external pressures.

- To the extent that economic advance requires regional cooperation, as it does, for example, in the case of large hydroelectric sales by Nepal to India, such cooperation means accepting obligations that constrain independent action and that can be seen as erosions of autonomy and even sovereignty.

Within Bangladesh and Nepal, and even within India, this dilemma is perceived differently in different sectors and by contesting political elites, but it has a real influence on cooperation and, hence, on development in the region.

2.2 Current Constraints and Strategic Choices

The most fundamental constraint on improved per capita incomes in this region is that the decline in the rate of growth of the population is disappointingly slow. Greater success in slowing population growth would greatly improve each country's prospects, Bangladesh and Nepal especially, of being able to feed and employ its future populations, as discussed above in Chapter 1.

In regard to water and agricultural policy, for India and Bangladesh a leading constraint is the historical commitment of the decision-making elites, and especially the governments' large bureaucratic and technical establishments, to the primacy of visible surface water. A major scientific and technical transition is now going on in the field of water supply. The alluvial plains of the Ganges-Brahmaputra basin hold the world's largest reserve of fresh, annually replenished groundwater.

However, a full awareness of the volume and usability of groundwater is a very recent development. Analysis and exploitation of groundwater for irrigation were not possible until widespread diffusion of the drilled well, known as a tubewell in the subcontinent, and diesel and electric pumps. This diffusion began about 1950 and is still going on today. Because tubewells taking water from the region's generally high water table are a manageable investment even for a single farm, and because use of tubewells complements remarkably use of the fertilizers and high-yielding varieties of the green revolution, they have spread rapidly and are continuing to do so among farmers who can obtain credit and purchase them on reasonable terms.

Many in South Asia are aware of the wastefulness of thinking in terms of surface water only rather than the entire water resource, much of which is underground. But in a pronounced and costly lag, the political and civil engineering establishments are only slowly detaching themselves from the historical orthodoxy that the only real water is the water that you can see, that is, surface water. They continue to be committed to large diversion dams and long gravity-distribution canals, which have political impact through the construction and maintenance work that they offer and through their physical impressiveness. Such systems transformed the agriculture of India's northwestern region in the past 150 years, and there is a powerful tendency to repeat them in the very different and essentially more abundant water ecology of the Eastern Waters basin.

Surface water is scarce in the dry season, and important quarrels have always arisen about entitlement to shares of it; such quarrels continue with an apparent life of their own in many cases. There is long-standing tension between Bangladesh and India, for example, about the sharing and augmentation of surface waters, but if the potentialities of groundwater were more generously and fairly evaluated simultaneously by both sides, this quarrel could be considerably relaxed. It appears likely that the surface water sharing and augmentation problem between Bangladesh and India itself tends to inhibit groundwater exploration and use. This is because each side maintains its claim for surface water by pointing to its current uses of water and its needs and by asserting that it has no alternative sources of water. Thus, if either country was to proceed with a major development of groundwater, it would tend to undercut that country's case that it needed a greater share of surface water. The desire not to weaken one's position in the international arena, therefore, may have the effect of restraining full recognition and exploitation of the groundwater resource.

Slow and uneven recognition of the abundance and full usefulness of groundwater, and of the particular challenges of its management, must be counted as one of the constraints on full water development in the region. Mounting or not mounting an effort to remedy this problem must be counted as one of the strategic choices in the region.

A separate important strategic choice is raised by Bangladesh's current mobilization of an elaborate decisional process in response to the floods of 1987 and 1988. To all evidence, this process is pointing to a national policy determination to seek the large-scale embankment of the country's major rivers (with donor assistance).

A further strategic issue is the need to cast aside long-standing inhibitions on both sides and arrange the development of Nepal's hydropower potential and the sale of hydropower to India on a large scale. This is particularly pressing for India because of its current deficit in power, which is evidenced by the massive brownouts and load shedding (average power cut of 20 percent during peak periods) practiced in most Indian cities. The recent extremely rapid rate of growth of the Indian economy (8 percent) is greatly exacerbating the problems of electricity shortages. To meet these demands, India will have to add 38,000 MW—more than half the generating capacity built since 1947—during the eighth five-year plan period (1990-1995). *India Today* (1989) reported that even if the 57 thermal and hydroelectric plants expected to be scheduled during the 1990-1995 Five-Year Plan (at a cost equivalent of approximately $50 billion) are brought on line on schedule, the target may fall short by as much as 11,000 MW.

Oil, natural gas, and nuclear fuels are limited in supply in India. They will not make a major contribution to the expanded future electricity supply, even with a possible shift to thorium as a nuclear fuel.

India will have to make hard choices in its long-term power planning. It appears advantageous for India to preserve its coal reserve for the western and southern regions and to work with Nepal and Bhutan to exploit the large hydro potential in their portions of the Ganges-Brahmaputra river systems nearer to Indian consumption centers.

2.3 Geography, Climate, and Natural Resources of the Basin

2.3.1 Tectonics, Geology, and Meteorology

The Indian subcontinent is an individual tectonic plate which, in the geologic period of 60 million years ago, was moving roughly north at a rate of about 15 to 20 centimeters per year (Molnar, 1986). About 40 million years ago the Indian plate began to meet and pass underneath what is now Tibet, or the southern edge of the main Eurasian plate, and its movement slowed to about 5 cm a year. This collision elevated the Tibetan plateau and created the still geologically young and erodible Himalayan mountain range, which essentially consists of scrapings from the forward edge of the Indian plate forced back over the advancing mass.

The process continues in the present: India moves about 5 cm a year under Tibet, the central Great Himalayas rise about 1 cm a year in altitude, and slippage in the process generates "a roughly annual moderate earthquake and the rare, but all too frequent great earthquakes" (Molnar, 1986:154). A 1968 marine seismic expedition in the Bay of Bengal estimated that the undersea fan of sediment from the Himalayas deposited in the bay by the Ganges-Brahmaputra rivers was 1,000 km wide, perhaps over 12 km in depth, and 3,000 km long—that is, extending far south of Sri Lanka. A calculation back from this would indicate that the Himalayan area gives up 0.7 m in eroded depth every 1,000 years (Curray and Moore, 1971).

Thus, the north Indian plain consists of a great geological trench running below the very young Himalayas and filled to a depth of several kilometers by alluvium eroded from the mountains. Although moving at a geologic pace, the process is an active and dynamic one. Tectonic movement continues to raise the mountains, and massive and complex erosional processes continue carrying the mountains' mass in the form of sediment toward the valley and the sea.

A key agent of this process is water, or better, the gigantic hydrological cycle—the continuous evaporation by solar heat of water from the sea into the atmosphere and its return. The world's highest rainfall is recorded at Cherrapunji in the Kasi hills of the Indian state of Assam, south of the Himalayas and just north of the Syhlet district of northeastern Bangladesh, where 3.81 m of water fell during one five-day period in August 1841.

In the cold heights, there are large deposits of water in the form of ice. Permanent ice covers an estimated 30,000 km^2 in the Himalayas, 17 percent of the total area of the range. These glaciated heights, along with those of Tibet to the north, give rise to the Ganges and Brahmaputra rivers. The sources of the two rivers are extraordinarily close together, before the Ganges and the Brahmaputra begin their very divergent eastward courses, south and north of the Himalayas respectively, to meet within a few miles of the sea in the Bengal delta (Figure 1). In the intervening space, the Ganges in particular is fed by a roughly parallel set of large tributaries, the Jamuna, the Gagara, the Gandak, and the Kosi, each a system in itself that rises in Tibet or the Himalayas and flows south to the plain.

The rivers rush in the mountains and the hills and then slow abruptly on coming into the plain so that each has two very distinct sections: a steep, rapidly flowing one and a slow-moving one. Water's capacity to carry sediment depends in large part on its speed of flow; thus, the pattern of the subcontinental rivers is that they make large deposits, inland deltas, at the point where they suddenly decelerate.

The Ganges-Brahmaputra watershed is basically abundant in water, with an overall average of 1,500 millimeters of rainfall a year. In general, annual rainfall decreases as one moves west; from 3,000 mm at the Bangladesh coast, to 600 mm in Rajasthan in the extreme west, and 450 mm in Lhasa, Tibet, in the rain shadow of the Himalayas. Thus, storage of relatively scarce water for use in the dry season is the dominant problem in the Uttar Pradesh and western Bihar states of India, and flood control is of greater importance in the Indian state of West Bengal and in Bangladesh. Put very broadly, the ideal would be to move water from the wet season into the dry season, and from the east to the west.

Of the immense volume of water precipitated by the monsoon, a good deal less than half will return to the sea entirely on the surface as run-off. Water also evaporates directly from the land, and in large volume descends into the soil. There, it moves toward the sea parallel to the movement of surface waters, although at a much slower pace. At a given moment in the Gangetic basin, many times the water present on the surface in the rivers and lakes exists in the valley's alluvial earth. Among the richest soils in the world, this earth remains unconsolidated (i.e., not hardened into rock) to depths of 6,000 m and more.

Table 2

Salient Characteristics of the Greater Ganges Basin

		Ganges				Brahmaputra		
Item	Unit	India	Nepal	Bangladesh	Total or Average Figure for Basin	India	Bangladesh	Total or Average Figure for Basin
AREA								
Geographical Area	Mha	86.14	14.08	6.74	106.96[a]	18.71	4.70	23.41[c]
Cultivable Area at Present Cultivation	Mha	60.30	3.98	3.64	67.92	12.15	3.00	15.15
POPULATION								
1971 Census	Million	221.19	11.29	27.03	259.51	17.65	24.83	42.48
Population Density	Per km^2	257.00	80.00	401.00	243.00	94.00	528.00	181.00
Agr. Population	Million	149.74	10.34	19.06	179.14	11.93	17.50	29.43
Agr. Population	%	67.60	91.60	70.50	69.03	67.60	70.50	69.28
WATER								
Mean Annual Rainfall	cm/yr	60-200	100-250	150-300	120.00	212.00	200.00	212.00
Total Annual Runoff	mhm	55.01[b]	--	Neg	55.01	51.25	10.25	61.50
Irrigation Potential (present)	Mha	17.81	1.20	2.95	21.96	2.30	1.46	3.76
ENERGY								
Hydropower Potential	Mkw	13.27	85.00	Neg	98.27	13.43	Neg	13.43
Hydropower Installed	Mkw	1.83	0.41	Neg	2.24	00.18	Neg	0.18
Hydropower Installed	%	13.79	0.49	Neg	2.33	1.34	0.00	1.34
UNIT FIGURES								
Land Per Capita	ha	0.39	1.25	0.25	0.40	1.06	0.19	0.55
Utilizable Water/Unit Cultivable Land	cm	116.00	--	--	--	171.00	--	--
Cropping Intensity	%	125.00	--	--	--	118.00	--	--
Irrigation Intensity	%	23.00	--	--	--	21.30	--	--
Utilized Water Resource								
Surface	mhm	18.5	--	--	--	0.61	--	--
Ground	mhm	10.64	--	--	--	2.07	--	--
Total	mhm	29.14	--	--	--	2.68	--	--

[a] Excludes 2.9 Mha in Tibet.
[b] Includes run-off of Nepal.
[c] Excludes 29.3 Mha in Tibet and 5.29 Mha in Bhutan

Source: Chaturvedi and Rogers (1985:82)

Table 2 (continued)

Salient Characteristics of the Greater Ganges Basin

Item	Unit	Barak/Meghna India	Barak/Meghna Bangladesh	Barak/Meghna Total or Average Figure for Basin	Total for Greater Ganges Basin	Total in Each Country India	Total in Each Country Nepal	Total in Each Country Bangladesh
AREA								
Geographical Area	Mha	4.40	3.62	8.02	138.39	109.25	14.08	15.06
Cultivable Area at Present Cultivation	Mha	1.11	2.87	3.98	87.05	73.56	3.98	9.51
POPULATION								
1971 Census	Million	5.33	19.10	24.43	326.42	244.17	11.29	70.96
Population Density	Per km^2	121.00	528.00	305.00	236.00	223.00	80.00	471.00
Agr. Population	Mllion	3.60	13.46	17.06	222.03	165.27	10.34	50.02
Agr. Population	%	67.60	70.50	69.83	68.02	67.69	91.58	70.50
WATER								
Mean Annual Rainfall	cm/yr	450.00	240.00	350.000	--	--	--	--
Total Annual Runoff	mhm	6.00	5.10	11.100	127.61	112.26	--	--
Irrigation Potential (present)	Mha	0.115	0.47	0.585	26.305	20.225	1.202	4.88
ENERGY								
Hydropower Potential	Mkw	2.50	Neg	2.50	114.2	29.2	85.00	Neg
Hydropower Installed	Mkw	0.08	Neg	0.08	2.5	2.09	0.41	Neg
Hydropower Installed	%	3.20	Neg	3.20	2.23	7.16	0.49	Neg
UNIT FIGURES								
Land Per Capita	ha	0.82	0.189	0.33	0.42	0.45	1.25	0.18
Utilizable Water/Unit Cultivable Land	cm	379.00	--	--	--	--	--	--
Cropping Intensity	%	124.00	--	--	--	--	--	--
Irrigation Intensity	%	13.00	--	--	--	--	--	--
Utilized Water Resource								
Surface	mhm	0.20	--	--	--	19.31	--	--
Ground	mhm	0.80	--	--	--	13.64	--	--
Total	mhm	1.03	--	--	--	32.95	--	--

Even in the dry season, the water table is often higher than the bottom of river beds. This means that if water is pumped out of a river, the bed downstream of that point will be refilled to a significant degree by in-seepage of groundwater. Similarly, if water is diverted to an unlined canal or a dry riverbed, a large amount of it will seep into the ground, raising the local water table, from which it can be extracted through tubewells. Fully 50 percent of the total basin area, excluding Tibet, can be defined as cultivable with current agricultural technologies. The natural resources of the Ganges-Brahmaputra basin are now stressed by the density and growth of population, but they are not basically meager or inadequate, nor have their agricultural and energy potentials been fully tapped. Table 2 gives an overview of the current state of land use, water, and hydro energy resources in India, Bangladesh, and Nepal.

2.3.2 Climate—The Monsoon

On a long-term basis there is a remarkable degree of regularity in the occurrence of the four-month rainy season, which is the mainstay of South Asian agrarian populations, but there are large annual variations in the amount of rain, in where and when it falls within the region, and in the timing of the onset and withdrawal of the rains. Figure 2 is a schematic of the dynamics of the southwest monsoon. The caption that accompanied the original sketch read in part:

> *The monsoon is born when summer advances and heats the Asian land mass faster than the Indian Ocean. Giant low pressure areas or hot spots develop over Rajasthan and Central India. The winds reverse direction dramatically and blow from the southwest carrying dense rain-bearing clouds that strike the west coast and move gradually northward ... [meteorologists] have also recorded an ocean current from Somalia that cools the Arabian sea just before the monsoon and have found that the Himalayan snow cover and a high pressure zone over Tibet have a bearing on the rains.* (*India Today*, June 30, 1988:73)

Statistical analysis of up to 150 years of monthly rainfall records at 11 sites in the lower reaches of the basin suggests no long-term trend up or down in the regional monsoon rainfall nor any statistically significant cycles or periodicities (Rogers et al., 1989). Figure 3 charts 150 years of rainfall data for Calcutta. The 1988 Calcutta monsoon rainfall of 1,322 mm lies well within the observed range in Figure 3.

A 1989 analysis of regional rainfall confirms an east-west alternation within the basin whereby droughts over central and northwest India take place in years of excess rainfall over northeast India/Bangladesh and vice versa (Shukla, 1987, 1989). It appears that the El Nino anomaly off Peru (years when the surface temperatures of the central and eastern Pacific Ocean are above normal) has a predictive value in that it is associated with a weak southwest monsoon, droughts over central and western India, and flooding in the eastern part of the region (Assam and Bangladesh) in those years. This important research on the monsoon is likely to increase in productivity as India applies a new supercomputer to meteorological analysis.

Under this broad east-west alternation pattern, during a dry year in western India, Bangladesh could experience floods due to the combined effects of greater-than-average rainfall locally and increased drainage from the Brahmaputra River. But excessive rainfall over central and western India can cause flooding in Bangladesh due to increased drainage from the Ganges river system, even though in those years the rainfall is below average in Bangladesh. This exposure on both sides makes Bangladesh one of the most flood-prone regions in the world.

Many rainfall stations in the basin have over 100 years of monthly rainfall data, although the conversion of the rainfall into streamflow has not been monitored for such long periods of time. Regrettably, and contrary to India's exemplary handling of meteorological data, much of India's streamflow data is currently withheld from both Indian and international scientists by the government. Many questions concerning surface water availability could be quickly resolved by an impartial analysis of those data.

2.3.3 Energy Resources

The energy resources of the basin include gas, oil, coal, and hydropower. A small oil industry is located in Assam, and natural gas reserves are being exploited and confirmed in Bangladesh in substantial quantities. India exploits major deposits of coal in the Asansol-Dhanbad area northwest of Calcutta in the state of West Bengal, but as the best seams are mined the costs of production are expected to rise.

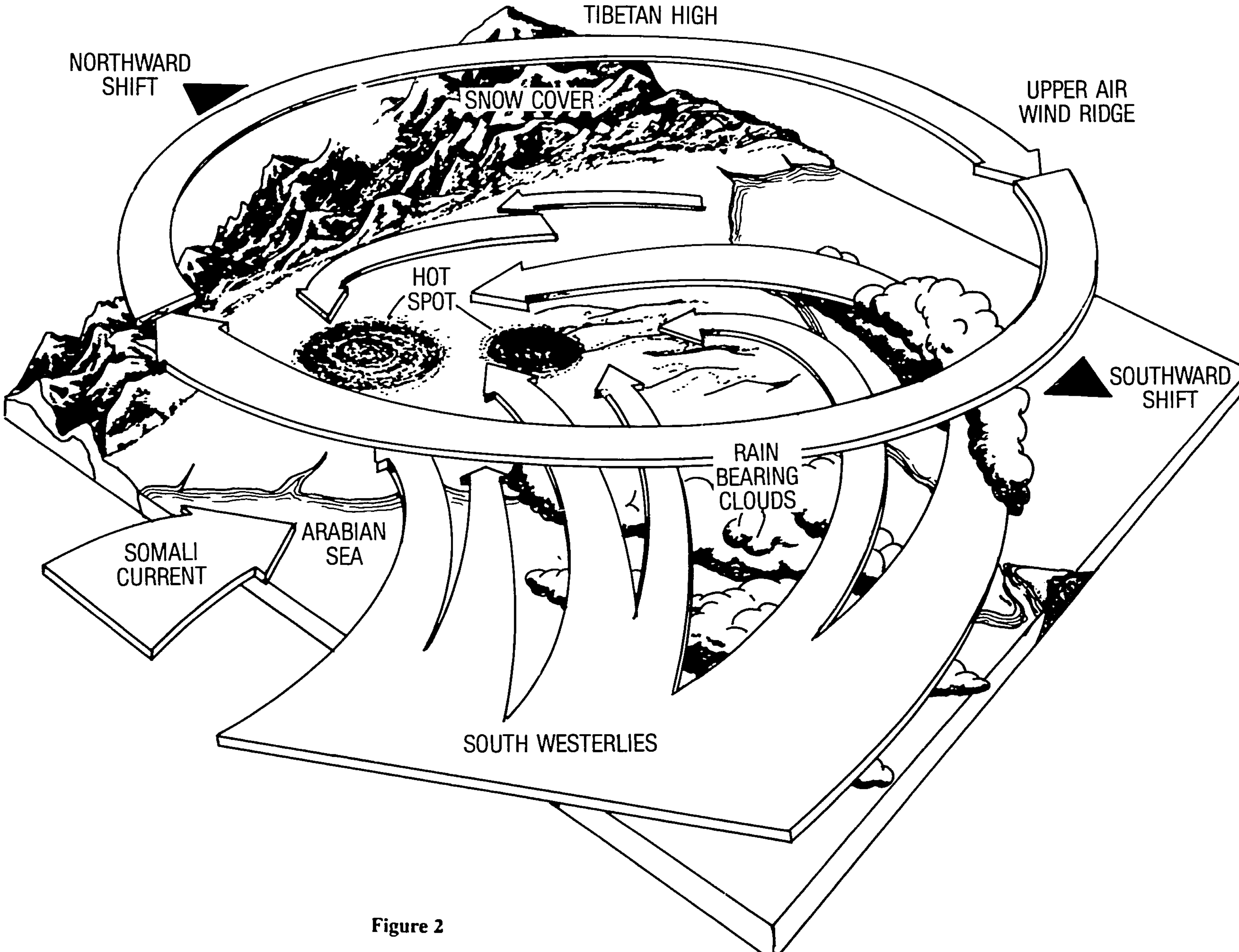


Figure 2

Dynamics of the Southwest Monsoon

Source: Adapted from India Today, 30 June 1988: 74

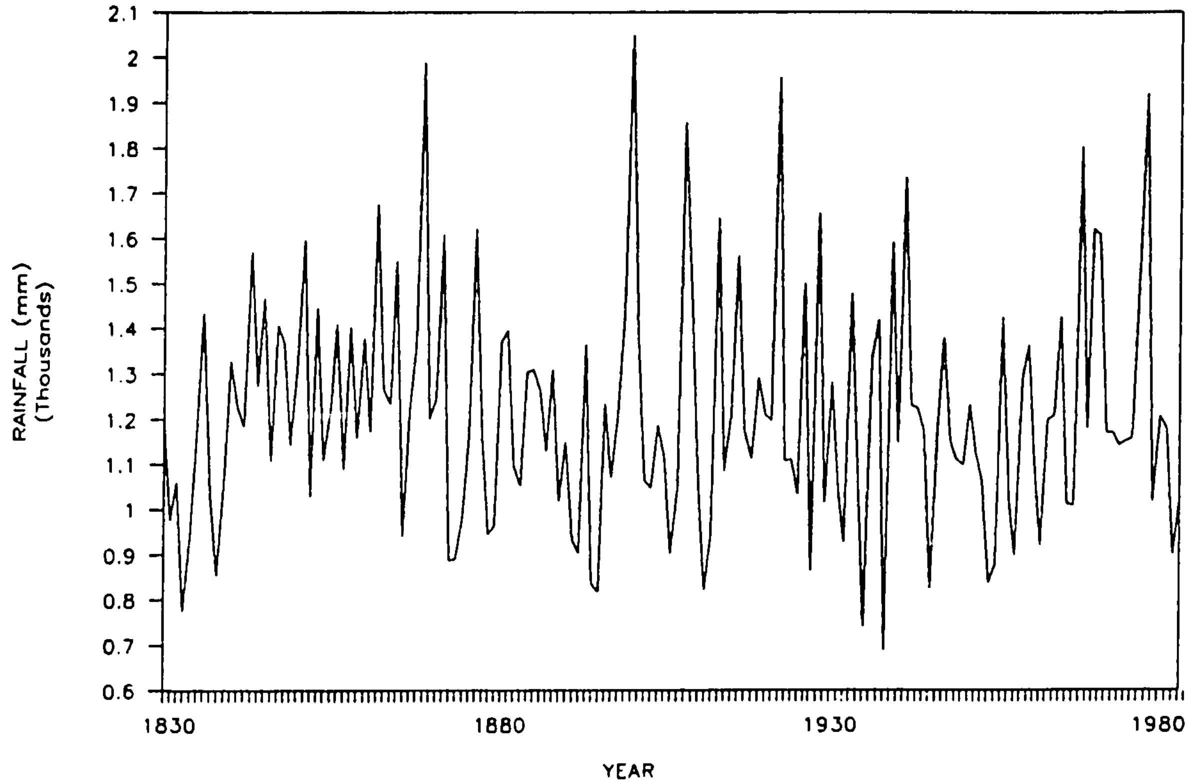


Figure 3

Calcutta Monsoon Rainfall (June-September, 1829-1983)

Source: Rogers et al. (1989)

Bangladesh obtains 150 megawatts of hydropower from the Karnaphuli Dam in its southeastern Chittagong Hill tracts, but it does not have significant further hydro potential.

Enormous hydropower potential exists, however, both in the Ganges and the Brahmaputra river systems. The Ganges river system has an estimated potential to generate 93,700 MW at 60 percent load factor. The share for sites in India is 10,700 MW and in Nepal, 83,000 MW. The Brahmaputra river system has a potential to generate 54,950 MW; the share for India is 34,950 MW and for Bhutan, 20,000 MW. In addition, a run-of-the-river project (i.e., with no significant storage reservoir) at the Brahamaputra's eastern bend could generate 18,000 MW if the river was diverted by structures in China and a powerhouse was built in India.

Full exploitation of hydropower is itself a major component of developing the region's water resources. The strategic issue of large-scale hydropower development in Nepal for sale to India is discussed in this section for that reason, but also because the availability of energy for pumping is a requirement for the development of groundwater. In Bangladesh, small diesel engines are widely used, but electrified pumps would be considerably more efficient. Continued spread of tubewells in the Indian Gangetic plain depends greatly on the availability of power and, hence, in the long term is tied to progress in tapping Nepal's hydropower potential.

Juxtaposed with the hydropower potential of the Himalayas is a massive unmet demand for electricity in northern India. India's planners recognize that for technical and economic equilibrium, its power-supply grid (network of electricity transmission lines) requires a greater proportion of electricity from hydropower generation in relation to thermal fossil fuel power generation in the future, and they have taken it as a goal to increase the share of hydropower. For example, India, operating largely through state-level electric utilities, subsidizes power consumption to all users. Its average tariff for 1984-1985 was rupees 0.60 per kilowatt hour, compared with a generating cost of Rs 0.83, partly due to operating below a 60 percent plant load factor. India's deficit in power is evidenced by the massive brownouts and load shedding (average power cut of 20 percent during peak periods) practiced in most large Indian cities.

Nonetheless, India can be expected to consider thoroughly its domestic alternatives, primarily thermal, before turning to imported power. Out of India's total 54,000 MW generating capacity as of March 1988, 35,300 MW are provided by thermal plants, which vary in installed capacity from 50 MW to 1,200 MW. The current annual requirement for coal for thermal power is about 90 million tons. Most of the thermal plants are located near power-consumption centers, and as a result, long-distance transport of coal is a major bottleneck for thermal power generation. In the future the Government of India plans to set up many more very large power plants at coal mine-head locations and, rather than ship coal, deliver power over long distances through 400 kilovolt or higher voltage transmission lines.

Even apart from the problems of air pollution and combustion contributions to atmospheric carbon dioxide, future use of thermal power has important drawbacks for India. The all-India reserve of coal is rather small to support long-term demand for electricity. The coal has a high ash content and the deposits are unevenly distributed. About 70 percent of the coal reserve is in eastern India. Both mining and transporting coal become difficult during the monsoon. The cost of new thermal power generation will be considerably higher than the current Rs 0.83 per kWh. If it is assumed that 60 percent of India's power requirement in 2005 will come from coal, then India's coal reserves for power generation could be estimated at little more than 100 years, and perhaps less.

Oil, natural gas, and nuclear fuels, as noted, are limited in supply in India. They will not make a major contribution to the expanded future electricity supply, even with a possible shift to thorium as a nuclear fuel.

India has the capacity both in expertise and material supply—for example, domestic manufacture of very large turbines—to undertake complex hydroelectric projects. India's massive future power needs, however, as well as the remoteness of its huge upper Brahmaputra sites (which share the seismic uncertainties of all the Himalayan locations) and the potential complications of China's territorial claims in that region remaining from the border war of 1962, underlie the earlier assessment that India should preserve its coal reserve for its western and southern regions and work with Nepal and Bhutan to exploit the large hydro potential in their portions of the Ganges-Brahmaputra river systems nearer to Indian consumption centers.

India's expected peaking shortage by the end of the seventh Five-Year Plan (1985-1990) is estimated at 9,000 to 10,000 MW. Hydropower can be configured as base power from run-of-the-river projects, which are much cheaper to build and easier to operate than stored-water hydro plants, or it can provide peaking power when the generating site includes a storage dam. A single river can efficiently offer both types of power when one or two run-of-the-river projects in the higher altitudes are combined with a major storage dam in the foothills. Hence, overall, it is appropriate to compare hydropower generation costs with thermal costs in both base load and peaking categories.

India's total domestic hydropower potential at 60 percent load factor is estimated at 85,554 MW, of which it can be expected that India will be able to exploit economically 35,000 MW. This quantity of hydro generation does not cover hydropower's projected 40 percent share of 819 billion kWh of energy needed by 2005; it leaves a shortfall of 51,000 MW, which in principle could be imported. India will have to turn in some form to power generation in Nepal and, secondarily, in Bhutan for power on the order of 50,000 MW. But, as discussed in the next chapter, important problems regarding how to get into realistic discussions with Nepal on how hydroelectric capacity can be developed, and at what price power will be supplied, will have to be resolved first.

3

SOCIAL AND POLITICAL PATTERNS AND ISSUES

3.1 General Framework: Unitary and Federal Countries

In South Asia, in the broad questions of water management and economic development, the lead role is played by national governments. With the important exception of the private tubewells, these are not matters in which market forces or private sector initiatives play much of a direct role in designing and making what are large-scale infrastructure investments. This is directly the case in Nepal and Bangladesh, which are administratively unitary nations in form. For the purposes of external observers, it is also essentially the case in India, although India is a federal country with 22 states and a division of powers between the national and state levels broadly comparable to that in the United States.

The Indian constitution provides expressly that, in the first instance, water management and irrigation is a "state subject" rather than a "Centre" concern. The states of India are substantial and important units: Uttar Pradesh has close to 140 million people and tens of thousands of state employees concerned with irrigation alone. State governments can bring substantial pressures to bear on the national government on a domestic, or even an international, water question, for example, a possible reservation of Ganges water for Bangladesh. Nonetheless, at a broad level, New Delhi predominates because it adjudicates the frequent water conflicts between states and because India has generally experienced a centralizing trend in its governmental affairs. The Centre is now the primary source of planning, budgetary resources, and advanced expertise for water projects, although in water as in other subjects, Centre-state relations are a permanent joust. In September 1987, the National Water Council, chaired by Prime Minister Rajiv Gandhi and including state-level political leaders, adopted a National Water Policy, which further strengthened the Centre in relation to the states. That policy said that national perspectives would prevail in water matters rather than state or local ones, that water planning within India would follow hydrological watersheds rather than internal state boundaries, and that one state's surplus waters could be transferred to water-poor areas in another state if needed for the best use of the resource.

The national governments of the region are themselves complex organizations with many constituencies and bureaucratic-political interests, and the societies to which each government is responding also have complicated mixtures of traditional and modern attitudes, sectoral differences of interest, and greater and lesser access to power. Prosperous farmers tend to be patrons with many clients in their localities, and individually and as a group they have substantial political power—as well as irrigation needs. The play of institutional and "political" logics is difficult to predict, but they doubtless rank with straight economic and technical justifications in their influence on major investment decisions.

An important variation in the pattern of governmental responsibility is relatively recent: In this alluvial basin, shallow tubewells with diesel or, more economically, electric pumps are within the reach of the medium-scale farmer. With increasing governmental approbation, their use has spread widely in both India and Bangladesh, greatly increasing the growth of irrigation and the percentage contribution of groundwater to all irrigation in the past 20 years. The farmers often depend on government support in maintaining water tables (this often means replenishment of groundwater by seepage from the canals of large surface irrigation systems) and in making purchase loans and rural electricity available, but an important factor in the tubewell's rapid spread and its large economic contribution is that it gives the individual farmer great freedom in his investment and production decisions. Tubewells have played a major role in the agricultural boom in the Indian Punjab and are already an important part of wintertime, green revolution cultivation in eastern India and Bangladesh.

3.2 A Common Procedure: Five-Year Development Plans, but Different Capacities

India, Nepal, and Bangladesh all manage their development investments through technocratic five-year plans developed by planning ministry staffs in the executive branch and ultimately approved by a parliament or similar body. The plans are driven by government efforts to respond to public desires, by accepted traditions in development methods that are ingrained in large bureaucracies, and by estimates of cost-benefit ratios, and they attempt to spend available resources rationally to build national wealth and well-being and to support long-standing national goals, such as foodgrain self-reliance. The plans are also influenced by the personal commitment and political strength of individual leaders, by pendulum swings between such values as centralization-decentralization and private-public sector emphasis, and by awareness of the political power of beneficiary or claimant groups (e.g., the irrigation-hungry farmers of north India). In the longer term, the five-year plans doubtless also express more complex and diffuse national dispositions, such as ambivalence about rapid economic growth versus stability, which is seen as protecting the existing social structure as a whole.

The design of development plans in all three countries, of course, comes after a political decision-making process, first, about how much of the overall national product will be taxed and spent by the government and, second, about how much of the government's share will go to defense and other permanent and traditional governmental activities and how much will go to economic development. Neither of these two decisions can be taken for granted. The first decision, the allocation of domestic GNP between private and public resources, reflects the general capacity of the society to take collective action, and it is significantly higher in India, even with the large underground economy taken into account, than in Bangladesh or Nepal. The allocation of the government's resources between developmental and other purposes is also not fixed—after India's 1962 border war with China, for example, defense greatly increased its claim on the GNP.

Within the government's development budget there are also major allocational decisions to be made between, for example, the industrial and agricultural sectors and among such sectors as transportation, energy production, and education. These decisions are influenced by considerations of rational developmental sequences and also by vigorous constituencies among professional development economists, in the parliament and political parties, and among the general public.

In Nepal and Bangladesh, development budgets are heavily dependent on foreign loans and grant assistance, and thus they are significantly influenced by the development views of international financial institutions, such as the World Bank and the Asian Development Bank, and by donor countries, such as the United States. In both doctrine and practice, India has always been heavily committed to autonomy in its development decisions. But even more than in the past, today's India finances the great bulk of its development investments from its own resources and can pay for any particular project at will. As its nuclear capacity and space program make clear, India has modern technical capacities.

The political mechanisms and forces that can support or oppose large public water investments *within* each country are discussed next. Then, the histories and attitudes are considered that come into play when the issue is *cooperation among countries* in managing large water resources in the basin.

3.2.1 India

To support its drive for economic development and economic autonomy, India has traditionally had high domestic savings rates, heavy taxation, and a large government sector with both heavy regulatory powers and extensive participation in the economy. Now in the seventh of its five-year plans, India has had under way for 40 years a sizable and carefully thought out investment program to increase its agricultural yields, in large part through heavy investments in irrigation works. Of the 113 million ha nationwide that are considered irrigable, 68 million ha of that potential (37 million from tubewells and minor irrigation and 31 million from major and medium-sized projects) had been at least nominally achieved at the end of 1985. India has 57 million irrigable ha in the Ganges-Brahmaputra basin, of which 22 million were irrigated by the end of 1985. (See Figure 4 for map of India.)

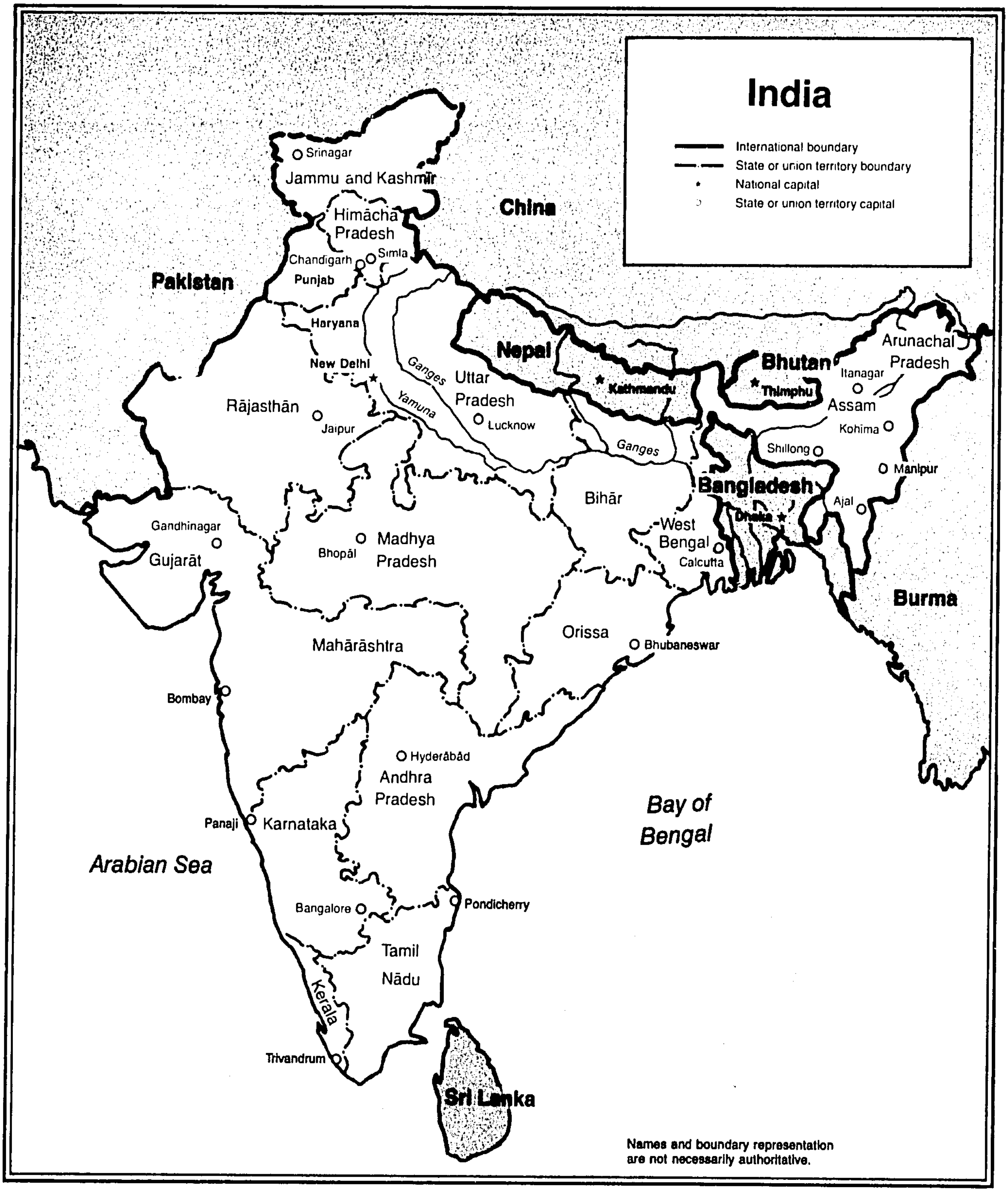

India
International boundary
State or union territory boundary
National capital
State or union territory capital
China
Pakistan
Srinagar
Jammu and Kashmir
Himācha Pradesh
Chandigarh
Simla
Punjab
Haryana
New Delhi
Rājasthān
Jaipur
Ganges
Yamuna
Uttar Pradesh
Lucknow
Nepal
Kathmandu
Bhutan
Thimphu
Arunachal Pradesh
Itanagar
Assam
Kohima
Shillong
Manipur
Bangladesh
Dhaka
Ajal
Bihār
West Bengal
Calcutta
Gandhinagar
Gujarāt
Bhopāl
Madhya Pradesh
Burma
Orissa
Bhubaneswar
Mahārāshtra
Bombay
Hyderābād
Andhra Pradesh
Bay of Bengal
Panaji
Karnataka
Arabian Sea
Pondicherry
Bangalore
Tamil Nādu
Kerala
Trivandrum
Sri Lanka
Names and boundary representation are not necessarily authoritative.

Figure 4

It is widely commented that the major irrigation drive within the national development effort came to be overfocused on the planning of visible, heavy structures (e.g., dams and canals), actual construction tended to stretch out over very long periods, and full water utilization by farmers lagged even more. Relatively new technologies, such as tubewells and conjunctive use of groundwater and surface water only slowly overcame older official orthodoxies. Recent five-year plans have concentrated money on completing projects in progress and on encouraging full use of existing irrigation capacities; intensified concern is now being focused on the slow-growth eastern region of the country in the Gangetic basin.

Within the same planning process, India has steadily extended some form of protection to areas particularly threatened by floods, which regularly inflict over two billion rupees worth of damage a year. It also aims to develop hydroelectric generating capacity to maintain a ratio of 40 to 60 in relation to thermal generation (the latter including a small share of nuclear power). Both general capacity and the hydro share have lagged, however, and efforts are under way to catch up and to correct the balance. India also is increasingly active against water pollution, and there is a substantial and growing environmental movement, to which the government is often responsive. For all these efforts in the water field, in general India has the required technical staff and planning, administrative, and decision-making machinery, culminating in the parliamentary system.

Although more money would make programs go faster, the Indian water development effort does not suffer critically from a shortage of financial resources. In general, it is adequately financed from domestic resources, and in addition India has access to external loans, primarily from the World Bank but with significant other external aid as well, including a current set of multiyear U.S. programs in water management totaling about $200 million.

At present, a significant increase in external aid to cover unmet needs in water development is not at issue. Not every element in India's water planning and management may function to the optimum, and not all decisions, or even all policy lines, will necessarily prove right in retrospect, but there is no emergency in this field in India. Water development is a well-defined and well-understood need of long standing, and a large, highly experienced policy and implementation structure, also created over many years, is in action to accomplish it.

3.2.2 Nepal

Since 1950, Nepal, like India and Bangladesh, has had a population growth rate well above 2 percent per year; the population has grown in 40 years from about 7 to 17 million people (1986). In this same period, Nepal's strip of plains territory, known as the Terai, which runs along its borders with the Indian states of Uttar Pradesh and Bihar, has been largely cleared of malarial mosquito infestation and has absorbed a good deal of the population growth; there has also been migration into the Terai from neighboring Indian territory. (See Figure 5 for map of Nepal.) The population of the middle hills, socially and demographically the national heartland, has greatly increased in density. Kathmandu has grown from a small but highly developed trading city (serving the mountain pass route from the Indian plains to Tibet) into a sprawling metropolis. Nepal has long since outgrown its economic role as an entrepot between India and China, and apart from tourism, it has not really found an economic vocation. Nepalese are emigrating to Sikkim, now a fully incorporated state of India, into the Darjeeling area of West Bengal, and into the plains of India along the Terai.

Without major new forms of economic production, the growth of the population has had deleterious effects on Nepalese villages, particularly in that around human settlements tree growth is not fast enough to replace trees, branches, and bushes cut for fuel or eaten by grazing animals. Villagers, often women, must go farther and farther to gather their daily supply of wood, which often means a trek of many hours. (As discussed in section 4.5, there are no grounds for considering deforestation in Nepal as responsible for flooding in the plains below; although a misplaced belief to this effect is widespread, it has not entered into official exchanges between the governments and is unlikely to do so.)

Nepal has had less firm development plans and, in general, a less autonomous and self-assured drive toward investment and economic advance than has India. In large measure the improved agricultural capacity that has been developed in Nepal, along with a far larger educational system and government apparatus and a substantial tourist industry, has barely kept pace with population growth.

In the field of water, government-developed irrigation diversions totaled 267,000 ha by 1985, of which 252,000 ha are in the Terai and the remainder in the Kathmandu Valley. In addition, an estimated

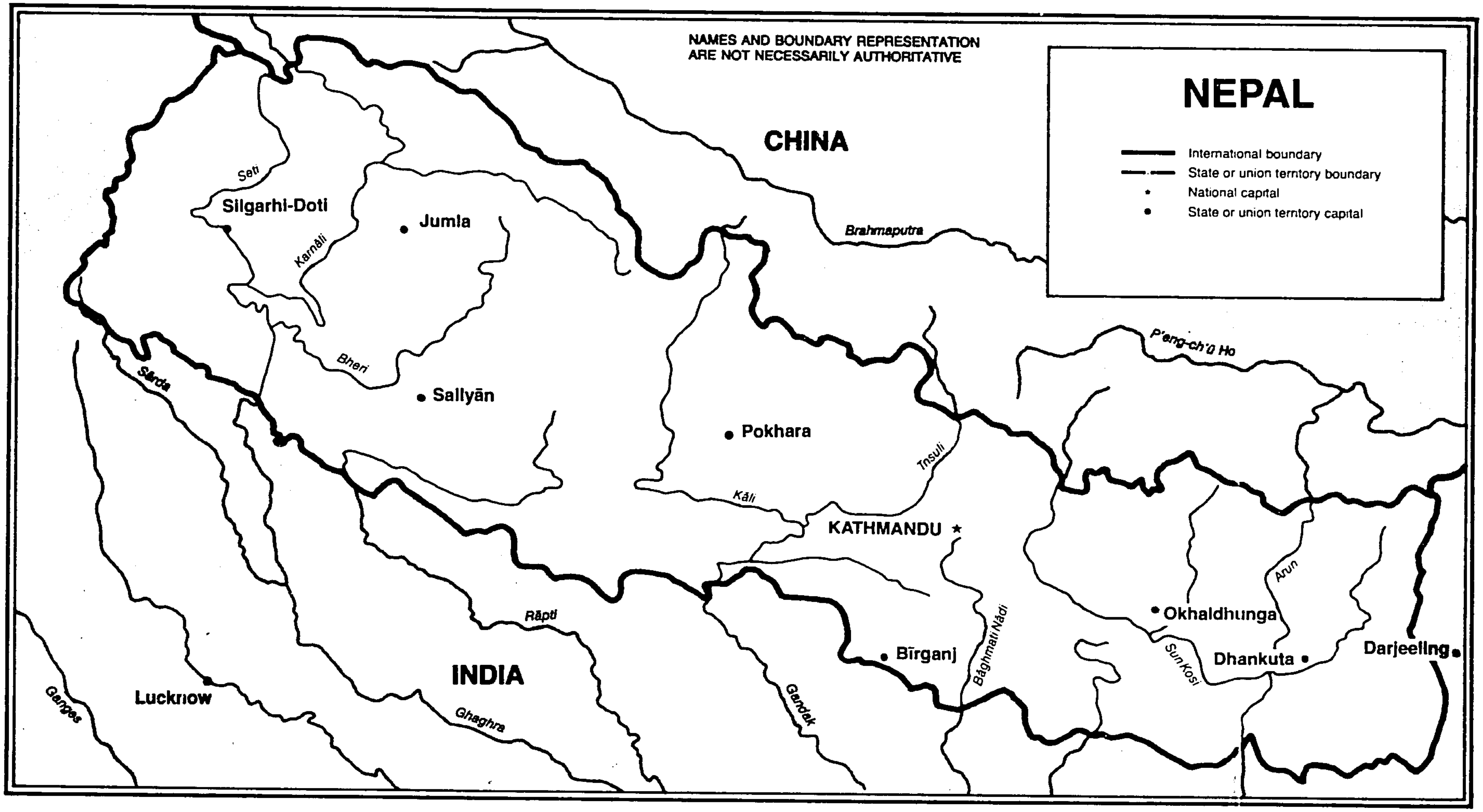

NAMES AND BOUNDARY REPRESENTATION
ARE NOT NECESSARILY AUTHORITATIVE
NEPAL
International boundary
State or union territory boundary
National capital
State or union territory capital
CHINA
Brahmaputra
Seti
Silgarhi-Doti
Jumla
Karnāli
Bheri
Sallyān
Sārda
Pokhara
Trisuli
Kāli
KATHMANDU
P'eng-ch'ü Ho
Arun
Okhaldhunga
Sun Kosi
Dhankuta
Darjeeling
Bīrganj
Bāghmati Nādi
Gandak
Rāpti
INDIA
Lucknow
Ghaghra
Ganges

Figure 5

276,000 ha are irrigated by farmer-developed and managed schemes. Also, micro- to medium-sized hydroelectric installations for internal use have been completed, for a total capacity of 129 MW as of 1985.

The role of Nepal's mountainous terrain in the water development of the basin as a whole is essentially to offer a potential for very large-scale water storage and hydropower generation. Neither stored water nor electricity in major quantities is usable in Nepal itself. Thus, unlike India and Bangladesh, Nepal does not have a domestic water management problem that is of regional interest—the challenge, rather, is one of making the internal determinations necessary to export the country's primary economic resource.

The problem can be seen as having four interlocked stages:

1. achieving internally the equilibrium and capacity to make the decisions required; they are momentous ones for this small nation;

2. negotiating the terms of sale with India;

3. determining how much of the investment, design, and execution of the projects can be done by Nepal with the help of international financial institutions (e.g., the World Bank) and nonregional donors (e.g., the United States, the European Community, or Japan) and how much must be done by India within Nepal; and then over several decades,

4. pursuing the projects themselves.

Harnessing Nepal's major Himalayan river systems, the Pancheswar, Karnali, Gandaki, and Kosi, and selling the power, and perhaps water storage benefits, to India are discussed below in section 3.3 as a regional question. Such sales have been looked on as the country's economic salvation for decades, but they remain at the wish-speculation-apprehension stage. Despite massive power shortages in north India, no firm arrangement has yet been struck with India, and no earth has yet been turned on projects sizable enough to be of basin-wide significance.

3.2.3 Bangladesh

The fertile delta of both the Ganges and the Brahmaputra, which is now Bangladesh (see Figure 6), has always been densely settled, but it experienced the beginning of its high population growth in the 1960s, which has taken it from 44 million in 1951 to over 110 million today and a projected 166 million in 2005. In the century before 1947, the British conception of diversion irrigation as a protective measure against drought-caused famine did not come into play in the delta, richer in water than peninsular India or the Gangetic plains to the west and north, and there were no large-scale irrigation projects in Bengal.

In the 1947-1971 Pakistani period, with World Bank and U.S. support, construction of a massive coastal embankment was revived. It is an earth-moving project on the scale of the Great Wall of China, intended to protect the expanding population of the estuary from land and forest degradation, through the intrusion of salt water, and from monsoon and tidal flooding. It has continued to move toward completion, to serve its basic function, and to be reasonably well maintained to the present. The coastal embankment cannot be considered general protection against occurrences such as the floods of 1987 and 1988 because it is aimed at the particular and geographically limited threats from the sea, but it is worth noting that the Bay of Bengal cyclone that struck the coast of Bangladesh on November 29, 1988, may have cost as many lives as were lost in the flood of late August-September. Without the coastal embankment, and modern warning systems, that event would have caused many additional deaths.

In the 1960s, as an Indian capacity to divert the Ganges at the border by means of the Farakka Barrage loomed, studies and projects were conducted, with World Bank and U.S. support, to evaluate the situation. Of particular concern were (1) the extent to which the western parts of the estuary in East Pakistan were losing their fresh flows as a consequence of a long-term movement of the Ganges distributaries to the east and (2) how to remedy the claimed drying out of ricelands and the great Sundarbans mangrove forest (home of the Bengal tiger) in the southwestern part of the country. In the 1960s and 1970s, after Bangladesh (with Indian support) had achieved independence from Pakistan and green revolution seeds and techniques became available, large surface irrigation networks using pumped river water were attempted in the Ganges/Kobadak and Chandpur projects, and the use of tubewells began to increase dramatically.

Regular river embanking for flood control has also been done extensively in Bangladesh. The right bank of the Brahmaputra River is largely embanked to a height of 5 to 6 m, and many other areas of that and

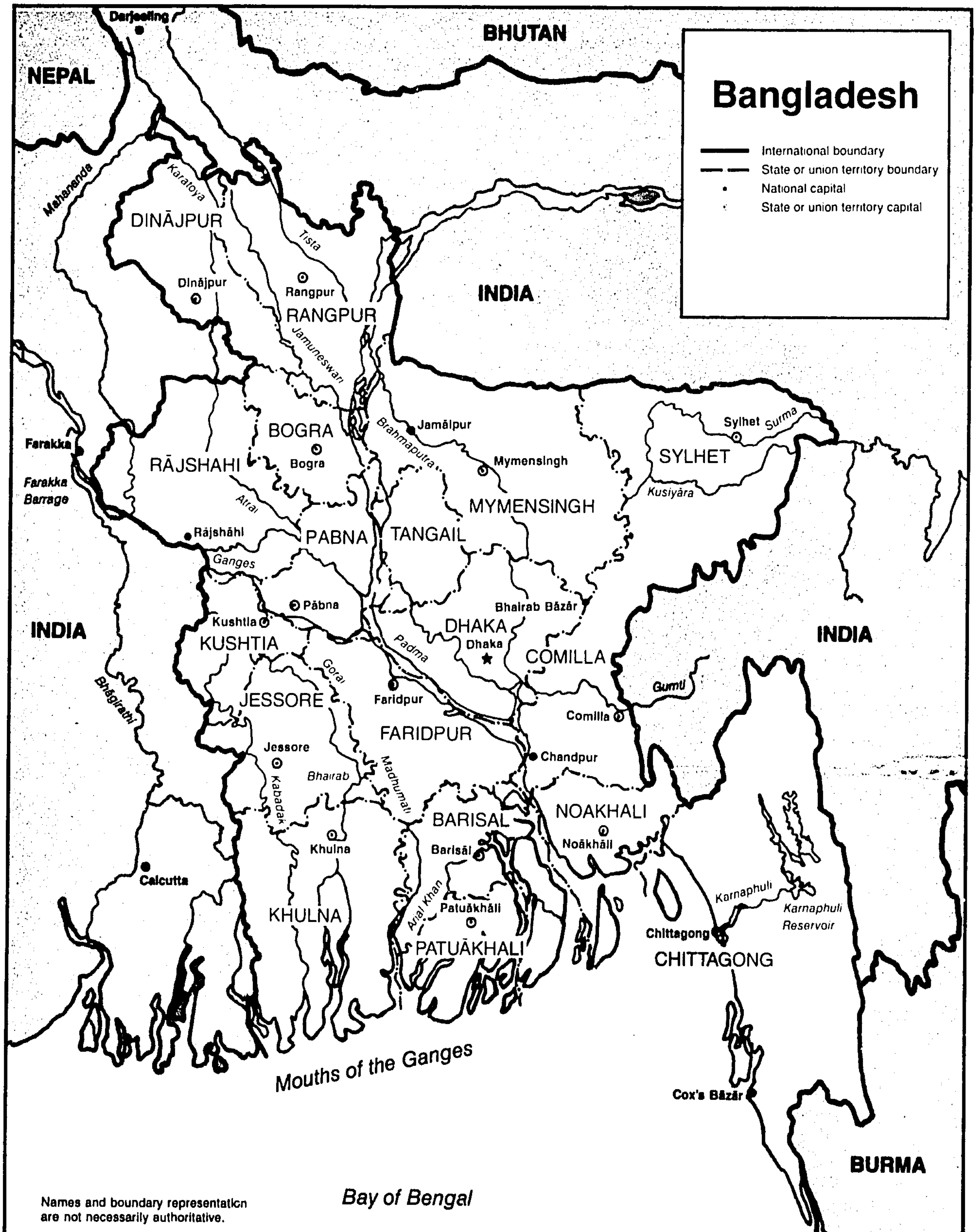

Bangladesh
International boundary
State or union territory boundary
National capital
State or union territory capital
BHUTAN
NEPAL
Darjeeling
INDIA
INDIA
INDIA
BURMA
Mahananda
Karatoya
Tista
DINĀJPUR
Dinājpur
Rangpur
RANGPUR
Jamuneswari
BOGRA
Bogra
RĀJSHAHI
Atrai
Rājshāhi
Farakka
Farakka Barrage
Ganges
PABNA
Pābna
TANGAIL
Jamālpur
Brahmaputra
Mymensingh
MYMENSINGH
Sylhet
Surma
SYLHET
Kusiyāra
Bhairab Bāzār
DHAKA
Dhaka
Padma
COMILLA
Comilla
Gumti
Kushtia
KUSHTIA
Gorai
Bhāgīrathi
JESSORE
Faridpur
FARIDPUR
Jessore
Bhairab
Kabadak
Madhumati
Chandpur
NOAKHALI
Noākhāli
BARISAL
Barisāl
Khulna
KHULNA
Calcutta
Arial Khan
Patuākhāli
PATUĀKHALI
Karnaphuli
Karnaphuli Reservoir
Chittagong
CHITTAGONG
Cox's Bāzār
Mouths of the Ganges
Bay of Bengal
Names and boundary representation are not necessarily authoritative.

Figure 6

other rivers are embanked as well. The older, centrally planned embankments were given generally good ratings by a United Nations Development Program mission that surveyed the 1987 flood area, but the same technical team said that the multiplicity of small polders and embankments put up by localities, which usually are poorly maintained and often damaged by villagers who want to evacuate water or channel it into a particular plot, were of very little or even negative value in a major flood.

Since 1972, Bangladesh has made substantial progress in reducing its exposure to crop loss from either excess or lack of water through the improvement of flood protection or drainage on almost 2 million ha out of its total cultivable land of 8.4 million ha. It has extended dry season irrigation by small surface water pumps and tubewells to 2 million additional ha. (In the same period, 1973-1988, population growth has increased the need for food by 55 percent and increased rural work-seekers from 18 to over 26 million.)

Under its three five-year plans since Independence, Bangladesh has spent about 15 percent of its development resources, predominantly from external sources, on irrigation and flood control. In the early 1980s, with staffing led by the Chicago firm Harza Engineering Company International, it developed a National Water Plan. With groundwater and unchanged inflows on the major rivers estimated to provide just enough water overall within the country's borders to meet requirements for the next 20 years, the National Water Plan calls for the investment of about $6 billion over that period. Full exploitation of currently estimated available (top aquifer) groundwater would be achieved over the period, adding 2.3 million ha of irrigation, and surface water would be developed to irrigate 1.2 million ha, bringing Bangladesh from 26 to 72 percent irrigation of its total irrigable area. The plan would provide flood protection works for 1.8 million ha. The plan takes no position on the feasibility of the massive project, urged by other water consultants to Bangladesh, of embanking the major rivers and constructing two barrages and an internal link canal between the Brahmaputra and the Ganges within Bangladesh, because it views that as work that, if justified, would be done for the period after 2005.

In response to the floods of 1987 and 1988, Bangladesh in the spring of 1989 began an extensive review and consultative process, which it now appears is headed for the conclusion that flood safety for the country requires a multiyear program of large embankments along the major rivers. The goal, as expressed by the Minister of Irrigation in March 1989, is that "the water which enters the country from the outside, will be conducted to the sea with the greatest possible directness, and with no damage to us." A team sponsored by the United Nations Development Program is working with officials of the Water Resources Ministry on a study, and a 30-person team of engineers has been sent by France to assist in studying the question of embankments. The views of a set of bilateral consultative task forces set up with regional countries will also be taken into account, and in this framework a team of Chinese experts has consulted with Bangladesh.

The government believes that it is imperative for it to make a conclusive, and even dramatic, response to the floods that have ravaged the country for two consecutive years and have led many to fear that high floods will come again this year and, at worst, become a permanent annual feature of the country's life. Reportedly, the opposition parties as well are pressing on the government the responsibility to protect the country from floods, and ministers and other officials have made clear the government's belief that vigorous and visible steps by the government against the flood danger are essential to the political, and even the deeper social, stability of the country.

For Bangladesh's embryonic industrial sector, with investments in plant and machinery, floods can be very damaging and alarming. But there is a great contrast between the small, modern, urban sector of the society and the overwhelmingly traditional, poor, rural majority. The ways of living, of moving about, and of being housed for the great majority of Bangladeshis in the villages have evolved over centuries of unpredictably recurring floods. The population's adaptations to cope with the total but relatively short-term disruption of flooding are very strong. In 1988, and for many in 1987 as well, villagers had to leave their houses for as much as two weeks because of the flood and live under very difficult circumstances on roofs, in boats, or on embankments, but that is a great deal more tolerable than the more extended apprehension and helplessness and the far more severe crop loss that result from drought. Heavy crop loss from either cause can result in loss of land to creditors, which is greatly and justly feared by cultivator families, but that is more likely from a drought than a flood, because normally a flood leaves the ground with abundant water in the early *rabi* season (mid-fall), and with extra effort an additional or replacement crop can be grown in the sunny winter without any further rainfall.

3.3 Is There a Need for Regional Cooperation?

In its entirety, the Ganges-Brahmaputra watershed encompasses India, Nepal, Bangladesh, Bhutan, and China. This section discusses the potential benefits and limitations of water cooperation *across* national boundaries and the institutional and social forces that encourage or impede it.

3.3.1 South Asian Association for Regional Cooperation

Since 1983 there has existed among the seven governments of the larger South Asian region a South Asian Association for Regional Cooperation (SAARC), which on its face could be an excellent vehicle for cooperation. It may one day prove to be so, but SAARC now is consolidating itself very cautiously, dominated by the fact that in contrast to the Association of South East Asian Nations or the European Community, a single member, India, is virtually twice as large as all the other members put together. SAARC deals with technical matters that concern all its members rather than the four-country subset involved in the Ganges-Brahmaputra basin (India, Nepal, Bangladesh, and Bhutan—outside the basin are Pakistan, Sri Lanka, and the Maldives). Moreover, to ensure its survival in its still early years, SAARC's charter specifically states that "bilateral and contentious issues shall be excluded from the deliberations." Water management is well established as just such a central and contentious concern, and despite Bangladesh's desire to bring it before SAARC, India does not want an exception to the rule. Although SAARC may be able to facilitate certain joint administrative activities, and the informal meetings of South Asian leaders in the course of SAARC gatherings have proven extremely useful, it is unlikely that SAARC will make a significant substantive contribution to water cooperation among the Ganges-Brahmaputra countries in the foreseeable future.

3.3.2 China

China is now only marginally and potentially involved as a basin country. Although China's 18 percent share in the geographical extent of the basin is substantial, the upper reaches in the Tibetan Autonomous Region of China of some of the glacier-melt rivers (notably the Brahmaputra and the Kosi) are of relatively small volume before they cross the Himalayas. It is on the southern slopes and lowlands, after leaving Chinese territory, that the rivers develop their great quantities of water from the southwest monsoon. Because of this, and the sparse population of Tibet, it is unlikely that China as an upper riparian will in the foreseeable future make any major consumptive uses of these rivers, but China at any point could assert a greater interest in basin matters.

More important for the relatively long-range future, some of the most dramatic hydroelectric and storage sites in the entire system, indeed in the world, are on the Brahmaputra River just as it passes through the eastern Himalayas and turns south and west into India. In a short space of run, the water drops 2,000 m and also experiences a greatly increased wet season flow from south slope monsoon rains. One location, known as Dihang for the river's name in that stretch, according to India's estimates, could offer 25,000 MW of power and 33 billion cubic meters (1 billion m^3 = 1 km^3 of water) of storage, about the volume of water at the Hoover Dam. However, there are major liabilities for development: In addition to severe earthquake problems in this zone and the remoteness of the hydroelectric generating sites from major power-consuming centers in any country, sovereignty over much of the relevant area has been disputed between China and India since the China-India mountain war took place there and in Ladakh in 1962. It is now under the administration of India, and it appears likely that China will recognize India's sovereignty in this eastern of the two regions disputed from the war in the eventual overall and final resolution of the war's issues.

After the August-September 1988 floods, Bangladesh's President H.M. Ershad included China in his regional visits to seek water cooperation; this assertive gesture may have been motivated by a Bangladeshi desire to bring in another regional superpower as a counterweight to India's predominance. China's response to President Ershad was to agree to establish a bilateral working committee and to send a technical advisory team to help Bangladesh with flood control measures within Bangladesh, but at least for the moment, despite prompting from Bangladesh, China has made no public reference to taking a position or role in Ganges-Brahmaputra regional water matters, as such.

The December 1988 visit of Prime Minister Rajiv Gandhi to Beijing was evidently a step toward an easing of the tensions in the Asian region between India and China, although there was no public evidence of progress toward a permanent settlement of the territorial issues of the China-India border war of 27 years ago. For the foreseeable future, it is expected that India will hope that China maintains its generally nonparticipatory and hands-off posture with regard to Ganges-Brahmaputra basin affairs, because an active Chinese interest would end the present configuration in which India deals only with smaller neighboring countries.

3.3.3 Bhutan

Apart from China, the basin is a recognizably Delhi-centric world. Bhutan (population 1.3 million) is a traditionalist south slope Himalayan kingdom, with some Nepalese population, governed by a Buddhist monarchy emanating from its majority of Tibetan descent and culture. Bhutan has chosen to restrict rapid modernization and contacts with the outside world, and it has experienced neither economic advance for the bulk of its people nor sharp population growth and pressure on its land. In a 1949 treaty with India, Bhutan agreed to be guided by the advice of India in regard to its external relations, although the kingdom has in the past decade established its own representation at the United Nations and sent ambassadors to Dhaka and Kathmandu as well as New Delhi. India considers Bhutan to be within its Himalayan crest defense perimeter, and it stations troops there, keeping them away, in general, from population centers and out of sight. India gives Bhutan substantial development aid, and self-contained Indian engineering crews build and maintain roads in the mountain kingdom.

In the 1980s, a 336 MW run-of-the-river hydroelectric generating plant was constructed at Chukha, on the Wangchu River, a Brahmaputra tributary in western Bhutan, with commissioning completed in 1988. The financing of Rs 2.4 billion (about $160 million) was partly loans and partly grant aid to Bhutan from India. India also provided all the construction and technical work on a turnkey basis, and it is purchasing virtually all the power for absorption into its power-starved eastern grid. The proceeds to Bhutan of the power sales, which will amount to about Rs 470 million ($31 million) per year, will in large part replace long-standing Indian aid to Bhutan.

The Chukha project has no flood control implications for the Indian state of Assam, nor for Bangladesh farther downstream, nor is it expected that flood control storage of a size to restrain Brahmaputra flooding significantly would be constructed in Bhutan's generally populated valleys.

Although both India and Bhutan professed satisfaction at this arrangement on the project's completion, Chukha was undoubtedly made possible by a relationship between a dominant regional power and a very small country. Such an arrangement would be acceptable to Nepal or Bangladesh only with great difficulty. Bhutan is now considering proposals from India for two larger projects lower on the same river, which would generate 1,000 MW each, with an eventual prospect of additional projects on rivers farther to the east in Bhutan.

The evidently successful Chukha project is an important marker for Indian-Nepalese negotiations on power construction and sales. It is not trivial in size, and it may open the way to further projects, which will make Bhutan in the future a significant source of power for India. It is estimated that Bhutan's rivers ultimately could produce 20,000 MW, which can be measured against India's current total generating capacity of about 50,000 MW.

3.3.4 Nepal

Nepal, with an estimated 17 million people (1986), is an ethnically heterogeneous mountain kingdom that was treated as fully distinct from British India since its war with the British in 1816-1818. Soon after India's independence in 1947, there were impulses in India to bring Nepal into the Indian Union, as certain princely states within India were compelled to do at that time, but in 1950 India recognized Nepal's independence by sending an ambassador to Kathmandu. In 1954, Indian support made possible the restoration of King Tribhuvan to the throne at the expense of the Rana clan of hereditary prime ministers, which had sequestered the royal family and for several generations almost entirely closed Nepal to contacts with the outside world. Tribhuvan's grandson, Birendra, is now king.

India, aside from being the source of Nepal's predominant Hindu culture, is Nepal's economic metropolis, from which Nepal imports the bulk of its industrial or modern goods. Nepal has a substantial trade deficit with India, only partly covered by an Indian aid program to Nepal and by conversion to Indian rupees of Nepal's hard currency earnings from tourism. As a Hindu monarchy, Nepal has long been able to claim a special respect from many Indians. Many of Nepal's businessmen and investors are Indian. Nepal benefits from outside aid and finance programs totaling about $500 million per year. Nepal's anxieties about being landlocked, and

India's concerns about Nepal's serving as a base for smuggling into India's controlled economy, were somewhat alleviated by the Trade and Transit treaties achieved in 1978. Currently, however, trade between the two countries has been disrupted over renegotiation of the treaties, which expired in March 1989. Nepal has made repeated international approaches seeking to be guaranteed a status as a "Zone of Peace" in the event of conflict among its neighbors; India has not recognized the Zone of Peace because it believes the basic provisions of the proposal are covered by the 1950 Indo-Nepal Friendship Treaty.

For decades, for many Nepalese, their nation's economic hope has lain in realizing the hydroelectric potential of its mountainous rivers and selling the power to India. There is no doubt that northern India needs the power; it is probable that electric energy shortages are the critical drag on economic development of both agriculture and industry in that part of India, which has a population of more than 300 million. Hydroelectricity, in the long run, would appear to be, by far, both the least expensive and least ecologically damaging solution. But the deal, even the first major deal, has yet to be agreed.

Why the impasse? A number of factors help to explain the problem:

1. Large-scale hydro development, although economical in comparison with thermal and nuclear production, requires very long lead times. If the proposed large dam on the Karnali River at Chisapani in remote western Nepal was technically, financially, and diplomatically agreed to today, it would probably produce power for India in 2005, at best. India's acute power shortage and abundant coal have for many years shifted the emphasis to thermal plants, which have shorter construction times, although India's planners are now trying to redress the balance in favor of hydro investments.

2. In both Nepal and India, to the outside observer, there would appear to be an exaggerated sense that the game between them is a zero-sum one; fear of being the "loser" in an exchange inhibits opening serious negotiations. Perhaps particularly in Nepal, there is a deep apprehension that there will not be a level playing field, and that giant India will take advantage in a way that cannot be acceptable to Nepalese as nationalists. Nepal, although many times smaller than India, feels an obligation to validate its independence and sovereign equality in contacts with India.

   In this context, it can be seen as the safer policy to avoid the game through indefinite postponement or nonresponse, although Nepalese assert that it is India that is the source of delay on, for example, the potential large dam on the Karnali River. When national consensus is not strong, such defensively nationalistic views among even a small segment of the political community can exercise great influence against impulses for trust and broader cooperation.

3. A more humdrum and bureaucratic nationalism, a vision and an internal discourse that stop unreflectingly at the national borders, also plays an inhibiting role. India does not catalog sites in Nepal among its potential energy sources, and it may therefore work less systematically toward realizing them.

4. Although India, at least in its own view, can be magnanimous to a noncompeting principality such as Bhutan, it finds it difficult to grant status and material value freely to regional countries that go to great lengths to assert their independence. As is normal for a regional power, India is eager to have recognition of its leadership from the smaller surrounding countries, as well as to realize benefits from each exchange with them. Its incorporation of princely states as large as Hyderabad and Kashmir, then of Goa, and more recently, Sikkim, give pause to small, close neighbors.

   Nepal attempts, at times, to balance its relations between China and India, but its Hindu background, the reality of its recent history, its location on the southern slopes of the Himalayas, and its proximity to the heartland of India while it is a long distance from the population centers of China, all make this difficult.

The existence of social and political constraints on capturing Nepal's hydropower does not mean that no technical obstacles exist. The main one is the implication for dam building of the seismic activity of the Himalayan area, which overlies the active meeting of two tectonic plates. Faults are numerous, and a Richter scale 6.7 earthquake of August 28, 1988, killed several thousand persons in the Kathmandu region. In recent years, techniques have been developed to make dams quake proof or resistant, but they are not entirely proven, and they increase the cost of the structures. Large populations are settled in the river valleys below dam sites, which mandates extreme caution about assuming the risk of a dam with significant stored water bursting under earthquake stresses.

The seismic question is of greater or lesser importance according to whether high-volume water storage is part of the dam's design. The capacity to impound large amounts of water in the mountains could be important to controlling floods on adjacent parts of the plains if the dams included large reservoirs and the timing of filling and emptying them was governed by that purpose.

Stored water can also be released according to the need of downstream farmers for irrigation (i.e., to augment the low flow of the Ganges), which is a major economic value in the dry season of a monsoon zone; the timing of gathering and releasing water for irrigation would be partially complementary with the schedule for flood control. It would be economically logical for India to pay Nepal for irrigation and flood control benefits, although reportedly in the case of Karnali, India has not recognized these nonpower benefits. A relatively large storage capacity would also permit hydropower to be drawn from a river when the power is needed, rather than primarily during the high season of the river. Such "firm" or even "peaking" power is of greater value, and brings a higher price, than electricity the consumer cannot rely on or cannot match to the fluctuations of his needs.

Against these benefits of storage is the consideration that a hydro plant that takes the energy of the river as the water comes by, without storage and timed release (a run-of-the-river plant), is a great deal less expensive and quicker to construct and does not create the potential for a catastrophic release of water in the event of an earthquake/damburst. The Himalayan rivers are generally heavily laden with silt, which is deposited when a river's motion comes to a standstill in a reservoir lake. Thus, storage capacity is not a permanent asset because the space behind the structure gradually fills with solid material; each dam will eventually become simply a shelf that can provide run-of-the-river power but that has no "live storage" space left for flood control or irrigation use.

A fundamental of relations in the basin is the advantage enjoyed per se by an upstream country (upper riparian), a structural element of the situation that is particularly important to Bangladesh and India. It might be expected that Nepal's position as the upper riparian in relation to India would confer on Kathmandu a substantial increment of bargaining power vis-a-vis New Delhi. That is not the case, because the classic and genuine advantage is that the upper riparian has first access to a scarce resource for his own use or can externalize a disadvantage and pass it down the river. But this advantage does not apply significantly in the case of Nepal and India, because Nepal does not have the irrigable land to take enough water to deprive India to an appreciable degree, nor is it practical for Nepal to reduce flooding in its territory by actively venting high water to India. Rather, Nepal needs to capture the energy resource available from the waters in Nepalese territory (a nonconsumptive use) and sell it to India. India does have a need for electrical energy, but more to the point, it has a monopoly buyer (monopsony) position. Although India does have alternative sources of power, Nepal has no alternative markets, internally or externally, for the large quantities of power, and thus, initiative if not control in the bargaining situation reverts to India. As in all the other cases, this bargaining dominance is supplemented by India's well-established advantages in size, wealth, skills, and so on. In the sense of the expected leverage, Nepal is a pseudo upper riparian, since it can neither control nor use the water that flows through it to India.

3.3.5 Bangladesh

With over 110 million people in contrast to Nepal's 17 million (and in an entirely contrasting delta environment but at about the same per capita income level of $150 per year), Bangladesh might be expected to have a heavier weight in its dealings with India. Such is not the case, however, because riverine Bangladesh is for all practical purposes surrounded by India on its land frontiers and is a lower riparian to India on virtually all its rivers, including both the Ganges and the Brahmaputra.

Being higher on the water flow gives powerful advantages, if the upper riparian is strong enough to use and keep them. Unlike Nepal in relation to India, India in relation to Bangladesh is very strong. Leaving aside considerations of international law and the responsibilities of neighbors, which India in fact has never set aside, if India simply looked after its own interests in the next 20 or 30 years—acting, for example, as if the ocean began at its border—it could well handle its flood waters in Assam by confining the Brahmaputra within embankments. The increased excess water would then flow into Bangladesh at the wrong time, worsening floods there. In the dry season, India could take all the scarce surface water in almost all the rivers, except the Brahmaputra, so that none flowed to Bangladesh at all from the Ganges or many of the secondary streams when it was most needed.

Through the 1960s and early 1970s, India constructed a billion dollar, fully gated low dam (barrage) across the Ganges at Farakka just upstream of where the Ganges enters Bangladesh. The gates of the barrage stand open in the wet season, producing no change in the river's flow, but in the dry season the barrage diverts water into an otherwise dying channel of the main river that lies inside India. Lower on this old river is Calcutta; the barrage was built to protect the city's port from silting up. In the dry season, the Farakka Barrage is like a faucet that can virtually turn off the flow of surface water in the Ganges into Bangladesh.

In fact, India does not subscribe to a view of international law that would permit it to ignore the interests and claims of Bangladesh, and it has never threatened to cut off all Ganges water. Throughout the planning and early construction of the barrage at Farakka, India resisted the discussions on Ganges water sharing persistently sought by Pakistan, since Bangladesh was then East Pakistan. In the mid-1970s, as India was completing the Farakka Barrage, it was drawn into concrete discussion of the need for sharing dry season water when Bangladesh inscribed the issue on the agenda of the United Nations General Assembly. Although New Delhi always accepted the principle of a Bangladeshi entitlement, it evidently agreed to talks at that time at least partially in response to the prospect of embarrassment in the United Nations.

International law says in a broad and nonenforceable way that upper and lower riparians should take each other's needs and interests into account. Although it is unlikely that any real process of international law could have gotten under way (India's consent would have been required for international adjudication of the case), when the Farakka water conflict was framed in the United Nations, India agreed to negotiate. After the change of government from the Congress to the Janata party in the winter of 1977, India agreed, for a five-year period beginning in the fall of 1977, to limit use of the Farakka Barrage to diverting about one-third of the lowest season water for Calcutta, leaving roughly two-thirds for release to Bangladesh. The agreement on water sharing was renewed in 1982 for three years, and again in 1985, expiring in May 1988. The agreement is not in force in 1989; India asserts that of its free will it intends to provide an unspecified quantity of low season water to its neighbor Bangladesh but that the old provisions of the agreement are no longer binding and the agreement's renewal can only be based on a more forthcoming Bangladeshi position. In the meantime, with joint observation teams no longer at the barrage, Bangladeshi and Indian estimates of how much water is being allowed to pass through have sharply diverged. India says it has proposed that, even in the absence of an agreement, joint observation be resumed.

In the Indian outlook, Bangladeshi concessions might likely come in the form of "augmenting" the dry season waters. The Indo-Bangladesh agreement on current water sharing was paired at each signing with a longer term undertaking, intrinsically more important, that both countries would work together to seek ways to bring about "augmentation" of available water in the dry season. The Indo-Bangladesh Joint Rivers Commission, a periodically meeting body set up in 1972 in the era of good feeling between Prime Minister Indira Gandhi and Prime Minister Mujibur Rahman immediately after Bangladesh's independence, was to handle this task.

The discussion of augmentation has been deadlocked since close to its beginning. In 1978 India offered a plan to regulate the Brahmaputra by two major dams on its passage through the eastern Himalayas. At the same time, India made a proposal to augment the Ganges low flow by bringing 3,000 cubic meters per second (cumecs) of Brahmaputra water to the Ganges at Farakka from Jogighopa in Assam by means of a canal across northwest Bangladash. Bangladesh is adamant that this use of its territory is politically and physically impossible, and it has countered with a proposal to increase dry season flows in the Ganges by storing water from the wet season in seven dams to be built in Nepal. India reiterated its 1978 proposals to President Ershad when he visited Prime Minister Gandhi in New Delhi in the wake of the floods of 1988. Although Bangladesh's counterproposal of dams in Nepal has not been supported by Nepal, Bangladesh's resistance to an Indian link canal across its territory has not diminished. Bangladesh has explored alternative proposals to increase dry season water in its southwestern quadrant through a link canal from the Brahmaputra to the Ganges within Bangladeshi territory.

On the rivers themselves, it is the nature of the lower riparian's situation that Bangladesh has few cards to play. As discussed above, India is physically placed so that it can take the lion's share of dry season water, and so some potential flood control policies for India's Assam State could worsen the flood situation in Bangladesh. As the downstream party, Bangladesh has no way to affect India similarly. In the general politics of the region, Bangladesh again has no strength to balance against India's size, technical advancement, financial resources, and geographical position.

Bangladesh has repeatedly called for water matters to be handled by the basin countries as a group. India has consistently rejected convening a multilateral forum for the discussion of basin issues, and it shows no weakening in its commitment to bilateralism. However, it is very doubtful that a multilateral basin approach would be of substantial assistance to Bangladesh, since the concrete interests of no other participant among India, Nepal, Bhutan, and China are the same as those of Bangladesh. The cooperation needed between Nepal and India on dam building and power sales has little similarity to what Bangladesh seeks with India on water sharing, augmentation, and flood mitigation. Neither has much to say on the challenges each confronts in dealing with New Delhi, and Bhutan and China similarly have little to offer.

One possibility is that Bangladesh could adjust its rhetoric in the direction of greater cooperativeness with India. This is difficult, however, for Bangladesh, because a "small" nation's nationalism in such a situation is largely built on standing up against the paramount regional power. Moreover, in contrast to the Hindu kingdom of Nepal, Bangladesh is quite assertively a Muslim majority nation. Appearing to accede to Indian pressures is unpalatable to any Bangladeshi government, and particularly difficult for the current one. In a country whose politics have reflected a division between its Muslim and its Bengali traditions, President Ershad's government lays stress on Islam as the unifying principle of the nation. Although this is probably a domestic political asset for the Bangladeshi government, it means that relations with India have as their point of departure one of the subcontinent's most enduring antagonisms, which does not bode well for cooperation in general relations or in water matters.

3.3.6 India

For Indian officials, Ganges-Brahmaputra water development on a day-to-day basis is defined and dealt with in a national manner, rather than on a larger logic, such as that of the basin. This cannot be surprising in the age of the nation-state and populations intensely imbued with the ideas of nationalism. India, like the United States, has many individuals aware of and motivated by concerns broader than national ones, but the majority of its people and its government representatives operate within the framework that their primary community is the nation-state and that it is entirely natural and justifiable that it should pursue its interests.

India could follow what would ultimately be more cooperative basin/regional policies in several ways:

- by taking a longer time perspective, in which national and regional interests were seen to coincide;
- by doing projects within India, on the basis of benefits for India itself, that had accidental beneficial externalities for neighbors;
- by taking actions within India specifically with the intention of benefiting a neighbor, in a context of the neighbor's reciprocating, either materially or with diplomatic support or deference; or
- by taking actions within India with the intention to benefit a neighbor without expectation of immediate reciprocity, but with a general motive of cooperation or of benefiting the other country.

Cooperation between India and Bhutan appears to be well established on a footing that is not equal, but which is satisfactory to both parties and productive of cooperative arrangements and mutually beneficial outputs, and which to all evidence will continue and expand.

Prospective cooperation between India and upper riparian Nepal comes primarily under the heading of material reciprocity, and this would appear to be adequate. To all evidence there is an economic hydropower agreement of classic mutual benefit to be made, and no further motivation, altruistic or otherwise, is necessary. India could give Nepal a "bankable purchase order" for power at a certain price, and Nepal could invest in the capacity and provide the power.

There is one immaterial but potentially critical problem, which in fact may well account for a good deal of the Nepalese ambivalence over the many slow years until now: To gain Nepal's free consent to the arrangement, India must permit Nepal an unambiguously arms-length status. The price that

India offers for the electricity must be one that is attractive to an unpressured Nepal. However, over future decades, the result of the deal will be to increase economic integration between the two countries, which could be considered a sacrifice on Nepal's part against a goal of independence from India.

Second, very much reflecting the above, the financing and construction of a very large hydroelectric facility, such as a Karnali high dam (10,000 MW of peaking power), could range substantially along an important dimension. At one extreme, it could be an encapsulated Indian project in Nepalese territory, like Chukha in Bhutan. At the other extreme, it could be handled by the Nepalese government, perhaps genuinely accepting large risks and doubtless relying heavily on nonregional countries and institutions for support. In the latter case, the dam building could be a set of projects of the World Bank, or of Japan, or of large international construction firms working with and through the Nepalese government, with India genuinely limited to the role of purchaser. Most likely it will be at some middle position on this range, although geography alone strongly favors a large Indian role, for example, as a source of construction labor, regardless of the form of the arrangements.

This latter dilemma, as well as the problem of selling to a monopsony buyer, could very largely be avoided by developing smaller projects without storage, such as on the bend on the Karnali some miles above the proposed dam and the site on the Kosi river system known as Arun III. The latter, a run-of-the-river plant, will produce about 400 MW of power, of which Nepal could consume immediately 200 MW, leaving 200 MW available for sale to India, but alternatively consumable within Nepal. The absence of a large storage reservoir reduces the technical risk from seismicity and eliminates the progressive loss of function through sedimentation. In addition, the smaller scale and alternative uses of the power reduce financial risk. India and Nepal are in discussion now about possible sale of base power from a project at Arun III, and should agreement be reached, the pricing arrangements for the power could well serve very constructively as a benchmark and an icebreaker for subsequent power contracts, including much larger ones.

Cooperation between India and Bangladesh is more problematical. Within the water area, the Joint Rivers Commission exists for the two countries to communicate, and indeed through the commission and ad hoc bodies there is an active pattern of diplomacy, which has developed numerous knowledgeable officials on both sides. But as a lower riparian, Bangladesh has little to exchange with New Delhi to satisfy its own strongly felt need for dry season water and, probably eventually, for wet season upstream flood mitigation measures on the Brahmaputra. The one major issue is eventual agreement for New Delhi to build the Ganges-Brahmaputra link canal across Bangladeshi territory, assuming that the interbasin link is technically sound. Over 10 years after its initial proposal, India continues to press for a softening of Bangladesh's attitude on a possible link canal across Bangladeshi territory, but Dhaka remains adamant in its resistance.

4

FLOOD MANAGEMENT

Flood control should not be considered as an end in itself, rather it is a means to an end. Flood control has to be viewed within the broad context of the economic and social development in the country.

—National Commission on Floods, (India), 1980: I:227

In the extremely seasonal setting of the Eastern Waters basin, water interventions can be divided into those that will mitigate the floods, those that will make water available in the dry season, and those that will achieve some measure of both. It should be said at the outset, however, that the volume, high sediment, and energies of the Bangladesh river system in flood and the lack of high or unpopulated ground in the main section of the country raise serious doubts regarding the existence of any effective method for physically mitigating flooding significantly in Bangladesh.

4.1 Types of Flooding

In Bangladesh floods of the following types are commonly encountered (UNDP, 1988a):

1. Flash floods in the eastern and northern rivers. These are characterized by a sharp rise followed by relatively rapid recession a few days later; they often cause high water velocities that damage crops and properties.

2. Floods due to high-intensity rainfalls. The very high rainfall intensities and durations in the monsoon season often generate water volumes in excess of the local drainage capacity, causing local floods.

3. Monsoon floods from the major rivers. The major rivers generally rise slowly over a period of 10 to 20 days, or more. Water spilling over the banks of major rivers and tributaries causes the most extensive flood damage, particularly when the three major rivers rise simultaneously.

4. Floods due to storm surges/tidal waves in the coastal area. The coastal areas of Bangladesh consist of large estuaries, extensive tidal flats, and low-lying islands. Storm surges caused by tropical cyclones cause extensive damage to life and property. Cyclones are predominant during the pre- and postmonsoon periods (April-May and October-November, respectively).

The different kinds of flood that occur in Bangladesh make combating their effects very difficult: A well-conceived policy or structure to manage one kind of flood can be useless or even harmful in another flooding situation.

The focus of this discussion is major flood disasters of wide geographic extent, such as that of 1988, which are generally combined rainfall/river floods. The strategy for dealing with such floods is heavily dependent on the origin of the flood waters, but in reality it is difficult to untangle entirely the effects of high incoming streamflow and torrential local rainfall.

The usual sequence starts with flash floods in the eastern hill streams during the pre-monsoon period in the months of April and May. Onset of the monsoon generally occurs in June, and the Meghna and the Brahmaputra reach flood peaks during July and August; the Ganges normally peaks during August and September.

The timing and duration of high incoming river levels in relation to regional or local rainstorms decide whether any location in the basin, but particularly the Bangladesh delta, has a normal flood, which is a positive event for agriculture, or a high flood. Simultaneous peaking of both the Ganges and Brahmaputra, as in 1988, makes the congestion problem much more serious than the normal month-apart peakings of the rivers. Torrential rainstorms in any part of the lower basin can cause devastating floods almost overnight when superimposed on a congested river system (often linked to high tides in the Bay of Bengal).

There are few confirmed numbers about the relative magnitudes of the different sources of water. The Bangladesh National Water Plan (1986) reported that under average conditions, from June to September, 775 billion m^3 of water flow into Bangladesh through the three main rivers and that an additional 184 billion m^3 of streamflow is generated by rainfall in Bangladesh. (For comparison, the annual flow of the U.S. Colorado River at Yuma, Arizona, is 12 billion m^3.) Brammer (1982) reports observing that most of the areal extent of flooding is caused by the ponding of rainfall, which cannot drain off due to high river levels. That water is clear. In most floods, the silty floodwater from the rivers reaches a relatively small proportion of the flooded land. In those areas, however, the silty water deposits new alluvium, which accounts for the phosphorus and potash content of those soils (due to the seasonal cycle of reduction and oxidation of the mineral-rich soils). In the rain-flooded areas, however, the nitrogen fertility is provided by biological activity in the floodwater itself, especially blue-green algae. It is probable that these organisms provide up to 30 kg/ha of nitrogen annually in areas flooded by clear-water rain.

4.2 Physical and Economic Magnitude of Floods

There is, unfortunately, no unambiguous measure of the size of a flood. It can be measured in terms of stage (height of water) and duration, the quantities of water involved, or the economic damages caused. For policymaking, a calculation of economic losses is probably the best measure to use, but that often creates a misimpression that the floods are becoming physically worse, because with economic development each year more assets are placed at risk. Hence, a flood today usually causes considerably more damage than a similar-sized earlier one.

It seems reasonable to believe that the 1988 floods were the worst ever in terms of economic losses. A review of historical rainfall records going back to 1829 (see Figure 3, which shows the case of Calcutta; see also Shukla, 1987), however, indicates that the past century must have had floods of equal physical magnitude, and data on flood levels in selected recent years (see Table 3) indicate that the 1988

Table 3

Flood Stages and Affected Areas, Bangladesh
(river level in feet)

	1954	1955	1974	1987	1988	Mean
Bahadurabad	65.5	65.95	66.42	64.55	67.96	66.08
Serajganj	45.3		46.67	47.79	49.60	47.34
Goalundo			31.48	31.22	32.24	31.65
Rajshahi	61.2		60.81	63.82	62.32	62.04
Hardinge Bridge	47.4		47.17	48.54	48.77	47.97
Bhairab Bazar	25		25	22.66	24.83	24.37
Chandpur		17.54	17.1	15.42	16.87	16.73
Dhaka		23.25	21.7	21.78	24.86	22.90
Narayanganji	20.45		20.45	19.81	21.98	20.67
Affected Area (1000 sq km)	36.78	38.85	52.52	54.95	66.36	

Sources: Flood stages (Choudhury, 1988:11); area affected (Hossain et al., 1987:20).

flood was not a tremendously greater physical event than two of the four other severe floods in the past 35 years. In a study of the historical record of natural calamities, scarcities, and famines in 17 districts of Bangladesh between 1757 and 1970, Currey (1988) compiled a chart, shown here as Figure 7, that shows the frequency and spatial variability of these various calamities. The floods seem to be clustered in both time and space; for example, floods were very frequent in the 1770s, 1780s, and 1790s, but were almost nonexistent in the 1920s and 1930s. Back-to-back floods, such as occurred in 1987 and 1988, appear quite common in the record. This chart indicates that much remains to be learned from careful review of the historical records of the basin.

There are also no reliable estimates of the amount of the economic damages caused by floods. In addition to the direct losses to agriculture, industry, and individual households, floods cause disruptions that have ripple effects throughout the economy, not just in the flooded areas and not just during the period of actual inundation. During large floods, such as occurred in 1988 in Bangladesh and Assam and in 1987 in West Bengal, Bihar, and Bangladesh, the economy becomes paralyzed for periods of weeks, or even months, and takes further time to return to normal. Moreover, the perpetual threat of flood loss probably inhibits investment to a significant but unknown degree. Estimates of the benefits of flood reduction must therefore take relief from these invisible flood damages into account, just as they must give weight to the human miseries caused to people driven out of their homes, an estimated 30 million in the case of the 1988 flood in Bangladesh.

Floods are also serious problems in India. In fact, the average annual loss of lives and property far exceeds that in Bangladesh (National Commission on Floods, 1980). On the average, between 1953 and 1976, 1,240 lives were lost and 77,000 cattle and property valued at Rs 2.1 billion were destroyed annually. The bulk of the losses are experienced in five states—Bihar, Uttar Pradesh, West Bengal, Assam, and Orissa—of which the contiguous region in northern Bihar and eastern Uttar Pradesh are much more severely affected. The central government's outlay for flood control has traditionally been slightly less than 1 percent of the total economic development plan.

Kumra and Rao (1985:iv) reviewed flood assessments in India and concluded that "crop damages are showing a steady decline ... whereas a distinct rise in non-crop damages is noticed, indicating indirectly the general growth of the developmental activities in the flood prone areas." This supports a picture of stable or declining flood flows and increasing nonagricultural assets at risk as a result of development.

4.3 The Flood of 1988 in Bangladesh

The Brahmaputra reached flood stage in early July and had two early peaks, on July 10 and July 30. The floods rose to great heights during August and September and equaled or surpassed previous records in terms of extent and severity (see Table 3). About 90 percent of the floodwater was reportedly carried into Bangladesh from across the national boundary by the Brahmaputra, Ganges, and the Meghna, but it originated largely from torrential rains very close to and over the Bangladesh border, rather than from higher in the watersheds. There was a synchronization of a late peak on the Brahmaputra (August 30) with the normal peak (September 2) on the Ganges—less than three days later—and this was aggravated by high tides in the Bay of Bengal. Out of 34 water-level stations monitored, the highest recorded floods were exceeded at 10 stations. The 1987 peaks were exceeded at 22 of the stations. An expected frequency (return period) of once in 100 years has been suggested as a measure of the severity of the flood. (For more details, see UNDP, 1988a.)

4.4 Agricultural Production and Floods

Floods affect agricultural production in a variety of complex ways, bearing in mind that mild or normal flooding is beneficial in that it provides water to summer crops, soil moisture to winter crops, and some soil improvement through silt deposition. The agricultural costs of excessive floods can be divided into short-term damages to that year's crop and, apart from that, the long-term costs to crop production due to underinvestment in high yield varieties, fertilizer, irrigation, labor, and other costly inputs because of the risk of loss through floods. The analysis by localities presented below indicates that both short- and long-term costs are less than would be expected, which contributes to the image of Bangladesh as a deltaic society surprisingly resistant to floods through social adaptation of many generations.

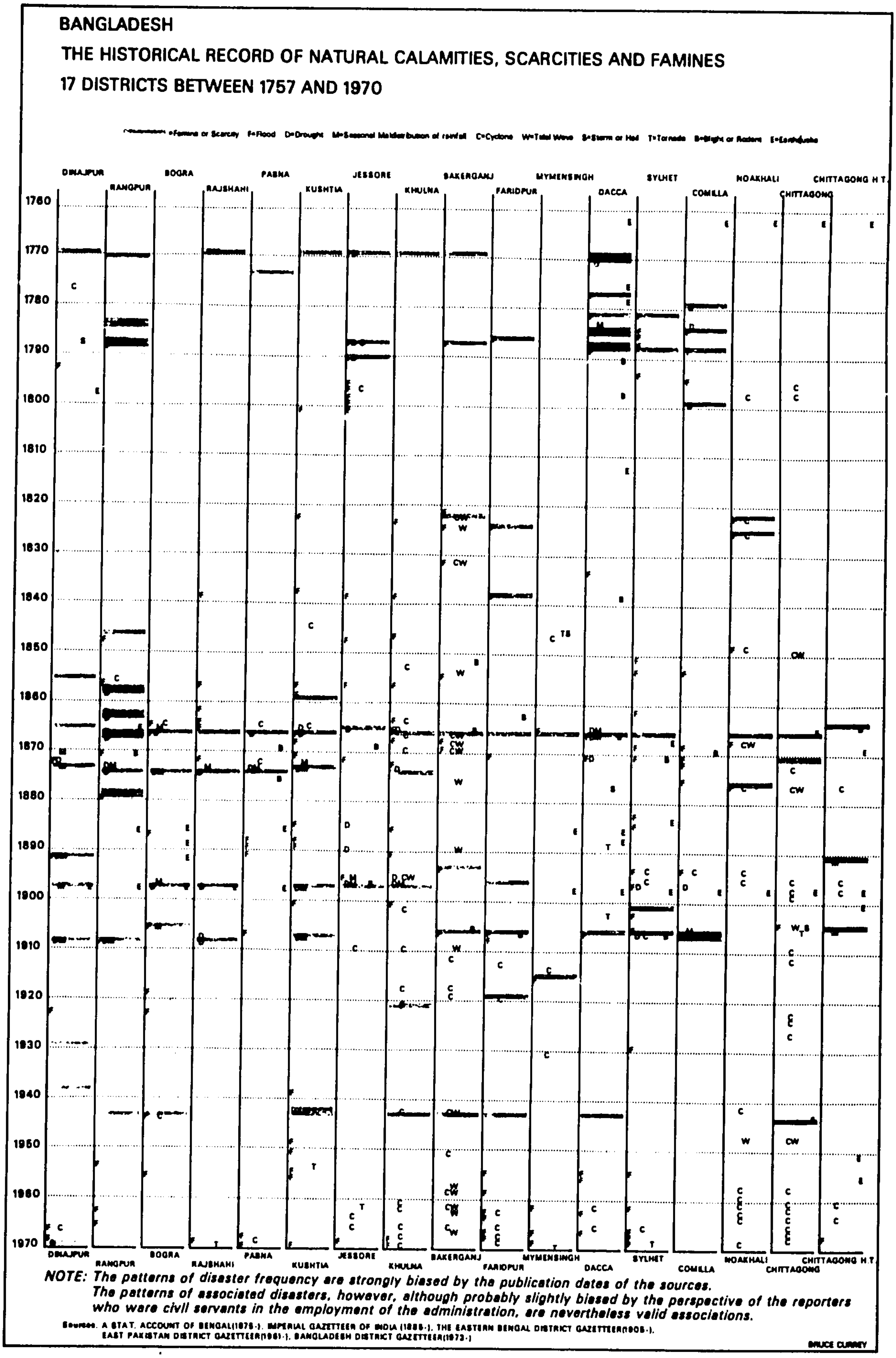


Figure 7

History of Calamities in Bangladesh (1974-1988)

Source: Currey (1988).

4.4.1 Short-term Costs

Figure 8 provides an overview of rice and wheat production in Bangladesh from 1974 through to estimates for the 1988 crop year (Hurdus, 1988). The severe flood years are indicated by an "f" on the horizontal axis of this figure. It is noteworthy that the 1987 flood, considered the worst on record only after that of 1988, is associated with the highest production of grain, because of an exceptionally good *boro* rice (dry season) crop. Recent revisions of the estimates of the total 1988-1989 grain crop indicate that it might be as large or larger than the bumper 1987 crop (Hash, 1989).

Thus, although an individual farm family can indeed be severely hurt, direct flood losses have very little effect on annual foodgrain production in Bangladesh. The reason, as Hurdus (1988) points out, is that damage in the *aus* or *aman* rice seasons (early and late monsoon planting, respectively) is largely offset by better soil moisture conditions and the farmers' willingness to plant more area and apply more inputs in compensation in the *rabi* season.

The Bangladesh Institute for Development Studies surveyed flood damages in 62 villages across Bangladesh after the floods subsided in October 1988 (Hossain, 1988a). Based on this nationwide survey, the institute estimated that, nationwide, the total damage resulting from the loss of housing, livestock, household supplies, forestry and fishery products, and crops and from the costs of medical treatment amounted to about 466 million takas—4.1 percent of the national income. For the income groups in the flood-affected areas, this ranged from an income loss of 15.1 percent for the functionally landless to as much as 20.7 percent for large landowners.

4.4.2 Long-term Costs

The *aus* and *aman* rice crops that are affected by floods are the traditional main crops in Bengal. *Aman* rice remains the most extensively planted and the largest crop in the year, but most of the total growth of production in recent years has stemmed from the new irrigated dry season rice and wheat crops. Low levels of investment in modern inputs for the traditional wet season crops are almost certainly due in part to the risk of loss of inputs by flooding, but perhaps the best way to analyze the long-term effects of floods is by comparing the agricultural performance of regions with different degrees of flooding.

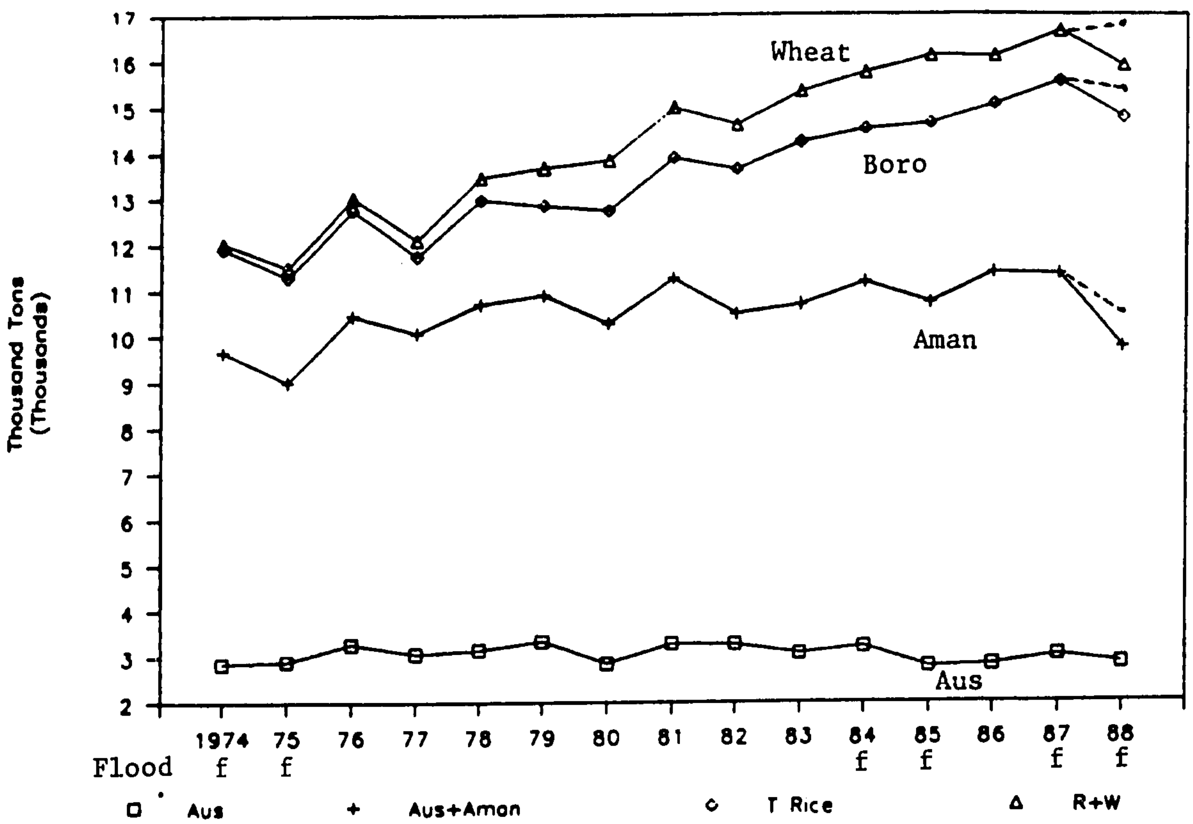
The Bangladesh National Water Plan (1986: II:10, 61-62) estimates that 35 percent of the net cultivated area of Bangladesh is "shallowly flooded" (30 to 90 cm deep in a normal year); 16 percent is "moderately flooded" (90 to 180 cm); and 12 percent is "deeply flooded" (over 180 cm); the remaining 37 percent is not flooded. The map shown in Figure 9, which is a computerized version of data given in the National Water Plan, shows the areas of Bangladesh that are subject to flooding to depths less than and greater than 90 cm in a normal year, in relation to the major rivers. Table 4 shows the same information expressed as a percentage of the total area of each district. The table is arranged in order of decreasing percentage of the area affected by deep floods. It is assumed that in exceptionally severe flood years, these percentages increase roughly in proportion.

Table 4

Depth of Flooding in Districts of Bangladesh

	Percent of District Area	
	0 to 90 cm	≥ 90 cm
Bogra	22	78
Pabna	25	75
Comilla	32	68
Faridpur	32	68
Tangail	38	62
Sylhet	42	58
Dhaka	43	57
Mymensingh	45	55
Jessore	46	54
Rajshahi	60	40
Noakhali	78	22
Barisal	84	16
Kushtia	87	13
Khulna	91	9
Rangpur	94	6
Chittagong	97	3
Patuakhali	98	2
Rangumati	100	0
Bandarban	100	0
Dinajpur	100	0
Total Area (Mha)	9.7	4.73
Percent of Total	67.2	32.8

Source: Computer Assisted Development Inc., 1989.



Crop Year 1988-89 corresponds to Flood Year 1988

Dotted lines for 1988-89 are revised estimates from Hash (1989).

Figure 8

Rice and Wheat Production in Bangladesh
Crop Years 1974-75 to 1983-89

Sources: Hash (1989), Hurdus (1988), and *Statistical Yearbook for Bangladesh, 1987.*

Tables 5 through 7 explore relationships between the more flooded districts and the less flooded districts. The variables examined mainly cover district populations and agricultural inputs and outputs. The surprising feature of these tables is that there is indeed very little difference between the two sets of districts in terms of the variables examined.

With respect to population (Table 5), the two sets of districts have nearly the same population and are growing at nearly the same rate. There are more persons per hectare in the more flooded districts—8.1 compared with 5.8. The percentage of the population that is urban is less in the most flooded districts (9 percent compared with 14 percent) but rural populations are growing at about the same rate in the two sets of districts.

In terms of agriculture, Table 6 shows that the two sets of districts are virtually the same in terms of percentage of the cultivated area in crops and agricultural value added per hectare and per rural person. However, production, area, and yield of crops all are growing faster in the more flooded districts.

Table 6 also shows that the more flooded districts have slightly more irrigated area as a percentage of the total cultivated area, use sightly more fertilizer per hectare, and have a slightly greater percentage use of modern varieties of rice. Average yields of modern and local varieties are virtually the same in the two sets of districts.

Table 7 provides a rationale for these otherwise counterintuitive findings: They are largely due to different seasonal crop systems in the two sets of districts. The percentage of rice production in the early *kharif* season (*aus* rice) is about the same, but the late wet *kharif* season contributes only 47 percent of total production in the more flooded districts, compared with 64 percent in the less flooded districts. The converse holds in the dry *rabi* season, which contributes 30 percent of total production of the more flooded districts, but only 14 percent for the less flooded districts

In sum, the loss of production due to floods in the more flooded districts is compensated for by good moisture conditions for the *boro* rice and other *rabi* crops, while the less flooded districts gain from the moderation of the wet *kharif* season but suffer moisture deficiency in the *rabi* season. In the early *kharif* season (*aus* rice) they are on about the same footing. These figures show the adaptability of the Bangladeshi cultivation system to the water regime and the need for more irrigation in the less flooded districts.

4.5 Causes of Floods

Certain large-scale geomorphological mechanisms have been suggested as affecting the magnitude and timing of floods in this basin. In particular, deforestation and the thinning of forest cover in the hills above the plains has been asserted to be important. This has come into controversy, however, and the discussion that follows is heavily influenced by new research findings of Ives and Messerli (1989).

4.5.1 Deforestation: Sorting out a Complex Case

Massive population growth in the Himalayas since about 1950 has significantly augmented pressure on the mountain forests through increased fuelwood and grazing requirements and the clearing of forest land for agriculture. The World Bank and other agencies have predicted elimination of all accessible forest cover in Nepal by a specific date, such as the year 2000. In many localities it appears true that massive gullying, landsliding, and general soil erosion are devastating the life-support base of the mountain communities.

But more important, the implied downstream impacts—increase in rapid and direct run-off of precipitation during the summer monsoon, siltation, and reduced streamflow during the dry season—are held to be a primary cause of assertedly increasing flooding on the Brahmaputra and Ganges plains. It is therefore reasoned that reforestation of the mountains would reverse this process.

On the contrary, as noted above, there is no evidence of a trend to greater physical flooding in the region. Such a reforestation response, particularly if performed as a massive external intervention and without local participation of the subsistence farmer at all levels, could increase rather than ameliorate environmental and socioeconomic problems in the Himalayas, and although costly, almost certainly would prove to be a misdirected and futile method of trying to alleviate flooding on the plains.

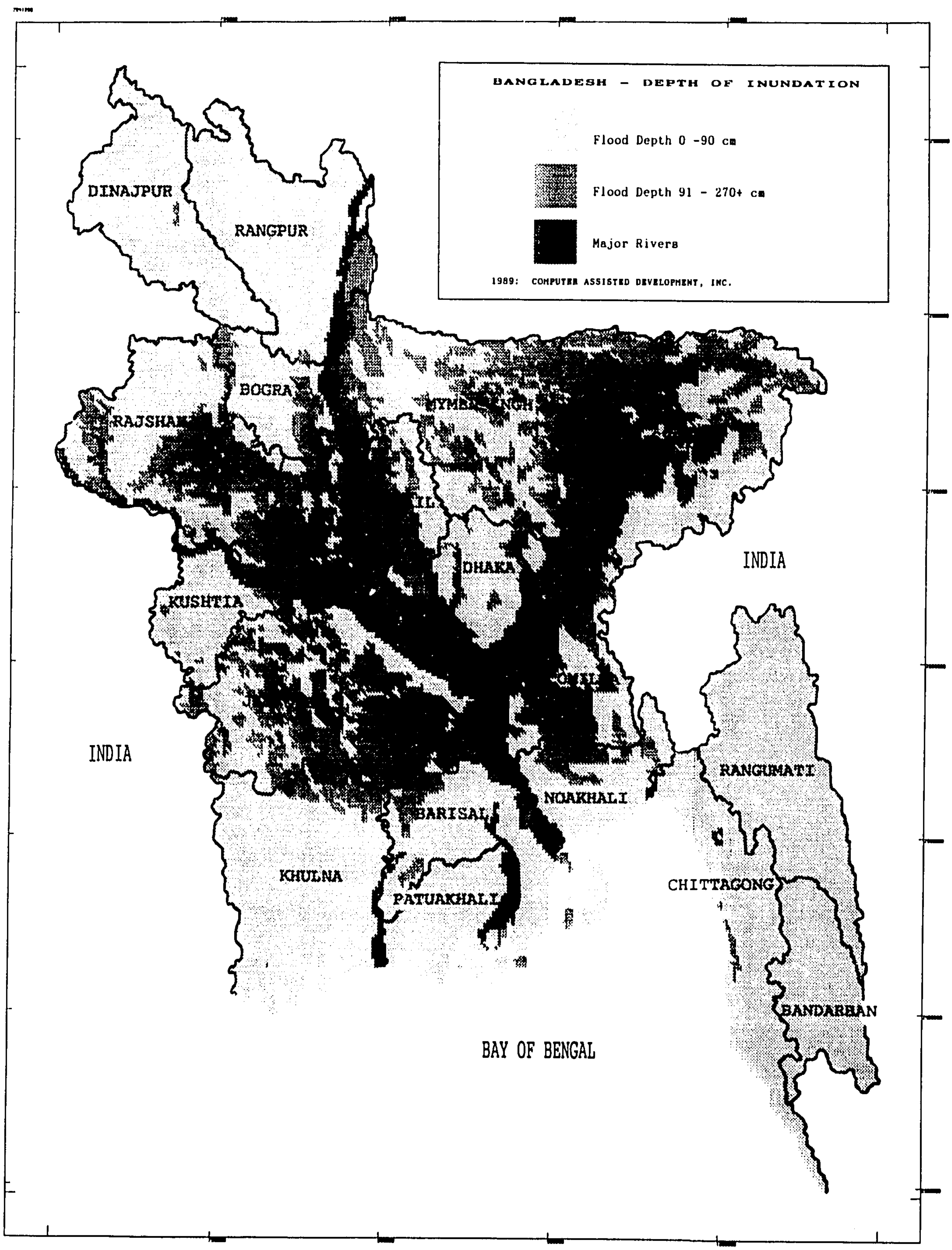


Figure 9

Flooding Levels in Bangladesh, by District

Table 5

Comparison of Population Data on More Flooded and Less Flooded Districts in Bangladesh

Region	Percent Area Flooded > 90 cm	Population 1981 (1000)	Growth 1974-81	% T Pop 1981	Area (1000 ha) 1985-86	Persons Per ha	Urban 1981 %	Urban Growth 1974-81	Rural Growth 1974-81
Bangladesh	33	87120	122		14482	6.0	15	211	113
Dhaka	57	10014	132	11	747	13.4	39	171	115
Other		77106	112	89	13735	5.6	12	233	113
MORE FLOODED									
Bogra	78	2728	122	3.1	389	7.0	7	245	118
Pabna	75	3424	122	3.9	486	7.0	12	186	116
Faridpur	68	4764	117	5.5	699	6.8	7	283	112
Comilla	68	6881	118	7.9	672	10.2	8	226	113
Tangail	62	2444	118	2.8	337	7.2	8	170	115
Sylhet	58	5656	119	6.5	1272	4.4	9	378	112
Mymensingh	55	6568	119	7.5	404	16.2	10	155	116
Jessore	54	4020	121	4.6	658	6.1	11		
LESS FLOODED									
Rajshahi	40	5270	123	6.0	947	5.6	10	221	118
Noakhali	22	3816	118	4.4	546	7.0	11	597	108
Barisal	16	4667	119	5.4	723	6.5	12	521	108
Kushtia	13	2292	122	2.6	355	6.5	15	212	113
Khulna	9	4329	122	5.0	1205	3.6	22	187	111
Rangpur	6	6510	120	7.5	960	6.8	11	271	112
Chittagong	3	5491	127	6.3	701	7.8	31	189	111
Patuakhali	2	1843	123	2.1	476	3.9	9	449	115
Dinajpur	0	3200	124	3.7	676	4.7	9	242	119
Total/Average									
More Flooded		36485	120	42	4917	8.1	9	235	115
Less Flooded		37418	122	43	6588	5.8	14	321	113

Source: Statistical Yearbook for Bangladesh, 1987.

Table 6

Comparison of Agricultural Data on More Flooded and Less Flooded Districts in Bangladesh

Region	Cult Area (1000 ha)	Crops % Total	Multiple Cropping	V Added in Agr Taka/ha	1983-84 Crops/ R Pop	Annual Growth, %: Crop Production	Annual Growth, %: Area	Annual Growth, %: Yield
Bangladesh	11560	76	154	9392	1721			
Dhaka	572	67	138	10939	1240			
Other	10988		16	-1547	481			
MORE FLOODED								
Bogra	299	87	184	9731	2104	5.4	1.8	3.6
Pabna	389	85	157	8372	1629	3.4	0.5	2.9
Faridpur	513	71	165	7104	1333	2.5	0.4	2.1
Comilla	554	77	167	10240	1425	3.0	1.5	1.6
Tangail	302	84	171	10954	2054	4.8	1.2	3.6
Sylhet	926	83	141	10356	1950	3.0	3.1	-0.1
Mymensingh	342	86	198	17977	1964	3.5	0.8	2.7
Jessore	516	83	135	8518	1623	0.4	-0.7	1.1
LESS FLOODED								
Rajshahi	735	85	132	8896	1761	2.2	-0.1	2.2
Noakhali	453	85	155	10141	1630	-1.2	-1.4	0.2
Barisal	520	82	147	9083	1561			
Kushtia	294	84	149	8073	1629	2.9	-0.6	3.5
Khulna	1018	56	131	9197	1569	1.8	1.4	0.5
Rangpur	742	85	192	8369	1974	3.4	0.3	3.1
Chittagong	564	64	155	15683	1883	2.5	0.9	1.6
Patuakhali	341	78	141	7942	2026	1.8	2.3	-0.5
Dinajpur	550	84	136	8308	1963	3.2	1.3	1.8
More Flooded	3841	82	165	10406	1760	3.3	1.1	2.2
Less Flooded	5217	78	149	9521	1777	2.1	0.5	1.6

Source: Statistical Yearbook for Bangladesh, 1987.

Table 6 (continued)

Comparison of Agricultural Data in More Flooded and Less Flooded Districts in Bangladesh

Region	Irrigated Area (1000 ha)	% Irrigated	Fert. kg/ha	Rice Area 1986-87 (1000 ha) Local	Modern	% Modern	Rice Production (1000 tons) Local	Modern	% Modern	Rice Yield (tons/ha) Local	Modern
				Modern and Local Varieties of Rice							
Bangladesh	2098	15	20	7478	3132	30	8204	6959	46	1.09	2.22
Dhaka	132	19	33	368	153	29	391	386	50	1.06	2.52
Other	1965	15	20	7146	2979	30	7813	6573	46	1.09	2.20
MORE FLOODED											
Bogra	134	25	44	242	185	43	297	441	60	1.24	2.40
Pabna	81	14	29	289	69	19	274	182	40	0.94	2.64
Faridpur	45	5	8	522	59	10	455	164	26	0.86	2.77
Comilla	170	19	33	410	280	41	434	581	57	1.06	2.08
Tangail	87	20	26	254	92	27	242	252	51	0.96	2.74
Sylhet	188	19	9	671	210	24	745	406	35	1.11	1.93
Mymensingh	88	14	16	269	243	47	278	475	63	1.04	1.95
Jessore	120	18	21	410	113	22	458	267	37	1.11	2.37
LESS FLOODED											
Rajshahi	159	17	21	490	176	26	525	427	45	1.06	2.42
Noakhali	33	6	18	317	231	42	350	431	55	1.11	1.88
Barisal	47	7	10	537	91	14	589	186	24	1.09	2.05
Kushtia	110	28	34	177	69	28	178	151	46	1.01	2.20
Khulna	32	6	11	414	55	12	470	116	20	1.14	2.10
Rangpur	193	14	16	660	285	30	807	644	44	1.21	2.25
Chittagong	131	29	36	106	321	75	138	722	84	1.31	2.25
Patuakhali	5.7	1	4	402	21	5	471	34	7	1.16	1.58
Dinajpur	81	12	20	382	126	25	468	262	36	1.24	2.08
Total/Average											
More Flooded	913	54	166	3067	1251	29	3183	2768	47	1.04	2.36
Less Flooded	793	46	151	3486	1375	28	3996	2973	43	1.15	2.09

Table 7

Comparison of Data on Seasonal Rice Production in More Flooded and Less Flooded Districts in Bangladesh (1000 tons)

Region	Total	Average 1980-85			Percent District Total		
		Aus	Aman	Boro	Aus	Aman	Boro
Bangladesh	14171	3126	7728	3317	22	55	23
Dhaka	854	177	361	316	21	42	37
Other	13317	2949	7367	3001	22	55	23
MORE FLOODED							
Bogra	648	115	387	146	18	60	23
Pabna	446	117	214	115	26	48	26
Faridpur	462	136	214	112	29	46	24
Comilla	1015	226	490	299	22	48	29
Tangail	505	100	191	214	20	38	42
Sylhet	1183	199	542	442	17	46	37
Mymensingh	1611	381	678	552	24	42	34
Jessore	568	184	304	80	32	54	14
LESS FLOODED							
Rajshahi	825	160	530	135	19	64	16
Noakhali	692	156	380	156	23	55	23
Barisal	720	176	450	94	24	63	13
Kushtia	222	133	81	8	60	36	4
Khulna	633	55	528	50	9	83	8
Rangpur	1292	297	876	119	23	68	9
Chittagong	917	144	457	316	16	50	34
Patuakhali	428	66	346	16	15	81	4
Dinajpur	703	182	490	31	26	70	4
More Flooded	6438	1458	3020	1960	23	47	30
Less Flooded	6432	1369	4138	925	21	64	14

Source: Statistical Yearbook for Bangladesh, 1987.

Rapid population growth appears to have begun about 1900 and to have accelerated after 1950; in specific regions, such as the Nepal Terai (the flatlands immediately along the foot of the mountains near the border with India), it has possibly exceeded 4.0 percent per annum. This undoubtedly places new pressures on available natural resources, but it does not directly translate into deforestation. In certain areas for which good documentation is available, deforestation in the hills and mountains was in full swing 200 years ago and appears to have peaked from the 1900s to the 1920s; natural reforestation plus reforestation by peasant farmer planting initiatives since about 1973-1975 has been well demonstrated in certain areas.

Landslide volume and frequency in mountainous Nepal are inversely related to population density (Ives and Messerli, 1989). The subsistence hill farmer frequently repairs damaged agricultural terraces, even to the extent of re-terracing entire landslide deposits. The effects of such repair have been documented by repeat photography in specific areas.

Much of the actual forest reduction since 1950 in Nepal has been on the flatlands of the Terai, which were cleared of malarial mosquitos at that time and subjected to more intense settlement. Tree removal has taken the form of commercial logging and clear-cutting for both planned and spontaneous farmer in-migration. Deforestation in such plains areas is a significantly different phenomenon from deforestation in the mountains.

Hamilton (1987) has drawn attention to the danger of assuming that deforestation is necessarily harmful without considering the mode of deforestation and the new use to which the cleared, or partially cleared, land is put. Thus, if forested hillslopes are replaced by well-maintained, terraced agriculture, the new use may be an improvement, in terms of soil conservation and regulation of run-off, over the original relatively undisturbed forest.

Concerning the downstream effects into the plains at long distances from the hills, it must be emphasized, first, that there is little available empirical data, especially long-term data, on streamflow and sediment transfer for any of the Himalayan tributaries or main streams. It is clear that natural sedimentation of the streams from the Himalayas, entirely independent of human settlement, is massive: Over geologic time such sediment has filled the Gangetic plain to depths of 2,000 m and more, and it has created a broad sediment fan up to 12,000 m deep extending into the Bay of Bengal well south of Sri Lanka.

Studies by Coleman (1969) show radical changes within a year (see Figure 10 for changes at various river cross sections during 1965-1966), or between several years, in the sediment movement in the Brahmaputra in Bangladesh. His work also shows, however, a remarkable stability in the broad range (13 to 19 km) of the braided river courses from 1830 to 1963. These data seem to support the general hypothesis that there is wide natural background variation but no secular trend in the sediment yields.

Partly because of the limitations of the data and partly from the direct analysis of limited data from the Teesta, Sun Kosi, Brahmaputra, and Ganges basins, Ives and Messerli (1989) concluded that there is no evidence to support any direct relationship between man-caused landscape changes in the Himalayas and changes in the hydrology and sediment transfer in rivers in the plains. The Himalaya-plains system is so vast and dynamic, dominated by such immense erosive processes from the geologically young mountains, that natural processes alone are adequate to account for the large-scale run-off and sedimentation patterns. Flooding is a naturally recurring phenomenon and is usually the result of torrential rain in particular areas. It would occur with or without a human presence in the northeastern subcontinent.

Locally, flooding and excessive sedimentation on the plains may be due to human intervention on the plains, but they cannot be attributed to the activities of subsistence farmers in the mountains. As attention is focused on progressively smaller watersheds, down to a few hectares, human impact undoubtedly can be more identifiable, but even the micro-scale periodic torrential rainfalls, or such specialized processes as the outburst of glacial lakes, are often more important than the negative effects of human activities.

This does not mean that soil conservation practices are either unnecessary or ineffective for specific and local purposes. That is an entirely separate issue, which should not be confused by unjustified macro-scale claims that a few million subsistence hill farmers are undermining the life support of several hundred million people on the plains. Forestation of mountain watersheds and extensive soil conservation measures are valuable for their own sake and may be vital for the well-being of the hill farmer. Analysis provides no basis, however, for foreign-aid agencies and national governments to invest in such activities to solve sedimentation and flooding problems on the plains.

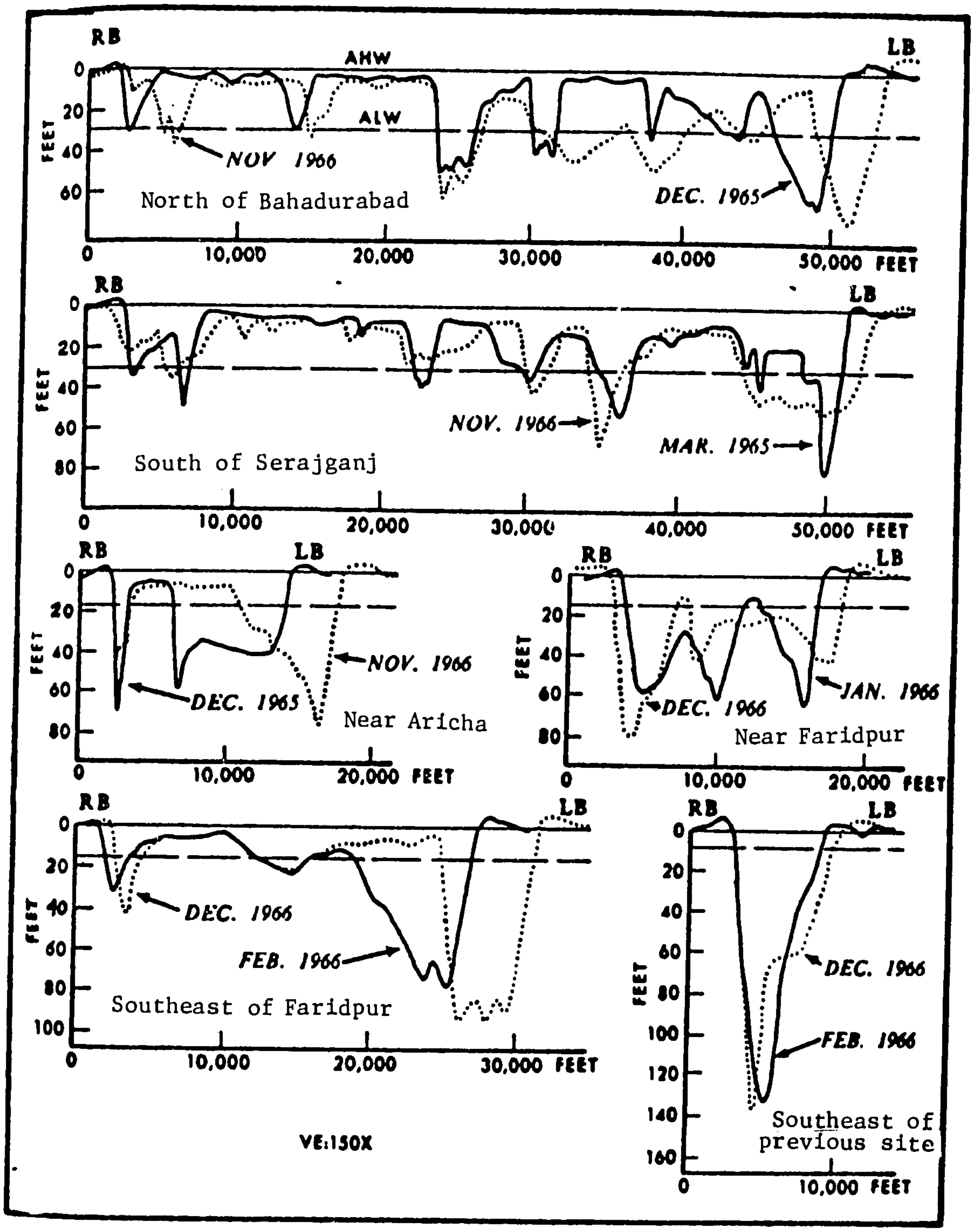


Figure 10

Comparative Cross-Section of the Brahmaputra River, 1965-1966

Source: Coleman (1969)

4.5.2 Upstream River-training Works

On the Ganges and Brahmaputra, and on many secondary rivers, India has constructed a variety of river training and diversion works. These types of works can cause local aggradation (raising through siltation) and degradation (lowering through scouring) of the riverbed directly downstream, although these effects rarely extend for long distances and thus as a rule do not significantly cross national borders. A potential rather than a current issue between India and Bangladesh on the Brahmaputra could be more important: Upstream embankments can increase the physical magnitude of the flows lower down the river, because peak water that was previously "stored" on land flooded upstream will, after embanking, remain confined in the stream and thereby raise peak levels downstream. A major embankment approach to protecting Assam from Brahmaputra flooding would, in principle, increase peak flows into Bangladesh. Downstream effects could also be a problem on the Ganges. For example, Sharma (1983) reports on severe erosion in India downstream of Farakka due to the reduction of sediment in the Ganges waters.

4.5.3 Global Change in Climate

Many climatologists believe that the global climate is warming, which would be expected to increase precipitation as well as temperature in this part of the northern hemisphere. Malik (1988) reports that computer models of the Commonwealth Scientific and Industrial Research Organization in Australia predict that the Eastern Waters basin would be wetter in the future if the greenhouse effect turns out to be real. The hypothesized temperature rise would increase snow-melt, which would cause increased spring run-off in the rivers and could lead to large increases in the mean sea level (up to 1 m by the year 2075). Malik projects that large parts of Bangladesh would go under water, depending on the predicted rise in sea level. As much as 15 percent would be inundated for a 1-m rise. If these projections do indeed turn out to be correct, then the long-term water problems in the basin will be much more difficult to deal with than currently imagined.

The hypothesized effects have not yet been convincingly demonstrated with real data in real locations, however. Even the 0.5 degree Celsius rise, which is asserted to have already happened during this century, is very hard to distinguish from statistical noise (non-trend variations) in the voluminous temperature record data. It is extremely unlikely that these effects have had any impact so far on the magnitude of the recent floods in Bangladesh. Water planners in Bangladesh, and elsewhere, should take careful note of developments in this regard, but immediate alarm in Bangladesh about the greenhouse effect appears to be very much premature.

4.5.4 Earthquakes

The earthquakes of August 6 and August 21, 1988 (Richter 5.6 and 6.7, respectively) in Bihar and Nepal have also been suggested as an exacerbating factor in the 1988 flood. No evidence has been presented in support of this, although in general water planning, seismicity cannot be ignored. Earthquakes, such as the major one in June 1950 on the upper Brahmaputra, can cause blocking of drainage and important changes in river courses and silt loads.

4.6 What Can be Done About Floods?

There are three basic approaches to limiting the damage of flooding. It is very likely that an actual flood management policy would be a combination of elements drawn from each, since this is a domain in which it is unhelpful to think in terms of single solutions.

The first approach, "flood reduction," attempts to decrease the amount of water in an area at a given time through surface or underground storage. The second, "flood diversion," attempts to channel a given flow of water away from specific areas through embankments or dredging. The third, "flood proofing," uses refuges and warning systems to limit the economic and social damages caused by floods without major investments in physical control of the floodwaters themselves.

4.6.1 Flood Reduction through Water Storage

For this approach, the fundamental question is "What quantity of water would have to be kept off the land in Bangladesh to prevent floods?" There are various methods of estimating this figure, and wide room for disagreement. Here, the approach is taken of working backward from the estimated 1988 inundation of 1 m of water over 66,000 km^2 (Caritas, 1988) for 15 days, to estimate that 66 billion m^3 of storage, the actual quantity of water outside the banks in 1988, could be expected to make a significant reduction of 1 m in the flooding depth. This number, however, is a first approximation. Flood mitigation depends on which one of many kinds of flood is targeted, where the water is to be stored, and the operating rules of the storages.

Upstream Storage

An approach often suggested for controlling the floods in Bangladesh, both in the popular literature and in technical reports, is building storage reservoirs behind dams on the mountainous upstream reaches of the major rivers or on their tributaries. To have the same effect in Bangladesh, however, storing water a thousand kilometers upstream in a multipurpose reservoir in Nepal would require significantly greater amounts of storage space than storing the water on the plains at or just above the site of the flooding in Bangladesh itself. The upstream stored water would first reduce the flood stages in the rivers flowing across the plains to Bangladesh. Water that now floods land on the plains in India would drain out into the rivers because of the reduced flows. The net effect of this could be little, or no, reduction in the flood peaks in Bangladesh.

Water storage is a powerful tool that can serve irrigation and hydropower generation as well as flood control. These purposes, unfortunately, are often in conflict with respect to the timing of the water releases and, on the other hand, the holding back of the water. The hydropower and irrigation interests argue for keeping the reservoir as full as possible to maximize the potential water and energy available from the reservoir; the people downstream who are at risk from flooding want to keep the reservoir as empty as possible during the flood season so that it has space to absorb excess water. In a monsoon climate these conflicts are magnified by the extreme wetness of the monsoon period and the extreme dryness of the subsequent dry seasons. It is unlikely, for example, even if there had been sufficient storage in the upstream reaches during the 1988 floods, that the power interests would have allowed the reservoirs to hold open enough flood storage space so late in the monsoon season as to abate the flood. Even in the best arranged systems within single countries, it is not always possible to resolve these conflicts in a satisfactory manner.

Surface storage reservoirs are a conventional technology, and several of the large dams of the world are located in the Indian subcontinent. A world-class-sized reservoir, such as the Bhakra Dam project in northwestern India, which holds 7 billion m^3 of water in live storage, is likely to cost in the range of $2 to $4 billion. The cost of similar storages in eastern India, Nepal, Bhutan, and China is likely to be significantly higher due to the fact that seismic activity in the eastern part of the Himalayan region would greatly increase the cost and complexity of the dam structure and foundation designs. Moreover, due to the extremely high sediment loads in the Himalayan streams, which would be deposited in the reservoir when the water loses its velocity, the total amount of storage originally provided to ensure a useful dam life of more than 50 years would have to be much larger for this region than in other parts of the world. The steep and narrow valleys of the Himalayan region also offer few large storage sites that could be developed with relatively low dams.

Estimating that as much as 66 billion m^3 of storage on the plains, or its equivalent in the hills, would be required to make a significant impact on a major flood in Bangladesh leads to the question, "Are these amounts of sto·age technically and economically feasible?"

There are few reliable estimates of potential upstream storages in the basin. Colombi (1988) cites the following possibilities:

Sites	Storage Volume (billion m^3)
Ganges in India	63
Ganges in Nepal	83
Brahmaputra in N.E. India	66
Meghna in Tripura	13
Total	225

Colombi also estimated that 50 to 60 years would be required to develop these storages, and that considering the competing demands for use of the storage space for irrigation and hydropower management, at best 20 percent of the capacity might be retained for flood storage in July and August. By September there would be tremendous pressure on the agencies operating the dams to reduce that to about 10 percent of capacity. This means that after massive dam construction cumulatively valued at about $60 billion, only about 22 billion m^3 of storage, for the most part far upstream, would have been available at the moment in the monsoon when the 1988 floods occurred. Colombi estimated a 0.4-m reduction in flood peak in Bangladesh as a result of this. Another expert

(Simons, 1988) estimates only a 0.2-m reduction in stage (flood height) for this flow reduction. These dams, therefore, would have to be primarily financially justified by the hydropower they would produce, not flood control. They could also significantly augment the low flows in the Ganges, but their flood control benefits are not sufficient to warrant their construction.

An important tool for assessing the usefulness of flood reduction efforts is the "stage-discharge curve," that is, the relationship between the flow and the elevation of water in a riverbed. Figure 11 shows such a curve for the Padma River at Goalundo, just south of the junction of the Ganges and the Brahmaputra. Note that the height of the water remains essentially unchanged over a very large range of flow. As the flow increases from 28,300 to 99,100 cumecs, the stage of the river rises only about .3 m. This relatively unchanging height (stage) of the river in the face of additions or subtractions of very large volumes of water is due to the fact that as more water enters the river, the channel's carrying capacity increases through an increase in the velocity of flow made possible by the smoothing out of sediment dunes on the river bottom. Under these conditions, flood reduction projects designed to reduce the depth of the flood by withholding water are not likely to be very effective over substantial parts of the flood flow curve.

As an example, studies done by Simons (1982) indicate that for the combined Ganges and Brahmaputra in Bangladesh, the reduction of stage within the main channel for a decrease of 5,100 cumecs in flood discharge would be on the order of only 0.1 m. Unfortunately, however, this is not the whole story because these rivers exhibit some unusual behaviors. Figure 11 shows that the 100-year flood stage (about 148,000 cumecs here) is a full 2 m higher than the curve. The stage rises only 0.15 m from 56,600 to 99,000 cumecs, but it rises 2 m for an additional 42,000 cumecs. Clearly, some highly nonlinear behavior is exhibited by these rivers at high stages. This simple example indicates the need to carry out extensive field studies on these rivers before any construction causing changes in stage is contemplated.

Underground Storage

Underground storage is of particular importance for two reasons. First, in its primary effect it creates water availability in the dry season, and thus, apart from its flood mitigation benefits, it is a low-flow augmentation measure. Second, it is already being put into practice in the region on a large and growing scale.

The Top Aquifer. Underground storage results automatically, in a certain sense, when farmers plant dry season crops and use tubewell irrigation. The water that they pump up in the dry months creates space in the top aquifer (lowers the water table), which is refilled (recharged) each year by natural seepage in the water-abundant monsoon summer months. A large fraction of the water used for irrigation in the dry season is evaporated on the surface either directly or by transpiration through the leaves of the crop and is a true subtraction from the local water balance. The wet season seepage into the aquifer that refills the underground space created by dry season pumping and evaporation is a subtraction from flood flows and, in principle, serves to moderate floods.

With large-scale dry season tubewell irrigation, recharge can be a very large factor indeed. In Gangetic India it now probably amounts to 100 billion m^3, that is, on the order of one-quarter of the annual river flow in the Ganges, and it can be expected to double in the next several decades. Bangladesh is estimated in the National Water Plan to have 17 billion m^3 of annually rechargeable groundwater available for tubewell use, which in principle means that monsoon run-off will be diminished by a similar amount. This latter storage is of particular value because it is geographically close to the flooding that needs to be reduced. However, underground storage has the liability, at least at present volumes, that the recharge probably generally takes place rapidly at the beginning of the monsoon and, with the water tables full again by the end of July, little underground space is available to relieve excess late season flows. Recent serious floods in the region, including those of 1987 and 1988 in Bangladesh, have come very late in the season, but it would be premature to say that the spread of tubewells in the Gangetic plain has moderated or ended early monsoon floods.

Underground storage could be increased by special actions to withdraw more water in the dry season or to speed up its reentry into the aquifer in the wet season (artificial recharge). Investments for these purposes have been proposed (Revelle and Lakshminarayana, 1975), but this report considers only the effect of dry season irrigation operations carried out for their own benefit by farmers in the Gangetic plain.

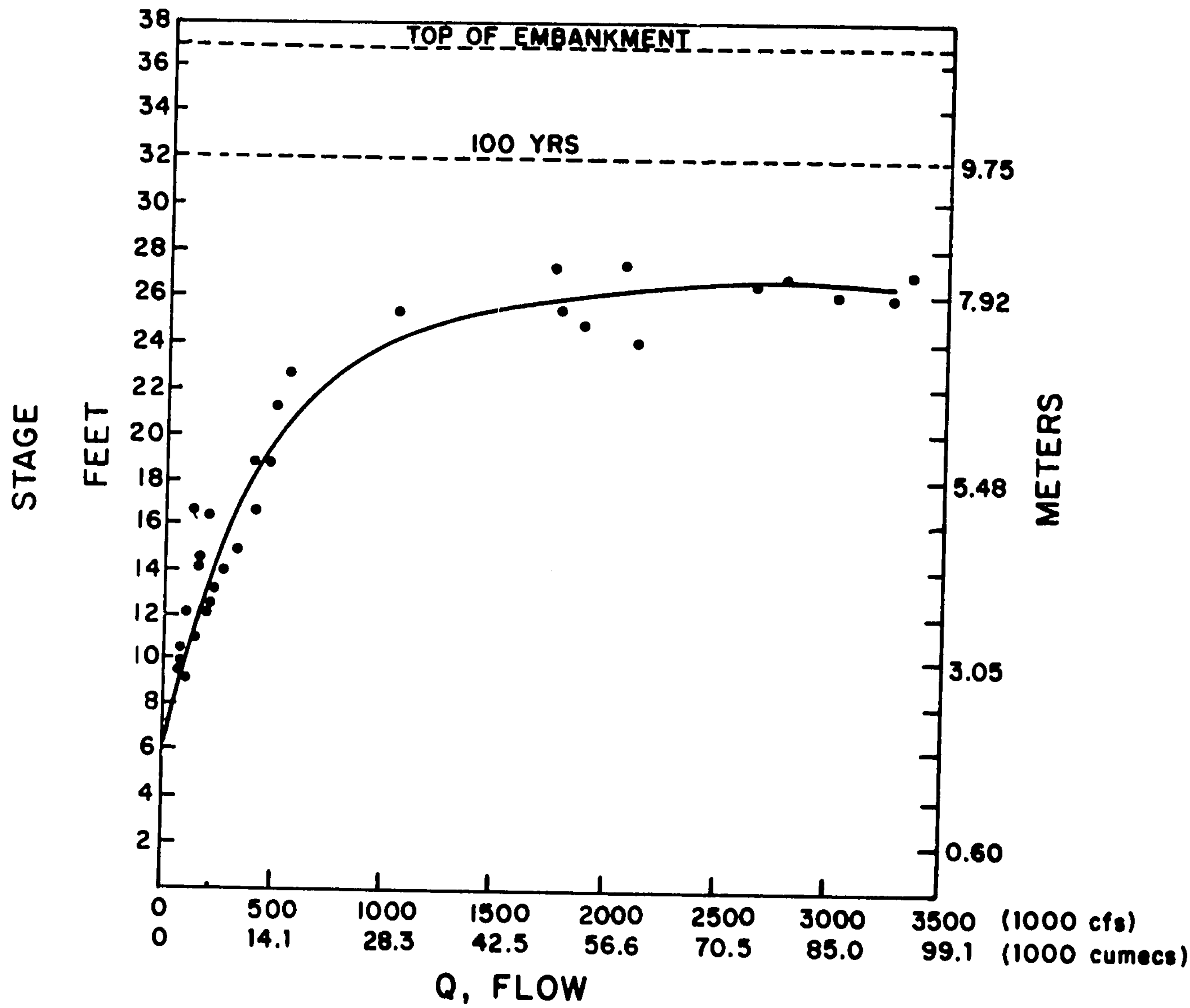


Figure 11

Stage-Discharge Curve, Padma River

Source: Simons (1988)

Continued large-scale expansion of underground storage, however, will require large amounts of additional energy to pump the water, and the main prospective increase in power availability in the region stands to come from development of Himalayan electricity. This kind of underground storage involves a beneficial mixture of government investment and private investment. In other words, if the hydropower infrastructure investments are secured by the government, then the private actions of the individual upstream farmers could lead to large, positive external effects in reducing flooding downstream.

The Deep Aquifers. A second subsurface storage approach relies on recent findings in plate tectonics to propose a truly innovative step. One effect of the Indian subcontinent's continuing movement (about 5 cm/year) under Tibet is the gradual pulling down of the "Bhabar" zone in the Terai at the foot of the Siwalik mountain range. The Bhabar geological zone of large boulders is a band 6 to 8 km wide that runs the entire length of the Himalayas. It has been widely known for some time (Charles and Dutt, 1982; Dutt, 1971) as a zone of extremely rapid groundwater recharge, but only recently oil and gas drilling (Jones, 1986) in the Ganges basin has revealed that it is at least 1,800 m deep and that it contains fresh water to those depths. Jones (1978) has suggested that the deep aquifers on the Ganges plains be exploited for irrigation during the dry season, and in 1986 he identified the Bhabar zone as the source of recharge of the deep artesian aquifers. Jones (1988) suggested that the Bhabar zone and the deep aquifers could be operated together to provide significant flood storage in addition to irrigation. This could be achieved by recharging the previously depleted Bhabar zone from the monsoon flows of the Himalayan rivers. This approach is still in the conceptual stage, but it appears attractive because it provides dry season water as well as mitigates the floods.

Surface Storage on the Plains

Constructing large surface storages on the plains themselves is an option that has never been seriously explored in the Ganges-Brahmaputra basin. It is only remotely likely to be applied in such a densely populated terrain, but it merits some consideration by Bangladesh. There appear to be two approaches to this option.

The first approach suggests that the areas that are flooded frequently be used to store additional floodwaters. For example, in northeast Bangladesh's Sylhet depression, flooding of up to 6 m in depth is annually experienced over a wide area. If a low embankment 1.5 m high was built around the area, as much as 3 billion m^3 could be stored additionally in that depression. This is equivalent in active storage volume upstream to a very large reservoir. Similar surface storage could be developed in the Chalan Bil and Faridpur areas in Bangladesh and in frequently flooded sites in Assam, Bihar, and West Bengal. Such storages could provide up to 20 billion m^3 of storage on the plains, which could help mitigate some of the worst flood damage, particularly when carried out in combination with other flood mitigation methods.

The second approach could be new construction of embanked enclosures on the plains where deep flooding is not an annual occurrence. No data are available on the potential costs of these storages, but it is known that the Chinese have for a long time constructed such relief storage to avoid embankment overtopping. For example, one such storage basin of 1,000 km^2 with a storage of 7 billion m^3 was constructed on the plains in the Yangtze basin in 1955 in 75 days time with a labor force of 330,000. Such economical surface storages could have significant benefit in addition to flood control: With planned flooding of an area, large fisheries can be developed; during the winter, stored water could be released for downstream irrigation; and finally, when the storage is drained, a crop could be grown on the residual moisture in the area.

4.6.2 Flood Diversion Approaches: Embankments and Drainage Improvements

Embankments

The oldest approach to flood diversion is to build embankments around the area to be protected or along the rivers threatening floods. Embankments have been built extensively worldwide for millennia, including on the Mississippi. They are widely used in Bangladesh and in parts of the plains in eastern India threatened by floods, particularly Bihar, Assam, and West Bengal.

There are several conceptual approaches to embankments. The first is to attempt to ensure that the river never overflows its banks anywhere along its length. The second is to allow the river to overflow into areas not considered to be important and to embank the remainder of the river. This allows for lower embankments in the downstream reaches of the river. The third approach is to provide embankments only to protect areas of particular concern such as cities and industries, in which case the actual length and the height of the construction works are much less than for full river embankments.

In Bangladesh, another type of embankment has been under continual development since the end of the eighteenth century and for a purpose quite distinct from the control of river/rainfall floods. These are the coastal embankments designed to protect coastal farmland and habitations against tidal storm surges. These surges can be of two main types: those due to the regular effects of monthly tide cycles and exceptional surges due to storms in the Bay of Bengal. Surges can range from about a meter of seasonal rise during the monsoon to sudden rises of 6 to 9 m due to cyclonic activity in the Bay of Bengal, often experienced in October or November. The low embankments are of little or no use against these latter surges, and the population has to rely on storm warnings and shelters on high ground for its protection. The odd-shaped 5,791 km of the coastal embankments of Bangladesh are generally effective, however, and in the magnitude of the works themselves can be considered one of the important engineering achievements of man.

The most important requirement for the successful employment of earth embankments for flood control (assuming correct design, construction methods, and materials) is careful maintenance. This amounts to continuous supplementing and rebuilding of the earthworks because they tend to settle as their foundations become saturated (and can be totally lost if significant seismic activity occurs). In the lower reaches of the Mississippi River, annual maintenance costs exceed $1 million per river mile when the cost of providing river training is included. The cost of maintaining the embankments themselves is trivial compared with the provision and retrofitting of the river-training works.

If, as in the case of Bangladesh, the rivers carry large sediment loads, the embankments must be periodically raised in height as the riverbed rises due to sedimentation within the embankments. This may eventually be seen as too large a commitment of resources and as too great a risk for the population, which may eventually end up living at elevations below the level of the riverbed itself. Such considerations finally led the Chinese to modify their reliance on embankments as the sole means of providing flood protection against the Yangtze and Yellow rivers on the plains.

Numerous other difficult problems and drawbacks are associated with embankments. Upstream embankments, for example, if built on the Brahmaputra in northern Bangladesh, would keep water in the river that otherwise would spill out and be stored in the flooded areas. This channeled water increases the flood stage that must be embanked or otherwise managed downstream in the districts of the country closest to the sea. Embankments also make it very difficult to give the beneficial "normal" wet season waters access to the land, and they block drainage from the lands bordering a river into the stream, so that often rainstorm flooding takes place behind an embankment and can be very difficult to relieve. Moreover, rural population densities in Bangladesh are such that people must inevitably live close to a river, on the river side of the embankment. For them, it is expected that the embankment would increase the danger of flooding. A study by Stewart (1989) of two samples each of 300 households, one inside the Meghna-Donagoda embankment and one outside the embankment, in October and November 1988 found, however, that the average material damage was worse inside the embankment. In other words, the flood-protected people suffered worse flood damage than the people without flood protection. This often happens in Bangladesh because the drainage after the flood is much more rapid on the river side of the embankments than in the protected areas. To avoid this type of problem, pumped drainage must be installed inside the embanked area, which is very expensive.

Embankments also create serious problems with fisheries. Not only are the spawning areas for the fish cut off, but the juvenile fish that survive do not have easy access to the rivers and estuaries. The importance of this impact cannot be overestimated because fisheries provide over 70 percent of the animal protein in a typical Bangladeshi diet, support over 1 million fishermen (an estimated 73 percent of rural households undertake some sort of fishing each year), and are a major and growing source of export earnings.

Because in a setting such as Bangladesh the rivers are very dynamic, shifting laterally over short time periods, under normal practice it would be necessary to set the embankments back a considerable distance from the river channels. A program would also have to be in place that permitted rapid changes in the alignment of the embankments in order to avoid loss through channel migration. The embankments would require stabilization and, considering available methods of achieving the degree of stabilization required, initial construction costs and permanent maintenance costs would be astronomical. In order to provide significant flood protection by embankments along the main rivers, the crest of the embankments would have to be maintained at about 7 m above mean sea level at the junction of the Padma and the Meghna. Bangladesh's National Flood Protection Program (1988) estimated that this could be achieved at a capital cost of $6 billion. Annual operating costs could be estimated to be on the order of $600 million.

Several flood mitigation proposals now under study by the government call for the construction of large-scale river embankments in Bangladesh. It is extremely unlikely that economic benefits to Bangladesh remotely sufficient to justify the investment and recurring costs of embankments could be shown, and even more unlikely that embankments would be the best use of Bangladesh's extremely limited domestic, or even foreign-donated, resources.

Drainage Improvements

In many cases floods can be abated by the improvement of the drainage system. This is the case in rivers that carry large sediment loads that are deposited in the river channels during flood recession, which increases subsequent flood stages in the river channels. Drainage can be improved by dredging the deposited material directly from the river using large hydraulic dredging machinery. In Bangladesh, however, the quantities of sediment that are transported and deposited by the rivers coming from the Himalayas each year are so immense that it appears unlikely that any serious headway could be made by moving the deposited sediment by mechanical means. For example, it is estimated that the annual throughput of sediment by the main rivers to the Bay of Bengal is about 2.5 billion tons, in the form of suspended sediment and dunes and sand bars that move along the bed. As an example of the cost of dredging in a much less sediment-laden river, the U.S. Army Corps of Engineers spends $10 million annually to keep the navigation channel open at the mouth of the Mississippi River.

There is some possibility, however, of clearing the drainage of the distributaries in the delta, which could relieve some (albeit a small amount) of the drainage congestion farther downstream. For example, dredging the mouth of the Arial Khan and the Gorai rivers could reduce the flow downstream in the Padma by up to 2,830 cumecs. Similar dredging could route 2,830 cumecs around the junction of the Brahmaputra and the Ganges by way of the Old Brahmaputra channel. These by themselves are large numbers, but they are small in relation to the 99,000 to 148,000 cumecs flowing in the joined Ganges and Brahmaputra in the flood season.

As mentioned above, much of the flooding in the lower reaches of the basin is due to heavy rainfall being unable to drain quickly off the land. Improving land drainage is extremely important in deltaic settings. In Bangladesh every effort should be made to ensure that no obstacles are placed in the way of the natural drainages. This means that road and railway embankments need to be carefully designed with drainage culverts of appropriate size. The Government of Bangladesh conducts a large number of earth-moving projects, including canals and drainages, each year in its Food for Work Program, largely using food to pay unemployed villagers for their labor. These works tend to be organized and designed on a very local basis, with as much stress on their food relief aspect as the value of the works achieved. The study team sent by the United Nations Development Program (UNDP, 1987) judged such local drainage works to be damaging to the general flood drainage in the 1987 flood more often than they were helpful. It is important that local projects, at a minimum, be reviewed by engineers for their fit into larger drainage patterns so that their contributions will be positive. Similarly, at the next level down, coordination among the land owners in a region is highly desirable to ensure that farm drainages complement rather than obstruct the wider drainage pattern.

Much of the effort in drainage improvement would go toward improving the natural drainage system, but it may be possible to identify places where man-made flood bypasses could be constructed. For example, in Bangladesh the right bank of the Padma is a naturally low-lying area and could be made into a flood bypass by a small amount of excavation and river-training works. It may also be possible to construct drainageways such that the floods bypass the capital city of Dhaka. No detailed engineering studies are available to assess the costs and the benefits of these types of works, however.

General Considerations on Diversion Strategies

Flood depth and duration are not the only, or perhaps even the major, cause of flood damage. A good part of the damage of a flood is caused by the energy of the flood, primarily the velocity of the flow of water. Thus, the farther away from the main channel the flood is, the less its energy content and destructive force.

Flood diversion projects tend to be more reliable and, therefore, effective the more they are designed to control the depth of water and the less they are designed to control the energy of water. This is because the structures are subject to destruction by the same massive energy forces they attempt to divert. It is a liability of the diversion approach that the potential benefit of the facilities is highest in the most flood-energy damaged areas, just where the reliability and effectiveness of the facilities are likely to be the lowest.

An excellent example of this is an area along the east bank of the Padma, near the town of Chandpur. The Padma has been migrating eastward for several years and endangering the Chandpur irrigation project area. A series of dikes have been erected to alleviate this threat. If effective, these dikes would have very great benefits. However, in 1988 the Padma in a few days moved its channel 550 m eastward, where it dug a new channel 45 m deep. The probability of effectively controlling the Padma at this location is virtually zero.

Figure 10 above shows how the rivers in Bangladesh can change their channels by very large distances and great depths within one flood cycle. For example, at the section southeast of Faridpur, the river moved its bank laterally 1,500 m and dug a new channel 30 m deep (moving about 100 million tons of sediment per river mile) over the period February to December 1966.

Flood diversion projects also have the inherent disadvantage that they simply move the water from one place to another place in the system. Although it is the goal to move the water from a place where it does greater damage to one where it does less, actual outcomes are very difficult to predict in a large, complex, and poorly understood hydraulic system. The erosion problems cited above, for example, could have been caused by upstream works.

Thus, the benefits of flood diversion projects at one site are often offset by costs at another site, and it is very difficult to know which is greater. In Bangladesh, farmers who are disadvantaged by flood diversion embankments commonly destroy their effect by cutting openings in them, no matter how beneficial the structures may be to others.

Because of the unpredictable and episodic (stochastic) nature of floods, all estimates of benefits from flood control investments must be in the form of mathematical expectations, a highly technical subject, which is only illustrated here. Assume, for example, that a flood control project is designed to prevent the damage of a once-in-25-year flood, estimated at $10 million. To estimate the current value of this project, its benefits must be put on an annual basis. The probability of this flood in any given year is 1 out of 25, or 4 percent. Thus, the mathematical expectation of annual benefits is $400,000. At a discount rate of 15 percent, the current value of this stream of benefits is about $2.64 million, that is, although a flood may do $10 million in damages, a control project costing more than $2.6 million is not economically justifiable.

Reviewing flood reduction and diversion investments, which by their nature are almost always large investments, it may be said that, in principle,

- Flood reduction (storage) programs usually can only be justified in terms of other benefits, such as irrigation and hydropower.
- Flood diversion projects are most feasible when they are designed to control the damage due to the depth and duration of floods, not the energy of floods.
- The mathematical expectation of benefits makes the return on flood control projects smaller the lower the frequency of the floods. Since the most severe floods are also the least frequent, the apparently high benefit of reducing or diverting severe floods is greatly reduced by their low mathematical expectation.

Urban Protection

Ring dikes could be effectively utilized to protect intensive land uses, such as important cities and public works. This method of providing local protection would be more cost-effective and more easily maintained than an overall flood control program seeking to improve conditions in all of Bangladesh. A ring dike to protect the city of Dhaka has been suggested many times and is feasible from an engineering sense, but it would still require large sums of money to complete the project and maintain it.

4.6.3 Flood Proofing

The Bangladesh National Water Plan addresses most of its flood control and drainage projects to small embankments and submersible dikes in the higher, low energy, regions of the floodplain and by avoiding river-training projects, for the most part. In addition, although it is also considering flood diversion embankments, the Bangladesh government is wisely planning to alleviate flood damage to the population by improving warning times and creating elevated refuges near villages, which will be equipped for providing food and medical services to people. The cost-effectiveness of these individually small, "soft" measures, which fall in the category of "flood proofing," is much greater, both in terms of human welfare and economics, than "hard" attempts to control these powerful rivers. The Government of Bangladesh endorsed numerous flood-proofing policies in its "Guiding Principles" on flood management (see Chapter 6), which was promulgated in November 1988.

Most of the flood-proofing approaches are already in use, or under consideration for use, in Bangladesh and the other flood-prone areas in the region. They typically rely on low capital, certainly low foreign-exchange, costs and a high level of public participation and management inputs. In its actual emergency flood responses, Bangladesh has performed with distinction, and the army in particular has brought its planning capacity, discipline, and tight organization to bear with great effectiveness. There is no shortage of challenges or of room for growth in this approach because at its upper end the type of management required can make use of high-quality data, rapid communication, and intensive coordination between agencies, which are difficult to develop in any country.

In the category of flood precautions, moving flood-sensitive goods (e.g., electric motors) from the ground floor to higher levels, putting new buildings on stilts or plinths, building dikes around individual structures, replacing the local building materials with more flood-resistant materials, and building low bunds around sensitive crops are some of the myriad flood-proofing methods currently in use in the region.

After the flood of 1988, villagers reported, with gratitude to the government, that it was the Public Works Department's paved roadways, customarily elevated 3 or more meters above the surrounding fields, that had served as their havens. In the villagers' minds, the elevated roads were the reason that actual drowning deaths were extremely rare. Through its relatively new decentralization of government, which concentrates both resources and decisional autonomy at the lowest administrative level—the *upazilla*, a unit with about 250,000 people—the government could well review the distribution of such natural or constructed elevations over the flood-prone parts of the country and ensure that the entire population in high flood-danger zones has access to them and that there are provisions for taking tents, clean water, and antidiarrheal rehydration solutions to the elevations at the time of floods.

To supplement, as needed, roads and railway embankments, raised flood refuges could be built with local labor and be provided with temporary shelter, flood supplies, medicines, communications equipment, and the like, similar to the cyclone shelters that are available in many of the coastal areas. The cyclones of October 19 and November 29, 1988, would have been much greater disasters if a cyclone protection program had not been implemented in the coastal districts in the late 1970s.

An important aspect of flood proofing is the adjustment of crop calendars. This practice is currently followed in those parts of Bangladesh where submersible embankments have been utilized to delay flooding for a few weeks to enable the *rabi* (winter) crop to be harvested before the land becomes flooded in the spring. The crop calendar (an example is shown in Figure 12) could also be expanded to include entirely new crops or new rotations depending on what other technical options are used to deal with the floods.

Flood warning systems are already in place and are used in the flood-prone areas of the basin. In conjunction with the Joint Task Force formed in the fall of 1988 at the request of President Ershad of Bangladesh, India has volunteered to set up a quicker-response system of flood warning with Bangladesh and to assist with the necessary computer programming and flood modeling to make rapid use of the data. This can make a very large contribution to mitigating flood effects, and it appears to be an area of fruitful international scientific exchange both among the countries in the region and the rest of the international community.

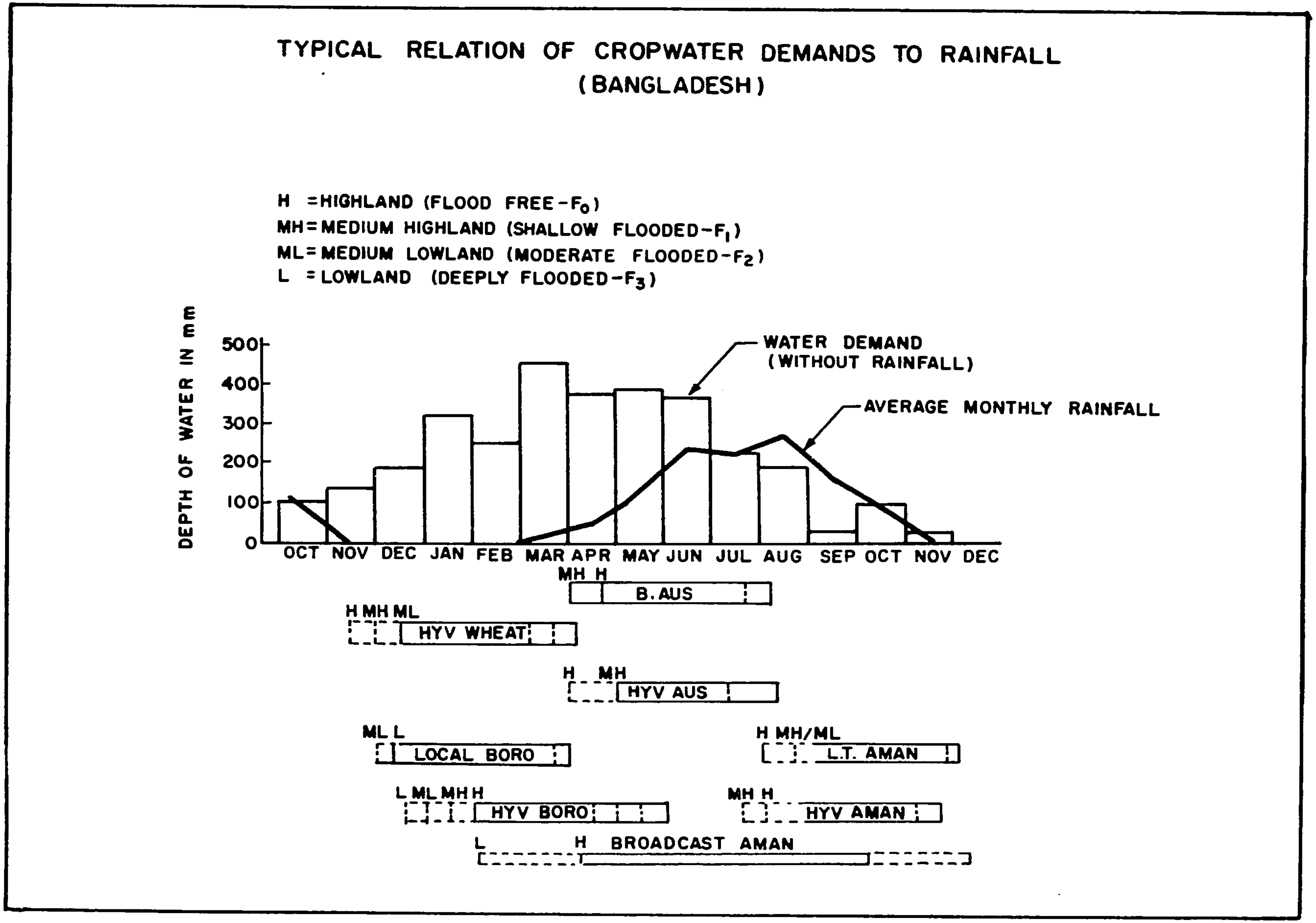


Figure 12

Crop Calendar, Bangladesh

Adapted from National Water Plan (1986):28, Figure 9.

Finally, floodplain zoning should be utilized to limit future exposure to flood damages. Floodplain zoning is very effective in many industrialized countries, where insurance incentives are created to get people and industries to move out of the flood-prone areas. Due to the density of settlement in the lower part of the basin, including Bangladesh, it may be difficult to implement floodplain zoning because many of the land users do not have options to locate anywhere but in the floodplains.

5

THE DRY SEASON, LOW FLOWS, IRRIGATION, AND AGRICULTURAL DEVELOPMENT

5.1 Low-flow Augmentation Approaches

The storage approaches outlined in Chapter 3 combine low-flow augmentation with flood mitigation and usually draw most if not all of their economic justification from their dry season service. In addition, three approaches are specifically aimed at low-flow augmentation. These are (1) interbasin transfer, (2) the use of floating pumping stations on the Brahmaputra in Bangladesh, and (3) the local exploitation of groundwater recharge in Bangladesh solely for dry season irrigation. (A fuller description of these options is given in Rogers, 1989.)

5.1.1 Interbasin Transfer

Several versions of proposed interbasin transfer arrangements aim to augment the low dry season surface flows in the moribund (drying out), western part of the Ganges distributary system, which straddles the India-Bangladesh border (see Figure 13). This goal is an extension of the purpose that motivated construction of the Farakka Barrage in the 1960s and 1970s. The barrage at Farakka now diverts Ganges water to the western side of its distributary system, keeping the water within India for the purposes of Calcutta, the major city and port.

Dry season Ganges water continues to be scarce, perhaps increasingly so, with the continued large demand for it in the upstream agricultural plains of Uttar Pradesh and Bihar. Since the construction of Farakka, India and Bangladesh have agreed to seek ways to augment low season Ganges water, which both countries believe is insufficient for their needs.

The interbasin transfer proposals arise in this context; they seek to transfer a portion of the Brahmaputra's water into the lower Ganges basin. The transferred Brahmaputra water would provide more surface water to the port of Calcutta in India, or in the case of Bangladesh, to the Khulna/Sundarbans southwestern section of the country, which adjoins the Calcutta region. On both sides of the border, this area is believed to suffer from siltation and salination attributed to inadequate river flows.

Three possibilities are commonly discussed:

1. canal transfer of 2,830 cumecs of Brahmaputra water from Assam to West Bengal through Bangladesh, or

2. the transfer of water from the Brahmaputra to the Ganges entirely within the boundaries of Bangladesh, and possibly,

3. transfer of Brahmaputra water from Bangladesh to India from headworks and canals entirely within Bangladesh.

The first of these is India's proposal to Bangladesh to meet the requirement to augment the availability of water in the dry season (Ministry of Agriculture and Irrigation, 1978). It is linked to India's proposed construction of major reservoirs and hydropower facilities on the Dihang and Subansiri rivers, high on the Brahmaputra system, and at Tipaimukh on the Meghna. For India, it is a way to reclaim what many Indians believe is its share of the use of the water-abundant Brahmaputra. They perceive the Brahmaputra as one-third of their national river water resource, and the only large part not yet threatened with exhaustion by a need for water (including urban drinking water), which is increasing throughout the country with economic development and population growth. Even after the diversion of 1,100 cumecs by the Farakka Barrage (which was reduced to a diversion of 58 cumecs in the driest weeks, according to the Indo-Bangladeshi agreement

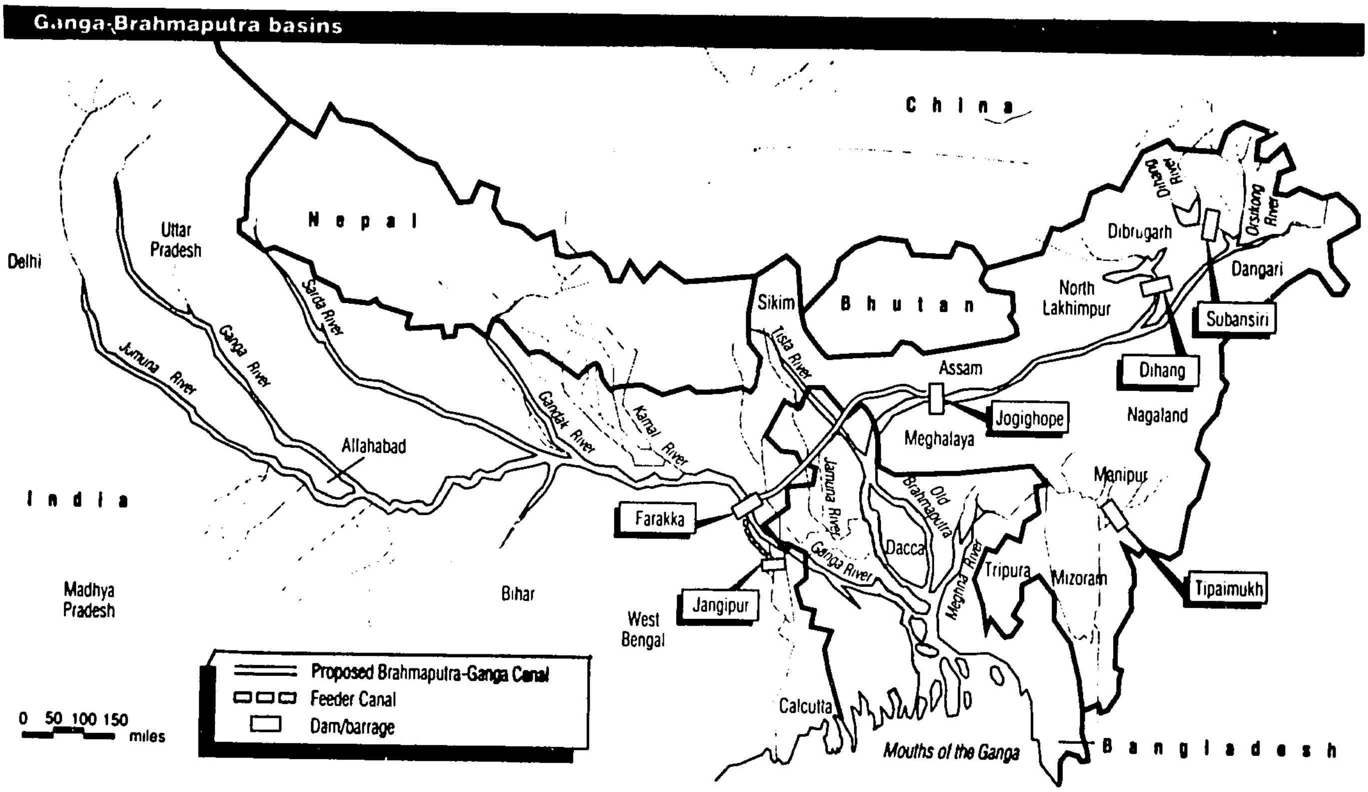


Figure 13

Proposed Ganges-Brahmaputra Interbasin Transfer Arrangements

Adapted with permission from Far Eastern Economic Review, 2 February 1989: 20 (Andy Tang).

that was in force between 1979 and 1988), the Calcutta port is seen to be in need of more water. An additional eastern source, in India's outlook, would release additional Ganges water for irrigation from the river upstream in Uttar Pradesh and Bihar. Indeed, in the relatively long-range future, India may want to consider testing conceptions, long discussed in futurist circles, of long-distance transfers of water from the northern to the dry middle and southern parts of the subcontinent. A transfer of Brahmaputra water into the Indian Ganges basin could serve as a first step in such a plan.

As discussed in Chapter 3, Bangladesh regards such a canal as an invasion of its independence and sovereignty. It has been adamant in its opposition to it, both publicly and in discussions of the Joint Rivers Commission. Bangladesh, however, is left with its bitter complaints about the desiccating and salinating effects in its southwest quadrant of India's Farakka withdrawals from the Ganges. Dhaka has therefore talked about transferring Brahmaputra water from within Bangladesh to that region by means of a diversion canal at about Bahadurabad, which would move water to the Kushtia region of the Ganges through a combination of canals and river courses; this conception is reflected in transfer option 2 above.

It is possible that from such a transfer arrangement within Bangladesh, water could be sold or traded into the Calcutta region, thereby helping to meet Indian needs in West Bengal, but without the threatening implications for Bangladesh of a canal through its territory "controlled on both ends by India." This is option 3 on the list above.

Options 2 and 3 are essentially answers to the challenge of the first, Indian, idea. Engineering studies that may exist for any of these possibilities were not available to the study team, and all of the options must be considered complicated and costly propositions that, on face value, would be difficult to execute technically and even more difficult to justify economically.

All these transfer proposals and the conflict that is associated with them are products of the outlook that concentrates on surface water to the exclusion of tapping the groundwater resource. Especially in the case of the long-distance, 2,830-cumec canal with several river crossings proposed by India, it is an open question whether transfer headworks and canals can be completed at anything approaching a cost that is in reasonable relationship to the benefits to be obtained. It may prove that the decade's tension between the two countries on this subject was unnecessary. There has been no public engineering and cost comparison between bringing water into the drying southwestern quadrant of the Ganges estuary by the interbasin canal transfer method discussed here and the more dispersed method of obtaining functionally equivalent water by tubewells from the aquifer below the locations where the water is actually used, whether in Uttar Pradesh, Bihar, west Bengal, or the Khulna region of Bangladesh. Nor has there been evidence of consideration of testing and tapping deeper, potentially artesian, aquifers.

An entirely separate potential interbasin transfer, which has received little notice, is to divert water on the Tibetan Plateau from the Brahmaputra (there called the Tsangpo) to the Ganges via the Kali Gandaki. This option was discussed by Sharma (1983). The difference in elevation between the beds of the two rivers is very small in Tibet and the watershed-dividing ridge between them is narrow (approximately 30 km) and only 75 m high. These are well within the limits of modern engineering technology. Sharma suggests that in geological time the Kali Gandaki may have been the outlet of the Tsangpo. The advantages of this diversion are that the engineering cost would be small and that, in addition to augmenting the low flow of the Ganges, substantial amounts of hydropower could become available close to the Indian load centers on the northern grid. The main disadvantage would be that three countries, China, Nepal, and India, would have to come to agreement on a project. Unfortunately, few data are available on the flows in the Brahmaputra (Tsangpo) in this area or the availability of suitable diversion and storage sites. It might turn out that with sufficient storage and large enough flows, substantial local power production and some flood relief downstream on the Brahmaputra could be obtained. This diversion arrangement is a candidate for study and suggests taking a careful look at using the Kosi for similar purposes.

5.1.2 Floating Pumping Stations

A technical proposal for augmenting the low flows in the system in Bangladesh during the dry season has been discussed for some time in Bangladesh (National Water Plan, 1986): to take irrigation water from the flows of the Brahmaputra, which cannot be diverted by conventional methods without great expense, by using large floating pumping stations. Preliminary analysis (Seckler and Molder, 1989) indicated that for irrigation use on the margins of major rivers, this proposal may not be economically viable. It appears that the lands that would receive pumped water from the river can get it more efficiently from tubewells drilled at their immediate locations. For diversions out of the immediate basin, however, these pumping stations may be more economical per unit of water delivered than competing surface water proposals. This concept needs further study.

5.1.3 Local Underground Storage

It is known that groundwater recharge conditions are favorable throughout the alluvial basin in Bangladesh (National Water Plan, 1986: Summary Report). Under present conditions, however, much of this potential recharge is rejected as the available groundwater storage fills before the end of the recharge season. Hence, a program such as outlined above for storage development in the shallow aquifer (section 4.6.1) could be implemented in Bangladesh, and substantial amounts of water could be made available for dry season irrigation. The National Water Plan (1986) estimates that, by expanding tubewell pumping use to its practical maximum, as much as 17 billion m^3 of additional water storage could be made available for irrigation and low-flow augmentation each year in Bangladesh.

5.2 Overview of Agriculture in Eastern India

The agricultural situation in eastern India has been thoroughly analyzed in a two-volume report by the Reserve Bank of India (1984), under the chairmanship of S.R. Sen. This is the definitive current work on the subject, and it is as relevant to the Eastern Waters region as a whole as it is to eastern India.

Eastern India historically was the country's most productive agricultural region, but it has failed to keep up with other regions in adopting modern methods and organization and is now the least productive agricultural region of India (Table 8). In 1950-1951 eastern India had the country's highest average foodgrain yields; in 1980-1981 it had the lowest, except for the very arid western region. Relative backwardness on the output side is predictably associated, as shown in Table 9, with the low use of modern agricultural inputs, in which the eastern region is substantially below the others.

Table 8

Trends in Foodgrains Yield, India

State/Region	Triennial average (kg/ha) 1950-51	1960-61	1970-71	1980-81
West Bengal	916	949	1170	1290
Orissa	540	758	839	779
Bihar	513	714	820	914
East Uttar Pradesh	673[a]	694	822	957
Eastern Region[b]	644[c]	765	897	970
Western Region[d]	390	524	551	649
Southern Region[e]	554	731	897	1149
Northern Region[f]	608[g]	788	1150	1493
All India	541	671	820	975

[a] For Uttar Pradesh as a whole.
[b] Includes West Bengal, Orissa, Bihar, and East Uttar Pradesh.
[c] Includes entire Uttar Pradesh; separate data for East Uttar Pradesh are not available.
[d] Includes Maharashtra, Gujarat, Madhya Pradesh, and Rajasthan.
[e] Includes Andhra Pradesh, Tamil Nadu, Karnataka, and Kerala.
[f] Includes Punjab, Haryana, and Uttar Pradesh (excluding East Uttar Pradesh).
[g] Excludes Uttar Pradesh.

Source: Reserve Bank of India (1984).

The Sen report correctly identifies three primary and highly interrelated causes for the backwardness of this region: (1) deficient public sector investments, (2) lack of adequate water control, and (3) deficient public and private institutions. The report shows that public investment per agricultural worker in the eastern region has been only about one-third of the investment in the highly favored northern region through the four plan periods of 1969-1985. The problems of eastern India reflect one of the major development lessons of India: that vigorous private sector development requires large-scale public sector investments in transportation, energy, research, and other infrastructural support systems.

Table 9

Statewide Levels of Intensification of Input Use, India

State/Region	Percent of Net Sown Area Irrigated 1978-79	Intensity of Land Use with Irrigation, 1978-79 (Percent)	Fert. in kg/ha of Gross Sown Area, 1981-82	Percentage of Cereals Area Under HYV, 1980-81	Percentage of Villages Electrified, 1982-83	No. of Private Energized Wells per 100 ha Net Sown Area, 1981-82
EASTERN REGION						
West Bengal	40.5	118.0	32.8	40.2	45.3	4.7
Orissa	18.8	138.2	9.9	22.3	43.4	31.9
Bihar	34.7	125.2	18.0	42.8	43.2	19.9
East Uttar Pradesh	50.2	112.1	49.6	47.4	33.0	24.3
Total	36.0	122.8	26.4	37.7	31.0	13.6
WESTERN REGION						
Maharashtra	10.4	121.6	26.6	39.0	84.2	39.4
Gujarat	18.0	112.9	38.6	49.2	76.8	26.4
Madhya Pradesh	12.3	104.2	10.9	22.2	46.3	18.8
Kerala	18.7	119.2	7.9	19.8	50.2	51.1
Total	14.2	114.6	18.7	37.8	59.2	25.1
SOUTHERN REGION						
Andhra Pradesh	32.2	128.5	50.0	42.7	75.9	43.8
Tamil Nadu	46.0	132.9	66.7	65.4	99.4	151.2
Karnataka	13.7	121.9	34.4	30.9	67.9	32.2
Kerala	10.3	155.3	32.9	39.2	100.0	46.0
Total	27.1	129.7	47.3	44.2	78.5	62.3
NORTHERN REGION						
Punjab	78.1	168.8	123.7	87.7	100.0	73.6
Haryana	52.5	155.3	45.5	66.7	100.0	65.0
Uttar Pradesh (excluding East Uttar Pradesh)	53.4	122.0	53.4	45.8	51.2	26.4
Total	58.6	141.2	68.4	59.6	61.6	44.0
All-India	26.6	126.7	34.6	39.7	39.7	32.6

Source: Reserve Bank of India (1984).

Concerning water, the report (Reserve Bank of India, 1984: I:20) says,

> *In Eastern India, water for crop production is available in relatively uncontrolled manner. It is too much and too uneven during monsoon and too little in the dry season. Heavy and highly uncertain rainfall in most parts of the region causes frequent flooding and waterlogging and makes crop cultivation during the kharif season extremely hazardous. Lack of adequate drainage facilities and flood control arrangements restrain the farmers from applying the recommended doses of fertilizers. Even when the recommended doses are used, they yield poor results as flooding or waterlogging limit the full realization of the fertilizer response potential of the high yielding varieties of seeds.*

However, as the report also observes, eastern India has the greatest underutilized reserve of groundwater in India. It stresses that if energy, drainage, and flood control can be brought to the region, the potential for tubewell irrigation is enormous.

Eastern India simultaneously suffers from a problem of too small and weak, and too large and powerful, organizations. On the one hand, in east Uttar Pradesh and Bihar, 75 to 80 percent of farm operators hold 1 ha or less, which is too small to support a tubewell. On the other hand, "even with significant land reform programmes carried out through various legislative measures, concealed tenancy exists and semi-feudal agrarian systems still operate over large areas" (Reserve Bank of India, 1984: I:21).

In sum, the problems of eastern India and of the Eastern Waters basin as a whole could hardly be put better than in the following paragraph (Reserve Bank of India, 1984: I:25):

> *We are of the opinion that if the Eastern Region has settled down to a low level of productivity, it is not so much because its farmers lack dynamism and motivation. It is because the prevailing organizational, promotional and supporting services for practicing modern agriculture impose such high risk and heavy managerial responsibility upon the farm operators far beyond the capability and capital resources of the small and marginal farmers, that they become helplessly dependent upon the semi-monopolistic public and private organizations. The present system is inflexible and provides little scope for maneuverability to the farm operators of the region. The poor input delivery system, low level of research and technical support and inadequate marketing facilities have made them reluctant to intensify agriculture and diversify cropping patterns. The smallness and fragmented nature of their holdings, inadequate and erratic power supply and the complex bureaucratic procedures have discouraged them from utilizing the available facilities for investment in pumps and other modern farm machinery.*

5.3 Overview of Agriculture in Bangladesh

Like adjacent eastern India, the agricultural system of Bangladesh is governed by alternating periods of water surpluses and deficiencies. The water regime of Bangladesh has made it one of the most rice-intensive agricultural systems of the world. In 1987, rice contributed 93 percent of total foodgrain production and 84 percent of the total irrigated area was in rice. Figure 12 showed the crop calendar for rice in relation to water demands and flood areas. Both nature and farmers in Bangladesh have adapted themselves to its unique water regime in many sophisticated ways. One of the remarkable adaptations of nature is "deep-water rice" (a component of "broadcast *aman*" in Figure 12). Although not high yielding, this variety of rice is able to float on the rising tide of the flood, growing at a rate of up to 10 cm per day to a height of 6 m, then ride the flood down as it recedes.

The ingenuity of nature in this example is fully matched by that of the Bengali farmers. They are able to produce under conditions of both drought and flood to a truly remarkable degree—to a degree, indeed, as has been seen, that annual agricultural production remains remarkably stable in extremes both of drought and flood.

5.3.1 Fisheries

Bangladesh, more than any other country in South Asia, relies heavily on fish to meet its protein needs. Supplying an estimated 70 to 80 percent share of total animal protein consumption (National Water Plan 1986: I:4.1), and earning the second largest foreign-exchange revenue after jute, fishery production is a very important element of the national economy. Yet, the need to manage scarce water resources for dry season irrigation and to control floods during the monsoon means that fisheries are often relegated to a secondary level of planning concern. For all water interventions, it is important to be aware of the basic fishery production systems, identify clearly those water development and flood control choices that would make fishing more difficult, and propose area-specific balances between competing interests (National Water Plan, 1986: Summary Report:34).

Inland fishing, which produces more than three times the offshore catch, is divided into open-water capture fishery (61 percent of national fish catch total) and closed-water culture fishery (15 percent of total) (National Water Plan, 1986: I:4.1).

Capture fishing consists primarily of netting fish; almost 50 percent is based on flooded land and about 40 percent is based on rivers and estuaries. In general, the inland capture fishery of Bangladesh is in direct—and currently often losing—competition with agriculture for use of floodplains. Major flood control and drainage works for agriculture would interrupt not only the 30 percent of national fish production that is taken on flooded land, but also the 30 percent that is taken in the rivers and estuaries because the river fish use the flooded fields as spawning grounds.

For the pond fish culture, which is largely shrimp requiring brackish water, the problem is to minimize the negative effects of using high-salinity water on other uses in the coastal zone, such as agriculture and domestic needs, while supporting the export-oriented aquaculture industry (National Water Plan, 1986: Summary Report:35).

Since fisheries are a major source of both nutrition and income in rural areas, proposals for water resource management in Bangladesh will be most effective if they provide carefully for the protection of fishing, rather than concentrating in a given area on a direct solution for just one resource problem (e.g., floods or rice production). A careful area-by-area evaluation of the contributions of agriculture and fishing should be the basis of deciding how much water (and land) should be allocated to fisheries and how much to irrigation in the dry season. In a similar vein, flood control measures should be structured to minimize adverse effects on spawning patterns and food availability for fish.

5.3.2 The National Water Plan

Covering 1985 to 2005, the National Water Plan (1986) of the Master Plan Organization (MPO) is addressed to the problems of drought and flood, but it is organized around the need to produce enough food to support the growing population by the most efficient means available. Table 10 provides a summary of the objectives of the plan.

Assuming constant per capita foodgrain demand, 30.5 million mt of foodgrain production will be required in Bangladesh by the year 2005, an increase of 67 percent over the 1985 level, which implies an average annual increase of 600,000 mt per year. If it is assumed that yield per hectare increases 10 percent over this period, then the combination of irrigation development and flood control and drainage works projected under the National Water Plan will satisfy this requirement. Under the proposed investment program of $6 billion over 20 years, irrigated area is projected to increase from 1.92 million to 5.44 million ha, an increase of 183 percent, or an annual average growth of 176,000 ha. The area under flood control and drainage works is projected to increase from 2.59 million to 4.39 million ha, an increase of 69 percent.

The National Water Plan estimates that Bangladesh has sufficient ground and surface water resources for an additional 4.9 million ha of irrigated land, which, if developed in addition to the existing irrigated area of 1.92 million ha, would bring total irrigated area to 6.82 million ha, or 75 percent of the net cultivated area. This rate of expansion of irrigated area is nearly twice the 87,500 ha per year average rate of the 1977-1985 period. However, for reasons explained below, the projection of foodgrain production in relation to irrigation development in the National Water Plan appears to be too conservative.

That is the "good news," so to speak. The "bad news" is that the rate of growth of irrigation since 1985 has been very low—perhaps even negative, taking into account unmet tubewell replacement needs. Clearly, the future of Bangladesh depends on getting tubewells and irrigation moving again.

5.3.3 Agricultural Production and Irrigation

Figure 14 illustrates a major problem facing agriculture in Bangladesh. Per capita grain production substantially decreased from 1961 to 1973, then increased through to 1985, but has been decreasing since. Major reasons for this problem are the following:

1. the virtual halt in the growth of irrigation over the past few years, a problem examined below; and

2. the rapidly increasing density of population per unit of agricultural land (see Figure 15).

Irrigation investments are the "lead input"—they show direct positive effects on agricultural production and rural employment in areas such as the eastern Gangetic basin. Farming is now using all the arable area, and increases in food production have to come from increased yields and multiple cropping. Irrigation makes dry season crops possible, and it increases wet season yields by establishing a more favorable water regime for crops. As important, it induces farmers to invest in other inputs, such as high-yielding seeds, fertilizers, and additional labor by reducing the risk of loss of these investments from drought. Irrigation, in sum, provides the stage on which all the other yield-increasing inputs perform their roles.

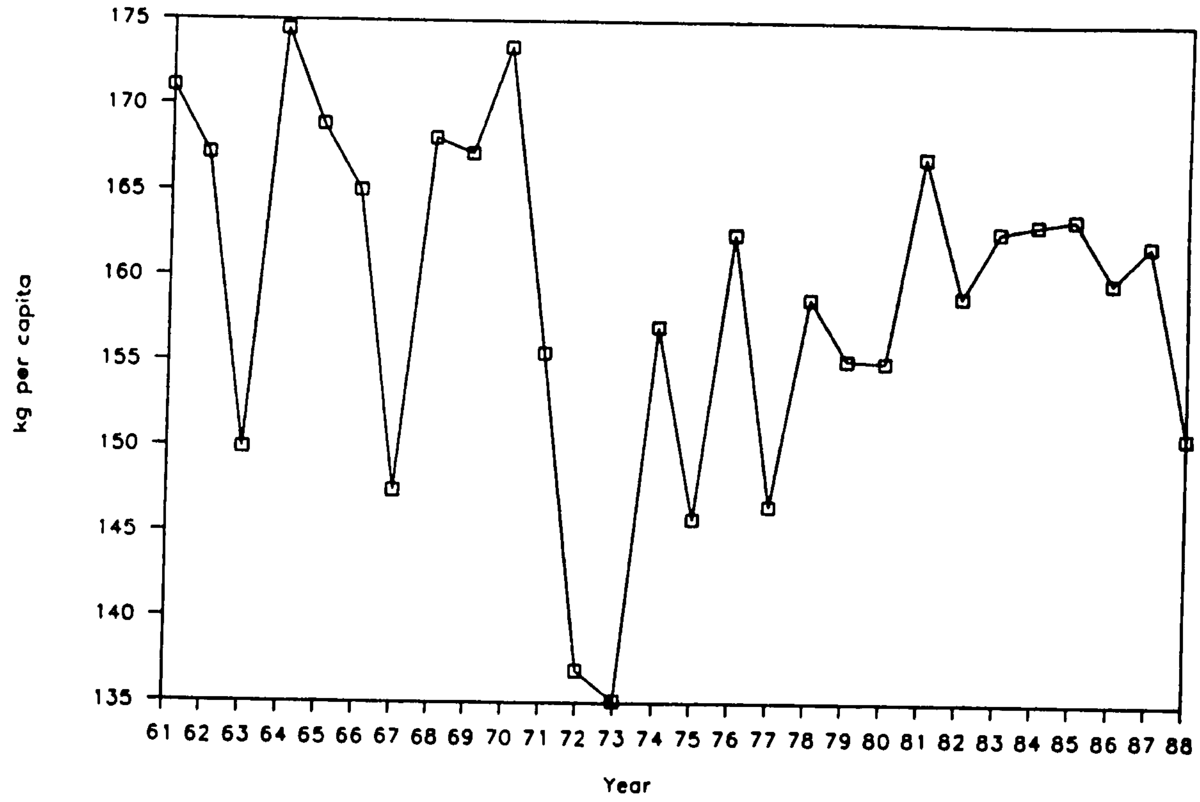


Figure 14

Trends in Per Capita Grain Production, Bangladesh

Source: Statistical Yearbook for Bangladesh, 1987.

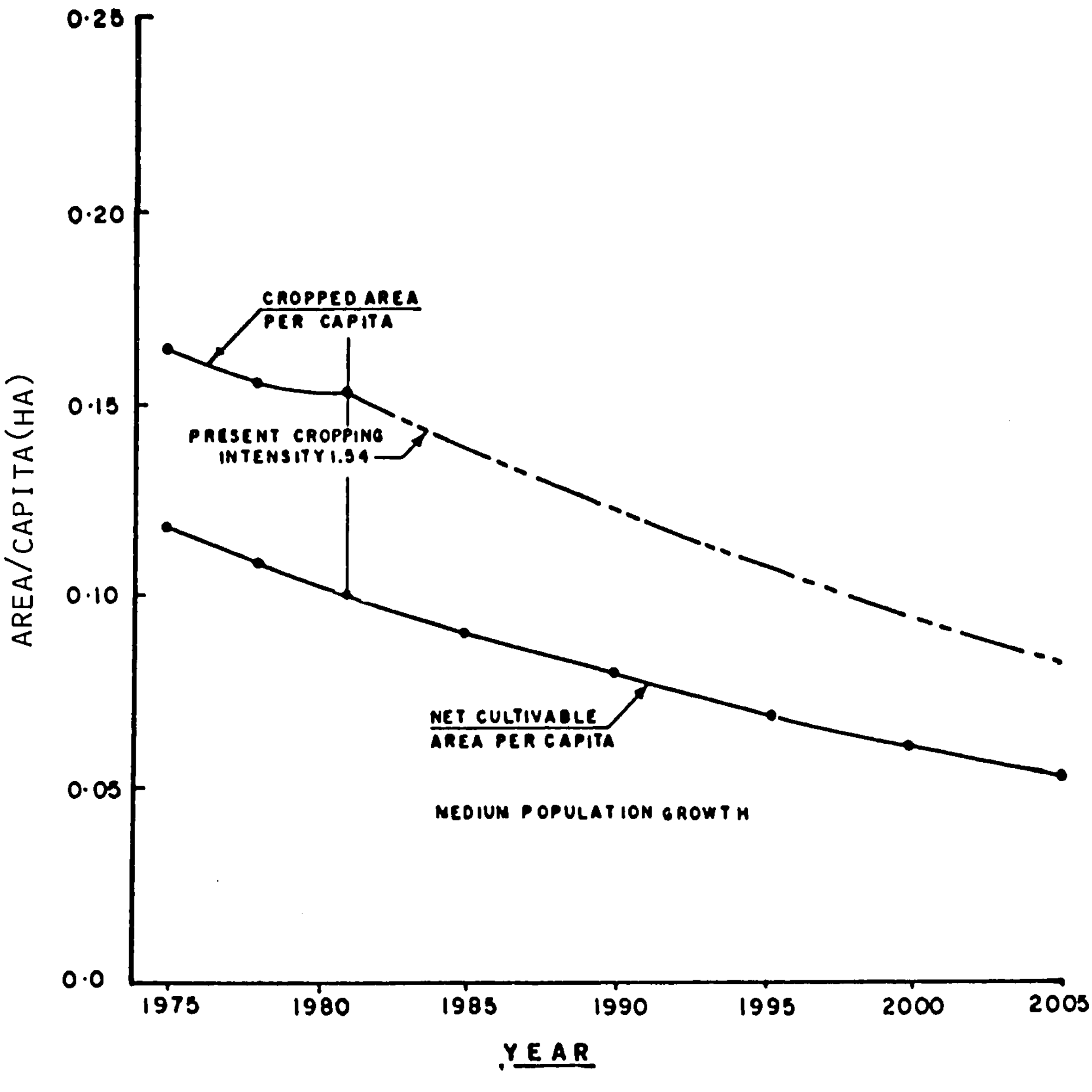


Figure 15

Decline in Cropped Area Per Capita in Bangladesh, 1975-2005

Source: National Water Plan (1985): I: Figure 3-2.

Table 10

Bangladesh National Water Plan

Outcome of Plan Implementation

Year	Plan Period	Foodgrain Demand[a] Const. (Mmt)	Foodgrain Demand[a] Incr. (Mmt)	Foodgrain Production Current Yield (Mmt)	Foodgrain Production Future Yield (Mmt)	Irrig. (Mha)	Cumulative Land Development Flood Control Drainage (Mha)	Cumulative Land Development Value Added[b] (bil. Tk)	Employment (M man-days)	Energy Demand Diesel (Mlt)	Energy Demand Electric (Mkwh)
1984/85	Base	18.3	18.4	16.1	-	1.92	2.59	68	1,704	63	92
1989/90	TFYP	20.9	21.7	19.6	20.5	3.26	3.06	82	1,903	104	254
1994/95	FFYP	23.8	25.1	23.3	26.0	4.21	3.50	98	2,128	137	358
1999/00	FiFYP	27.1	29.2	26.2	29.2	5.04	3.94	109	2,295	153	526
2004/05	SiFYP	30.5	33.8	27.5	30.7	5.44	4.39	115	2,371	152	625
Increase Under NWP				11.4	14.6	3.52	1.8	47	667	89	533

[a] Constant availability per capita demand for Master Plan Organization's medium population growth. Increasing per cap:ta demand at 4 percent GNP growth and medium population growth (National Water Plan, 1986: II: Ch. 9).

[b] Value added in crop production at 1983 shadow prices.

Sources: National Water Plan, 1986: III: Ch. 15, Ch. 16, and Table 3.

A regression analysis of the relationship between irrigation development and foodgrain production in Bangladesh over the period 1974 to 1986 reveals that an increase in irrigated area of 10 percent is associated with an increase in foodgrain production of 6 percent, an elasticity of 0.60.

As noted above, the National Water Plan estimates that to increase foodgrain production by 67 percent an increase of irrigated area of 183 percent would be required. This implies an elasticity of foodgrain production with respect to irrigation of 0.37, which is only 62 percent of the above elasticity. Thus, the amount of irrigation required to meet the target of constant per capita foodgrain production may be only 108,000 ha per year rather than the 175,000 ha estimated in National Water Plan. On balance, the regression estimate is likely to be the better guide to policy. This is good news for Bangladesh.

5.3.4 Irrigation Potential and Growth

The regional distribution of actual irrigation by type and irrigation potential is shown in Figure 16. Only about 25 percent of the irrigation potential has been developed. Given that only 28 percent of the cropped area is subject to flood depths over 90 cm in a normal year and there is no flooding in the *rabi* season, there is large scope for irrigation development either without, or before, investment in flood control.

Figure 17 shows the growth of various kinds of irrigation systems: low lift pumps (LLP), shallow tubewells (STW), deep tubewells (DTW), and traditional methods. These modern methods are used on about 78 percent of the total irrigated area of nearly 2 million ha; the remainder is irrigated by traditional systems, such as hand-operated swing buckets.

Development of shallow tubewells has accounted for most of the growth of irrigation in recent years. However, although the data are not entirely clear, it appears that growth of shallow tubewells has drastically decreased in the past three years. Gisselquist (1988), for example, believes that the net growth of area irrigated by shallow tubewells, after accounting for replacement needs for old shallow tubewells, has actually turned negative. He attributes this to a variety of government policies adverse to private sector tubewell development and to a drastic decrease in credit availability for irrigation.

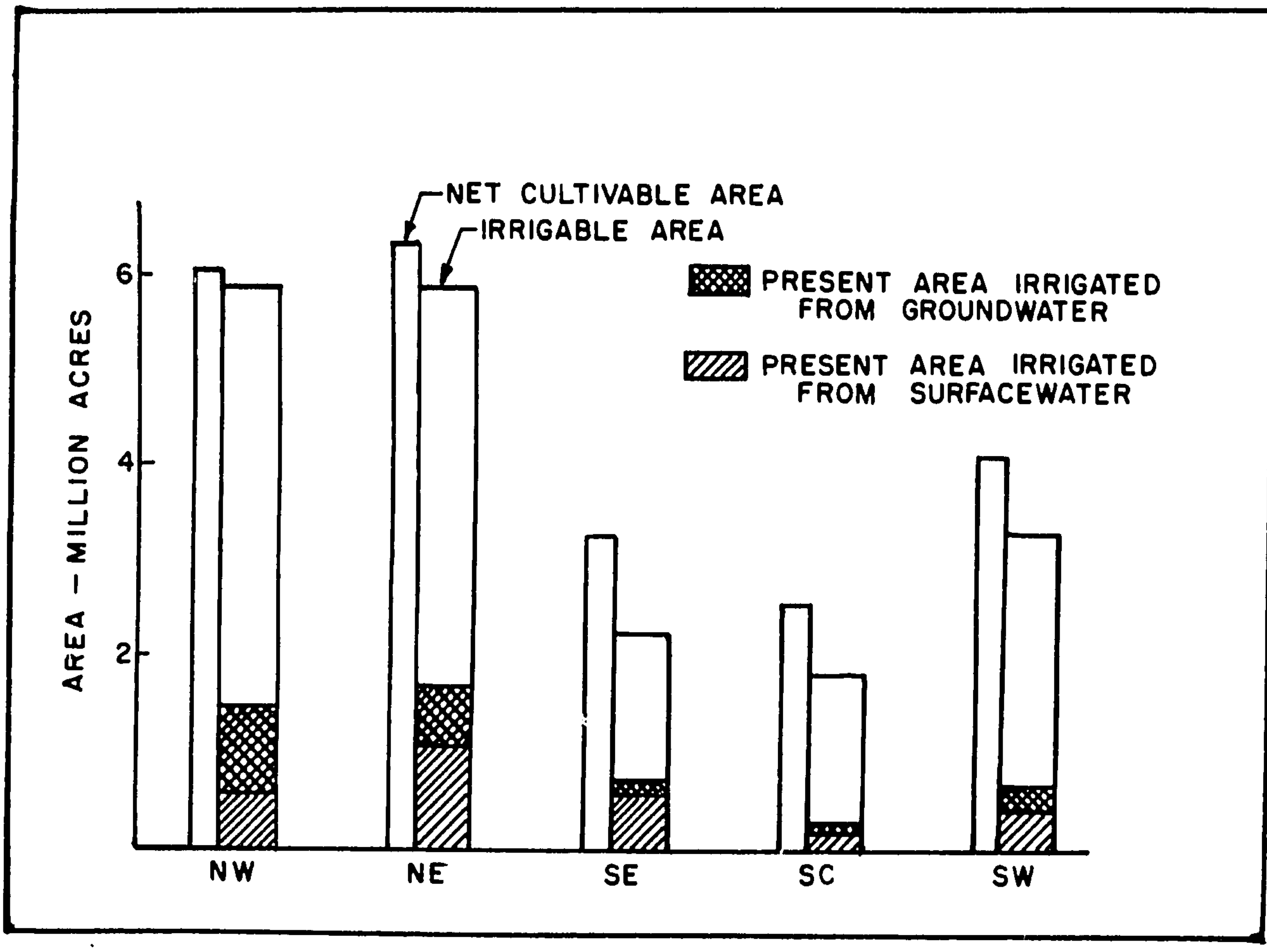


Figure 16

Regional Irrigation Development, Bangladesh

Source: National Water Plan (1986): Figure 2-3.

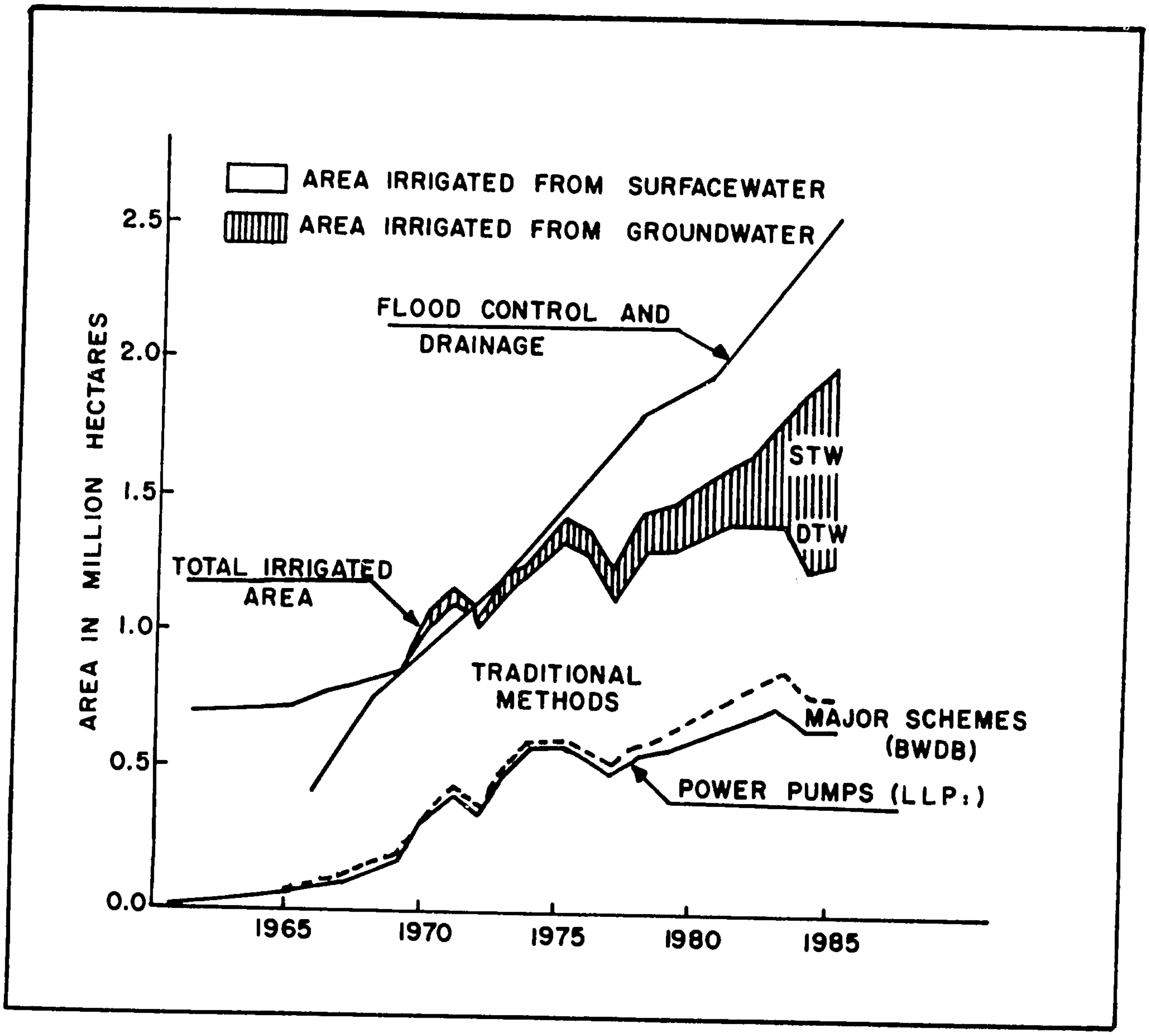


Figure 17

Growth of Irrigation Flood Control and Drainage in Bangladesh, 1964-1985

The current value of the total costs of diesel shallow tubewells (including all capital, energy, operations, and maintenance) is estimated at Tk 27,753 per hectare of gross irrigated area—or slightly less than $1,000 per hectare. The corresponding figures for diesel and electric deep tubewells are Tk 45,513 and Tk 30,512 per ha, respectively. The figures for other parts of the Gangetic plain in India and Nepal should be close to these figures.

In comparison, a new surface irrigation system in India costs about $3,000 per hectare of gross irrigated area, and both the actual area irrigated and the quality of irrigation are likely to be lower than desired. Thus, tubewells in this region are only one-third to one-half the cost, with perhaps twice the effectiveness, of a gravity irrigation system. It is clear that tubewells should play the lead role in irrigation development, as irrigation plays the lead role in agricultural development.

5.3.5 Irrigation Policies for Bangladesh

As in eastern India, Bangladesh's signal advantage for irrigation development is its vast and relatively shallow aquifer available for tubewell development. Less geologically favored countries must rely on massive gravity irrigation systems, which are more expensive, provide less effective irrigation, and require investment and operations and management by public agencies. Given the appropriate policy environment, the private sector is fully capable of carrying out irrigation development in Bangladesh. With some reservations and remaining controversy, the Bangladesh government has made private tubewell development the basis of its irrigation policy.

What are the appropriate governmental policies to realize the benefits offered by tubewells?

Credit: If they reach water, as they generally do throughout Bangladesh, reasonably well-managed shallow tubewells yield favorable rates of return to farmers. But the cost of a shallow tubewell is greater than the total annual income of a typical Bengali farmer. Effective credit policies and programs are absolutely necessary to private development of irrigation in Bangladesh. It is reported (Gisselquist, 1988) that the supply of credit for irrigation has been drastically decreased in the past three years; this appears to be the primary reason for the sharp slowdown in tubewell installations.

Regulation: A condition of an effectively functioning private sector is that the public sector regulates areas in which the market fails, such as external costs and benefits. Although extraordinarily adapted to private initiative, tubewells create classic externalities that must be regulated. One of the worst occurs when deep tubewells are permitted to draw down water tables below the reach of shallow tubewells. Then, everybody is forced to invest in deep tubewells, at enormous capital and energy cost, with zero, or even negative, gain in irrigation service. Deep wells clearly should be prohibited in areas where shallow ones will work. It is also apparent that when an entire zone of shallow tubewells is "in clear and present danger" of lowering the water table to the point that everybody in the zone pays excessive energy costs of pumping, that zone should also be subject to regulation of the numbers and use of tubewells. No well regulations should be introduced until, on the basis of detailed empirical evidence, drawdown of the aquifer shows that it is necessary. Beyond meeting these needs and providing a reasonable legal framework for irrigation cooperatives, regulations tend to be counterproductive.

Macro Policies: Two macro policies are of interest here. The Bangladeshi government now permits duty-free import of small engines intended for agricultural use, while the tariff for industrial use is 50 percent. This creates a definitional gray zone subject to abuse and encourages foreign dumping of small diesel engines, which tends to suppress local assembly. Thus, it is likely to be more sensible to impose a lower import tariff on all small engines.

The second macro issue is that of the foreign-exchange cost of energy for irrigation. This is already a serious burden on Bangladesh and will become more severe as the National Water Plan unfolds. Electricity is the only practical alternative to current reliance on imported diesel fuel for irrigation, and indeed, electrical operation is economically superior. The primary source of electricity should be the large natural gas resources of Bangladesh. Although it is not economically feasible to pipe natural gas to individual tubewells, it would be feasible to pipe it to local and small-scale, gas-based electrical generating stations for subsequent distribution to farmers.

In sum, of all the agricultural challenges confronting Bangladesh, and even eastern India, perhaps none is more focal and urgent than creating a policy framework to encourage private sector development of tubewells.

6

RECOMMENDATIONS

The recommendations that follow are based on the data reviewed, the views of the governments and international officials in the region and in Washington, D.C., and the professional judgment of the study team and its consultants. Not all important issues are necessarily covered by a recommendation unless they are judged to be amenable to specific action by a government or donor or they are in need of technical or scientific research. The recommendations are intended not only for use by U.S. government agencies, but also for consideration by the region's governments, international agencies, and other donor countries. The recommendations are divided into the following categories: general recommendations, action recommendations, and technical and scientific research recommendations.

6.1 General Recommendations

6.1.1 Necessary Awareness of Being Outsiders

Water management in South Asia, which is critical to the well-being and economic prospects of 250 million of the poorest people on earth, should be of concern to the United States and to all members of the world community with resources or skills that can help moderate drought and flood there. As seen in the Bangladesh floods of 1987 and 1988, or in the Bihar drought of 1967-1968, when the United States reportedly sent one-fifth of its wheat crop in relief, excess and shortage of water in this densely populated basin can make a substantial claim on external resources.

The United States is equipped to make a contribution to harnessing the basin's water through its wealth of qualified people and technical expertise gained from its own extensive water resources development. A substantial number of South Asian water scientists and engineers have done their professional studies in the United States, and technical credibility in the region also flows from past U.S. cooperation in, for example, eastern India's Damodar Valley project, which was modeled on the Tennessee Valley Authority, and an extended series of technical consultancies in East Pakistan and Bangladesh.

The United States and all nonregional countries, however, should be clear from the outset that they are outsiders to the region, and they should understand the limits on their roles that this legitimately implies. This is particularly important with regard to the central and largest country of the region. In doctrine and practice, India has since its independence in 1947 been committed to developmental self-reliance. Even more than in the past, today's India finances the great bulk of its large development investments from its own resources, and it can pay for any particular project at will. As its nuclear capacity and space program make clear, India has modern technical capabilities. The United States' small and currently declining economic aid to India gives it no voice in the overall design of India's development program. Even the World Bank, which provides far greater resources, plays a limited role in major Indian investment decisions.

6.1.2 No Overall Regional Water Development Program Necessary

In the longer term, it will be increasingly desirable for the riparian countries to coordinate their water development programs. At present, however, the quest for an overarching cooperative regional water development initiative is likely to retard rather than speed agreement on the specific water arrangements that will bring concrete benefit to the basin population. With few exceptions, which include constructing hydropower capacity in Nepal based on Indian purchase commitments, the most important and immediate practical measures to be taken are in-country.

Concerning research, much can be contributed by work done on a national basis, but greater impetus for cooperative studies, or for exchanges and discussions of the results of nationally based research work, would be very desirable.

6.1.3 Intensify Study and Institutionalization of Groundwater Use

All possible steps should be taken to obtain the greatest possible understanding of groundwater in this area extraordinarily rich in it, and to use that understanding to exploit renewable groundwater to the full for irrigation and for storage of monsoon flows. The diffusion of groundwater use is undoubtedly going on at a historically rapid rate. The need is not to convince farmers that electric or diesel tubewells are a good investment, but rather to encourage the regional governments to move more quickly in the full acceptance and legitimization of this relatively "new technology."

6.1.4 Exercise Caution against "Single Solution" Approaches

Water management in this highly water-dependent environment is a complex and multifaceted challenge. It is of the greatest importance that a broad and integrative approach be taken. Major concerns that lie outside a major policy goal such as flood control, for example, improvement of fisheries (the major source of animal protein in the Bangladeshi diet and an important source of export earnings), must not be ignored or overridden. It is to be expected that combinations of interventions and adaptations will be shaped over a number of multiyear planning cycles. Over time they will, for example, cumulatively mitigate the threat of floods in Bangladesh while husbanding that nation's internal and external resources, maintaining its productive base, and avoiding unnecessary environmental damages. Despite the appeal of simplicity, the search for single, conclusive solutions, for example, embankment protection from floods in the great delta, is almost certain to lead to waste and disappointment.

6.1.5 Indian and Bangladeshi Hydrological and Meteorological Data Should Be Shared Internationally

India could increase the rationality and creativity of its own internal water-policy processes by ending the practice of restricting access to hydrological data to certain government officials. This would also increase the trust and confidence of India's neighbors in their water dealings with the central country of the region.

During the recent floods Bangladesh did not regularly report rainfall data to the World Meteorological Organization in the standard way. This retarded dissemination and analysis that could have been of benefit to Bangladesh itself.

6.1.6 Broadened Analysis of Engineering Projects

In considering river-training, protective embankments, roads, and other engineering works, there has not been enough involvement of economists and physical, biological, and social scientists in estimating true benefits and costs, the environmental and social impact of these works, and who will ultimately benefit. Experts in these fields should be assigned to work with engineering teams to examine these issues in pre-feasibility and feasibility studies.

6.2 Action Recommendations

6.2.1 Immediate Pursuit of Elements of the Government of Bangladesh's Guiding Principles

In response to the floods of 1988, the Government of Bangladesh formulated 11 "Guiding Principles" for national policy on floods (Ministry of Irrigation, 1988). Of those 11 principles, 7 present short-run actions that can immediately help the population deal with future floods. These selected guiding principles contain the important "soft" program of flood proofing, discussed throughout this report, and also provide for a professional, and necessarily central, coordination of local constructions affecting the flow of water, especially Food for Work Programs. As immediate steps, the Government of Bangladesh should actively pursue the following of its Guiding Principles:

- Phased implementation of a comprehensive Flood Plan aimed at protection of urban, rural, commercial, industrial, and public utility centers and communication networks; controlled flooding, wherever possible and appropriate, to meet the needs of agriculture, fisheries, navigation, urban flushing, and soil productivity; and recharging the surface water/groundwater resource with minimum dislocation of the environment.

- Effective land and water management for protected and unprotected areas, including irrigation, drainage, compartmentalization, drainage decongestion, land use, cropping patterns, environment, ecology, erosion/sedimentation control, and so on.

- Strengthening and equipping the disaster management machinery, including building infrastructure, for quick and effective communication and transmission during disasters.

- Improvement of the flood forecasting system and establishment of a reliable and comprehensive flood-warning system with adequate lead times and at the same time evolving techniques for dissemination.

- Development of floodplain zoning as a flexible instrument to accommodate necessary engineering measures and allocate space for habitation patterns, economic activities, and environmental assets.

- Coordinated planning and construction of all rural roads, highways, and railway embankments, including provision for unimpeded drainage.

- Encouraging maximum possible popular participation by beneficiaries in the planning, implementation, and operation and maintenance of flood protection infrastructure and facilities.

The donor countries and the other riparian countries should endorse these seven principles as valuable first steps for Bangladesh's response to the floods.

Substantially greater caution, however, is in order with regard to the commitment by Bangladesh, or donors, to the remaining principles, which urge large-scale physical structures to manage water movement through Bangladesh. To implement those principles would take, at an absolute minimum, a decade, and as such they are measures that cannot have an immediate effect on the country's flood vulnerability. The Government of Bangladesh is aware of the long delay before reaping benefits from those proposals, and it is prudently reviewing them before committing itself to them.

A greatly improved knowledge of the behavior of the rivers and their sediment movement is unquestionably one prerequisite for heavy embankment and river-training investments. Several of the recommendations below for research and technology development have a bearing on this.

6.2.2 Execution of Bangladesh's National Water Plan

As the result of five years of work, led by its Master Planning Organization, the Government of Bangladesh has in its National Water Plan an excellent study of its water resource. The plan incorporates a series of investment programs that have been endorsed by the government (sitting under President Ershad's chairmanship as the National Water Council of Bangladesh) and by the main international donors. Taken together, the programs represent planned outlays of $6 billion over 20 years for flood control and drainage works and tubewell irrigation projects. They were chosen and prioritized to meet Bangladesh's food production needs until 2005. The overall logic and balance of the National Water Plan, as well as the merits of its projects and programs, have been carefully reviewed and extensively debated; their implementation should not be interrupted as Bangladesh takes the needed time to explore the next phase of flood control engineering options.

Unfortunately, delays in implementing the National Water Plan have already led to foregone benefits in the billions of dollars. There is an urgent need for the World Bank, as coordinator of the Aid to Bangladesh Consortium, to take a lead in mobilizing donor support for this plan.

6.2.3 Intensify Efforts to Achieve Interregional Power Development and Use

It is virtually certain that construction of hydropower facilities in Nepal, either run-of-the-river or with storage, and the sale of the electricity to India, would benefit both countries. The United States should support the necessary discussions, particularly those concerning the Arun III site, and be ready to contribute to advance in this direction. In the long run, the very large-scale use of pumped tubewells in the plains is contingent on this, which greatly increases the already substantial importance of progress on this front.

Similarly, Bangladesh should be encouraged to develop its considerable natural gas for generating electricity to sell within the region.

6.2.4 Research Coordination

Optimal management of water in the Ganges-Brahmaputra basin raises many scientific and technical questions amenable to productive research. Certain priority lines of research are suggested below, but a well-prepared conference in the region in the second half of 1989 or early 1990 on a research agenda, division of labor, and arrangements to share results, could be of great value. It should be organized by regional entities and, ideally, include participation by technical people based in government departments, planning bodies, universities, and institutes of the region. A conference itself, and probably some of the lines of research flowing from it, could be an effective vehicle for economic development support to the region by the U.S. Agency for International Development, international financial institutions, or private foundations.

6.3 Recommended Scientific and Technical Research

The actions recommended above provide sufficient time before other major decisions have to be made to build the strong base of scientific and technical knowledge necessary to design effective further actions for the development of the basin. The following areas merit priority consideration.

6.3.1 Monsoon Hydrology

Tremendous strides have been made in the past decade by the regional and international scientific communities in understanding the heat balances, the movement of air masses, and the precipitation mechanisms of the southwest monsoon. These subjects together could be described as "monsoon meteorology." The Indian Meteorological Department is now ready to make good early forecasts about the magnitude and the timing of the onset of the monsoon rains. This is critical information for scores of millions of farmers and for government agricultural support policies. The improved understanding did not come easily, but only from many years of painstaking research by the global meteorological community, with Indian scientists in many cases taking the lead. That research program could be used as a model for some of the programs suggested below.

The achievements in monsoon meteorology now make it possible to take a step beyond weather analysis and to improve "monsoon hydrology." Emphasis should now be placed on advancing from the analysis of rainfall to an understanding of the rain's conversion into run-off in the streams and its infiltration into the ground. This step is critical to understanding sediment transport and floods in the Himalayan region. Hydrology is a science largely developed in Europe and North America, where extremely intense and long-duration rainstorms are not regularly experienced and water does not act on such steep and fragile terrain as the Himalayas. New scientific approaches may have to be developed to study these phenomena.

6.3.2 Water Balances on the River Basins

A detailed water balance should be calculated for the Ganges River basin. Through a series of measurements, a water balance will follow water from its descent as rain, through its flow either underground or on the surface, and until it evaporates or reenters the sea. Understanding such a balance is fundamental to sound planning for irrigation and flood management. It is particularly so because new issues have emerged, such as the effects on the basin's large-scale hydrology of massive diversions and pumping for irrigation, the exchange of water between the water table and river courses, how much groundwater can be pumped without depleting supplies for the long term, or how much and what kind of flood abatement can be provided by underground storage. It is important that water flows also be examined in a historical setting to establish what, if any, shifts over time in river volumes and the annual distribution of river peaks and low flows (summarized in a "hydrograph") are due to man's actions, such as upstream irrigation. Similarly, the effects of future water abstractions on the hydrograph need to be estimated.

Calculating this balance will not be a trivial task. It will depend on continued meteorological research into the monsoon and on careful review of all the available data on the hydrological cycle in the basin. There are thousands of rainfall stations in the basin, many with records going back more than 100 years and many reporting daily rainfall data. Each of these records should be carefully appraised for reliability by competent scientists (with computer support) before being accepted for use or discarded. Many thousands of tubewells and dug wells on the plains have been monitored for groundwater fluctuations; their data, like historical surface water (streamflow) measurements, should also be carefully appraised before being incorporated into a balance.

Water balances for the Brahmaputra and Meghna basins, while ultimately needed, are less pressing due to the lack of serious development options for these regions within the next 30 years.

6.3.3 Sediment Balances

Part of the current tension among riparians is due to unconfirmed suspicions about sediment movements and accumulations as causes of downstream flooding. To put this question to rest and also to aid in the technical appraisal of embankment and river-training works, sediment balances should be established for the three major landform types of the region—the mountains, the plains, and the coastal deltas.

The development of accurate descriptions of sediment origins, volumes, and movements will depend on new scientific measurement methods, on monitoring the actual behavior of the silt under monsoon hydrological regimes, and on sophisticated mathematical modeling. Part of the study should carefully reexamine the role of forests and other land uses in relation to sediment loads. Further study of the undersea sediment deposits in the Bay of Bengal is also needed, particularly elucidation of a great canyon in the deposited fan, known as the Swatch of No Ground, which probably plays a role in the marked absence of new land formed by sediment at the main river outfall from Bangladesh into the sea.

Under this heading, mention should also be made of flood management's need for extremely precise and detailed maps showing elevations, in the case of much of Bangladesh, to differences of one or two feet. For purposes of flood warning, mathematical models that predict the development of flood patterns from rainfall, river level, and tidal reports should continue to be given attention, as the United Nations Development Program and Danish development assistance now do. Prospective Indo-Bangladeshi cooperation in this field should make a major contribution to regional flood security.

6.3.4 Geology and Seismology of the Himalayas

Specification of the earthquake risk in the region is critical to making correct decisions on whether high dams and large storage reservoirs can be built at many otherwise excellent sites in the Himalayas. Both the rewards and the risks of such projects are very high, but fundamental geological and seismological understanding is of the essence to the basic safety of the projects. This will also contribute to evaluating the potentially great usefulness to the regional populations of the Bhabar zone formation and the related deep aquifers.

6.3.5 Potential for Underground Storage of Flood Waters

The concepts supporting underground storage of water have not been given the detailed scientific assessment that they warrant. In the near future a careful study combining detailed empirical field work and modeling should be made of the Ganges plains to explore these concepts. Without such studies the issue will remain unresolved and will be a source of contention between the scientific community and the engineering bureaucracies. Two approaches have been discussed. The first approach relies on the intensification of current groundwater development using the recharge to the shallow aquifers, which involves conventional technologies for groundwater extraction and recharge. To establish how this works overall, however, it is necessary to monitor existing tubewells and carefully combine observations of water extraction and groundwater and surface water movements, using computer models.

The other approach involves using the Bhabar zone, located along the meeting line of the Himalayan foothills and the plains, as a recharge area for deep aquifers. For this, much more investigation and much higher budgets would be needed. The presumed extremely high porosity of the Bhabar zone and the belief that it is the primary entry point for surface water into the deep artesian aquifers under the plains make it a very high priority for geological research. It has been proposed that with dry season evacuation by artesian wells, the space created in the Bhabar zone could be used to store monsoon flows for later irrigation uses while at the same time reducing the downstream floods. Detailed field geology investigations of this very particularistic formation at an active tectonic seam, coupled with model studies, are clearly in order.

Clarifying the potentially very useful hydrological characteristics of the Bhabar zone will probably also require the drilling of a significant numbers of wells.

6.3.6 Rural Electrification for Tubewells and Other Uses

The strategy for agricultural development outlined in this report depends heavily on tubewell capture of groundwater, which depends in turn on energy availability at dispersed rural well sites. Broad study of how the large and rather seasonal energy needs of large numbers of additional tubewells of different sizes can be met on a national and regional basis would be extremely useful. Detailed studies are needed to consider the costs and benefits of generating and distributing power to achieve these goals and to explore strategies for such power supply in all parts of the basin. In this perspective, two particular questions could well be addressed:

- Run-of-the-river versus Storage Hydroelectric Plants: Regarding the development of hydropower in Nepal for export to the plains, the focus at present seems to be divided between plants with large storage reservoirs offering premium-priced peaking power, particularly the Chisapani project on the Karnali River, and run-of-the-river plants, exemplified by Arun III. As discussed above, it is not entirely clear which is the best strategy for Nepal to pursue for the initial steps in a program of power exports. In relation to predictions of power demand in the plains, which would neccessarily increase greatly if large-scale rural and tubewell electrification was explicitly targeted, careful analyses should be carried out of storage versus run-of-the-river power from the Himalayas, or their optimum combination.

- A Regional Power Grid: Unlike water, power can move in both directions along a grid. In Europe, and between Canada and the United States, great efficiencies are realized through exchanges of power to meet peak loads at different times in different consumption centers. Sharing of power for this purpose and to take advantage of different compositions of generating equipment (hydro, coal, natural gas, and nuclear) among Bangladesh, Nepal, Bhutan, and India could be similarly efficient and bear exploration. It could be objected that political relations among the countries could not support such cooperation in the foreseeable future, but electricity exchanges in other settings have proven to be businesslike and resistant to political tensions.

6.3.7 River Mechanics

Following up on the seminal work of Coleman (1969) on the Brahmaputra, detailed hydrographic analysis of the regional rivers is needed. This involves extensive field measurement to map numerous cross sections of the river courses over a long time series. It is a fundamental basis for engineering pre-feasibility studies of projects such as bridges and embankments. For example, the Directorate of River Morphology, Research and Training of the Bangladesh Water Board, which was abolished in 1982, should be reinstated.

6.3.8 Interbasin Transfer of Water

Much of the current conflict over water between Bangladesh and India comes from the issue of low-flow augmentation of the Ganges waters. To help resolve this issue there is need for a series of studies on the technical feasibility of diverting water from the Brahmaputra to the Ganges. Even the most widely promoted option, the Indian plan for a link canal through Bangladesh, appears to need substantial technical assessment before it could be called feasible. Creative thinking should explore and assess other interbasin options, including transfers of water from Assam to West Bengal via a series of diversions that would ensure a navigation link for Nepal to the sea. Trans-Himalayan prospects, using the Gandak or the Kosi as conduits for diversions from the Tsangpo, could also be examined.

6.3.9 Research in Support of Flood Proofing

Social scientists, crop systems specialists, and others should study how people in rural areas live with the floods. What kinds of safety measures do they undertake, both at the family and community level? How are crop systems adjusted to flood expectations? Once these factors are better understood, more effective measures for helping the population live with the floods can be implemented.

Agricultural research should be expanded in areas dealing with the variability of the water during the monsoon period, with the goal of developing flood-resilient varieties of rice and other crops and improving cropping patterns. This work is as relevant to the Indian parts of the basin as to the Bangladeshi and could well be done cooperatively between the two countries.

Research should be done at the *upazilla* (subdistrict) level on the effects of floods on agricultural and other indicators in Bangladesh. This research would be enormously helpful in defining the most flood-stressed areas and the costs and benefits of flood proofing. Such research should include the use of computerized geographical information systems to estimate the severity of flooding in *upazillas*, based on topographical maps and interviews with villagers, and econometric analysis of the effects of floods on indicator variables in *upazillas*.

REFERENCES

Brammer, Hugh, 1982: "Agriculture and Food Production in Polder Areas," photocopy, paper presented at International Polders Conference, Lelystadt, Netherlands.

Caritas Bangladesh, 1987: "Flood Recovery Report—1987," Dhaka.

Caritas Bangladesh, 1988: "Bulletin No. 2: Flood—1988," Dhaka.

Charlu, T.G.K. and D.K. Dutt, 1982: *Groundwater Development in India.* Rural Electrification Corporation, New Delhi.

Chaturvedi, Mahesh C. and Peter Rogers, 1985: *Water Resources Systems Planning: Some Case Studies for India*, Indian Academy of Sciences, Bangalore.

Choudhury, A.M., 1988: "Flood-1988," Bangladesh Space Research and Remote Sensing Organization (SPARRSO), Dhaka.

Coleman, James M., 1969: "Brahmaputra River: Channel Processes and Sedimentation," *Sedimentary Geology* 3(2/3).

Colombi, J.S., 1988: "Flood Control Strategy," notes of a visit by J.S Brichieri-Colombi to the Ministry of Irrigation, Flood Control and Water Development, Dhaka.

Curray, Joseph R. and David G. Moore, 1971: "Growth of the Bengal Deep-Sea Fan and Denudation in the Himalayas," *Geological Society of America Bulletin* 82:563-572.

Currey, Bruce, 1988: "Bangladesh: The Historical Record of Natural Calamities, Scarcities and Famines, 17 Districts Between 1957-1970," Winrock International, Dhaka.

Dutt, D.K., 1971: "Tentative Assessment of Geohydrological Conditions In Pantnagar Area of Uttar Pradesh," *Ground Water and Water Well Engineering* 1(1) July. (A quarterly journal of the Central Ground Water Board, Ministry of Agriculture, Government of India, New Delhi.)

Gisselquist, David, 1988: "Economic and Administrative Issues," in *Bangladesh Minor Irrigation Subsector Study*, World Bank.

Hamilton, Lawrence S., 1987: "What Are the Impacts of Himalayan Deforestation on the Ganges-Brahmaputra Lowlands and Delta? Assumptions and Facts," *Mountain Research and Development* 7(3):256-263.

Hash, Charles T., 1989: "Outlook for the 1988/89 Aman Crop and Early Prospects of 1988/89 Wheat and Boro Crops," memorandum, Office of Food and Agriculture, USAID Dhaka, 11 January 1989. (This is an updated version of the Hurdus (1988) memorandum.)

Hossain, Mahabub, 1988a: "Effects of the 1988 Floods on Rural Economy: An Assessment from a Rapid Household Survey," photocopy, Bangladesh Institute for Development Studies, Dhaka.

Hossain, Mahabub, 1988b: *Nature and the Impact of the Green Revolution in Bangladesh*, Research Report 67, International Food Policy Research Institute, Washington, D.C.

Hossain, Mosharaff, A.T. Islam, and Sanat Saha, 1987: *Floods in Bangladesh*, Universities Research Center, Dhaka.

Hurdus, Alan R., 1988: "Outlook for the 1988/89 Aman Crop and Early Projections for the 1988/89 Wheat and Boro Crops," memorandum, Office of Food and Agriculture, USAID Bangladesh, 18 October 1988.

India Today, 1988: "Monsoon: Unravelling the Mystique," New Delhi, 30 June:72-75.

India Today, 1989: "Power: Seeking Radical Solutions," New Delhi, 31 January: 62-64.

Ives, Jack D. and Bruno Messerli, 1989: *The Himalayan Dilemma: Reconciling Development and Conservation*, Routledge, London.

Jones, Paul H., 1986: *Deep Aquifer Exploration Project in the Nepal Terai*, unpublished paper prepared for the World Bank, South Asia Region.

Jones, Paul H., 1987: "Deep Aquifer Exploration Project in the Ganges and Bengal Basins in India," prepared for the World Bank by P.H. Jones Hydrogeology, Inc.

Jones, Paul H., 1988: "Consultant's Report" to the Eastern Waters Study, Harvard University, Cambridge, Massachusetts.

Kumra, O.P. and A.V. Rao, 1985: "Flood Damage Assessment—A Review," sessions on flood estimation and control, 6-7 December 1985, Rorkee University, India.

Malik, Michael, 1988: "Fear of Flooding," *Far Eastern Economic Review* 142 (151): 20-22.

Mellor, J., and G. Desai, eds., 1985: *Agricultural Change and Rural Poverty, Variations on a Theme by Dharm Narain*, published for the International Food Policy Research Institute by the Johns Hopkins University Press, Baltimore and London.

Ministry of Agriculture and Irrigation (India), 1978: "Proposal for Augmenting Dry Season Flow in the Ganga," photocopy, New Delhi.

Ministry of Irrigation (Bangladesh), 1986: *National Water Plan*, Vol. I, "Sector Analysis"; Vol. II, "Resources"; Vol. III, "Alternative Plans"; and "Summary Report"; Dhaka.

Ministry of Irrigation (Bangladesh), 1988: "National Flood Protection Programme," Dhaka.

Molnar, Peter, 1986: "The Structure of Moutain Ranges," *Scientific American* 225.

National Commission on Floods (India), 1980: *Flood Commission Report*, 2 vol., New Delhi.

Reserve Bank of India, 1984: *Agricultural Productivity in Eastern India*, 2 vol., Report of the Committee on Agricultural Productivity in Eastern India, New Delhi.

Revelle, Roger and V. Lakshminarayana, 1975: "The Ganges Water Machine," *Science* 9 May:611-616.

Rizvi, S., ed., 1969: *East Pakistan District Gazetteers*, Government of East Pakistan (Bangladesh), Dhaka.

Rogers, Peter, 1989: "Opportunities for Development: Technical Features, Costs, Risks, and Limitations," working paper for Eastern Waters Study, Harvard University, Cambridge, Massachusetts.

Rogers, Peter, John T. Quinn, and G. Christakos, 1989: "Notes on Time Series and Kriging of Rainfall Records in the Ganges-Brahmaputra Basin," Eastern Waters Study computational notes, Harvard University, Cambridge, Massachusetts.

Seckler, David and David Molden, 1989: "Irrigation: Economics and Policy," working paper for Eastern Waters Study, Winrock International, Morrilton, Arkansas.

Seckler, David and R.K. Sampath, 1985: *Production and Poverty in Indian Agriculture*, Working Paper No. 1, International School for Agricultural and Resource Development, Colorado State University, Fort Collins.

Sharma, Chandra, 1983: *Water and Energy Resources of the Himalayan Block*, Mrs. Sangeeta Sharma (publ.), Kathmandu, Nepal.

Shukla, J., 1987: "Interannual Variability of Monsoons," in *Monsoons*, Jay S. Fein and Pamela L. Stephens, eds., John Wiley & Sons, New York.

Shukla, J., 1989: "Consultant's Report: Interannual Variability of Summer Monsoon Rainfall Over Bangladesh," Eastern Waters Study, University of Maryland, College Park.

Simons, Daryl B., 1988: *Consultant's Report on Bangladesh Flooding Mitigation*, Eastern Waters Study, 15 December 1988.

Simons, Li and Associates, 1982: *Engineering Analysis of Fluvial Systems*, Fort Collins, Colorado.

Stewart, K, 1989: "Post Flood: Assessment and Nutritional Status of Children in Matlab, Bangladesh," paper presented in *Regional and Global Environmental Perspectives*, Dhaka, 4-6 March.

UNDP (United Nations Development Program), 1988a: *Flood Policy Study: Draft Inception Report of the Joint Government of Bangladesh and United Nations Development Program Teams*, November.

UNDP (United Nations Development Program), 1988b: *Report of the Mission on 1987 Flood Occurrence Analysis and Recommended Action* (Project BGD/87/039), Vol. 1, "Main Report"; Vol. 2, "Annexes."