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**WATER RESOURCES IN THE NORTHEAST:
STATE OF THE KNOWLEDGE BASE**

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Table of contents

| | |
|---|----|
| 1. Background..... | 1 |
| 2. Context..... | 1 |
| 3. Present status of knowledge base..... | 1 |
| 4. Characteristics of the water resources of the Northeast..... | 3 |
| 4.1 General features..... | 3 |
| 4.2 Brahmaputra basin..... | 4 |
| 4.3 Barak basin..... | 7 |
| 5. Water resource availability in major water bodies..... | 7 |
| 6. Groundwater resources..... | 7 |
| 7. Potential for rainwater harvesting in the Northeast..... | 8 |
| 8. Current water demands in the Northeast..... | 9 |
| 8.1 Environmental water requirements for conservation of river courses..... | 9 |
| 8.2 Environmental water requirements related to conservation sites..... | 10 |
| 8.3 Water supply characteristics..... | 10 |
| 9. Future water demand..... | 10 |
| 9.1 Water demand in the subbasins of the Brahmaputra..... | 10 |
| 9.2 Total gross and net water demands..... | 10 |
| 9.3 Future water demand and food requirements in northeast India..... | 13 |
| 9.4 International dimensions..... | 13 |
| 10. Current and future utilization of water resources..... | 14 |
| 10.1 Regional hydropower potential of the northeastern states..... | 14 |
| 10.2 Irrigation..... | 14 |
| 10.3 Navigation..... | 14 |
| 10.4 Fisheries..... | 15 |
| 10.5 Water tourism and recreation..... | 15 |
| 11. Water resource projects..... | 15 |
| 11.1 Water resource development and stakeholder coordination..... | 15 |
| 11.2 Tradeoff issues..... | 16 |
| 12. Technical and engineering challenges..... | 16 |
| 12.1 Technical challenges of development of water infrastructure in the region..... | 16 |

| | |
|--|----|
| 12.2 Impact of climate change..... | 17 |
| 13. Quality of knowledge and identification of gaps..... | 17 |
| 14. Conclusions | 19 |
| Reference list..... | 21 |

Tables

| | |
|---|----|
| Table 1. Water resource attributes: Northeast compared to all India..... | 3 |
| Table 2. Land use pattern of the Brahmaputra and Barak valleys..... | 3 |
| Table 3. Salient features of the Brahmaputra basin..... | 5 |
| Table 4. Groundwater resources of northeast India..... | 8 |
| Table 5. Water withdrawals and water accounting in river basins of India..... | 12 |
| Table 6. Total gross and net water demands..... | 13 |

Figure

| | |
|--|---|
| Figure 1. Percentage contribution to yield by tributaries of the Brahmaputra | 4 |
|--|---|

1. Background

In recent years, due to the increased availability of rapid and advanced testing and monitoring tools, remarkable progress has been made in generating vital data and developing a sound knowledge base in all fields of natural resources. Yet, regions like the northeastern part of India continue to face the daunting task of creating baseline data for the chronically data-poor water sector. The need for such data is apparent: despite the region's huge water resource potential, it still accounts for some of the most water-starved pockets of the country. Aggravating the situation is widespread poverty, with its associated risk of depletion of the natural resource base and accompanying environmental problems. The region also faces an increasing incidence of unrest and insurgency related to growing unemployment, a stagnant economy with slow development, and a lack of the means to utilize available resources to support productive livelihoods.

A long-term water resource management program designed to develop a critical mass of indigenous productivity with the requisite technical, economic, and sociocultural means for sustainable development is an urgent need. Also required is an increase in the capacity of and demand for local expertise to provide comprehensive evaluations of available water resources and ways of utilizing them. The future of the Northeast rests significantly on how effectively concerted endeavors are made in the complex field of food security and water productivity. With Arsenic and fluoride contamination of groundwater posing serious health threats, the water quality issue too deserves increased attention.

2. Context

The value of the water resources of the Northeast is yet to be fully appraised, or the dynamics of the massive Brahmaputra-Barak system fully understood. The first step towards achievement of this task is construction of a sound knowledge base, the lack of which is negatively impacting the planning and implementation of development and management initiatives. Considering the urgent need for ensuring the safety of people's lives and properties from water hazards, promoting social and economic development, and improving ecological services and impacts, it is important to take stock of the current status of the knowledge base and make all possible efforts to strengthen it.

Besides augmenting the available stock of information, research studies need to be oriented towards building a knowledge-driven decision support system. Assessment and synthesis are bound to be limited in the early stages due to lack of comprehensive data, but in due course can constitute the core of a strategic plan of action for the promotion of a water resource development and management program that is designed to ensure sustainable livelihoods for the people of the region. A policy group could factor such a knowledge base into an overall strategy that could initiate practical measures and set definite goals for water resource management endeavors and enterprises.

3. Present status of knowledge base

There is increasing recognition of the need to address not just the spatial and temporal variations of water flow and availability, but also the social, economic, and environmental dimensions of water issues, including quality and quantity assessment of water demand by

various users and sectors (agriculture, domestic, industrial, environmental). Thus, one prime objective of developing such a systematic and wide-ranging knowledge base is to examine quantitatively and qualitatively the current understanding of integrated freshwater resource management in the region, including the status of freshwater resources, existing policy packages on freshwater resources, and alternative policy packages. Data collection processes supporting this effort might encompass such areas as freshwater resource availability (surface and groundwater resources), water demand by various sectors, and assessment of future water availability.

Any knowledge base should be sufficiently complete and appropriately structured to enable best possible action. It should improve information flow from local management realities to decisionmakers and back, enabling increased engagement of stakeholders, integration of data, and fundraising to build and extend information systems. Knowledge management in the water resource sector in the Northeast should therefore be concerned with the development and exploitation of water-centered knowledge focusing upon:

- Identifying utilizable knowledge from previous studies
- Accessing the knowledge, however limited, stored with different agencies and institutions
- Transferring the knowledge in a form that facilitates use
- Continuously working towards filling knowledge gaps
- Improving weak monitoring and quality control
- Maintaining, sustaining, improving, and updating existing knowledge
- Use of knowledge as a tool for sustainable, reasonable, and equitable water utilization
- Appreciation of the complexity of water issues and respect for traditions
- Wise decisions based on quality knowledge
- Holistic policy development based on a sound knowledge base
- Knowledge-driven solutions.

Within the Northeast, the inconsistency of available data in certain cases, the complete lack of data in many cases, and the weak existing hydrological networks in the region act as barriers to the development of a reliable knowledge base. Before initiating any plan of action, it is necessary to evaluate the current status of the hydrological networks and databases in the region. Such an exercise should give due consideration to all categories of data, whether related to natural phenomena, economy and society, or regulatory structures, if integrated water resource management is not to remain a theoretical exercise. It should also be recognized that in the Northeast, the knowledge to be garnered and managed is both explicit, documented knowledge and tacit, subjective knowledge. Management of knowledge therefore entails a wide range of processes associated with the identification, sharing, and creation of knowledge. Systems for the creation and maintenance of knowledge repositories do exist in some form or other in such state departments and agencies as the Brahmaputra Board and the Central Water Commission, but a mechanism to cultivate and facilitate the sharing of knowledge and organizational learning is lacking.

4. Characteristics of the water resources of the Northeast

4.1 General features

The Northeast is distinguished from the rest of the country by several water resource attributes, a number of which are identified in table 1.

Recent satellite imagery of the Brahmaputra and Barak valleys indicates that the land use is predominantly agricultural land and forest cover (table 2).

Table 1. Water resource attributes: Northeast compared to all India

| Attribute | Northeast | All India |
|---|--|------------------------------------|
| Total water resource potential | 537.2 cubic kilometers (30 percent of national total) | 1,791 cubic kilometers |
| Per capita water availability | 18,400 cubic meters | 2,208 cubic meters |
| Hydropower potential | 66,065 megawatts (44 percent of national total) | 148,701 megawatts |
| Hydropower potential developed so far | 3 percent | 16 percent |
| Irrigation potential | 4.26 million hectares | |
| Present coverage of irrigation | 20 percent of existing potential (0.85 million hectares) | 56.4 percent of existing potential |
| Total replenishable groundwater potential | 26.55 cubic kilometers per year (6 percent of national total) | 431.42 cubic kilometers per year |
| Groundwater potential developed so far | 4.3 percent | 32 percent |

Source: Adapted from Goswami 2001.

Table 2. Land use pattern of the Brahmaputra and Barak valleys

| Type of cover | Area (hectares) | % of total area |
|-------------------|------------------|-----------------|
| Forest | 1,726,400 | 21.98 |
| Agricultural land | 4,248,600 | 54.11 |
| Built-up area | 21,100 | 0.27 |
| Water bodies | 567,200 | 7.10 |
| Wasteland | 315,700 | 4.02 |
| Others | 983,300 | 12.52 |
| Total | 7,852,300 | 100.00 |

Source: North Eastern Council 2002.

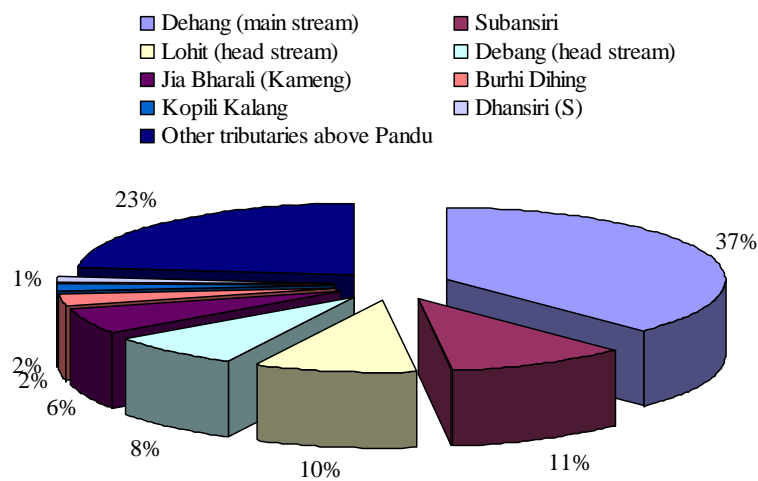
4.2 Brahmaputra basin

The Brahmaputra is a major international river with a drainage area of 580,000 square kilometers, 50.5 percent of which lie in China, 33.6 percent in India, 8.1 percent in Bangladesh, and 7.8 percent in Bhutan. Its basin in India is shared by Arunachal Pradesh (41.9 percent), Assam (36.3 percent), Nagaland (5.6 percent), Meghalaya (6.1 percent), Sikkim (3.7 percent), and West Bengal (6.5 percent). The first 1,625 kilometers of the Brahmaputra lie in Tibet, the next 918 kilometers in India, and the remaining 337 kilometers in Bangladesh. The basin lies between latitudes 23°N and 32°N and longitudes 82°E and 97°E, and is of irregular shape: the maximum east-west length is 1,540 kilometers and the maximum north-south width is 682 kilometers (Dutta and Singh 2004). The average width of the valley is about 86 kilometers, of which the river itself often occupies up to 20 kilometers. Throughout its course in India the Brahmaputra is highly braided, with some well-defined stable banks where the river width is narrow. All along its course, abundant wetlands and back swamps are common in the floodplain.

The average annual rainfall in the basin ranges from 100 to 400 centimeters, most of which occurs during the monsoon months of May/June to September. At present there are 336 ordinary rain gauges and 113 self-recording rain gauges in the basin. The World Meteorological Organization has calculated that an additional 68 self-recording rain gauges and 636 ordinary rain gauges are needed in the Brahmaputra catchment area to meet its data collection standards; nor are these standards met by the Barak basin rain gauge network.

The maximum peak of the Brahmaputra recorded at Pandu is 72,794 cubic meters per second (cumecs) on 23 August 1962, and at Jogighopa, 78,449 cumecs in 1972. The low water discharge at Pandu is about 2,300 cumecs during January or February. The observed maximum high flood level at Pandu is 49.66 meters. The average annual runoff (yield) of the Brahmaputra at Pandu is 49.43 million hectare-meters, of which about 80 percent occurs during the monsoon. The maximum annual yield was 64.39 million hectare-meters in 1977 (Water Resources Department 2004). Major contributions to Brahmaputra yield come from a few large tributaries (figure 1).

Figure 1. Percentage contribution to yield by tributaries of the Brahmaputra



The average discharge at the mouth of the Brahmaputra, at 19,830 cubic meters per second ($19.83 \times 10^3 \text{m}^3\text{s}^{-1}$), places it joint fourth with the Hwang Ho of the world's great rivers, after the Amazon ($99.15 \times 10^3 \text{m}^3\text{s}^{-1}$), Congo ($39.66 \times 10^3 \text{m}^3\text{s}^{-1}$), and Yangtze ($21.80 \times 10^3 \text{m}^3\text{s}^{-1}$) (Goswami 1998). The salient features of the Brahmaputra are given in table 3.

Table 3. Salient features of the Brahmaputra basin

| Feature | Statistic |
|--|---|
| 1. Total catchment area | 580,000 km ² |
| Catchment area within China | 293,000 km ² |
| Catchment area within India | 195,000 km ² |
| Catchment area within Bhutan | 45,000 km ² |
| Catchment area within Bangladesh | 47,000 km ² |
| 2. Length from source to confluence with Ganges | 2,880 km |
| Length within Tibet (China) | 1,625 km |
| Length within India | 918 km |
| Length within Bangladesh to confluence with Ganges | 337 km |
| 3. Gradient | |
| Reach within Tibet | 0.00260 |
| Reach between Indo-China border and Kobo in India | 0.00190 |
| Reach between Kobo and Dhubri | 0.00014 |
| Reach within Bangladesh, first 60 km from India border | 0.00009 |
| Next 106 km reach | 0.00008 |
| Next 92 km reach | 0.00004 |
| Next 79 km reach | 0.00003 |
| 4. Discharge characteristics | |
| Maximum discharge at Pandu (Assam) on 23-08-62 | 72,794 m ³ s ⁻¹ |
| Minimum discharge at Pandu on 20-02-68 | 1,757 m ³ s ⁻¹ |
| Mean annual flood discharge at Pandu | 51,156 m ³ s ⁻¹ |
| Mean annual dry season discharge at Pandu | 4,420 m ³ s ⁻¹ |
| Mean monsoon flow (June to October) Shigatse (Tibet) | 507 million m ³ |
| Pasighat (India) | 3,979 million m ³ |
| 5. Discharge per unit area of basin | |
| Tsela D'Zong (China) | 0.01 m ³ s ⁻¹ km ⁻² |
| Pasighat (Arunachal) | 0.023 m ³ s ⁻¹ km ⁻² |
| Pandu (Assam) | 0.03 m ³ s ⁻¹ km ⁻² |
| Bahadurabad (Bangladesh) | 0.032 m ³ s ⁻¹ km ⁻² |
| 6. Sediment load | |
| Average annual suspended load during flood at Pandu | 4x10 ⁸ metric tons |
| Daily mean sediment load during flood at Pandu | 2.12 million metric tons |
| 7. Sediment yield | |
| Tsela D'Zong (China) | 100 metric tons km ⁻² |
| Pasighat (Arunachal) | 340 metric tons km ⁻² |
| Pandu (Assam) | 804 metric tons km ⁻² |
| Bahadurabad (Bangladesh) | 1,128 metric tons km ⁻² |
| 8. Mean basin rainfall (excluding Bhutan and Tibet) | 230 cm |
| 9. Basin land use (in India) | |

| | |
|-------------------------------|---|
| Total forest cover | 114,992.08 km ² |
| Total agricultural land | 50,473.84 km ² |
| 10. Basin population in India | 30.4 million (143 persons/km ²) |

Source: Compiled from Goswami 1998.

4.3 Barak basin

Parts of the Barak basin are found within India, Myanmar, and Bangladesh; the area within India is 41,723 square kilometers and contains a population of 6.2 million in the states of Meghalaya, Manipur, Mizoram, Assam, Tripura, and Nagaland. Before entering Bangladesh, the river bifurcates into two streams called the Surma and Kushiara. Lower down the river is called the Meghna and joins the combined flow of the Ganges and the Brahmaputra. The principal tributaries of the Barak in India are the Jiri, Dhaleshwari, Singla, Longai, Sonai, and Katakhal.

An average annual surface water potential of 585.6 cubic kilometers has been assessed in this basin. Out of this, 24 cubic kilometers is utilizable water. The average annual yield of the Barak at Lakhipur has been calculated at 14,077 million cubic meters, while monsoon and nonmonsoon averages are 12,073 and 2,004 million cubic meters respectively (Brahmaputra Board 1988). As with the Brahmaputra, floods are an annual threat in the Barak basin, where the maximum flood-prone area is about 4.33 million hectares. The annual average rainfall is 3,400 millimeters, with a highest recorded total of 4,194 millimeters in 1989. The cultivable area of the basin is about 13.04 million hectares, which is 7.1 percent of the total cultivable area of the country.

5. Water resource availability in major water bodies

More than 3,500 wetlands, covering 101,232 hectares in the Brahmaputra valley, which have great significance as unique habitats for many varieties of flora and fauna and also as natural floodwater retention basins (though the total capacity has not yet been assessed), are becoming degraded due to various factors, such as (a) accumulation of deposits, including sand, silt, clay, and pebbles, reducing the depth of wetlands; (b) blockage of feeder channels; (c) construction of embankments, irrigation channels, and roads; and (d) encroachment and cultivation following reduction of the depth of swamp areas.

In Manipur there are about 155 wetlands covering an area of 52,959 hectares, of which Loktak Lake (6,475 hectares) is one of the largest freshwater lakes in India. The Barak valley has a number of floodplain wetlands harboring a great variety of aquatic macrophytes. At present there are nine important flooded depressions (*haors*) in the valley, with a total area of 134 square kilometers. There are more than 10 natural lakes in the Sikkim Himalayas, both spring fed and river fed, that are major storehouses of water and contribute significantly to the stability of water ecology in the region.

6. Groundwater resources

Except for Tripura, which has a net groundwater availability calculated at 2.3 billion cubic meters, the level of groundwater development in the states of the Northeast is low. Assam has the highest groundwater potential among the northeastern states, but only 12.83 percent of groundwater potential is currently utilized. The status of groundwater development in the states of the Northeast is shown in table 4.

Manipur has a total groundwater potential of 3,153.67 million cubic meters, of which 2,680.61 million cubic meters is utilizable. The total annual groundwater recharge is 0.38 billion cubic meters. The net groundwater availability of the state is 0.34 billion cubic meters after deducting

the natural discharge outside the monsoon season. In Nagaland groundwater development is only 2.86 percent, due to a variety of factors including the complex topography and geology, potential for tectonic activity, and lack of appropriate infrastructure and capacity.

Groundwater has played and will continue to play a key role in meeting the water needs of the Northeast, augmenting the abundant rainfall and surface water resulting from the geomorphological and climatic conditions prevailing in the region (though a number of factors, including the very steep gradients characteristic of the area, result in most rainfall being lost in surface runoff). One major aquifer underlies the area to the north of the Brahmaputra, while three to four prolific aquifer systems of Quaternary age underlie the south bank area. To reduce depletion of the groundwater resources of the region, the Central Groundwater Board has explored other options for small-scale freshwater collection, including the development of springs and rooftop rainwater harvesting.

Table 4. Groundwater resources of northeast India

| State | Total replenishable groundwater resources | Provision for domestic, industrial & other uses | Available groundwater resources for irrigation | Net draft | Balance of groundwater resources for future use | Level of groundwater development |
|-------------------|---|---|--|-----------|---|----------------------------------|
| | Billion cubic meters per year | | | | | % |
| Arunachal Pradesh | 1.44 | 0.22 | 1.22 | ... | 1.22 | ... |
| Assam | 24.89 | 3.71 | 21.01 | 1.84 | 19.17 | 8.75 |
| Manipur | 3.15 | 0.47 | 2.68 | ... | 2.68 | ... |
| Meghalaya | 0.54 | 0.08 | 0.46 | 0.02 | 0.44 | 3.97 |
| Mizoram | -- | -- | -- | -- | -- | -- |
| Nagaland | 0.72 | 0.11 | 0.62 | ... | 0.62 | ... |
| Tripura | 0.66 | 0.10 | 0.56 | 0.19 | 0.38 | 33.43 |
| Sikkim | -- | -- | -- | -- | -- | -- |

-- Not yet available.

... Zero or insignificant.

Source: Central Groundwater Board, India.

7. Potential for rainwater harvesting in the Northeast

Although monsoonal rainfall is heavy, the people of the Northeast suffer from acute dry season water shortages every year. The geological formations often do not retain water, runoff is rapid, and springs and small streams soon dry up when there is no rain. However, indigenous rainwater harvesting systems are used for cultivation, some of them ingenious. Settled

agriculture is practiced using irrigated terrace cultivation in parts of Nagaland and in a few villages of Meghalaya; channels are dug to irrigate these fields. The other chief indigenous type of irrigation is the bamboo irrigation system found in parts of Meghalaya, and in some villages in the Mokokchung district of Nagaland.

In response to the water crisis faced by the state every winter, the Mizoram Government has taken up rainwater harvesting on a large scale. The method used involves fitting semicircular rain gutters, fabricated from galvanized metal sheets, to the eaves of roofs to collect rainwater, which is then stored in reservoirs for use during the dry season. Sikkim has, in recent years, evolved efficient water harvesting systems that support traditional land management systems. Mizoram also is making good headway with rooftop rainwater harvesting, though other states of the region are still at the experimental stage.

The technologies of rainwater management are highly location specific and must consider a range of physiographic, environmental, technical, and socioeconomic factors. The main aim is to conserve rainwater where it falls: in the soil profile up to its maximum capacity, and in storage structures for crop irrigation at a later stage. Ultimately the approaches have to be compatible with the socioeconomic requirements and characteristics of the target population.

8. Current water demands in the Northeast

Irrigation is the largest consumptive use of water in the Brahmaputra-Barak basin, accounting for almost 91 percent of total water consumption. However, most of the waters withdrawn for irrigation are lost as non-beneficial depletion. Such losses can be reduced by using effective irrigation practices, including precision irrigation techniques, adjustment of crop planting to match less evaporative periods of demand, and increased reuse of water. Overall irrigation efficiency in the Brahmaputra basin is 32 percent, and potential annual evapotranspiration is calculated as 1,144 millimeters, which is lowest among the basins (Amarasinghe and others 2004).

8.1 Environmental water requirements for conservation of river courses

Most Indian rivers, particularly the Brahmaputra, have very variable monsoon-driven hydrological regimes, with 60–80 percent of the total flow concentrated in 3–4 wet months. The total environmental flow requirements for such Indian rivers, estimated on the basis of information calculated by Smakhtin, Revenga, and Döll (2004), range between 20 percent and 27 percent of the renewable water resources.

Little attempt has been made so far to establish environmental flow requirements for the rivers of the Northeast and define their costs, benefits, and incentives. Given that flow restoration is likely to involve a reallocation of water from current uses and users to in-stream uses, for example aiming to benefit fish and wildlife, the social and economic impacts are likely to be significant. However, the results of such regulation may vary substantially from one situation to another. Outcomes will depend on whether, and to what extent, the net economic returns generated by environment-oriented flows exceed those generated by the development of river water resources according to other criteria. For example, many rivers in the Northeastern Region flow past tea gardens that use fertilizers and pesticides intensively, stretching the

carrying capacity of rivers, and a proportion of the funds required to restore environmental flow may need to be raised using the polluter pays principle.

8.2 Environmental water requirements related to conservation sites

A key step in any wetland conservation strategy is to define the desired ecological character of the wetlands. In the Northeast, this critical aspect has not been given due importance and the wetlands are already in danger of losing their ecological character, mainly due to eutrophication. Incorporation of wetlands into an integrated river basin management plan is of utmost necessity for proper management of water resources. However, such integration is yet to take place in the region, including for those sites designated under the Convention on Wetlands of International Importance especially as Waterfowl Habitat (the Ramsar Convention).

8.3 Water supply characteristics

Of the total water withdrawals of 9.9 cubic kilometers from the Brahmaputra (compared to 267 cubic kilometers for the Ganges), irrigation accounts for 81 percent, domestic withdrawal 10 percent, and industrial withdrawal 9 percent (table 5). The potential utilizable water resources of the basin have been calculated at 50 cubic kilometers, of which 90 percent remains undeveloped. Of those resources that have been developed, certain processes result in their depletion during usage, for example evapotranspiration from irrigated fields. It is estimated that 3 percent of total utilizable water resources in the Brahmaputra basin are currently lost in this way (table 5).

9. Future water demand

9.1 Water demand in the subbasins of the Brahmaputra

In projecting future water demand, in almost all subbasins maximum available irrigated area has been taken to be constant up to 2050 and no significant fluctuation in future water requirements has been projected. In computing water demand for irrigation in different decades, it has been assumed that the minimum area required for meeting the food grain requirements of the subbasin populations in any particular year will be brought under assured irrigation. To calculate the food grain requirement, the daily per capita consumption has been assumed to be 590 grams and the average yield per hectare of pre-kharif and kharif paddy under irrigated conditions is taken as 6 metric tons per hectare per year (Mohile 2001).

9.2 Total gross and net water demands

A gross demand of 62.4 billion cubic meters and a net demand of 27.6 billion cubic meters has been projected by 2050 for meeting domestic, industrial, livestock, and agricultural requirements (table 6). The dependable flow of the Brahmaputra and Barak in the lean flow period is estimated to be in the order of 3,000 cubic meters per second and 45 cubic meters per second respectively at their exit points. The total groundwater potential of the two subbasins, at about 31 billion cubic meters per year, can support, for 240 days per year, a draft of about 1,500 cubic meters per second. From a simple hydrological point of view, the groundwater draft may in the long run lead to more reduction in surface flows. But together, from both sources, about 3,000 cubic meters per second of water is available (Mohile 2001). The net withdrawal from the

system, including groundwater, would be in the order of 239 cubic meters per second in February, which is lower than the lean flow of 304 cubic meters per second. It is suggested therefore that the low lean flow may be sufficient to meet demand, subject to satisfying any environmental flow requirement.

Table 5. Water withdrawals and water accounting in river basins of India

| River basins | Water withdrawals | | | Total renewable water resources | Water accounting | | | | | | |
|----------------------|-----------------------|-------------------------------|-----------|---------------------------------|--|--|---------------------|------------------------|------------------------------|-------------------------------------|------------------------|
| | Total km ³ | Sector withdrawal, % of total | | | Potentially utilizable water resources | % of potential utilizable water resources (PUWR) | | | | | |
| | | Irrigation | Domestic | | | Industrial | Process evaporation | Nonprocess evaporation | Unutilizable outflow of PUWR | Unutilizable outflow of return flow | PUWR not yet developed |
| | % | % | % | km ³ | km ³ | % | % | % | % | % | |
| All basins | 645 | 91 | 5 | 4 | 1887 | 1034 | 24.4 | 11 | 2.9 | 3.1 | 59 |
| Sabarmati | 4.4 | 78 | 15 | 7 | 3.8 | 4.8 | 46 | 12 | 5.9 | 3.2 | 33 |
| Subarnarekha | 6.4 | 88 | 8 | 4 | 12.4 | 8.5 | 21 | 13 | 4.4 | 3.8 | 58 |
| Mahi | 5.3 | 89 | 5 | 6 | 11.0 | 6.6 | 39 | 19 | 3.7 | 2.9 | 35 |
| Meghna | 2.4 | 79 | 13 | 8 | 48.4 | 10.2 | 5 | 5 | 1.9 | 2.7 | 85 |
| Brahmani & Baitarani | 8.8 | 91 | 6 | 3 | 28.5 | 21.7 | 12 | 10 | 2.1 | 2.0 | 74 |
| Pennar | 14.0 | 94 | 4 | 2 | 6.3 | 10.3 | 60 | 18 | 5.2 | 7.9 | 9 |
| Tapi | 7.8 | 87 | 7 | 6 | 14.9 | 21.2 | 17 | 10 | 1.9 | 1.4 | 69 |
| Cauvery | 17.9 | 89 | 6 | 5 | 21.4 | 27.8 | 24 | 13 | 3.3 | 2.8 | 57 |
| Narmada | 12.4 | 92 | 5 | 4 | 45.6 | 43.9 | 12 | 6 | 1.3 | 1.2 | 80 |
| Mahanadi | 19.9 | 91 | 5 | 4 | 66.9 | 63.6 | 10 | 7 | 1.6 | 2.2 | 79 |
| Brahmaputra | 9.9 | 81 | 10 | 9 | 585.6 | 50.0 | 3 | 4 | 1.5 | 2.4 | 90 |
| Krishna | 41.0 | 90 | 6 | 4 | 78.1 | 77.9 | 24 | 13 | 2.4 | 2.0 | 59 |
| Godavari | 41.1 | 91 | 6 | 4 | 110.5 | 109.8 | 16 | 7 | 1.7 | 2.3 | 73 |
| Indus | 81.6 | 97 | 2 | 2 | 73.3 | 60.3 | 48 | 25 | 5.2 | 6.1 | 16 |
| Ganges | 266.8 | 91 | 5 | 4 | 525.0 | 386.5 | 26 | 11 | 3.2 | 3.0 | 56 |

Source: Amarasinghe and others 2004.

Table 6. Total gross and net water demands

| Sector | Gross demand (bcm)^a | Consumption (%) | Net demand (bcm)^a |
|---------------------------------|---|------------------------|---|
| Domestic water supply: | | | |
| Rural, domestic | 2.920 | --- | --- |
| Rural, livestock | 0.694 | --- | --- |
| <i>Total rural</i> | <i>3.614</i> | <i>50</i> | <i>1.807</i> |
| <i>Urban</i> | <i>1.533</i> | <i>30</i> | <i>0.459</i> |
| Subtotal domestic (1) | 5.147 | | 2.266 |
| Industrial (2) | 5.147 | 20 | 1.060 |
| Agricultural water supply: | | | |
| Surface water | 35.200 | 44 | 15.500 |
| Irrigation | --- | --- | --- |
| Groundwater | 16.900 | 50 | 8.500 |
| Subtotal agriculture (3) | 52.100 | --- | 24.300 |
| Total (1+2+3) | 62.394 | | 27.630 |

a. bcm = billion cubic meters.

Source: Mohile 2001.

9.3 Future water demand and food requirements in northeast India

Using the medium projection of India's 2050 population at 1.64 billion, the population of northeast India by 2050 is estimated to increase to about 80 million from its present 38 million. Based upon present consumption of around 500 grams per capita per day, the projected 2050 population of 80 million would require 16 million metric tons of food grain annually (Mohile 2001). However, development of irrigation in this part of India is not encouraging and the region is food deficient. Production of food grain in 2002 was only 5.9 million metric tons. Unless adequate attention is paid to increasing food production, the region will have to depend largely on imports. However, considering the large water potential and land availability, self-sufficiency is a desirable and achievable goal (Mohile 2001).

9.4 International dimensions

The Brahmaputra-Ganges-Meghna system gives rise to perhaps the most complex of all international water negotiations. The combined scale of the environmental, social, and technical issues has no equivalent anywhere else in the world. Given the scale of these problems and the paucity of regional resources that can be garnered to address them, it is not surprising that the negotiation of international cooperation should be protracted and uncertain.

In a memorandum of understanding, signed between India and China in January 2002, China agreed to provide India with rainfall, water level, discharge, and other relevant data on the Yarlung, Zangbo, and Brahmaputra rivers from the three stations of Nugesha, Yangcun, and Nuxia during the flood season. The information is being furnished from 1 June to 15 October every year and is used for flood forecasting in the Northeast.

10. Current and future utilization of water resources

The Brahmaputra Board was established as a statutory body under the Ministry of Water Resources to plan and implement projects to harness the Brahmaputra-Barak system for hydropower, flood control, and economic development. The board has so far identified a series of drainage development schemes, including hydropower dams, embankment reinforcements, and multipurpose projects, which have been included in the respective master plans approved by the Government of India. Several studies suggest that it is likely to be economically unfeasible to transport water from the Brahmaputra to other states, but by harnessing the huge hydropower potential and diverting power to other states the benefits of the waters of the Brahmaputra can still flow to other parts of India (Biswas and Uitto 2001). The hydropower potential developed in the Northeastern Region so far, including those projects under construction, is only about 6 percent of the total assessed potential.

10.1 Regional hydropower potential of the northeastern states

More than 80 percent of the hydropower potential of the region is located in Arunachal Pradesh (32 percent of the national potential). The Dihang, Dibang, Kameng, Subansiri, Teesta, Kolong-Kopili, and Lohit, along with upper Brahmaputra, are the main rivers identified for projects in the Brahmaputra basin. The number of projects identified for the Barak and lower Brahmaputra is comparatively smaller. Four hydroelectric projects have already been executed without any flood storage provision on rivers flowing through Assam.

10.2 Irrigation

According to the Central Water Commission, the total irrigation potential of the northeastern states is estimated at 3,665,000 hectares (NEDFi 2002). Assam has the highest irrigation potential at 2,670 cubic kilometers. However, both in Assam and Arunachal Pradesh, the ratio of gross irrigated area to gross cropped area has declined over the years, indicating that many secondary crops are no longer irrigated due to absence of adequate facilities.

There is need for irrigation during the kharif I season. During the nonmonsoon period of moisture stress, average crop yield is only 1 metric ton per hectare, compared to 3–4 metric tons per hectare in parts of the country with established irrigation. The records of the Central Water Commission indicate that, except for Assam, the states of the Northeast do not have comprehensive irrigation statistics.

A perusal of the projected values indicates that, at the present rate, the irrigation potential likely to be realized by the end of 2020 will be 1,612,000 hectares, considerably short of the total net area sown of 2,700,000 hectares. The aggregated irrigation requirements for the Brahmaputra basin is estimated to be 1.95 million hectare-meters for the kharif I season and 3.25 million hectare-meters for the rabi season, while the total figure for the basin as a whole stands at 5.2 million hectare-meters (Goswami 2004).

10.3 Navigation

Assam's navigable inland waterways extend to 1,983 kilometers out of India's total of 14,544 kilometers and include stretches on 44 rivers, the longest being the Brahmaputra (720 kilometers from Dibrugarh to Dhubri). The Northeastern Region as a whole has the longest navigable waterway network in India, with a cumulative length of 3,844 kilometers. In the

monsoon season, the velocity of the water current is as high as 8–10 kilometers per hour. During this period, although the channel depth for navigation is ample, identification of channel route is complicated.

10.4 Fisheries

The fishery potential of the region is 400,000 metric tons annually; the existing production level is 160,000 metric tons. Floodplain fisheries are dynamic systems and enhancement is only successful if the strategy adopted is appropriate to local conditions. Flexibility is essential as floodplains are complex environments, in both space and time, with a range of hydrological factors operating. For augmentation of fish production and improving the socioeconomic condition of people below the poverty line, the Department of Fisheries, Assam, secured World Bank assistance for the Assam Rural Infrastructure and Agricultural Services project, with a fund provision of Rs. 283,740,000 for a period of eight years commencing 1995–1996. Development of pond and tank fisheries, beel and open water fisheries, infrastructure development, training of farmers and officers, demonstration projects, and fish health care were among the main elements of the project.

10.5 Water tourism and recreation

The water tourism opportunities and adventure sports potential of the Brahmaputra-Barak system have hardly been harnessed so far. Except for small-scale localized initiatives and occasional one-off events, there are very few recreation sites available. In Sikkim, the rivers Teesta and Rangit offer long stretches that are ideal for safe rafting. The Teesta has a series of rapids of varying intensity offering one of the finest rafting stretches in the world.

11. Water resource projects

The Government of India's plan to double electricity generation in the country, termed the 50,000-megawatt hydro initiative, proposes 162 new hydroelectric projects in 16 states, of which 62 are in the Northeast, with a proposed installed capacity of 30,416 megawatts. Most of the rivers for which projects are planned are interstate rivers. Flood control and other programs at basin and sub-basin level are therefore dependent for their success on interstate cooperation and a spirit of accommodation for the larger benefit of the region's people.

Anti-erosion measures include continuous bank revetment with launching apron, closing of breaches, raising and strengthening existing embankments, construction of check bunds, channel cutting, providing boulder and other protection works, bank pitching, and other temporary river training works. Detailed proposals for augmenting and improving the existing flood management infrastructure for a 10-year planning period have been prepared, and an ambitious plan for flood control has been submitted by the Government of Assam to the Asian Development Bank for funding in 2006.

11.1 Water resource development and stakeholder coordination

Little documentation is available on the water resource development initiatives of allied agencies, for example in the rural development and forestry sectors, and the concordance or otherwise of their visions of water resource development. Coordination of activities is hindered by several factors, including lack of communication between different departments;

institutional instability and corruption; weak interstate coordination; lack of priority given to water conservation issues; and absence of demonstrated successful endeavors.

There is no regional consensus about how to confront various water sector issues in a systematic and balanced manner. Stakeholders have diverse proposals and views, some of them contradictory. Convergence of views requires transparent and mutual dialogue amongst the stakeholders leading to collective construction of a future scenario for the development of the water sector in the region and the guidelines to achieve it. Thus, there is scope in the Northeastern Region to promote an extensive regional dialogue and participatory strategic planning process to produce a common agenda for water resource development within an overall strategy for sustainable development. An agenda for sustainable and harmonious water resource development, recognized by stakeholders and adopted by the North Eastern Council or the Ministry of Development of North Eastern Region (MoDONER), needs to be put in place. There is also a need for improved coordination mechanisms among governmental and nongovernmental stakeholders, which will help prevent duplication of actions and improve the returns on financial investments. Of particular importance is formulation of a river basin strategy for water resource development in the Brahmaputra and Barak basins, approved and adopted by the North Eastern Council or MoDONER. The establishment of relationships and dialogue processes capable of analyzing discrepancies and points of conflict, and the exploration of avenues by which agreements can be negotiated, are expected to pave the way for consensus.

11.2 Tradeoff issues

Tradeoff is still not a familiar concept in the water resource sector of the region, but the need for tradeoff is already obvious in several ongoing activities, such as those related to flood and erosion control measures; and road, rail, and navigation within the communication sector. For example, embankments constructed by a state government to prevent flooding often result in an increase in water levels all along the river, overloading other drainage structures and threatening communication infrastructure, including bridges, railways, and roads.

12. Technical and engineering challenges

12.1 Technical challenges of development of water infrastructure in the region

The excessive flow of the Brahmaputra and Barak rivers and their tributaries during the annual monsoon causes floods, erosion, and drainage problems that continue to afflict the Northeast. In addition, the adverse physiography of the region, excessive sedimentation, frequent earthquakes, landslides, deforestation and watershed degradation, and encroachment of the riverine area all pose unusual challenges to the development of water infrastructure in the region. The problems of the Barak valley, with its high elevation, large areas subject to inundation and drainage congestion, and prolonged high water regime, are particularly complex.

12.2 Impact of climate change

A colossal water and sediment load, one of the highest in the world, flows through the Brahmaputra-Barak system during the southwest monsoon, and the impact of climate change on this phenomenon is of critical consequence to the region. Singh (1998) suggests that a rise in surface temperatures in the high Himalayas will lead to increased snow melt, resulting in greater incidence of flooding in rivers flowing from the Himalayan catchments, including the Brahmaputra. An assessment of the implications of climate change for hydrological regimes and water resources in the Brahmaputra basin using scenarios developed from the Hadley Center model simulations indicates that, once the snow melt effect has passed, by the year 2050, the average annual runoff in the Brahmaputra River will decline by 14 per cent.

13. Quality of knowledge and identification of gaps

Organized documentation of the bibliography related to technical and engineering knowledge on the water resources of the Northeast is limited. The Brahmaputra Board has prepared three master plans: master plan I for the main stream of the Brahmaputra, master plan II for the Barak and its tributaries, and master plan III for the 39 tributaries of the Brahmaputra and eight rivers of Tripura for flood management in the Brahmaputra and Barak valleys. The master plans envisage storage dams, embankments, anti-erosion measures, town protection works, and schemes to prevent drainage congestion in the flood-prone areas of the Northeast, and are the only few comprehensive documents available with a synthesis of available relevant information. Each of the master plans is also accompanied by one or more atlas volumes containing relevant maps and drawings of the basin.

Quality control and quality assessment of the knowledge base remains a critical issue. Present gaps must be filled in order to build a dependable knowledge base. There is a need for continuing support to improve water flow monitoring and assessment. A thorough assessment of water quality and midterm and long-term threats to water quality, analysis of alternatives that can address these threats, and the development of suitable basin model components to facilitate integrated water quantity and quality analysis will ensure that the knowledge base and the basin modeling package can adequately deal with these issues. Adequate and consistent funding remains a key prerequisite.

The state of the knowledge base as it currently stands can be summarized as follows:

- The knowledge base is weak in almost all disciplines, both technical and non-technical.
- The Brahmaputra and Barak basins and other water systems are insufficiently studied.
- A regional but non-uniform database exists; data characterization remains a problem, rendering comparison of different sources difficult.
- The current database needs verification and updating.
- Master plans are comprehensive documents but have their limitations; for example, the costing of implementation of a project is often tentative, and projections made for irrigation and municipal and industrial requirements at sub-basin level are not uniform.
- Knowledge is often qualitative rather than quantitative.
- Access to equivalent monitoring programs in other riparian countries is needed.
- Existing mechanisms within umbrella organizations need strengthening.

- The field-based work force is a vital source of practical knowledge.
- Hydrometric and water quality monitoring mechanisms need strengthening.
- The existing climate-surface-groundwater observation network needs improvement.
- Divergent procedures hamper accuracy and ability to use available data.
- Coverage of groundwater quality data needs to be wider.
- There is a likelihood of inaccuracy in estimation of flood damage and related statistics.
- Water-related studies by research institutions are limited.
- Some anticipated changes (for example climate change impact) are not clearly understood.
- Environmental issues are of major concern but are not given priority.
- Building a knowledge base into an effective tool requires consistent work over large areas and for long years, and requires working relations and data exchange between sector institutions. Neither is in place at the moment.
- Data collection staff needs to work in a coordinated fashion with others working on water resource assessment so that data continue to be relevant to current problems, adequate for assessment, and reliable, high-quality source material for users.
- Data need to be converted into information and knowledge, which in turn feed into decision support systems, assisting in addressing priority issues.

To overcome at least some of the above drawbacks of the current knowledge base, steps as follows can be explored:

- Develop forecasting tools that more closely integrate science and technology
- Strengthen water quantity and quality monitoring and assessment to consolidate the knowledge base
- Integrate traditional knowledge where appropriate
- Ensure stakeholder participation in water management to provide input to the knowledge base
- Fill knowledge gaps through sound information systems, better access and exchange, and open information policies; enhance education, communication, and participation to facilitate community involvement, contributing to improved planning and management
- Attempt to fill the knowledge gaps through systematic, proactive, and participatory processes
- Improve the hydrometeorological monitoring system using on-line sensors and data loggers
- Use radar alternatives for real-time measurement of velocity and depth profiles across streams; improve rainfall data by combining rain gauge data with weather radar data
- Use hydrological and meteorological information for general water resource management in addition to flood forecasting

- Ensure availability of data for evaluation of completed water management projects by competent experts
- Create linkages between water development and monitoring of water use; undertake specific studies targeting assessment of supply and demand
- Undertake model studies for analysis, planning, and management of a wide range of water resource and environmental problems
- Apply more widely remote sensing and Geographic Information System (GIS) technology for development of water resource action plans
- Map water hazards and groundwater
- Assess water harvesting potential
- Carry out tradeoff analysis and potential conflict resolution assessment
- Collaborate cross-sectorally to obtain a broad knowledge base
- Undertake climate change impact study in different water user sectors
- Integrate land and water management for food and environmental security
- Account for environmental water requirements in water resource assessment
- Assess potential future impact of virtual water trade
- Develop strategy for evolution of water management in the context of South and Southeast Asia
- Calculate fund requirements
- Integrate quality control and quality assurance
- Draw a long-term human resource development and training plan

14. Conclusions

Addressing all of the above needs immediately is unlikely to be possible. However, there are several priorities that need to be addressed to bring the current knowledge base to a level capable of supporting any meaningful water resource management initiative. Strengthening water quantity and quality monitoring and assessment is an urgent need, and requires integration of scientific and technological approaches to produce better forecasting. A modern hydrometeorological monitoring system with on-line sensors and data loggers needs to be built up. Similarly, radar alternatives for real-time measurement of velocity and depth profiles across streams and channels must be in place, alongside an improved rainfall dataset combining rain gauge data with weather radar data. With such real-time data, model studies for analysis, planning, and management of a wide range of water resource and environmental challenges will be possible, enabling achievement of tangible goals. Following the innovative approach used for the Yellow River, it should be possible, once a dependable data-processing system befitting the complex water resource scenario of the Northeast is in place, to use prototype and model simulations of the Brahmaputra-Barak system as an important decision-making tool.

The extent of people's dependence on a large river system like the Brahmaputra-Barak has rarely been fully integrated into appropriate water management efforts. In order to achieve this,

knowledge of all aspects of the Brahmaputra-Barak system, taking into account its strategic location and how it will respond to future geophysical, biological, and socioeconomic changes, must be improved. Such scientific knowledge could form the basis for sustainable technological responses and integrated, interdisciplinary efforts able to convincingly link development – for example of hydropower – with societal benefits, such as flood hazard mitigation. Such a holistic approach would aim to integrate a wide range of objectives, such as improved forecasting, sounder water resource management, minimization of water hazards, natural resource conservation, watershed protection, and carbon sequestration.

Reference list

- Amarasinghe, U. A., B. R. Sharma, N. Aloysius, C. Scott, V. Smakhtin, C. de Fraiture, and A. K. Shukla. 2004. *Spatial Variation in Water Supply and Demand across the River Basins of India*. Research Report 83. International Water Management Institute, Colombo, Sri Lanka.
- Biswas, Asit K., and Juha I. Uitto, eds. 2001. *Sustainable Development of the Ganges-Brahmaputra-Meghna Basins*. Oxford University Press, New Delhi, India.
- Brahmaputra Board. 1988. *Barak Master Plan*. Brahmaputra Board, Guwahati, Assam, India.
- Dutta, B., and V. P. Singh. 2004. "Hydrology." In V. P. Singh, N. Sharma, C. Shekhar, and P. Ojha, eds., *The Brahmaputra Basin Water Resources*. Kluwer Academic Publishers, Dordrecht, Netherlands.
- Goswami, D. C. 1998. "Fluvial Regime and Flood Hydrology of the Brahmaputra River, Assam." *Memoirs of the Geological Society of India* 41:53-75.
- Goswami, D. C. 2001. *Himalayan Catchment and the Hydrologic Regime of Brahmaputra River, India: Selected Case Studies*. Available at www.cig.ensmp.fr.
- Goswami, D. C. 2004. *Flood Forecasting in the Brahmaputra River, India: A Case Study*. Available at www.southasianfloods.org.
- Mohile, A. D. 2001. "Brahmaputra: Issues in Development." In Asit K. Biswas and Juha I. Uitto, eds., *Sustainable Development of the Ganges-Brahmaputra-Meghna Basins*. Oxford University Press, New Delhi, India.
- NEDFi (North East Development Finance Corporation). 2002. *NER Databank*. NEDFi, Guwahati, India.
- North Eastern Council. 2002. *Basic Statistics of NER 2002*. North Eastern Council, Shillong, India.
- Singh, R. B. 1998. *Towards Promoting PUB Monitoring Network and Predicting Erosion Vulnerability in the Ungauged Basin of the Indian Himalaya Using Remote Sensing and GIS*. Available at www.cig.ensmp.fr.
- Smakhtin, V, C. Revenga, and P. Döll. 2004. *Taking into Account Environmental Water Requirements in Global-Scale Water Resources Assessments*. Comprehensive Assessment Research Report No. 2. International Water Management Institute, Colombo, Sri Lanka.
- Water Resources Department. 2004. *Vision 2020 Report*. Government of Assam.