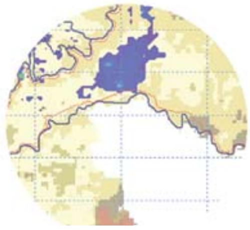
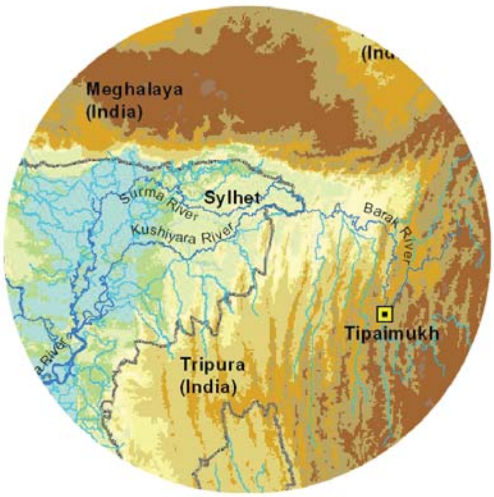
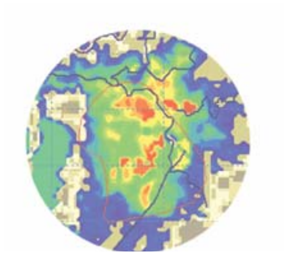
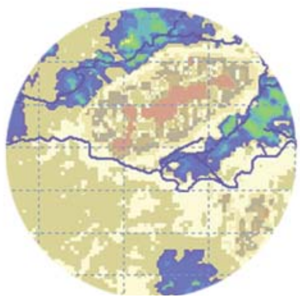




Hydrological Impact Study of Tipaimukh Dam Project of India on Bangladesh





Institute of Water Modelling (IWM)
April 2005

Hydrological Impact Study of Tipaimukh Dam of India on Bangladesh

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About IWM

Institute of Water Modelling (IWM) provides world–class services in the field of Water Modelling, Computational Hydraulics & Allied Sciences for improved integrated Water Resources Management. It is a unique organization in the region having sustainable technological capability in developing mathematical models and decision support systems for both surface and ground water and related environment. The applications of IWM modelling tolls cover a wide range of water related aspects such as: flood control, flood forecasting, irrigation and drainage, water resources management, river morphology, salinity and sediment transport, coastal hydraulics, port, coast and estuary management, environmental impact assessment, bridge hydraulics and related infrastructure development.

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Preface

The Hydrological Impact Study of Tipaimukh Dam Project has been completed by Flood Management Division as one of the research projects being carried out by Research and Development (R&D) unit of Institute of Water Modelling (IWM).

Bangladesh and India is sharing as many as 54 trans-boundary rivers with each other. Out of those 54 rivers, the respective Indian water management authorities have been heavily modifying annual flows of 48 rivers. The very consequences of those modifications are unprecedented and affecting the overall economy of the country. The experience is already very bad in the northwest and southwest region of Bangladesh due to Farakka Barrage on Ganges River, and it is expected that this will occur more in future for the other rivers also.

The Barak River flow alteration and withdrawal by constructing a hydroelectric dam at Tipaimukh and a barrage at Fulertal is one of the recent planning by India. The Barak River is the single largest contributory river to the northeast region of Bangladesh. It is being believed that any large scale water storage and diversion in the upstream of the Barak River will cause an adverse impact in the Surma-Kusiyara River System of the region. The analysis of this study, due to time and resource constraint, has concentrated only on the changes in hydrology of the river system and floodplain-wetland *(haor)* of Sylhet-Moulvibazar district that would be the most probable case during post-dam condition. A short qualitative assessment has also been done on the morphological impact of the region in response of such changes. In addition, a theoretical discussion has been presented here on the possible dam break aspect, considering the highly seismic instability of the northeast region of India and Bangladesh.

The study itself is not the end but the beginning for more comprehensive study at the Government level.

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The study team would like to give their thanks to the respective officials of Joint River Commission (JRC) of Bangladesh, Bangladesh Water Development Board (BWDB) for giving their important suggestion during the conceptualization of this research study. Special thanks must goes to Mr. Tauhidul Anwar Khan, Chairman of JRC Bangladesh who shared his knowledge and experience on the disputes as well as on the transboundary river basin management.

The study team believe the present hydrological impact study of Tipaimukh Dam could not have been done successfully if Zakir Kibria, the central person of Bangla Praxis had not been able to collect and provide the *Detailed Project Report of Tipaimukh Hydroelectric (Multipurpose) Project* along with other important documents. The study team is indebted to him for his assistance.

The study team must gratefully acknowledge the helpful encouragement of Mr. Emaduddin Ahmad, Executive Director of IWM.

The study team also express their gratitude to other members of Flood Management Division of IWM who were involved in different stages of this study and provided volunteered services.

Acronyms and Abbreviations

BWDB	Bangladesh Water Developmet Board
DHI	Danish Hydraulic Institute
DPR	Detailed Project Report
FAP	Flood Action Plan
FPCO	Flood Plan Coordination Organisation
FRL	Full Reservoir Level
FSL	Full Supply Level
GBM	Ganges-Brahmputra-Meghna
GWH	Giga Watt Hour
Ha.	Hectare
HR	Hydropower Reservoir
ICOLD	International Commission on Large Dam
IWM	Institute of Water Modelling
JRC	Joint River Commission
km	Kilometer
MDDL	Minimum Draw Down Level
MIKE 11	One Dimensional River Modelling Software developed by DHI
MIKE Flood	Flood Propagation Model developed by DHI
MMSL	meter Mean Sea Level
MW	Mega Watt
NAM	Rainfall-Runoff Model (Nedbor Afstromings Model)
NEEPCO	North Eastern Electric Power Corporation Limited
NER	North East Region
NERM	North East Region Model
RIS	Reservoir Induced Seismicity
SAARC	South Asian Association of Regional Co-operation
Sq. km.	Square Kilometer
USA	United States of America
WL	Water Level

Chapter 1

Introduction

Background of the Study

Bangladesh and India is sharing as many as 54 trans-boundary rivers with each other. Being a lower riparian country of the GBM Basin, Bangladesh receives as much water as it is 'allowed' to enter into Bangladesh through these rivers. The question of 'allowance' is used to bring the fact to the surface once again that out of those 54 trans-boundary rivers, annual flow of 48 rivers are now heavily modified by the respective Indian water management authorities. In this epoch of modification, there remain in one hand, rivers like the mighty Ganges on the western part of the country, ever-unpredictable Teesta on the northeastern part, violent Gumti on eastern part, flashy Manu on the northeastern, and on other hand, many other small river courses entering into Bangladesh. The nature of modification varies from storage and withdrawal to regulate the seasonal flows to sudden opening the gates of those regulators to release out the extra water holding upstream of those regulators. The very consequences of those modifications, as we now understand, are unprecedented. The impacts bear numerous dimensions – eco-hydrological, morphological, geological, biodiversity and environmental, climatic change and desertification, socio-economical, and finally political. We have already experienced those very badly in the northwest and southwest region of Bangladesh due to Farakka Barrage on Ganges River, we are going to observe more and more in future for the other rivers also.

Currently Central Water Commission of India is planning to divert, control, and withdraw more and more water from those common rivers between Bangladesh and India. Barak River flow alteration and withdrawal by constructing a hydroelectric dam at Tipaimukh and Fulertal Barrage is one of those planning. The last havoc that Bangladesh can ever imagine is about to come when it is being strongly believed that India is planning to divert the Brahamaputra flow to the water 'deficit' states of India.

This report though is on the study carried out by Institute of Water Modelling (IWM) to understand the most probable scenario that will be seen in the northeast region of Bangladesh in near future, in terms of hydrological change if there is a 168.5 meter rock-filled earthen dam constructed on the Barak River at Tipaimukh.

The Tipaimukh Dam on the Barak River is now neither a concept nor just a mere proposal of the Central Water Commission of India. It is very much on its way to be constructed with an aim to produce an estimated 1,500 MW electric power with firm power generation of 401 MW[1].

[1] NEEPCO, *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, Shillong 2000, ch. IV p. 3.

The proposed Tipaimukh Dam- a 162.8 m high rock-filled earthen dam is going to be constructed on the Barak River at 500 m. downstream of the confluence of the Barak and Tuivai River near Tipaimukh village in Manipur state (see Figure 1.1), where the Barak River takes a 220^0 bend from southwest ward direction to northerly direction and flows through a stretch of more than 24 km. downstream of Tipaimukh[2].

It has been confirmed that the whole project would submerge nearly 311 sq. km. of land permanently in India, of which around 229.11 sq. km. areas are reserve forest, remaining are agricultural and settlement land.[3] The local and indigenous people of Manipur and Mizoram state of India, eminent engineers, geologists, environmentalists have opposed the dam proposal right from the beginning of its conceptualization. It is being claimed from their side that this project would result in a massive socio-economic, ecological and environmental disaster, at both riparian of upstream and downstream of the dam. However, overruling those claims the Central Water Commission of India and NEEPCO (North Eastern Electric Power Corporation Limited), the assigned organization for carrying out the project, have asserted that the project would moderate the annual flood in the Barak sub-basin along with potential power generation facilities of 1500 MW. They have also enforced their statement in favor of the dam by saying that it would make feasible the proposed pick up barrage near Fulertal, about 100 km. upstream from Amalshid (Bangladesh-India border) and 95 km downstream of the dam to develop the Cachar Irrigation Project (see Figure 1.2) and enhance the navigability of the Barak and its tributaries during the dry season as a complementary benefit of the Tipaimukh Dam Project[4].

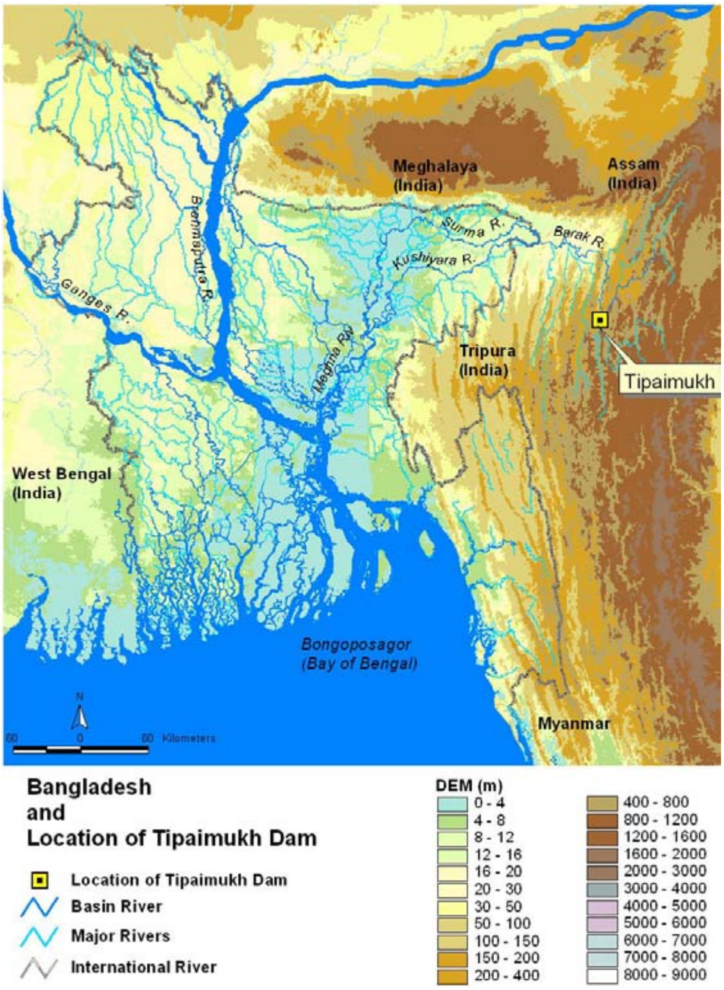

Figure 1.1 Location of Tipaimukh Dam, India

[2] Ibid., ch. I p. 5.

[3] Ibid., ch. III, p. 3.

[4] Ibid., ch. II, pp. 1-16.

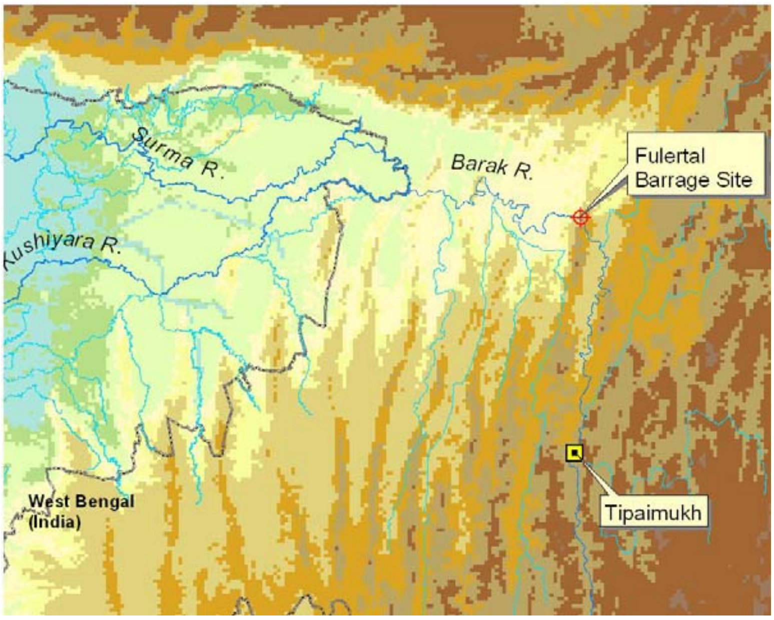

Figure 1.2 Proposed location of pick-up barrage at Fulertal

Meanwhile, this is the brief introduction of the Tipaimukh Dam Project on which so many claims and counter claims are continuing on both sides of the project, by pro-dam side and anti-dam people of India. But this is only the one side of the whole issue. The other side lies on the much concerned perspective of potential hydro-morphological, ecological, socio-economical impacts of the dam project on the Barak River which are likely to be happened in the downstream region, particularly in the northeast region of Bangladesh in future. Some of the impacts may be realized within a very short time as an immediate impact, while some of the environmental effects of the dam may not be realized for hundreds of years after construction. That's why it has been claimed, as Patrick McCully said in his book *Silenced Rivers, The Ecology and Politics of Large Dams* that, 'A dam can thus be regarded as a huge, long-term and largely irreversible environmental experiment without a control'.[5]

This type of apprehension has not been aroused for not only that Bangladesh is the downstream riparian of the Meghna Basin but also for the core hydrological misconception of how we understand and characterize the river basin and the eco-hydrological system it produces. How natural phenomena like rivers and its flood have been conceptualized – in psychologically, materially and the symbolically – in a era of supremacy of 'modern science' and how this supremacy can be maneuvered to meet the nationalistic development goal of a modern country that is also a question to ponder about.

So there are many dimensions of such a mega project aiming to exploit the natural resources like water. The present study, however, is limited on three aspects. Firstly, a preliminary study on how and to what extent the Tipaimukh Dam Project on the Barak River may cause a hydrological impact on the northeast region of Bangladesh using the advanced modelling tools like MIKE 11 and MIKE Flood. Secondly, an analytical examination of whether this changed hydrology would have any negative impact on the river-floodplain ecosystem, morphology of the region and if it has then how. Thirdly, a more theoretical investigation on the potential threat that a large dam always poses to the inhabitants of the downstream, of dam break and the

[5] Patrick McCully, *Silenced Rivers, The Ecology and Politics of Large Dams*, Zed Books, London 1996, p. 31.

catastrophic consequences of such, including the seismic factor of the dam site as well as of the whole region.

Objective of the Study

The main objective of the study can be asserted as to assess the probable impacts, which are likely to be happened due to the operation of proposed Tipaimukh Hydro Electric Dam (Multipurpose) Project of India by storing, regulating, withdrawal or diversion of the Barak River flow on the northeast region of Bangladesh.

The specific objectives are:

- Assessment of the most probable hydrological change that may happen in the Barak-Surma-Kushiyara river system during Tipaimukh Dam operation scenario.
- Investigation on how the changed hydrology would influence the natural and usual inundation pattern of floodplain and wetland (*haors*) of the northeast region of Bangladesh and its effects on the riverine ecosystem.
- Qualitative assessment of the probable impacts of Tipaimukh Dam Project on the morphology of the Surma-Kushiyara river system.
- An investigation on the potential threat of dam break and its consequences on the downstream.

Methodology

The comprehensiveness of the present study, as the study team has realized, is how and to what extent of accuracy the estimation or forecasting of the probable Barak River flow during post-dam scenario can be achieved. This is the main challenge what the study team has faced. It was not an easy task as there were limited amount of data and information regarding the project itself and the Indian part of Meghna Basin (Barak sub-basin) available in Bangladesh. It has been formulated that if the probable river flow at Amalshid point of the Barak River, where the river enters into the territory of Bangladesh and diverts into its two distributaries – the Surma and Kushiyara River – could be estimated effectively for the post-dam scenario then it would act as the basis of how the changed round the year flow pattern is going to make an effect on the Surma-Kushiyara river system.

Meanwhile, to investigate the probable flow in the Barak River during post-dam scenario, *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, published by North Eastern Electric Power Corporation Ltd. (NEEPCO), India in the year of 2000 has been the single most important document on which the study team had to rely heavily with some cautious judgment. The *DPR on Tipaimukh Hydro Electric (Multipurpose) Project* revels some salient features of the project, which have been found valuable to estimate the probable river flow during the dam in full operation. Using those data and information, the Barak River flow at Amalshid point for the post-dam condition has been generated, considering that the pre-dam hydrological events at Amalshid would continue as same as it had been for the period of 1971 to 2001 in future if there is no hydropower project operating on the Barak River.

The existing North East Region Model (NERM) 2002-'03 has been used as base model during these periods, while the generated post-dam flow at Amalshid has been used as the changed upstream boundary of the Barak River for NERM to run the model for post-dam condition.

Besides that, using the statistical analysis of Amalshid discharge during the last 30 years, different hydrological years have been selected (see Table 1.1) and simulation of hydrodynamic model of NERM based on MIKE 11 HD and NAM for those different hydrologic years have been carried out for both pre and post-dam condition.

Table 1.1 Selected hydrological events and corresponding years

Event	Year
Average (1 in 2.33 yrs) monsoon	1996
Drier Than Average Monsoon Year	1999
Average dry year	1976
Critical dry year	1979
Next year after critical dry year	1980
1 in 5 yrs pre-monsoon	1981
1 in 5 yrs monsoon	1981
1 in 10 yrs pre-monsoon	1993
1 in 10 yrs monsoon	1976
1 in 25 yrs pre-monsoon	2000
1 in 25 yrs monsoon	1990
1 in 50 yrs pre-monsoon	1991

The simulation results for both pre and post-dam conditions have been analyzed and the changes in river hydrology have been presented in tables and charts. But what do these changes in river dynamics in numeric value actually mean to the river basin from eco-hydrological, morphological, environmental perspective that has also been attempted to analyze in the present study. To understand the pre-dam and post-dam inundation pattern of the northeast region of Bangladesh, especially for Sylhet and Moulvibazar district, flood propagation model MIKE Flood has been used.

On the other hand, a qualitative morphological impact assessment has been attempted with relatively more simplistic and straight forward approach based on the changes as found in the river hydrology.

The probable attenuation of mean annual monsoon flood and the augmentation in dry season flow of the Barak River has been also analyzed. An attempt was there to investigate the implications of those alterations in the natural annual river flow of the river system. In every large dam projects, the dam initiators argue that the dam will solve the flood problem of the downstream regions, thereby it should be considered as beneficial for the downstream region. Thus, whether the attenuation of average annual monsoon flood is desirable by any means has also been examined. It has been further discussed whether the augmentation of dry season flow would still happen in extreme dry event (in critical dry years) or it would make the condition more acute for consecutive years of dry spell in a the Barak Basin.

Literature Review

During this study it has been found that there are serious lack of scientific documentation and data /information in Bangladesh to assess the probable impact of Tipaimukh Dam Project of India on Bangladesh. Though a wide spread of discussion, analysis, comments, protests are ongoing around in Bangladesh from policy makers to experts to general people, lack of proper technical backings to support the issue is still wanting.

Nevertheless, FAP 6 did the most important study on this issue, particularly on the availability of water in the Surma-Kushiyara river system after post-dam (plus Cachar Irrigation Project of India) scenario and the dam failure impact, back in 1993.

The study analyzed several scenarios. Future scenarios reflected the major changes expected to occur by 2015 due to implementation of the Tipaimukh Dam/Cachar Plain Irrigation Project in India. It is stated in the report that the information on Tipaimukh Dam/Cachar Palin irrigation design and operation is sketchy. Information was obtained through the Joint Rivers Commission, though minimally adequate, used to make preliminary assessment of impacts on the region. The study recognizes that regulation of the Barak's flow by Tipaimukh Dam would provide India with opportunity to irrigate the Cachar Plain, which will involve a loss of water from the Barak. As such it is a valid matter of concern to the northeast region of Bangladesh. As the amount of water withdrawal was not known, it had been assumed in the study that the total depth of irrigation water to be applied is 1 meter and the water is diverted on a continuous basis during the six dry months (November to April). Mathematical model (MIKE 11) had been used to predict the changes in water level and discharges in different rivers. In the study, the DAMBREAK module of the MIKE 11 model was also used to create post-dam failure scenarios for illustrative purpose only.

The impact of the Tipaimukh Dam and Cachar Plain Irrigation scheme in the region had been analyzed in two phases: operational period and pre-operational period (during reservoir filling). The study identified that significant impacts on the region will result from implementation of the said project. The impact had been analyzed for an average flow year. Findings suggest that the flood flows on the Barak River will be moderated. Peak flow at Amalshid would be reduced by about 25% and flood water volume would be reduced by 20%. The corresponding water level at Amalshid would be reduced by about 1.6 meter. Similar changes had been expected in the Surma and Kushiyara River. This would reduce the frequency of spills from the Kushiyara and Upper Surma River, reduces the extent of inundation in the Sylhet Basin and reduce channel erosion and sediment transport rates along the two rivers. But Pre-monsoon flood levels between Madna and Sherpur will increase affecting 5000 km^2 of the central Sylhet depression, including existing submersible embankment projects. The study also suggested that the post-project condition would increase winter discharge and siltation as well along the Kalni River. Overall dry season flow would be increased by 60 %. In addition, pre and post-monsoon water levels will rise by as much as 1.5 meter at Markuli. The study also concluded that the sediment deposition in the channel and adjacent floodplain will increase and will adversely affect the fisheries and navigation.

Apart from the FAP 6 study, there is no proper study so far done on the possible impact of Tipaimukh Dam in Bangladesh. Few booklets, papers and editorial columns are only available in the Internet and local newspapers addressing the issue. On the other hand, lots of writings including scientific, well-researched papers are available in the Internet from the Indian side. Though most of those writings are essentially focusing on the effects of the Tipaimukh Dam Project on local indigenous people of Manipur and Mizoram states of India, possible threat on the biodiversity and ecology of the entire dam site, possibility of dam induced flood in downstream Barak valley, seismic factor of the dam site, etc. Most importantly they are challenging the very core concept of national development agenda of India by opposing the ongoing and proposed construction of large dams in the river basin.

Hence, as this study is concentrating on the potential impact of Tipaimukh Dam on Bangladesh, the following paragraphs of this section will mention some of the analysis, comments associated to those impacts on the northeast region of Bangladesh, both from Bangladeshi and Indian writers.

One of the important publications regarding the probable impacts of Tipaiumukh Dam Project is *DAM or Damage: Tipaimukh Hydroelectric Dam Project,* edited by **Zakir Kibria** of Bangladesh and **Roy Laifungbam** of India addressing the issues on which people of both upper and lower riparian have much concern[6]. Especially on socio-economic, hydro-geological, environmental impacts of such mega project.

Himanshu Upadhyaya, an independent researcher working on Public Finance and Accountability issues in India, wrote in his article 'On, off, viable, scrapped, …'[7] that the project would block the flow of the country's major riverine network in the northeast and deliver a fatal blow to the downstream communities in Bangladesh. He also asserted that the project would have consequences of no less magnitude than the Farakka Barrage across the Ganges to the northwest of Bangladesh.

Quamrul Islam Siddiqui, the president of the Institution of Engineers and chairman of the Global Water Partnership, Bangladesh said in a daily news paper that after completion of the project, Bangladesh would get less water in three rivers- the Meghna, the Surma and Kushiyara. Tipaimukh can spell disaster for Bangladesh.[8]

Shahidul Islam Chowdhury wrote in his article 'Hydel Plant to Dry up the Meghna' in the daily newspaper *the New Age* of Bangladesh that the Tipaimukh Dam Project could inflict on Bangladesh's economic, ecological and human catastrophes.[9] He also warned that the project also could hit the country fatally, and in no less a magnitude than the Farakka Barrage across the Ganges. Mr. Chowdhury quoted Dr. **Ainiun Nishat** that Bangladesh could not stop the commissioning of the Tipaimukh Project, however, the government can attempt to find out how the project would operate during the rainy and dry seasons and negotiate to ensure the flow of the rivers. Some experts believed even if the project has already been given permission to proceed, there is still scope for negotiations between the two neighbors on the issue.

On the other hand, **Reaz Ahmad** in Dhaka with **Pallab Bhattacharya** in New Delhi wrote that the water interlink project was the last straw to Bangladesh after the central Indian government also approved budget for the much-debated Tipaimukh Hydro Electric (Multipurpose) High Dam Project, proposed to be constructed at the confluence of Barak and Tuivai River in

[6] Zakir Kibria and Roy Laifungbam (eds.), T*ipaimukh Hydroelectric Multipurpose Project: Dam or Damage,* Rivers for Life Vol. 1, Bangla Praxis and Centre for Organization Research & Education, Dhaka 2003.
[7] *The India Together,* India November 2004, url: www.indiatogether.org/2004/nov/env-mandam.htm (last visited on January 05, 2005)
[8] Ibid.
[9] The New Age, Bangladesh July 2003, url: www.newagebd.com/july4th03/220703/front.html (last visited on January 05, 2005)

Manipur.[10] They referred to experts fear where it is being said that the water diversion from Barak for power generation will have a negative impact on water-flow pattern in the Surma and Kushiyara River in Sylhet, which ultimately carry water to the Meghna.

Wahid Palash in his paper 'Tipaimukh Dam: A Lower Riparian Perspective' on the probable impacts of the dam on the downstream riparian discussed that any large scale change in natural water flow hydrograph, sediment and nutrient carrying features of these rivers are likely to have an destructive impacts on the ecology of the entire basin area.[11] He asserted that Tipaimukh Dam would also create such havoc on a co-riparian basis, irrespective of consumptive or non-consumptive use of water behind the dam. He expressed that the real danger of this project remained underneath the tectonic plate of the site as this site had huge potentiality to be affected by severe earthquake, and in such cases, the catastrophic dam break would no longer be conjectural; it would surely be followed by disastrous consequences on the livelihood, on the people living at downstream region of the dam.

[10] *The Daily Star*, Bangladesh October 2003, url: www.thedailystar.net/2003/10/01/d3100101011.htm

[11] Wahid Palash, 'Tipaimukh Dam: A Lower Riparian Perspective' in Zakir Kibria and Roy Laifungbam (eds.) T*ipaimukh Hydroelectric Multipurpose Project: Dam or Damage,* Rivers for Life Vol. 1, Bangla Praxis and Centre for Organization Research & Education, Dhaka 2003

Chapter 2

Meghna Basin and Northeast Region of Bangladesh

Location and Geography

Bangladesh is the site of the world's largest alluvial delta, and the formation of this delta is solely associated with the very distinguished water and sediment carrying features of the mighty Ganges-Brahamaputra-Meghna (GBM) Basin (see Figure 2.1). The total drainage area of these river systems is more than 1.55 million sq.km. of which about 0.12 million sq.km. (7.5 per cent) lies within Bangladesh.[1] GBM river system is, therefore, a continental system stretching across five countries: India, Nepal, Bhutan, China and Bangladesh, of which Meghna Basin is the smallest but one of the most unpredictable and chaotic basins in the world by hydrologic means. About 10 percent of the world's humanity lives in GBM region, which contains only 1.2 percent of the world's landmass. The region is characterized by endemic poverty-being home to about 40 percent of the total number of poor people residing in the developing world.[2]

Larger portion of the northeast region of Bangladesh falls within the Meghna Basin. Meghna Basin, on the other hand, bounded by Indian Shield on the west, by Madhupur tract on southwest, by Meghalaya Foothills, Shillong Plateau and North Cachar Hills on the north, by Tripura Hills on the south; and the basin extends towards the northeastern states of India comprising western part of Manipur and northern part of Mizoram and Tripura (see Figure 2.2). The total basin area of Meghna is 82,000 sq.km., out of which 47,000 sq.km. and 35,000 sq.km. lie in India and Bangladesh, respectively.[3]

The northeast region of Bangladesh encompasses 2.42 million hectares of land. The topography is irregular, falling from the piedmont hills near India across gently sloping plains to the Sylhet Depression near the geographic center of the region.[4] The region is a triangular shaped wedged, roughly 250 km east to west and 120 km north to south.[5] The region is bounded by the Old Brahamaputra River on the west, by the Meghalaya Foothills and Shillong Plateau on the north, and by the Tripura Hills on the southeast. It consists of two portions, the larger comprising

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[1] M.M. Hoque, S.M.U. Ahmed, A.B. Siddique, 'Generation of Boundary Hydrographs for Flood Prediction in the Major Rivers of Bangladesh' in Mir M. Ali et al. (eds.), *Bangladesh Floods, Views from Home and Abroad,* The University Press Limited, Dhaka 1998, p. 77.

[2] Ashraf-ul-Alam Tutu, 'Draft Concept Note on Peoples River Commission', Dhaka.

[3] A.H. Khan, 'International Water management Issue: South Asian Perspective' in Mir M. Ali et al. (eds.), *Bangladesh Floods, Views from Home and Abroad,* The University Press Limited, Dhaka 1998, p. 220.

[4] FAP 6, *Northeast Regional Water Management Project*, Interim Report, FPCO, January 1993, p. A-1.

[5] FAP 6, *Specialist Study, River Sedimentation and Morphology,* Draft Final Report, FPCO, May 1993, p. 3.

20,261 sq.km. or 83.5 per cent of the region, lying within the Meghna Basin. The smaller portion comprising 4,004 sq.km. or 16.5 per cent of the region, lies on the left bank of the Old Brahamaputra and Lakhya River.

Although the two portions of the region experience essentially the same climate and are similar geologically, they differ significantly in the number and nature of their cross-boundary inflows. The Meghna portion receives many flashy inflows from the adjacent Indian states of Tripura, which lies south of the region, and Meghalaya to the north. It also receives the substantial outflow of the Barak River Basin, which lies to the east and occupies parts of the Indian states of Assam, Mizoram and Manipur. In contrast, the Old Brahamaputra and Lakhya portion receives only floodwaters spilling into the Old Brahamaputra from the Jamuna and Brahamaputra River[6].

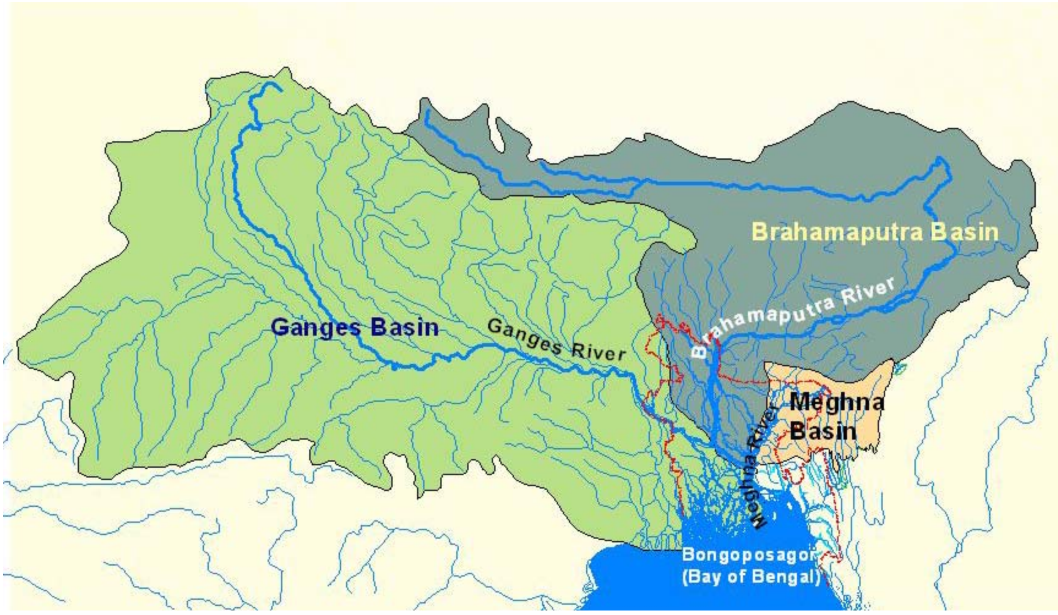


Figure 2.1 Ganges-Brahmaputra-Meghna (GBM) Basin

The Contemporary State of the Hydrologic System

The Meghna Basin comprises five main river sub-basins: Sylhet Basin (Surma-Kushiyara river system) within the northeast region of Bangladesh and on the western part of Meghna Basin, Barak Basin on the eastern part, Meghalaya Foothills Basin and Susang Hill on the north and Trpira Hill Basin on the south.

Sylhet (Surma-Kushiyara) Basin

Sylhet sub-basin actually comprises larger portion of northeast region of Bangladesh (83.5 per cent). The basin is bordered by floodplain land from the Old Brahmaputra River on the west and from the Barak River on the east, by uplands of the Meghalaya Foothills on the north and by uplands and Piedmont floodplains along the south. As it has been mentioned earlier discussing on the northeast region, the topography is of the basin is irregular, falling from the piedmont hills near India across gently sloping plains to the Sylhet Depression near the geographic center

[6] FAP 6, *Northeast Regional Water Management Project,* Interim Report, p. A-9.

of the region. The interfluvial depressions, commonly known as the *Haor* are the dominant features of this basin. The large saucer shaped *haor* region covering an area of 8,000 sq.km., which is the largest single inland depression in the country.[7] There are as many as 47 major *haors* in the whole *haor* region.[8] The main streams traversing the Depression include Surma, Kalni, Kushiyara, Baulai and Dhanu River. Highly sinuous, meandering sand-bed channels with cohesive banks characterize the streams.

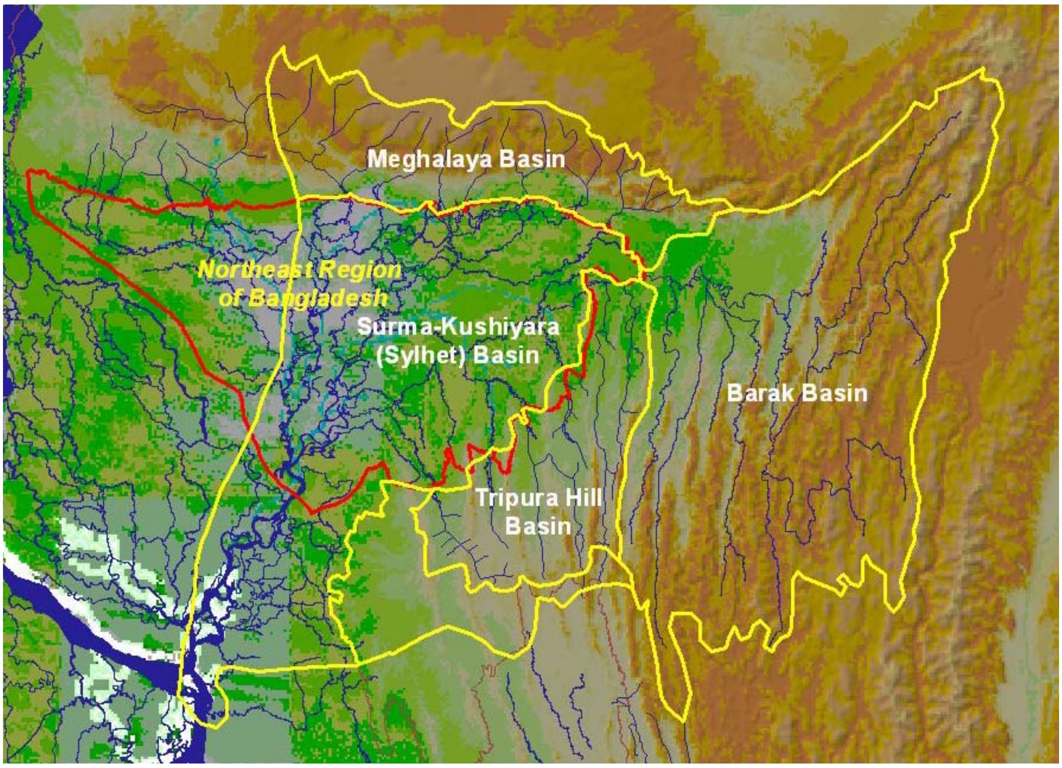


Figure 2.2 Meghna Basin and northeast region of Bangladesh

Between May to October the entire central portion of the basin becomes deeply flooded in most years. Across the Sylhet Basin, rainfall during the southwest monsoon ranges from around 1400 mm (about 65 per cent of annual total in this particular region) in southwest to around 4100 mm (69 per cent) in the northeast at the border of Meghalaya. In contrast, the northeast monsoon brings dry air into the region basin China and rainfall in this season ranges from around 85 mm (4 per cent) in the southwest to around 220 mm (4 per cent) in the northwest. The spring reversal from around 493 mm (23 per cent) in the southwest to around 1287 mm (21 per cent) in the northeast, and the autumn reversal by decreasing sporadic rainfall, the rainfall ranging from around 171 mm (8 per cent) in the southwest to around 316 mm (6 per cent) in the northeast.[9]

All the surface water originating in the Barak, Meghalaya Foothills, Tripura Hills sub-basin actually enter to the Sylhet (Surma-Kushiyara River) sub-Basin, flow towards the outlet of the whole Meghna Basin. Bhairab Bazar is considered as the outlet, which is 20 km. downstream of Bilapur, the joining point of the Surma and Kushiyara river system after being bifurcated at

[7] M.R. Rahman, J.H. Chowdhury, 'Impacts of Flood Control Project in Bangladesh' in Mir M. Ali et al. (eds.), *Bangladesh Floods, Views from Home and Abroad,* The University Press Limited, Dhaka 1998, p. 58.
[8] S.I. Ali, 'Haor Basin Eco-System' in *Environmental Aspects of Surface Water System of Bangladesh,* University Press Limited, Dhaka 1990 (cited in Ibid., p. 58).
[9] FAP 6, *Northeast Regional Water Management Project,* p. A-9.

Amalshid from the Barak River. The recorded maximum discharge of the Meghna Basin at Bhairab Bazar was 19, 800 m^3/s.[10]

Barak Basin

The Barak River drains 25,260 sq.km. of land in the states of Assam, Manipur and Mizoram in India. The basin has a relief of over 3,000 meter and much of the land is extremely mountainous.[11] The Barak River is the main channel of this basin, originates from the hill complex near Mao at the border of Nagaland and Manipur, southeast of Japvo peak. It runs westward for some distance forming the boundary of Nagaland and Manipur and then suddenly turns southward and flows through Manipur until it reaches Tipaimukh at the southwestern corner of that state. It then takes a sharp northward turn, forms firstly the boundary of Manipur and Mizoram and then Manipur and Cachar district of Assam. Thus, flowing northward for about 60 km, it again sharply turns westward at Jirimukh and flows through Cachar Plain sluggishly.[12] In the western part of the Cachar plain the river gives out two branches near Indo-Bangla border, close to Amalshid of Sylhet district. The northern branch is known as the Surma, the southern branch is called the Kushiyara. The river system of both the branches again join together at Bilapur on the Upper Meghna River in Bangladesh.

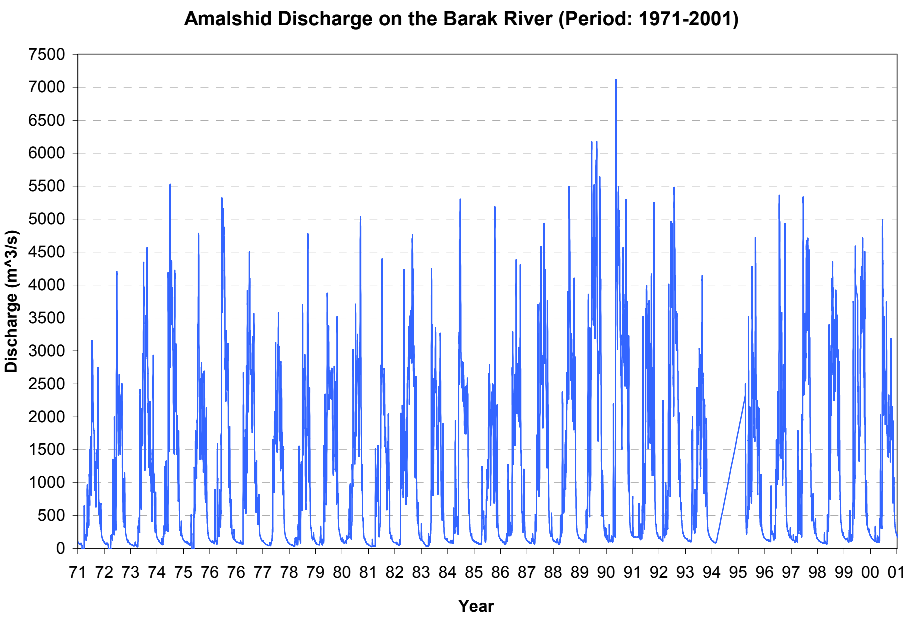


Figure 2.3 Discharge hydrograph of Amalshid on the Barak River

The total length of the Barak-Surma-Kushiyara River is about 902 km. of which 403 km. is in Bangladesh.[13] Its important right-bank tributaries include Makru and Jiri in Manipur and Labak, Madhura , Dalu, Jatinga and Larang in the Barak Plain. The major left-bank tributaries are Irang

10 A.H. Khan, 'International Water management Issue: South Asian Perspective' in Mir M. Ali et al. (eds.), *Bangladesh Floods, Views from Home and Abroad,* The University Press Limited, Dhaka 1998, p. 220.

11 FAP 6, *Specialist Study, River Sedimentation and Morphology,* Draft Final Report, FPCO, May 1993, p. 18.

12 Physiography' in *Mirror of Assam,* url: www.vedanti.com/Assam_Mirror/Physiography.htm (Last visited on April 04, 2005)

13 A.H. Khan, 'International Water management Issue: South Asian Perspective', p. 220.

and Tuivai (Tipai) in Manipur and Sonai, Rukni, Katakhal, Dhaleswari, Singla and Langai in Cachar Plain.

Mean annual rainfall varies from about 3,000 mm in the western part of the basin to about 1,700 mm in the east[14].

Table 2.1 Statistical analysis of Amalshid discharge on the Barak River (Period: 1965-2001)

Discharge (m^3/s)		
Maximum	Mean	Standard Deviation
7115	1168	1287

The river sedimentation and morphological study carried by FAP 6 suggests that roughly 1,440 tonnes/km^2 of sediment is yield in the Barak River and the corresponding annual sediment inflow from the Barak River at Amalshid is 36.5 million tones/year. The study also mentioned that the presented figure is estimated using the regional analysis of Jansen and Painter, while it includes both the wash load and suspended material load components.[15]

The description on the hydrological process involved in the Meghalaya Foothills, Susang Hills and Tripura Hills watershed have been reproduced here briefly from the discussion presented in the report of 'River Sedimentation and Morphology', *Northeast Regional Water Management Project (FAP 6).*[16]

Meghalaya Foothills Basin

Streams draining the Meghalaya Foothills include Lubha River, Hari River, Dauki River, Ohalai gang, Chela River, Jhalukhali River, Jadukata River, Lengura River and Someswari River. The watersheds are all located in the Shillong Plateau, a large elevated block of Pre-Cambrian Basement rock that has been draped over by late Mesozoic and Cenozoic sediments.

The total Meghalaya catchment area amounts to 13,466 sq.km. which represents 20.4 per cent of the regions external catchment area. The two largest catchments are the Jadukata River catchment (2,500 sq.km.) and Someswari River catchment (2,480 sq.km.).

The average annual rainfall tends to increase with elevation, reaching up to 12,000 mm/year near the headwaters of the Cheala River catchment. In general, rainfall amounts decrease towards the eastern and western limits of the Foothills. Even so, annual rainfalls still exceed 10,000 mm over the headwaters of the Jadukata River and Jhalukhali River.

Runoff generated from the Meghalaya Foothills streams is very flashy and of very high intensity. Published records indicate peak daily discharges reached around 2,800 m^3/s in 1988 and 1991 on the Ohalai Gang (8.2 $m^3/s/km^2$), and around 3,150 m^3/s on the Someswari River in 1988 (1.5 $m^3/s/km^2$).

[14] FAP 6, *Specialist Study, River Sedimentation and Morphology,* p. 18.
[15] Ibid., p. 22.
[16] Ibid., pp. 22-25.

Daily discharges exceeded 5,000 m^3/s twice on Jadukata River in 1991, with the maximum discharge intensity being 2.07 m^3/s /km^2. These flows are more than twice the highest daily discharge recorded on the Surma River at Sylhet.

Given the huge flood flow volumes that can be generated, steep catchment slopes and the presence of relatively erodible sedimentary rocks, it is expected that the sediment yields from these basins would be extremely high. Site observations and air photo interpretation indicate the Someswari River, Jadukata River, Jhalukhali River are indeed transporting huge quantities of predominately sand-sized sediments. Sediment yields from the Dhalai gang and Dauki River are also very large, although the sediment is much coarser, being composed of a mixture of coarse sand, gravel, cobbles and boulders.

Susang Hills Basin

The Susang Hills are drained by three main rivers: Bhogai River, Chillikhali River, Malijhee River. These catchments range in size from 453 sq.km to 118 sq.km. The Chillikhali and Malijhee catchments are of low relief (150 meter) while the Bhogai River catchment is more mountainous. Rainfall volumes range between 2,700 - 3,500 mm/year, generally decreasing to the west. Runoff intensities, although lower than the Meghalaya streams, are still high. For example, measurements on the Bhogai River indicated maximum daily discharges have reached 1,240 m^3/s, which corresponds to a runoff intensity of 2.74 $m^3/s/km^2$. The long-term mean discharge between 1964-1991 was 38 m^3/s, which corresponds to a depth of runoff of 2,645 mm.

No information is available on the sediment yields from these streams. However, given the lower relief and lower rainfall over the basins it is believed that the sediment yields would be relatively low. Using the regional sediment yield data, a figure of 1,000 tonnes/km^2 was adopted as a preliminary estimate for these streams. This implies the three catchments supply in the order of 700,000 tonnes/year of sand load.

Tripura Hill

Streams draining the Tripura Hills include the Juri River, Manu River, Dhalai River, Karangi River, Khowai River and Sutang River. The catchment areas are defined by five prominent north-south trending ridges that project from India into the region. These long linear ridges are plunging anticlines composed primarily of sandstone, siltstone and shale. The intervening basins are long and narrow and have wide, flat valley floors. Relief is relatively low; typically less than 1,000 meter. Rainfall averages around 2,300 mm/year in the headwaters.

There have been several extreme floods in the 1980's and comparatively lower flood discharges in the 1960's and 1970's. However, the runoff rates are substantially lower than the catchments draining the Meghalaya or Susang Hills catchments. For example, the flood of record on the Khowai River was reported to reach 1,050 m^3/s in 1988, which corresponds to a runoff of 0.94 $m^3/s/km^2$. This is less than half of the runoff intensity from recent floods on the Jadukata River.

A review of satellite photos and topographic maps from the 1950's suggests the sediment yields from the headwaters of the Tripura watersheds has increased substantially in recent years. Land clearing for agriculture and plantations is one likely cause of the changes.

Estimated annual loads are approximately 1.2 million tonnes/year on Khowai River and 3.5 million tonnes/year on Manu River. The year-to-year variation in sediment loads was found to be particularly high on the Khowai River. For example, the load in transported during five days of high flows in 1988 exceeded the sediment load supplied during the previous five years! This illustrates the critical effect that extreme flood events can have on the sedimentation processes in the region

Chapter 3

Data and Information Used in the Study

Availability of Data and Information

As it has been mentioned earlier that the major short-comings of the present study is associated with the lack of proper data and information regarding the Tipaimukh Hydro Electric (Multipurpose) Project of India itself and hydro-meteorological, geological and morphological data of the Barak sub-basin. Though the data and information found in the *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project* regarding the dam, dam operation, reservoir and possible withdrawal for irrigation purpose through the barrage at Fulertal are found relatively adequate to calculate the possible release from dam. Nevertheless, these data and information regarding the dam are only useful when there are available adequate hydro-meteorological, geological data of Barak sub-basin to calculate the historical river flow that occurred at Tipaimukh point. The accuracy of probable dam release is heavily dependent upon how effectively the inflow at dam site on the Barak River could be estimated.

Meanwhile, it would be relevant to mention here about the data requirement the study team felt necessary for an effective study considering the objectives of the present study. According to their view, the following data and information are most essential[1]:

- Hydro-meteorological data of the upper riparian region of Meghna Basin, i.e. Barak sub-basin.
- Topographic survey of the Barak River (river cross-section, landuse pattern of the basin, etc.).
- Hydraulic data measurement (Water Level and Discharge at various point).
- Morphological features of the Barak-Surma-Kushiyara river system (sediment data, deposition and erosion pattern).
- Geological features of the Meghna Basin

During the data and information collection phase of the study, the team had visited few of the relevant organizations of Bangladesh including Joint River Commission (JRC), Bangladesh; Bangladesh Water Development Board (BWDB); SAARC Meteorological Centre, Bangladesh; Bangla Praxis, Bangladesh. Distinguished persons of those organizations gave valuable direction and suggestion on the study programme. But the most disappointing fact was other than the report of FAP 6 published by FPCO in 1993 where a preliminary study on probable impact of Tipaimukh Dam was reported and the *DPR on Tipaimukh Hydro Electric (Multipurpose) Project*

[1] Considering enough data for lower riparian northeast region of Bangladesh are available

published by NEEPCO, India and collected from Bangla Praxis, Bangladesh, no specific data and information was available from these organization.

Data and Information Found in *DPR on Tipaimukh Project*

The *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, published by North Eastern Electric Power Corporation Ltd. (NEEPCO) 2000 has been collected for the purpose of this study. Lots of information is presented in that report related to the dam project. The data and information, which are found useful for the present study from that report, have been presented below:[2]

Key features of Tipaimukh Dam

Height: 162.8 m high rock-filled earthen dam
Power generation potential: 1,500 MW (with a load factor of 28%)
Firm power generation: 412 MW (revised 401 MW)
Annual generation: 3,536 GWH
No. of units: 10
Capacity per unit: 150 MW
Average head: 125 meter.

Reservoir data

Area-elevation and capacity-elevation curve of the reservoir can be graphically presented as in Figure 3.1.

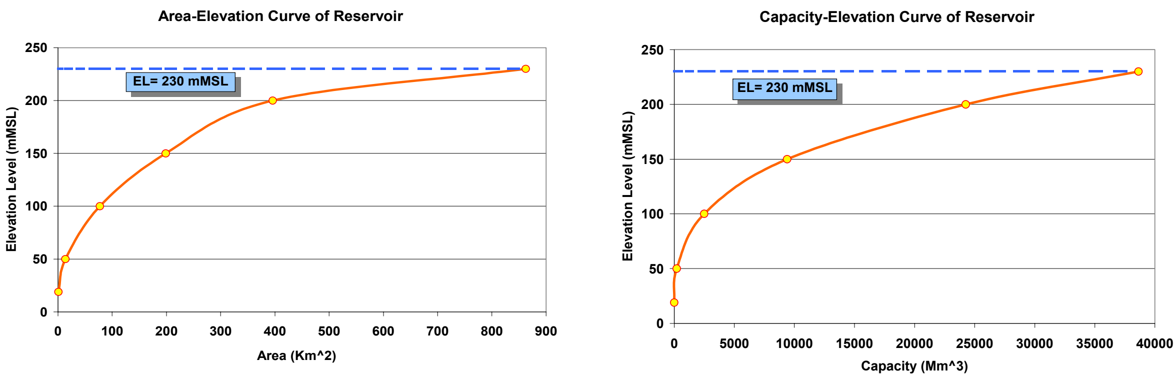


Figure 3.1 Area-Elevation and Capacity-Elevation curve of Tipamukh Dam Reservoir

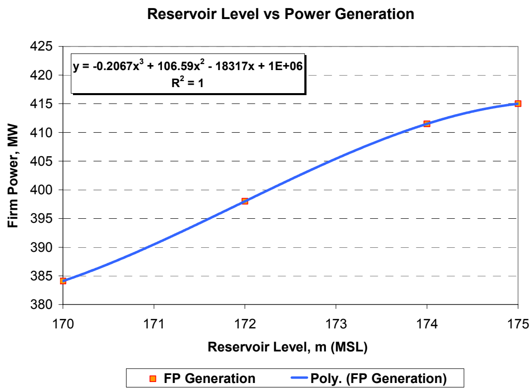
Power generation data

Information and data on power generation of the dam project can be summarized as in Table 3.1. Graphical representations of some of those data have been illustrated in Figure 3.2.

[2] NEEPCO, *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, Shillong 2000, ch. I, III-IV, VIII.

Table 3.1 Data related to power generation of Tipaimukh Dam Project

Item	Value /Quantity
Maximum power generation	1,400 MW
Load Factor	28%
Firm power generation	401 MW (earlier 412 MW)
Design head	125 m.
Full Reservoir Level (FRL)	174 mMSL
Minimum Draw Down Level (MDDL)	136.1 mMSL
Full Supply Level (FSL)	172.5 mMSL
Flood moderation	Reservoir storage from FSL 172.5 m to FRL 174.0 m
Head loss due to friction	3% of the design head
Turbine /Generator efficiency	85%
Reservoir level-power generation curve	Figure 3.2
Tail water curve	Figure 3.2



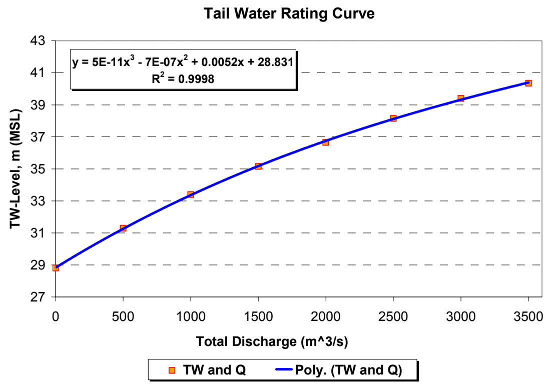


Figure 3.2 Level vs. Power Generation curve and Tail Water Rating Curve for the reservoir

Reservoir operation strategy

Round the year dam operation strategy including the assigned or suggested rule curve for the monsoon period only can be described as in the follows:

- If possible, maintain reservoir level at rule curve level in each monsoon month.
- Deviation from the rule curve is permissible for the purpose of providing release for firm generation.
- If the unregulated inflows in the reservoir exceed the release for firm energy and other downstream water demands then store all surplus inflows in the reservoir, to get the reservoir level back to the rule curve level, if possible[3].

[3] This ensures that a dry period is entered with the maximum possible volume of water in storage.

- If the reservoir water level reaches the rule curve level and unregulated inflow in the reservoir exceeds the releases required for firm energy generation, then generate secondary energy to minimize the spill from the reservoir.

The report has also mentioned that the above reservoir operation policy would result in the following energy generation practices:

- Generate only firm power during dry season, November to May.

- Generate secondary energy during wet season, June to October, if possible to minimize spill.

Figure 3.3 shows the suggested or desired and assumed rule curve[4] for the reservoir operation in an ideal case. Though it has been revealed during the reservoir and hydropower simulation for the period of 1971 to 2001 that maintaining the following rule curve wouldn't be possible for every year. This is, perhaps the most common feature of every hydropower project. It has been observed in many large hydropower projects that the rule curve that had been asked to maintain at the end of every month couldn't be maintained for every year.

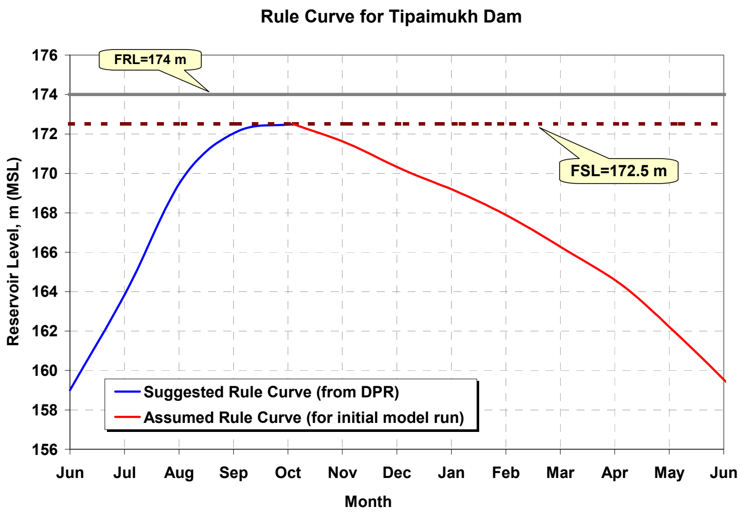


Figure 3.3 *DPR* suggested or desired rule curve (for June to October) and assumed rule curve for rest of the period

[4] This month end rule curve has been used in the Hydro Power Reservoir Model.

Discharge data

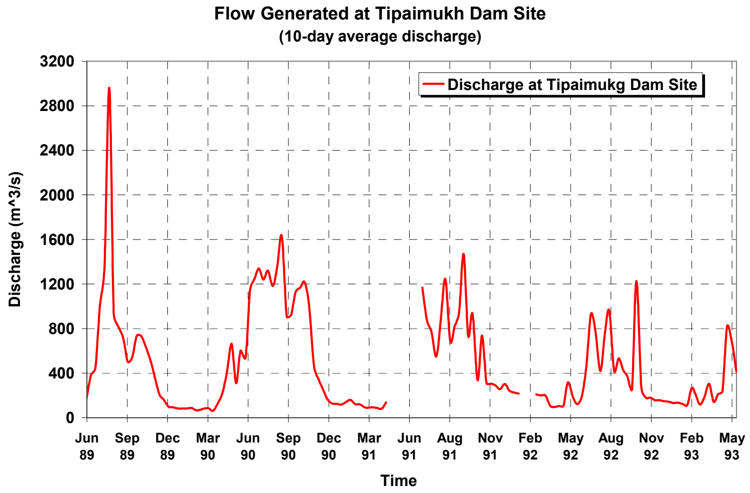


Figure 3.4: 10-day average discharge at Tipaimukh on the Barak River

Possible withdrawal of water for irrigation purpose

There is a proposal of developing the Cachar Irrigation Project by constructing a barrage at Fulertal in the Cachar plain of India, some 95 km. downstream of the Tipaimukh Dam and 100 km. upstream from Amalshid point of Bangladesh. The extra water for this irrigation project would be met from the possible augmented flow of the Barak River during the dry period for post-dam condition. Thus the possible monthly withdrawal from the Barak River has also been considered in the present impact study. Figure 3.5 depicts the amount of monthly water withdrawal from the Barak River for the irrigation project as provided in the *DPR on Tipaimukh Project*.

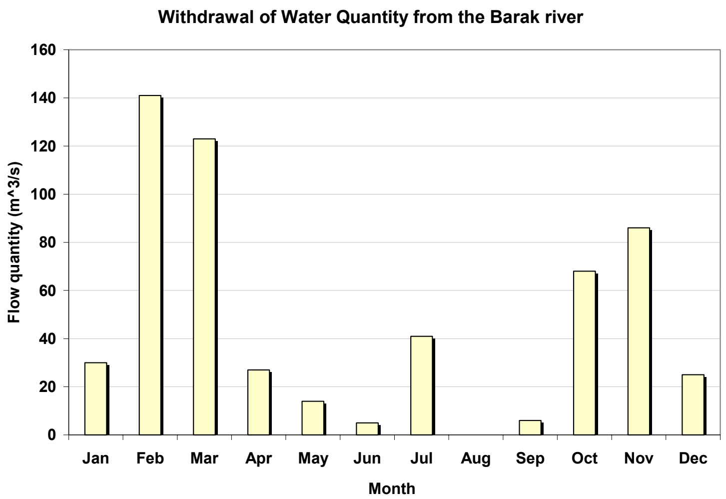


Figure 3.5: Possible withdrawal of water from the Barak River for irrigation project in Cachar plain, India

Boundary Generation for Post-Dam Scenario at Amalshid on the Barak River

This part of the report first presents the analyses on the basis of selecting Amalshid point on the Barak River as one of the inflow boundaries of the NERM to assess the hydrological impact of the dam project. In second stage, how this inflow boundary at Amalshid would be influenced by the Tipaimukh Dam operation that has been discussed.

As mentioned earlier, the already developed hydrologic and hydrodynamic model on the river system of northeast region of Bangladesh (NERM) has been used for the present impact study. Other than changing the boundary condition, the NERM model setup remains same as it is for the NERM 2002-'03 validation model. In this model, combined flow at Amalshid point on the Surma and Kushiyara River is used as the inflow boundary on the Barak River.[5] Amalshid point on the Barak River actually receives all the water generated in the Barak sub-basin and a simple relationship, therefore, can be established between the discharge at Amalshid and Tipaimukh point on the Barak River.

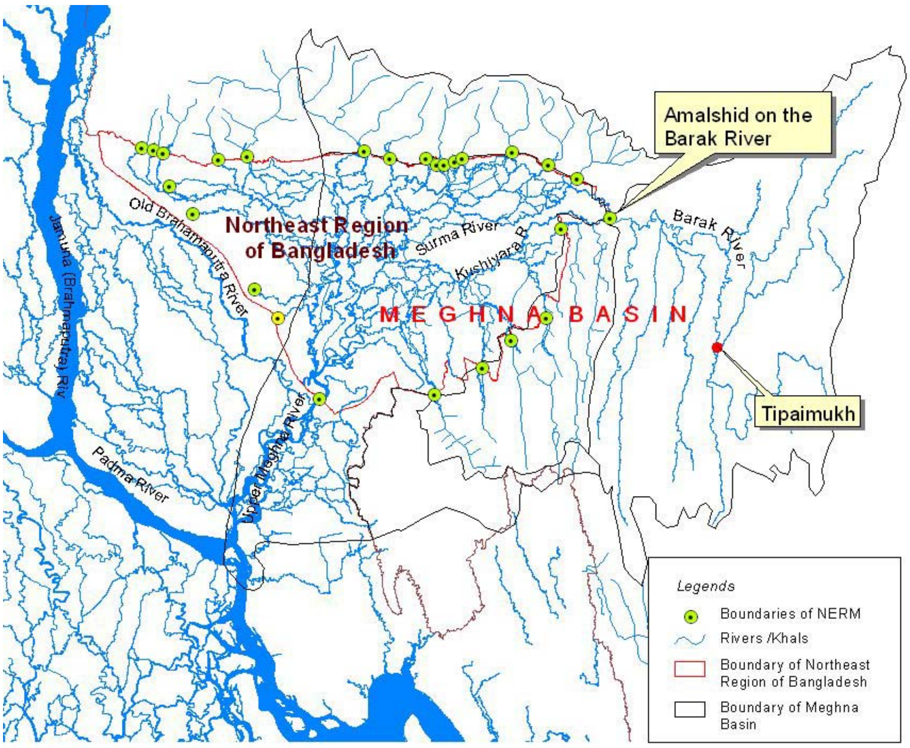


Figure 3.6 Meghna Basin and model boundaries of NERM

Before going to the detail discussion on boundary estimation, one point should be made clear first. The study team is of the opinion that the Cachar Irrigation Project of India has been planned as a supplementary project to the Tipaimukh Dam Project. In other words, Cachar Irrigation Project cannot be implemented unless and otherwise there is augmented flow on the Barak River during the dry period. Hence, proposed monthly withdrawal of Barak flow under this irrigation project has also been considered for the estimation of altered or modified

[5] Amalshid point on the Barak River is located at 20 km. upstream from the bifurcation point of the Barak River to the Surma-Kushiyara River.

Amalshid flow for the post-dam and irrigation condition. However, 'post-dam and irrigation' scenario has been termed as only 'post-dam' scenario in this report.

Base or Pre-dam Flow at Tipaimuk and Amalshid

The big challenge that has been negotiated by the study team is the estimation of post-dam flow of the Barak River at Amalshid point. As there is very scantly hydro-meteorological data available for this study, a simple co-relationship had to be developed between the flow occurred at Tipaimukh and Amalshid point on the Barak River. In the *DPR of Tipaimukh Project* of India, 10-day average discharge occurred during the period of June 1989 to May 1993 at Tipaimukh Dam site is provided. This limited amount of data acts as the basis of all boundary estimation for the post-dam and irrigation scenario.

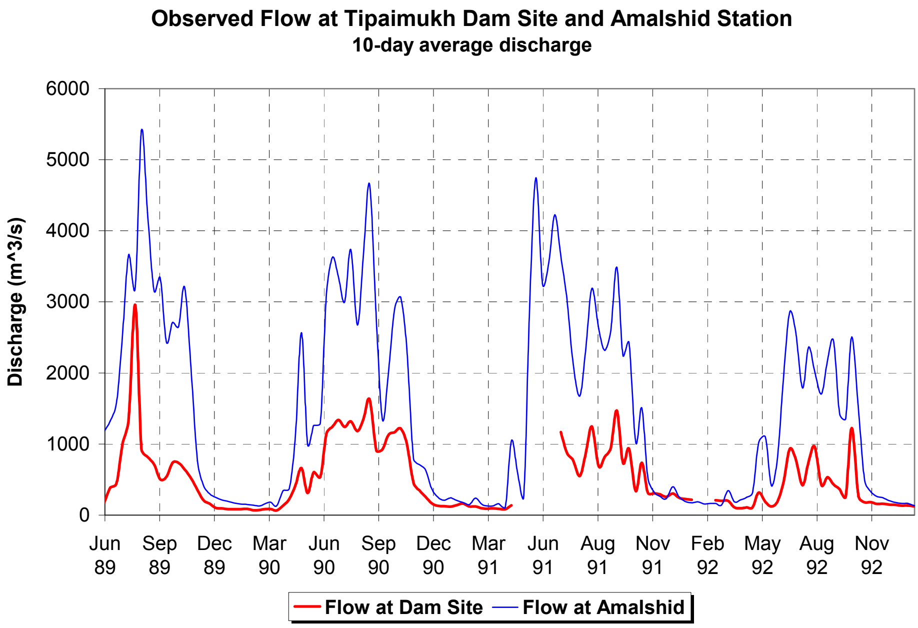


Figure 3.7 Observed Tipaimukh and Amalshid discharge

In addition, Barak discharge data at Amalshid is also available for this period. Using these two data, decade (10 day average) wise simple and straightforward average relationships, R[6] for each decade of every month round the year has been developed for the period of June 1989 to May 1993 (see Table 3.2). As the rating daily discharge data at Amalshid on the Barak River from 1971 to 2001 is available, the developed co-relationships R then have been multiplied with that rating discharge of Amalshid to get the daily discharge data for Tipaimukh point during the same period. Therefore, a synthesized daily discharge data at Tipaimukh point on the Barak River is now available for the period mentioned above, and the monthly average of this daily discharge data then has been considered as the inflow to the reservoir of the dam project.

[6] R = Flow at Tipaimukh / Flow at Amalshid

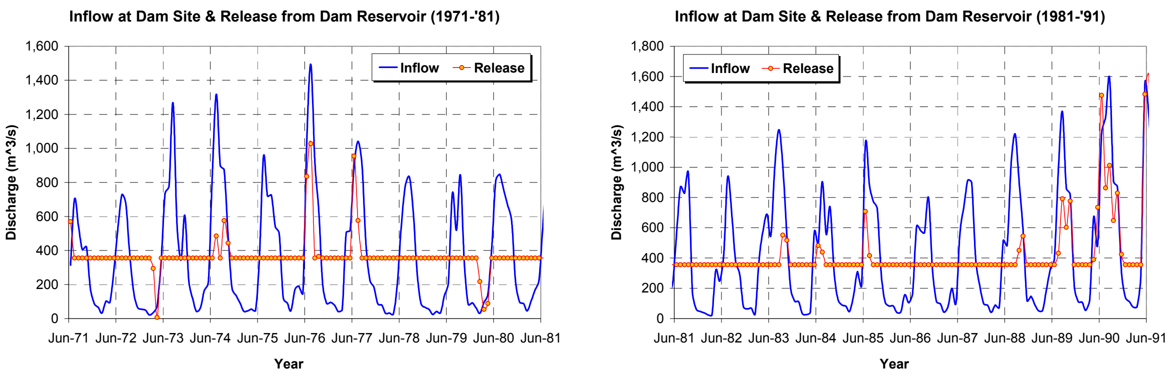
Table 3.2 Decade wise ratio, R for each decade of every month between the discharge at Tipaimukh and Amalshid

Month	Decade	Ratio, R	Month	Decade	Ratio, R
Pre-monsoon (Apr – May)			Post-monsoon (Oct - Nov)		
Apr	1 to 10	0.45	Oct	1 to 10	0.30
	11 to 20	0.44		11 to 20	0.38
	21 to 30	0.41		21 to 30	0.33
May	1 to 10	0.33	Nov	1 to 10	0.45
	11 to 20	0.35		11 to 20	0.51
	21 to 31	0.29		21 to 31	0.63
Monsoon (Jun – Sep)			Dry (Dec – Jan)		
Jun	1 to 10	0.27	Dec	1 to 10	0.67
	11 to 20	0.29		11 to 20	0.72
	21 to 30	0.31		21 to 30	0.63
Jul	1 to 10	0.36	Jan	1 to 10	0.73
	11 to 20	0.35		11 to 20	0.86
	21 to 31	0.48		21 to 31	0.89
Aug	1 to 10	0.31	Feb	1 to 10	0.63
	11 to 20	0.35		11 to 20	0.53
	21 to 31	0.27		21 to 31	0.48
Sep	1 to 10	0.36	Mar	1 to 10	0.72
	11 to 20	0.33		11 to 20	0.82
	21 to 30	0.34		21 to 30	0.56

R = Discharge at Tipaimuk / Discharge at Amalshid

Possible Release From the Tipaimukh Dam Reservoir

As the inflow to the reservoir has been generated for the period of 1971 to 2001, the outflow or release from the reservoir has been estimated after fulfilling all the conditions and provisions for the reservoir operation strategy set in the *DPR* for hydroelectric power generation. To estimate the possible outflow from the reservoir, a spreadsheet model named as Hydropower Reservoir Model (HR Model) has been developed. The model algorithm, presented in Figure A-1 of Annex has been applied to generate the release from the reservoir for the period of 1971 to 2001 (see Figure 3.8).



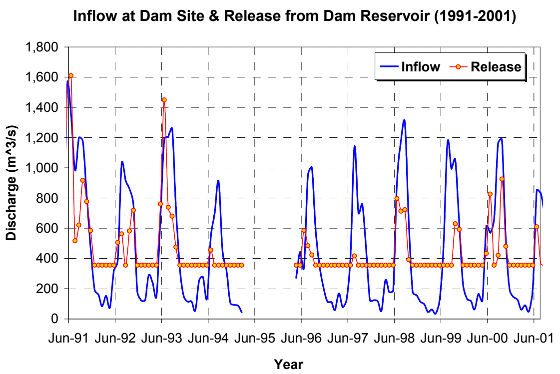


Figure 3.8 Estimated Reservoir inflow and release for post-dam scenario

Post-dam Flow at Amalshid on the Barak River

Just mentioned above, the daily Tipaimukh discharge data has been generated first by multiplying the decade wise relationship for every month round the year with the daily Amalshid rating discharge.

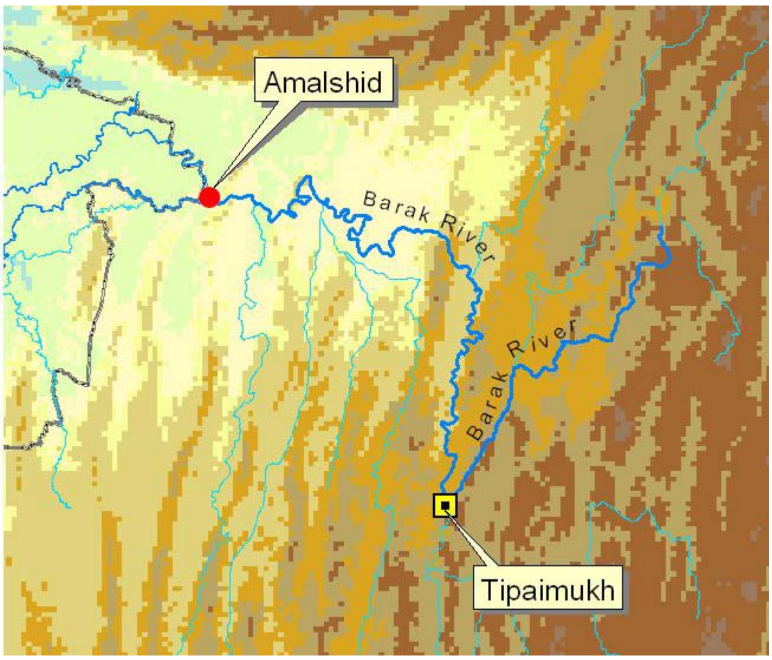


Figure 3.9 In-between river reach of Barak River: from Tipaimuk to Amalshid

Averaging the earlier calculated daily discharge data at Tipaimukh Dam site, monthly inflow to the Tipaimukh Reservoir has been then generated.

The Hydropower Reservoir Model has been used to calculate the possible monthly release from the reservoir.

To calculate the post-dam daily discharge at Amalshid on the Barak River, flow contribution by the in-between river reach – from Tipaimukh to Amalshid of the Barak River – to the overall Amalshid discharge has been calculated first by multiplying the ratio, 1-R[7], with the daily discharge data at Amalshid for the period of 1971 to 2001.

Subtracting the quantity of monthly irrigation water requirement in the Cachar Plain from the amount of release of the reservoir, net monthly flow contribution in to the river reach between Tipaimukh and Amalshid has been achieved. This monthly net post-dam flow has been added to the daily flow contributed by the mentioned river reach of the Barak to get the ultimate daily flow at Amalshid point for post-dam condition over the period of 1971 to 2001.

This discharge data has been used as a modified Barak inflow boundary to the river system of NERM to simulate the different hydrologic events, i.e. average monsoon, average dry to critical dry, 1 in 5 or 10 years pre-monsoon and monsoon, etc.

Overall steps to calculate the post-dam discharge at Amalshid can be described as following:
(also see Figure 3.10)

Step 1

Pre-Dam Tipaimukh Flow (Daily) = Pre-Dam Amalshid Flow (Daily) * Decade wise Ratio, R

Step 2

Pre-Dam Tipaimukh Flow (Monthly) = Monthly averaging the Pre-Dam Tipaimukh Flow (Daily)

This discharge data then used in HR Model to get the monthly release from the dam

Step 3

Release from Dam (Monthly)
= Output of HR Model where the input is Pre-Dam Tipaimukh Flow (Monthly)

Step 4

Subtracting monthly irrigation water requirement from this monthly dam release to get the ultimate changed monthly Barak flow due to both dam and irrigation projects.

Therefore,
Changed Barak Flow due to Dam and Irrigation Project (Monthly)
= Release from Dam (Monthly) – Irrigation Water Requirement (Monthly)

Step 5

Contribution of In-between River Reach from Tipaimkuh to Amalshid (Daily)

[7] 1-R = Flow Contribution to the In-between River Reach (Between Tipaimukh to Amalshid) / Flow at Amalshid

= Pre-Dam Amalshid Flow (Daily) * (1-R)

Step 6

<u>Post-Dam Amalshid Flow (Daily)</u>

= Changed Barak Flow due to Dam and Irrigation (Monthly)
+ <u>In-between River Reach from Tipaimkuh to Amalshid (Daily)</u>

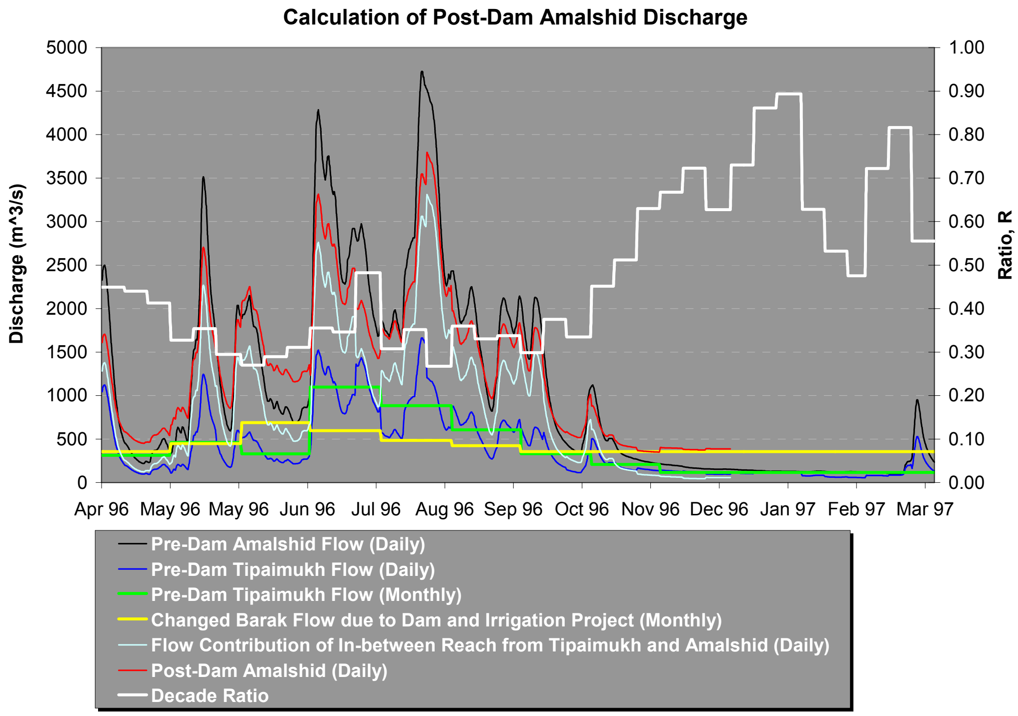


Figure 3.10 Hydrograph representing the steps of calculation of post-dam Amalshid discharge

Chapter 4

Hydrological Impacts of the Dam on the Surma-Kushiyara River System

Impacts of Post-Dam Barak River Flow

It is unanimous that any dam constructed across the river does alter the usual flow pattern of the river and it would happen for Tipaimukh Dam Project also. But how much this alteration would happen, that has to be investigated properly to understand the probable change in river ecosystem of the downstream river reach. As the Barak, the Surma-Kushiyara sub-basin (Sylhet Basin) form the single entity of vibrant Meghna Basin, any large-scale change in upstream flow due to flow constriction, diversion or storage should have an impact on the downstream river and floodplain hydrology-morphology-environment-ecology, as a whole on the socio-economic activities. The present study has found that the alteration of natural flow of the Barak as well as of the Surma-Kushiyara River would be a large scale one. The findings of the study regarding this have been presented in the following sections.

To discuss the hydrological impact of Tipaimukh Dam Project on the Surma-Kushiyara river system, three major hydrological seasons (Monsoon, Pre-monsoon and Dry) of a hydrological year (April to March, formulated by BWDB Hydrology) have been chosen. These hydrological seasons consist of following months for the northeast region of Bangladesh.[1]

Pre-monsoon: April – May
Monsoon: June – September
Dry: December – March

Five major locations have been selected (see Figure 4.1) to assess the overall hydrological impact, in terms of change in water availability (volume and discharge) and river stage (water level). Of which three are on the Kushiyara River (Amalshid, Fenchuganj, Sherpur) and two are on the Surma River (Kanairghat and Sylhet).

[1] FAP 6, *Northeast Regional Water Management Project,* Interim Report, FPCO, January 1993, p. A-1.

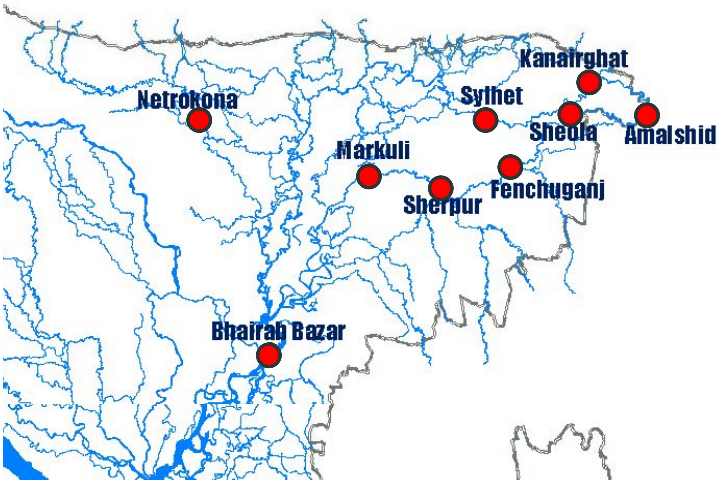


Figure 4.1 Location of analysis

Change in Monsoon Flow

For Average Year

As it has been stated earlier that from the statistical analysis of Barak discharge at Amalshid for the last 30 years, different hydrological events have been selected (see Table 1.1). From the frequency analysis of available data, hydrological year 1996 has been found as the average monsoon year for Amalshid flow.

It would be better first to present the status of probable post-dam Amalshid discharge with respect to pre-dam discharge for this average year.

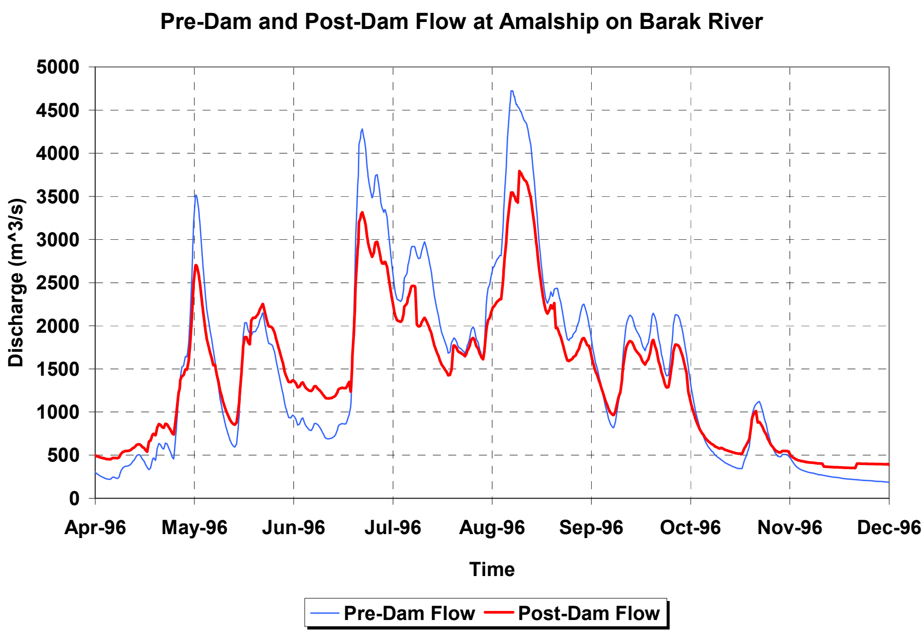


Figure 4.2 Boundary (Amalshid on the Barak River) discharge for pre-dam and post-dam scenario during average annual monsoon event

From the analysis it has also been found that for the average monsoon year, Barak monsoon flow for the whole season on average would be substantially reduced due to the reservoir operation (see Figure 4.2). Generally July, August and September flow would be reduced on a large scale. In respect of volume it would be on the average 23%, 16% and 15%, respectively. The reason behind this is overtly related to the dam operation strategy where it has been opted that reservoir level in each monsoon month should be maintained at rule curve level and if the unregulated inflows in the reservoir exceed the minimum release for firm energy and other downstream water demands then all the surplus inflows in the reservoir should be stored.[2] Actually it is very common for a hydropower reservoir operation that the dry period is entered with the maximum possible volume of water in storage so that the firm power generation during the dry season could be ensured.

Figure 4.3 shows the hydrological impact on the Kushiyara river system where maximum water level would fall more than 1 meter from the pre-dam condition at Amalshid station on Kushiyara River. The figure also shows that this water level fall would continue to even Markuli, though the fall in water level would be relatively small (0.12 meter). Average water level fall during the month July for Fenchuganj, Sherpur and Markuli would be around 0.23 meter, 0.15 meter, 0.08 meter, respectively (see Figure 4.4).

Discharge and water level hydrographs for the Surma river system have been shown in Figure 4.5. The reduction in discharge as well as water level would not be as large as in the case for Kushiyara River. Generally the Kusihiyara River receives greater portion of the Barak flow and thus any dramatic change in the Barak flow will affect the Kushiyara River and its floodplain hydrology with a greater extent. However, maximum water level fall during the month of July for Kanairghat and Sylhet station would be around 0.7 meter and 0.25 meter, respectively. Average water level for the same would be around 0.53 meter and 0.22 meter lower than the pre-dam condition (see Figure 4.4).

Table A-1 in Annex shows the overall average changes in water availability (volume), discharge and water level for the Surma-Kushiyara river system during average monsoon season for pre and post dam condition.

[2] NEEPCO, *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, Shillong 2000, ch. IV p. 7.

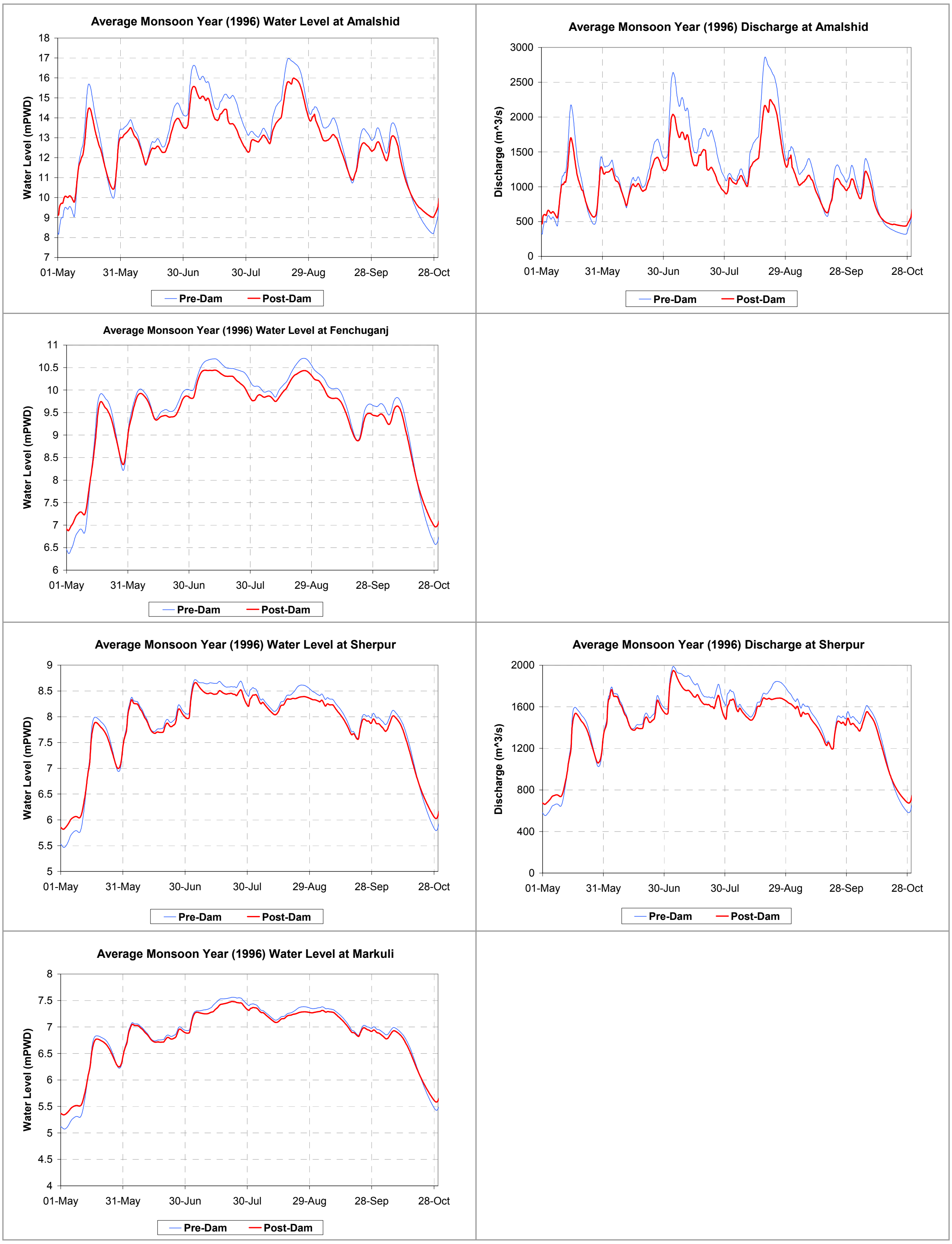


Figure 4.3 Hydrological impact on the Kushiyara River during average monsoon season

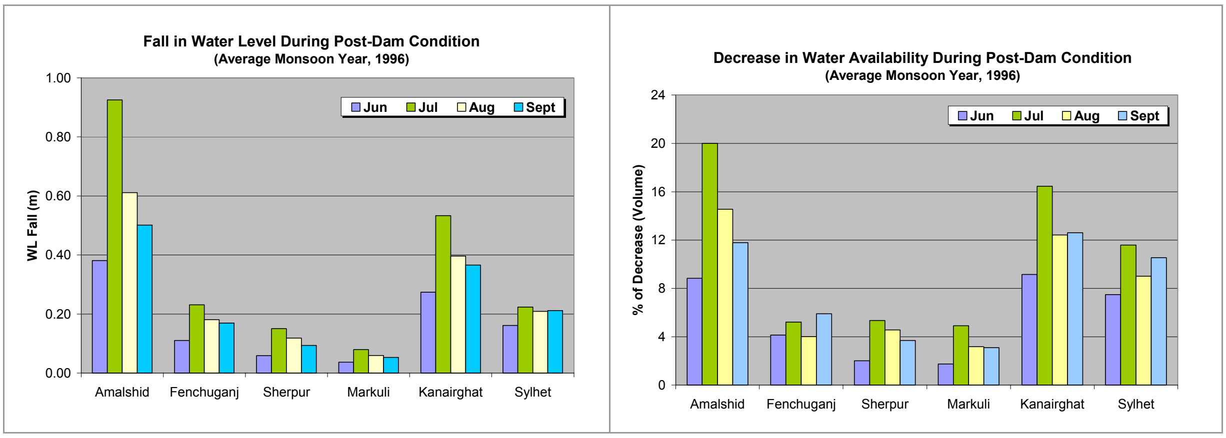


Figure 4.4 Average water level fall and volume reduction in the Surma-Kushiyara river system during average monsoon season

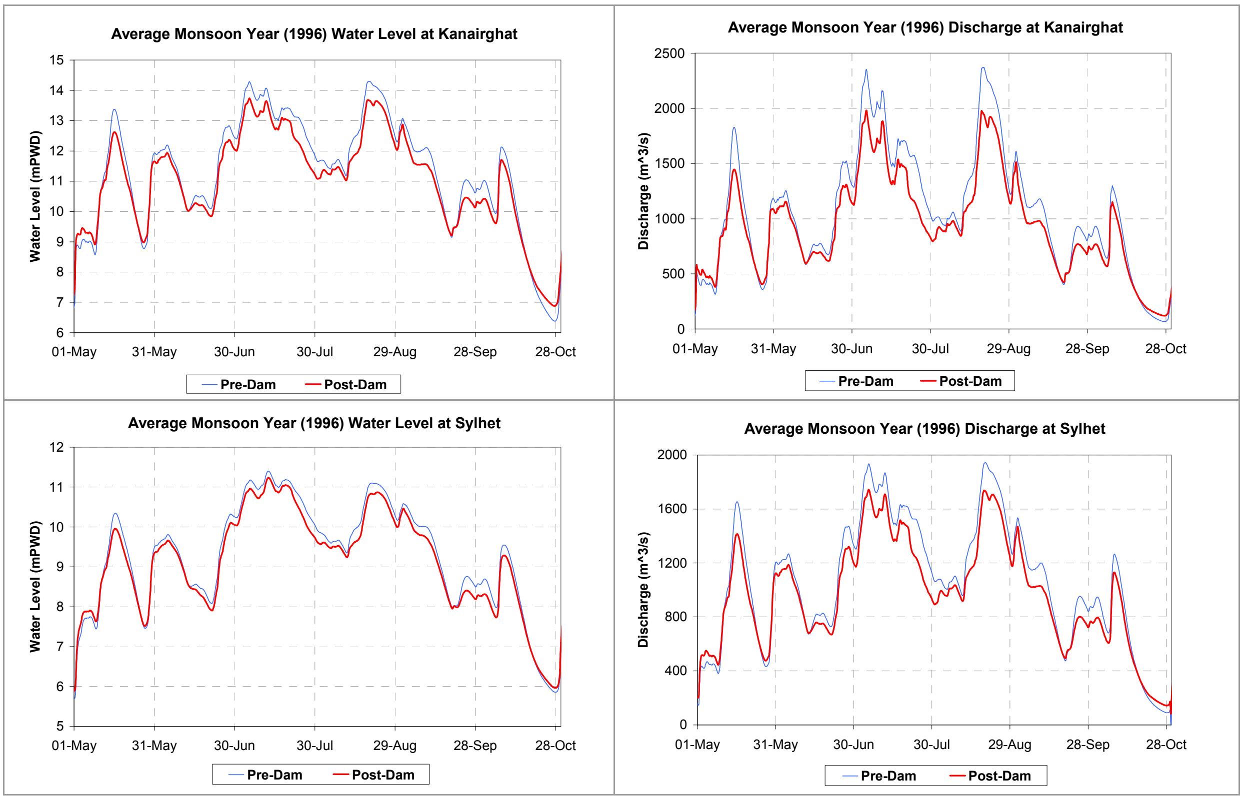


Figure 4.5 Hydrological impact on the Surma River during average monsoon season

For Drier Than Average Monsoon Year

When it is discussed about an average monsoon year, there must have some monsoon years of which average as well as peak flow fall below that of average monsoon season. The monsoon season of year 1999 was such event, which can be considered as a relatively drier year than the average monsoon year. To investigate the impact for post-dam scenario, hydrological assessment for this year has also been done. The assessment shows dam operation at Tipaimukh on the Barak River would likely to have more impact in terms of overall monsoon flow reduction (see Figure 4.6, 4.7, 4.8 and Table A-2 in Annex).

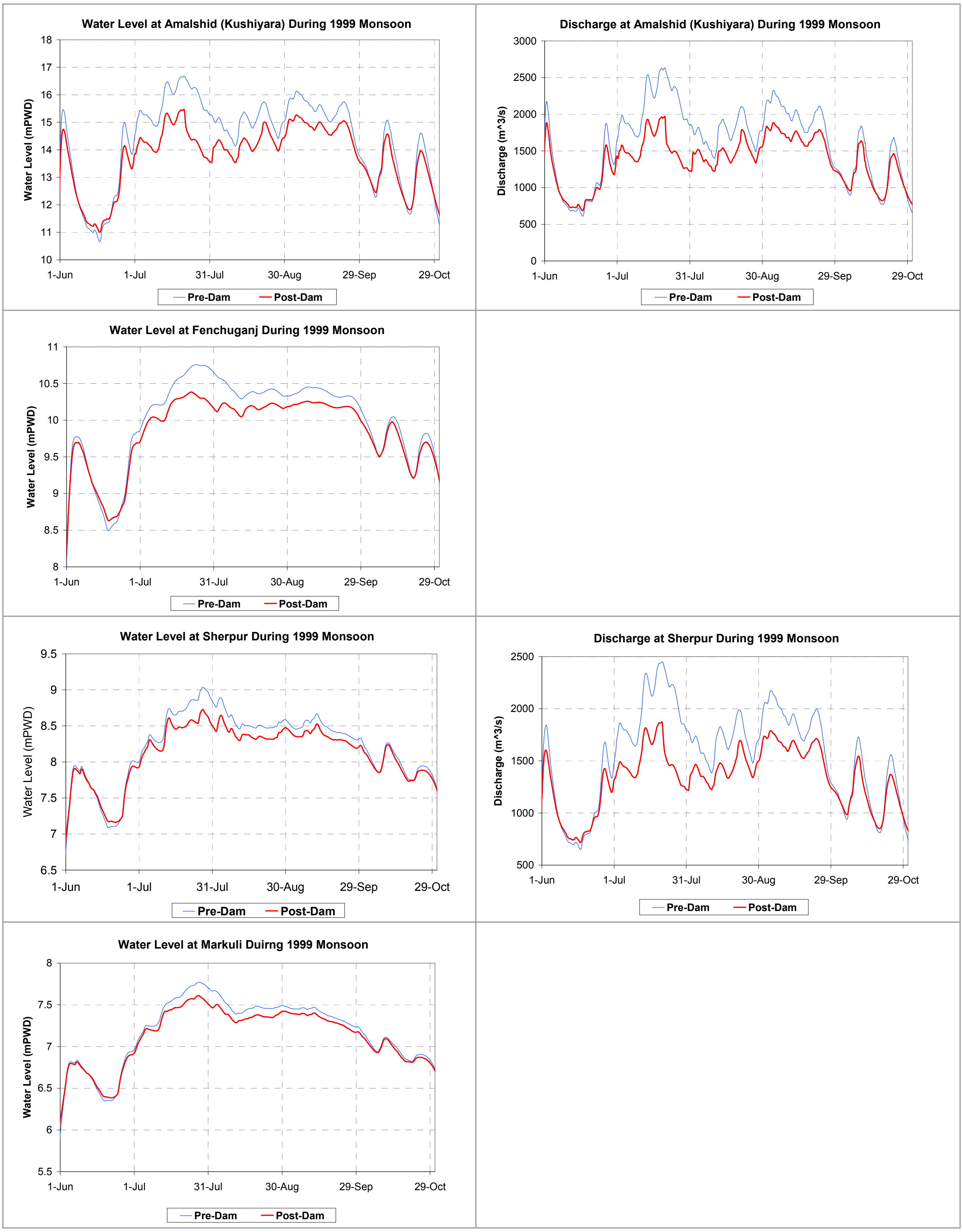


Figure 4.6 Hydrological impact on the Kushiyara River during relatively dry monsoon season

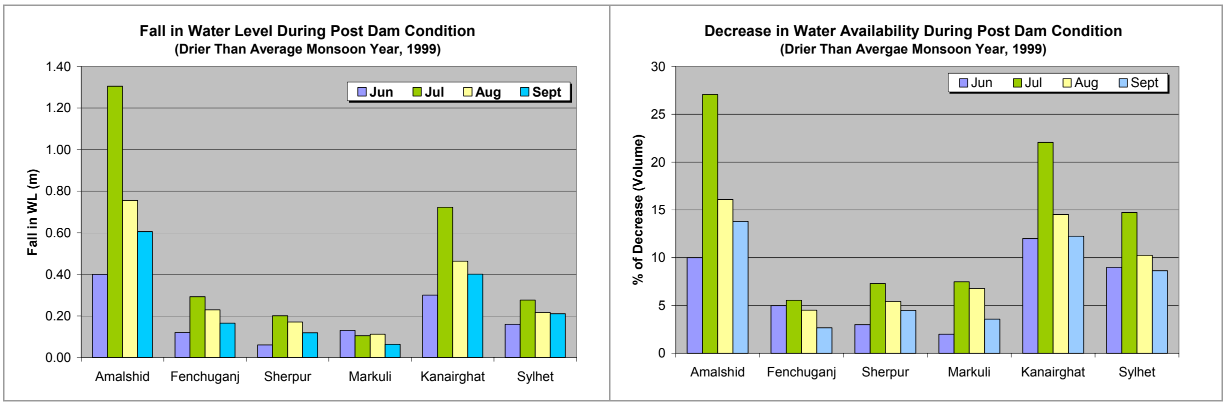


Figure 4.7 Average water level fall and volume reduction in the Surma-Kushiyara river system during relatively dry monsoon season

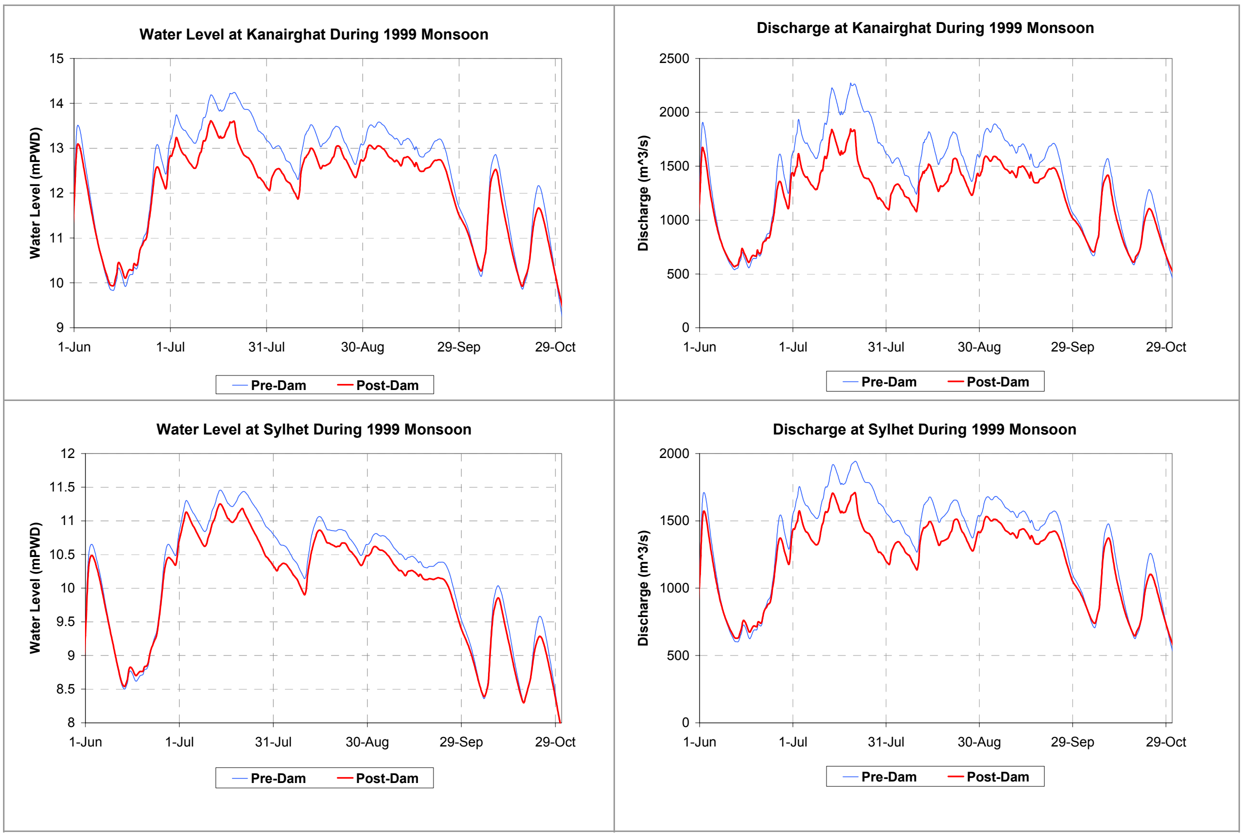


Figure 4.8 Hydrological impact on the Surma River during relatively dry monsoon season

It has been found that July, August and September flow would be reduced as much as 27%, 16% and 14%, respectively, 4%, 2% and 2% higher than the volume reduction found for average monsoon year.

From the analysis of those two monsoon years, one is average monsoon year (1996) and the other one is relatively dry monsoon year (1999), the conclusion, therefore, can be made that the post-dam scenario would affect more on relatively drier monsoon year than the average monsoon year. And this is actually bound to happen. As the total rainfall on the Barak Basin has a direct relationship with the Barak flow, thus the relatively drier Barak flow depicts the lesser inflow to the dam reservoir. In such case, there might be less water available for downstream release from dam after producing firm power and maintaining (as ling as possible) the reservoir level same or closer to the assigned rule curve level for each monsoon month.

For 1 in 5, 1 in 10 and 1 in 25 Years Monsoon

1 in 5, 1 in 10 or 1 in 25 years hydrological (or meteorological) event represents the magnitude of water flow (or rainfall) in a hydrological system by which the event likely to recur every 5, 10 or 25 years. Thus these magnitudes are larger than that of average or mean annual flood (a flood likely to recur on average every 2.3 years). For impact study on the hydrology of the Barak-Kushiyara-Surma system due to Tipaimukh Dam Project, the years representing those events have also been investigated.

Generally, 1 in 5 years monsoon flood is considered as normal monsoon year. In other words, the magnitude of flood, which recurs every 5 years, does not create any sense of anxiety among the people living in and around the floodplain of alluvial river system like the Barak-Surma-Kushiyara River. Only 1 in 10, 25 or more years flood events are regarded as moderate to severe or devastating flood.

From the analysis it has been found that the hydrological impact of the dam on the river system involved for 1 in 5 years monsoon would be more or less identical to the average monsoon year. Only there would be slightly more reducing of the flood event as is expected to happen. Figure 4.9 and Table A-3 in Annex imply these.

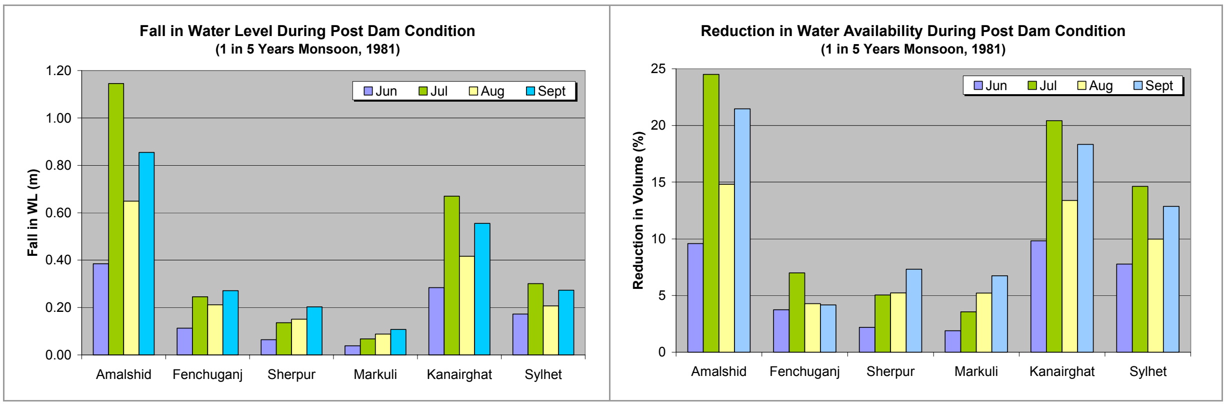


Figure 4.9 Average water level fall and volume reduction in the Surma-Kushiyara river system during 1 in 5 years monsoon season

On the contrary, dam operation – as has been understood from the study – would not moderate 1 in 10 or 25 or more years flood events effectively. For example, maximum reduction of Barak's peak flow at just upstream of the bifurcation point to the Surma-Kushiyara River in the month July would be on an average only 13% for 1 in 10 years monsoon season (here for hydrological year 1976), much lower than the reduction may happen during average, below average or 1 in 5 years monsoon (23 to 27%). Peak water level would fall by around 0.5 meter, much less than the fall that would happen during average, below average or 1 in 5 years monsoon season (1 to 1.25 meter). As far more severe flood event like 1 in 25 years flood season is concerned, reduction in peak discharge and water level would be minimal; only 3% and 0.11 meter, respectively. Table 4.1 shows the overall peak flood attenuation status during the post-dam scenario for the different hydrologic events.

Table 4.1 Peak analysis

Event	Discharge			Water Level		
	Pre-dam	Post-dam	% of reduction	Pre-dam	Post-dam	Water Level Fall
Avg. monsoon year	4711	3563	23	16.99	15.99	1.00
Below avg, monsoon year	4340	3153	27	16.68	15.47	1.21
1 in 5 years monsoon	5275	3881	26	17.44	16.23	1.21
1 in 10 years monsoon	5324	4615	13	17.57	17.04	0.53
1 in 25 years monsoon	6132	5946	3	18.01	17.9	0.11

The above analysis implicitly suggests that the dam would have more impact on the average or moderate monsoon flow rather than the high to severe or devastating flood events. The findings actually depicts that the project would reduce, ironically, the normal or usual flooding that is considered necessary for maintaining the integrity of river-floodplain ecosystem of the northeast region of Bangladesh, and leave the extreme events (high to severe flood) with relatively small or insignificant effect. And this has been the case experienced in most of the hydropower storage dam projects. The Warragamba Dam in Australia, for example, reduces the average annual flood by more than half, while the size of the flood likely to recur every 50 years barely changed.[3]

The consequences of reducing the normal flooding of the river system, has been scrutinized and presented in the next chapter.

Change in Pre-monsoon Flow

Pre-monsoon flow assessments have been done for different hydrological events, like 1 in 5 years pre-monsoon (1981), 1 in 10 years pre-monsoon (1993), 1 in 25 years pre-monsoon (2000), and 1 in 50 years pre-monsoon (1991).

Overall inflow from the Barak River to the Surma-Kushiyara river system would be markedly increased due to a confirmed release from hydropower dam for 1 in 5 years pre-monsoon season (see Figure 4.10, 4.11 and Table A-4 in Annex). Analysis shows that the average volume of water for the month of April and May would increase by 25% and 15% for Amashid station and 16% and 12% for Markuli station on the Kushiyara River. On the other hand, April and May water volume would increase by 28% and 10% for Kanairghat and 24% and 10% for Sylhet station on the Surma River. Average water level rise for Amalshid and Markuli would be around 0.74 meter and 0.28 meter for the month April. For the month May these would be around 0.73 meter and 0.22 meter, respectively.

[3] G.E. Petts, *Impunded Rivers: Perspective for Ecological management,* John Willey, Chichester 1984, p. 119 (cited in McCully, *Silenced Rivers,* p. 47).

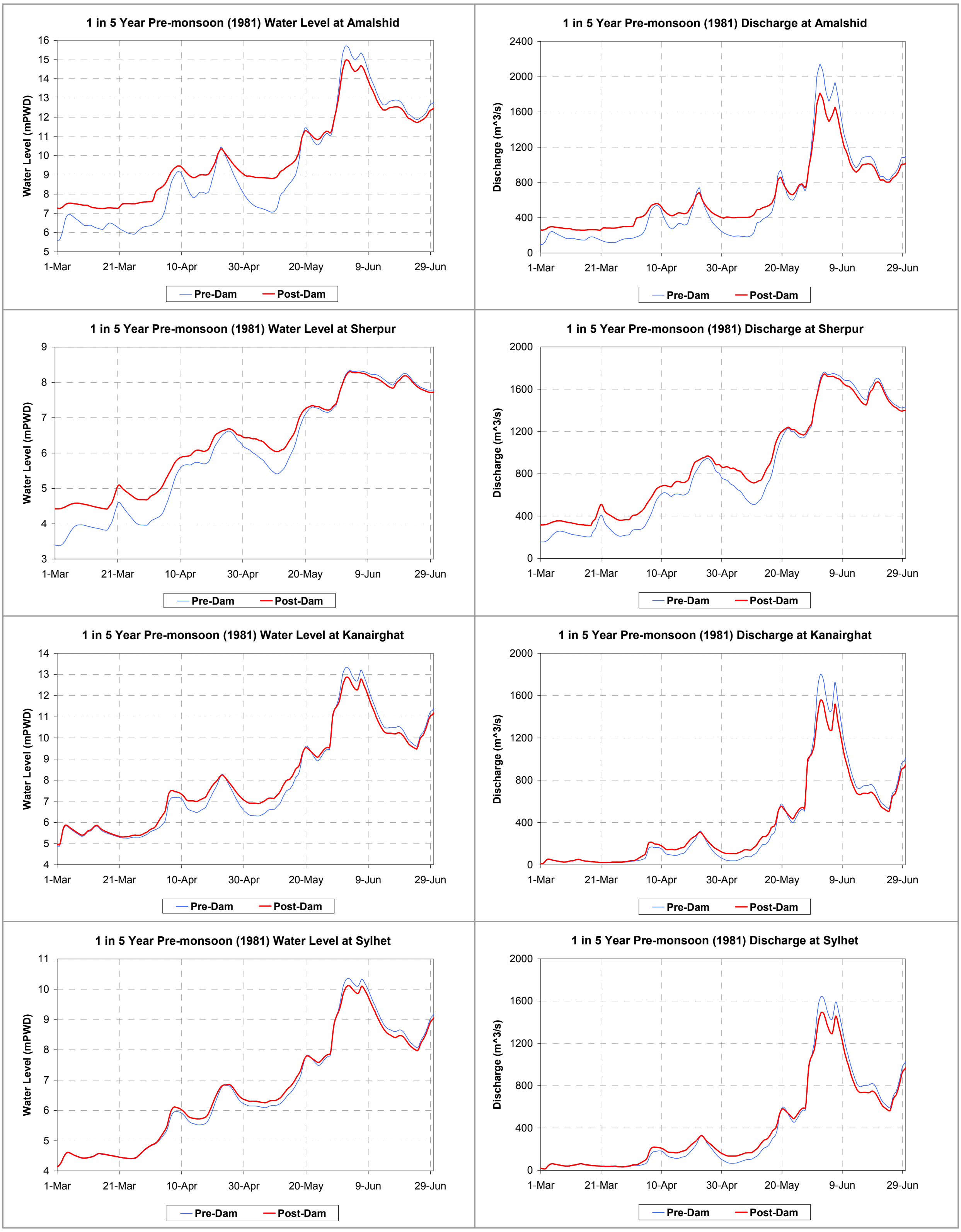


Figure 4.10 Hydrological impact on the Surma-Kushiyara river system during 1 in 5 years pre-monsoon season

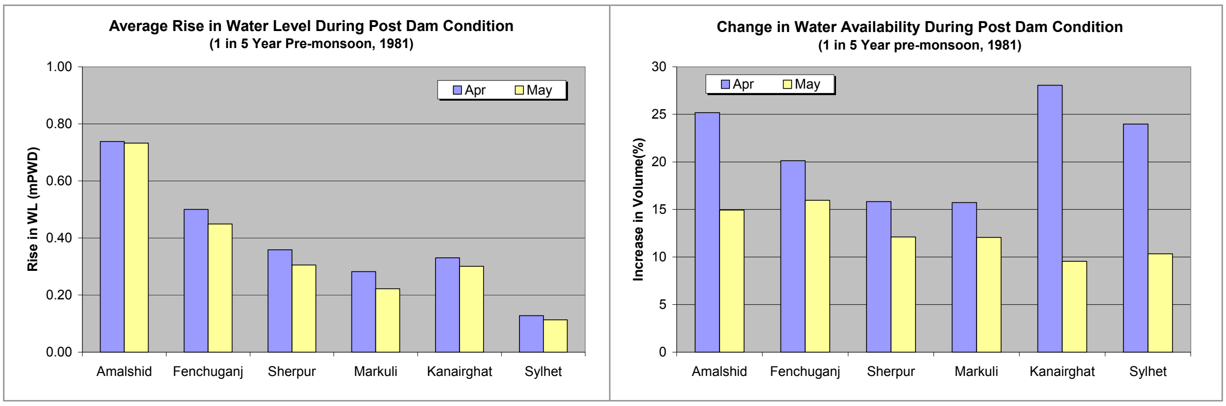


Figure 4.11 Average water level rise and volume increase in the Surma-Kushiyara river system during 1 in 5 years pre-monsoon season

It should be made clear that though the average quantity of water as well as river stage would increase during the pre-monsoon period for post-dam scenario, peak discharge and water level for pre and post-dam condition would remain relatively closer to each other.

Change in Dry Flow

Dry flow assessments have been done for three hydrological events, one for average dry year (1976), one for critical dry year (1979) and remaining one interestingly for the year after most critical dry year (1980). Analysis for 1980 has been done for a particular reason. Analysis of the historical discharge data at Amalshid on the Barak River reveals that from 1978 to 1981, the Barak Basin experienced a continuous dry spell. Monsoon flow as well as dry flow was substantially less than that of average monsoon and dry year flows at that period (see Figure 4.12).

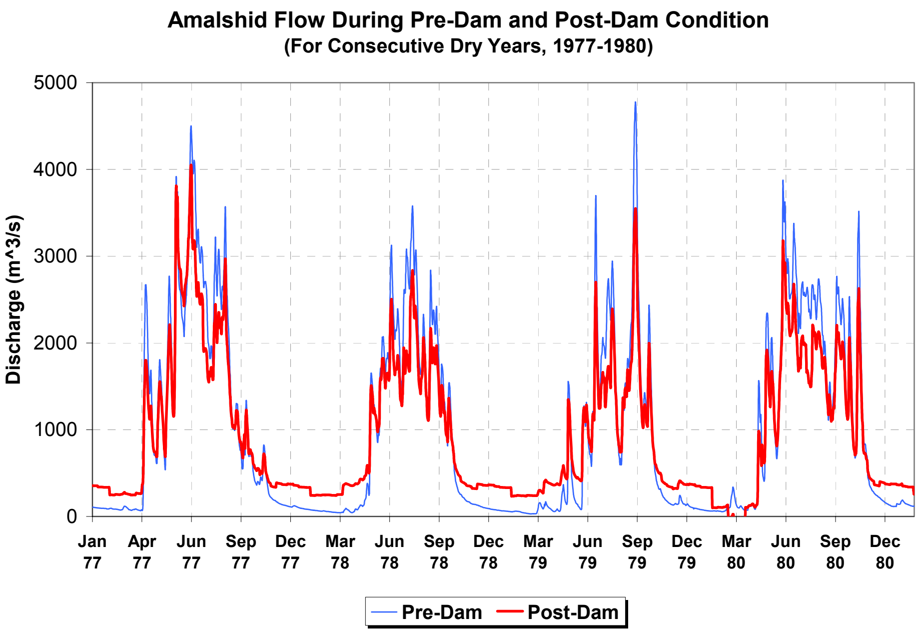


Figure 4.12 Flow at Amalshid for pre-dam and post-dam condition during a continuous dry spell between 1978 to 1981

Therefore, the study team felt that the very next year dry season of critical dry year for pre-dam condition should be included in the hydrological impact assessment to see what would likely to be the dry flow during post-dam scenario if there persists a several years of consecutive dry spell in the Barak Basin.

For average dry year (1976)

Generally augmentation of average dry flow for the downstream river reach happens due to a confirm release from any hydropower project and that would be the case also for the Tipaimukh Dam Project. Though there should be a clear assessment of how this augmented flow would be used by the Indian authority in the Cachar Plain, downstream of the dam. Because as stated before, the Central Water Commission of India has a decision to develop the Cachar Irrigation Project by constructing a pick-up barrage at Fulertal. According to the information provided in the *DPR of Tipaimukh Dam Project*, they are going to withdraw a certain amount of water from the Barak River (see Figure 3.5), especially during the dry period. It has been seen that even after the withdrawal from the augmented water in the Barak River as per the quantity given in the *DPR*, there remains a considerable amount of water, which would be much higher than the present pre-dam dry flow. But what would happen if the Indian authority goes for a higher amount of water withdrawal than the figures presented today for extended irrigation or other activities in future – that remains a big question mark for the people of downstream.

Overall Barak flow at Amalshid would increase by 121% in volume and by 1.48 meter in water level for the whole dry season. From the NER Model simulation, it has been seen that maximum augmentation would happen during the month of January when the average flow would increase by 222 m^3/s (99%) and water level by 2.09 meter. February and March flow would not increase as much as in the case for January, still increment would be substantial, like flow would increase by 160 m^3/s and 148 m^3/s, respectively for the months of February and March. Figure 4.13, and Table A-5 in Annex show the possible pattern of flow augmentation during the period of December to March in the Surma-Kushiyara river system.

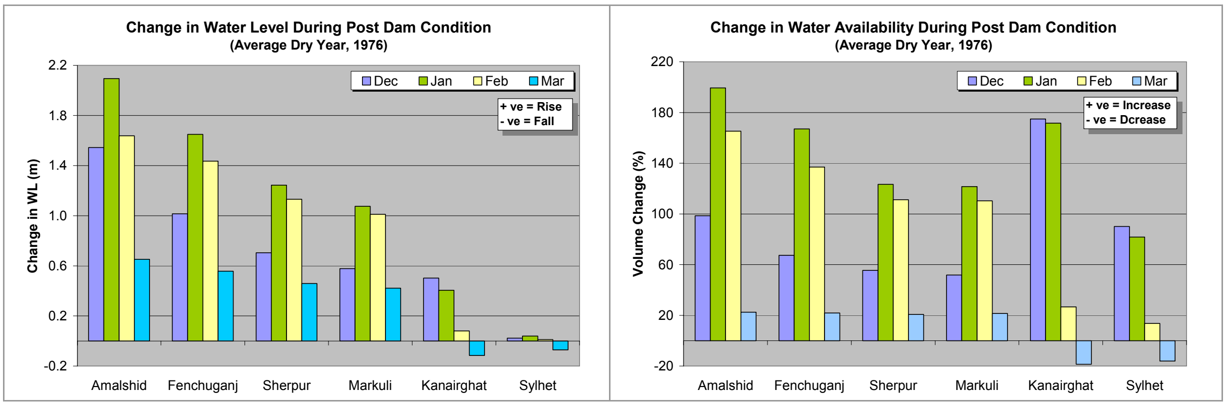


Figure 4.13 Average change in water level and volume of the Surma-Kushiyara river system during an average dry year

For critical dry year and year after critical dry year

From the historical data analysis, it has been found that the Barak Basin experienced a continuous dry spell during the period of 1978 to 1981, where monsoon flow as well as dry flow was substantially less than that of average monsoon and dry year flows. Now, out of those years, 1979 dry period was most critical with respect to low flow analysis. The very next year, 1980, was also a relatively drier year. For this reason, simulation of Hydropower Reservoir Model suggests that though the firm power generation could be maintained during the critical dry year (1979), it might not be possible for the next year of critical dry year. To confirm the firm power generation during the critical dry year, the reservoir level would be drawn closer or identical to its minimum operational level (Minimum Draw Down Level, MDDL) (see Figure 4.14).

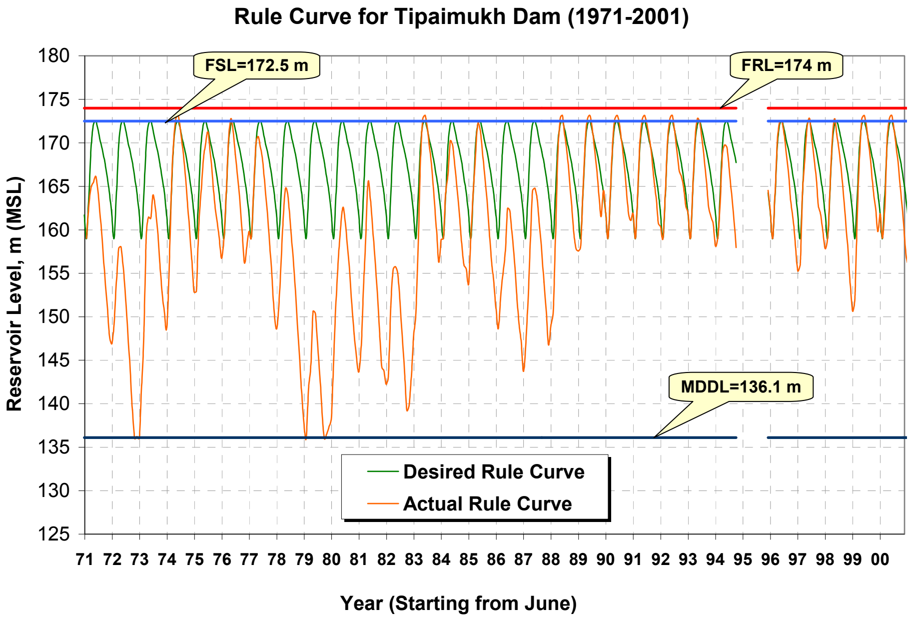


Figure 4.14 Desired and actual rule curve of Tipaimukh hydroelectric reservoir operation

In this context, the reservoir nearly to its minimum operational level would enter the next monsoon season (1980) with a critical storage level. If the next monsoon year (say 1980) is also relatively a drier year once again, the reservoir level would not reach to such at the end of the monsoon level where the confirm release for firm power generation could be ensured for the next dry period (February and March of 1981, in particular). If it is done then the reservoir level would be drawn to lower than the MDDL and this is strictly prohibited as per the reservoir rule curve.[4] Thus the, hydropower project would not produce its firm power for those months, consequent overall release might be strikingly lower than the flow for pre-dam condition. In addition, what ever water would be released under this situation, there may remain much less water to flow through the Barak-Surma-Kushiyara River as a substantial amount of water will be withdrawn for Cachar Irrigation Project and the findings of the study also suggest the same. Figure 4.15 shows the sudden fall in dry flow at Amalshid on the Kushiyara River in the month March to such an extent that the discharge may become well below the most critical dry flow ever experienced in this river for the last 30 years. And this feature, as understandably, would be seen for every point of which the study results have been presented in this report (see Figure 4.16 and Table A-6 in Annex).

[4] NEEPCO, *Detailed Project Report on Tipaimukh Hydro Electric (Multipurpose) Project*, Shillong 2000, ch. IV p. 3.

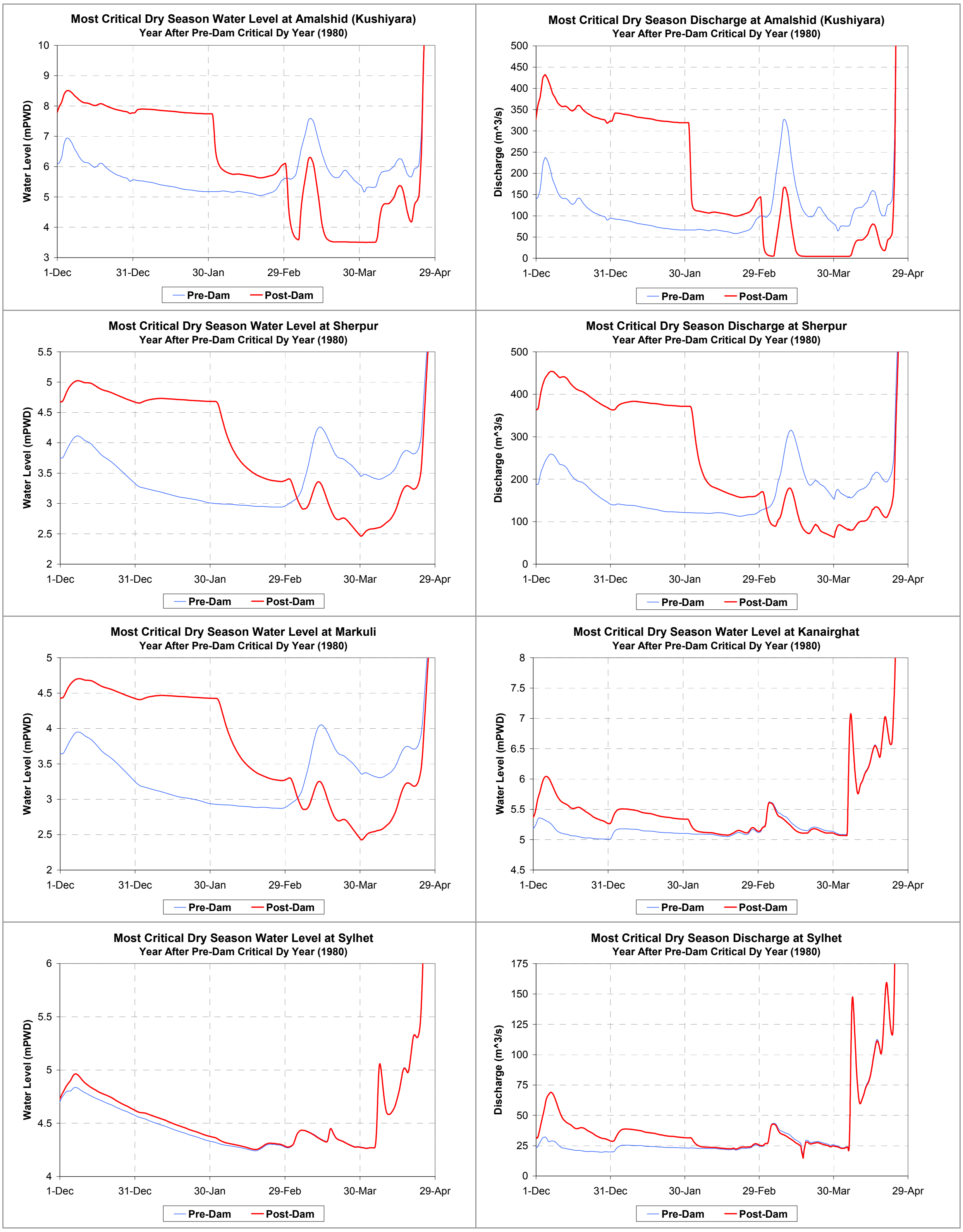


Figure 4.15 Hydrological impact on the Surma-Kushiyara river system during most critical dry season for post-dam condition (next year after pre-dam critical dry season)

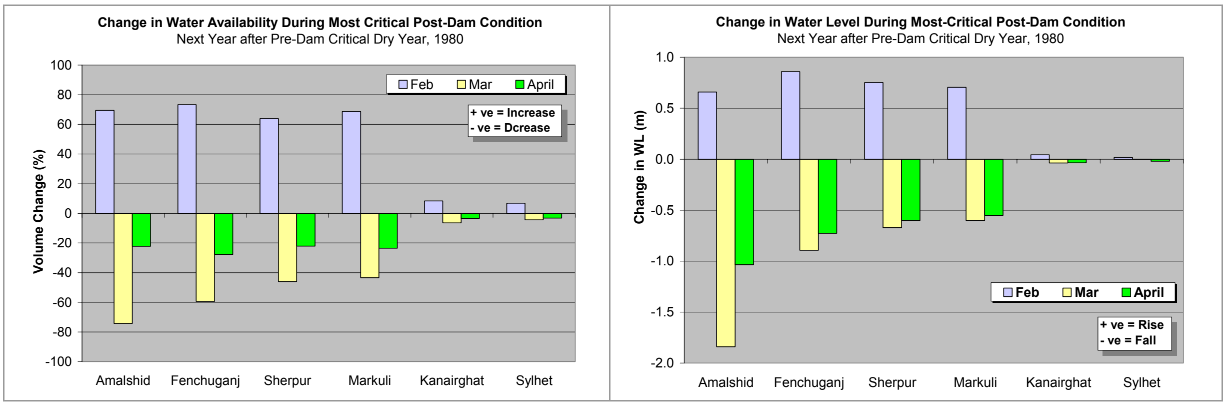


Figure 4.16 Average change in water level and volume of the Surma-Kushiyara river system during most critical post-dam condition

Analysis shows that for this particular event, inflow from Barak River during the month of March and April would decrease severely. And this reduction in Barak flow will hit the Kushiyara river system quite a lot margin rather than, as understandably, the Surma river system. For example, average flow for the month March would be as low as 38 m^3/s, 67 m^3/s, 108 m^3/s, and 112 m^3/s at Amalshid, Fenchuganj, Sherpur and Markuli respectively. This would be around 74%, 59%, 46% and 43% less on average, respectively, than it actually happens during pre-dam scenario. The alarming case is that for a substantial period of month March, there would be virtually no flow in the Barak, as such as, in the Kushiyara River at Amaslhid point! (see Figure 4.15). Moreover, this low flow condition can continue to end of the month April if there occurs much lower than usual precipitation for that month in the Cachar valley, as it was the case in 1980. As such, average discharge would reduce around 22%, 27%, 22% and 23% on average at Amalshid, Fenchuganj, Sherpur and Markuli, respectively for the month April.

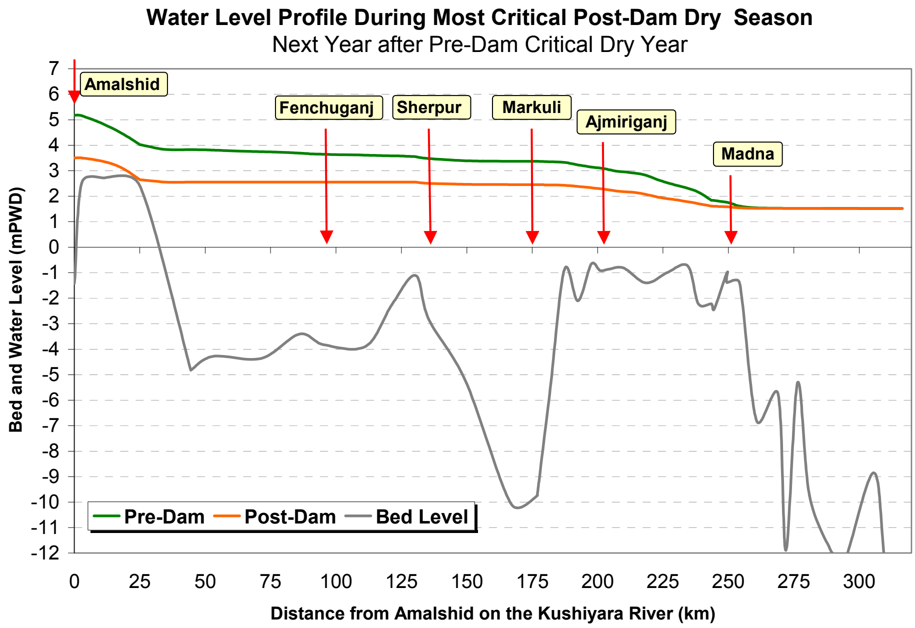


Figure 4.17 Lowest water level profile of the Kushiyara river system (Month 31, 1980)

The most destructive consequence of this event will be big drop in water level along the whole Kushiyara River. Water level profile of the Kushiyara River (see Figure 4.17) shows that the water level drop in post-dam scenario would continue up to Madna, more than 250 km downstream from the bifurcation point of Barak River into the Surma-Kushiyara River. From Amalshid to nearly Madna on Dhaleswari River, the water level reduction would vary from 1.7 meter to 0.2 meter. For example, water level may fall by 1.7 meter at Amalshid on the Kushiyara River, by 1.1 meter at Fenchuganj, by 1.0 meter at Sherpur, by 0.9 meter at Markului, by 0.8 meter at Ajmiriganj and by 0.2 meter at Madna station.

Chapter 5

Impacts of Dam Resulting From Change in Hydrology

Moderation of Flood or Detrimental Effects on Floodplain Ecosystem

Like every hydroelectric project, Tipaimukh Dam Project of India will definitely reduce the usual or normal flood intensity of the Barak-Surma-Kushiyara river system. The present study suggests that the average reduction of June to September flow at Amalshid on the Barak River during average monsoon year would be around 11% (for June), 23% (for July), 16% (for August) and 15% (for September) for post-dam condition. Similar or even greater reduction may happen for the below average monsoon or 1 in 5 years monsoon season. On the contrary, flood attenuation during the flood events similar to 1 in 10 or 1 in 25 years flood would not be as high as it would happen for normal or average flood season. As far as the peak attenuations at Amalshid on the Barak River are concerned, Table 4.1 shows that for a relatively dry monsoon flood to average or 1 in 5 years flood events, peak flow would reduce as much as 23% to 27% in magnitude and 1 to 1.25 meter in water level, while these would be only 13% and 0.53 meter for 1 in 10 years monsoon event and 3% and 0.11 meter for 1 in 25 years monsoon event.

Many would say, especially from the Indian dam initiator and by some of the Bangladeshi experts as well, that the project is going to reduce the flood intensity for the downstream region; hence this would solve the flood problem in the northeast region of Bangladesh, against which Bangladesh is fighting over the years. Their conclusion would be directed towards a notion that the Tipaimukh Dam Project of India should be regarded as harmless or even beneficial to Bangladesh! But would it be really like this? The study team, however, has the other idea.

Impact on Floodplain and H*aors*: From Model Results

Flood propagation model MIKE Flood has been used to examine the effect of hydrological change – which would likely to happen in the Barak flow due to dam operation – on normal or average annual flooding pattern in the northeast region of Bangladesh, Sylhet and Moulvibazar district in particular. The simulation period of the model covers the highest peak flow through the Barak River at Amalshid point for average or normal flooding year; e.g. 1996 monsoon. The study has also carried out an indicative impact assessment on the natural inundation pattern of some of the *haors* (wetlands) and the project area in this part of the region as case studies basis. The results what have been found from the model simulation are frightening.

Figure 5.1 shows the two flood inundation maps on the same date (August 25 9:00 AM, 1996) of which the top one represents the pre-dam scenario and the bottom one represents the post-dam scenario. Comparison of those two flood maps of Sylhet and larger part of Moulvibazar district shows distinguished reduction in inundation area. In fact, all the floodplain and the *haor* (wetland of the region) of these two districts, which are usually influenced by the seasonal rise and fall of the Surma-Kushiyara River flow, would be essentially affected by the low flow condition during the normal monsoon season in post-dam condition. On the other hand, the loss of wetland may not be realized by observing the total loss of inundation area only; rather the shift from inundation area of greater depth of to a shallow depth area is one of the key indicators to investigate this loss.

Hence the analysis reveals that around 30,213 ha. (26%) of inundated area[1] of Sylhet district for pre-dam average monsoon event would become completely dry [2] for post-dam condition. This 30,213 ha. of pre-dam inundated but post-dam dry land includes 1,017 ha. (which is 26% of same land type for pre-dam condition) of F4 land, 5,310 ha. (20%) of F3 land, 8,946 ha. (23%) of F2 land, 12,456 ha. (31%) of F1 land and 2,484 ha. (38%) of F0 land type of the district (see Table 5.1)

Table 5.1 Pre and post-dam inundation pattern of Sylhet district

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	218655	248868	30213		14
Inundated area						
F0	0 - 0.3 m	6597	4113		2484	38
F1	0.3 - 0.9 m	40554	28098		12456	31
F2	0.9 - 1.8 m	39015	30069		8946	23
F3	1.8 - 3.6 m	27162	21852		5310	20
F4	> 3.6 m	3843	2826		1017	26
Total inundated area						
F0 – F4	> 0 m	117171	86958		30213	26

For Moulvibazar district, this loss may be relatively less, but still can be considered a substantial loss. Like, around 5,220 ha. (11%) of pre-dam inundated area would become complete dry land, which includes 1,512 ha. (which is 22% of same land type for pre-dam condition) of F4 land, 1,863 ha (8%) of F3 land, 1,332 ha. (13%) of F2 land, 243 ha. (3%) of F1 land and 270 ha. (64%) of F0 land (see Table 5.2).

[1] In terms of inundation induced by the over topping the bank of the river

[2] Only inundation due to local rainfall would happen there. The local rainfall has not been considered for developing the inundation map, though the surface runoff from the numerous number of sub-catchments of the region, simulated by Rainfall-Runoff model have been accumulated to the river course as a point or distributaries source in the Hydrodynamic model of MIKE 11.

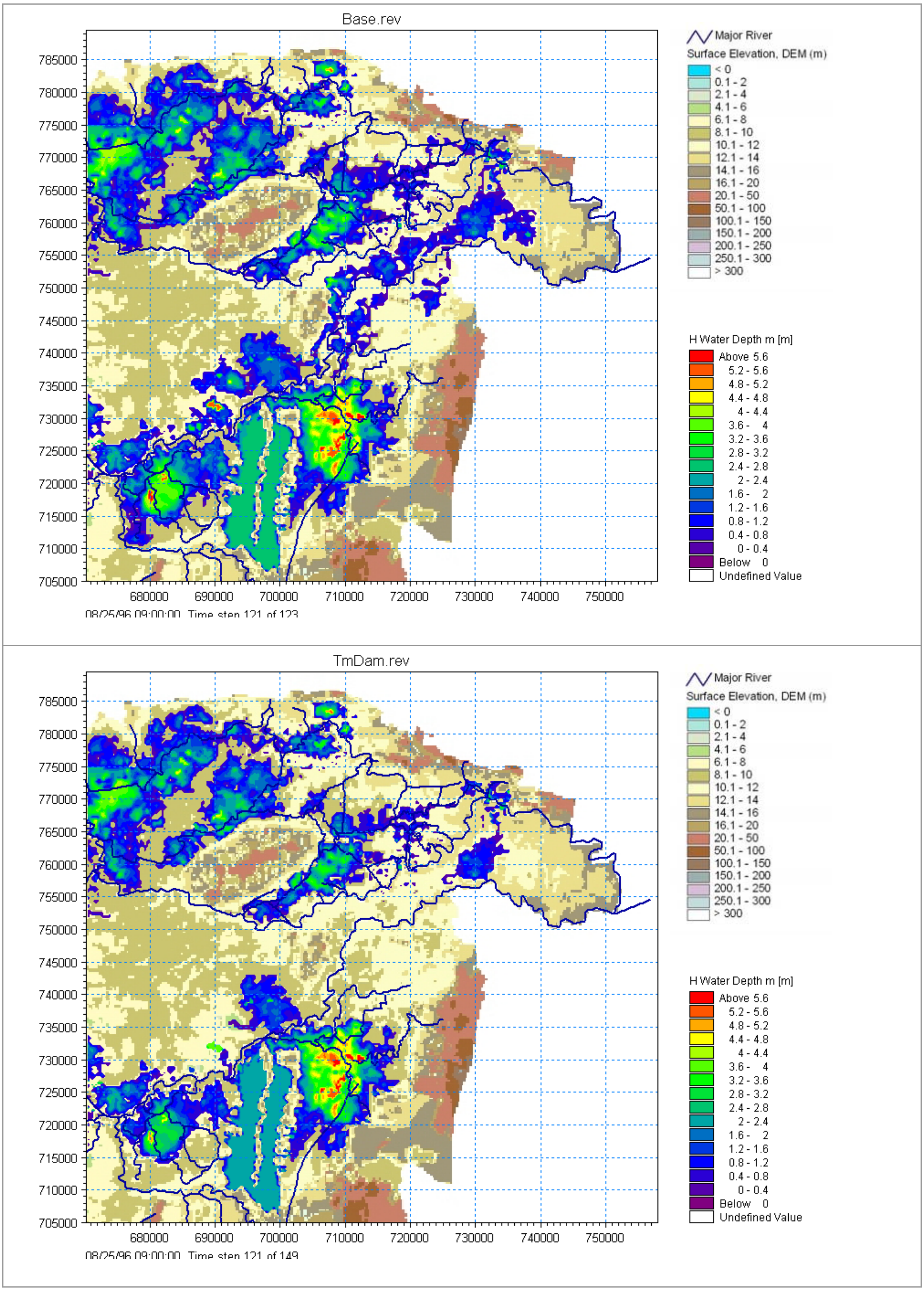


Figure 5.1 Average monsoon year flood map of Sylhet-Moulvibazar district for pre-dam scenario (top) and post-dam scenario (bottom)

Analysis also suggests that the most effected area would be the system involved in the Kusiyara River as the Kushiyara River shares the bigger portion of the Barak flow. The Kushiyara floodplain would be reduced in a large scale. For example, some of the portion of the Kushiyara River would loose its connection with the surroundings floodplain completely (see Figure 5.2). Figure 5.2 and Table 5.3 show that 15,633 ha. (71%) of pre-dam inundated area in the 65 km. long floodplain of right bank of the Kushiyara River inside the Upper Surma-Kushiyara Project of BWDB would become completely dry during post-dam average year condition. In the process of this drying, 135 ha. of F4 land would become extinct which is actually 100% of that particular land type for the pre-dam condition. Similarly, 783 ha. (81%) of F3 land, 3,888 ha. (73%) of F2 land, 5,418 ha. land of F1 and 945 ha. (68%) of F0 land may be lost due to post-dam low flow condition.

Table 5.2 Pre and post-dam inundation pattern of Moulvibazar district

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	194544	199764	5220		3
Inundated area						
F0	0 - 0.3 m	423	153		270	64
F1	0.3 - 0.9 m	8910	8667		243	3
F2	0.9 - 1.8 m	10197	8865		1332	13
F3	1.8 - 3.6 m	22356	20493		1863	8
F4	> 3.6 m	6822	5310		1512	22
Total inundated area						
F0 – F4	> 0 m	48708	43488		5220	11

Table 5.3 Pre and post-dam inundation pattern of the Upper Surma-Kushiyara Project

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	37251	48420	11169		30
Inundated area						
F0	0 - 0.3 m	1386	441		945	68
F1	0.3 - 0.9 m	7785	2367		5418	70
F2	0.9 - 1.8 m	5355	1467		3888	73
F3	1.8 - 3.6 m	972	189		783	81
F4	> 3.6 m	135	0		135	100
Total inundated area						
F0 – F4	> 0 m	15633	4464		11169	71

Figure 5.2 also shows that the Kushiyara-Bardal *haor* at the left bank of the Kushiyara River would become completely dry in an average monsoon year for post-dam scenario. There would be no flooding in this *haor* area at all! (see Table 5.4)

There is another *haor* showing in the same figure, called Damrir *haor* on the right bank of the Kushiyara River, and this one would face same the fate as it would be for the other two *haors* in this part of the region. Though the overall reduction in pre-dam inundation area would be relatively less (765 ha., 13%) than that of others two, still the loss of greater depth inundation land type is huge in respect of pre-dam inundation area. For example, 27 ha (100%) of F4 and 297 ha. (67%) of F3 land would no longer remain exist in this *haor* for the post-dam condition (see Table 5.5).

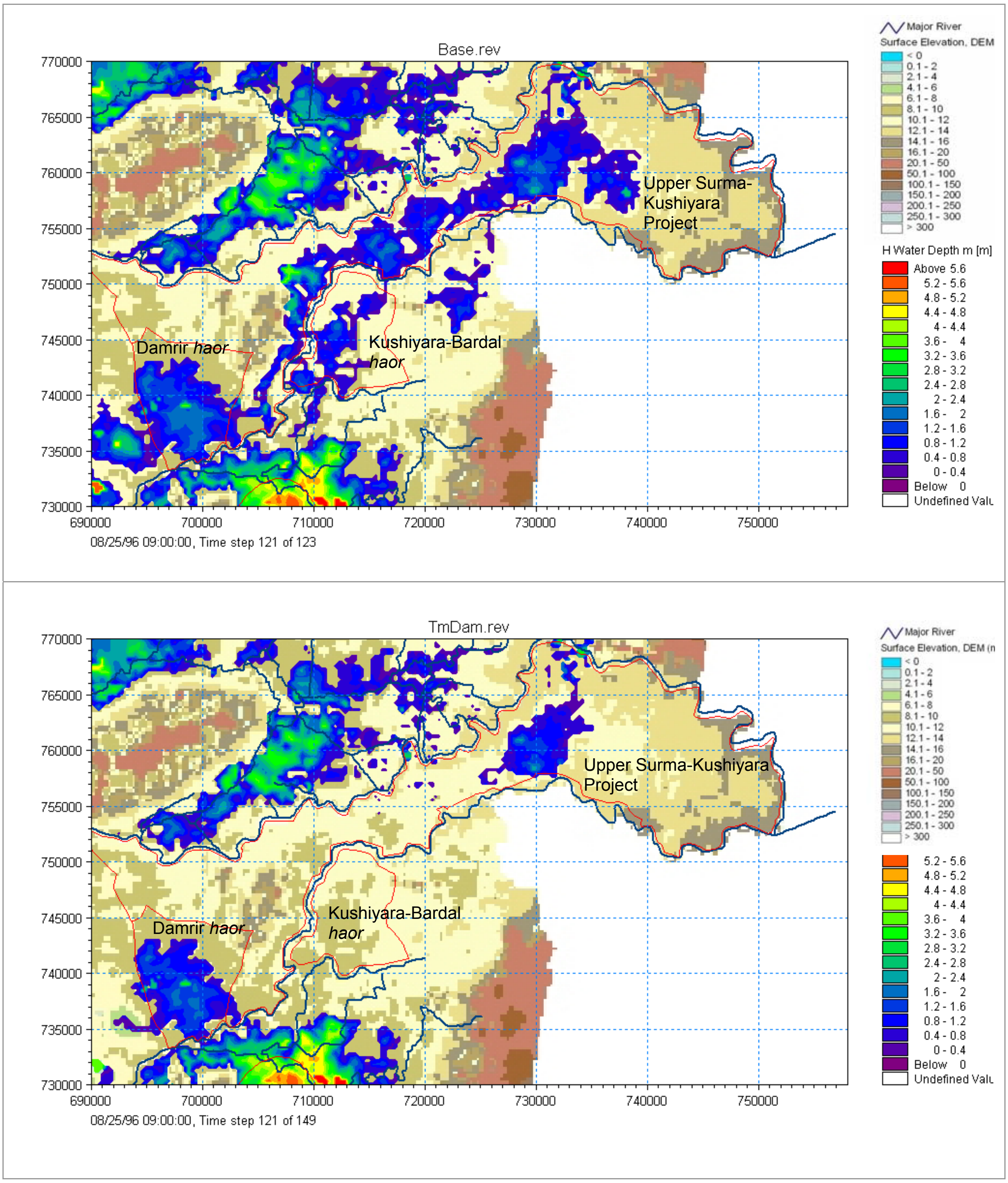


Figure 5.2 Average monsoon year flood map of right bank of Kushiyara River for pre-dam scenario (top) and post-dam scenario (bottom)

Table 5.4 Pre and post-dam inundation pattern of the Kushiyara-Bardal *haor*

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	4266	6975	2709		64
Inundated area						
F0	0 - 0.3 m	261	0		261	100
F1	0.3 - 0.9 m	1575	0		1575	100
F2	0.9 - 1.8 m	837	0		837	100
F3	1.8 - 3.6 m	36	0		36	100
F4	> 3.6 m	0	0		0	-
Total inundated area						
F0 – F4	> 0 m	2709	0		2709	100

Table 5.5 Pre and post-dam inundation pattern of the Damrir *haor*

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	3843	4608	765		20
Inundated area						
F0	0 - 0.3 m	81	18		63	78
F1	0.3 - 0.9 m	1872	2070	198		11
F2	0.9 - 1.8 m	3600	3024		576	16
F3	1.8 - 3.6 m	441	144		297	67
F4	> 3.6 m	27	0		27	100
Total inundated area						
F0 – F4	> 0 m	6021	5256		765	13

Figure 5.3 shows the impacts of low flow condition in the Kushiyara River on two other important *haors* of the region, Kawardighi *haor* and Hakaluki *haor*. Table 5.6 illustrates that 2,979 ha. (26%) of pre-dam inundated land would no longer be flooded during post-dam condition. On average 207 ha. (87%) of F4 land, 1,134 ha. (24%) of F3 land would become extinct, while there would not remain any shallow depth inundated area within this *haor* during post-dam condition.

Table 5.6 Pre and post-dam inundation pattern of the Kawardighi *haor*

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	3042	6021	2979		98
Inundated area						
F0	0 - 0.3 m	243	0		243	100
F1	0.3 - 0.9 m	2070	1971		99	5
F2	0.9 - 1.8 m	2853	2691		162	6
F3	1.8 - 3.6 m	4653	3519		1134	24
F4	> 3.6 m	1548	207		1341	87
Total inundated area						
F0 – F4	> 0 m	11367	8388		2979	26

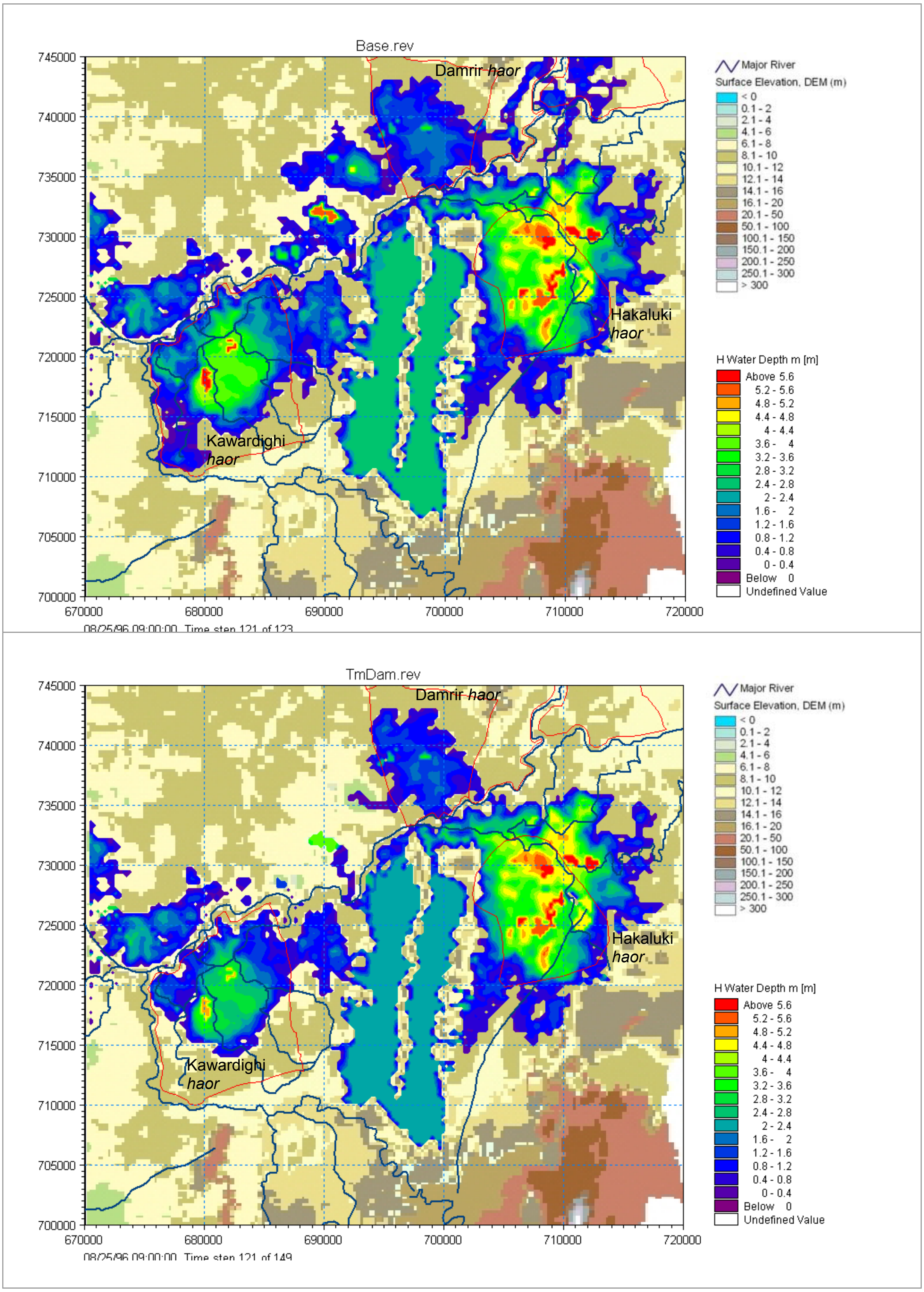


Figure 5.3 Average monsoon year flood map of Hakaluki and Hail *haor* for pre-dam scenario (top) and post-dam scenario (bottom)

In comparison to the effects that may hit over other *haors* in Sylhet and Moulvibazar district, impacts on which have been studied her, there would be relatively less effects on the Hakaluki *haor* (see Figure 5.3 and Table 5.7). Actually the Hakaluki *haor* is also fed by the rivers like the Juri originating from the Tripura Hill sub-basin, and that may be the probable reason why the Hakaluki *haor* is not influenced so much by the low flow of the Kushiyara River.

Table 5.5 Pre and post-dam inundation pattern of the Hakaluki *haor*

Type	Depth	Pre-dam	Post-dam	Area increased	Area decreased	%
Completely dry area						
	<= 0 m	207	270	63		30
Inundated area						
F0	0 - 0.3 m	18	0		18	100
F1	0.3 - 0.9 m	585	621	36		6
F2	0.9 - 1.8 m	846	801		45	5
F3	1.8 - 3.6 m	3483	3636	153		4
F4	> 3.6 m	4302	4113		189	4
Total inundated area						
F0 – F4	> 0 m	9234	9171		63	1

It should be remembered that these impact analysis on floodplain and *haors* are done only for average annual monsoon event. And whenever we talk about average year, there should be some years, which represent the monsoon events below that average. Therefore, the impacts on floodplain and *haors* in terms of loss as well as shifting from area of greater depth to area of shallow depth should be aggravated more in those below average monsoon years. In addition, as it has been stated before that the flood events resembling the 1 in 5 years floods are also considered as a normal or closer to average flood events, so the impacts in those years would be similar with average monsoon events by and large. In contrast of that, the size of the flood likely to recur every 10, 25 or 50 years would be barely changed between pre and post-dam scenario as we have found that the moderating of those flood events would be comparatively very less. Hence, based on the impact analysis presented in this report, it can be said that at least 6 to 7 out of 10 consecutive years, the Surma-Kushiyara river system will suffer drying effect firmly!

Impacts on Riverine Ecosystem

From the analysis presented above, we can conclude that the Tipaimukh Dam Project of India would affect the floodplains' as well as *haors'* hydrology to a considerable scale. The following section will, however, describe some theoretical aspects of such impacts on the overall riverine ecosystem of the Surma-Kushiyara River. In other words, what the country is going to face due to such hydrological effects on floodplains and *haors* in true sense has been presented here from a river-floodplain-wetland ecosystem perspective, though in a very elementary manner.

It would be better first to illustrate briefly how the physical system, involved in a river geo-hydrology, works. Figure 5.4 shows the ecosystem components representing various geomorphologic areas of an alluvial system. The ecosystem is contained within the watershed boundaries, and is organized into the following areas: upland, tributaries and streams, riparian vegetation both wetland and floodplain areas, non-riparian vegetation, and the main river channel that ultimately exports water and materials in the water from the watershed.[3] The figure does not show the groundwater component. The groundwater flow regime is an important component in the alluvial systems like the Surma-Kushiyara system.

Tributaries contributing to main channel flow will be considered as a part of the drainage basin. Non-riparian wetland vegetation areas could be linked hydrologically with the stream main channel via seepage through groundwater, and, in turn, can be influenced by the flow in the main channel.

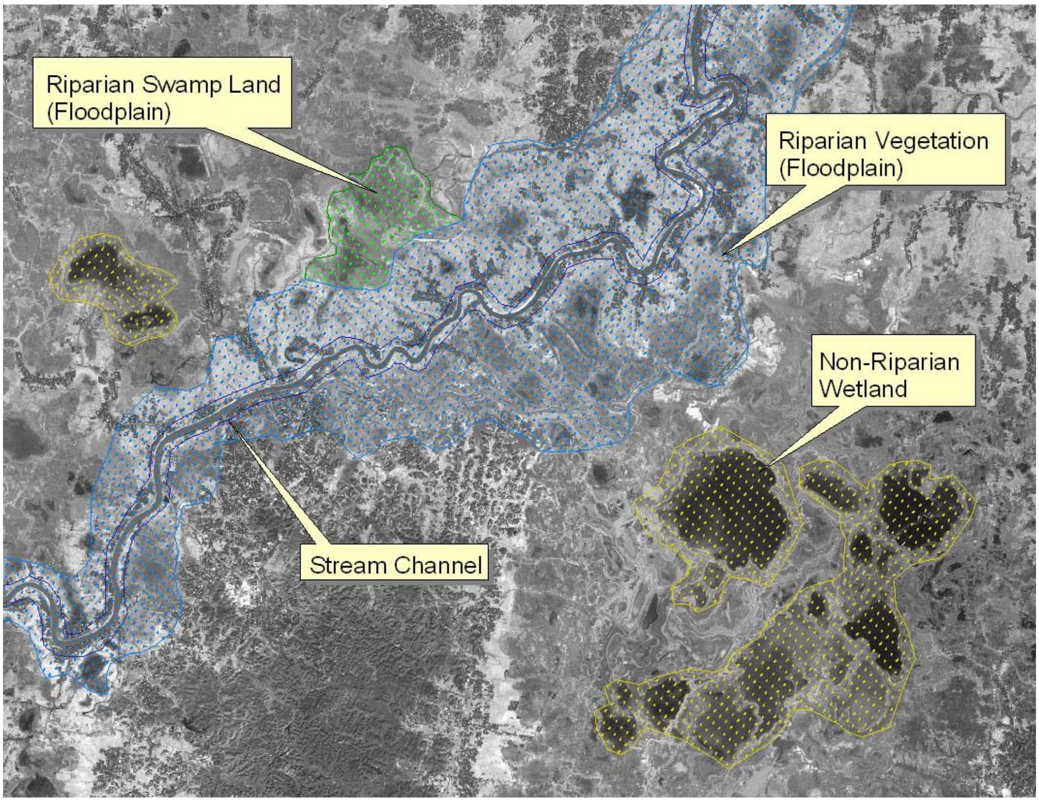


Figure 5.4 Conceptual representation of physical system involved in an alluvial river system

Now, any large scale reduction or withdrawal of flow from a natural river flow may impact water quality and quantity, sediment transport and bottom sediment properties; and these changes may in turn impact the ecology of the ecosystem. It has been already shown that the reduction in annual normal flood flow of the Barak River due to the Tipaimukh Dam operation would be a large scale one. In such case, the most probable consequences as has been found in the flood inundation map analysis between pre and post-dam scenario is not only isolating the Surma-Kushiyara River from its floodplain but also the floodplain of these two rivers, especially for the Kushiyara River, would no longer remain a floodplain at all in future, turning what fish biologists term a 'floodplain river' into a 'reservoir river'.[4] Similarly, areal shrinkage and shifting from deep inundated wetland to shallow inundated wetland as well, will be the complete destructive effects on the most resourceful natural perennial wetland (*haors)* of northeast region of Bangladesh.

[3] Ann Arbor, 'Developing Tolls for Assessing the Impacts of Water Withdrawals in the Great Lake Lawrence Basin', Limno-Tech, Michigan May 2004.

[4] R.L. Wellcome, *Fisheries Ecology of Floodplain Rivers,* Longman, London 1979 (cited in McCully, *Silenced Rivers,* p. 31).

The possible impacts of the Tipaimuk Dam what have been just mentioned above, would destroy what ecologist Peter Bayley terms the 'flood pulse advantages' of the river-floodplain-wetland system. Flood pulse advantages are considered the main reason for the astonishing diversity and productivity of rivers and floodplains. On a per unit area basis the diversity of fauna in rivers is 65 times greater than in the seas. Peter Bayley informs that the annual floods on tropical rivers are estimated to produce fish yields a hundred times higher than in rivers without floodplains, and, on a per hectare basis, around four times more than in tropical lakes or reservoirs[5]. This actually emphasizes the fact that the river and floodplain ecosystem are actually closely adapted to the annual cycle of flooding and drying. As such, riverine habitat and species are fundamentally dependent on how well this integrity between the river and the floodplain is sustained. Matrick McCully explains:

> 'Many species depend on seasonal droughts or pulse of nutrients or water to give the signals to start reproduction, hatching, migration or other important lifecycle stages. Annual floods replenish wetlands not only with water but also with nutrients, while flooded manure from both domestic and wild animals on the floodplain enriches the river. Floods sweep fish eggs and fry into floodplain backwaters and lakes where they hatch and grow before joining the river again after the next annual floods'.[6]

Silt-enrichment should the other consideration in this context. During monsoon, rivers carry not only water but also enormous of solids of various sizes from the highly erodible land of this region on to the floodplains. Larger portion of the total amount of these solids are usually silts. And the rivers use to overtop the banks during monsoon season; the clay-humus rich silt contained in the upper layer is deposited on the soils, increasing its fertility many times. For thousands of years our farmers have considered silt deposition to be beneficial.[7] Now if the floodplain is turned free from annual flooding by arresting river water within the river course and make it dry for a number of years, this silt-enrichment to the agricultural land of floodplain will no longer be possible. In consequence, this will affect the agricultural activities of the floodplain by two ways: firstly, it will decrease the natural productivity of the floodplain agricultural land in a severe manner; secondly, to maintain the overall productivity of the land, farmers will have no option other than to use more and more fertilizer and that will make the condition even more critical. Overall implications will be thus essentially on the socio-economic activities of the region.

The analysis presented above, therefore, might prove those pro-dam claims wrong in two ways: firstly there is every reason to forecast that the dam project would reduce the average annual flood in large scale, while the size of the flood likely to recur every 10, 25 or 50 years, which actually cause suffering to the people, would be barely changed. Secondly, the reduction of average annual flood should not be regarded as an advantage by any means as the ecological and agricultural impact of such would be huge in terms of total destruction of river-floodplain-wetland habitat of the Surma-Kushiyara river system and the overall productivity of the land and water of the northeast region of Bangladesh.

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[5] P.B. Bayley, 'The Flood Pulse Advantages and the Restoration of River-Floodplain Systems', *Regulated Rivers: Research and Management,* Vol. 6, 1991 (cited in McCully, *Silenced Rivers,* p. 49).

[6] Patrick McCully, *Silenced Rivers, The Ecology and Politics of Large Dams*, Zed Books, London 1996, p. 47.

[7] Haroun Er Rashid, 'Some Rncironmental Concerns Abour Water resource Development Planis in Bangladesh' in Mir M. Ali et al. (eds.), *Bangladesh Floods, Views from Home and Abroad,* The University Press Limited, Dhaka 1998, p. 118.

Impact on Morphology

As the present study has not so far used any particular tool to assess the overall morphological impact of Tipaimukh Dam Project of India on northeast region of Bangladesh, the current analysis aims towards a conceptual impact assessment on the morphology of the Surma-Kushiyara river system.

It is being experienced that much of the impacts of dam on downstream habitats is through the changes in the sediment load of the river. All rivers carry some sediment as they erode their watershed. When the river is held behind a dam in the reservoir for a period of time, most of the sediment, especially the heavy gravels and cobbles, will be trapped in the reservoir, and settle to the bottom. And this very typical sediment trapping feature of the reservoir starve the river downstream of its normal sediment load. Large reservoirs and dams without low-level outlets will typically trap more than 90 per cent, and sometimes almost 100 per cent, of incoming sediment.[8] The water thus released from the dam is nearly free from sediments, and is said to be 'hungry' water, which will recapture its sediment load by eroding the downstream bed and banks. The sediment picked up by the hungry river may be deposited further downstream, and erosion (degradation) of the riverbed below the dam will then be replaced by its raising (aggradation) further downstream.[9] It is not likely that this sediment eroding features of 'hungry water' is stopped within few kilometer of downstream river reach; rather the erosion can continue to as long as 150 km. downstream of the dam. For example, within nine years of the closure of Hoover Dam, hungry water had washed away more than 110 million cubic meters of material from the first 145 kilometers of riverbed below the dam, lowering it in places by more than 4 meters.[10]

In the context of the discussion presented above, it can be said that the overall sediment rate and the morphology of the Barak-Surma-Kiushiyara will no longer remain its usual form if there is a Tipaimukh Dam operating on the Barak River. It cannot be though said exactly what is the most certain change that would likely to be happened in the sediment transport rate as well as erosion and deposition pattern in the Barak-Surma-Kushiyara river system during post-dam condition without any proper morphological study. The situation is getting more complex considering the dual storage of the Barak flow; first in the upstream of the dam itself and second by the Fulertal Barrage. However, looking through the probable hydrological changes in the river system for the post-dam scenario, it may not be wrong to say that the sediment aggradations or deposition would increase a lot, particularly during the late monsoon and post-monsoon season as the average flow for these seasons would be considerably less than the pre-dam condition. This deposition will raise the riverbed followed by turning the average monsoon flood to a moderate or sever flood in the region. On the other hand, erosion or degradation would increase in the Barak and upper Kushiyara River quite a lot during the winter and dry season, as the average dry flow would increase. In effect of that, there would be a certain possibility that this newly eroded sediment will deposit in the further downstream of the Kushiyara and Kalni River.

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[8] Patrick McCully, *Silenced Rivers, The Ecology and Politics of Large Dams*, Zed Books, London 1996, p. 33.
[9] Ibid. p. 33.
[10] Ibid. p. 34.

During reservoir filling period, unusually low flow releases can cause serious impacts on the morphology of the downstream. It would cause more deposition in the Barak-Surma-Kushiyara river system, consequent of blocking the mouth of certain tributaries channel originating from the Surma-Kushiyara River.

Chapter 6

Other Impacts of Dams: A More Theoretical Examination

Dam Break: Its Consequences as a Catastrophic Event

Dam break – another big issue whenever it is talked about the impact of any hydroelectric dam project on the downstream region. This section starts with the comments of Joseph Ellam, Pennsylvania State Director of Dam Safety, made back in 1987, 'With the exception of nuclear power plants, no man-made structure has a greater potential for killing a large number of people than a dam'.[1]

What Does the History Tell About It

Detail information and statistics on dam failure data around the world are scarce. Numbers of cases even have been found where the respective authority of the states concealed the news of such catastrophic event. Dam burst in different parts of the world for the last century has killed thousands of people. Understandably, these people are essentially the inhabitants of the downstream region. The country specific information, as much as available, is given in Patrick McCully's book *Silenced Rivers, The Ecology and Politics of Large Dams.*[2] According to the International Commission on Large Dam (ICOLD) investigation, it shows that around 2.2 per cent of all dams built before 1950 have failed and 0.5 per cent of dams built since then. It also says that these data explicitly exclude China and thus also likely to be incomplete for other countries. Inside China, some 3200 dams have failed since 1950, 4 per cent of the 80,000 classified dams in the country. ICOLD has identified 164 major dam failures in the period from 1900 to 1965[3].

In recent memories, numbers of dam failures have been reported in Pakistan and Afghanistan during a wave of heavy rain and snow fall hitting over the whole northern area of Indus Basin and northeastern part of Afghanistan in the month of February. More than 500 peoples are reportedly died due to dam-burst induced and other flooding.

This is the consequence, therefore, if there happens a dam break or failure. But many other things can go wrong with a dam. The two main reasons for dam failures are 'overtopping'

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[1] Cited in Patrick McCully, *Silenced Rivers, The Ecology and Politics of Large Dams*, Zed Books, London 1996, p. 115.
[2] Patrick McCully, *Silenced Rivers,* pp. 117-121.
[3] ICOLD 1983 (cited in FAP 6, *Initial Environmental Evaluation: Northwest Regional Water Management Plan,* Draft Final Report, FPCO, May 1994, p. 60).

(responsible for around 40 per cent of failure) and foundation problems (around 30 per cent).[4] Numerous cases have been recorded where dam operators had to release additional water exceeding maximum capacity of dam reservoir through spillways to prevent the dam from overtopping. Center for Science and Environment, India have recorded many of those examples regarding the dam induced flood. One of those examples says,

> 'Many other deadly floods have been blamed on emergency releases from Indian dams. In 1978 nearly 65,000 people in the Punjab were made homeless by floods exacerbated by forced discharges from Bhakra Dam. A member of a committee set up to investigate the floods admitted that Bhakra had been close to being overtopped and stated that 'If something had happened to the dam, then half of Punjab would have been inundated.' Eleven years later a similar flood occurred. This time an official from the agency in charge of managing Bhakra argued that if the water had not been discharged 'one of the worst catastrophes in living memory' would have occurred.'[5]

Considering the fact depicted above, it can be firmly said that the people living downstream of the Tipaimukh Dam – people of Barak valley of India and northeast region of Bangladesh as well – will be compounded by the ever-present possibility of dam failure.

Ever More Possibility of Dam Break: A Seismic Factor

The exact location of Tipaimukh Dam Project – 500 m. downstream from the confluence of the Barak and the Tuivai Rivers in the southwestern corner of Manipur (24^0 14' N and 93^0 1.3' E approximately) has created a huge tension among the people living in the downstream Barak valley and northeast region of Bangladesh. This apprehension has been expressed in writings of many both in India and Bangladesh. Like Wahid Palash in his same paper says:

> 'The real danger of this project remains underneath the tectonic plate of the project site as this site has huge potentiality to be affected by severe earthquake, and in such cases, the catastrophic dam break would no longer be conjectural; it would surely be followed by disastrous consequences on the livelihood, on the people living at downstream region of the dam.'[6]

Earthquakes are common natural calamities experienced in northeast India. The region falls in the immediate neighborhood of the newly formed Himalayan Mountain zone. Interaction between the Indian and Burmese plates makes the entire northeast region of India and Bangladesh highly seismically active, making this region one of the most earthquake prone areas in the world. According to the R.K. Ranjan Singh of Manipur University, the proposed Tipaimukh Project area and its adjoining areas are basically composed of the Surma group of rocks characterized by folds and faults. The entire locality has well-developed fractures and hidden faults called blind thrusts.[7] Singh also suggested that the proposed Tipaimukh Dam axis is located on one of such type faults, which are potentially active and may be the foci and/or epicentres for future earthquakes. Singh in his same paper mentioned that the earthquake

[4] Patrick McCully, *Silenced Rivers,* p. 117.

[5] Dogra, B. 1992. *The Debate on Large Dams.* Centre for Science and Environment, New Delhi. p. 63 (cited in Wahid Palash, 'Tipaimukh Dam: A Lower Riparian Perspective' in Zakir Kibria and Roy Laifungbam (eds.) T*ipaimukh Hydroelectric Multipurpose Project: Dam or Damage,* Rivers for Life Vol. 1, Bangla Praxis and Centre for Organization Research & Education, Dhaka 2003).

[6] Wahid Palash, 'Tipaimukh Dam: A Lower Riparian Perspective'.

[7] R.K. Ranjan Singh, 'Tipaimukh' in *The Ecologist Asia,* Vol. 11 No. 1 January-March 2003, Mumbai, p. 77.

epicentres of magnitude 6 M and above have been observed in the northeast region of India during the last 200 years and within a 100 km. radius of Tipaimukh, two earthquakes of +7 M magnitude have taken place in the last 150 years. He asserted that the epicentre of the last one, in the year 1957, was at an aerial distance of about 75 km. from the dam site in an east-northeast direction.

Moreover, FAP 6 study on the possibility of earthquake of the northeast part of Bangladesh and India suggests that,

> 'The likelihood that during 1991-2015, the region would experience an earthquake of magnitude 7.6 (similar to the 1918 event, return period of 30 to 50 years) is between 40 and 60%; of magnitude 8.7 (similar to the 1897 event, the largest on record, return period of 300 to 1000 years) is perhaps 2 to 5%, assuming the events are random and can be described with a simple binomial probability model.'[8]

Table 6.1 Major earthquakes affecting the region

Date	Epicenter	Magnitude
April 2, 1762	Arakon Yoma	8.4
July 14, 1885	Bengal	7.0
June 12, 1897	Shillong	8.7
July 8, 1918	Srimangal, Sylhet	7.6
August 15, 1950	Assam	8.5

Source: FAP 6, *River Sedimentation and Morphology, 1993*

Therefore, there remains every reason for the people living in the downstream region of the proposed Tipaumukh dam to consider themselves as in the constant threat of ever possibility of dams burst due to a massive earthquake in the region.

FAP 6 Findings

No specific work has been done so far in the present study to assess the hydrological response of Barak-Surma-Kushiyara River as regards to the possible risk of Tipaukmukh Dam failure. Under the FAP 6 study, this risk analysis has been carried out with some modelling tools. However, it is worth mentioning that the findings of that study are stated again in this report to understand the potentiality of occurring catastrophic event if such dam failure would happen for Tipaimukh Dam in near future. The following section will illustrate the study on Tipaimukh Dam Failure and its findings as stated in the report of FAP 6:[9]

> 'A dam break is a catastrophic failure of a dam which results in the sudden draining of the reservoir and a severe flood wave that causes destruction and in many cases death downstream.
>
> Two examples illustrate the types of failures that have been reported. The most famous, the Teton Dam in the United States, was a 90 m high earth-fill dam which failed in 1.25 hours. The flood wave, which was released, had a peak discharge of 65,000 m3/s at the dam and a height of 20 m high in the downstream canyon. The Huaccoto Dam in Peru

[8] FAP 6, *Initial Environmental Evaluation, Northeast Regional Water management Plan,* Draft Final Report, FPCO, May 1994, pp. 59-60

[9] Ibid., pp. 60-61.

was 170 m high, similar to the Tipaimukh Dam; it failed over 48 hours due to a natural landslide in the reservoir.

Generally, a flood wave travels downstream at a rate in the order of 10 km/hr although velocities as high as 30 km/hr have been reported near failure sites. From these wave velocities, it would appear that the initial flood wave could travel the 200 km distance from Tipaimukh Dam site to the eastern limit of Bangladesh within 24 hours having a height of perhaps 5 m. Peak flooding would occur some 24 to 48 hours later. High inflows would persist for ten days or longer and the flooded area would likely take several weeks to drain.

The Tipaimukh reservoir is huge (15,000 Mm^3) compared with experience reported in the literature. In the event of a significant unplanned discharge, the river system in Bangladesh would respond (drain) rather slowly, as characterized by the outflow rate relative to the floodplain storage volume), such that most of the water released would remain ponded over the Northeast Region for some time. Assuming a release volume of 10 Mm^3 and a ponded area of 100 km^2, the depth of flooding would be an average of 1.0 m above the normal flood level.

<u>For illustrative purposes only</u>, we show modelled flood waves for a test case of an instantaneous failure, 50 m wide extending to 100 m below the crest of the dam. …It can be seen from this that substantial attenuation of the flood wave would occur upstream of Amalshid and that the flood wave at Amalshid is a long-duration event. Depending on the breech geometry and peak discharge, the flood peak would occur at Amalshid approximately 2 to 3 days after the dam break had occurred and flooding would continue for ten days or more. The flood levels at Amalshid would rise to approximately 25 m PWD, which is at approximately 8 m above the floodplain level. This flood level depends on the boundary assumptions which were made and could be less depending on floodplain conveyance.'

Reservoir Induced Seismicity: Facts or False Deduction

In recent days, people who are actively participating in the study of impact of large dams – that have been already experienced in many parts of the world – and on the potentiality of deadly impacts that a dam might create in a river basin are firmly pointing out a very important feature of possible relationship between a dam reservoir and the earthquake of the respective region. And that is being called Reservoir Induced Seismicity (RIS). People who are working on this issue have already presented some of the mind-boggling examples of such deadly feature. As far as their claims, it is now well established that large dams can trigger earthquake, though they notice that not many general public know about it.[10] However, experts around the world concur that the higher the water column in a reservoir, the higher is the risk of Reservoir Induced Seismicity (RIS). Studies indicate that dams higher than 150 m. usually have a 30% RIS factor.[11]

Expert analyses suggest that today there is evidence linking earth tremors and reservoir operation for more than 70 dams.[12] In other words, reservoirs are believed to have induced five out of the

[10] McCully, *Silenced Rivers,* p. 112.

[11] R.K. Ranjan Singh, 'Tipaimukh' in *The Ecologist Asia,* Vol. 11 No. 1 January-March 2003, Mumbai, p. 77.

[12] H.K. Gupta, *Reservoir-Induced Earthquakes,* Elsevier, Amsterdam 1992 (cited in McCully, *Silenced Rivers,* p. 114).

nine earthquakes on the Indian peninsula in the 1980s, which were strong enough to cause damage.[13]

Experts are, however, not yet sure about the actual mechanisms of RIS and they admit that it is impossible to predict accurately which dams will induce earthquakes or how strong the tremors are likely to be with the current knowledge on the diffuse aspects of seismology. Even though the most widely accepted explanation of how dams cause earthquakes is related to the extra water pressure created in the micro-cracks and fissures in the ground under and near a reservoir. When the pressure of the water in the rocks increases, it acts to lubricate faults, which already under tectonic strain, but are prevented from slipping by the friction of the rock surfaces.[14]

But there lies a wide range of debates on the issue of RIS. How the extra pressure of reservoir water on the soil structure or other aspects of reservoir dam do really matter for inducing earthquakes – many discussant who are not convinced with the theory of RIS ask this question. This is why Seismologist Harsh Gupta, Vice-Chancellor of Cochin University in India and a professor at the University of Texas, USA, notes a 'general reluctance in parts of the engineering community, worldwide, to accept the significance or even the existence of the phenomenon of reservoir-induced seism city'.[15] The dam industry also strongly opposes the idea of RIS by saying that there is no relationship between impoundment of large reservoir and seismic characteristics of the reservoir site.

Nevertheless, numerous numbers of evidences are found where seismic activity of the reservoir site was increased and strongest earthquakes were recorded ever within the few years of reservoir impoundment.

The above analysis openly shows that the Tipaimukh Dam, going to be sited not only at one of the seismically active region of the world – northeast region of India – but also on one of the most instable thrusts of that region, has an unprecedented potentiality of suffering from dam failure as well as inducing seismic instability of the region (who knows!) far more than the present.

[13] L. Seeber, Lamont-Doherty Earth Observatory, personal communication, 18 January 1995 (cited in McCully, *Silenced Rivers,* p. 112).
[14] H.K. Gupta, *Reservoir-Induced Earthquakes* (cited McCully, *Silenced Rivers,* p. 114).
[15] Ibid. p.114.

Chapter 7

Conclusion

General

The report has described the overall activities that had been adopted during this impact study of Tipaimukh Dam Project of India on Bangladesh. The objectives as well as analysis of the present study has emphasized more on assessment of the hydrological change that will be the case during post-dam condition. In addition, there was an attempt to examine how and to what extent this changed hydrology would affect the general flooding pattern of the eastern part of the northeast region of Bangladesh, Sylhet and Moulvibazar district in particular. The consequences on the perennial wetland like *haors* of that region and how these consequences can do destruction to the integrity of river-floodplain-wetland ecosystem – that has also been discussed. A qualitative and preliminary analysis has been done on the possible morphological in the rivers of northeast region of the country. In addition, a generalized discussion has been done on the possibility of dam failure and its catastrophic consequences on the downstream region in the context of seismic instability of the region as well as the claimed relationship between storage reservoirs with the even more possibility of earthquake, termed as Reservoir Induced Seismicity (RIS).

Findings

Meanwhile, the overall findings of the study have been summarized in six broad categories, like hydrological impact, impact on flooding pattern and on river-floodplain-wetland ecosystem, impact on morphology, impact on water quality, dam-beak and general.

Impacts on Hydrology

In general category, hydrology has mainly two components, surface water hydrology and ground water hydrology. This report mainly concentrates on the impact of dam on the surface water hydrology of the region. Lack of proper data and information on ground water hydrology for the Barak Basin in India as well as little but not enough data for northeast region of the country itself are the main constraint of not taking the ground water hydrological study. Therefore, the study and findings as well on the probable impact of Tipaiumukh Dam of India on the hydrology of northeast region of Bangladesh are essentially impact on surface water hydrology, and that are as following:

- Average annual monsoon inflow from the Barak River at Amalshid to the Surma-Kushiyara River system would be reduced around 10% for month June, 23% for month July, 16% for month August and 15% for month September. Water level would fall by more than 1 meter on average during the month July at Amalshid station on the Kushiyara River, while this would be around 0.25 meter, 0.15 meter and 0.1 meter at Fenchuganj, Sherpur and Markuli station, respectively. On the other hand, at Kanairghat and Sylhet station on the Surma River, average water level would drop by 0.75 meter and 0.25 meter, respectively in the same month.

Table 7.1 Impact during average monsoon season

Month / Type	Jun	Jul	Aug	Sep		
Decrease in mean flow at Amalshid on the Barak (%)	10	23	16	15		
Station / Type	**Amalshid (Kushiyara)**	**Fenchuganj**	**Sherpur**	**Markuli**	**Kanairghat**	**Sylhet**
Average fall in water level (meter)	1	0.25	0.15	0.1	0.75	0.25

- During relatively drier monsoon year, dam would have more impact on the availability of monsoon water in the Barak-Surma-Kushiyara River than the average annual monsoon year. Like for the month July, August and September, flow would be reduced as much as 27%, 16% and 14%, respectively, 4%, 2% and 2% higher than the volume reduction found for average monsoon year.

Table 7.2 Impact during drier year than average monsoon season

Month / Type	Jun	Jul	Aug	Sep
Decrease in mean flow at Amalshid on the Barak (%)	9	27	16	14

- Impact on 1 in 5 years monsoon would be more or less identical to the average monsoon year. Only there would be slightly more decreasing of monsoon flow.

- On the contrary, dam operation would have much less impact on the flood events similar to 1 in 10, 1 in 25 or more years flood events. Peak analysis at the bifurcation point of the Barak River suggests that reduction of July flow would be on average only 13% for 1 in 10 years monsoon season which is much lower than the reduction found for average, below average or 1 in 5 years monsoon (23 to 27%). Peak water level at the same point would drop by around 0.5 meter, much less than the drop found for average, below average or 1 in 5 years monsoon season (1 to 1.25 meter). For 1 in 25 years flood season, reduction in peak discharge and water level may be only 3% and 0.11 meter, respectively.

Table 7.3 Peak flow attenuation

Event / Type	Average monsoon	Drier year than average monsoon	1 in 5 years monsoon	1 in 10 years monsoon	1 in 25 years monsoon
Flow reduction (%)	23	27	26	13	3
Fall in Water level (meter)	1	1.25	1.21	0.5	0.11

- Pre-monsoon flow in the Barak River at Amalshid station would be substantially increased due to a 'confirmed' release from hydropower dam. Analysis shows that the average flow of water for the month of April and May would increase by 25% and 15% for Amashid station and 16% and 12% for Markuli station on the Kushiyara River. On the other hand, for the month of April and May, water flow may increase by 28% and 10% for Kanairghat station and 24% and 10% for Sylhet station on the Surma River. Average water level rise for Amalshid and Markuli on the Kushiyara River would be around 0.74 meter and 0.28 meter respectively for the month of April. For the month of May these would be 0.73 meter and 0.22 meter respectively.

Table 7.4 Impact during average pre-monsoon

Month / Type	Apr	May		
Increase in mean flow at Amalshid on the Barak (%)	25	15		
Station / Type	**Amalshid (Kushiyara)**	**Markuli**	**Kanairghat**	**Sylhet**
Average rise in water level (meter)	0.73	0.25	0.32	0.12

- Overall Barak flow at Amalshid during average dry season would increase by 121% and water level by 1.48 meter during dry season. Maximum augmentation would happen for the month of January when the average flow would increase by 222 m^3/s (99%) and water level by 2.09 meter. February and March flow would not increase as much as for the case in January. Still augmentation would be substantial, like flow would increase by 160 m^3/s and 55 m^3/s, respectively for the month of February and March.

Table 7.5 Impact during average dry year

Month / Type	Dec	Jan	Feb	Mar
Increase in mean flow at Amalshid on the Barak (%)	23	121	99	13
Average rise in Water level (meter)	1	1.48	2.1	0.5

- But the augmentation of the Surma-Kushiyara River would no longer exist if there continues a consecutive drier hydrologic years in a basin scale, like the period of 1977 to 1980. In such case, analysis reveals that even if it was possible to maintain confirmed release from dam to produce firm power for the Tipaimukh Project during the critical dry year of pre-dam scenario, it would not be possible for the next year dry season.

  In this particular scenario, inflow from Barak River for month of March and April may decrease severely. This reduction in Barak flow will affect the Kushiyara river system quite a long margin than the Surma river system. The reduced flow at Amalshid for the month March and April would be only 38 m^3/s and 244 m^3/s respectively, 74% and 22% less than if there is no dam on the Barak River.

  Drop in water level of the Kushiyara River may be from 1.8 meter at Amalshid on Kushiyara to 0.8 meter at Madna on the Dhaleswari River, some 250 km downstream from Amalshid (Kusiyara) station.

Table 7.6 Impact during critical dry year for post-dam condition

Month / Type	Mar	Apr		
Decrease in mean flow at Amalshid on the Barak (%)	77	22		
Station / Type	**Amalshid**	**Sherpur**	**Ajmiriganj**	**Madna**
Average fall in water level (meter)	1.7	1.0	0.8	0.2

- There is a certain evidence that the Tipaimukh Dam on the Barak river would reduce the below average, average or 1 in 5 annual flood in a large scale, while the size of the flood likely to recur every 10, 25 or 50 years would barely change.

Impact on Inundation Pattern and River-Floodplain-Wetland Ecosystem

The impact found in this study can be summarized as below:

- Model simulation of flood propagation model MIKE Flood reveals that Sylhet and Moulvibazar district will be effected more due to the Tipaimukh Dam operation regarding their natural monsoon flooding patter. For Sylhet district, total inundated area would be reduced by 30,123 ha. (26%) during post-dam scenario than it actually happens in pre-dam average monsoon season. For Moulvibazar district, this would be around 5,220 ha. (11%).

- 71% of the Upper Surma-Kushiyara Project area would no longer be flooded during average monsoon season for post-dam condition. The Kusyiara River would cut its connection with its right bank floodplain for around 65 km. reach. As a result the river at this part will become 'reservoir river'; rather than a most valuable 'floodplain river'

- The Kushiyara-Bardal *haor* on the left bank of the Kushiyara River would become completely dry during average monsoon year dry due to Tipaimukh dam operation.

- The Kawardighi *haor* would also lose around 2,979 ha. (26 %) of its usual inundated land during average monsoon year.

- Impact on Damrir *haor* and Hakaluki *haor* would be relatively less in comparison to other *haors* of the Sylhet and Moulvibazar district.

Table 7.7 Impact status on the major perennial and seasonal wetland of Sylhet and Moulvibazar district

Month / Type	Severely effected	Moderately effected	Less effected
The Upper-Kushiyara Project	√		
The Kushiyara-Bardal *haor*	√		
Kawardighi *haor*		√	
Damrir *haor*			√
Hakaluki *haor*			√

- There is no way to forget the fact that findings presented above have been found for the analysis of average monsoon year, therefore, for a monsoon drier than the average, the impacts would certainly be more.

- The above impacts on the river-floodplain-wetland would destroy the natural integrity of the ecosystem involved within these physical system, thereby, the consequences of that will be the loss of riverine habitat and species, lack of enrichment of land with the nutrient full silt leading to the ultimate decline in the natural productivity of the two most abundant resources of Bangladesh – land and water.

Impact on Morphology

As it is mentioned before that the present study has not adapted any special approach to investigate the post-dam morphology of the northeast region of Bangladesh and only applied a general hypothetical analysis, therefore, the findings presented below should be considered as an attempt to generalize the morphological impact; rather than be particular. The qualitative assessment, thus, can be summarized as below:

- The erosion just downstream of the Tipaimukh Dam would be excessively high and this erosion would continue as long as hundred kilometre downstream or more.
- This excessive erosion in the first 100 or 150 km. of Barak River downstream of the dam would increase the overall deposition in the lower Barak River, thereby, in the Surma-Kushiyara River system. Low flow during late monsoon and post-monsoon will accelerate this deposition in the region.
- The probable deposition during late monsoon and post-monsoon season will raise the overall bed level of the rivers, and for a extreme case it would block the mouth of certain tributaries originating from the Kushiyara River.
- Bed level would rise and that will induce the average monsoon flood to become a moderate to sever flood in the floodplain of the Surma-Kushiyara.
- There would be possibility of increasing erosion in the upper Kushiyara River, and this will cause more deposition in the downstream of Kushiyara River and in Kalni River.

Dam Break and Its Consequences

Study on the possibility of dam break and other failure was necessarily based on the secondary data and information source. However, the study found that the dam break is not as atypical as it is thought to be; rather reasonable numbers of dam breaks are recorded in different parts of the world over the years. Therefore, the people living in the downstream of any dam remains in a constant threat of catastrophe being occurred by dam-bursts and dam induced other floods. The apprehension like this is intensified further when the very seismic characteristics, its activities as well as the instability of the Tipaimukh Dam site and the region as a whole is taken into the consideration. The claimed Reservoir Induced Siesmicity (RIS) is another important feature of any large dam project that should be considered in the analysis of safety ground of Tipaimukh Dam Project.

Limitation of the Study

The present study, however, has number of limitations. The limitation arises partly because of lack of proper data and information to conduct a comprehensive study to predict the most possible scenario during post-dam condition on the northeast region of Bangladesh, and partly because of limitation in the existing knowledge to judge the response of river-floodplain-wetland ecology in altered hydrological and climatologic condition. Time and resource constraint also was a barrier for a comprehensive study. In addition, first two reasons led to numerous other limitations including lot of assuming, homogenising the natural system, averaging the hydrologic events followed by excluding the high and low extreme values of the events, over simplified parameterisation, etc.

The following section will describe some of those limitations regarding this study.

As it has been mentioned before that there were little amount of data and information available in Bangladesh regarding the Tipaimukh Hydro Electric (Multipurpose) Project on the Barak River of India and the overall geological-hydrological (both surface and groundwater)-meteorological-morphological-land coverage information of the Barak Basin. To understand the response of a river system due to any change in hydrology or other aspects, it is necessary to characterise the river system and identify the most sensitive variables and parameters. Undoubtedly, the present study has not been is such position to do so, particularly for the Barak Basin of India. As such the study had to rely on the limited amount of hydrological data provided in the *DPR on the Tipaimukh Project* and adapting rather a simple relationship to estimate the probable inflow to the Tipaimukh reservoir. The major limitation in the context of flow estimation at Tipaimuk point at pre-dam condition is that only observed discharge data of 4 years (from Jun 1989 to May 1993) at Tipaimukh was available from *DPR*, though on a 10-day average basis. So, averaging as so as simplifying the hydrological events remain there from the very beginning of study. The co-relations thus found between the discharge data at Amalshid and Tipaimukh on the Barak River for each of decades of particular month during these 4 years are then assumed to be applicable for the other periods and used to calculate the daily discharge data at Tipaimukh. This is the other assumption that the present study had to made. The big limitation occurs when the monthly average inflow data are generated by averaging that daily discharge data at Tipaimukh point over the period of 1971 to 2001 and simulate the Hydropower Reservoir Model to find out the monthly release. Because, natural event like runoff does not essentially occur the same way as it has been applied in the reservoir operation; rather it is natural to have events like extreme low to extreme high turbulent flow and relatively calm and smooth flow. It is common for shifting between each other of those events to happen even within half an hour in mountainous river catchment like upstream of Tipaimukh.

It would be indicative to present a typical release hydrograph from Kaptai Hydropower Project, Chaittagong, Bangladesh to illustrate the actual case that happens for a rainfed reservoir hydropower project (see Figure 7.1).

Though the reservoir operation model (HR Model) counts all the specification and requirements and dam operation strategy in different hydrologic season to calculate the possible release from dam, still this release from dam is calculated on a monthly average basis (see Figure 7.2). There are lot of variable, however, that have not been considered in this model, like evaporation and seepage loss from the reservoir, filling up the reservoir causing reduction in the pre-defined capacity of the reservoir. These are very important factors that have a substantial influence on the overall release from the reservoir.

Hence, the changed Amalshid discharge during post-dam condition calculated by adding the daily flow contribution to the in-between Barak River reach from Tipaimukh to Amalshid, estimated once again using the same simplified decade wise relationships, with this monthly reservoir release and considering the monthly irrigation water requirement for Cachar Irrigation Project is inhabitant with simplification. Therefore, the calculated post-dam Amalshid discharge contains lot of ambiguities and this should be considered as one of the main limitation of the study.

On the other hand, the present study has not assessed the impact of dam on the downstream water quality, on aquatic habitat, fish migration and lot of other important issues. It has been also kept silent on the potential greenhouse gas emission from the reservoir. The recent studies expresses that the hydropower project would no longer be considered as a safest power production technology as there has been found strong evidence that the storage reservoir do also emit green house gas and the emission is considerable. Therefore, this feature should have a serious implication on the global climate change in future.

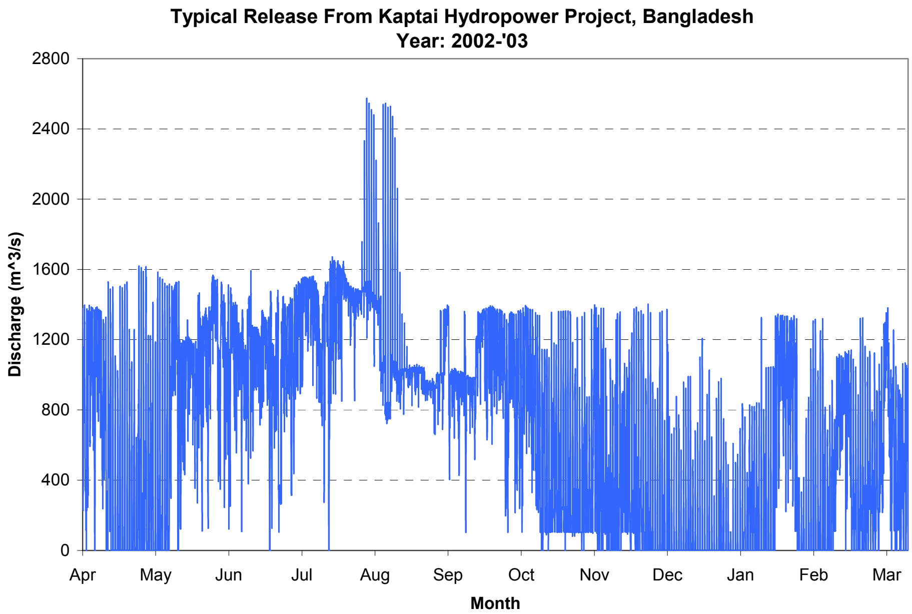

Figure 7.1 Typical release from a rainfed hydropower reservoir (example from Kaptai Dam Project)

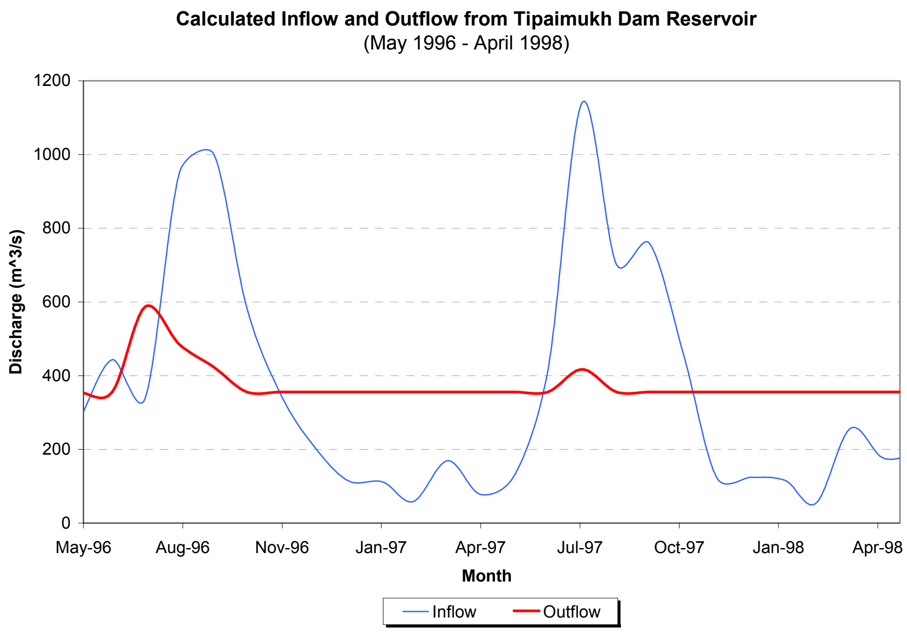

Figure 7.2 Typical inflow and outflow from the Tipaimukh reservoir that have been used in the present study

Last But Not Least

HOWEVER, despite all those limitations as previously mentioned, the study team believe that the present study is of great importance regarding examination of the potential impacts that would likely affect the northeast region of Bangladesh due to the construction and operation of Tipaimukh Dam on the Barak River. One point should be emphasized here with regards to limitations arising in the study from averaging or simplifying the hydrological events with respect to impacts from a negative aspect, this simplifying or averaging the hydrological events can overshadow those impacts. Thus it will be difficult to understand the impacts that will occur for below average and extreme low hydrological conditions.

Meanwhile, to understand the impact of a dam on the downstream region, hydrological assessment would come first. Though it should be kept in mind that most of the impacts of river engineering, whether it is hydrological itself or originated from the change in hydrology, are extremely difficult, and in many cases impossible to predict with certainty.[1] The Indian initiator of this project are continuously arguing that the project would not cause any harm on the hydro-morphological-environmental integrity of the lower riparian country, here in northeast region of Bangladesh, by any degree. In addition, some of the experts in Bangladesh also claim that as the dam site is far away from the territorial border of Bangladesh and a long distance river reach of the Barak has to be travelled before entering into Bangladesh, there would be a minimum effect inside Bangladesh due to such project. The only effect they are expecting is the status of base flow of the Barak River, though they also believe that augmentation of dry flow for maintaining a minimum water release from the dam would be considered as a beneficial effect for Bangladesh. On the contrary, it is being claimed by many other experts of the country who are opposing the dam project of India by saying that some of the immediate impacts of a dam which could be considered as devastating one can be predicted with our existing knowledge on river ecology, but many other catastrophic impacts cannot be explained properly other than only predicting the probability of occurrence of those. In this context, a quote can be made from the book *Silenced Rivers, Ecology and Politics of Large Dams* where the writer emphasized that, theories on the ecological dynamics of rivers are mainly based on short-term studies of small temperate watersheds[2]…while the great majority of the world's large dams and all of the major dams have been completed within the last six decades, some of the environmental effects of a dam may not be realized for hundreds of years after construction.[3]

World Commission on Large Dam (WCD), founded to assess the socio-economic-environmental aspect the large dam all over the world, comments that the large dams generally have a range of extensive impacts on rivers, watersheds and aquatic ecosystem – these impacts are more negative than positive and, in many cases, have led to irreversible loss of species and ecosystems.[4]

For the time being, the present study attempts to examine the most probable hydrological changes that will happen in the Surma-Kushiyara river system of northeast region of Bangladesh after the Tipaimukh Dam Project of India on the Barak River comes into operation. As

[1] Patrick McCully, *Silenced Rivers, The Ecology and Politics of Large Dams*, Zed Books, London 1996, p. 30.

[2] Ibid. p. 30

[3] G.E. Petts, *Impunded Rivers: Perspective for Ecological management,* John Willey, Chichester 1984, p. 119 (cited in McCully, *Silenced Rivers,* p. 31).

[4] WCD, Dams and Development, A New Framework for Decision-Making, Earthscan, London 2000, p. xxxi.

mentioned earlier, there are several other aspects on which a large dam across a natural river system can make an adverse impact, both in upstream and downstream region. The findings of the present study, thus, could be regarded as the stepping stone of any future investigation on those probable impacts of Tipaimukh Dam on Bangladesh.

Annex

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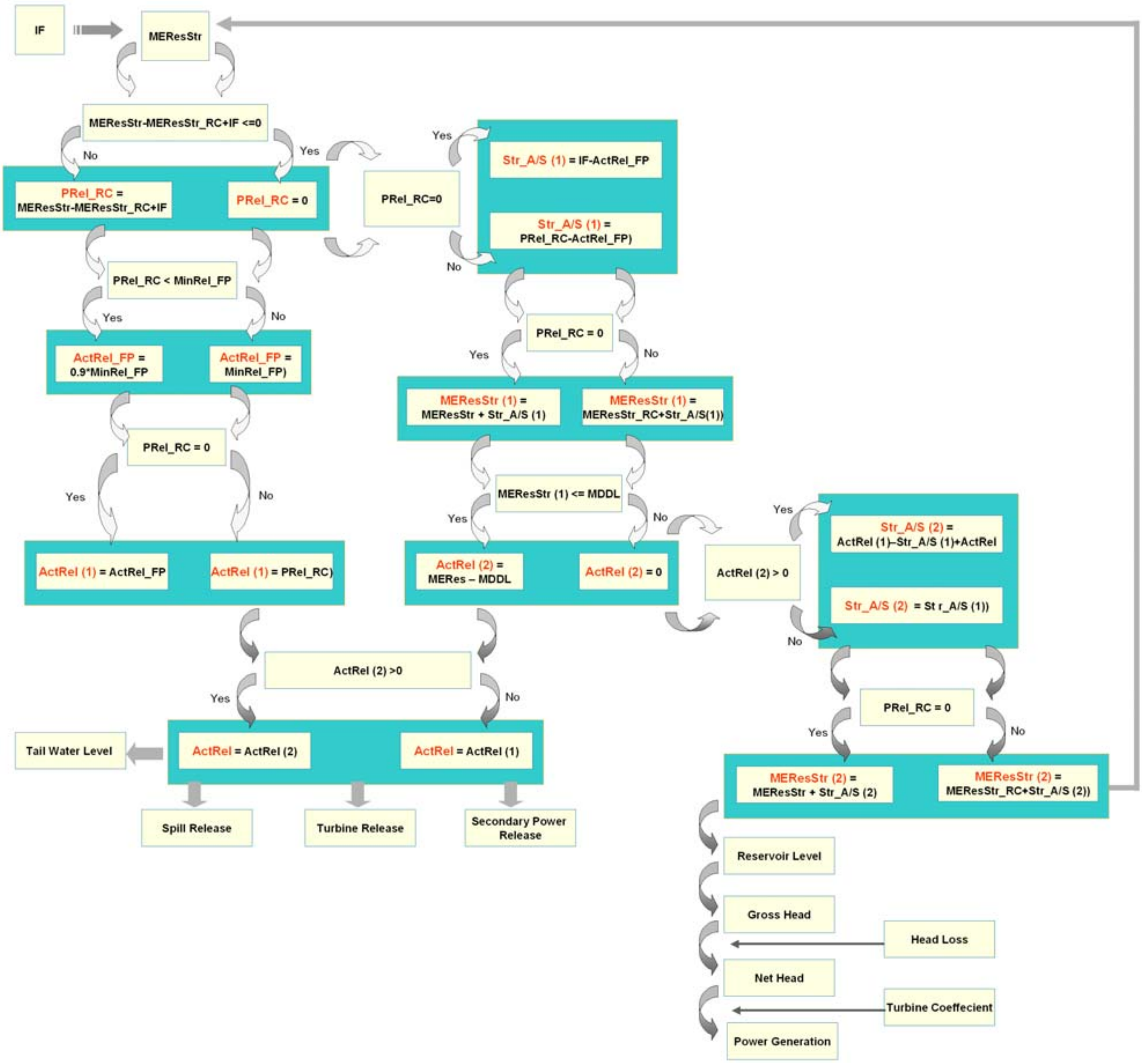
Tables and Figures

Figure A-1 Model algorithm of Hydropower Reservoir Model



Term	Meaning
IF	Inflow
MEResStr	Month End Reservoir Storage (initial)
MEResStr_RC	Month End Reservoir Storage for maintaining Rule Curve storage
Prel_RC	Possible Release after maintaining Rule Curve
Str_A/S (1)	Storage Added or Subtracted (1st assessment)
MinRel_FP	Minimum Release for Firm Power Generation
ActRel_FP	Actual Release for Firm Power Generation
MEResStr (1)	Month End Reservoir Storage at end of month (1st assessment)
ActRel (1)	Monthly average Actual Release (1st assessment)
MDDL	Minimum Draw Down Level of the reservoir for power generation
ActRel (2)	Monthly average Actual Release (2nd assessment)
Str-A/S (2)	Storage Added or Subtracted (2nd assessment)
ActRel	Monthly average Actual Release (final output)

Table A-1 Available water (volume), discharge and water level in the Surma-Kushiyara river system during average monsoon season for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Jun	Pre-Dam	3127	3631	4043	3957	2588	2674
		Post-Dam	2850	3480	3961	3888	2351	2474
		% incr./decr.	-9	-4	-2	-2	-9	-7
	Jul	Pre-Dam	4786	4579	4799	4497	4449	4186
		Post-Dam	3829	4341	4542	4276	3717	3701
		% incr./decr.	-20	-5	-5	-5	-16	-12
	Aug	Pre-Dam	4703	4382	4533	4236	3984	3752
		Post-Dam	4019	4206	4326	4102	3490	3414
		% incr./decr.	-15	-4	-5	-3	-12	-9
	Sept	Pre-Dam	2904	3586	3855	3693	2369	2476
		Post-Dam	2562	3374	3712	3579	2070	2215
		% incr./decr.	-12	-6	-4	-3	-13	-11
Average Discharge	Jun	Pre-Dam	1206	1401	1560	1527	999	1032
		Post-Dam	1100	1343	1529	1500	907	954
		% incr./decr.	-9	-4	-2	-2	-9	-7
	Jul	Pre-Dam	1787	1709	1792	1679	1660	1562
		Post-Dam	1429	1620	1696	1597	1387	1381
		% incr./decr.	-20	-5	-5	-5	-16	-12
	Aug	Pre-Dam	1757	1636	1692	1582	1489	1402
		Post-Dam	1501	1571	1615	1531	1304	1276
		% incr./decr.	-15	-4	-5	-3	-12	-9
	Sept	Pre-Dam	1120	1383	1487	1424	912	954
		Post-Dam	988	1301	1432	1380	797	853
		% incr./decr.	-12	-6	-4	-3	-13	-11
Average Water Level	Jun	Pre-Dam	13.25	9.71	8.00	6.88	11.32	9.18
		Post-Dam	12.87	9.60	7.94	6.85	11.05	9.02
		incr./decr.	-0.38	-0.11	-0.06	-0.04	-0.27	-0.16
	Jul	Pre-Dam	15.01	10.45	8.58	7.40	13.20	10.84
		Post-Dam	14.08	10.22	8.43	7.33	12.67	10.62
		incr./decr.	-0.93	-0.23	-0.15	-0.08	-0.53	-0.22
	Aug	Pre-Dam	14.75	10.26	8.40	7.30	12.66	10.23
		Post-Dam	14.14	10.08	8.29	7.24	12.27	10.02
		incr./decr.	-0.61	-0.18	-0.12	-0.06	-0.40	-0.21
	Sept	Pre-Dam	12.97	9.71	8.08	7.13	11.10	9.19
		Post-Dam	12.47	9.54	7.99	7.08	10.73	8.98
		incr./decr.	-0.50	-0.17	-0.09	-0.05	-0.37	-0.21

Table A-2 Available water (volume), discharge and water level in the Surma-Kushiyara river system during drier monsoon season than average for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Jun	Pre-Dam	2895	3150	3449	3375	2573	2615
		Post-Dam	2731	3109	3444	3376	2429	2519
		% incr./decr.	-6	-1	0	0	-6	-4
	Jul	Pre-Dam	5699	4522	4778	4493	5085	4621
		Post-Dam	4157	4271	4428	4157	3963	3940
		% incr./decr.	-27	-6	-7	-7	-22	-15
	Aug	Pre-Dam	4694	4530	4623	4408	4215	4048
		Post-Dam	3939	4326	4372	4110	3603	3633
		% incr./decr.	-16	-5	-5	-7	-15	-10
	Sept	Pre-Dam	4946	4346	4386	4063	4131	3878
		Post-Dam	4263	4230	4189	3918	3625	3543
		% incr./decr.	-14	-3	-4	-4	-12	-9
Average Discharge	Jun	Pre-Dam	1117	1217	1332	1303	994	1010
		Post-Dam	1054	1201	1329	1303	938	973
		% incr./decr.	-6	-1	0	0	-6	-4
	Jul	Pre-Dam	2128	1689	1784	1678	1898	1725
		Post-Dam	1551	1595	1654	1552	1479	1471
		% incr./decr.	-27	-6	-7	-8	-22	-15
	Aug	Pre-Dam	1753	1691	1726	1645	1574	1512
		Post-Dam	1472	1615	1632	1534	1346	1357
		% incr./decr.	-16	-4	-5	-7	-14	-10
	Sept	Pre-Dam	1906	1676	1692	1568	1592	1495
		Post-Dam	1643	1631	1616	1512	1397	1366
		% incr./decr.	-14	-3	-4	-4	-12	-9
Average Water Level	Jun	Pre-Dam	12.64	9.16	7.55	6.60	11.35	9.53
		Post-Dam	12.47	9.14	7.55	6.61	11.25	9.49
		incr./decr.	-0.17	-0.01	0.00	0.00	-0.10	-0.05
	Jul	Pre-Dam	15.76	10.46	8.62	7.48	13.67	11.15
		Post-Dam	14.45	10.17	8.42	7.38	12.95	10.88
		incr./decr.	-1.31	-0.29	-0.20	-0.10	-0.72	-0.28
	Aug	Pre-Dam	14.99	10.40	8.57	7.49	13.05	10.68
		Post-Dam	14.24	10.17	8.40	7.38	12.59	10.46
		incr./decr.	-0.76	-0.23	-0.17	-0.11	-0.46	-0.22
	Sept	Pre-Dam	15.32	10.35	8.46	7.38	12.97	10.35
		Post-Dam	14.71	10.18	8.34	7.32	12.57	10.14
		incr./decr.	-0.60	-0.16	-0.12	-0.06	-0.40	-0.21

Table A-3 Available water (volume), discharge and water level in the Surma-Kushiyara river system during 1 in 5 years monsoon season for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Jun	Pre-Dam	3245	3715	4179	4086	2606	2663
		Post-Dam	2934	3576	4087	4009	2350	2456
		% incr./decr.	-10	-4	-2	-2	-10	-8
	Jul	Pre-Dam	4688	4455	4687	4458	4322	4067
		Post-Dam	3539	4143	4450	4300	3439	3472
		% incr./decr.	-25	-7	-5	-4	-20	-15
	Aug	Pre-Dam	4261	4438	4783	4575	3701	3658
		Post-Dam	3629	4248	4533	4336	3205	3293
		% incr./decr.	-15	-4	-5	-5	-13	-10
	Sept	Pre-Dam	4875	4292	4625	4430	3950	3655
		Post-Dam	3829	4113	4286	4131	3226	3185
		% incr./decr.	-21	-4	-7	-7	-18	-13
Average Discharge	Jun	Pre-Dam	1250	1433	1612	1576	1004	1026
		Post-Dam	1131	1380	1577	1546	906	947
		% incr./decr.	-10	-4	-2	-2	-10	-8
	Jul	Pre-Dam	1753	1664	1751	1665	1616	1520
		Post-Dam	1323	1548	1662	1606	1285	1297
		% incr./decr.	-25	-7	-5	-4	-20	-15
	Aug	Pre-Dam	1590	1657	1785	1708	1380	1365
		Post-Dam	1355	1586	1692	1619	1196	1229
		% incr./decr.	-15	-4	-5	-5	-13	-10
	Sept	Pre-Dam	1878	1655	1783	1708	1521	1408
		Post-Dam	1475	1586	1653	1593	1243	1227
		% incr./decr.	-21	-4	-7	-7	-18	-13
Average Water Level	Jun	Pre-Dam	13.37	9.81	8.10	6.95	11.26	9.15
		Post-Dam	12.99	9.70	8.04	6.91	10.98	8.98
		incr./decr.	-0.38	-0.11	-0.06	-0.04	-0.28	-0.17
	Jul	Pre-Dam	14.86	10.30	8.44	7.25	13.03	10.55
		Post-Dam	13.71	10.05	8.30	7.18	12.36	10.25
		incr./decr.	-1.15	-0.25	-0.14	-0.07	-0.67	-0.30
	Aug	Pre-Dam	14.48	10.40	8.65	7.52	12.54	10.35
		Post-Dam	13.83	10.18	8.49	7.43	12.12	10.14
		incr./decr.	-0.65	-0.21	-0.15	-0.09	-0.42	-0.21
	Sept	Pre-Dam	14.91	10.45	8.62	7.48	12.63	10.31
		Post-Dam	14.06	10.18	8.42	7.37	12.08	10.04
		incr./decr.	-0.85	-0.27	-0.20	-0.11	-0.55	-0.27

Table A-4 Available water (volume), discharge and water level in the Surma-Kushiyara river system during 1 in 5 years pre-monsoon season for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Apr	Pre-Dam	1002	1275	1641	1674	357	405
		Post-Dam	1255	1532	1900	1938	458	502
		% incr./decr.	25	20	16	16	28	24
	May	Pre-Dam	1508	1769	2402	2411	989	1024
		Post-Dam	1733	2052	2693	2702	1083	1130
		% incr./decr.	15	16	12	12	10	10
Average Discharge	Apr	Pre-Dam	387	493	634	647	138	156
		Post-Dam	484	592	734	748	177	194
		% incr./decr.	25	20	16	16	28	24
	May	Pre-Dam	567	662	899	902	372	385
		Post-Dam	650	767	1007	1010	407	424
		% incr./decr.	15	16	12	12	9	10
Average Water Level	Apr	Pre-Dam	8.45	6.43	5.64	5.18	6.93	5.91
		Post-Dam	9.19	6.93	6.00	5.47	7.26	6.04
		incr./decr.	0.74	0.50	0.36	0.28	0.33	0.13
	May	Pre-Dam	9.48	7.38	6.46	5.82	8.28	7.09
		Post-Dam	10.21	7.83	6.77	6.05	8.58	7.20
		incr./decr.	0.73	0.45	0.31	0.22	0.30	0.11

Table A-5 Available water (volume), discharge and water level in the Surma-Kushiyara river system during average dry season for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Dec	Pre-Dam	493	649	748	771	35	66
		Post-Dam	980	1086	1164	1171	96	126
		% incr./decr.	99	67	56	52	175	90
	Jan	Pre-Dam	298	355	478	483	19	39
		Post-Dam	892	948	1068	1070	51	72
		% incr./decr.	199	167	123	122	172	82
	Feb	Pre-Dam	243	302	375	379	15	33
		Post-Dam	644	716	791	796	19	37
		% incr./decr.	165	137	111	110	27	14
	Mar	Pre-Dam	661	707	760	752	291	335
		Post-Dam	810	861	917	914	237	281
		% incr./decr.	22	22	21	21	-19	-16
Average Discharge	Dec	Pre-Dam	184	241	279	287	13	25
		Post-Dam	366	405	434	437	36	47
		% incr./decr.	99	68	56	52	176	90
	Jan	Pre-Dam	111	132	178	180	7	15
		Post-Dam	333	354	399	399	19	27
		% incr./decr.	200	167	123	122	171	82
	Feb	Pre-Dam	97	120	149	151	6	13
		Post-Dam	257	285	316	318	8	15
		% incr./decr.	165	137	111	110	26	14
	Mar	Pre-Dam	247	264	284	281	109	125
		Post-Dam	302	322	342	341	89	105
		% incr./decr.	22	22	21	21	-19	-16
Average Water Level	Dec	Pre-Dam	6.61	4.74	4.27	4.10	5.12	4.83
		Post-Dam	8.15	5.76	4.98	4.68	5.62	4.85
		incr./decr.	1.54	1.01	0.71	0.58	0.50	0.02
	Jan	Pre-Dam	5.77	3.85	3.56	3.46	4.80	4.50
		Post-Dam	7.86	5.49	4.81	4.53	5.21	4.54
		incr./decr.	2.09	1.65	1.24	1.08	0.40	0.04
	Feb	Pre-Dam	5.59	3.58	3.30	3.21	4.70	4.33
		Post-Dam	7.23	5.01	4.43	4.22	4.78	4.34
		incr./decr.	1.64	1.44	1.13	1.01	0.08	0.01
	Mar	Pre-Dam	6.92	4.64	4.07	3.87	6.29	5.57
		Post-Dam	7.57	5.19	4.53	4.29	6.18	5.50
		incr./decr.	0.65	0.56	0.46	0.42	-0.12	-0.07

Table A-6 Available water (volume), discharge and water level in the Surma-Kushiyara river system during next dry season of pre-dam critical dry year for pre and post dam condition

Station name/Item	Month	Option	Amalshid	Fenchuganj	Sherpur	Markuli	Kanairghat	Sylhet
Volume (Mm^3)	Mar	Pre-Dam	400	444	537	532	60	81
		Post-Dam	103	180	290	301	56	78
		% incr./decr.	-74	-59	-46	-43	-6	-4
	Apr	Pre-Dam	809	675	866	850	660	646
		Post-Dam	629	488	675	651	637	626
		% incr./decr.	-22	-28	-22	-23	-3	-3
Average Discharge	Mar	Pre-Dam	149	166	201	199	22	30
		Post-Dam	38	67	108	112	21	29
		% incr./decr.	-74	-59	-46	-43	-6	-4
	Apr	Pre-Dam	313	262	336	330	256	251
		Post-Dam	244	190	262	253	247	243
		% incr./decr.	-22	-27	-22	-23	-3	-3
Average Water Level	Mar	Pre-Dam	6.12	4.01	3.64	3.51	5.27	4.35
		Post-Dam	4.28	3.12	2.97	2.91	5.23	4.35
		incr./decr.	-1.84	-0.89	-0.67	-0.60	-0.04	0.00
	Apr	Pre-Dam	7.10	4.65	4.19	3.95	7.20	5.59
		Post-Dam	6.07	3.92	3.58	3.40	7.16	5.57
		incr./decr.	-1.04	-0.73	-0.60	-0.55	-0.04	-0.02

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