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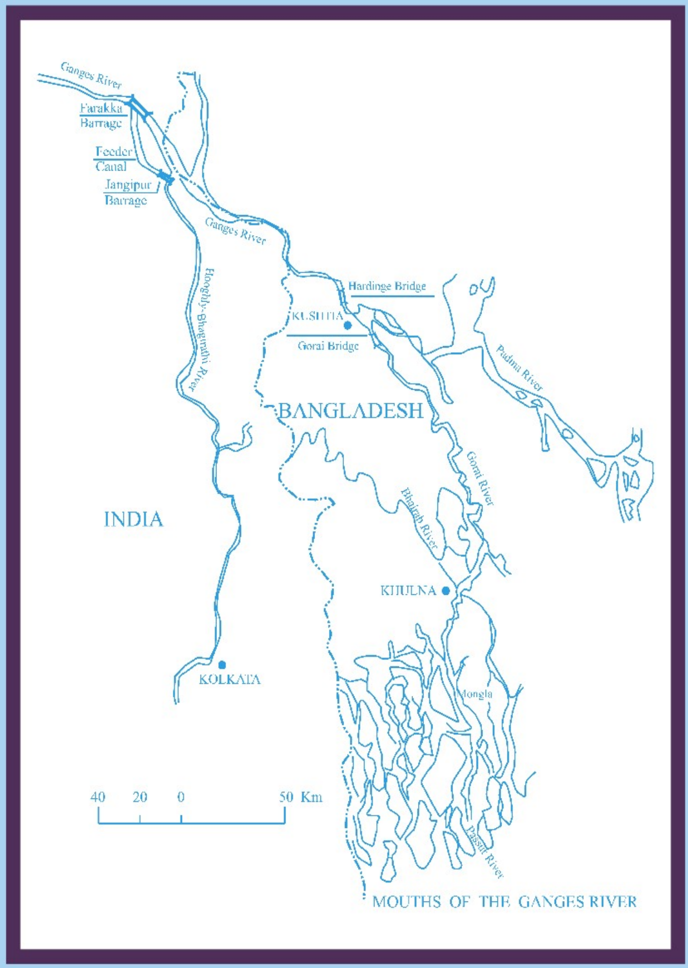
THE GANGA

Water Use in the Indian Subcontinent

by

Pranab Kumar Parua



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Consulting Engineering, Asian Development Bank

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Springer

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The author dedicates this book to his beloved parents Late Sudhir Chandra Parua and Late Santa Bala Parua and hopes to receive their blessings from Heaven. He further hopes that their Souls rest in Peace in Heaven.

Foreword

From time immemorial the Bengal Delta had been an important maritime destination for traders from all parts of the world. The actual location of the port of call varied from time to time in line with the natural hydrographic changes. From the early decades of the second millennium AD, traders from the European continent also joined the traders from the Arab countries, who had been the Forerunners in maritime trading with India. Daring traders and fortune seekers from Denmark, Holland, Belgium and England arrived at different ports of call along the Hooghly river. The river had been, in the meantime, losing its pre-eminence as the main outlet channel of the sacred Ganga into the Bay of Bengal, owing to a shift of flow towards east near Rajmahal into the Padma, which had been so long, carried very small part of the large volume of flow.

On a cloudy afternoon on August 24, 1690 the British seafarer Job Charnock rested his oars at Kolkata and started a new chapter in the life of a sleepy village, bordering the Sunderbans which was 'a tangled region of estuaries, rivers and water courses, enclosing a vast number of islands of various shapes and sizes.' and infested with a large variety of wild animals. In the language of the British Nobel Laureate (1907) Rudyard Kipling (1865–1936).

> Thus the midday halt of Charnock **** grew a city.****
> Chance directed, chance erected, laid and built
> On the silt -
> Palace, byre, hovel - poverty and pride -
> Side by side;

The city grew at a fast rate, true to the epithet of the second largest city of the British Empire and drew princes and paupers alike from all parts of the globe in their search of a better fortune. As a result, Kolkata became a vibrant, cosmopolitan city resplendent with manifestations of high levels of commerce and culture. And in this growth process the port of Kolkata played a pivotal role.

However from the day one, the Calcutta Port seems to have experienced navigational problems with particular reference to the availability of draught. Due to the twin problems of reduced upland flow and the extraordinary large volume of sediment, brought down from the upper catchment, the state of the navigation channel deteriorated and consequently the existence of the Calcutta Port became extremely tenuous. Demand for deeper draughts for incoming ships of larger and larger capacity compounded the problem.

In 1795 there was a proposal to shift the port to Diamond Harbour. Again in 1863 a port was set up in Canning on the river Matla. The Matla silted up and the port died. Concern for the preservation of the port remained unresolved. From 1653 to 1957 at least 16 experts and expert committees studied the problem and suggested remedial measures. In this connection, mention may be made of Sir Arthur Cotton (1853), Major Hirst (1914–1915), Stevenson-Moore (1914–1916), Sir William Willcocks (1930), S. C. Majumdar (1953) and Dr. Ing. W. Hensen (1957). The reduction in upland flow ultimately became so acute that during the 1960s the upland supply remained completely cut-off from the Padma for full nine months. In most of the reports, mentioned earlier, the basic recommendation was a barrage across the Ganga to ensure diversion of sufficient headwater supplies for a lasting preservation of the Calcutta Port. Specially Dr. Hensen had concluded that the best and only technical solution of the problem is the construction of a barrage across the Ganga at Farakka, with which the upland discharge into the Bhagirathi-Hooghly can be regulated to stop the long-term deterioration of the river.

In 1960, a WHO consultant team expressed concern over increasing salinity in the river water at the intake point at Palta water works and warned ‘If measures are not taken to increase the flow of fresh water down the Hooghly and so prevent the intrusion of salt water into the reach in which the Palta intake is situated, the raw water will become so saline that it will be unusable over a period of weeks or even months. The seriousness of this threat should not be minimized since all the indications are that the salinity will increase and that this situation may in consequence arise within a few years’ time.’ Even while marking the partition of Bengal in 1947, Sir Radcliffe took notice of this matter very seriously and retained Murshidabad, which was a Muslim majority district in West Bengal and in exchange allowed the Hindu - majority district Khulna to be included in East Pakistan, so that eventual construction of the Farakka barrage does not pose any problem.

The objectives of the Farakka barrage project were:

1. Preservation and the maintenance of the Calcutta Port and the regime and navigability of the Bhagirathi-Hooghly river.
2. Considerable improvement of communication facilities including a rail-road link to north Bengal, drainage and sanitation.
3. Improvement of water supply including reduction in salinity, in Calcutta and its industrial suburbs.

The barrage was inaugurated in 1975. Since then it has partially fulfilled its first objective. The failure to achieve this objective fully is primarily due to lack of availability of sufficient flow of the river at Farakka during the lean season. But the second and third objectives have been achieved successfully. The percentage of salinity has gone down to such an extent that not only the salinity of the river - water is within permissible limits at Palta water works but it is being utilized for irrigation of summer crops successfully in the coastal areas of Hooghly, Howrah, Midnapore and 24-Parganas districts.

However, there has been lot of criticism on the after - effects of the barrage. The criticism mainly centered round the following items:

(1) Accelerated bank erosion on the left bank on the upstream of the barrage and on the right bank downstream.
(2) Failure to divert adequate volume of flow during the lean season.
(3) Failure to reach a long-time agreement with Bangladesh regarding distribution of water at Farakka during the lean season.
(4) Drainage congestion owing to excavation of the Feeder Canal cutting across existing drainage lines.
(5) Flooding in the upstream reaches of the barrage pond owing to afflux.

Any major anthropogenic intervention on a river is bound to result in remarkable changes in its behaviour. The changes may not be always benign or favourable. Steps have to be taken to ameliorate the situation. Moreover since bank erosion results in loss of agricultural land and habitations particularly belonging to the economically weaker sections of the society, the human distress has been rightly focused in the media. This matter has to be addressed with sympathy and understanding. At the same time the technical aspect of the problem needs to be analysed and addressed accordingly.

Dr. Pranab Kumar Parua, who has a civil engineering background has a Ph.D from the Jadavpur University. The topic of his Ph.D thesis was associated with stability of banks of Bhagirathi-Hooghly river. Moreover, he has spent his entire service career in the Farakka Barrage Project and Calcutta Port Trust (1965–2002) and was intimately associated with its design, construction and maintenance. He had been associated with river hydrology, bank erosion and the river training works of the Bhagirathi-Hooghly river in the Calcutta Port Trust as Engineer-on-Special Duty of Hydraulic Study Department from 1985 to 1988. Judging from his credentials it will be rather difficult to find a more knowledgeable person to deal with this complex subject.

He has chosen a broad canvas for his discourses. The Ganga is a sacred river to millions of Hindus. Dr. Parua has rightly started with the mythological aspects of the river. He has further charted the evolution of its physiography through the ages beginning with the tectonic movement of the continental plates. Deterioration of the river in the recent past has also been documented. In fact, the Chapters 6 and 7 have been utilized to examine the causes and extent of gradual deterioration of the Bhagirathi-Hooghly rivers and the different expert opinions on the probable reasons for such deterioration of the navigation channel and the possible alternatives to resuscitate the river and reactivate Calcutta Port. Next he has discussed the sensitive question of sharing of water between India and Bangladesh and furnished examples of International Agreements elsewhere. Given the fact that water resource is getting scarce the world over in the face of rising demand, these agreements can hardly satisfy both the upstream and the downstream co-basin States. Under the circumstances, he has rightly emphasized on regional co-operation. The author has also discussed the river bank erosion problems in Malda and Murshidabad districts of West Bengal, its causes and possible remedial measures including Expert Committee recommendations.

Finally, the author has concluded that unless the lean season flow of the Ganga at Farakka is augmented by some means, the flow is bound to decrease in near future and both the countries would suffer. In this connection he has touched upon interlinking of rivers. He has mooted a proposal for augmentation of the Ganga flow by constructing a barrage across the river Brahmaputra in Bangladesh and a link canal through Bangladesh and India. However this is a very controversial issue and even if technically feasible, will raise serious socio-economic and political questions. Moreover impact on the environment as a result of implementation of such schemes may be almost impossible to reconcile. So at the present moment, I feel, the possibility of implementation of such schemes is not very encouraging.

Dr. Parua has done a splendid job, focusing on all the relevant issues, as far as possible. Assuming that he had been, to some extent, restricted in presenting relevant data owing to the classified nature of the data, he has offered a remarkable volume on the controversial subject. However, I hope that in future he would look into other issues on the present subject as well as other allied subjects concerning other important rivers in West Bengal and beyond.

West Bengal, India Dr. S. S. Ganguly
January 16, 2009

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River Ganga at Varanasi

Introduction

The Ganga, as the Ganges is known in Indian languages, has a long history of piety, woven in many mythologies, all along its course, from the Himalayas to its confluence in the Bay of Bengal (a part of the Indian Ocean). Its holiness is enshrined in Hindu epics and scriptures, such as the *Ramayana*, the *Mahabharata*, the *Veda*s, the *Purana*s and so on. About no other river, T. S. Eliot's memorable phrase, 'The river is a strong brown god' in 'The Dry Salvages' is truer. The Hindus sprinkle its water for purification and worship and take bath in it in the belief, supported by scriptures that it cleanses their sins. They arduously trek to its source in a snow-bound Himalayan glacier, Gangotri and downstream at Haridwar, float lighted oil lamps on its water after dusk in memory of their deceased elders. In earlier days, the Hindus used to leave their dying kith and kin on its shores, or lodge them in Varanasi on its bank, so that their souls could ascend to heaven when they died.

The geo-hydro-morphometry of the Ganga has also a long and varied history and undergone dramatic changes, as it has been continuously fed by many tributaries from both sides but overwhelmingly by rivers originating in the Himalayas in Indian territory. Many empires and governments rose and fell along its banks and political upheavals occurred in the Indian provinces and Bangladesh. Geologically, the Ganga delta emerged from severe dynamic and varied interactions of sea-level fluctuations, upheaval of land mass, changing shore-lines and the shifting courses of the rivers and formation of new ones. It nourished India's many-layered civilization and earned from India's first post-Independence Prime Minister, Jawaharlal Nehru the exalted name, 'River of India'. Navigation on its long course boosted movement of men and materials. On its long banks human settlements developed and all-round progress took place across centuries.

After descending from the Himalayas, the main course of the Ganga flowed southeast and passed through Indian provinces of Uttarakhand, Uttar Pradesh, Bihar, Jharkhand, West Bengal and East Bengal/East Pakistan which has come to be known as Bangladesh from 1972. It bifurcated near Jangipur in Murshidabad district; one course flowed into Bangladesh, taking the name of the Padma; the other flowed through West Bengal, taking the name of the Bhagirathi-Hooghly and fell into the Bay of Bengal at Sagar and the Padma estuaries in West Bengal and Bangladesh respectively. While the upper Ganga flood-plain in the northern provinces up to Bihar is composed largely of older alluvium, through which the river coursed in variable depths, the flood-plains of the middle and the lower Ganges are generally composed of young alluvium. Extensive flood-affected valleys and plains grew on both banks and its width in some places in Bangladesh varies from a whopping 10 to 20 km. These plains were created by flow and ebb tides which bring from the sea sediment loads of varying thickness. The lower Gangetic flood-plain faces a lot of hazards like flood and erosion. The erosive might of the Ganges is seen more in West Bengal and Bangladesh than elsewhere in its course. Here, its shifting channel with unpredictable direction of current and changing pattern of silt deposition led to severe bank erosion and swallowed densely populated human habitats like Dhulian town in Murshidabad district of West Bengal.

In the lower Gangetic flood-plains, the Ganga flows into two streams – as the Bhagirathi in India and as the Padma in Bangladesh. The Bhagirathi is an older channel which once carried the main flow and on its two banks stood famous ancient cities. Its basin was very fertile, right from Murshidabad to the Sundarbans in the south before its estuary in the Bay of Bengal, because of flood and silt. Gradual silt deposition on its bed and mouth choked it and increased the salinity of its water upward in the delta and made it unfit for drinking and other household uses, navigation, irrigation and caused disastrous floods in monsoon months by overflowing its banks and embankments.

The Ganga basin is among the most densely populated river basins in the world. About eight per cent of the world's population lives in this basin. The monsoon precipitation varies widely along the foothills of the Himalayas and gradually diminishes as it travels from south-east to north-west. Variation of time and space in monsoon precipitation gives rise to fluctuations in the flow with over 75% of the flow concentration in three to four monsoon months only. The three major trans-Himalayan tributaries – the Ghagra, the Gandak and the Saptakosi – contribute about 7% of the natural and traditional dry-season flow and 41% of the total annual flow of the Ganga.

The Bhagirathi-Hooghly, as the Ganga's stream below Farakka in Murshidabad in India is called, carried its major lean-season flow before the 16th century AD, as mentioned in old records and inferred from the banks of the Padma, its eastern course. The establishments of European traders, set up along its banks also evidence the existence of a deep navigable channel on which sailed big boats and vessels for human transport and trading. This prompted British traders to develop a deep-draft inland port on its bank near what is now known as Kolkata. Large industries came up, availing port and other facilities. This favourable situation did not last long owing to sundry morphological changes in the river. The most crucial change was a shift in the offtake point of the Bhagirathi from the Ganga, downstream and gradual silting of its mouth. This reduced the upland discharge into the river from its parent river, the Ganga and upward movement of tide-borne silt from the estuary and its deposition over the bed. This also shallowed the navigation channel, reduced the width and formed sand-bars within. Movement of ships and handling of cargo and other port facilities declined, day by day and the situation became so critical that the British government in India considered several measures, like shift of port facilities, creating alternative navigation routes upland and in the estuary, deep dredging of the channel to facilitate ship movement, and bank stabilization to channelize the flow etc. in consultation with experts, but yielded no result. Meanwhile, various views converged in favour of increasing the upland discharge by diverting water from the Ganga into a long and wide feeder canal by throwing a barrage across it and artificially heading up the water and building a reservoir, upstream. Though the proposal was mooted in the British regime, over a century ago, it could materialize 16 years after India's Independence from the British in 1947. In 1963 work started on a barrage at Farakka and was completed in 12 years; it was commissioned with fanfare in 1975.

Experts recommended discharge of minimum 40,000 cusecs (1,132 cumecs) through the barrage to prevent siltation and scouring the deposited silt on the river-bed to regenerate it to pre-1935 condition when vessels up to 7.9 m draft vessels could ply in Calcutta Port area, round the year. Accordingly, 40,000 cusecs of the Ganga water began to flow through the Bhagirathi-Hooghly from June 1975. The situation, however, did not last long because of opposition by Bangladesh which geographically is a lower riparian country.

After the barrage was commissioned in 1975, there have been many political upheavals in the two countries. Their representatives engaged in a kind of tug-of-war on the quantum of water to be diverted and released through the barrage. After a series of meetings, discussions and conferences at technical and administrative levels, a five-year agreement was reached on the ratio of sharing the lean-season flow in 1977, two years after commissioning. It envisaged a permanent solution on augmentation of the lean-season flow of the Ganga at Farakka within its validity, which eluded in spite of best efforts by both countries, as neither side accepted the other's proposal on augmentation and stuck to their own views.

This short-term agreement was extended twice – in 1982 and 1985 – through separate Memoranda of Understanding (MOU) for two and three years, again without an abiding solution. Seven more years passed after the expiry of the second MOU without any further agreement or MOU on sharing the lean-season flow of the Ganga at Farakka. India went on releasing water to Bangladesh, downstream under the Friendship and Mutual Cooperation Treaty.

At last, in 1996 a 30-year agreement was signed between India and Bangladesh in December, 1996 on water-sharing, bypassing the issue of augmentation of the lean-season flow; this is still being followed.

Regarding the requirement of minimum water for flushing the Bhagirathi-Hooghly up to Calcutta Port area, the general consensus among the experts was to bring the river back to 1924 condition by augmenting its flow by about 65,000 cusecs, as assessed by the Calcutta Port Trust. However, considering the limited availability of lean-season flow in the Ganga, it was considered judicious to bring it back to 1935–1936 condition, for which the minimum requirement was 40,000 cusecs. In 1935–1936, the river's depth in the port area was a little over 9 m and the low water-crossings were over 6.5 m with the governing Balari bar at its best. The observations of Dr. Walter Hensen in 1957, 1966 and 1971 were also in favour of 40,000 cusecs as the minimum requirement for resuscitation of the river and rejuvenation of Calcutta Port. Many other experts also held the same view. All these experts emphasized the requirement of headwater supply of the Hooghly at Kalna, about 310 km downstream of Farakka and within the tidal reach of the Bay of Bengal. Losses owing to various reasons would occur in this long stretch and therefore, the requirement of water at Farakka should be actually much more than 40,000 cusecs. Moreover, while assessing the minimum requirement of headwater supply before commissioning of the feeder canal, it was recommended that it would carry the full discharge of 40,000 cusecs throughout the year, including in the lean months for five years and a study team would observe its effects and those of varying discharge for the next two years, until review after seven years.

However, this did not come to pass, as the Agreement came into force two years after the commissioning of the canal and the recommended observations could not be made. In fact, the feeder canal never received the full discharge of 40,000 cusecs afterward. The 30-year Treaty is still in force between India and Bangladesh and according to it, India's share of the discharge would vary between 25,000 and 35,000 cusecs in the lean season from March to May and that of Bangladesh in the same period would vary between 27,000 and 35,000 cusecs. The period of five months – from January to May – was subdivided in 15 ten-daily periods, as done earlier and the available water was distributed between the two countries with these ten-daily periods. Thus, the Bhagirathi-Hooghly would not receive 40,000 cusecs in this period, when the need for more water would be the maximum, owing to upward sand movement from the sea into the river. The positive effects of upland discharge of 40,000 cusecs, which were felt by the Calcutta Port authority, were no longer seen. The adverse effects of reducing the discharge were manifold, e.g., rise of the river-bed following siltation, increase of salinity and bore-tides etc. which restrict ship movement in the port area and affect port activities. Moreover, there was no specific provision for augmentation of the Ganga flow at Farakka to make up the deficits of the two countries. It was unfortunate that the signatories of the two countries, comprising politicians, bureaucrats and technocrats did not realize this vital point, while getting the Treaty signed by the Prime Ministers of two countries, though provisions existed in earlier agreements and MOUs. It is ironical that Jyoti Basu, then Chief Minister of West Bengal, who in the same capacity, had opposed the Treaty of 1977 when another Janata government, led by Morarji Desai was in power, took extra initiative in signing the 1996 Treaty, when the Janata Party government, headed by H. D. Deve Gowda was Prime Minister in New Delhi. The 1996 Treaty was not technically sound and had a number of defects, which have been discussed in length in this book.

The Ganga's flow at Farakka has been going down, as per official records and would naturally reduce further. This would be due to increased use of its water by a burgeoning population for various activities, industrialization and urbanization. It would be urgently necessary, therefore, to augment its flow to meet these demands. This author believes that this would be possible by linking the Brahmaputra with the Ganga at upstream of Farakka barrage and by transfer of 70,000–80,000 cusecs from the Brahmaputra basin to that of the Ganga; this will pose no problem, as the Brahmaputra goes in spate in March, about two to three months before the Ganga does in June. The author has given a proposal on the line where a barrage will be constructed across the Brahmaputra in Bangladesh which will be linked to the Ganga at Farakka upstream of the barrage with a canal passing through Bangladesh and India for diversion of water.

There is also need for regional a cooperation among the riparian countries – India, Bangladesh, Nepal, Bhutan and China for their development and progress, accruing from rivers. Development of water resources by judicious management and utilization for human benefits are a crying need, as the regions are very rich in water resources. Three big rivers – the Ganga, the Brahmaputra and the Meghna (GBM) – flow through their basins and an enormous volume of their water flows, not harnessed for any purpose, into the sea in every monsoon season. This mammoth supply is not used for meeting the demands. Being the largest water-carriers in monsoon months, the Ganga and the Brahmaputra need prime attention of concerned governments for any water resource development schemes within the GBM basin areas. The South Asia Regional water Vision 2025 has also stressed the raising of standard of living of the people of these regions through coordinated and integrated development as well as management of water resources. As a number of countries will have to be involved to this end, the issue cannot be just bilateral but will call for a multilateral approach and cooperation among the concerned countries. Keeping in view the all-round progress, brought about by other big rivers of the world in their basins, e.g., the Mekong, the Colorado, the Columbia, the Volga, the Senegal, the Indus, the Saigon, and La Plata with the assistance of world bodies like the UNO, the World Bank, the UNDP, the Asian Development Bank etc. multilateral cooperation and understanding are absolutely necessary for the development of the GBM basins in South Asia.

The problem of loss of arable land in continuous bank erosion, both in India and Bangladesh, is of course an impediment to the development and management of water resources. Several river reaches in India, especially in Jharkhand and West Bengal are severely affected. It becomes more acute in monsoon months, when the rivers are full and the bank soil is saturated by rains and tides. The swollen rivers erode, heartlessly, whole villages, prime agricultural land with crops as well as industrial and commercial complexes. It occurs every year, in spite of huge expenses by governments to arrest it. The situation is no different in Bangladesh where the Padma and the Meghna do the same devastation.

These are no less serious than the problems of sharing of the Ganga water at Farakka and augmentation of its flow for meeting lean-season demands in India and needs to be equally addressed by the governments of India and Bangladesh, involving or not involving the governments of Nepal, Bhutan and China, as they deem fit.

New Delhi, India Dr. Pranab Kumar Parua

Acknowledgement

Rivers have always fascinated me since childhood; they never stale in my imagination. My ancestral house was a mere 10 km away from a tributary of the Ganga, the Haldi in south Bengal. This fascination deepened, when after graduating in civil engineering from Kolkata I got a job with the Farakka Barrage Project in 1965 and served it for over three decades. In various capacities up the ladder I had the opportunity to observe India's holiest and mightiest river, the Ganga, day and night, as I lived at Farakka for the greater part of my career. I travelled extensively on and along it and many of its tributaries in connection with my work and inspected its fragile banks where erosion is most acute and alarming. I wrote more than 40 publications on various facets of the river and its problems. I attended and took part in many meetings, seminars, conferences etc. both public and private, which gave me access to many crucial data, used in this book.

I am thankful to Dr. Sitangshu Sekhar Ganguly, former Secretary of Irrigation & Waterways in the West Bengal government for guidance on collecting old records and writing the Foreword to this book. I am also deeply thankful to Kolkata port officials for letting me use a lot of relevant port statistics and data. I also acknowledge with gratitude the assistance from S. K. Sahoo, S. N. Mohanta, both engineers, and Jaba Thakuria, Secretary of the Consulting Engineering Services, India, all posted in Guwahati, in preparing the drawings etc. from my hand-drawn sketches on computer and for fairing some material, used in this book.

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I am grateful to the chairman, Kolkata Port Trust and the Chief Hydraulic Engineer, Hydraulic Study Department, Kolkata Port Trust for according kind permission to use some hydrological data of the river Ganga and the river Bhagirathi-Hooghly and some Port statistics in the book.

My thanksgiving will not be complete without acknowledging the encouragement and help of my esteemed publisher, M/S Springer without whose kind interest, this book would not have seen the light of the day. Should any reader seek more clarification, or be inclined to point out any error of omission or commission, he/she can freely do so on my e-mail address, drparua@emailaccount.com., drparua@yahoo.co.in

Dr. Pranab Kumar Parua

Notations and Abbreviations

m^3 – cubic metre.

ft^3 – cubic foot.

m^2 – square metre.

ft^2 – square foot.

m – metre.

ft – foot.

Mm^3 – Million cubic metre.

Mm^3– Million cubic Metre.

d_{50} – 50% diameter of particle retained on sieve.

Cumec – Cubic metre per second.

Cusec, cfs – Cubic foot per second.

ppm – parts per million.

Crore – Ten million.

Lakh – One-tenth million.

GATT – General Agreement on Trade and Tariff.

UNDP – United Nations Development Programme.

IDB – International Development Bank.

OAS – Organisation of American States.

JRC – Joint Rivers Commission.

JCE – Joint Committee of Experts.

FAO – Food and Agriculture Organisation.

UNEP – United Nations Environment Programme.

WMO – World Meteorological Organisation.

IADB – Inter-American Development Bank.

ECAFE – Economic Commission of Asia and Far East.

FRG – Federal Republic of Germany.

NWFP – North West Frontier Province.

DVC – Damodar Valley Corporation.

UNO – United Nations Organisation.

ESCAP – Economic and Social Commission of Asia and Pacific.

MOU – Memorandum of Understanding.

GBM – Gangta Brahmaputra Meghna.

FBP – Farakka Barrage Project.

NTPC – National Thermal Power Corporation.

HFL – High Flood Level.

LWL – Low Water Level.

KODS – Khidirpur Old Dock Sill.

FBA – Farakka Barrage Authority.

CBIP – Central Board of Irrigation and Power.

WB – World Bank, West Bengal.

ADB – Asian Development Bank.

OSD – Officer on Special Duty.

IWTA – Inland Water Transport Authority.

P & R – Planning and Research.

GBWRD – Ganga Barrage Water Resources Department.

I & WD – Irrigation and Waterways Department.

GOWB – Government of West Bengal.

R & D – Research and Development.

ER – Eastern Rivers.

GOI – Government of India.

MOWR – Ministry Of Water Resources.

IAH – Indian Association of Hydrologists.

RRI – River Research Institute.

CWPC – Central Water & Power Commission.

Words with Different Spellings

1. Ganges – Ganga.
2. Sagar – Saugar.
3. Karthikeya – Kartikaya.
4. Gangaridi – Gangaridai.
5. Vedic – Veidic.
6. Hugli – Hooghly – Hooghli.
7. Bastumghata – Baishnabghata.
8. Kailash – Kailasha.
9. Saravar – Sarovar.
10. Garwal – Garhwal.
11. Meirut – Meerut.
12. Mungyer – Mungher.
13. Barhampur – Berhampur – Berhampore.
14. Nabadwip – Nabadweep.
15. Midnapur – Midnapore.
16. Tamralipta – Tamluk.
17. Padda – Padma.
18. Pakistan – Pakisthan.
19. Mungher – Mungyer.
20. Kakdwip – Kakdweep.
21. Comilla – Cumilla.
22. Chitaganj – Chitaganje – Chattagram.
23. Rupnarayan – Rupnarayana – Rupnarain.
24. Burhganga – Buriganga.
25. Damodar – Damoder.
26. Serampur – Serampore.
27. Chandernagar – Chandannagar.
28. Teesta – Tista.
29. Sheebganje – Shibganje.
30. Kosi – Koshi.
31. Sherwell – Sherwill.
32. Kidderpore – Khidirpur – Khidirpore.
33. Rangafala – Rangafalla.

34. Cossipore – Cossipur.
35. Kalpi – Kulpi.
36. Willcock – Willcocks.
37. Falta – Phalta.
38. Mujibur – Mujibar – Mujib.
39. Mostaque – Mustaque – Mushtaq.
40. Jagjivan – Jagajivan.
41. Siddarth – Siddartha – Sidhartha.
42. Karotoya – korotoya.
43. Sheikh – Sk.
44. Rajib – Rajiv.
45. Amjad – Amzad.
46. Garai – Gorai.
47. Wajed – Wazed.

Chapter 1
The *Ganga* in Mythologies

The Legend

Indians look upon their rivers with reverence and consider them holy. From time immemorial, their mythologies have been harping on the sacredness of rivers but there is none holier and popular than the Ganga. In the great Hindu epic, the Ramayana, written in Sanskrit by sage Valmiki between 1400 and 1000 BC, which remains the bedrock of the Hindu civilisation, she is personified as a goddess. In Hindu mythology, she is the eldest daughter of Himavat and Menoka; her sister being Uma, or goddess Durga who is worshipped in autumn and spring by Bengalis, particularly. The Ganga became the wife of King Santanu and bore a son, Bhisma, who is known as Gangeya, after his mother. She is also the mother of Kartikeya, the chief celestial warrior whom she bore, being in love with Agni. She has many other names too – Bhadra-soma, Gandini, Kirati, Devabhuti, Hara-Sekhara, Khapaga, Mandakini, Tripathaga or *Trisrota*; the last means three streams, flowing in heaven, earth and hell (in the third, she is called Patal-Ganga). In Hindu mythology, she plays various roles – a child of Brahma, wife of Shiva, the metaphysical offspring of Vishnu, mother of eight Vasus and of Kartikeya. In the Rigveda, she is mentioned twice. Before descending on earth, she flowed in heaven and was the consort of gods. She was brought down to the earth by a scion of King Sagara whose 60,000 sons were burnt to death by the angry gaze of a philosopher sage, Kapil (founder of *Sankhya Darshana*) when they were looking for their missing sacrificial horse for the Ashwamedha Yagna and had arrogantly scattered ashes on his hermitage. They could be revived and their souls delivered in heaven if the Ganga flowed over and purified their ashes. King Sagara's scions performed pious rites to bring down the Ganga on the earth but their two generations failed.

The third generation king, Bhagirath obtained the blessings of Lord Brahma through *tapasya* (penance) and succeeded in breaking, The Ganga's obstinacy of flowing only in heaven. She was angry at being brought down to earth. The heavenly king, Indra's tusker, Airabat pierced the hills of the Himalayas to contain her tremendous surge, unsuccessfully. Being entreated by gods, Lord Shiva caught her on his brow and checked her turbulence with his matted locks to save the earth from the shock of her fall. Because of this action, Shiva is called Gangadhar, or 'Holder of the Ganga'. She descended from Shiva's brow in several streams, four according

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to some and ten according to others, but the number generally accepted is seven. She is thus called *Sapta-Sindhava*, i.e., the seven Sindhus or rivers, of which the Ganga proper is one. She followed King Bhagirath, blowing a conch-shell as he trekked southeast and flowing over the plains of north and eastern India, reached the place where the ashes of King Sagara's sons lay. As she flowed over them, their souls were delivered and ascended to the heaven. She flowed into the sea which is now called the Bay of Bengal, a part of the Indian Ocean.

In the *Mahabharata* (400 BC), the great Hindu epic written and compiled after the Ramayana, the Ganga is both a goddess and an earthly woman. In the Buddhist and Jain scriptures too, she is mentioned with reverence. From the third century AD she was invoked in rituals of birth, initiation, marriage and death. In many ancient Western and Chinese chronicles, she figures in the name of a vast continent, Gangaridi, i.e., the land whose heart is the Ganga. The name of its capital and of the river flowing by it is the Ganga. Ptolemy, Megasthenes and other travellers in India between 300 and 200 BC praised the defensive prowess of Gangaridi. The Mauryan emperor, Chandragupta whom even Alexander dared not confront, is said to have reigned over the kingdom.

In the post-Vedic era, the Hindu Puranas (ancient history-based literature) mention Viyad Ganga, or heavenly Ganga, which flows from the toe of Vishnu. The descent mythology figured in them before the Ramayana. The civilizations of Harappa-Mohenjodaro and of the Ramayana flourished at the same time. It follows, therefore, that the kingdoms, described in the Ramayana, existed on the banks of the Ganga and were ruled by the native Dasas, or the immigrant Aryans who gradually moved from the Indus Valley to that of the Ganga between 1400 and 1000 BC. As the Ramayana is believed to have been written in the post-Vedic period, the kings figuring in it might have been Aryans. Therefore, the people in the Vedic age might have been Dasas as well as invaders of the Indus Valley, whereas the people in the Ramayana age might have been Aryan city-dwellers. From this time onward, for centuries, the mixed civilization had sporadic and irregular growth. The people continued to fight against flood and famine which were caused by the rivers.

> Then didst thou set the obstructed rivers flowing
> And win the floods that were enthralled by Dasas.

Both Dasas and Aryans considered rivers as sacred and thus recited their names while bathing, as their ancestors did for centuries:

> May the waters of the Ganga, Yamuna, Godavari, Saraswati, Narmada, Sindhu and Kaveri mingle with the waters – here and now!

In another legend, Manas Sarovar in Tibet, stretching at the foot of Mount Kailash, is the source of the river. This natural lake, sprawling over 500 km^2 at an altitude of 5000 m, has been attracting Hindu and Buddhist pilgrims and devotees since the early Christian era from India, China, Tibet and Japan. Three other great Indian rivers – the Yamuna, the Indus and the Brahmaputra – are believed to be also originating from this natural lake, literally.

In course of time, the fame and sacredness of the Ganga reached the Western world. She figured in the imagination of poets, writers and travellers. In poetry, T S Eliot, Heine, Andrew Marvell, and Goethe, to name a few, referred to her with reverence. Roman and Italian poets – Virgil, Ovid and Dante – also mentioned the Ganga. Hart Henry in a long poem narrated the mythology of the Ganga's descent on the earth to revive King Sagara's 60,000 sons and deliver their souls for ascent to heaven. I quote a stanza from the long poem.

> Ganga, whose waves in heaven flow
> Is daughter of the lord of snow?
> Win Siva that his aid be lent
> To hold her in her mid-descent,
> For earth alone will never bear
> Those torrents hurled from upper air.

Columbus on his fourth voyage to the New World heard the natives of Panama speak of the great river, The Ganga which lay 10 days' journey ahead from the coast. Megasthenes described the Ganga as the largest river of the world. Ptolemy's account and the graphic, showing the descent of the river on earth influenced and attracted geographists. Alexander imagined the river to be the farthest limit of the earth and while invading India, aspired to reach it. She figured in the translations and commentaries of ancient Indian texts by Max Mueller, William Jones etc. In New Testament, the tale of river Physon in the Garden of Eden has strange similarity with the Hindu mythology of the Ganga's descent on earth, giving rise to the hypothesis that the Ganga and the Physon was the same river. It persisted throughout the Middle Ages until the end of the 15th century and was held by Saint Augustine, Saint Ambrosa and Saint Jerome.

The Ganga mythology not only described her descent on earth but narrated her journey to the sea also. Great engineers like Travernier (1666), Bernier (1669), Rennel (1760), Sherwill (1857), Fergusson (1863) and Reaks (1919) drew many conclusions from, and laid great importance on, the incidents narrated in the mythologies about the Ganga and other sacred Indian rivers as well as from the views of learned men on them. The place where the Ganga merged with the Yamuna and Saraswati near Allahabad is called 'Juktabeni' i.e., three plaits of holy hair tied together and the place where its two tributaries – Yamuna and Saraswati – come out of the Bhagirathi at Triveni in West Bengal is called 'Muktabeni', i.e., the 'plaits separated'. The diversion of the Ganga to the Padma was caused, according to Captain Sherwill, by the collapse of the left bank, which he attributed to another legend in the Ramayana. A sage, Jahnu drank up the Ganga in retaliation of her washing away his holy copper utensils when she was following Bhagirath. He entreated the angry sage who pleased with his prayers, let her out through his thigh (hence Jahnabi, another name of the Ganga) and allowed her to flow again.

According to another mythology, Bhagirath was tired in his long journey from Haridwar and when he stopped for eating, the Ganga who had also stopped heard sound from a shell and taking it to be that from Bhagirath's conch-shell, followed the former which was actually blown by Padmavati, after whom the diversion was called the Padma. Seeing she was diverting, Bhagirath blew his conch-shell, at which realizing her mistake, the Ganga returned to follow him southward. In Chandi Mangal, a long poem by Kavikankan Mukundaram (1400 AD) a merchant, Lakshapati, on his way to Sri Lanka (then Singhal) along the bank of Ajoy river crossed the Ganga at Konnagar, Kolkata, Kalighat, Bostom Ghata (presently Baishnab Ghata), Mogra etc. The Ramayana mentions Sagar Sangam, i.e., the marriage the Ganga with the sea to which it flows in the Bay of Bengal. An island has emerged at the holy confluence, called Sagar Dweep where a fair is held annually on Makar Sankranti day, i.e., the end of winter solstice, usually in mid-January.

India's greatest Sanskrit poet, Kalidasa (500 AD) thus describes the Himalayan city of Alaka (perhaps so named, being on the bank of Alakananda):

> Where maidens whom the gods would gladly wed,
> Are fanned by breezes, cooled by the Ganga's foam
> In the shadows that the trees of heaven spread.

People, all over the world, believe their mythologies. The ones about the Ganga, which is one of the mightiest and longest of the world's rivers, are no exception.

Chapter 2
The Real *Ganga* In India and Bangladesh

According to ancient Hindu, Buddhist, Tibetan and Chinese scriptures, Mount Kailash, 6,100 m high, in the vast snowy reaches of Tibet, beyond the Indian Himalayas, is the home of the Ganga. Flowing down the mountain slopes, it enters India. The *Manas Sarovar*, the Lake of Mind, lies at the foot of the Kailash and is believed to be another source of the Ganga. The natural lake has been attracting pilgrims and traders since the Christian era, namely Hindus and Buddhists of Tibet, China, Japan and other countries. Its water sprawls over about 500 km_2 at an altitude of about 5,000 m. Four great Indian rivers, The Ganga, the Yamuna, the Indus and the Brahmaputra- are believed to be flowing from Manas Sarovar. However, the visible source of the Ganga is the Gangotri glacier in north Garhwal district of Uttar Pradesh (now Uttarakhand), a few 100 km south of the Mount Kailash. It is nearly 30 km long and five km wide and is surrounded by 7,000–8,000 m high mountain peaks. The two main tributaries of the Ganga – the Alakananda and the Bhagirathil – also originate from the glacier and flowing past the holy villages of Badrinath and Gangotri, join at Deva Prayag, take the name of the Ganga and flows south, about 280 km, to reach the plains at Rishikesh and 30 km more to reach Haridwar. The land route to Gangotri meanders through steep mountain slopes across the Bhagirathi valley, through dense forests of cedar and pine and very similar-looking small hilly towns. Haridwar, mythologically the gate of God (Lord Vishnu), is a popular pilgrimage city, where Hindus gather between May and September, to perform religious rites (Fig. 2.1). Photographs 2.1 and 2.2 shows the Ganga water coming out of Hill cave at Kedarnath and the meeting point of Alakananda and Bhagirathi at Deva Prayag.

Flowing about 160 km south-east from Haridwar, the Ganga enters Muzaffarnagar district of Uttar Pradesh and travels further south. The discharge partly diverts here through the Upper Ganga canal, starting from Haridwar. The course of Upper Ganga from Gomukh to Haridwar is about 375 km. From Haridwar to Farakka in West Bengal, the 1,730 km course is called the Middle Ganga, flanked by flood-prone plains. Flowing through five UP districts – Muzaffarnagar, Bijnor, Meerut, Aligarh and Moradabad, it takes a wide sweep southeast at Nangal in Bijnor district for several kilometres. In Meerut and Moradabad, it flows on a wide bed, often changing its course. Flowing about 770 km from Haridwar, it joins the

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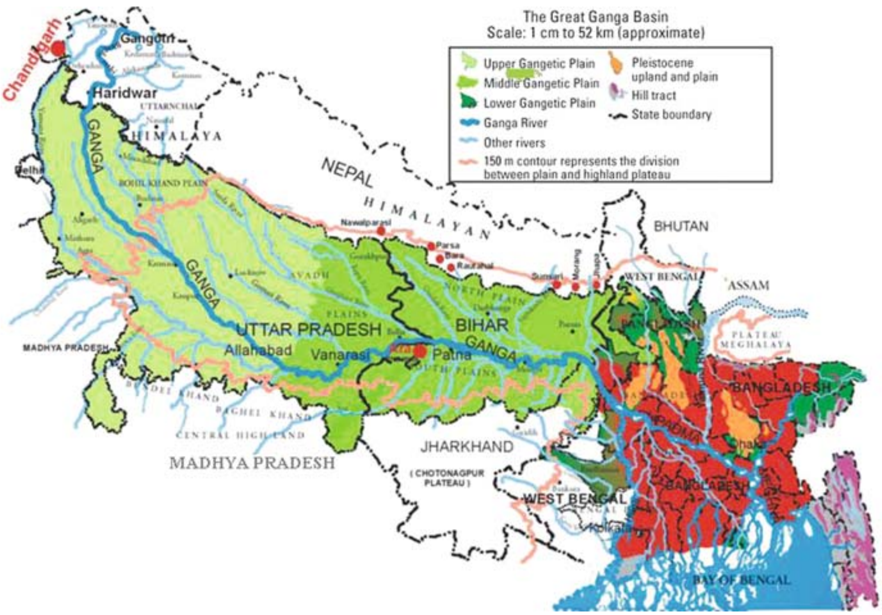
Fig. 2.1 Source and descent of the Ganga river

Yamuna and invisible (sub-surface) Saraswati at Allahabad and travelling some 145 km enters Rohtas district of Bihar and passes through Saharsa, Patna, Mungher, Bhagalpur, Sahebganj and Rajmahal. It swings round the Rajmahal Hills opposite Manihari Ghat and flowing further south enters West Bengal near Farakka in Murshidabad district. It bifurcates at about 50 km south of Farakka, at Giria in Murshidabad district. From Allahabad to Farakka where its delta starts, the Ganga's course is about 960 km. The left arm flows southeast through Murshidabad district and finally enters Bangladesh at about 56 km further south. This arm, after it enters Bangladesh, is called Padma. Photograph 2.3 shows the Ganga river at Hardwar.



It is believed that the Bhagirathi was the main flow, a few hundred years ago. Captain Sherwill said it was the main river from Rajmahal to sagar Island in olden days, which in due course became insignificant; the present course through the Padma is of later origin. It was formed by the opening out of the left bank near Sibganj in Malda district, opposite Farakka. This, he says, occurred slowly after a sudden collapse of the left bank, made of yellow sand. He says, this catastrophe is mentioned in the mythology of the angry sage, Jahnu swallowing the Ganga in retaliation of her washing away his holy utensils, as narrated in the Ramayana. Sherwill considered this anecdote in the epic as a mythological representation of a natural calamity that occurred at Sibganj, which sage Valmiki might have witnessed. He also believed that the silting of tributaries between the Bhagirathi and the Brahmaputra was caused by this collapse. This is corroborated by the fact that the outfall of the Ganga to the sea is believed to have existed near Malda, a few centuries ago, when the largest delta in the world occupying over 58,750 km^2, which is a little over one-fourth of undivided Bengal – was formed by the silt and sand deposits of the Ganga, the Brahmaputra and the Meghna. Of this, about 21,000 km^2 are in West Bengal. The existence of ancient localities, once famous and prosperous centres of art, culture and industry, namely Gour, Murshidabad, Beharampur, Katwa, Nabadweep, Kolkata, Howrah and the industries on both banks, indicate that the right arm, the Bhagirathi was the main flow before the left channel, the Padma drew increasing discharge from the end of the 18th century.

Photograph. 2.1 Ganga water coming out of hill cave at kedarnath

However, the right arm continued to flow southward through West Bengal for another 530 km, or so, before it fell into the Bay of Bengal, near the sagar island, off Diamond Harbour in West Bengal. It flowed through the districts of Murshidabad, Nadia, Burdwan, Hooghly, North and South 24-Parganas, Kolkata, Howrah and Midnapur. The course from Farakka to Nabadweep is non-tidal but further down, tides from the Bay of Bengal flow and ebb. As stated, the left arm enters Bangladesh after flowing about 50 km into Murshidabad and travelling 220 km further south-east across Bangladesh, it joins the Brahmaputra at Aricha, near the well-known Goalanda Ghat in Faridpur district. Flowing further down for about 100 km, it joins Meghna and this combined course, also known as Meghna, falls into the Bay of Bengal, travelling some 120 km. Towards the end, the river breaks into a number of estuaries which pass by dense forests of the Sundarbans. The Brahmaputra is sometimes called the Yamuna in Bangladesh and many people believe that from Goalanda downstream, the combined discharge of the Yamuna and the Ganga takes

Photograph. 2.2 Meeting point of Alskanda and Bhagirathi at Devaprayag

Photograph. 2.3 Ganga at Hardwar

the name of the Padma which is sometimes incorrectly called the Ganga. This channel came into being by the diverted flow of the Ganga and the Brahmaputra and for most part of the year; the Brahmaputra contributes more to it than the Ganga. The Padma's total length from Goalanda to the Bay of Bengal is about 220 km. Refer Fig. 2.2.

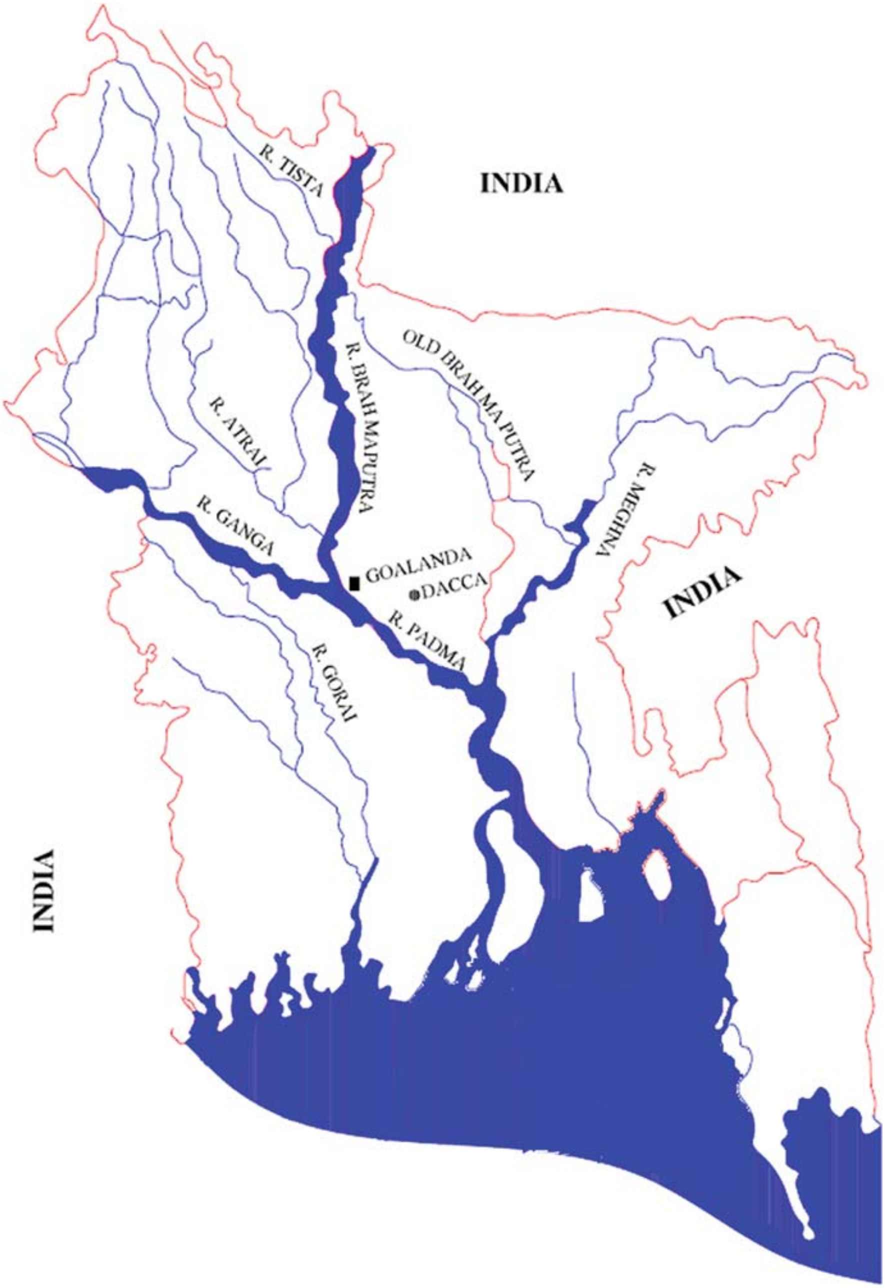


Fig. 2.2 River Ganga – Padma, Brahmaputra and Maghna in Bangladesh

Tributaries and Diversions

Before the Bhagirathi and the Alakananda join to form the Ganga, three other rivers – The Mandakini, the Dhouli and the Pindar – flow into them. Coming down the plains up to Haridwar, the Upper Ganga canal takes off from a weir at a place, 240 km below where Narora Barrage has been constructed; from there the Lower Ganga canal takes off. An anicut was built across it at Haridwar in 1839 and the construction of the Upper Ganga canal was completed in 1864 and was gradually extended up to Varanasi. Narora Barrage came up in 1880 along with the Lower Ganga canal, resulting in further diversion. From the barrage site, the river flows about 530 km to reach Allahabad (past the *ghats* of Mirzapur) where the Yamuna and the invisible Saraswati merge with it. Rama Ganga, the first major tributary of the Ganga, joins it from the left in Hardoi district of Uttar Pradesh, another tributary from the left is the Gomati which flows into it, just south of Varanasi. The other tributaries which join it from the right are the Chambal, the Sindhu, the Betwa, the Ken and the Tons.

After exit from Uttar Pradesh, the Ganga enters Bihar in Rohtas district and is joined by two other tributaries – the Ghagra from the left in Chapra district and the Sone from the right near Maner. Another tributary from the left, the Gandak joins it near Patna. Further down, it receives the Kosi from left at Pathar Ghat in Saharsa district. Past the Sone, other small tributaries join it from the right – the Punpun, the Kiul, the Maan, the Chandan and the Gerua, one after the other. As the Ganga enters West Bengal, river Gumani joins it near Farakka from the right. Its tributaries in West Bengal from the left are the Fulahar, the Bhagirathi (another river, not the Ganga) and the Pagla – all in Malda district. Pagla is now totally blocked by embankment to prevent flood. Before splitting into two distinct streams in Murshidabad, a small tributary, the Bagmari joins it from the right, near Dhulian. Near Jangipur in Murshidabad, the river branches off into two channels, the main river flows south-east as the Ganga-Padma and another one flows southwards as the Bhagirathi (Fig. 2.3).

Immediately after this diversion, two small tributaries – the Bansloi and the Pagla – join the Bhagirathi, near Jangipur on the right bank. Soon after it enters Nadia district, the Babla joins it from the right and carries the discharges of a number of small tributaries – The Dwaraka, the Brahmani, the Mor, the Mayurakshi, the Kana and the Koya and joins the Bhagirathi at about 140 km downstream from its offtake from the Ganga. The Ajoy, also a tributary from the right, joins it further down, near Katwa in Burdwan district and carries the combined discharges of itself, the Hingola and the Kumar. These four rivers originate from Santal Parganas in Jharkhand and go dry except in monsoon months. The only tributary from left is Jalangi which takes off from the Ganga at about 15 km west of Akhriganj in Murshidabad and joins Bhairab, another offshoot of the Ganga, before it flows into the Bhagirathi near Nabadweep in Nadia district.

After taking the discharge of the Jalangi on left bank, about 230 km from the offtake point, the Ganga takes the name of the Hooghly which is subject to diurnal tides. The water-level fluctuates twice daily and the range varies according to the tide

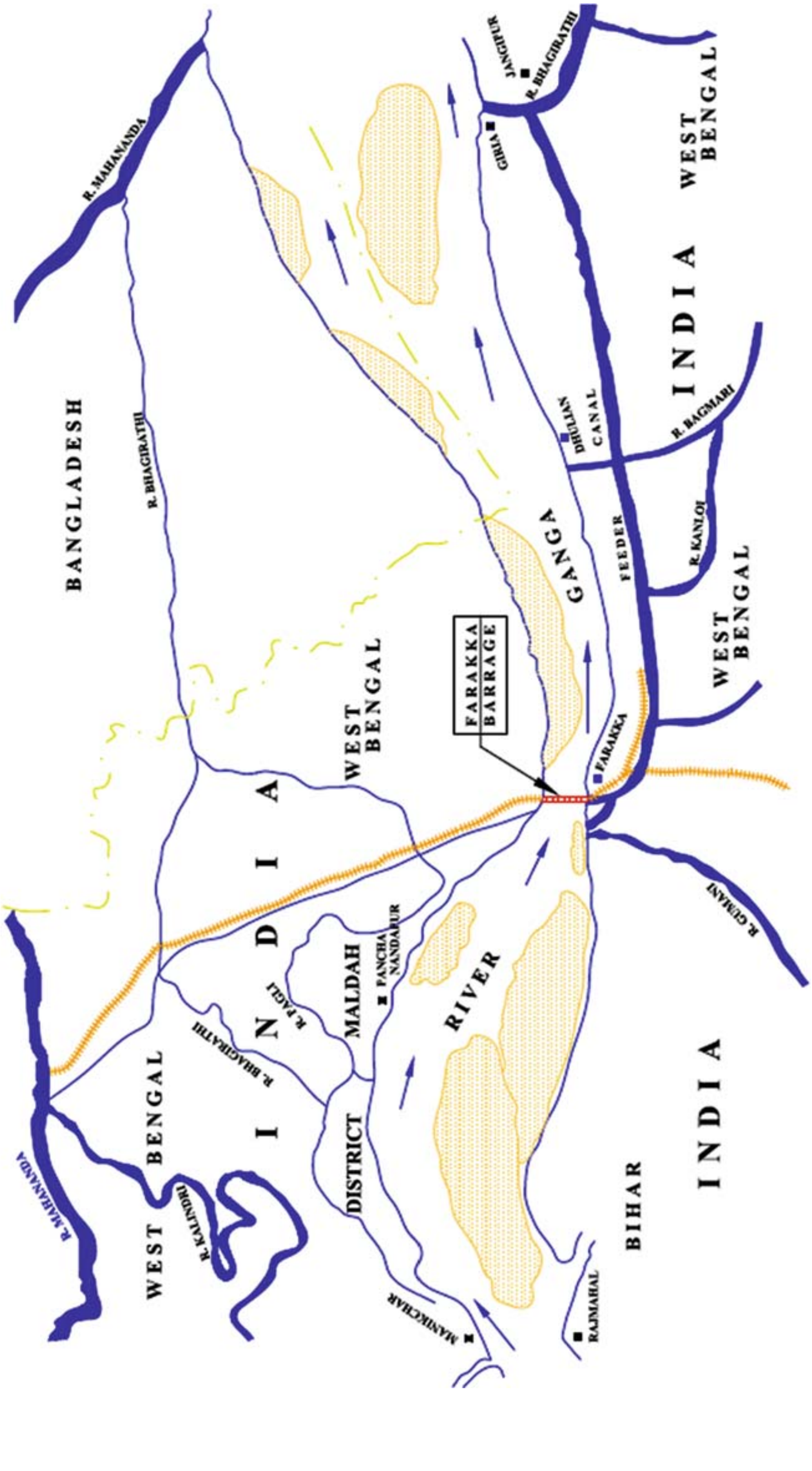


Fig. 2.3 Ganga river in West Bengal

generated in the Bay of Bengal. The Hooghly's first tributary is the Churni from left near Chakdaha in Nadia district, which offtakes from the Padma in Bangladesh and branches from Mathabhanga. The Damodar which originates in the Chhotonagpur Hills in Jharkhand and flows through parts of Bihar and West Bengal joins the Hooghly from right near Uluberia in Howrah. It is now shackled by a number of dams across it, built by the Damodar Valley Corporation and remains virtually stagnant, except in rainy months. Below its outfall, the Rupnarayan joins the Hooghly from right and deflects the combined discharge toward left up to Diamond Harbour in south 24-Parganas. It carries the combined discharge of the Damodar (partly) and the Darakeswar, the Silavati and the Kangsavati and joins the Hooghly near Tamluk (the famous Tamralipta port in ancient India) in East Midnapur district. The dams across the Damodar have considerably tamed the turbulent river, reducing its reservoir capacity in monsoon months.

From Diamond Harbour the Hooghly flows south up to its journey to its confluence in the Bay of Bengal, near the sagar Island. On this course, the first river to join it from the right is the Haldi on whose bank Haldia port has come up. The river carries the discharges of the Keleghai and the lower segment of the Kangsavati and flows into the Hooghly through a fairly wide estuary at Sondia near Sutahata in East Midnapur district. Further down, Rasulpur, the last tributary of the Ganga, joins it from right, near Hijli in Midnapur. It practically discharges at the sea-face below which the Bay of Bengal starts. The total length of the Ganga in India from its origin at Gomukh to its confluence at Sagar Island is about 2,645 km, or 1,660 miles.

The name Padda or Padma generally applies to the Ganga as far up as the point where the Ganga flows in two streams near Jangipur. One branch, the Bhagirathi flows south through West Bengal and the other into Bangladesh, carrying the monsoon and non-monsoon flows through Murshidabad and Nadia districts. In fact, the river has made a natural division of the two countries, which were one before 1947 except for six years – from 1905 to 1911 – when it was bifurcated by the British Raj in Kolkata. Its right bank is now India and the left bank is Bangladesh for some 50 km. The right branch begins in Nadia district in India (West Bengal) and the left branch in Rajshahi district of Bangladesh where its first tributary from left is the Mahananda which joins it near Nawabganj in Rajshahi. As Harun Er Rashid said in 1979:

> It is hydrologically more correct to call the river the Ganga down to its confluence with the Yamuna. . .. The river between Aricha and Sureswar is, therefore, best called the Padma, for it has every right to be regarded as a separate river. The Padma is 120 kilometres long and 4–5 kilometres wide. The very important Goalanda-Chandpur steamer route is mostly on this river.

About 100 km south of Goalanda, the Meghna joins the Padma and its direction changes from south-east to south up to its outfall into the sea (Bay of Bengal). The lower Meghna, the largest river in Bangladesh, carries the discharges of the Padma and the upper Meghna and is joined by the Dhaleswari from the left. All the three rivers are very large and at their confluence are about 15 km wide. The Padma-Meghna estuary starts from the confluence and the southward journey of the river

Table 2.1 Length of the river Ganga

Place to place	Ganga-Bhagirathi-Hooghly course (km)	Place to place	Ganga-Padma-Meghna course (km)	Remarks
1	2	3	4	5
Gangotri (Source) to Rishikesh	345	Gangotri (Source) to Rishikesh	345	1) Direction of Ganga-Bhagirathi-Hooghly course changes from north-south to south-east to south. 2) Direction of Ganga-Padma-Meghna course changes from north-south to south-east
Rishikesh to Farakka	1,760	Rishikesh to Farakka	1,760	
Farakka to Ahiran (Mouth of Bhagirathi)	45	Farakka to Jalangi Bazar (India–Bangladesh Border)	105	
Ahiran to Nabadwip (confluence of Jalangi river)	185	Jalangi Bazar to Goalanda Ghat (confluence of Brahmaputra)	220	
Nabadwip to Calcutta (Rabindra Setu)	210	Goalanda Ghat to Meghna outfall	100	
Calcutta to outfall to sea near Saugar Island	100	Meghna outfall to Cox Bazar (sea face)	120	
Total	2,645		2,650	

continues for another 150 km or so, before it flows into the sea. The total length of the Ganga along the Padma's course up to the outfall of the Meghna is about 2,650 km, or 1,655 miles.

Table 2.1 shows the total length of the river through two separate channels.

Chapter 3
The *Ganga* Geology

The Ganga Basin

According to the theory of plate tectonics, the crust of the earth is formed by a number of relatively rigid plates. They shift and move because of their spread and subduction of sea-floors. The continental mass broke up and re-formed several times in 4½ billion (4,500 million) years of the earth's history. In course of development, the shape of the earth changed continuously, owing to various geological processes. Some of these are so slow that it is practically impossible for anybody, within his life-span, to detect them but when these occur across billions of years, they enormously transform the earth's shape. Eruptions of volcanoes and quakes are of short duration and their effects are directly observed. Geologists have established that in the history of the earth's development, there have been numerous crucial changes of its physiographic conditions, renewing the organic world.

In the early Triassic period, most of the earth's land formed a single continental mass, called Pangaea; it was surrounded by one ocean, called Panthalassa. The last continental break-up occurred about 200 million years ago when the plates began moving in diverse directions. Pangaea first split into two masses – Laurasia and Gondwana. Laurasia later broke into three – the westernmost mass featured North America and the two eastern masses formed most of the Asian-European land mass. The Asian mass is believed to be carried on two plates – the Eurasian and the East Asian. In the Jurassic period, the Indian portion of the Gondwana mass split and began to move north, toward Asia. Apparently, the Indian portion was on the same plate as Australia and both moved north, as the plate shifted owing to the sea-floor spread in the newly formed the Indian Ocean. It swung north fast and collided with the East Asian and Eurasian plates in the Eocene period (54–38 million years ago). This led to the rise of the Himalayas in the north and the Arakan Yomas on the east. The Indian plate was subducted under the East Asian plate along the Himalayas but along the Arakan Yomas, the two plates were connected by a transform fault, as shown in a Fig. 3.1.

In the Oligocene period (40–30 million years ago) a part of the north-eastern Indian mass fractured and sank below the sea-level. It was filled over the next 37 million years to form the Bengal Basin. Bangladesh was formed on a mass of sediment, left by very old rocks of the Gondwana continent. On the two sides of the

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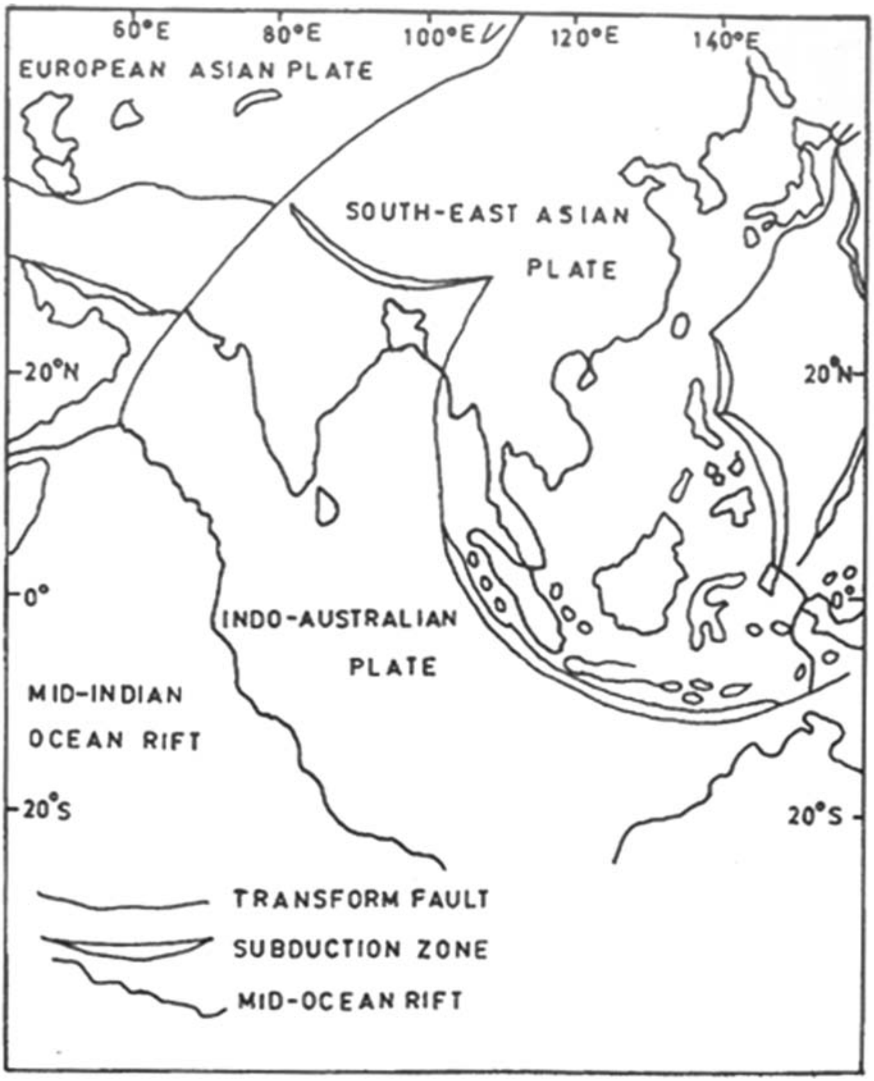

Fig. 3.1 Tectonic plates (Rashid, H. E.)

Bengal Basin, old rocks emerged to form the Maghalaya Plateau in the east and the Chhotonagpur Plateau in the west, as shown in Fig. 3.2.

The narrow part of the Basin, in between the two plateaus, is called the Garo-Rajmahal gap. Because of proximity of a major subduction fault on the north and a transform fault on the east, the Bengal Basin and its adjacent areas are tectonically very active. Large areas were uplifted and some sank, even in recent time. It has been postulated that these tectonic activities might have been due to a deep and major

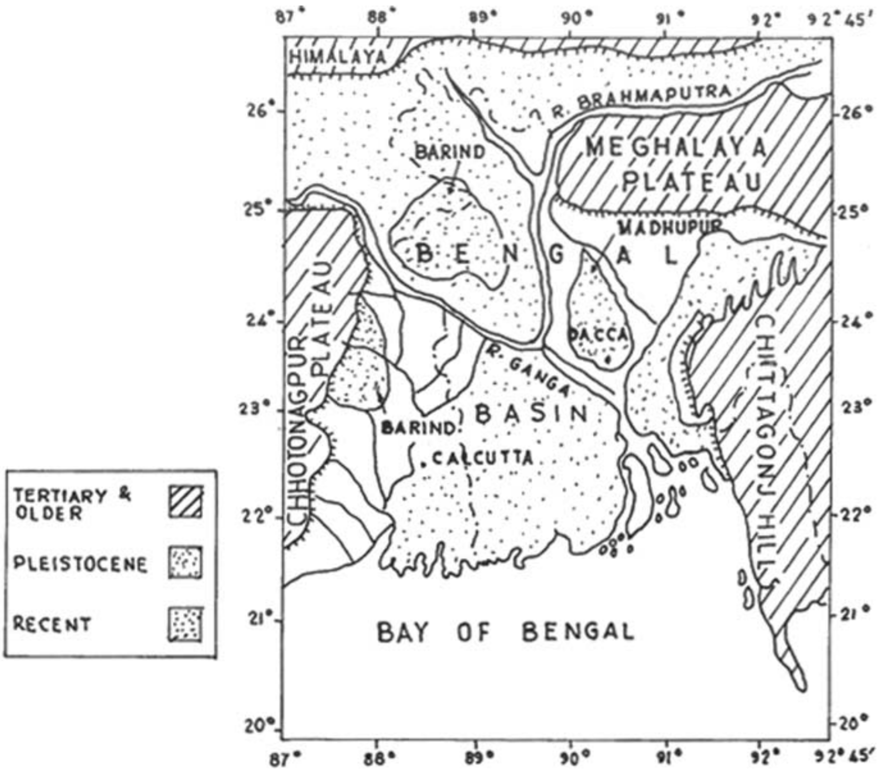

Fig. 3.2 Bengal basin

fault, or to a subsiding trough along the axis of the Ganga-Brahmaputra-Meghna (GBM) river system. This is likely to have caused changes in the courses of major rivers like these three.

Formation of a Delta

In the Tertiary period (16–15 million years ago), the Bengal Basin was filled by sediments, brought by the rivers from the east and the west, as there was no gap on the north. This was possible, because the three sides, especially the Himalayan side on the north, were highlands with steep slopes. The land-building process must have been accelerated by the Ganga and the Brahmaputra.

In the Pleistocene period (about 1.5 million years ago), the formation of the Garo-Rajmahal gap on the north changed the pattern of sedimentation, because of a complete change in the drainage of the Ganga and the Brahmaputra, which flowed southward and fell into the Bay of Bengal. Subsequent world-wide glaciations caused a significant fall in sea-level, which considerably increased the erosive power of the rivers, leading to a faster formation of delta about 15,000 years ago. Both the Pleistocene and later sediments were deposited by the GBM river system and formed a complex alluvial mass. Continuous deposition took place in the form of back swamp, meander-belt and channel-fill deposits. Lateral planations and shift of Ganga-Brahmaputra as well as their tributaries and distributaries led to their overlapping and burial by later deposits.

The Ganga discharges into the Basin from north-west after draining the foothills of the Himalayan range across more than 2,400 km. The Brahmaputra enters the Basin from north-east and drains the northern slope of the Himalayas, taking the name of its main Tibetan tributary, Tsang Po; their combined length is about 2,900 km. The Meghna drains the Sylhet Basin and parts of the adjacent plateau and Tripura hills, together draining about 0.15 million (150,000) cusecs. This huge discharge brings enormous sediments and helps form recent deposits. The bulk of the deltaic southern Bengal Basin is probably not more than 10,000 years old.

The Himalayan rivers originated from the still young and friable range. Frequency of earthquakes owing to the geological state of the region and heavy rains in the catchments because of elevation and general direction of the monsoon wind, cause frequent landslides and soil-erosion. Variation of extreme temperature and the friable nature of the Himalayan rocks enhance silt movement from the catchment. All these result in high silt charge in the mountain rivers. The non-Himalayan rivers in the Ganga sub-basin, on the contrary, originate at much lower altitudes and in less rainfall zones; they drain geologically more stable regions. Some of these rivers, particularly the major Vindhyan rivers like the Sone and the Tons, cascade where they cross sandstones, thereby reducing their effective gradient. As a result, these rivers carry less silt than the Himalayan rivers and therefore, run more stable courses.

The drainage pattern of the Himalayas reflects their geological past too. Instead of originating from the mighty Himalayas, the main drainages originate either in the northern plateau of the Tibetan Himalayas, or from the southern fans of the lesser of the Indian Himalayas. According to the theory of 'antecedent drainage', rivers like the Arun Kosi of the Ganga were flowing before the Himalayas took the present shape. Simultaneously with the mountain-building process in the Himalayas, these river-valleys are said to have upheaved and rejuvenated again and again. The theory explains, how some of the great rivers of the region drain not only the southern slopes of the mountains but do it on the northern slopes too, the limit of the valley being much further north than the main axis of the great range. It also explains the configuration and the enormous depth of the gorges, as the uplift of the ranges and the erosion of the upheaved valleys occurred at the same time. The Himalayan rivers often change their courses and alter bed-gradients, caused not only by the differential erosion, capture of one river by another, land-slips, glaciations etc. but by quakes too along the faulting belt, which characterises the southern flank of the Himalayas.

The Pleistocene alluvial terraces formed in four major regions and several small outliners that topographically stood above active flood plains. Of these four areas, two flank the basin on the east and the west; the other two lie within it. The latter two areas are known as the Barind and the Madhupur jingle. The Pleistocene sediments were deposited as flood plains of former Ganga-Brahmaputra river system, which are almost the same as those of the recent flood-plain. Recent sediments are dark, loosely compacted and have high water content and a variable but appreciable quantity of organic materials. Pleistocene sediments, on the contrary, are well-oxidised and typically reddish, brown or tan and mottled; water-content is low, resulting in firmer and more compacted material. Organic material in these sediments is commonly confirmed to the surface soil profile. Much of the Pleistocene deposits have either been eroded, or sank below recent alluvial deposits.

Himalayan rivers flow through poorly consolidated sedimentary rocks with a number of folds, faults and thrusts. Owing to high gradient and velocity, these rivers are highly erosive of softer materials, like pebbles, cobbles, boulders, coarse sands etc. which cut and carve out deep gorges and remove the materials as fine particles to act as sediment. Very often, landslides occur particularly during heavy rains and increase sediment loads.

The sediments in Bengal rivers are made primarily of fine sands and silts with little clay matrix. High sediment concentration makes the rivers constantly adjust the configurations of their beds in diverse flow regions. Thus, high volume of sediments, deposited in the basin, also erode because of change in flows. The deltaic region is always subsiding, owing mainly to consolidation of recent sediments. Broadly speaking, as Bose and Chakrabarti say, the whole of undivided Bengal is formed by the deltaic processes of the Ganga and the Brahmaputra. To be precise, the area bounded by the Bhagirathi-Hooghly on the west, by the Padma-Brahmaputra-Meghna on the east and north-east and the Bay of Bengal on the south is a proper delta, spread over about 54,750 km^2 within 21.5 and 25°N latitudes and 88.2 and 91°E longitudes (Fig. 3.3).

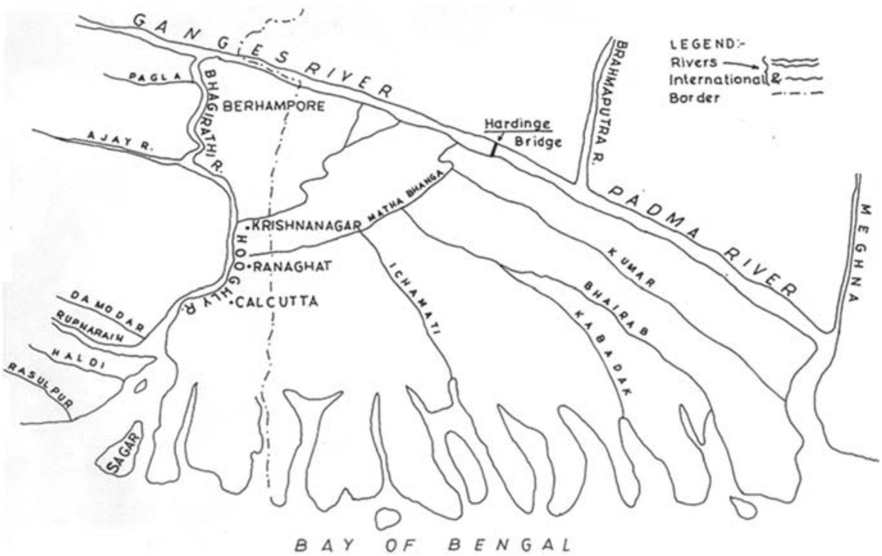

Fig. 3.3 Bengal delta (not to scale)

The delta in West Bengal is the western part of the main body and comprises Nadia, part of Murshidabad, North and South 24-Parganas, part of Howrah, Hooghly and East Midnapur districts as well as Kolkata. It is elongated north-south by about 350 km, while east to west at the narrowest part (mid-Nadia) is 120 km and is spread over about 20,110 km^2, including 4,220 km^2 of forests. It is intersected by many rivers and creeks, running generally in south and south-easterly courses with tidal estuaries on the sea-face. The Bhagirathi-Hooghly which forms the right arm of the

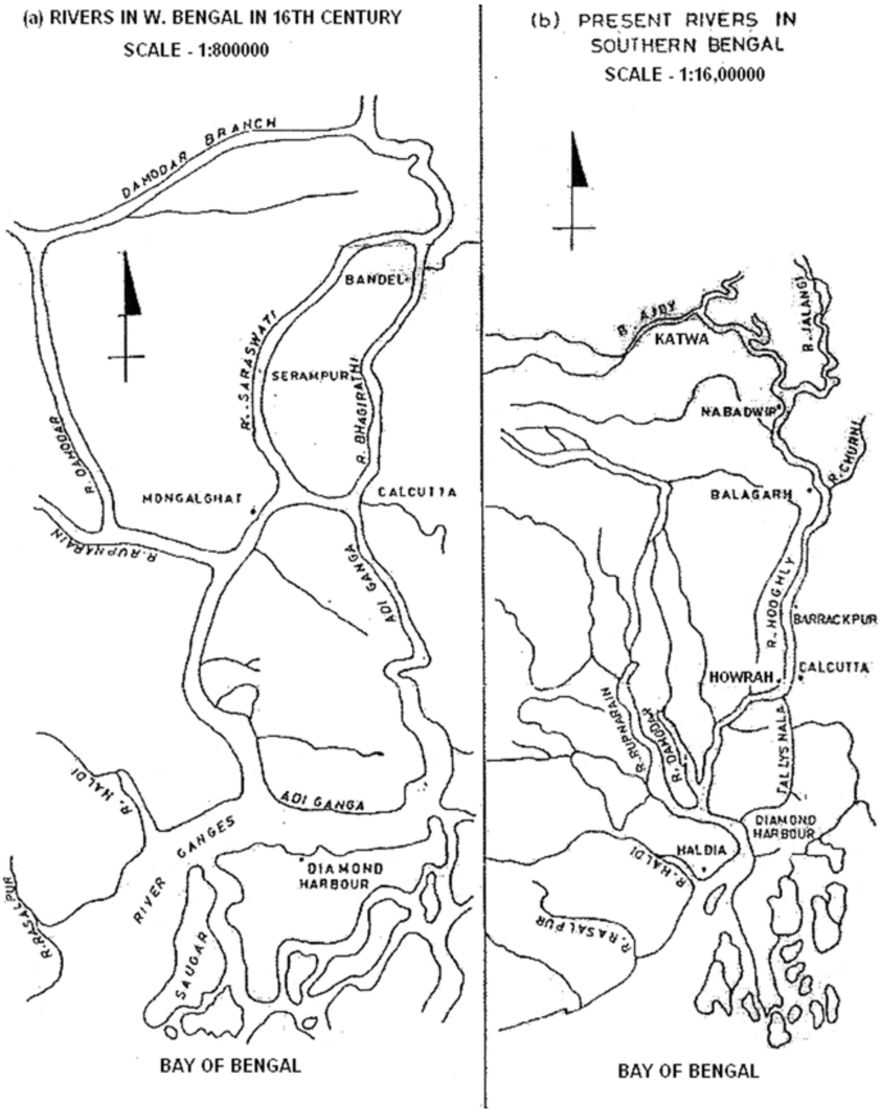

Fig. 3.4 Rivers in west and south Bengal past and present

delta, was the main channel of the Ganga hardly 600 years ago and flowed, as it does now, due south to the Saugar island, practically along the course of the present Hooghly river. The main river appears to have frequently changed its course below Gour in the last six centuries and successively discharged into the sea at different mouths, such as Matla, Kalinai, Kabadakh and Haringhata in the Sunderbans.

Major Changes Since 16th Century

Early in the 16th century, the main course of the Ganga's shift eastward to the present Padma may have been due to some tectonic changes and natural calamities, leading to rapid deterioration of the Bhagirathi. At Bandel in Hooghly district, the river bifurcated into the Saraswati and the Bhagirathi, alias Adi Ganga beside and below Kolkata. The Saraswati (not to be confused with the unseen river of the same name at Allahabad Sangam) was a major maritime river. A branch, ostensively a man-made channel at Kolkata, connected it with the Bhagirathi/Adi Ganga. At that time, the main course of the Damodar river used to flow into the main Bhagirathi at a few kilometres north of Triveni. In 1770, following a severe flood, the Damodar changed its course and flowed into the Bhagirathi, about 50 km south of Kolkata, causing a major change in its system. Above the changed confluence point, the Saraswati and the Bhagirathi became extinct and the Bhagirathi flowed along the present course of the Hooghly. The remnant of the Adi Ganga is believed to be the present Tolly's Nalla (Fig. 3.4).

Chapter 4
The *Ganga*'s Hydrology

Of the 2,645 km course of the Ganga from its origin in the Himalayas to its outfall in the Bay of Bengal, measured along the Bhagirathi-Hooghly, about 1,450 km lie within Uttaranchal and Uttar Pradesh, about 550 km within Bihar and about 520 km within West Bengal. The remaining course, of about 125 km, lies in border areas between Bihar and UP. According to K. L. Rao, a former Union Irrigation Minister of India, the Ganga basin in India is spread over 861,404 km^2 and across eight States including the national capital, Delhi. This is about 86.5% of the total Ganga basin, spread over about 1.06 million sq. km in India, 0.19 million sq. km in Nepal and 9,000 km^2 in Bangladesh. The distribution of the basin area among the Indian provinces is as in Table 4.1.

Of the total landmass of India (3,287,283 km^2), the Ganga basin comprises about 26.2%. It is the biggest river basin in India, whose average width is about 340 km. Seven major tributaries from the north and six from the south fall into it. The course is almost east-west in direction up to Jangipur in West Bengal; south of it, the direction is north-south along the Bhagirathi-Hooghly; in this reach, there are five major tributaries. The total catchment area of the northern tributaries is about 0.42 million sq. km and that of the southern tributaries is about 0.58 million sq. km. The drainage area of the tributaries of the Bhagirathi-Hooghly is 60,000 km^2.

Rainfall in India is greatly influenced by mountains. Their size, shape and alignment determine the quantity and spread of rains in various parts of the country.

Table 4.1 Basin areas of the Ganga in different states of India

Sl.No	Name of states	% of area	Covered area in lakh sq.km
1.	Uttar Pradesh	34.2	2.65
2.	Himachal Pradesh	0.5	0.06
3.	Punjab and Haryana	4.0	0.34
4.	Rajasthan	13.0	1.08
5.	Madhya Pradesh	23.1	2.02
6.	Bihar	16.7	1.55
7.	West Bengal	8.3	0.72
8.	National Capital Delhi	0.2	0.02

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Though the average rainfall over India is one of the highest in the world for a country of comparable size, it fluctuates widely in various regions. Because of heavier intensity of rainfall, the annual run-off from the region, north of the Ganga, is 0.75 m and that from the south is only 0.3 m, which makes the contribution of flow from the northern tributaries significantly more than that from southern tributaries. Nearly 60% of the water, flowing in the Ganga, comes from areas, north of its course. Peninsular streams together contribute the remaining 40%, though the catchment extends over 60% of the entire Ganga sub-basin. Thus, hydro logically, Himalayan rivers are of more importance than peninsular streams of the sub-basin (Fig. 4.1).

Distribution of rainfall on India is erratic and haphazard. Though the average annual rainfall over the entire country is about 105 cm, it varies widely from region to region. Over the Khasi and Jayantia Hills, it is about 1,000 cm, while toward north, in the Brahmaputra Valley, it is as low as 200 cm. On the west coast, about 600 cm of rains fall on the windward side of the Western Ghat hills and only 50–60 cm fall on the leeward side of the Ghat hills; the distance between the two is about 80 km. Such wide variations do not occur in plains beyond hilly regions. Similar phenomenon is noticed on the east coast where rainfall is highest near the coast but much less inland. On Aravalli ranges in north India, about 160 cm of rains fall in a year but only 60 cm fall on the surrounding plains. Similarly, in the northern plains, rainfall varies widely from 150 cm in West Bengal to about 15 cm in west

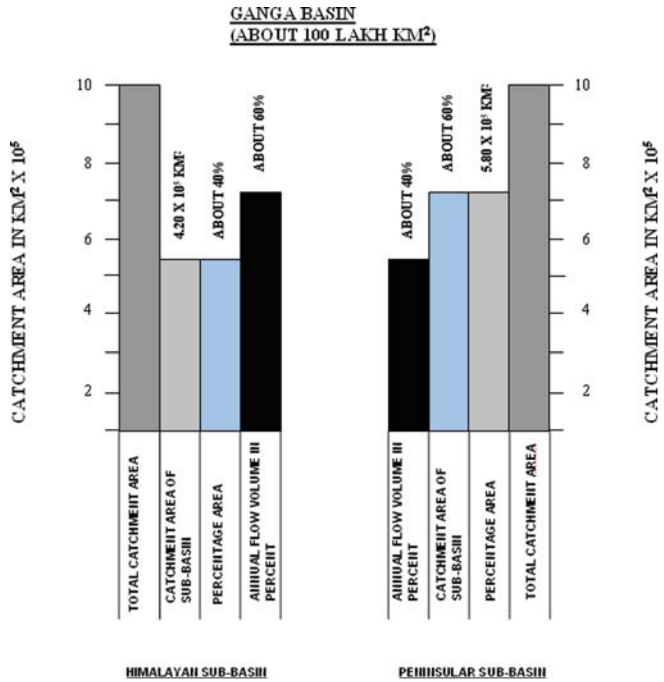

Fig. 4.1 Distribution of Ganga basin components

Rajasthan. The Himalayas are spread on the entire northern border of India with Pakistan, Afghanistan, Tibet, China, Nepal and Bhutan and all northern tributaries to the Ganga are fed by snow-melting water and rainfall from the southern side of the range. Here also, rains on the eastern Himalayas is more than those on western ranges, varying from 500 to 280 cm. Rainfall is also higher in the lower foothills and decreases in the upper ranges.

Over the whole of the Ganga basin, stretching from Dehradun in UP near which the Bhagirathi joins Alakananda in Uttarkashi district of Uttarakhand (carved out from UP) to south 24-Parganas district in West Bengal the annual rainfall averages about 90 cm but on Dehradun and nearby Haridwar, it is 210 and 150 cm, respectively. Its intensity wanes to about 100 cm in Aligarh in UP Bihar's Purnea district receives the highest rainfall of the State, about 170 cm while Mungher in the same State receives the lowest, about 95 cm. The annual rainfall on Farakka in West Bengal, is about 130 cm while on Kolkata and Howrah, it is about 150 cm. On Kakdweep in south 24-Parganas, about 160 cm rains fall in a year. The rainfall data on the Ganga basin follows in Table 4.2.

Table 4.2 Annual rainfall in Ganga basin

Sl. No.	Place	District	State	Annual rainfall (cm)
1	2	3	4	5
1	Bhagirathi-Alakananda junction	Uttarkashi	Uttarakhand	90.0
2	Dehradun	Dehradun	-Do-	210.0
3	Hardwar	Aligarh	-Do-	100.0
4	Purnia	Purnia	Bihar	170.0
5	Munghyr	Munghyr	-Do-	95.0
6	Ganga	Murshidabad	West Bengal	130.0
7	Calcutta	Calcutta	-Do-	150.0
8	Kakdwip	South 24-Paraganas	-Do-	160.0

Seasonal Distribution

Except in Kashmir, Tamilnadu and some other regions, winter rainfall is very meagre and much less than in other seasons over the rest of India (January–February). From March to May, rainfall is good over Kerala, Assam and Jammu & Kashmir. Between June and September, the south-west wind blows over most parts of the country, including the Ganga basin and brings good rains. Over two-thirds of annual rainfall occurs in this period except in a few places, as stated. Its sub-basin has distinct wet and dry seasons; the wet season receives about 75% of total annual downpour in monsoon months, from June to September, followed by a dry summer spell from March to May and a short winter from December to February. Water-flow in streams fluctuates considerably in both the seasons.

Unlike the Ganga sub-basin in India, the Padma sub-basin in Bangladesh receives abundant rains over various regions throughout the year. The climate is marked by high temperatures and humidity. The northern and north-eastern parts, comprising Sylhet, Mymensingh and Coomilla districts, receive 230–300 cm of rain and south-eastern Chittagong region receives about 250 cm. Rangpur and Dinajpur districts in the north-west are drier and receive 180–250 cm of rain. Rajshahi district in the west is the driest with less than 150 cm in a year. Southern Bangladesh, comprising Pabna, Kushtia, Faridpur, Jessore and Khulna districts gets abundance of rains, between 200 and 230 cm. Seasonal distribution of rains over Bangladesh is more uniform than over India. Except in 5 months, from November to March, the country gets good rains in other seven months, from April to October, with high intensity in three monsoon months, from June to August.

Low rainfall regions in India, where annual downpour is less than 80 cm, are scattered all over; the total area is also quite large. Most parts of Rajasthan, a part of Gujarat, Punjab, Uttar Pradesh, Andhra Pradesh, Karnataka, Tamilnadu, Orissa and West Bengal are arid or semi-arid regions, spread over about a million square kilometres, and receive only 40–80 cm of rains on an average in a year. About one-third of the total cultivated area in India suffers from low rainfall. On the contrary, minimum average rainfall over Bangladesh is about 120 cm.

The ground-water storage capacity in India is also limited and scattered all over the country. Arid and semi-arid regions in north, west and south have meagre reserves. Except in some parts of west Bengal, Orissa and Kerala, the ground-water level is at about 100 m below the surface. The total ground-water reserve in India may be about 0.25 million million (1,000 billion) cubic metres, of which about 0.01 million million cubic metres have been tapped and utilised for irrigation and drinking. Efforts are on to exploit more reserves for the burgeoning population. On the other hand, the normal sub-soil reserve of water in Bangladesh is comparatively higher because of favourable soil structure and topography in most parts of the country. The highest ground-water table in Bangladesh in monsoon months varies from 0.5 to 2 m below the surface in the delta, including the Padma sub-basin, and about 15 m in dry months, the average ranging from 1.5 to 3 m. Total quantity of ground-water reserve in Bangladesh is not known.

The north Indian Gangetic plain above Haridwar is composed of largely older alluvial high land (*banjar* in local parlance), through which the river carved out its valley between 15 and 30 m below the land surface. Its entire middle course, of about 1,500 km, from Haridwar to Farakka is through an extensive flood-prone valley, about 10 km wide, on either flank. The course is yearly visited by floods which deposit sand and clay of varying thickness. Much of the flood-plain is marshy and stretched on extinct river channels. The courses often change with either braided or meandering reaches. The bed is 1 km or more in width but much less above Haridwar. In the Himalayan part of the river, average elevation between the source and Haridwar where the Ganga descends on the plain is 13 m/km, whereas, down below on the plains in eastern Uttar Pradesh it is hardly 40 cm/km. This is even less in Farakka and Nabadweep, about 5 cm/km. The longitudinal section of the river is shown in Fig. 4.2.

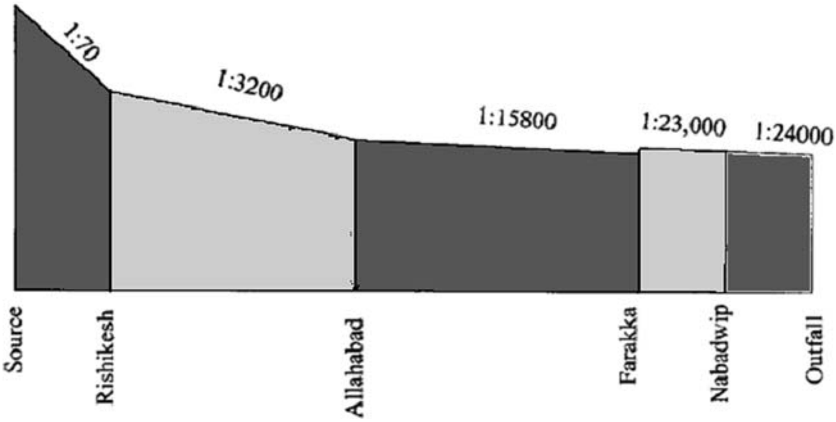

Fig. 4.2 Average bed slope of river Ganga along Bhagirathi-Hoogly

Apart from too sudden change in the longitudinal slope which affected the character and formation of the alluvial plain, the Ganga is also noted for enormous fluctuations of its flow. It drains a catchment of about 32,300 km^2 at Haridwar with total yearly run-off of 21,400 million cubic metres. Of this, the total monsoon discharge from June to September is about 16,000 cubic metres, i.e., 75%. The residual discharge of 5,400 m^3 is spread over other 8 months, from October to May, as shown in Table 4.3.

The average discharge in the Ganga at Haridwar in monsoon months is about 1,500 m^3/s; it falls below 200 m^3 in winter. The normal flood discharge goes above 5,860 m^3/s, almost every year. Further down, at Garh Mukteswar, the normal flood discharge is about 8,500 m^3/s owing to additional flows from some small tributaries.

The monsoon discharge goes up, further downstream. At Allahabad, before the Ganga meets Yamuna, its yearly run-off is about 59,000 million (59 billion) cubic metres; at this confluence, the Yamuna's run-off is much more than the Ganga's, about 93,000 million (93 billion) cubic metres. With more discharges from minor tributaries from both sides, the average annual run-offs at Patna and Farakka are of the order of 364,000 million (364 billion) and 459,000 million (459 billion) cubic

Table 4.3 Flow of water in the Ganga at hardwar (S. P. Das Gupta, 1975)

Period (season)	Run-off (Million m^3)	Flow (%)	Discharge (m^3/s)
June–September (monsoon)	15,952	75	1,523
October–December (Post-monsoon)	2,447	11	308
January–March (Winter)	1,507	7	194
April–May (summer)	1,487	7	282
Total	21,393	100	678

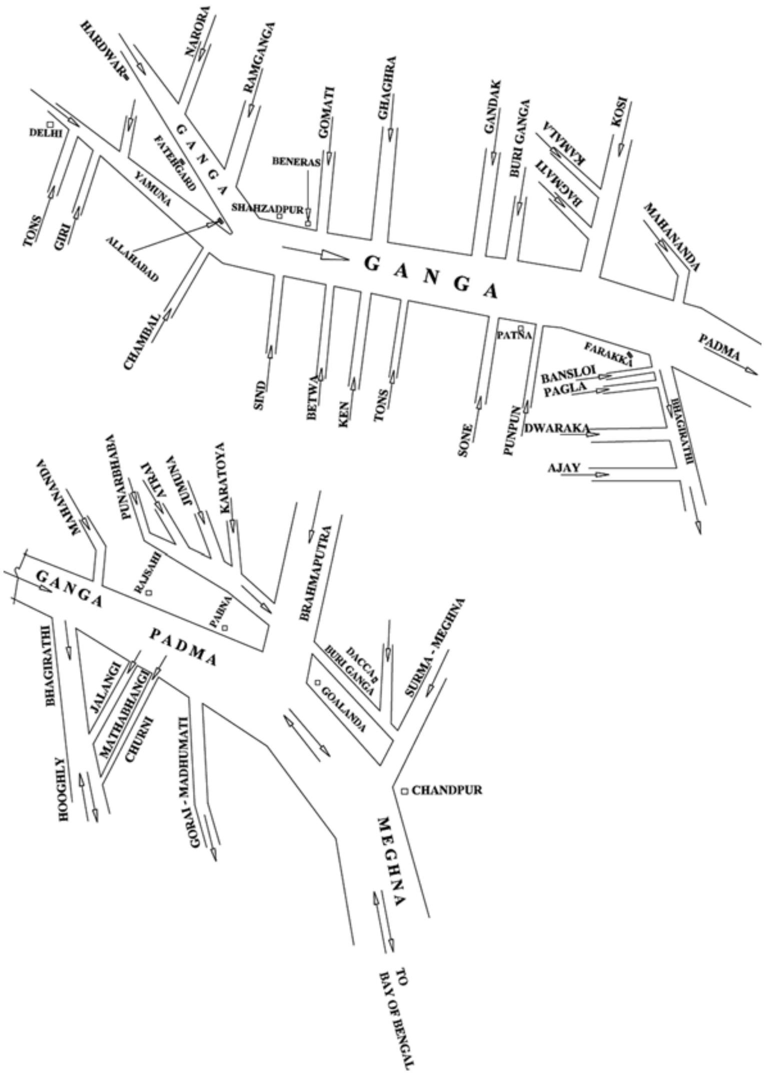

Fig. 4.3 Schematic line diagram showing the river Ganga-Padma-Meghna system and major tributaries and branches

metres, respectively. A schematic flow diagram of the Ganga and its tributaries is given in Fig. 4.3.

Enormous variation in the flow of the Ganga, augmented by inflows from the Himalayan and peninsular tributaries in monsoon months causes over-flooding of high banks on both sides and severe drainage congestion, resulting in flooding of land on both sides. The average yearly flows of the Ganga and its tributaries are given in Table 4.4.

Table 4.4 Average annual flow in the Ganga and its tributaries (K. L. Rao, 1975)

Sl. No.	Location along the Ganga	Name of tributary	Run-off in tributary (million m^3)	Run-off in Ganga (million m^3)
1	2	3	4	5
1	Hardwar	–	–	21,400
2	Allahabad	Yamuna	93,000	59,000
		a) Chambal	(30,000)	
		b) Ramganga	(15,300)	
3	Allahabad after confluence with Yamuna	–	–	152,000
4	Patna	–	–	364,000
		c) Tons	(5,900)	
		d) Sone and	(31,800)	
		others	(7,400)	
		e) Gomti	(94,400)	
		f) Ghagra	(52,200)	
		g) Gandak		
5	Farakka	h) Buri Gandak	–	459,000
		i) Kosi	(7,100)	
			(61,600)	
6	Haldia below the confluence of Haldi river	–	–	493,400
		j) Dwaraka	(4,700)	
		k) Ajay	(3,200)	
		l) Damodar	(12,200)	
		m) Rupnarayan	(4,400)	
		n) Haldi	(5,300)	

The intensity of maximum discharge in the Ganga rises, as it flows downstream, in keeping with the inflows of tributaries in different places, as shown in Table 4.5.

Before the Ganga bifurcates near Jangipur, south of Farakka, it is fed abundantly by all major tributaries, making the total flow and peak discharge quite high at Farakka, even though the yearly distribution is erratic and not uniform. The total flow from January to June is only 10% of the total in a year. From July to October, the flow is more than 85% of the annual discharge at Farakka. The peak flow in 21 years, from 1975 to 1995, was 539,835 million (539.835 billion) cubic metres, occurred in 1978. The total flow and the peak discharge at Farakka from 1975 to 1995 are shown in Table 4.6; this will be discussed later.

The schematic line diagram of the Bhagirathi-Hooghly with their tributaries is shown in Fig. 4.4.

The Bhagirathi-Hooghly drew less and less water from the parent river, the Ganga which was gradually decreasing from the 16th century, owing to aggradation of its bed and mouth by silt, brought with the flow. Yearwise variations of peak discharge in the river from 1973 at Jangipur, Berhampur and Purbasthali at 10, 80 and 220 km from the offtake point at Biswanathpur is shown in Table 4.7.

Table 4.5 Peak discharge observed at different places

State	Place	Peak discharge observed (m^3/s)
Uttar Pradesh	Garhmukteswar	6,940(1978)
	Kachla Bridge	9,554(1978)
	Kanpur	14,071(1961)
	Allahabad	58,377(1971)
	Varanasi	46,186(1971)
Bihar	Boxer	43,084(1969)
	Patna	65,849(1978)
	Hatidah	73,530(1969)
	Azamabad	83,047(1971)
West Bengal	Farakka	73,054(1980)
	Berhampur	3,862(1971)
	Purbasthali	4,409(1971)
	Kalna (Ebb)	6,908(1971)
	Kalna (Flood)	7,700(1978)

Table 4.6 Total flow and peak discharge observed in Ganga

Year	Total flow (Mm^3)	Flow between Jan & June (Mm^3)	Flow between Jul & Dec (Mm^3)	Flow ratio (Col 3:4)	Flow during monsoon months, Jul to Oct (Mm^3)	Peak discharge (Cumec)	Duration above 56,635 cumecs (2,000,000 cusecs) (days)
1	2	3	4	5	6	7	8
1975	426,250	31,010	395,240	1:12.74	329,250	63,300	5
1976	396,300	43,500	352,800	1:8.11	330,220	69,315	13
1977	433,930	36,560	397,370	1:10.87	364,690	57,470	2
1978	539,840	49,300	490,540	1:9.95	458,700	70,230	28
1979	256,620	42,330	214,290	1:5.06	197,740	42,770	–
1980	486,370	32,500	453,870	1:13.97	428,560	73,050	30
1981	390,250	37,380	352,870	1:9.44	329,440	57,030	2
1982	375,710	46,300	329,410	1:16.56	305,180	68,060	12
1983	373,280	33,020	340,270	1:10.31	308,060	60,480	4
1984	400,510	61,380	339,130	1:5.33	314,910	61,420	7
1985	448,470	32,270	416,200	1:12.90	365,890	57,315	2
1986	375,080	40,360	334,720	1:8.29	308,490	49,810	–
1987	398,140	35,580	362,560	1:10.15	335,140	73,925	7
1988	402,580	35,740	366,840	1:10.26	343,040	67,970	20
1989	343,750	45,200	298,550	1:6.60	275,420	36,760	–
1990	435,980	40,110	395,870	1:9.87	366,930	55,420	–
1991	370,110	43,960	326,150	1:7.42	306,090	69,730	13
1992	248,240	28,780	219,460	1:7.63	199,260	46,360	–
1993	340,660	28,670	311,990	1:10.88	279,480	54,230	–
1994	389,960	33,780	356,180	1:10.54	332,820	67,915	5
1995	363,550	43,370	320,180	1:7.38	290,730	49,800	–

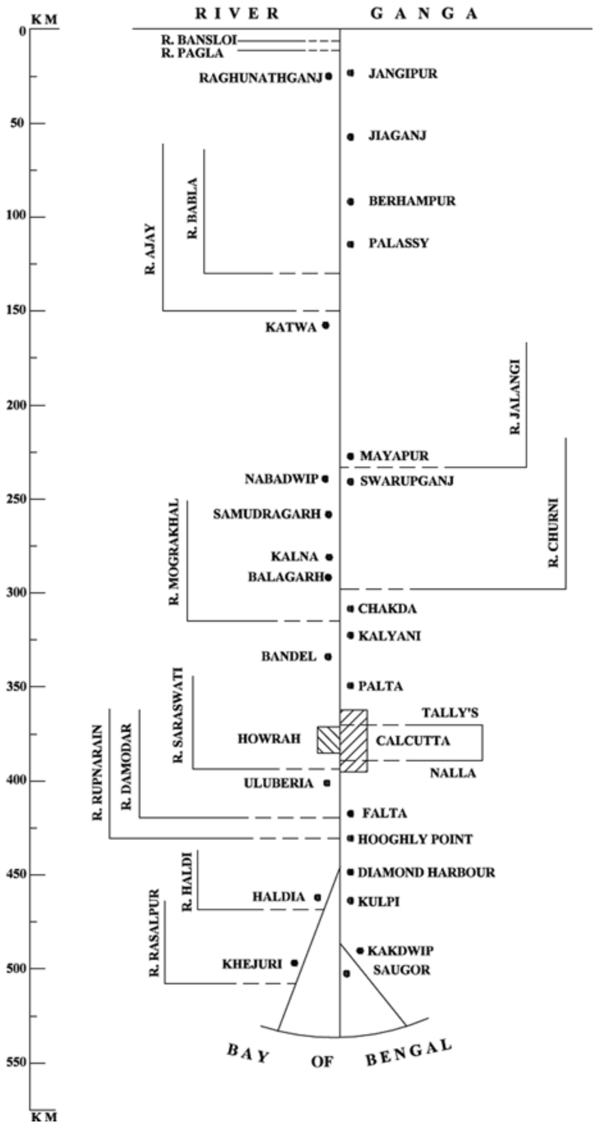

Fig. 4.4 River Bhagirathi-Hooghly and its tributries (*line diagram*)

The tidal range at the confluence near Sagar Island is one of the highest in the world, next only to the Amazon in Brazil, the Irrawaddy in Myanmar and the Meghna in Bangladesh. This goes up further in the hinterland of the estuary up to Diamond Harbour and gradually goes down up to Nabadweep. The initial increase from Sagar to Diamond Harbour is due mainly to the funnel-shape of the estuary which gradually narrows under the influence of the upland discharge. The range of

Table 4.7 Yearwise variation of peak discharge in the Bhagirathi

	Jangipur		Berhampore		Purbasthali	
Year	W. L. (m)	Discharge (cumec)	W. L.(m)	Discharge (cumec)	W. L.(m)	Discharge (cumec)
1	2	3	4	5	6	7
1973	21.30	1,669	18.45	1,785	8.35	2,795
1974	21.18	1,558	NA	NA	NA	NA
1975	19.35	1,249	16.02	1,175	8.25	2,718
1976	20.02	1,362	16.45	1,348	7.92	2,433
1977	19.95	1,327	16.50	1,358	8.40	2,766
1978	19.56	1,337	19.55	2,257	8.30	2,734
1979	20.65	1,438	16.65	1,387	6.90	1,736
1980	20.14	1,381	17.85	1,696	8.65	3,044
1981	20.10	1,368	17.60	1,650	8.50	2,861
1982	19.96	1,317	17.40	1,576	7.15	2,280
1983	19.94	1,317	17.25	1,562	9.10	3,311
1984	19.91	1,315	17.30	1,563	9.68	4,057
1985	19.98	1,329	16.40	1,333	8.35	2,733

Table 4.8 Tidal range (m) in Hooghly estuary (1986)

Month	Samudragarh	Garden reach	Diamond harbour	Haldia	Saugar
1	2	3	4	5	6
January	0.16	3.88	5.30	4.89	4.24
February	0.26	4.39	5.55	5.41	4.54
March	0.30	4.76	5.75	5.64	5.01
April	0.25	4.77	6.00	5.81	5.17
May	0.34	4.76	5.90	5.86	4.97
June	0.35	4.59	5.55	5.45	4.62
July	0.25	4.77	5.80	5.56	4.53
August	0.26	4.78	6.10	5.82	4.62
September	0.30	4.37	5.60	5.34	4.59
October	0.35	5.12	6.10	5.67	4.95
November	0.32	4.66	6.00	5.56	4.79
December	0.20	4.27	5.30	5.08	4.72

tide at the sea face and its variation at other places of the Hooghly in 1986 appear in Table 4.8.

Considering the hydraulic features, the entire 2,645 km-course of the Ganga can be divided into five major sections, which along with the river slopes in different stretches, are given in Table 4.9

The longitudinal slope of the river-bed corresponding to the length of the Ganga is shown in Fig. 4.2. The upward kink near Farakka, as shown in the figure is due to bed-level difference between the Ganga and the Bhagirathi.

Table 4.9 Average bed slope of the river Ganga

Stretch	Section	Length (Km)	Average bed slope
1	2	3	4
Source to Rishikesh	Mountainous	355	1 in 67
Rishikesh to Allahabad	Upper Plain	800	1 in 3,196
Allahabad to Farakka	Middle Plain	960	1 in 15,795
Farakka to Nabadwip	Deltaic nontidal Plain	230	1 in 23,000
Nabadwip to Outfall	Deltaic tidal Plain	310	1 in 24,000

The gigantic Brahmaputra-Yamuna joins the Ganga further down in Pabna district of Bangladesh; both in length and breadth, the combined river is one of the largest in the world. In rainy season, the width is nowhere less than 3 km; in some places, it even exceeds 6 km. The average rainy season discharge often exceeds 42,476 cumecs, i.e., 1.5 million cusecs, and the peak discharge in some years was over 70,793 cumecs, or 2.5 million cusecs. In discharge, it ranks with the world's seven largest rivers – the Amazon, the Congo, the La Plata, the Yangtze, the Mississippi and the Ganga, The total length of the Tsang po-Brahmaputra-Yamuna is about 2,900 km, draining a total area of about 573,000 km^2. Of this, about 289,000 km^2 area is in Tibet, 238,000 km^2 area is in India and 46,000 km^2 area is in Bangladesh. The drainage area, north of Bahadurabad and Bangladesh is about 530,000 km^2. The highest recorded peak discharge was 71,331 cumecs (2,519,000 cusecs) at Bahadurabad.

Further down, the Meghna joins the Ganga-Brahmaputra and the combined channel flows into the Bay of Bengal as Meghna. It alone has a peak discharge of about 12,200 cumecs and average of about 7,000 cumecs. It originates in the Barak Valley in Assam and enters Bangladesh near Sylhet town. The confluence of the Ganga-Brahmaputra-Meghna is more than 11 km wide in rainy months, making it again one of the largest rivers of the world.

Thus Bangladesh receives a vast quantity of water, round the year, from the three separate streams, estimated at 1.096 million cubic metre on an average in a year. If the total rainfall, estimated at 0.25 million cubic metre is added, a mind-boggling 1.346 million cubic metre of water flow through Bangladesh. A part of this huge water percolates under ground but the rest flows to the sea. This vast flow is second only to that of the Amazon and the total yearly volume of flow of the Padma-Meghna makes it the second largest river in the world. However, owing to large seasonal fluctuations in the flow, correlating with the quantum of rainfall in the Himalayan region in India, Nepal and Bhutan, the flow in August is almost seven times of that in February. The average monthly flow in these three rivers through Bangladesh is shown in Table 4.10.

It may be noted that the Brahmaputra gains the discharge from April, whereas the Ganga gains it from July, i.e., nearly 3 months afterward, each year. Moreover, high discharge prevails in the Brahmaputra for about seven months, from April to October but peaking in July and August. In the Ganga, high discharge obtains for

Table 4.10 Average monthly peak flow through river systems in Bangladesh (Mm^3)

Month	Ganges (Sara bridge)	Brahmaputra (Bahadurabad)	Meghna (BhairabBazar)	Total
1	2	3	4	5
January	8,300	13,900	1,600	23,800
February	6,600	10,400	1,200	18,200
March	6,200	12,600	1,700	20,500
April	5,300	17,700	2,400	25,400
May	5,300	42,400	5,200	52,900
June	11,200	84,200	9,900	105,300
July	47,900	118,000	20,900	186,800
August	100,500	120,800	22,200	243,500
September	95,800	94,100	21,300	211,200
October	47,200	58,800	16,700	122,700
November	18,400	27,200	8,000	53,600
December	11,200	18,000	2,700	31,900
Total	363,900	618,100	113,800	1,095,800

4 months, from July to October, peaking in August and September. Thus, plenty of water is available in Bangladesh for at least seven months in a year, as against for 4 months in India. In fact, out of the total area of about 141,000 km^2 of Bangladesh, some 9,000 km^2, i.e., about 6.50% covers water; this is one of the highest in the world. Compared to this, about one percent area of India, i.e., about 33,000 km^2 covers water.

Chapter 5
The *Ganga* Morphology

The Himalayan ranges from where the Ganga and its northern tributaries originate, are still young and friable. Frequency of earthquakes owing to tectonic changes in the region and heavy rains in the catchments owing to elevation, spread and direction of the ranges obstructing the monsoon wind, cause frequent landslides and erode the soil. Variations of extreme temperature and the friable nature of the rocks enhance silt deposits. All these lead to high silt charge in the Ganga and its northern tributaries. As against this, non-Himalayan rivers, flowing south of the Ganga sub-basin originate at much lower heights and in lower rainfall zones. They drain the regions which are geologically more stable and carry much less silt and therefore, have a more stable course than the Himalayan rivers.

As stated, the Ganga takes its name not from the origin in Gomukh in the Himalayas but from Devaprayag where the Alakananda and the Bhagirathi join. Its source is at an elevation of 7,010 m, from where it flows nearly 280 km before descending on the plains at Rishikesh. Haridwar is 30 km downstream, from where it flows southward over a wide bed of boulders, with its volume of water much diminished when it enters the Upper Ganga Canal at Mayapur on the right bank in Saharanpur district. Southward, its bed becomes sandy, depositing alluvium on the banks. The Ganga flows shallow and unfit for navigation until it reaches Nangal in Bijnor district of UP, from where it takes a wide sweep first southwest and then straight south from Balawali rail bridge. Field observations revealed that the river's course in this zone shifted westward for about 1½ km from its former course. For several kilometres beyond Daranagar village, the Ganga flows almost straight south; presently, it is moving eastward from the village, severely eroding the right bank (Fig. 5.1).

The river's morphology in this area is determined by the fluvial dynamics which sends a large volume of eroded material from the Himalayas to the flood plains. The deposits are generally made of fine sand, silt and clay. The braided pattern which starts right from Haridwar, is formed by alluvial deposits. Though braiding is the main feature in this zone, meanders also develop extensively along the course. Owing to braiding and meandering, the river's course oscillates from northwest to southeast and return with the alternate growth of alluvial fans in the river-bed. This oscillating course gives rise terraces, marshes, point-bar deposits too. The National Atlas Organisation reported in 1975 that from comparative study of aerial

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
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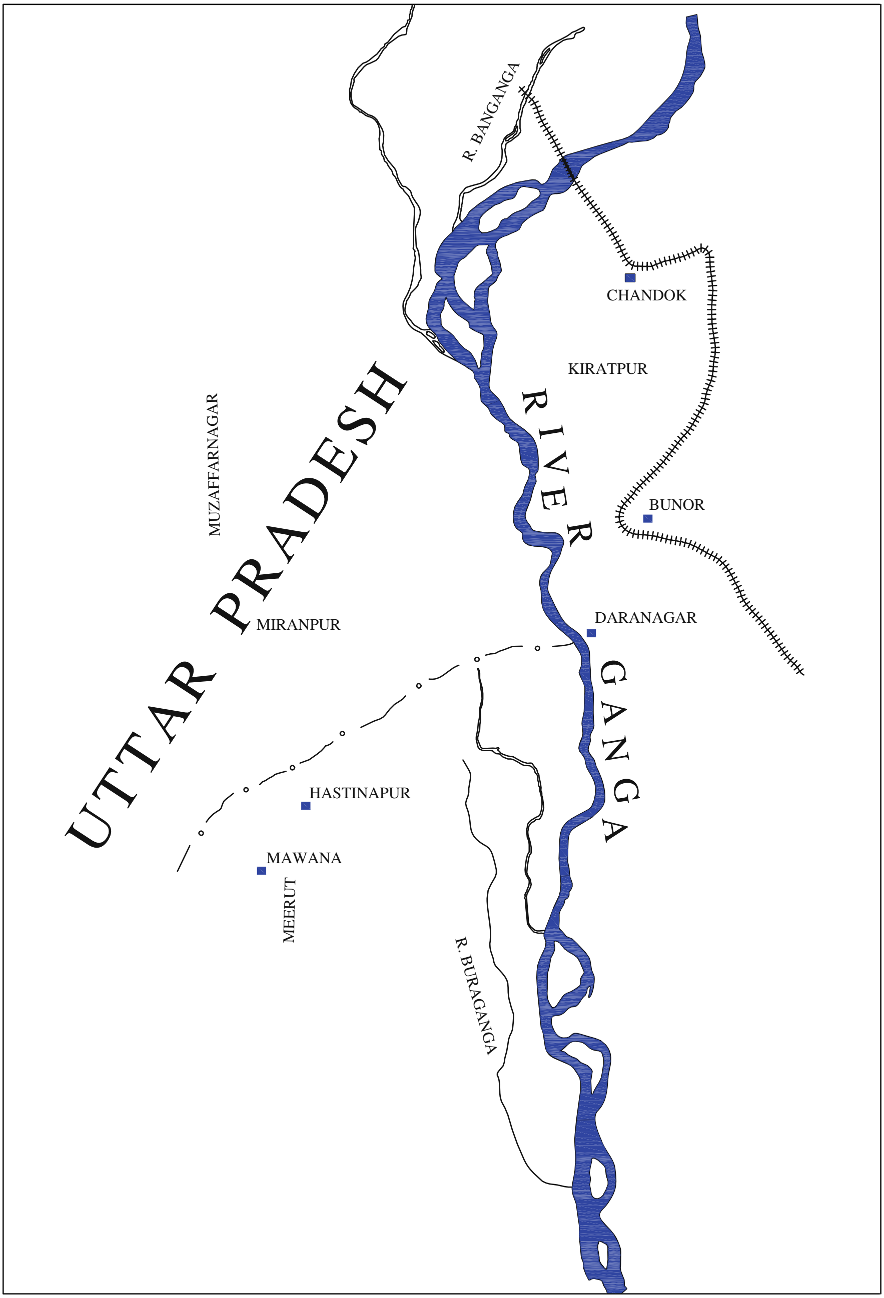


Fig. 5.1 Ganga in Uttar Pradesh

photography, taken in 1964 and the topographical map of the area surveyed in 1914, three positions of the Ganga were revealed in 50 years. The topographic survey indicated that the river shifted by about 6 km west of the previous course, which is now a deserted channel close to Bijnor terraces on the east. Aerial photographs in 1964 showed that the river had shifted further east by about 1 km from its course in 1914. The width of the flood-plain varies from 6 to 13 km in the north. Diversions in the course took place within this broad flood-plain. The last significant change in the main stream occurred after the 1953 flood, when it moved by some 2 km to the west to Shukartar, touching Hastinapur. Nowhere else the Ganga is so close to Hastinapur belt.

Alluvial terraces usually result from rejuvenation of a stream and consequent formation of steep-sided and flat surfaces above the bed. It may be brought about by increased gradient, either by tilting, or by increase in volume of water, or by decrease in silt-load. In this zone, the Ganga underwent several phases of change, filling its bed with sand-bars and islands, grown over with natural vegetation; this slowly diminished its discharging capacity. This may cause another diversion in near future, because if the Ganga cannot move further eastward, it is likely to move west, which seems to have already started. Its entire flood-plain belt is marked by low and elongated alluvial platforms, 2–6 m high, from the bed in dry season. Such platforms are typical alluvial terraces, made of sediments suspended in water after the flood recedes and deposits as levees on both banks, or as sand-bars in the river-bed. Eventually, these levees and bars rise above normal flood-limit and form flood-plain terraces which, in course of time, receive alluvium deposits, particularly during exceptional high floods.

The upper Ganga flood-plain is an elongated fluvial tract, stretching along both banks. Unlike adjoining old alluvium, the flood-plain has a more varied physical history and a different mode of human leaving. The Ganga's oscillating nature and its frequent high floods have lent dynamism to the natural and cultural landscape of the tract. The present form and trend of its regime are only a stage in its long and chequered history. The Burhiganga (literally,'Old Ganga') falls into it in numerous channels. The Ganga's recession was noticed by Taimur Long who invaded the region in 1398–1399 AD and mentioned in his mempor. Now a chain of swamps, the Burhiganga entered Meerut district of Uttar Pradesh from Muzaffarnagar, near Firozpur village and flowed southward to Garh Mukteswar where it joined the Ganga. According to the Mahabharata, Hastinapur, the capital of Kauravas, stood on the bank of the Ganga but no trace of it is seen now. It might have been washed away by the river in the beginning of the Kali Yuga (a Hindu Puranic aeon, corresponding to the Iron Age) over 3000 years ago, i.e., around 1000 BC. Taimur in his memoir mentioned Firozpur town as being on the right bank of the Ganga. Firozpur village near Ramraj on the right bank of the Burhiganga corresponds with Timur's Firozpur. If it is true, eastward recession of the Ganga from its old bed took place by about 10 km after 1400 AD. Over the ages, its course oscillated along the Burhiganga axis till about 1400 AD, after which it began to move eastward to its present course, past Daranagar village.

Floods are regular occurrence in this region, which peak in July and August but they do not make news, because other areas in the Ganga's flood-plain are affected simultaneously. Human habitation on this flood-plain, particularly in response to the hazard, has a lot in common with other parts of the country. Historically, the Gangetic plain has been a marginal preference for permanent human habitation. It was only a century ago that human habitation began in the flood-prone plains of the Ganga basin, which intensified after the Partition of the sub-continent in 1947 when hordes of displaced people migrated from Sind and western Punjab in Pakistan and settled in this region. The less densely populated flood-plains provided new sites for rehabilitation. Despite lack of experience in tackling occasional floods, the immigrants availed credit offered by the government and used modern techniques of farming commercial crops like sugarcane and wheat. The government gave land too to the refugees and helped them settle in unfamiliar and mostly flood-prone low land. For instance, the new Hastinapur town came up in this manner. The flood-plain hummed with noise of tractors, tilling the virgin land and new villages and growth centres emerged. Small-scale industries, like sugar and flour mills and petty engineering workshops also came up.

Thus in the upper catchment areas of the Ganga in parts of Uttarkashi, Chamoli, Pauri, Tehri, Dehradun and Almorah districts, many braided and meandering streams with swinging courses flowed into the Ganga. Soil erosion and gully formations took place in steep slopes. Deforestation and faulty farming caused frequent landslides. Mass rehabilitation encroached on the flood-basin and farming activities enhanced the silt-load, besides eroding banks, which in turn accelerated morphological changes in the river. The discharge suddenly increased below the confluence with Yamuna at Allahabad and caused more flood. Spills during high floods damaged the river and erosion increased near Varanasi, Balia, Mirzapur and Gaighat. Braiding and meandering also continued with the formation of alluvial fans, point-bars, swamps and marshy land, following deposition of alluvium, varying the river-width on the flood-plain from 5 to 15 km.

The Ganga enters Bihar near Buxar and after flowing about 450 km enters West Bengal near Maniharighat. On this long stretch, it also meandered and braided and the width on the flood-plain (*khadir*, in local parlance) goes up to about 15 km. Below Mokameh, it swung south from 1957 and eroded the south bank. Further down of Surajgarh, the river swung between Mungher and Mansi; it flowed in the vicinity of the former in 1936 but gradually moved north. By 1963, it eroded banks very fast, threatening the rail-line near Mansi. The peak discharge at Mokamah in 1969 was of the order of 73,620 cumecs. Spurs were put to shift the river southward and occupy the course it did in before 1936. Major sub-Himalayan tributaries, like Ghagra, Gandak and Kosi also brought huge quantities of silt, which changed braiding and meandering of the Ganga. It was observed that when the river went into high spate, the discharges from the tributaries were blocked, flooding the sub-basins and confluence points. This worsened when there was flood in the river and its tributaries, simultaneously (Fig. 5.2).

The Ganga's bank erosion in Bihar was primarily due to changes in the meandering courses. The stretch from Mokamah to Rajmahal was very badly erosive.

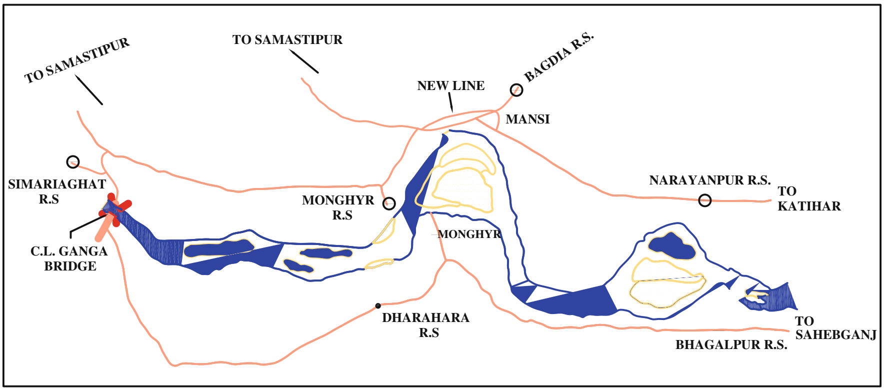


Fig. 5.2 Index plan showing Ganga river near Mansi railway station

Between Maniharighat and Rajmahal, the right bank is restricted by Rajmahal hill outcrops; the flood-plain spreads only on the left. The river swung southeast from near Rajmahal up to the confluence of Mora Kosi (dead Kosi) which joins the Fulahar near Bhutni Diara island in West Bengal on the left. It flows almost straight up to the confluence of the Fulahar, just below the island. Further down, it swung left at Manikchak in Maldah district of West Bengal and heavily eroded the left bank. Braiding and meandering continued and formed alluvial fans on the right. At some places, it has been bifurcated by point-bars in mid-stream, severely eroding the left bank. Erosion continued for about 35 km, from Manikchak to Farakka on the left, creating alluvial fans by soft deposits. Though the deep channel swings within the dominant waterway in the stretch, it is mostly located on the left side of the river and at some places, very close to the left bank which accelerates erosion. Alluvial fans continue on the right up to Farakka while the deep channel hugs the left bank (Fig. 5.3).

Human interference in any river, like navigation, transportation, irrigation, power generation, drinking water availability etc. has been the same in the Ganga too. The most important interference has been made at Farakka in West Bengal, where a barrage has been constructed mainly to partly divert its water to the Bhagirathi-Hooghly to rejuvenate it. Its benefits are being availed not only by India but by two Himalayan countries too – Nepal and Bhutan – but it has affected the morphology of the river, both up and down stream. It is very difficult for an alluvial river to remain both dynamic and stable and maintain its equilibrium in geological time. Such a stream retains this state if its discharge, sediment-load, size and bed slope are balanced. A change in any of these, or construction of a structure along, or across, is likely to disturb this equilibrium and aggrade, degrade or change its course. This continues for a long time till a new equilibrium is established. This is very important from engineering point of view too, as they both occupy considerable space and time. Owing to excessive aggradation, i.e., rise in the river-bed, the flood-level increases but the capacity of the channel decreases. Because of the latter, the channel

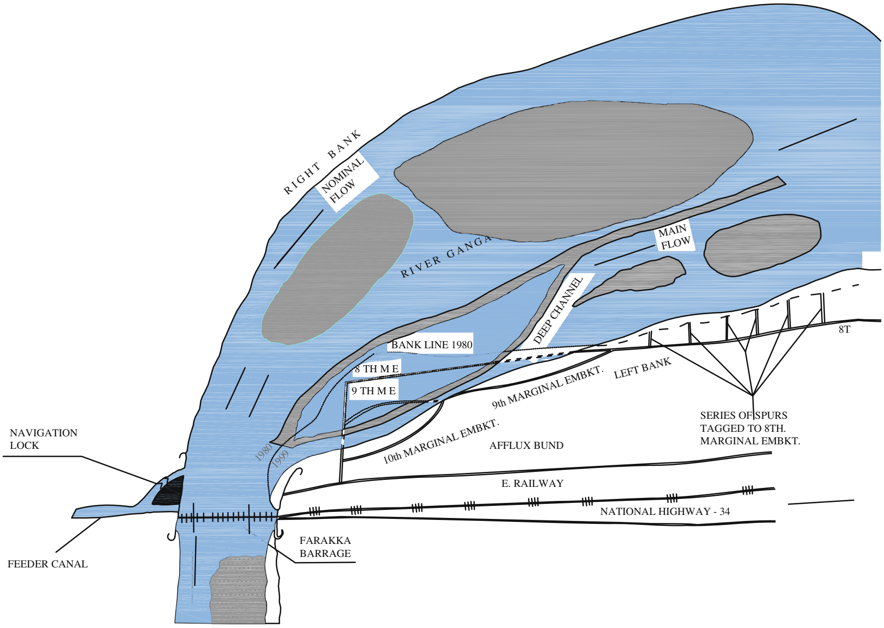


Fig. 5.3 River Ganga upstream of Farakka Barrage

cannot carry the required discharge in the present form and even at lower discharges causes flood. Otherwise, the channel will try to adjust its capacity by eroding the bed and the bank, if the materials are of friable nature. In an alluvial stream, the bed and the banks are normally made of materials which once got deposited during the change of courses, easing adjustment of their capacity. If the bed goes excessive low, it endangers structures on the bank, energy dissipation devices are affected and protection works and cut-offs downstream are disturbed, or damaged. Because of reduced depth of tail-water, the surrounding ground-water table also goes down which affects irrigation and drinking water supply downstream. However, aggradations and degradation give certain benefits too. The former raises the ground-water level which facilitates irrigation, drinking water-supply and navigation while the latter reduces flood hazard but their ill effects are severer than benefits. In both the cases erosion of bed and bank at some locations increase owing to reduced bed-gradient, inviting more concentration of the flowing water. A study of the Ganga's course revealed that it tends to both aggrade and degrade at many places.

The interference of the Ganga's regime by construction of the Farakka Barrage gave rise these problems and disadvantages. Changes in the water-level, discharge, sediment movement, bed-slope etc. caused aggradations and degradation of the bed and the entire reach from Rajmahal to Farakka in upstream and from Farakka to quite a distance downstream. Alluvial fans formed on the right side and the deep channel shifted to the left above the barrage. Bank erosion got worse, forming mobile and gradually-shifting point-bars at many places, mid-stream. The swinging river changed the channel by braiding and meandering, alternatively. One such point-bar developed upstream of the barrage on the right and is increasing in length, breadth and depth. This extension upstream is engulfing the mouth of the Feeder Canal at the Lock Channel entrance and causing the right channel shrink and stagnate as well as to erode the bank on the left. The growth of this bar left many long-term adverse effects and if unchecked along with other ill effects upstream of the barrage, may jeopardise its basic purpose. The morphological changes will continue to occur until the river adjusts to the changed conditions.

Downstream, on the left, there was a big alluvial fan which, moving up gradually before the construction of the Farakka Barrage, resulting flow concentration on the right and with the deep channel passing close to the right bank, eroded it. The fan extended up to about 30 km below Farakka; old Dhulian and Aurangabad towns on the right were also severely eroded. Moreover, the entire area was affected by occasional floods in monsoon months. After the barrage came up, the river-bed was degraded considerably and flood hazards reduced. The advance of the alluvial fan toward the barrage stopped. The left-side stream which existed before the barrage silted, leaving no trace of the channel. The fan is shrinking because of erosion of its right face, though reduced, following controlled discharge through the barrage, erosion has not stopped altogether and encroached land, necessitating very costly protective measures (Fig. 5.4).

Below Aurangabad – 20 km downstream – the river has two distinct channels, separated by a big point-bar, i.e., *char* land. Discharge through the right channel has reduced, giving more water way to the left which is very near Bangladesh border. There is very little habitation in the flood-plain, called *khadir*, in local parlance. The channel in the entire reach up to Jangipur, some 30 km, is mostly braided because of local meander zones up to the Bhagirathi off-take. The point-bars and alluvial fans are low and criss-crossed by channels which are all over-flooded in monsoon months. Erosion continues on both sides but as the left side is mostly *khadir* land and has little habitation, there is no hue and cry over this. The right bank which is thickly populated faced severe erosion in the 1970s, which afterward could be checked by protective measures (Fig. 5.5).

Below the off-take, the Bhagirathi flows for another 20 km into Indian territory and then along the border between the two countries for another 50 km or so. Here also, the river is predominantly braided with alluvial fans on the left and has low point-bars, intercepted by shallow channels owing to alluvium deposits. There were severe erosion on the right bank in the 1970s and 1980s; the right channel encroached on farm land and villages nearby. The erosion was checked for the first 15 km but further down, it is continuing. The most vulnerable reach where erosion is on is Akhriganj in Murshidabad where the densely populated area and the old town are affected occasionally. The left and right side channels have joined here, aggravating the situation. After flowing almost straight up to Lalgola, the river takes a left turn first and then a right turn above Akhriganj. The pattern changes from braided to meander before finally entering Bangladesh.

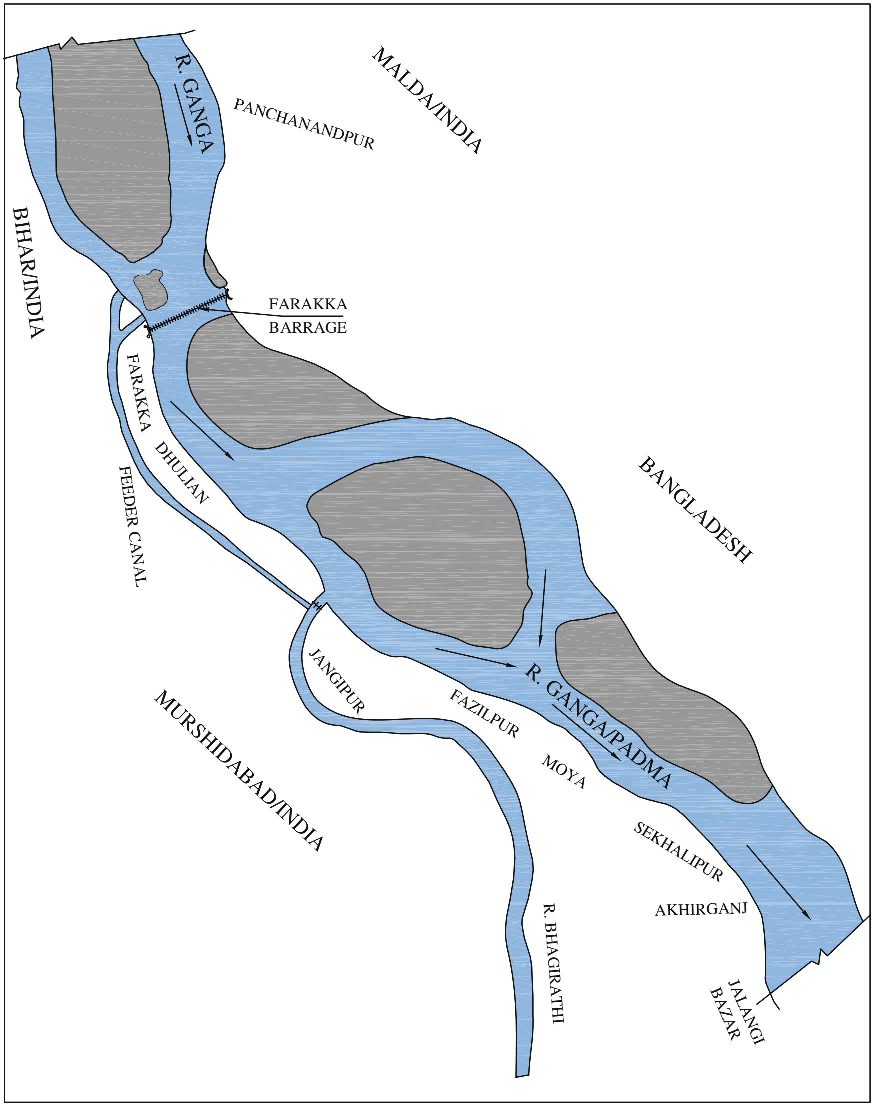


Fig. 5.4 Ganga/Padma river downstream of Farakka Barrage

The flow through the Bhagirathi is unidirectional toward the Hooghly (below Nabadweep) and the water-level rises between July and October but falls in the dry season from November to June. In its 230-km length, the Bhagirathi is fed by a number of major and minor tributaries from both sides – the major being the Bansloi, the Pagla, the Babla, and the Ajay on the right and the Jalangi on the left. All these except the Jalangi are ephemeral and bring sediment in monsoon season only. Before construction of the Farakka Barrage, the flow in the Bhagirathi was

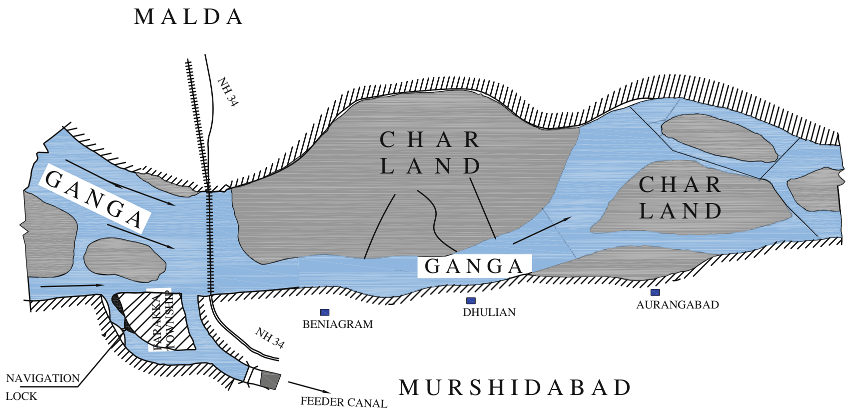


Fig. 5.5 River Ganga downstream of Farakka

very irregular; it used to be quite high in August and September but nominal, or nil, during rest of the year.

The Hooghly's flow is oscillating; the water-level fluctuates twice a day, owing to the tides and changes its hydro-morphology. Its estuary below Diamond Harbour being funnel-shaped, it restricts the optimum tidal influx which primarily governs the channel regime and its navigability. Before induction of the upland discharge from Farakka, the flow pushed the sand further up and made the river shallower. The induction of upland flow has reduced the sand movement considerably, degrading the river-bed.

In the pre-Farakka era, before the induction of upland discharge, the Bhagirathi-Hooghly reached a moribund state in its upper reach and a mature state in the middle reach from Nabadweep to Kolkata. However, the lower reach, south of Kolkata, remained active under tidal influence. Its cubic capacity decreased owing to deposition of silt and sand at the mouth and bed. After a barrage came up at Farakka, a discharge of 1,132 cumecs, or 40,000 cusecs, flows into the river in most part of the year, restrictions are imposed for the dry season, i.e., from January to May, when the discharge through the Feeder Canal reduced considerably, substantially improving the overall performance of the river. The bed started degrading and channel parameters, like width, hydraulic mean depth, cross-sectional area and the cubic capacity of the river increased. The moribund stage of the pre-Farakka condition gave way to the active stage in post-Farakka period.

An analysis of the channel pattern shows numerous meander stretches, separated by braids and also straight reaches at some places. There are four prominent braided reaches in the entire 450 km course of the river from Jangipur to Diamond Harbour, namely, the outfall to Raghunathpur (3 km), Chowrigachha to Suti (3 km), Katwa to Baladanga (12 km) and Zirat to Bansberia (3 km) – all north of Kolkata. In three braided reaches, the course is divided by the point-bars in mid-stream. There are many channels in Katwa-Baladanga reach where point-bars are intercepted by cross-channels. The river has a number of apparently straight reaches, uniting either a braided or a meander reach at the ends. Though these reaches have straight channels between high banks, especially at bankful stages, the thalweg of the reaches are actually wandering between the banks. The total length of the straight reaches may be about 140 km. Three major and lengthy reaches are from Murshidabad to Sonagai in the Bhagirathi and from Serampore to Garden Reach and Hooghly Point to Diamond Harbour in the Hooghly river.

An important feature of straight reaches is that the river is confined to the high banks in the same width and depth over a long period, while in braided reaches the parameters changed widely in different years. Unlike in braided reaches, the deposits on the bank are mostly of clay and silty clay in straight reaches, in which many alluvial fans form on both sides. Erosion of banks in these reaches is also less and spill-over in monsoon months are not common in straight reaches as in braided or meander reaches of the Bhagirathi-Hooghly. Meander reaches abound in the river, running to about 290 km. The bed-slope of these reaches is generally less than those of braided or straight reaches, adjoining them. Extensive erosion occurs in meander reaches as the banks are mostly made of silty fine sand, silty clay or clayey silt deposits. In many of such reaches, their length is much less than that of the straight length, raising tortuosity ratio. A 1986 survey showed that out of 59 meander loops, the ratio exceeded two in seven cases – six in the Bhagirathi and one in the Hooghly, all forming acute bends. In the Bhagirathi, the loops near Diara Balagachhi and Char-Chakundi in Murshidabad and near Purbasthali in Burdwan have very high tortuosity ratio – from four to five; in these two ends of the loops they try to join, forming cut-offs. In fact, two cut-offs occurred – one in Baidyanathpur in Murshidabad, at about 95 km downstream in 1984 and the other in Purbasthali at about 210 km downstream of the Bhagirathi off-take in 1990. The tortuosity ratio in both exceeded four, but in some places in spite of that there has not been any cut-off, owing perhaps to more erosive resistance of the bank materials.

The 1986 survey maps of the Bhagirathi-Hooghly showed that about 73% of the Bhagirathi's total length is meandering, 19% straight and 8% braided. The Hooghly meanders for about 56% of its length; it flows straight for about 43% and braids for only 1%. Of the total length, the joint river meanders for 64%, goes straight for about 31% and braids for only 5%. Thus, over all, the Bhagirathi-Hooghly is predominantly a meandering river.

Bank Erosion and Flood Control

Floods in the Ganga in Uttar Pradesh occur in areas below its confluence with the Yamuna at Allahabad. Downstream, its spills cause considerable damage during high floods. In Bihar, where high flood synchronises with high discharges of its tributaries, the river mouths are blocked by very high water-levels, causing widespread flood in the sub-basins. The main Ganga from Rajmahal to Lalgolaghat goes into occasional spates in vast areas, due mainly to drainage congestion and flood occurring at the same time in the Ganga and its tributaries like the Ghagra, the Gandak, the Kosi and the Mahananda, in which it is very severe. The September

1995 in Malda and West Dinajpur districts of West Bengal owing to flood-locking in the Mahananda after heavy and widespread rainfall caused heavy damages. The Yamuna, the Ganga's major right-bank tributary, threatened capital Delhi and inundated large areas in Haryana and Uttar Pradesh. Among right-bank tributaries, the rivers in the lowermost reaches, e.g., Mayurakshi, the Ajay and the Damodar inundate and cause acute drainage congestion. Called 'the Sorrow of Bengal' before a number of dams and reservoirs were built on it and its tributaries the Damodar used to flood south Bengal almost every year in the 1940s and 1950s; the Kangsavati, the Rupnarayan and the Haldi did the same, simultaneously.

The important among flood-control measures, taken in the Ganga sub-basin, include dams and storage reservoirs, barrages and marginal embankments, or flood-levees, as they are called. While the reservoirs are many, embankments running to over 5,000 km have been constructed along the banks of the Ganga and its tributaries. These are not very high and were built above the levels of dominant discharge of the rivers, leaving a sufficient margin beyond the water-edge. Embankments normally prevent high floods in the basin; some of these have falling aprons and protective slopes to control erosion and rotational slips during rains. Roads over these facilitate inspection and public use in monsoon months. Ill effects of jacketing a river by embankments are well-known; they aggrade river-beds, reduce bed-slopes and raising water-level, create further flood hazards.

Sir William Wilcock, a British irrigation engineer, who visited India in 1930, observed that embankments on the deltaic tributaries brought about adverse changes in their condition. He attributed changes in the courses of the Ganga's big torrential tributaries not to natural forces but to jacketing them by embankments. He added that if the spill was not restricted by artificial constructions, it would spread all over the land and leave very little silt on their beds. In such cases, the adjoining land would not rise beyond a foot in 100 years. With this, the river-bed would rise and no river would die. Very often, he said, engineers by obstructing the spread a spill, accelerated silt deposition in its own bed, or on its immediate surrounding and thus killed rivers.

Embankments, or levees, have been constructed on all rivers to control flood since ages, throwing up widely different views on their effect on the stability of rivers. One view is that rivers carrying high silt charge tend to lay their beds after construction of embankments; so they are to be periodically raised to control rising flood-levels. Therefore, they can help prevent floods in regions where the silt charge of the river is not too high, as in the Mahananda, the Godavari and the Krishna but on streams like the Yellow River of China, the Kangsavati in West Bengal, flood embankments have raised river-beds. Their heights are raised from time to time and the process goes on. This is the view of two Indian experts – S. L. Kumar and Kanwar Sain – but another expert, S. V. Chitale held that embankments enhanced a river's sediment-carrying capacity by augmenting discharge and hence did not aggrade it. If they are constructed with wide spacing in between, along an aggrading river, any increase in sediment transportation cannot stop aggradations and bed-levels would continue to rise; this cannot be due to embankments. He also held that tidal rivers have an inherent tendency to aggrade and hence embankments cannot arrest it but here again the rising beds are not due to embankments.

These are the adverse effects, caused by structures along, or across, the rivers – barrages, dams, bridges etc. Generally, upstream of a barrage, a river aggrades and downstream, it degrades but up to some distance, depending on the location of the barrage site. The erosive tendency also changes after a barrage or a bridge comes up. For instance, erosion of the right bank of the Ganga below Mokama developed only after the construction of a bridge near it. The barrage at Farakka did the same and changed the erosive pattern of the banks, both below and above it.

Bank erosion is associated sometimes with floods, particularly in alluvial rivers and in unstable reaches in the sub-mountainous regions. Meandering of the Ganga and of its tributaries changed their courses. When it did, it caused erosion in Uttar Pradesh, Bihar, Jharkhand and West Bengal. It is markedly prominent in the reach below Allahabad, from Mokama to Mansi to Narayanpur, from Manikchak to Farakka to Aurangabad, from Lalgola to Akhriganj, from Purbasthali to Nabadweep, from Howrah to Sankrail and from Diamond Harbour to Kulpi in West Bengal. Erosion is acute in the reach between Mokama and Mansi.

The Ganga has a meandering-cum-braiding pattern in this reach for a length of 85 km in 1780 to 110 km in 1965. The active channel has been swinging over a width of about 15 km, where alternate deep channels and alluvial fans formed. Below Mokama the river swung southward in 1957 and eroded the south bank. Below Surajgarh, it has been swinging between Mungher and Mansi; it flowed near Mungher in 1936 but started moving north and by 1963, eroded the bank near the rail tracks off Mansi station, to as high as 7.6 m, or 25 feet every day in rainy months and threatened roads and rail-lines. The meanders are never static but move downstream and cause cyclic changes once in 70 years or so, here and in other places on the course too. In such a meandering river, efforts to prevent erosion by drastic measures like long spurs obstruct the movement of meanders. The river would either damage the spur heavily, or other repercussions would follow at either above or below the spot which can cause sudden and considerable changes in the course by avulsions and cut-offs. It was, therefore, decided to give local protection by short spurs. A new technique of constructing spurs in large stone crates on the eroded bank was rather successful.

Further below Mansi, up to Narayanpur, severe erosion in 1973 threatened the National Highway No. 3 and the rail-line (see Fig. 5.2) and affected nearby villages. Simultaneously, the right bank also eroded too, below Mokama Bridge, near Berhaiya and engulfed some villages and farmlands. A cut-off occurred in the reach in 1965, reducing the river length from 17 to 9.70 km. In 1975 flood, the left bank from Ganaul to Narayanpur rail station was heavily eroded. It was observed that erosion here was by 119 m in 1962 and 1963. It increased to about 207 m, every year, between 1969 and 1975. Before the 1976 floods, the river's edge was about 750 m from the rail track and despite protective measures, it came closer to the line by about 460 m after the flood. As recommended by the high-level Tripathi Committee (1974) and the Ganga Erosion Committee (1977), spurs, bank revetment, bed bars, tagging embankments etc. were constructed, which checked erosion and diverted the main river to the right.

The left bank between Manikchak and Farakka in Malda district also experiences severe erosion. Before the barrage came up, the river upstream was straight and a big alluvial fan and a *char* land existed at about 20 km above. The downstream *char* land, which is now very near the barrage, was about 5 km away. This is shown in Fig. 5.4.

Survey data of 1939 and topo sheets of 1924 revealed that the river was meandering between Rajmahal and Lalgola. The 35.0 km course between Rajmahal and Farakka had two meander bends – one in its upper half and the other in the lower half, both on the right. The reach between Farakka and Dhulian, some 25 km, had one meander bend, leaving the main channel on the left. Similar alternate meander bends were seen even below Dhulian up to Lalgola and further down. The meandering pattern in 1939 indicated that below Farakka, the river would flow on the left as long as the main channel remained on the right, above Farakka. This was seen to have reversed in 1948–1949 survey maps, i.e., the main channel above Farakka flowed on the left and below it up to Dhulian, it flowed on the right. In 1956 survey, the river was seen to have reversed to the 1939 pattern (Figs. 5.6 and 5.7).

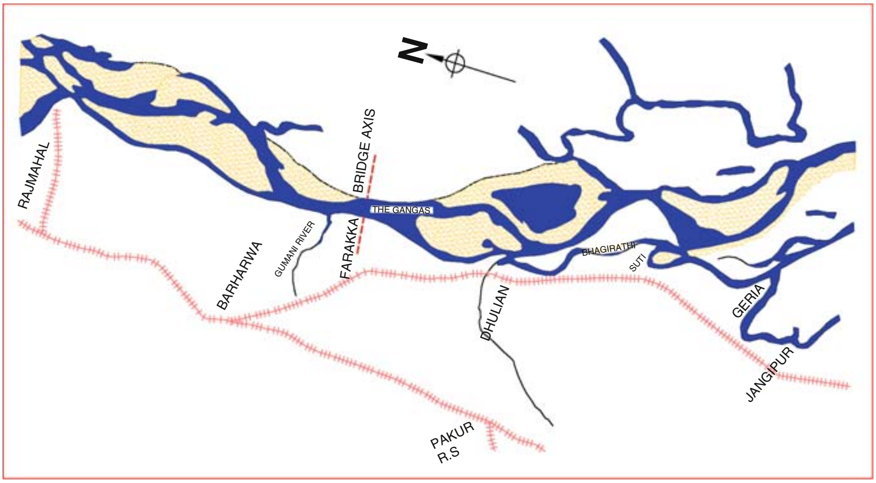


Fig. 5.6 Plan of the river Ganga showing 1939 course

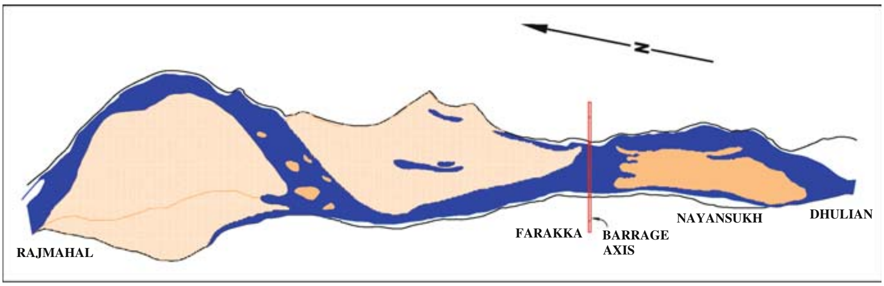


Fig. 5.7 Ganga river course around Farakka in 1956

The 1961–1962 survey did not show much change from the 1956 one in the meandering pattern. The channel was hugging the right bank up to 1.5 km above the barrage and thereafter it swung to the left. In fact, at the barrage site, it was about a kilometre away from the right bank. To avoid construction hazard at the earlier location, about 1.5 km upstream, the present site was chosen, which indicated that the river was swinging leftward, above Farakka, returning to the 1948–1949 course but the construction of the barrage at that location might have prevented such a shift.

The barrage was constructed in 1975 over the Ganga – probably the largest such in the world over the alluvial bed – by blocking the river in such a manner that Nature took time to adjust. Before it, it had two meander bends between Rajmahal and Farakka, One was intercepted by the barrage, to which the river adjusted. The latest survey of 1993–1994 revealed that the Ganga had combined two meander bends into one, from Rajmahal to Farakka, by keeping the deep channel on its left bank on Malda side, by eroding the left bank. The reach near Manikchak and the one from Panchanandapur to Farakka were severely affected for the last 20 years. The marginal embankment near Toffi village at about 7 km above breached in 1980 and despite constructing several spurs and strengthening them by stone apron and side-pitching with boulders in crates, the erosion was minimised but could not be wholly stopped. It shifted downstream and the embankment near Simultala village, at about 3 km above the barrage, was severely affected by breach in embankment in 1987. It breached nine times thereafter and gradually shifted toward the land, year after year. The areas are inundated quite often and farmland and villages submerged. Three to five kilometre wide and 5–7 km long land has so far gone into the river. On the right bank, a big alluvial fan has formed and is increasing day by day. A point-bar (*char* land) has recently come up toward the right, just above the barrage and is shrinking the right channel, which some day will jeopardise the operation and maintenance of the barrage. Experts say, this is natural for an alluvial river but would not have occurred if there was no barrage and adequate protective measures were taken upstream along with this human interference by spending a little. They were not taken because of callousness, ignorance and negligence of the government which now spends a fortune without much benefit. Photograph 5.1 shows the type of bank erosion near Panchanandapur on left bank in Malda district.

The banks near Manikchak and Gopalpur were also severely eroded. The marginal embankment and the protective measures taken in 1987 were damaged, causing widespread flood in the region. Erosion continued year after year, in various magnitudes up to 1999 and is likely to continue. Over a kilometre-wide land for about 5 km has been washed away. Owing to procrastination by the concerned government departments, protective measures of dubious value, as recommended by a model study in 1992 were not implemented until the monsoon of 1996. The measures included construction of two long spurs at Manikchak at 28 and 29 km above Farakka, to protrude deep by over 400 m to tag to the marginal embankment. These were to be made of crated stones, i.e., stones in a wire-net, over geo-textiles laid over the river-bed. This was postponed for various reasons.

Thus, the Ganga above the Farakka Barrage underwent morphological changes after it was constructed, which would continue to occur for some time yet to give

Photograph 5.1 Bank erosion near Panchnandapur in Malda district (See also Plate 1 on page 365 in the Colour Plate Section)

the river a dynamic stability. Any further interference by long spurs, diversion canals etc. may make the river swing leftward and aggravate erosion, which would require more time for the course to adjust to such changes and stabilise (Fig. 5.8). Photographs 5.2 and 5.3 show the breach of a portion of the marginal embankment and people taking shelter over the embankment.

As said, the 1960 survey showed the left channel as more active and larger than the right channel below Farakka. The right channel along Nayansukh village and Dhulian town was carrying less than 25% of the flood discharge in those days. It was observed that though the right channel was narrower than the left, the velocity of flood water in both was about 3 m/s and the channels were also quiet deep. This means, the erosion near Nayansukh and Dhulian could be due to the less active right channel because of increased flow in the narrower but deep secondary channel, a normal feature. The process continued for years and between 1945 and 1950, the river eroded about 1 km wide land near Dhulian town. In 1952–1953, erosion reached its zenith and old Dhulian town gave way. The 1939 survey surmised that the two bifurcated channels joined just below Dhulian town, where heavy flow concentration caused such devastation. The present Dhulian town came up at about 2 km downstream of the old town. Erosion lasted up to 1956 when the gap between the old and the new town also eroded so extensively from 1950 to 1960 that the old rail-line between Barharwa and Nimtita (to be precise, between Sankopara and Loharpur Halt) – a distance of about 13 km – had to be abandoned and a new line had to be laid away from the river-bank.

During the construction of the barrage, the earthen coffer dam, stretching from bay 1 to bay 52 on the right bank, was retained inside the river, from 1964 to 1969, although the sizes of the dam varied in different years. In the first year, the dam covered first three bays which were retained even in the flood season but in 1969

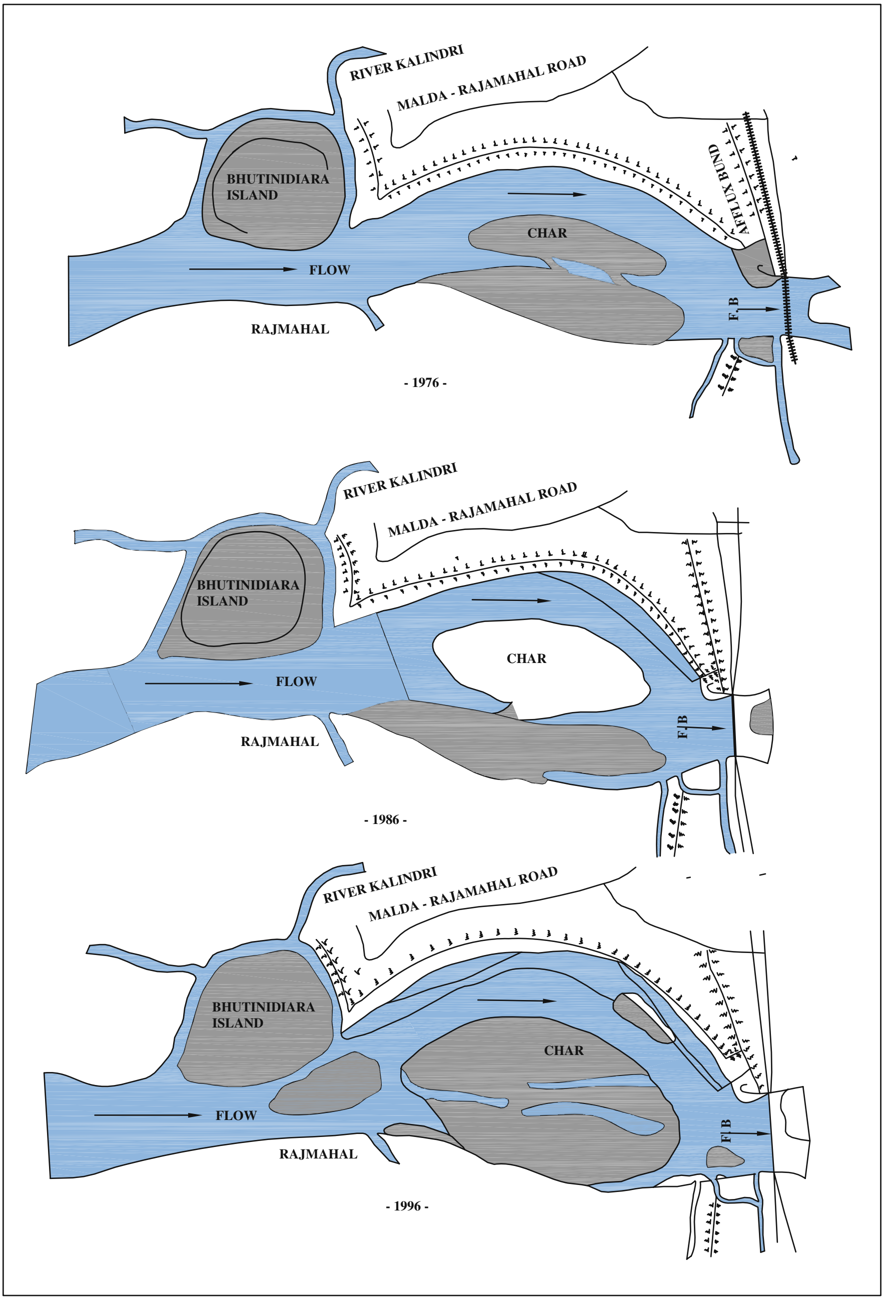
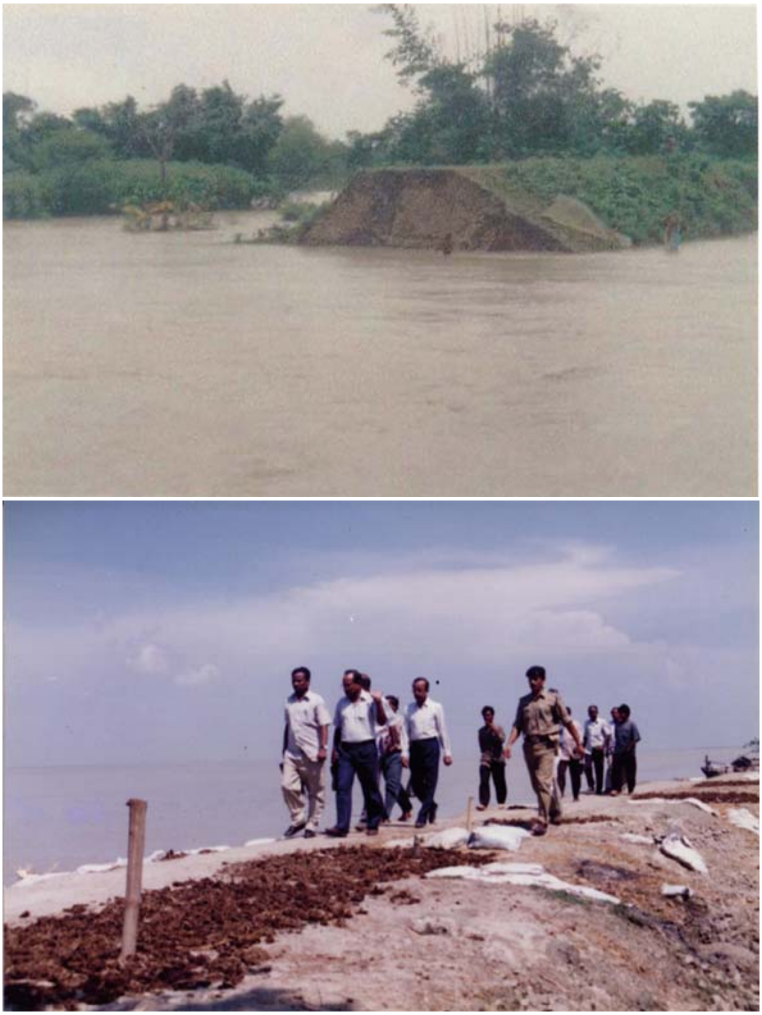


Fig. 5.8 Changes in river course between 1976 and 1996 on upstream of Farakka Barrage



Photograph 5.2 Breach of marginal embankment upstream of Farakka Barrage in Malda district during floods of 1998 (See also Plate 2 on page 366 in the Colour Plate Section)

monsoon season, the dam covering 52 bays was partly retained inside the river. Even with such obstruction, severe erosion threatened Aurangabad town below Dhulian in 1969. The right channel reportedly became very active and eroded the town by about 2 km in length and 150 m width in 1969 and took into it Suti police station. Since 1970, erosion near Dhulian and Aurangabad was checked by extensive protection measures and flow regulation through the right-bank bays of the barrage. Contour maps in 1971 indicated that the deep channel continued to remain on the left below the barrage. Although some left bank bays were throttled in 1970 and

Photograph 5.3 Flood affected people taking shelter over marginal embankment (See also Plate 3 on page 367 in the Colour Plate Section)

1971 floods, deep scours developed just below the closed bays, which meant that the main channel still remained on the left half of the barrage, downstream. These developments implied that the erosion of Dhulian and Aurangabad was not due to the construction of the barrage but to the joining of the two channels in the location, severely concentrating the flow.

Even before the formal opening of the barrage, in 1975, its gates were partly operated to regulate and pass the full flood discharge, downstream. The river's morphology began to change because of the barriers since 1970. The downstream shoal (alluvial fan) inside which was away from the barrage by about 2 km in 1960 moved toward it owing to the changed flow and silt deposition and finally reached within 500 m by 1980. The left active channel gradually shrank owing to the obstruction. The deep channel which was shifting leftward to the barrage with the flow stopped. The primary consideration for regulating the barrage gate was to keep the channel on the right, upstream so as to draw required silt-free water into the Feeder Canal. To achieve this, the right bays were kept open more during rising and falling floods. The cross current, or parallel flow, which developed in initial years of operation from right to left in front of the barrage was prevented by protecting scour holes and by constructing the submerged bed-bars at various bays, both below and above the barrage. Moreover, as the passage of water was blocked, the flow hit the land adjacent to the right guide bund and eroded it. The protective works of the bund were affected and had to be maintained at great cost. All these along with the throttling of the barrage gates, more on the left side, increased the siltation of the left channel below, which slowly dried up by 1983, or so and the mid-river *char* extended and joined the left bank. This way, the left channel below was completely blocked and local people started cultivating on it. It remained blocked, round the year, for over 2 km on the left and only a thin course flowed further down. It reduced the sudden flow concentration on the right bank, near Dhulian town which might have helped reduce the erosion near it and Aurangabad town afterward.

As the left channel was blocked, the flow enhanced on the right channel by creating cross, or parallel, flows downstream, from the left to the right, which created deep scour-holes in the bed and threatened to move toward the barrage. This was prevented by dumping stones etc. at a huge cost up to 1988, which stabilised the holes. The submerged bed-bars, constructed later, slowed down the formation of a cross-flow and pushed it to hit the *char* and arrested its advance toward the barrage. As a result, the flow got more passage below to join the right-side secondary channel. This eventually became the only channel below the barrage. Afterward for holding the entire flow, very high floods, above 50,000 cumecs occurred, completely submerging the *char* and distributing it over the entire width of the river. The huge concentration during both rising and falling floods started eroding the right bank, just below the barrage in villages like Beniagram, Bindugram, Jaffarganj, Nayansukh very critically from 1983, or so and orchards, mango groves, farmland etc were engulfed. Bank revetment and other protective measures were taken by the barrage authority and the State irrigation department at very high cost to control erosion up to Dhulian town but it was quite severe from 1984 to 1990 and again in 1995. Of the 20 km reach from Farakka to Dhulian about 10 km could be protected up to 1995 and erosion controlled. Work on the remaining portion was done in phases but about 150–300 m wide land was washed away.

Had the left channel been kept active after commissioning the barrage by properly regulating the barrage gates and artificial dredging, the flow could be maintained and erosion on the right bank minimised. The bed-bars below, at different bays required regular maintenance and extension. The deep channel is still very close to the right bank but meandered to the left, below Dhulian. It being almost straight up to Dhulian with a few local bends, it would not have been difficult to prevent, or reduce, serious erosion in this reach owing to excessive flow concentration and weak bank. Properly designed revetment by small bed-bars could hold the bank-line and keep the channel away from it. Any other technique for holding the bank-line, i.e. by long spurs might have helped divert the main flow toward the parent river but this would have definitely aggravate erosion, further down, at new Dhulian town, or below. The deep channel which shifted left, through another meander bend, would be disturbed because of upstream encroachment by spurs, making it shift to the right again, which would be disastrous and may restart erosion. The morphology of the alluvial channel which takes pretty long to attain dynamic stability would be disturbed again.

Other erosion zones further down, on the right bank, at Geria, just above the Bhagirathi offtake, Raghunathpur, Kutubpur etc. downstream, could be controlled by protective measures. Two channels united below Kutubpur and the combined discharge hugged the right bank, causing severe erosion. Farmland and villages were affected and very costly protective measures are now under way to protect them.

The meander bend on the right bank continued up to Akhriganj in Murshidabad before the river finally enters Bangladesh. This deep channel which is very active on the right bank caused severe erosion near Akhriganj and Jalangi *bazar* area for about 8 km since 1930, engulfing over 350 m wide land. In 1989 erosion here was more severe and a large landmass, including school, market and other buildings went into the river. Erosion continued up to 1995 and in spite of spending huge amounts by the State government to check erosion could not be totally stopped. Long spurs constructed in 1990 were severely outflanked. Erosion below the spurs increased, affecting civil structures and farm land.

The Bhagirathi-Hooghly became moribund in its upper reach in pre-barrage days. It used to be active only in monsoon months, when activities on it reduced and its silted mouth was over-flooded by the high Ganga level and again from October, or so, the flow decreased, rendering the river a stagnant pool. As there was practically no flow from November to June, there was no bank erosion in the upper reaches in those months except in monsoon months. Slips only occurred at some places owing to the drawdown state of the ground-water table. In the lower reach in the Bhagirathi and the Hooghly the condition was different, as it was a mature and active reach because of flows from the tributaries and the tides from the sea. Therefore, these reaches suffered bank erosion, round the year, which aggravated in monsoon months. After induction of upland discharge through the Feeder Canal, the joint river remains active throughout the year, regaining its life. This rejuvenation gave rise to erosion in many reaches, which is particularly severe in meander bends but less in braided and straight reaches. The most vulnerable erosion zones of the river, as revealed by the survey data of 1985–1986 are shown in Table 5.1.

The Table 5.1 shows that in 1985–1986, there were 26 major erosion-prone zones in the Bhagirathi-Hooghly. The first 16 were in the Bhagirathi and the last nine in the Hooghly. The approximate affected length and the nature of land loss are indicated in the table. Mostly farm land, villages and industries were affected. The total affected length on the left bank was about 40 km and about 45 km on the right bank, out of the total length of the joint river of 425 km from the offtake in Murshidabad to Falta in south 24-Parganas district. In many of these affected reaches, the river has been engulfing farm land, almost every year. The shift of bank line in four major reaches (two in each) – Purbasthali and Mayapur on left bank and Samudragarh and Zirat on right bank from 1976 to 1987 are shown in Table 5.2.

The continuous encroachment by the river on the land by the Mayapur reach from 1976 to 1987 is shown in Fig. 5.9 below. On the left bank stands the famous Vaishnaba temple and the headquarter of the ISCON and on the right the legendary Nabadweep town, abounding in Vaishnava temples and controversial birth place of Shri Chaitanya Dev, founder of the Hindu sect. It is also near the outfall of the Jalangi, a tributary of the Ganga. Over a million square metre of land went under water between 1976 and 1987; the old temple is now threatened. All the four reaches, as shown in Table 5.2, are within the meander loops. Erosion is severe on the concave side of the bend with alluvial fans formed on the opposite face. A study of erosion of the joint river in 1985–1986 showed that the annual erosion in the

Table 5.1 Vulnerable erosion zones of the Bhagirathi-Hooghly as per survey data of 1985–1986

Sl no	Location	Channel pattern	Distance from offtake (km)	Affected length L/Bank (km)	Affected length R/Bank (km)	Nature of land loss
1	2	3	4	5	6	7
1	Gobindapur	Meander	20.0	Nil	3.54	Agricultural land
2	Balagachi	Meander	47.0	Nil	3.93	Agricultural land
3	Baidyanathpur	Meander	96.0	1.05	1.05	Village
4	Chowrigacha	Meander	99.0	2.50	Nil	Village
5	Nagar	Meander	110.0	3.78	3.47	Village & agri Land
6	Ramnagar	Meander	132.0	Nil	2.83	Village & agri Land
7	Narayanpur	Meander	146.0	3.35	0.35	Village & agri Land
8	Katwa	Braided	157.0	0.36	3.20	Village
9	Kalikapur	Meander	168.0	Nil	3.14	Village
10	Charchakundi	Meander	174.0	6.45	5.69	Village & agri Land
11	Dampal	Meander	194.0	2.23	4.35	Village & agri Land
12	Bholadanga	Straight	203.0	Nil	2.05	Village & agri Land
13	Karkaria	Straight	209.0	4.23	Nil	Village & agri Land
14	Cutsali	Meander	220.0	3.04	5.03	Village & agri Land
15	Purbasthili	Meander	225.0	1.00	1.00	Village & agri Land
16	Mayapur	Meander	232.0	2.03	0.92	Do & temple
17	Satkhali	Meander	240.0	1.45	0.30	Agricultural land
18	Samudragarh	Meander	248.0	0.50	1.50	Do & office
19	Hatipota	Meander	255.0	0.70	0.60	-do-
20	Santipur	Meander	285.0	0.60	Nil	Village & agri Land
21	Fulia	Meander	293.0	2.10	0.20	Village & agri Land
22	Balagarh	Meander	300.0	0.20	0.50	Village & agri Land
23	Zirat	Braided	310.0	2.50	0.50	Village & agri Land
24	Sankrail	Meander	388.0	Nil	0.60	Industry
25	Falta	Straight	425.0	1.80	Nil	Industry
			Total	39.87 km	44.85 km	

Table 5.2 Migration of bankline in different meander loops of Bhagirathi-Hooghly between 1976 and 1987

Location and Bank	1976–1980 (m)	1980–1985 (m)	1985–1987 (m)	1976–1987 (m)	Total affected length (m)	Total land area lost between 1976–1987 (10^4 m^2)
1	2	3	4	5	6	7
Purbasthali (left-bank)	170	245	100	515	2080	107.10
Mayapur (left-bank)	144	256	104	504	2500	126.00
Samudragarh (right-bank)	45	30	45	120	800	9.60
Zirat (left-bank)	40	265	125	430	2500	107.50

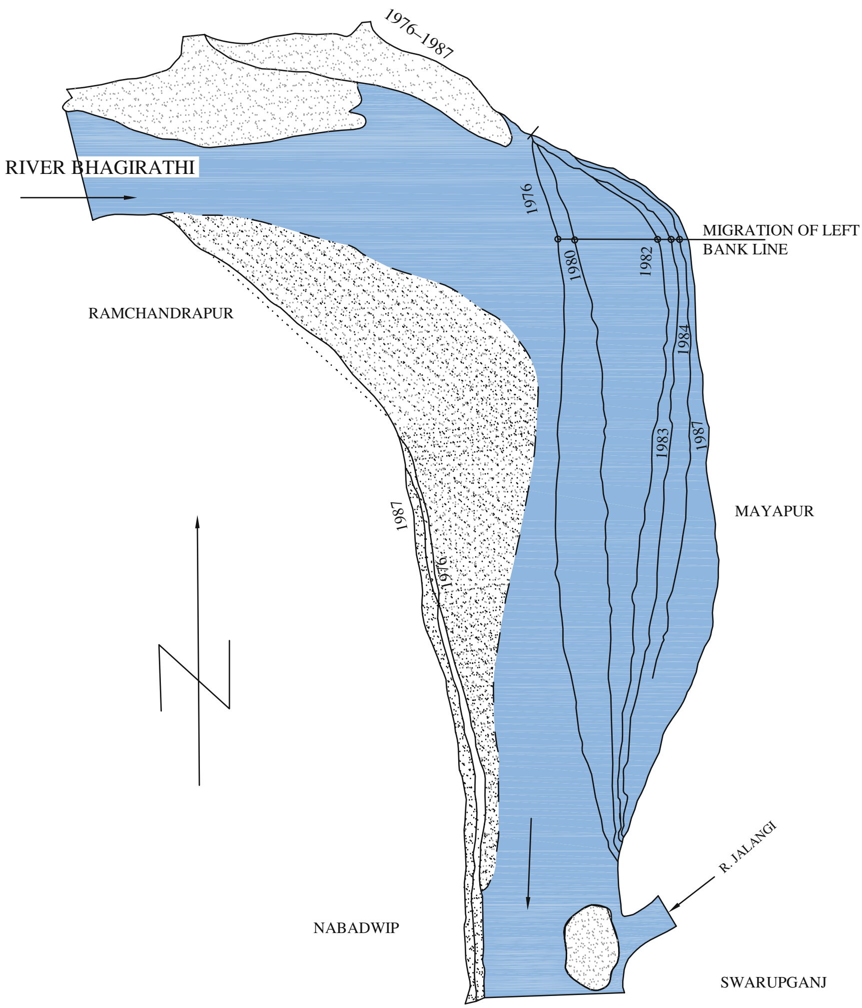


Fig. 5.9 Bankline migration near Mayapur reach

Bhagirathi alone is of the volume of about 8.5 million cubic metres and yearly land loss is about 220 hectares. It revealed that erosion in the Hooghly is much less than in the Bhagirathi, due probably to the presence of major towns and industries on both banks of the former and to protective measures taken by authorities to save their buildings etc. (Fig. 5.10). Photographs 5.4 and 5.5 show the type of bank erosion near village Palasi in Murshidabad district and Nayachara island in Hooghly estuary.

A noted village, Fazilpur, lies in the reach between the off-take point and Moya village where the distance between the Ganga and the Bhagirathi is the minimum, about 1.20 km only. In 1980, when the right channel was more active, severe erosion

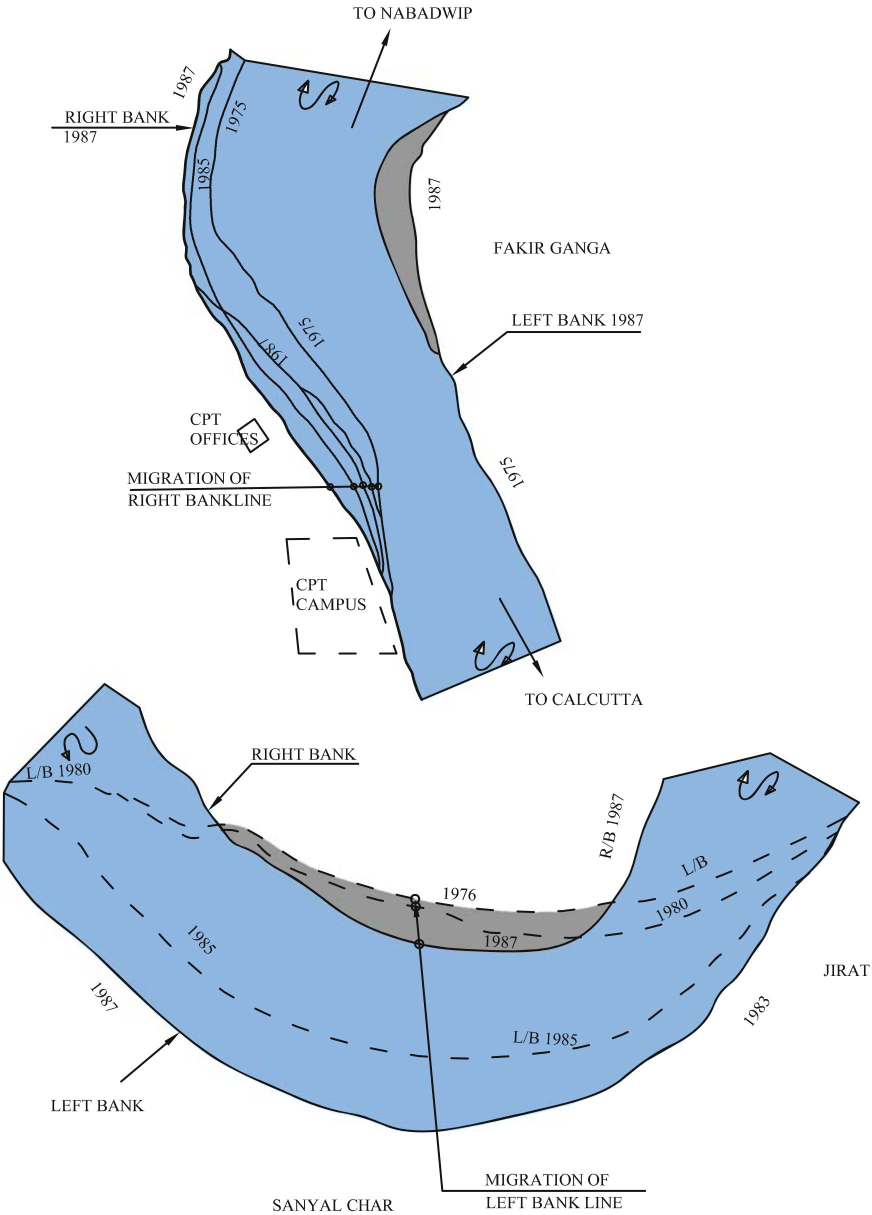


Fig. 5.10 Bank line migration near Jirat-Sanyalchar reach

occurred and a huge mass of land was engulfed. As a result, the distance between the rivers had been reducing gradually The position is shown in Fig. 5.4. Though the left afflux bund of Jangipur barrage and the Jangipur-Lalgola State highway are through this in-between land, there had been a lot of public criticism through the media

Photograph 5.4 Bank erosion of Bhagirathi near Palasi (See also Plate 4 on page 367 in the Colour Plate Section)

Photograph 5.5 Bank slip of Nayachara island near Haldia (See also Plate 5 on page 368 in the Colour Plate Section)

about the danger of joining the Ganga with the Bhagirathi at this place, because erosion would bring the two rivers closer and ultimately join them. If this occurs, the entire flood-water of the Ganga – about 2.7 million cusecs – would try to pass through the Bhagirathi, flood all south Bengal districts and Kolkata and would cause large-scale devastation. The Ganga bank was protected at this reach in early 1990 by armouring the slope and the bed with crated stone-boulders by the Farakka Barrage Authority, which arrested erosion. The zone has since silted up and the gap between the two rivers has been maintained at about 1.20 km for the last few years. Here the right channel has shrunk owing to siltation and the central *char* land has moved rightward.

Further down, the two channels have joined on the right side near village Moya forming a single one passing very close to the right side. The deepest channel is near the bank and the river has taken a concave shape. The afflux bund is very close and the frontage land between the bend and the bank has been eroding gradually. Before the flood season of 2000, a land width of about 120.0 m for a length of about 2.0 km has been washed out. The river is now flowing very close to the afflux bund and may breach the same in future by-passing the flood discharge of the Ganga towards the Bhagirathi and over-flooding the country side villages. Further down, the river has taken a sharp bend from right to left up to the village Sekhalipur with concave face on the right. Severe bank erosion has been occurring on the right. The river bank has been armoured heavily at the location by State Government and the bank has been acting like an armoured spur. The left side of the river is occupied by a big char land and the same is gradually advancing towards right and pushing the main channel further towards land.

Below Sekhalipur the deep channel flows on the right up to Jalangi Bazar, the last point of Indian territory before entering fully into Bangladesh after travelling a length of about 30 km. The place Akhriganj comes on the way which was affected by severe bank erosion since 1930. The efforts of the State Government to control erosion at this location have not been successful and the erosion process is continued. The river on the right side has entered Bangladesh in Kustia district in the name of the river Padma.

Chapter 6
Decline of Bhagirathi-Hooghly Channel

It has been established beyond doubt that until the 15th century AD, the major flow of the Ganga passed through its south-western channel, the Bhagirathi-Hooghly. A great volume of water passed through the Bhairab-Jalangi channel in Nadia district too. These two diversions built the south Bengal basin between them, through which the Ganga flowed into the sea. Only afterward, more and more water of the Ganga flowed into its south-eastern course, the Padma, making it the main channel. Some expert opinions, supporting this phenomenon are summed below.

Hamdi Bey wrote in The Sunday Statesman Miscellany (23 November 1986) that river Hooghly, the lower reach of the Bhagirathi was named after the busy Hugly town and port, well-known in the 16th and 17th centuries, by Portuguese settlers on its banks. He believes, Emperor Ashoka voyaged from Patliputra (modern Patna) to Tamralipta (now Tamluk) through the Hooghly. The river then fell into the Bay of Bengal which then extended some 150 km north from its present shore, near Diamond Harbour. Romans who came to India for trading in the 1st century, voyaged across the Arabian Sea and the Bay of Bengal, to places on the Western and Eastern coasts, respectively, entered Bengal through river Hooghly. Roman coins and potteries, found in various places on the east coast, conspicuously in Orissa and 24-Parganas district of West Bengal testify to this trade. Seals with inscriptions in Roman script have been discovered in excavations in Malda.

By 1520 AD, Portuguese merchants sailed from Bay of Bengal to the Hooghly but probably not beyond, to evade customs duty and in view of their notoriety for piracy, abduction and forcible conversion of local people to Christianity, or because of heavy silting of the Bhagirathi, as mentioned in their records. They traded from Hugli town and anchored most of their ships at Betor in Howrah, opposite the city which later came to be known as Calcutta. Dutch, British, French and Danish traders followed the Portuguese and settled at or near Hugli, Chinsurah, Chandannagar and Serampore. Even flat-bottom steam ships of low draft, which began plying from 1838, could not sail along the Bhagirathi for most of the year, because of shallowness. The volume of trade from Kolkata increased so much that an alternative route to the city's hinterland had to be found. The discovery of a steamer route through the creeks of the Sundarbans to the joint estuary of the *Ganga* and the *Brahmaputra* in present Bangladesh in the 19th century enabled foreign merchants to navigate up to Allahabad by steamers and up to Agra by boats.

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7_6,

Dr. Tomas Oldham said in 1870 that in olden days the main Ganga flowed through the Bhagirathi-Hooghly channel from the foot of Rajmahal Hills; subsequently, it diverted to the Padma, its south-easterly branch. Dr. B. Hamilton wrote in 1890 that after Kosi river joined it near Mungher in Bihar, the combined flow started diverting to the Padma as its wider basin could hold the discharge better than that of the Bhagirathi-Hooghly. Major Hirst, the then Director of the Survey of India stated in 1870 that the Indo-Gangetic plain, as far as Haridwar, was once under the sea. The land surface of undivided Bengal was gradually built up by the silt of rivers. At a point of time, a subsidence occurred, which caused a line from Jalpaiguri to the sea along the course of the Yamuna. To compensate this subsidence, certain tracts got elevated, such as the tract north of Dhaka, known as Madhupur jungle. These earth movements, giving rise to a series of elevations and depressions dominated the action of rivers in the delta and are still active. To these actions, Major Hirst attributes crucial changes of rivers, such as the changes in the courses of Teesta and Brahmaputra in the 18th century. Such changes might have diverted the main flow of the Ganga towards the Padma. He believed that the main river flowed on the bed of the present Bhagirathi; thereafter, through the Hooghly after separating from two tributaries – the Yamuna and the Saraswati near Triveni in West Bengal. It passed near the present channel of Saptarmukhi (meaning, Hundred Mouths) and ultimately fell in the Bay of Bengal, near the Saugar Island. According to him, the main channel of the Ganga diverted gradually to its eastward flowing branch, near Murshidabad. As a result, the main Ganga flowing from Rajmahal Hills to Saugar dwindled to the present Bhagirathi-Hooghly down to Kolkata, from where it was diverted by a cut canal, later on into the unseen channel of the Saraswati, south of Botanical garden in Howrah. This became the present estuary of the Hooghly, running from Kolkata to the sea. The eastern channel of the Ganga became the present river and was subsequently joined, around 1790 AD at Jaffareganj, by the Brahmaputra which changed its course from east of Dhaka to the west. These were due to earth movements, depressing one place and elevating another. He also believed that the death or decline of the tributaries across the Gangetic delta which previously took the discharges of the Ganga, occurred owing to persistent leaning of the river to the east, depriving them of their water through this eastward course; this has been reflected, to a great extent, by the westward shift of the course of the Brahmaputra.

In 1910 H. H. Haydene and E. H. Pascoe, Director and Superintendent respectively of the Geological Survey of India did not quite believe the elevation and subsidence theory. They did not think that either of these twin processes need to be considered to explain the human aspect of the development of Bengal rivers. They held that conditions prevailing on the Indo-Gangetic plain from early tertiary time were not dissimilar with those existing at the present and that there was a gradual subsidence, leading to the accumulation of enormously thick alluvial deposits. Therefore, the change of the Ganga course from the Bhagirathi-Hooghly to the Padma was not unusual. Supplies on the Ganga were caused by its continuous eastward shift, depriving the tributaries of their water through this course. This also was reflected, to a great extent, by the westward shift of the Brahmaputra.

In 1919, H. G. Reaks, River Surveyor of Calcutta Port wrote in his study of ‘The physical and hydraulic characteristics of the rivers of the delta’ that the Ganga and the Brahmaputra which contributed to the formation of the western portion of the delta, originated within about 160 km of each other but on the other side of the Himalayas and brought into Bengal the combined discharge from both slopes of the watershed, including the discharge from melting snows. As ascertained from early traditions, existence of old beds and from the histories of noted towns on its banks, the main Ganga stream flowed down south into the present Bhagirathi to about the vicinity of Triveni where three rivers separated. This, he wrote, was the most natural and direct course to the sea. At Triveni, the Saraswati branched, south-west, and flowed into the present Hooghly at Sankrail in Howrah and then, as Captain Sherwill and Ferguson say, flowed through Garden Reach and Tolly’s *Nullah* (also known as *Adi*, or original Ganga) in south Kolkata and past Baruipur in south 24-Parganas into the Sattaramukhi and Channel Creek, or Buri Ganga, to Ganga Sagar.

Captain Sherwill who was deputed in 1857 by the Government of India to ascertain the condition in the Hooghly was of the view that the Ganga flowed on the present bed of the Bhagirathi-Hooghly from Rajmahal Hills to Saugar Island in olden days, then far from being an insignificant branch as now. The present course along the Padma was of recent origin, formed by the opening out of the left bank of the Ganga near Shibganj in Malda. This occurred not slowly but as result of a catastrophe which he attributed to the sudden collapse of the left bank, made of loose yellow sand. He drew the conclusion from the Ramayana legend of sage Jahnu swallowing the Ganga in retaliation of her washing away his holy utensils. Captain Sherwill took it to be a symbolic presentation of the collapse at Shibganj, which Sages Jahnu and Valmiki might have witnessed.

According to S. C. Majumdar, there were two major river systems before this diversion, building up, more or less independently, a deltaic tract in western part of Bengal, west of Madhupur jungle. The Ganga did this in central Bengal and the Teesta in north Bengal. At an earlier stage, the Teesta was reinforced by the water of the Mahananda and the Koshi and before these probably of the Brahmaputra too before it flowed eastward to the Meghna and then merged with the Tsan Po of Tibet. These North Bengal rivers travelled to the sea together, probably through the Meghna estuary. Mr. Majumdar relied on Rennel’s map, prepared several centuries after the diversion when the Padma channel was fully settled. The map shows this combined outfall as Hoorsagar river, meeting the Padma, or the present Ganga north of Goalanda, slightly north of the present confluence of the Yamuna with the Ganga. The Padma probably existed then and might have existed much before too, being the easternmost branch of the Ganga and flowing, more or less, along the course, as shown in Rennel’s map, i.e., following the course of the Bhubaneswar, or the Arial Khan, as its lower portion is now called. It might have also had a connection with the combined outfall of North Bengal rivers, as also shown in the map. He mentioned that gradually, the Koshi and then the Mahananda broke off from North Bengal rivers and directly flowed into the Ganga higher up. Not only did this considerably weaken the combined outfall but also reinforced the Padma, which could then assert itself. Lastly, the change of the Ganga course near Gour mentioned by Major Hirst, by bringing the Padma more in a direct line of flow, enabled it draw the Ganga flow. As the natural tendency was also in its favour – the western part of the delta having been built more than the eastern – it began to develop rapidly at the expense of the Bhagirathi and other western branches (Fig. 6.1).

J. M. Coleman, studying the formation processes of river channels and sedimentation of the Brahmaputra in 1969 observed that it showed a fairly continuous

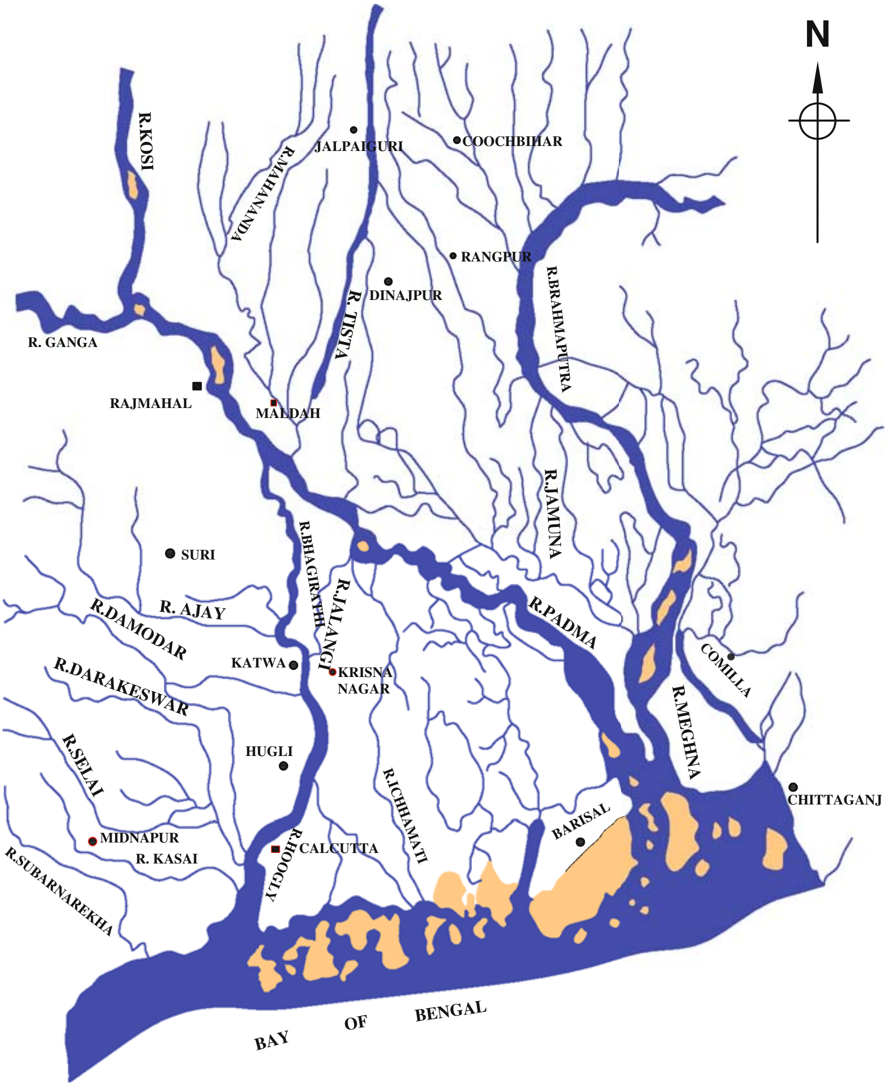


Fig. 6.1 Bengal rivers in 1764–1776 (Rennel's map) (See also Plate 6 on page 369 in the Colour Plate Section)

movement to southwest, while the Ganga was flowing northwest. As the two rivers joined, the movements apparently slowed near the confluence. Before the 16th century, much of the Ganga flow discharged directly into the Bay of Bengal via the Hooghly. Since then the channel shifted gradually to northeast, occupying and giving up several prominent courses into its present position.

In the Bengali epic 'Chandimangal' written by Kabikankan Mukundaram in 1477 AD (mentioned earlier), the voyage of Chand Sadagar to Singhal (now Ceylon) has been described along the Bhagirathi, which was quite deep and was carrying the main flow of the Ganga. It shows that so recently as 500 years ago, the main flow of the Ganga was through the Bhagirathi and Adi Ganga and thereafter the main current of the Ganga started flowing gradually through the easterly directed branch of the Ganga situated near Murshidabad.

Eminent Indian scientist, Meghnad Saha revealed an old map on the rivers of Bengal, in which the Padma's south-eastern flow is not seen. It shows the Ganga flowing along its present Bhagirathi bed. He argued that before the 15th century, the Padma did not exist but came to be noticed only afterward. He says, all well-known places of south Bengal were on the banks of the Bhagirathi-Hooghly. Secondly, unlike the Ganga, the Padma was never deemed a sacred river; it was one of sorrow and destruction.

South Bengal's king, Lakshman Sen fled to East Bengal (now Bangladesh) with his family from Nabadweep by land, not by the river after being defeated by Muslims from Arab. Experts like Travernier who visited India in 1666, Bernier who travelled through Bengal in 1667, Rennel whose map on the rivers of Bengal was published in 1769, Captain Sherwill, deputed in 1857 by the Government to study the condition of the Hooghly and Fergusson who gave an account of Bengal rivers to the Geological Survey of India in 1863 believed in the Hindu mythology about the Ganga and drew conclusions from the events narrated in it as well as valued the views of learned men, well-versed in Sanskrit. They all believed that the Bhagirathi was the main flow of the Ganga in olden days. These experts argued that the main Ganga took a south-easterly turn beyond the Koshi in Bihar and moved up to Rajmahal Hills. It then swang south, keeping the hills at right and flowed on the present Bhagirathi-Hooghly course to the Bay of Bengal. Before the 16th century, this was its main course and major riverine transportation up to the sea was carried on this channel. The Padma was then a minor tributary of the Ganga and no important town came up on its bank because of uncertainty of discharge, shallow and unstable banks and proneness to flood. At that time, the Bhagirathi was a deeper river with more stable banks and high water-flow round the year. Noted towns and places came up and flourished on its banks, like Azimganj, Beharampore, Palasi, Katwa, Kalna, Nabadweep, Halisahar. The French, the Portuguese, the Dutch and the British who came to this part of India to trade, sailed from the sea through the Ganga's waterway and settled on its prosperous banks, in places like Kolkata, Hooghly, Chinsurah, Chandan Nagar and Bandel. They further developed these towns and cities, using the large and deep waterway which also provided fast and easy access to the sea for retreat. Diversion of its flow to create the Padma began probably in the 16th century AD, following some tectonic changes, or a major catastrophe, diminishing the flow in the Bhagirathi-Hooghly channel. Similar tectonic change or catastrophe might have changed the Brahmaputra course too from east of Madhupur to its present course, west of this area. While many experts believe that the change in the Brahmaputra's course occurred between 1720 and 1830, that of the Ganga came much earlier, probably in the 14th or 15th century. As the Bengal delta was formed by the alluvial deposits of the Ganga, the Brahmaputra and the Meghna, not so long ago, the entire basin was susceptible to high tectonic and morphological changes. Added to this was human interference through agriculture and other activities which might have more often caused such changes.

Causes and Extent of Deterioration

Though more and more flow of the Ganga diverted to the Padma, no danger to the Bhagirathi-Hooghly river was seen until about 200 years ago. Rivers of Nadia – Bhairab, Jalangi and Mathabhanga-Churni were also carrying sufficient discharge from the Padma, round the year, which kept the Bhagirathi-Hooghly channel deep and wide. The tributaries from the right were also adding sufficient but ephemeral flow during monsoon months. This collective upland flow kept the entire river system clear and did not let it deteriorate through siltation. Gradual south-easterly diversion of the main flow from 18th century generated in the Ganga a tendency to flow through the Padma, making it gradually the main river. Even Nadia rivers carried less and less flow and became moribund.

In 1930, G. C. Chatterjee listed the causes of deterioration of the Ganga's distributaries. He compared a river to a headless estuary and observed that an estuary, the flow of whose feeder river had diminished, would die in no time. He imagined the Gangetic delta as a triangular island with its apex at the confluence of the Bhagirathi with the Ganga at Geria; its western boundary was the Bhagirathi-Hooghly and the eastern was a curvilinear line, formed by the bed of the Ganga from the apex of the mouth of the Gorai-Madhumati and the bed of the latter river. Its base-line was formed by the sea, between the outlets of the Hooghly and the Madhumati in the Bay of Bengal. The apex was not a point but a line prolonged like the beak of a bird whose two parts are the channel from Geria to near the foot of Rajmahal Hills. The upper part is formed by the bed of the Ganga and the lower by the Farakka channel – a dry branch of the Bhagirathi between Suti and the Bhagirathi offtake. It existed in those days but was covered with swamps, marshy land and agricultural fields. The mouth of the dry channel was not static; it was near Kissengunj but shifted gradually to Nurpur and is now at Geria. The upper part of the delta is traversed by Jalangi, a tributary of the Ganga and the lower part by Mathabhanga-Churni; both join the Hooghly at Nabadweep and Ranaghat.

Besides, the fluvial force, created by the current formed in rivers, flowing from mountainous regions, joins the tidal force and during ebb tide, scours the bed; it does the contrary during flow-tide. This way, it cleans the silt deposits in the lower reaches. It is obvious, therefore, that more water a river brings from its mountain source, more it will scour the bed during ebb tide. The Ganga water, carrying huge silt-load, has been restricted by the Lalthakuri embankment, the road from Jiaganj to Bhagawangola, Ranaghat to Lalgolaghat railway line – all on its left (western) bank. Their silt-load did not wash away and the rush of relatively silt-free water during ebb tide is restricted, causing siltation in the Bhagirathi-Hooghly and its offtake point at Geria. Mr. Chatterjee quoted British irrigation engineer, Sir William Willcock who held that if the spill is not restricted by artificial obstructions, the silt would spread all over the land and very little of it will be deposited in the river-bed. If this goes on, land adjacent to both banks will not be elevated more than a foot in 100 years and if the river-bed rises accordingly, no river should die.

In 1910, Hyden and Pasco wrote, quoting from Gaikie's Text Book of Geology (Volume I, page 499) that a characteristic feature of streams, large or small, is the tendency to flow in serpentine curves, when the angle of declivity is low and the general surface of the country is tolerably level. This is observed in every stream which traverses a flat plain. When a river enters a delta in its course, it assumes a new character. In previous parts of its journey, it is augmented by tributaries but now it begins to split into branches which wind, to and fro, on the flat alluvial plain, often coalescing and thus enclosing insular spaces of all dimensions. The feeble current, no longer able to bear all its sediment load, allows much of it to sink to the bottom and gather over the tracks which are submerged from time to time. Hence many of the channels are choked, while others open out in the plain and are in turn, abandoned. In this way, rivers change their channels, restlessly. Thus, the meandering nature of Nadia rivers and shift in their courses are not unique but common to all rivers flowing on flat plains.

Holding the same view, Fergusson added, all over the world, this characteristic is common in rivers, flowing on alluvial plains. Even great rivers, like the Mississippi and the Tigris, do this in a marked degree, as seen in their maps. The phenomenon is caused by the relation between the varying and erosive action of current and the resistance of the soil. Even though a fully silt-charged current, striking an erodible bank at a weak place cuts into it, naturally along the vulnerable portion. A concave bank, or a bight, is thus formed with relatively deep water on its face. The matter dislodged is carried downstream until the velocity of the current is gradually dissipated by the resistance of the bank as well as by cross-currents and eddies, created by the erosion. Being no longer able to carry it on, the current drops it and is deflected by the direction of the bank and its centrifugal action, affecting the other bank. The slope and the velocity being reduced, deposits take place over the whole cross-section and a bar is formed at the crossing. This creates a head and the slope, increasing the current, strikes on the other bank, below the crossing with increased velocity; the process is thus continued and goes in a cycle. The head of the Bhagirathi and its bed silted in this manner.

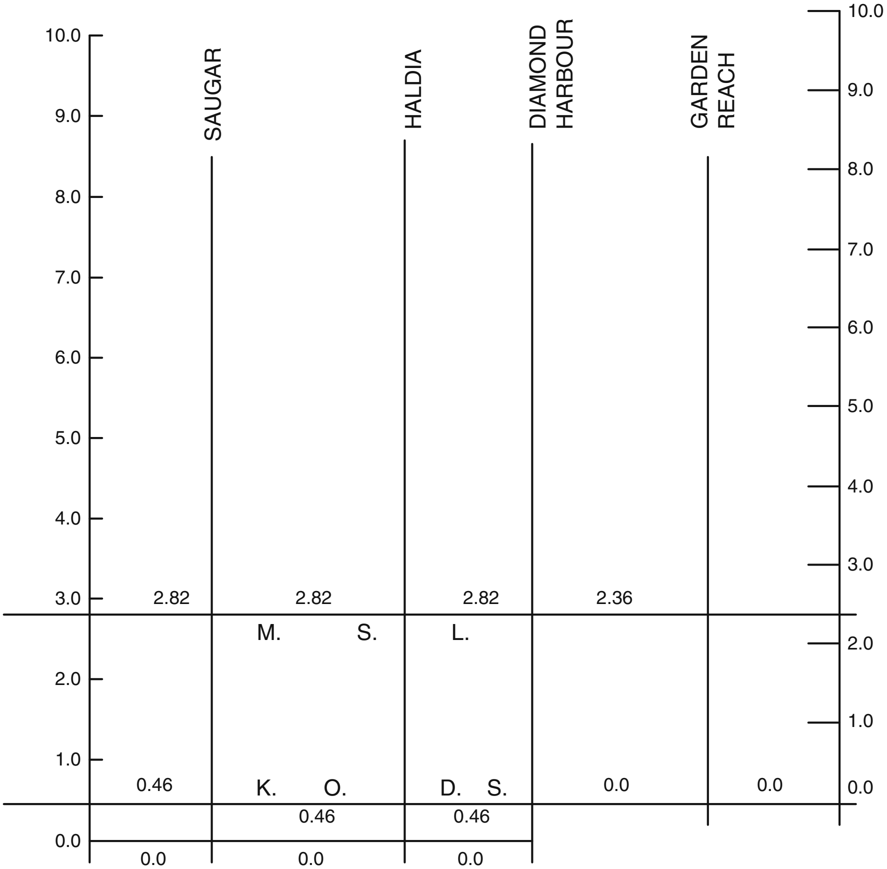
According to Friedkin, the swing of the river depends on its capacity to erode the banks, which increases the silt-load and heavier particles deposit over the bed, being unable to be carried with the current, and gradually forms the alluvial fan, or point bar inside the river-bed. The main current is thus deflected and erodes banks in a cycle of erosion and deposition.

In the light of the above, the fact remains that following gradual reduction of water volume of the Bhagirathi-Hooghly since the 16th century, the Bhagirathi basin was continuously silted. Its load started depositing at the mouth and the bed owing to the reduction in velocity and gradually raised the bed. The passage of water was blocked continuously, causing further reduction in flow. Reaks gave an account of such reduction in 1919. The Bhagirathi on which large boats plied throughout the dry season of 1840–1841 gradually worsened from next year. Boats of only 2′6″ draft could pass and in 1842–1843 it was more obstructed than in previous 5 years, giving rise to many complaints. With great difficulty, a depth of about 3 feet was maintained in the next dry season and by 1845–1886 a passage was secured for boats of 2′ draft. In the next season, the entrance was so unfavourable that it closed in February, 1846 and by May, the depth fell to one foot.... The entrance in 2008 tended south-east from the Bhagirathi about 5 km (3 miles) from the mouth and inclined downstream of the main current. The bed of the Bhagirathi at the entrance, which at the end of April 1913 was 54′9″ above Kidderpur (Khidirpur) Old Dock Sill (K.O.D.S.) and about 20′ feet higher than the bed of the Farakka channel, appears to have risen higher since, being 55′6″ at the end of October 1914, 57′6″at the end of October 1915, and in the last dry season of 1918, it was 62′9″ above datum. The Ganga level at the mouth falls lowest to about 50 feet above datum. The relationship of K.O.D.S. level with the G.T.S. level is shown in Fig. 6.2.

While the entrance is closed by sand, blocking any influx from the Ganga, the Bhagirathi, lower down, carries a stream which apparently increases progressively. This supply can only be due to percolation of subsoil water through the bed and the banks. Its source is usually attributed to the Ganga but this view cannot be easily accepted, because at a low stage, in the dry season with a sand bar blocking the mouth, the level of water in the Bhagirathi is much higher than in the Ganga, to the extent of 4′–5′ and even more. This water percolates through the sand at the entrance, draining the Bhagirathi into the Farakka channel. The Hooghly, Reaks added, 'is tidal throughout the dry season'. During ordinary spring tides in the dry season, a flood current is noticed as far up as about 13 km (7 miles) south of Nadia district and during the highest spring tides, a slight upward current is sometimes seen in Nadia.... Considering this normal natural phenomenon, the section of the Bhagirathi from Kalna to Dumurdaha is the tidal head of the river during the freshet season. The down-flowing current, surcharged with silt, meets the tide here; the velocity is checked and deposition occurs.

In 1774 and 1776 respectively, H. Wedderbourne and J. Richie who also studied the Hooghly conditions in those days, held that the river had deteriorated gradually, because of shoaling and contraction of its deep channels from accumulation of silt and that under such conditions, deterioration will continue. In a report to the Lieutenant Governor of Bengal, they said, every means has to be taken to avert a catastrophe, with the aid of highest engineering skill. They also recommended minute and periodical survey of the whole length and breadth of the river from Kolkata to the sea.

In 1853–1854, Piddington, a member of the Hooghly Commission, reviewed the deterioration from a more scientific angle. He said, 'I am of the opinion that it is



NOTES:- i) ALL LEVEL ARE IN METRES.
ii) K.O.D.S. REPRESENTS KIDDIRPUR OLD DOCK SILL LEVEL.
iii) M.S.L. REPRESENTS MEAN SEA LEVEL.

Fig. 6.2 Relationship between K.O.D.S. and M.S.L.

of the highest importance to the future state of the navigation of the river, at least from Calcutta to about Hooghly Point that the most strenuous endeavours should be made and every means used and every experiment tried to ensure a copious supply of water for as many months in the year as possible at the heads and along the courses of the three main feeders'.

H. Leonard, Superintending Engineer of the State Public Works Department was deputed in February 1864 to investigate and report on the condition of the Hooghly. He had visited all major European rivers which were being improved and consulted Sir Charles Hartley, engineer of the Danube Commission. He submitted a report in

June 1865, reviewing the general hydraulic factors in maintaining the river channels and the conditions at the critical points for investigation. He agreed with the majority of the 1853–1854 Committee that the Hooghly would certainly deteriorate, howsoever slowly, because of the agencies at work. The enormous quantity of silt, carried down every year, would be deposited in, or about, the debouche, lengthening the sand-heads and thus decreasing the scouring power of the stream.

In the latter part of the 19th century, traffic and trade in Kolkata port increased gradually and vessels of larger size and bigger capacity with more draft frequently visited the port. In 1853, the largest vessel to berth was 1810 tons' capacity. This steadily increased and in 1917, the biggest vessel that visited the port was of 12,989 ton capacity. The length and draft of vessel also increased from 368 feet in 1870 to 511 feet in 1917. Between 1830 and 1913, the draft increased from 17 to 28 feet but because of restrictions by the port authority, the pilots were not allowed to travel with vessels of more depth between Kolkata and Diamond Harbour. In 1830, a rule was revised to strictly forbid pilots, on threat of dismissal, to ply a vessel of more draft than 20 feet at any time of the year, even with the aid of competent steamers. Vessels with more draft had to discharge part of their cargo either at Sagar, or at Diamond Harbour, where transit facilities existed. In 1912–1913, before the 1st World War, 49 ships of over 27 feet and 12 of over 28 feet draft plied on the Hooghly. However, the increases in size and depth of vessels were not so much due to hydrological and hydrographical improvements in the navigation channel as to the change in the design of the cargo vessels and ships as well as to increase in port facilities. The navigation channel deteriorated owing to siltation in spite of increase in traffic and dredging as well as other measures, adopted to maintain the draft. From Kolkata to sea-face, 14 submerged sandbars exist, spread over, more or less, the entire cross-section of the river in different orientations which change according to seasons. Because of siltation, these also gradually choked and created more hazards for navigation. These bars needed constant survey and dredging to keep clear the passage of ships to and from Kolkata port.

To sum up on the basis of these opinions as well as causes and extent of deterioration of the Bhagirathi-Hooghly and according to records of Calcutta Port Trust, in olden days, it was the mainstream of the Ganga. It was through this channel that the Ganga found its way to the sea. From the 16th century, the Ganga tended to flow more and more through its eastern arm, the Padma across Bangladesh to flow into the sea. Because of heavy siltation in the mouth and reduced depth, the Bhagirathi drew less and less water into it, causing more and more siltation over its bed and the mouth. The bed of the mouth rose gradually and the mouth moved from Dhulian to Biswanathpur by 1950. The flow through it was possible in only three monsoon months and for nine remaining months it remained high and dry. The mixture of clay, silt and sand that enters the Bhagirathi with the Ganga water during monsoon months could not be flushed to the sea through the choked mouth, because of weak current after the rains. On the other hand, tides push this silt up and leave deposits on the bed. The sands deposited near the receiving end help disconnect the mouth from the Ganga and push the stream eastward. It also raises the river-bed, gradually. In the Hooghly, though the diurnal tides are evenly distributed below Saugar Island for 5 h daily, the situation is different near Kolkata. The flow-tide endures about 25% less than the ebb-tide, 5 and 7 h approximately; therefore, the intensity of flow-flux in the Hooghly is more than that of the ebb-flux. During flow-flux, huge quantity of sand and silt enters the Hooghly up to the tidal limit owing to very high velocity, forming a high wall of water. But because of longer duration of the ebb-flow, its velocity is reduced, causing partial deposition of sediments on the bed. Moreover, there is a slack period between the end of flow-tide and the beginning of ebb-tide and vice versa. Maximum deposits occur during the slack periods, the ebb-flow alone cannot scour the entire bed, resulting in gradual rise of the bed-level. Submerged bars also rise gradually owing to such deposition. The river capacity is thus decreased gradually, blocking the navigation channel. This, in turn, accelerates siltation, affecting the overall performance of the river. If the upland flow is maintained, the siltation cannot affect the river-bed much, as the ebb-flow is supplemented by upland discharge. Deposition is scoured and will keep the river-bed free and the navigation channel is also not affected. But if the upland flow is reduced, or stopped, siltation accelerates. Another adverse effect is that tides gradually push upward and the salinity of water increases. In this way, the rise in the bed level of the Hooghly has synchronised with that of the Bhagirathi and the entire Bhagirathi-Hooghly river system has been affected.

As stated, the Ganga carries huge silt-load during three monsoon months; except wash-load, it is nominal in nine dry months but increasing from June, near Farakka, the maximum silt-load being in August and September. It decreases thereafter and by the end of November, the flow becomes relatively free from silt-load. The total silt-load, carried by the Ganga at Farakka, from June to November, is about 180–200 million cubic metres. During monsoon, the discharge through the Bhagirathi from the offtake with the Ganga is unrestricted. The discharge carries more or less the same intensity of load from the Ganga. The total silt-load passed through the offtake of the Bhagirathi between June and November will be about 8–10 million cubic metres. The tributaries of the Bhagirathi-Hooghly also contribute sufficient silt-load during those monsoon months. A rough assessment of silt-load is given in Table 6.1.

The silt-load in the Bhagirathi has reduced at its offtake point after the construction of Farakka Barrage and the entry of discharge was controlled but owing to increased bank sloughing at various places in the river, as described before, about 8.5 million cubic metre soil is added to the flow, making no difference

Table 6.1 Annual silt load of the Bhagirathi-Hooghly tributaries

Sl. No.	Name of the tributaries	Silt load in million M3
1	Bhairab–Jalangi	10.0
2	Mathabhanga–Churni	2.0
3	Damodar	2.0
4	Rupnarayan	6.0
5	Haldi	4.0
6	Rasalpur	4.0
7	Others	2.0
Total		30.0

to the silt-load. The annual silt-load in the Hooghly, south of Haldia, is about 40–50 million cubic metres. Besides, because of continuous upland discharge through the feeder canal, the ebb-tide in the river is continuously supplemented, increasing the velocity of the ebb-tide and reducing the flow-tide. This has taken the slack-zone from Santipur-Kalna reach in the pre-barrage days to somewhere below Diamond Harbour in the post-barrage period where the silt-deposit has increased manifold, obstructing the navigation channel. As a result, Jiggerkhali flat, upstream of Haldia port, is expanding day by day and the navigation channel from Haldia port to Kolkata is now totally blocked. Construction of a guide-wall on the upstream of Nayachara island and other palliatives by the Calcutta Port Authority have not been able to open up this navigation channel alongside Haldia. Fortunately, the Rangafalla channel, opposite Haldia, has opened out and the navigation route through this channel has saved Kolkata port. Until and unless this huge silt-load in the navigation channel is cleared and further deposits prevented, the fate of Kolkata port will remain unstable.

The gradual deterioration of the Bhagirathi offtake near Biswanathpur can be explained by facts and circumstances. The offtake point has undergone a number of changes in the last 200 years, which were due to eastward shifts of the location from Dhulian, then Suti, then Geria and finally to Raghunathpur before the construction of barrages at Farakka and Ahiran near Raghunathpur. Each one of these changes assumed importance as long as they lasted. Their typical circumstances were associated with the opening of a new takeoff point as the former closed. Throughout their tenures, offtake points shifted continually toward east and the supply of water accordingly diminished from the parent river. Whether this arose out of alluviation at the heads, or from tectonic change of shifts in the remaining delta following change in the river courses in some place or other (i.e., the great shift of the Teesta), or because of swing of the river to the east, are matters of debate. None of these can, jointly, or separately, explain these unique phenomena of the Bhagirathi, near its offtake point from the Ganga. Dhulian offtake point was probably near the present Dhulian-Ganga railway station. Gradually, this offtake point, together with the Bhagirathi channel, was engulfed by the Ganga. Disastrous bank erosion, caused by high floods, between 1730 and 1740 is said to have given rise to the situation. At present, the Ganga near old Dhulian offtake point is about 5 km wide with a 2 km wide *char* island inside the river but the old Bhagirathi is nowhere to be seen. After it closed, the offtake point shifted to Suti, about 10 km downstream. In the beginning, the angle of obliquity of the off take point was probably acute, like that of any other distributaries, which gradually changed to an obtuse angle before it finally got choked. The remnant of the old channel can be seen here, even now. The next exit was formed at Geria, about 10 km further down and the same process was probably repeated, from acute angle to obtuse angle before it finally closed by silt deposition at the mouth. The closure of this offtake was first noticed on 26th November 1919, according to Basu and Chakravarty in 1972. Swamps, marshes and low pockets at Geria are tell-tale signs of an old channel. The point then shifted to the present location at Raghunathpur and the process repeated again. The mouth also gradually silted, reducing discharge into the Bhagirathi from the Ganga. When the mother river was in spate, the Bhagirathi got a good share of the flood-water, increasing from a mere one cusec to 3,000 cusecs in August and September. The higher discharge period, however, gradually reduced from the major part of the year to only about 2 months from the beginning of July to the end of August. For the remaining 10 months, the river at Raghunathpur was a dry bed with a few pools of shallow water, here and there. The floor of the Bhagirathi, near the offtake point, looked like a hanging valley, about 15 m higher than the bed of the Ganga.

River Below Offtake

The deterioration of the Bhagirathi-Hooghly began like this from the 16th century; the upland discharge gradually came down in monsoon months. The mouth was blocked by silt and the bed too silted following movement of sediment from the upland discharge and the sea, carried during the flow-tide. The Bhagirathi used to be nearly moribund in April and May with sand-bars and stagnant pools of water in between. Navigation became impossible in these months in the upper reach and even country boats could not ply. People crossed the river on foot and also by improvised bridges at various points and water for agriculture and drinking became scarce.

Though in the lower reach of the Bhagirathi, some tributaries fell into it and added some flow in monsoon months, the depth was not enough for navigation in lean season. The aggradation of the river-bed was caused by reduced flow from the Ganga at its mouth as also by less time over a number of years. Practically cut off from the mother-river by a wide sand island at the mouth, the river survived only by local rainfall, except in monsoon months. The dry weather flow was negligible, being on an average, 0–2 cusecs for 7 months, from December to June. Table 6.2

Table 6.2 Discharge at offtake point of Bhagirathi near Jangipur

	Water level and discharge				
Year	Minimum level (m) Discharge (cumec)		Maximum level (m) Discharge (cumec)		Time span (days)
1	2	3	4	5	6
1915	15.05	3.10	21.40	2,554	190
1920	16.86	5.80	20.70	1,892	150
1926	14.42	3.60	19.96	1,317	175
1930	14.92	13.30	21.26	2,109	170
1935	14.94	1.60	21.43	2,053	138
1940	14.88	4.60	20.69	2,006	165
1945	15.10	25.00	21.22	1,572	178
1950	15.00	20.10	20.86	1,927	136
1955	14.39	18.20	20.97	1,472	191
1960	14.73	17.10	20.85	1,773	156
1965	13.52	1.10	19.18	1,409	142
1970	14.48	3.70	19.45	1,306	122
1972	14.63	2.90	18.91	952	84

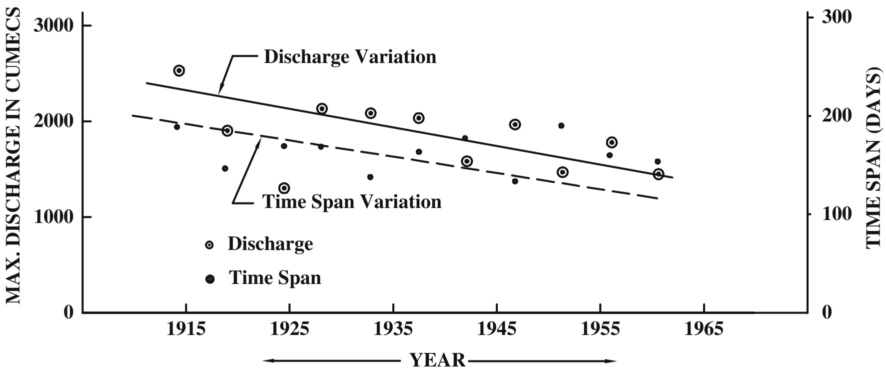


Fig. 6.3 Discharge and time span reduction at offtake point of Bhagirathi

shows the maximum discharge and the number of days for which it lasted at the offtake point near Jangipur from 1915 to 1972.

The water-level at this point depended on the maximum and minimum levels of the Ganga; therefore, fluctuations were not much. Minimum discharge depended on the condition of the site while the maximum discharge and the time-span came down substantially over the years with ups and downs in between. This shows that the inflow into the Bhagirathi gradually reduced in quantity and duration. This is clear from Fig. 6.3 where the average discharge and time-span variations have been given. It is seen that the two lines are almost parallel, which means that the uniform fall in the time-span depended on the reduction in the maximum discharge intensity at the offtake point (Fig. 6.3).

To ascertain the nature of deterioration of the river's non-tidal reach, the changes of low-water stages at selected places at Jangipur, Beharampore and Katwa may be examined. Before 1915, they had a rising trend which was seen more at the upper reach at Jangipur gauge than at Beharampore. By 1915, the mean trend of Jangipur and Beharampore gauge became almost flat while Katwa gauge showed a steeply falling trend. The bed gradient continued to be steep with rising sand deposits in the lower reach. Owing to decrease in discharge at the offtake point, the river practically remained stagnant in most part of the year. In the Hooghly tidal reach, the cubic capacity of channel between Nabadweep and Cossipore (140 km) was measured in different years from 1924 to 1963 and analysed in three segments. The capacity of the channel gradually deteriorated, as shown in Table 6.3.

It is seen that the cubic capacity came down as the river flowed downstream, because the movement of sand and silt from the sea along with flood-tide did not get sufficient force to return to seaward again during ebb-tide and deposited in the river-bed increasingly. Huge quantity of sediment moved up and down along with tidal water in an oscillating way and deposited gradually downstream in conducive situations. Between Cossipore and Hospital Point, the cubic capacity, taking together, or separately, the pre- and post-freshet season capacities, fell, indicating loss in the channel section. As the two banks were more or less stable because of industries,

Table 6.3 Loss of cubic capacity in Hooghly river between Nabadweep and Cossipore

Reach and length	Year	Cubic capacity $m^3 \times 10^6$	Total loss $m^3 \times 10^6$	Loss per year $m^3 \times 10^6$	Average loss per year $m^3 \times 10^6$	Percentage loss per year
1	2	3	4	5	6	7
Nabadwip	1937	26.60	3.21	0.23	0.20	0.75
to Kalna	1951	23.39	2.10	0.17		
(34 km)	1963	21.29				
Kalna to	1924	68.20	17.58	0.65	0.78	1.14
Bansberia	1951	50.62	10.95	0.91		
(56 km)	1963	39.67				
Bansberia to	1944	170.69	15.66	2.23	2.37	1.39
Cossipore	1951	155.03	29.97	2.50		
(50 km)	1963	125.06				

markets and other urban growth, the loss in the cubic capacity meant aggradation of the bed. A physical assessment indicated a loss of 0.3% per year in this reach. The decrease in the capacity is shown in Fig. 6.4.

Another physical assessment of the cubic capacity of the reach between Panchpara and Uluberia (below *Rabindra Setu*) showed reduction at 3.05 m below Khidirpur old dock sill (K.O.D.S.), as seen in Fig. 6.5.

It was difficult to assess loss or gain in cubic capacity, as no definite bank-line survey data were collected. The bank-line below Uluberia was unprotected and owing to industries, particularly brick-kilns on both banks, lines had shifted. The assessment below it showed both decrease and increase in the cubic capacity in certain river reaches. The hydraulic mean depth also varied in the river-bed as well as over the bars and crossings.

The basic problems of navigation in the Hooghly and especially over the bars and crossings increased manifold. The navigable depth gradually reduced, leading

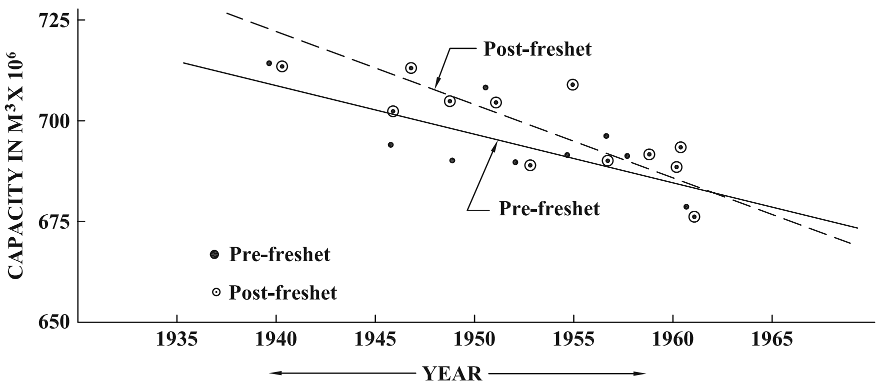


Fig. 6.4 Capacity reduction in Hooghly from Cossipore to hospital point

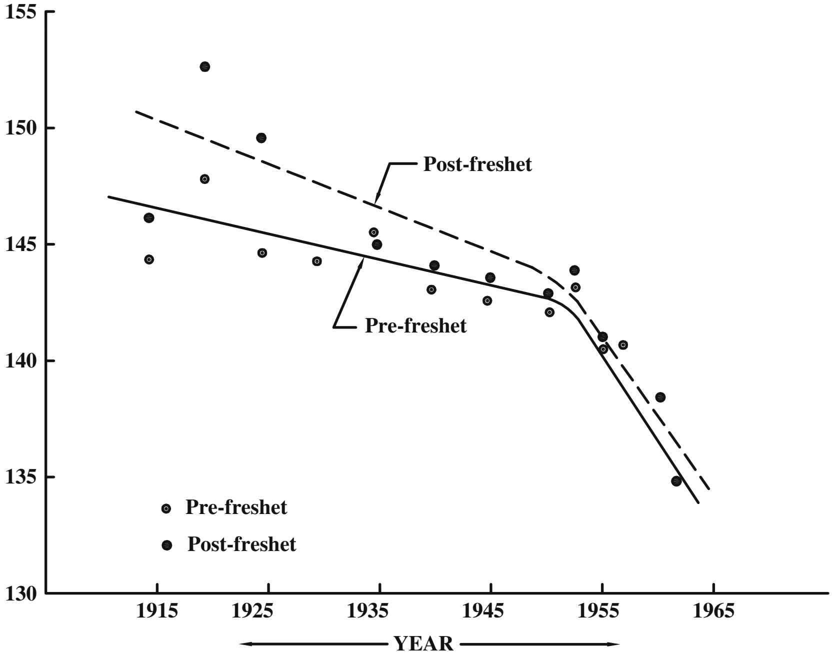


Fig. 6.5 Capacity reduction of Hooghly between Panchpara and Uluberia

to more dredging for maintaining the channel. The number of days when deep-draught vessels of 7.9 m plied to Kolkata port reduced from 291 days in 1938 to only about 38 days in 1964. Table 6.4 shows the number of days, used by 7.9 m draught vessels from 1933 to 1973.

Table 6.4 Record of 7.9 m draught vessels using Calcutta port

Year	No. of days	Year	No. of days
1938	291	1952	123
1939	242	1953	142
1940	200	1954	145
1941	160	1955	142
1942	128	1956	126
1943	116	1957	98
1944	94	1958	75
1945	90	1959	40
1946	98	1960	14
1947	99	1961	21
1948	90	1962	28
1949	99	1963	32
1950	115	1964	38
1951	112		

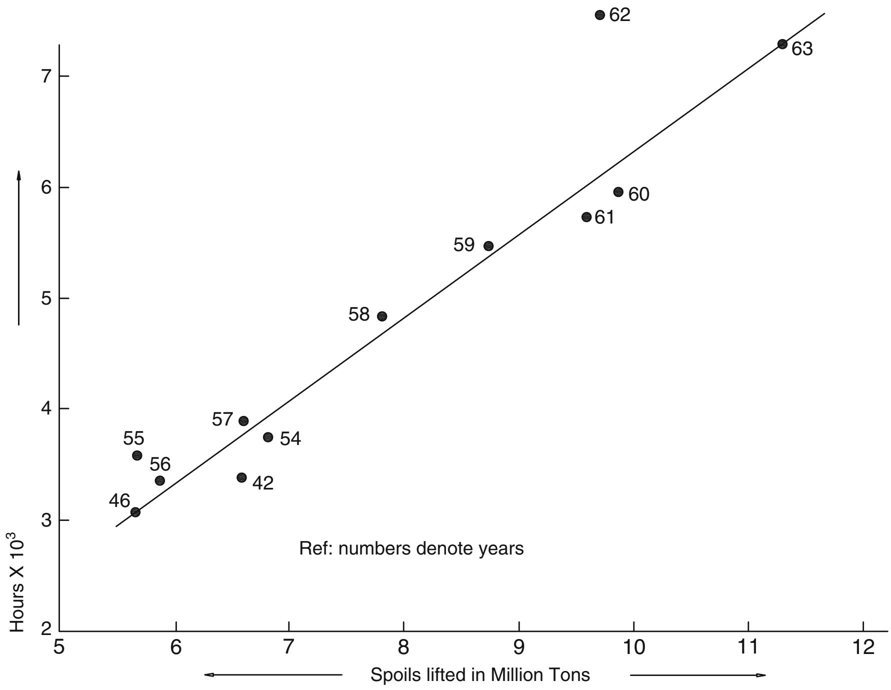


Fig. 6.6 Variation in quantum of dredging

The quantum and the cost of dredging in the channel as well as over the bars and crossings went up steadily, necessitating increase in port levies and maintenance costs but the port's losses were not made up. The quantum of dredging and total dredging hours from 1942 to 1963 is shown in Fig. 6.6.

As upland discharge reduced, tides dominated the upper reach, raising salinity of the river water. Supplies to Kolkata city and suburbs, to the industries on both banks and for agriculture in the basin areas were severely affected. The potable limit of salinity exceeded even up to Bansberia, about 50 km upstream of *Rabindra Setu* (the Howrah Bridge) in the lean season.

Chapter 7
Only a Barrage Can Save!

Jawaharlal Nehru wrote in his ‘Discovery of India’:

> The Ganga is above all the River of India which had held India’s heart captive and drawn unaccounted millions to her banks since the dawn of history. The story of the Ganga from her source to sea, from old times to new, is the story of India’s civilization and culture, of the rise and fall of empires, of great and proud cities, of the adventure of man and the quest of the mind which has so occupied India’s thinkers, of the richness and fulfillment of life as well as its denial and reunification of the ups and downs, of growth and decay of life and death.

The original river used to flow across the entire north and east India from Uttarakhand (a new province carved out of Uttar Pradesh on 9th November 2000) to West Bengal (then only Bengal) before the 16th century. Geologists say, before it diverted to the Padma eastward, there might have been two major channels, flowing more or less independently and building the deltaic tract in this part of Bengal, west of Madhupur jungle, viz., the Ganga flowed through central Bengal and the Teesta through south Bengal. Earlier, the Teesta was reinforced by the Mahananda and the Kosi and still earlier, perhaps also by the Brahmaputra before it coursed eastward to the Meghna, i.e., before it merged with the Tsan Po of Tibet as a much smaller stream than now. These north Bengal rivers flowed and fell together into the sea, probably through the Meghna estuary. This hypothesis fits in with the historical and mythological evidences, supporting the contention that the Bhagirathi was the main flow of the Ganga in olden days.

Captain Sherwill’s View

This was also the contention of Captain Sherwill and others (see Chapter 2). Much later, first the Kosi and then the Mahananda, separated from north Bengal rivers and flowed directly into the Ganga higher up. Major Hirst says, this ultimately reinforced the Ganga’s flow toward the Padma and shifted its course toward southeast, near the ancient town of Gour, now in Malda. The Padma flow became stronger and swelled rapidly, drawing from, and emaciating, the Bhagirathi and other western branches of the Ganga.

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7_7, © Springer Science+Business Media B.V. 2010

The problems of the Bhagirathi-Hooghly arose out of this diversion of the main flow of the Ganga in the 16th century toward the Padma. Previously, the Ganga threw its major flow through the Bhagirathi-Hooghly and Bhairab-Jalangi, together called Nadia rivers, which built the central Bengal between them. Not only water-level went low in these two rivers, branch rivers – Yamuna and Saraswati – also shrank and ultimately died. The Bhagirathi had link with the Ganga only in monsoon months; rest of the year it was detached, leading to silting up of its bed and mouth, which in turn further reduced the discharge. As Captain Sherwill warned:

> The process of silting up is rapidly proceeding in the beds of the Bhagirathi and Jalangi and of necessity must continue to do so the further the Sandheads advance into the sea.

Geographically, the general inclination of India toward south-east, or toward the centre of the deltaic basin, also affected the Bhagirathi, as the water of the Ganga is more inclined to proceed straight in its south-eastward course rather than turn into the Bhagirathi and flow in a due easterly/southward direction. Vast quantities of dry soil flow down from the higher land in summer months from February to June and the soil that is washed down in the rainy season, i.e., from June to September, together filled up the bed of the Bhagirathi.

Information on Nadia rivers is meagre but their existence is a fact. Not much is known, why are they so shallow. Levels from Rampore Bauleah on the Ganga, at the apex of the delta to the Sandheads, cross-levels from Chittagong to Tamluk and from Dhaka to Murshidabad should be carried out with mathematical precision. The north and south levels may prove that the beds of the Bhagirathi and Jalangi are much higher than that of the Ganga when its water-level goes down from the mouth of the Bhagirathi to Rampore Bauleah and that all attempts to set right these rivers will go in vain and serve no purpose.

In the natural course, these rivers have filled up, never to open again, as they were in ages gone by. Rajmahal once stood on the shore of the ocean but it is now far-off. Fleets once sailed up the Bhagirathi; they can no longer do that. Issuripore-Jessore was, not many hundred years ago, on the edge of the south water but all its neighbouring *jheel*s or lakes are now filled with brackish water. Nadia, from its name, was once a new island with salt water around; it is now 208 km from the sea and the site of a city up to whose garden walls, 80 years ago, the tidal wave, the bore rolled but now it no longer approaches the town – the tide rising and falling about two vertical inches only.

View of W. A. Lee

W. A. Lee of Calcutta Steam Navigation Company in a letter to the Secretary of Port Facilities Enquiry Committee in 1914 reported that the Ganga which spills into the channel of the Bhagirathi in rainy season, was unable to carry (away) as much silt as it brought (from the Ganga) and therefore, deposited it in the Bhagirathi and the Hooghly. The bed of the former is apparently rising and there is less water on the shoals in the dry season than there was 25 years ago. From Nadia to Kolkata, he added, the tides were deteriorating the river. If the ebb and flow tides were equal, they might have, almost continuously and uniformly, scoured and kept a channel open, for long periods but the flood tide is stronger than the ebb and carries more silt. At high water, when the flood tide stops, some silt is deposited; the ebb tide then ran down and scoured out much of the deposited silt. The silt deposited in the upper reaches was less subject to the scour of the ebb tide than that in the lower reaches. A river channel, subject only to the action of the tides, tended to silt up the upper reaches first and then deterioration gradually extended down through the whole length of the river, becoming more and more evident in the later stages, as the tidal capacity of the river diminishes more and more. . . .The Hooghly has deteriorated perceptively during the last quarter of a century in the upper 50 miles (80 km) of its tidal length and most, as one would naturally expect, in the first 20 miles (32 km) below Nadia.

The Hooghly River Commission

The Commission, set up by the Government of India in 1853–1854 and asked to study the condition of the river, reported that it has deteriorated gradually, owing to shoaling and contraction of its deep channel from accumulation of silt and that under the present condition, the deterioration would be progressive. Mr. Piddington, a member of the Commission, studied the deterioration from a scientific angle. He recognized the role of the freshets in maintaining the channel and added:

> I am of opinion that it is of the highest importance to the future state of navigation of the river, at least from Calcutta to about Hooghly Point, that the most strenuous endeavours should be made and every means used and every experiment tried to ensure a copious supply of water for as many months in the year as possible at the heads and along the courses of the three main feeders of the Hooghly. By 'three main feeders' he meant the Bhagirathi-Hooghly, the Bhairab-Jalangi and the Mathabhanga-Churni.

View of H. Leonard

H. Leonard, Superintending Engineer of the Public Works department, asked to report on the river in 1864, visited major European rivers which were being improved then. He consulted Sir Charles Hartley, Engineer of the Danube Commission and submitted a report in June, next year, reviewing the general hydraulic factors in the maintenance of the Hooghly and the condition of critical points for navigation. He agreed with the majority of the Commission that it was difficult to come to any other conclusion than that the Hooghly must deteriorate, howsoever slowly, considering the agencies at work on the river. First, the volume of silt, carried down, every year, by the river must be deposited in, or about, the debouche, lengthening out the sand heads and thus decreasing the scouring power of the stream. Secondly, there is the constant, though slow, widening of the lower section of the river, which tends to diminish this power and leave no room for the channels to change from side to side. Mr. Leonard agreed with the views of Mr. Obbard, the River Surveyor that between Mud Point and Kulpi, the Hooghly became worse since 1836 and very much worse than it had been in earlier times and that from Kulpi to Kolkata, it was neither better nor worse than it had previously been.

View of L. F. Vernon Harcourt

L. F. Vernon Harcourt, an authority on river engineering, whom the Bengal Chamber of Commerce assigned in 1896 a study of the condition of the Hooghly, submitted an exhaustive report after inspecting the rivers, the feeders and the main Ganga up to the sea, for about a month. The following is a relevant extract.

> ...Comparison of various charts and surveys of the river Hooghly shows that it is a fairly stable river, undergoing considerable fluctuations in depth, at some places according to the seasons and the volume of the freshets, but free from any general deterioration in its condition between Calcutta and the sea. The Hooghly ... affords no indication, either in the river, or in the estuary, or in its outlets, of progressive deterioration... Unless some unexpected change of the course of the Ganga should occur, so as to deprive the Nadia rivers of their annual supply and thereby materially reduce the discharge of the Hooghly, or unless the occurrence of some seismic, or cyclonic, disturbance should alter the existing conditions unfavourably, there is every prospect that ... the Hooghly will provide in future a considerably better waterway between Calcutta and the sea than it has done in the past.... The gradually increased draft of vessels, the extending demands of sea-going trade and the keen and growing competition of ports, have rendered very extensive improvement works, necessary for many rivers.... The Hooghly is better adapted for improvement than some rivers upon which successful works have been carried out.... A very careful study of all the navigable charts indicates that the Hooghly possesses considerable natural capabilities for navigation ... and that the navigable channel through the estuary ... be deepened to a moderate extent by a powerful suction dredger

View of H. G. Reaks

In 1919, H. G. Reaks, a River Surveyor of Calcutta Port, reported that an ordinary test of the condition of a modern navigable waterway is the limit of its capacity for the traffic of the port. If this expands in all directions to meet the demands of trade and particularly if difficulties have been experienced in the past, the natural presumption is that while the river may not have been used before to its full capacity, it cannot be said that it is deteriorating. The size and draft of vessels have been undergoing enormous changes from the 19th century. In 1853, the largest vessel visiting Calcutta port was 1810 tons. The size increased gradually to 2163 tons in 1860, 3128 tons in 1870, 4023 tons in 1880, 6037 tons in 1890, 7237 tons in 1900, 7705 tons in 1905, 8117 tons in 1911, 9600 tons in 1914 and 12,989 tons in 1917. Similarly, the length of vessels increased from 368 feet in 1870, 400 feet in 1880, 422 feet in 1890, 470 feet in 1900, 501 feet in 1911 and 511 feet in 1917.

Mr. Reaks added that bigger and bigger vessels of increased drafts were visiting Calcutta Port. Before 1830, though vessels of greater draft had, on occasions, plied on the river, pilots were prohibited from moving vessels, of more than 17 feet draft, at any time of the year, between Calcutta and Diamond Harbour. Under a revised rule in 1830, pilots were forbidden, on threat of dismissal, from moving a vessel of more than 20 feet draft, even with the aid of steamers. Vessels of greater draft had to offload part of their cargo either at Sagar island, or at Diamond Harbour. In 1860, no vessel of 23 feet and in 1870 over 24 feet draft visited the port. In 1880, the maximum draft was 25′2″, in 1890, it was 26′1″ from where it rose to 27′2″in 1900, to 28′3″ in 1903, to 29′3″ in 1911 and to 29′10″ in 1917. In 1912–1913, as many as 49 vessels of over 27 feet and 12 vessels of over 28 feet draft navigated the river.

However, increase in the size or draft of vessels was not wholly due to actual improvement of the river channels. In earlier years, because of less trade in the port, the channel was not fully utilized; it gradually increased with greater size of vessels. Moreover, in those days, a large volume of trade was carried in sail-vessels; before 1830, practically entire trade traffic to and from Kolkata was carried in sail-ships with but a few tugs. A sail-ship requires a wider and deeper channel than a steamer. A channel which would barely suffice for a ship of 18 feet draft, sailing up and down, may give ample facilities to a steamer of more draft, because it can navigate along the deepest line, or thread, of the channel. The supersession of sail-ships by steamers, therefore, permitted fuller use of available depth and an apparent, though not actual, improvement might have resulted from it. In the Hooghly, this change occurred in heavier traffic, some decades ago but improvement in traffic since about 1880 cannot, in any way, be ascribed to this development. Another factor which hastened the growth of traffic was provision of more facilities for navigation in the Hooghly. At the same time, increased frequency of surveys made possible more use of the port, by taking advantage of existing channels and more navigational aids in the way of plans, buoys, marks and good information network.

Government Survey

In spite of these, general deterioration of the Hooghly continued, affecting the services of Calcutta Port. Various projects were considered between 1830 and 1900 for improving the navigable approach to Kolkata. In 1831, the Government of India approved a detailed survey for excavating a ship canal from Kolkata to the head of the Matla river, avoiding altogether the existing navigable route through the Hooghly river. As a part of the scheme, a new port at Canning on the Matla was started in 1863 in conjunction with the Calcutta Port. Facilities were developed up to 1866 in the port but it did not pay off and was abandoned. The Matla Canal Scheme was again investigated in 1901 by Captain E. W. Petley who found that the route had further deteriorated since 1876. An alternative approach route to the Hooghly was finally settled ever since. Another proposal for creation of an auxiliary port near Channel Creek below Kolkata for avoiding the Hooghly channel in 1795 also did not succeed. Many other attempts to train the Hooghly channel and to keep it free from deterioration also failed. Attempts like cuts inside the channel, proposed diversion works of the tributaries, construction of training walls inside the channel, agitation dredging etc. also bore no fruit and the channel continued to deteriorate.

Many other experts who studied the river after 1919 attributed the problem to the reduction of head-water supply. The only solution, according to them, was to increase supply by suitable diversion of water from the parent river, the Ganga. It was mooted as early as 1853, when Sir Arthur Cotton, an eminent engineer and expert of river management, visited India. He suggested that a barrage at Rajmahal and a canal, linking the Ganga with the Bhagirathi be constructed to augment water in the Hooghly. This was not considered at that time, because of inadequate appreciation of the dangers of the situation.

Other experts and expert committees who also recommended increase of head-water supply, are Major Hirst (1914–1915), Stevenson Moore Committee (1916–1919), Sir William Willcocks (1930), T. M. Oag (1939), A. Wibster (1946), Chief Engineer (Special) of Calcutta Port, the Expert Committee on the river Hooghly and improvement of its head-water supply (1952), S. C. Majumdar (1953), Consulting Engineer, Government of West Bengal and ex-Member, Central Water Irrigation & Navigation Commission and Prof. (Dr.) Ing. W. Hensen (1957).

William Willcock described the Bhagirathi, the Jalangi, and the Mathabhanga as the 'overflow irrigation systems' in ancient Bengal, built up by great engineers like Bhagirath. Other experts believed that the Bhagirathi was a natural river and was once the main channel of the Ganga, diverting its discharge toward the sea. Mr. Willcock suggested construction of 'Nadia Barrage' with 180 openings of 25 feet each with overall barrage length of 6,460 feet between the abutments for diversion of headwater in Nadia rivers for irrigation, which would also help navigation and increase activities of Calcutta Port.

In October 1952, the Expert Committee, set up by the Government of India, reiterated the need for upland supplies and construction of a barrage across the Ganga for diverting its flow. In 1957, at the request of the Government of India, the Federal republic of Germany deputed Prof. (Dr.) Walter Hensen, Director of Franziue Institute of Soil and Waterways, Technical University, Hanover, to study the problems of Calcutta Port, the Hooghly and the Bhagirathi. After examining various phenomena, such as, the seasonal and long-term changes in depths over the bars and crossings, changes in salinity, intensity and frequency of bores etc., Prof. Hensen came to the following conclusion:

> The Hooghly and the Bhagirathi, if they are left to themselves, will gradually further deteriorate considerably. Ultimately, the depths and cross-sections... will so deteriorate as to carry only the run-off from its own catchment without any spill from the Ganga which she now receives. At present, portion of the Ganga water which is the upland discharge of the Hooghly received from the Bhagirathi and the Jalangi is about 65%. The present capacity will also decrease to a third of the existing capacity where the offtake of the Bhagirathi and the Jalangi from the Ganga gets completely closed for the whole year.... There will be catastrophe for the navigation and all other interests in the Hooghly.

He recommended

- A barrage across the Ganga, with which progressive deterioration of the Hooghly can be stopped and possibly improved gradually. If upland discharge is controlled, the freshet period can be prolonged and sudden freshet peaks which cause heavy sand movement and bank erosion will be flattened;

- The upper five bars and crossings at Panchpara, Sankrail, Munikhali, Pir Sareng, and Pujali will improve;
- The lower four bars at Eastern Gut, Moyapur, Roypur and Ninan will also improve with the construction of training works;
- With upland discharge and training works and/or dredging at some of the bars, there will be no additional difficulties at the bars and crossings. The measures adopted on the Ganga-Bhagirathi-Hooghly systems will not have any ill effects on the estuary below Diamond Harbour;
- The tidal reach will improve and the frequency and intensity of bores will decrease;
- Salinity in water supplied to Kolkata and industrial areas will diminish;
- The drainage capacity of the Bhagirathi and upper Hooghly will improve and flood hazards in the catchment areas will be reduced as well as sanitation and public health will ameliorate.

Minimum Upland Discharge

Based on the data given to him on hydraulics and hydrology of the Hooghly, Dr. Hensen suggested a sequence of upland discharge as under:

(i) January–April: 40,000–20,000 cusecs,
(ii) First Half of May: Up to 20,000 cusecs,
(iii) 15th May to 20th June: Up to 40,000 cusecs,
(iv) 20th June to 30th June: 40,000–60,000 cusecs,
(v) July–September: 60,000–140,000–80,000 cusecs, and
(vi) October–December: 80,000–40,000 cusecs.

He added that the model experiments will also have to determine the duration and quantity of the upland discharge that could be regulated to the best advantage.

Regarding insufficient collection of data, Dr. Hensen observed:

> In spite of exhaustive information which is available about the hydraulic, morphological and historical characteristics, it is not sufficient to determine with certainty all the details of the development of the Hooghly. For this, the period of intensive measurements which have to be taken in Nature, is too small. Only by carrying out these observations in a systematic way, one can obtain definite information about the Hooghly and the Bhagirathi. The work should consist of observations in Nature, their evaluation and theoretical analysis in the office and model experiments.

In 1962, Calcutta Port had set up a specialized Hydraulic Study Department to assess requirement of water, the morphological changes, collection and storage of data, physical and mathematical model studies and to advise various training measures and dredging. It also assessed water requirement from the Farakka Barrage for saving Calcutta port and set put their findings in the memorandum of February 1969 and submitted it to the government of India. It suggested the following methods for assessing requirement of water:

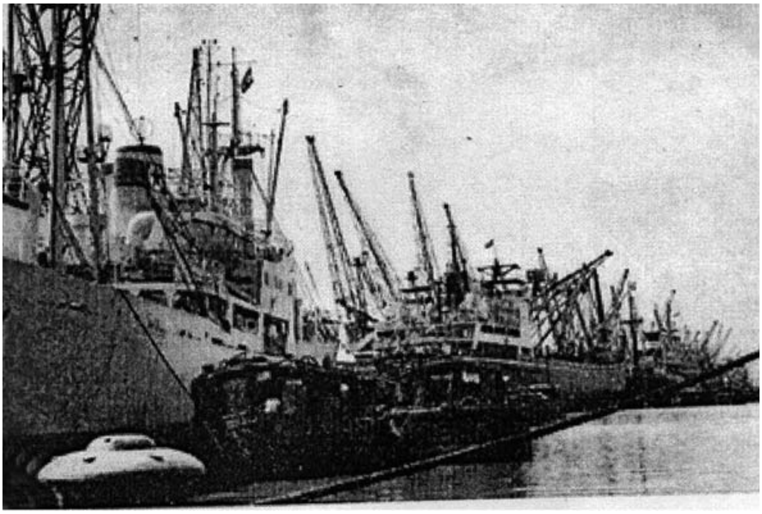
- Examination of low-water crossings,
- Loss of ebb flow owing to siltation,
- Requirement of flow following intrusion of salinity,
- System analysis in high-speed computer,
- Analysis with electric analogue model and harmonic analysis,
- Hydraulic model studies,
- Physical model, based on observed and prototype data.

A study of upper Hooghly above Kolkata, made on the basis of these data between 1924 and 1963, confirmed steady deterioration. The condition of river below Kolkata was also studied. It was seen that the cubic capacity in the section between Kashipur and Damodar outfall had decreased by 11 million cubic metres in 1917, by 39.26 million cubic metres in 1954 and by 64.17 million cubic metres in 1962. The rate of deterioration in 1954 was about 0.9 million cubic metres per year, as calculated by Prof. Hensen but it increased to about 3.4 million cubic metres per year, as calculated by Calcutta Port Commission from the data up to 1962. From 1963 to 1965, the government of West Bengal dredged about 4 million cubic metres of Ghusari sand near Kashipur for Salt Lake reclamation and dumped it on the marshes where a township, Salt Lake City came up with the spoils of dredging. This improved the reach between Kashipur and Damodar outfall, temporarily, but its condition worsened again in 1966. Thus, the progressive decline in the volume of water led to progressive loss of depths.

Prof. Hensen examined dredging data in the lower Hooghly between 1925 and 1956. Average dredging per year in this period was 3,614 h but from 1925 to 1965, it went up to 4,093 h and from 1956 to 1965 to 5,888 h. Annual dredging volume increased from 8 million tons in 1956 to about 10 million tons in 1965. Though freshets do a bit of scouring in dry season because of strong flow tide, the resultant re-distribution not only nullifies it but shrinks the volume even more. About 80% of the siltation occurs from February to May when the upland discharge is minimum.

At the instance of Prof. Hensen, mathematical studies were made by the department to assess the effects of deterioration on the tidal zone in the Hooghly. The navigational channel was excellent once upon a time and bore tides were few. Increase in tidal range and fall in depths of the navigable approaches had greatly increased the intensity and frequency of bore tides owing to shallow water. In shallow reaches, the velocity of tidal waves depend on elevation so that the troughs travel slower than the crests; the front of the wave rises steep, which causes the bores in the form of rushing high waves, breaking on the shallow part of the section. Up to 1950, 4 months – from November to February – were practically free from bore tides but afterward, these were a common feature throughout the non-freshet period. Bore tides damage river-side berths, jetties and moorings, push up their maintenance cost and can even immobilize them. As bores occur mostly with spring tides, they

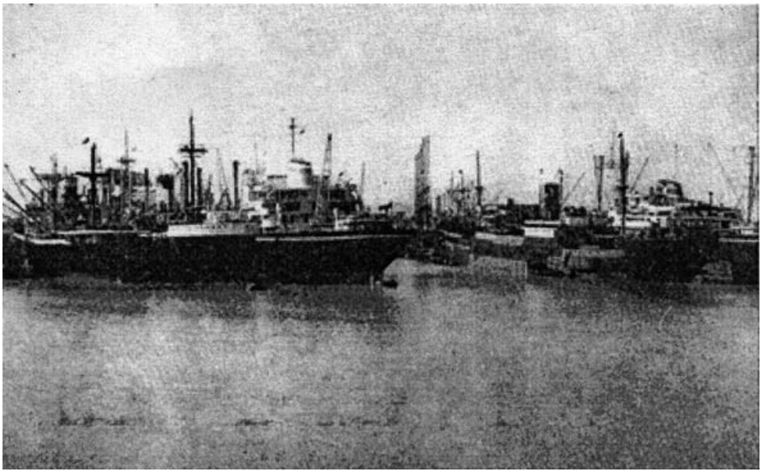
Photograph 7.1 The 'bore' hits a jetty



Photograph 7.2 Congestion of ships in the Kidderpore Docks during the bore tide restrictions in the port of Calcutta

cause congestion of shipping in the protected dock area. Photographs 7.1, 7.2 and 7.3, show the bore tide hitting a jetty, congestion of ships in the Kidderpore dock and congestion of ships in the King George's dock respectively.

The department also studied the effect of siltation on the tides and loss of energy. It was found that in 1917, peak losses of energy occurred in Chinsurah-Dumurdaha section, between 26 and 34 nautical miles, north of Kolkata while in 1955, these



Photograph 7.3 Congestion of ships in the King George's Dock during the bore tide restrictions in the port of Calcutta

occurred to the south of this section, between Garden Reach and Konnagar which is 9 nautical miles north of the city; the loss in the latter was 24.6 times more than in the former. This southerly movement of peak losses is a cause of deterioration of tidal and navigable status of the river and of removal of the barrier effect to improve tidal propagation. Hydraulic model studies by the Central Water and Power Research station, Pune confirmed the findings. Higher energy losses above Kolkata were gauged from special measurements of low water which showed that in a distance of 18.7 nautical miles, between Mayapur and Garden Reach, the low-water rose by about 0.35 m, while in a comparable length above Kolkata, it was three times more.

It follows, therefore, that to improve tidal propagation, the upper tidal compartment has to be improved. A scrutiny of depths and bore tides in 1935–1936 showed that in these respects, the Hooghly was better with a depth of over 9 m in the port area and on low-water crossings it was over 6.5 m, when the governing Balari bar was at its best. Though incidence of bores was more than in 1920, it was much less than at present. Thus, it was desirable to bring the river back to the 1920 condition, or to the second best condition in 1935–1936. To achieve this, the only possible ways could be (a) dredging the channel and dumping the spoils ashore, and (b) helping Nature to carry the silt-load to sea.

The reach above Kolkata needs about 3.35 million cubic metres of silt-dredging in a year and the reach below it up to Diamond Harbour needs about 3.40 million cubic metres but there was shortage of space for dumping spoils. Besides, dredging was not a permanent solution even with river-training unless the sand-drift features are reversed so that sand would not come in the navigation channel and the port area. Therefore, the only alternative was to optimize the head-water discharge.

Kolkata's need of drinking water is met by drawing from the Hooghly at Palta in south 24-Parganas, about 24 km north of the city, where a pump was installed in 1865 by the British Raj in Kolkata. Analysis of water at Palta showed increase in salinity; in 1900, it was about 50 ppm, in 1935, it rose to 350 ppm, in 1957 to 1,500 ppm and in 1966 to about 3,000 ppm, the potable limit of salinity being about 250 ppm. As salinity intrusion in the Hooghly, or any other river, is countered by increase of sweet water at the end of freshets, increasing salinity intrusion from 1900 to 1966 must have been due to gradual fall in sweet water supply from upland and also on loss of volume of water following shrinkage of sections. Increase in salinity posed problems to the railways and industries along the banks of the Hooghly; boilers and other machineries were scaled and corroded. Farm lands were affected, leading to low yield of crops etc.

Tube wells were sunk to supplement the city's water supply but their water was also brackish. Besides being almost equally high in salinity, tube well water was generally hard (total hardness varies from 700 to 900 parts and permanent hardness from 300 to 600 parts per million). The World Health Organization consultants who examined the water-supply problems of greater Kolkata observed that tube well water had high iron content too.

Salinity also depended on the relative strength of upland supplies. Together with the capacity of the river channel, this determined the building up of a sweet-water reservoir before the cessation of freshets. Because of the ever-varying tides and irregular upland supplies, salinity used to rise every day. To counter it, the only solution seemed to be an assured supply of controlled upland discharge to increase the channel capacity and build up a fresh-water reservoir. The report of the WHO consultant team in January 1960 said:

> If measures are not taken to increase the flow of fresh water down the Hooghly and so prevent the intrusion of salt water into the reach in which the Palta intake is situated, raw water becomes so saline that it will be unusable over a period of weeks, or even months. The seriousness of this threat should not be minimized since all the indications are that the salinity will increase and that this situation may in consequence arise within a few years' time. Moving intake upstream above Palta would only temporarily defer the threat, if supplementation of the Hooghly does not occur.

Hydraulic studies by Calcutta Port indicated average loss of river water volume in the reach above Kolkata up to Bansberia in Hooghly between 1944 and 1963 as 2.37 million cubic metre, per year for a stretch of 46 km, i.e., about 0.05 million cubic metre, per km per year. The average ebb tide excursion was of the order of 24 km, which meant a loss of about 1.20 million cubic metre per year. In 30 years, this storage would entail a loss in ebb discharge of 46,350 cusecs (1,312 cumecs). Thus, to revert to and maintain 1936 condition of the Hooghly, a minimum discharge of 46,350 cusecs (1,312 cumecs) would be necessary and to revert to and maintain the 1924 condition, it would require 64,890 cusecs (1,838 cumecs).

Prof. Hensen also stressed the importance of headwater discharge, as sustained discharge in a tidal river increases the duration and strength of the ebb tide and decreases those of the flow-tide. It also raises the water-level, i.e., increases depth of water. As bore tide depends on the depth, it influences them also. Calcutta Port Trust studied the probable rise of low water that would accrue from headwater discharge of 40,000 cusecs (1,132 cumecs) after commissioning of the Farakka Barrage. As observed hydrographs and levels were known, headwater effect could be isolated from tidal activity by use of statistical methods, first used in Central Water and Power Research Station, Pune but with not much success. Calcutta Port's Hydraulic Study Department developed a method using Fourier analysis for isolating the effect of 40,000 cusecs for any inlet tide at the mouth of the Hooghly estuary. The analysis showed that there would be one foot (0.30 m) rise of low-water on an average at Kolkata after headwater discharge of 40,000 cusecs, round the year, the correction factor being $\pm$ 3 in.

With this rise of low water, the incidence of bore tides near Kolkata was observed in 1961, 1963 and 1964 from March to May, when tides are generally high and strong and head water supply virtually nil, or negligible. On an average, the number of bores was 16 in March, 13 in April and 8 in May. If low water rose by a foot after headwater discharge, the number of bores fell by 70% in March, by 85% in April and 90% in May. As per assessments by Calcutta Port and the CWPRS, Pune, the tidal apex, i.e., the place where peak energy loss occurs, came down from Chinsurah-Dumurdaha section, between 26 and 30 nautical miles north of Kolkata to Garden Reach-Konnagar section, i.e., within 9 nautical miles north of the city in 1955. This was due to decrease in the volume of tidal compartment, shrinkage of cross-sectional area and increase in siltation in the river-bed.

Prof. Hensen who examined freshet discharge in Kalna held that it was decreasing. He said, the Bhagirathi being the main source of fresh water from the Ganga, supply decreased in the past 30 years, or so. In 1938, a peak discharge of 100,000 cusecs was possible but it came down to between 60,000 and 70,000 cusecs in 1957. Prof. Hensen demonstrated the sequence of rise of the river-bed, followed by encroachment of the tidal apex which moved further down in 1957. He examined various low-water crossings (bars) and held that to maintain a uniform and regular depth over these, round the year, a discharge of 80,000 cusecs was necessary but this much would not be available from the Ganga in the dry season.

Calcutta Port trust studied gradual deterioration of low-water crossings and found that with progress in shipping industry and invention of steam and oil engines, the gross tonnage of vehicles visiting the port increased from 0.70 million tonnes in 1862 to 6.8 million tonnes in 1912, to 7.75 million tonnes in 1939. During the World War-II, it had risen to 9.70 tonnes in 1944, which increased to 10.20 million tonnes in 1957. The port expected to handle a gross tonnage of 13.50 million tonnes by 1955 but the target was not reached mainly because of continuous fall in depths over the bars and crossings. These diminishing depths restricted the size and drafts of vessels which could ply on the Hooghly and enter the port. Because of strong tides, change in bed-levels and orientation of bars, navigation had to be carried on with utmost care. A large fleet of dredgers were engaged on the bars and sea-going ships had to be piloted by the Port officers from the Sand heads to the docks with wireless and depth-finding equipment. The cost of dredging in 1964–1965 was 16.90 million rupees which increased to 38.80 million rupees in 1973–1974 in addition to 12.50 million rupees paid in 2 years – from 1973 to 1975 – to private Indian and foreign companies for hire of dredgers. Some 1,200 ships visited the port, each way, every year. The port provided a number of anchorages and moorings and adopted special navigational procedures to take fullest advantage of tides but free flow of traffic was hindered by draft limitations. The bars and crossings which had to be negotiated in the course from Kolkata to Diamond Harbour were (their distance in kilometres from Calcutta port in brackets) Panchpara (8), Sankrail (10.5), Munikhali (14.5), Pirsareng (17), Poojali (21), Moyapur (35), Royapur (41), Ninan (58), Eastern Ghat (63) and Kukrahati (72).

The first five crossings between Garden Reach and Uluberia were being negotiated by ships of moderate to low draft, which could negotiate them in ebb tides. Ships of deep draft crossed these bars during night tide and anchor at Uluberia before ebb tide began. Dredgers constantly worked to maintain sufficient depth over these bars to let ships of moderate draft to leave on the ebb, as the number of ships that could leave on the night flow tide was restricted by lack of space and berths at Uluberia and Royapur anchorages. Deterioration of these bars was more in December when the upland supply stopped; their condition was worst at the end of the dry season in May. The cumulative result of these seasonal changes was long-term deterioration of the river, making it extremely difficult for even low to medium-draft ships to cross low-water bars during ebb tides. In spite of intensive dredging, the maximum depth over the bars and crossings went down between 1920 and 1954, as given in Table 7.1 below.

Study of the bars and crossings in freshet seasons led to the findings below:

- Separate channels were created by flood currents in dry season and freshet discharges during monsoon;
- During the monsoon, flood channels were affected by sands brought with freshet discharges;
- Depths over the bars and crossings increased following prolonged upland discharges but critical discharges varied for each bar and crossing;
- Most of the bars deteriorated when upland discharges decreased; this continued throughout the entire dry season;
- Depths over bars and crossings reduced, affecting the navigability of the channel from the sea, making dredging a temporary and partial palliative.

Table 7.1 Diminution in maximum low water depth over bars and crossings (between Kidderpore Docks and Hooghly Point, 34 n. miles)

Location of bars and crossings	Depths in 1920(m)	Depths in 1950(m)	Diminution	
			Actual	Percentage
1. Panchpara	8.54	6.33	2.21	26
2. Sankrail	7.11	5.06	2.05	29
3. Munikhali	8.31	4.88	3.43	42
4. Pir Sarang	7.47	5.34	2.13	29
5. Poojali	8.23	6.40	1.83	22
6. Moyapur	5.03	4.63	0.40	4
7. Roypur	5.23	4.45	0.78	15
8. Ninan	6.66	3.73	2.93	44
9. Eastern Gut	4.83	3.96	0.87	18

As desired by Prof. Hensen in 1957, the Hydraulic Study Department of the Calcutta Port Trust undertook studies on increase of siltation in the Hooghly, gradual decline of bars and crossings, increase of tides, salinity, fall in the water volume etc. and sent the findings to him and also submitted to the Government of India for reviewing the need of fresh water supply in the river for its resuscitation. Prof. Hensen visited Kolkata in 1966 and 1977, reviewed the collected data and came to the conclusion that the minimum requirement would be 40,000 cusecs. He told the Director of the River Research Institute, Kolkata, the Chief Engineer of the Farakka Barrage Project and the Chairman and technical officers of the Calcutta Port Trust that in the first half of May 1957, provisional discharge requirement was at least 20,000 cusecs, not less as interpreted by an erroneous translation of his German report. He studied the fresh data and revised the requirement upward to 40,000 cusecs as the minimum in dry months.

The RRI, a State Government outfit, carried out independent investigations by studying regime relationship of tidal inlets and prototype data and came to the conclusion that a maximum of 40,000 cusecs was required in dry season to obtain stability in the port reach. Studies were also carried out by Dr. D. V. Joglekar, Director of the CWPRS, Pune, A. C. Mitra, Chief Engineer (Irrigation) of Uttar Pradesh, Dr. J. J. Dronkers, Chief of Hydraulics and Research, Netherlands Government, Dr. K. L. Rao, India's Minister of Irrigation and Power and Debesh Mukherjee, the first General Manager of the Farakka Barrage Project.

Views of Indian Experts

Dr. Joglekar studied the siltation above Kolkata and the downstream shift of the effective barrier and thus of tidal energy and said in his report, dated 22nd January 1968:

> Loss in capacity above Calcutta has resulted in the increase of ranges . . . of flood currents in the dry season and incidental increase of re-distribution of sand in the dry season in the port reach, causing progressive loss of navigable depths.

Studies by him to evaluate the pattern of energy losses from the observed simultaneous spring-tide gauges, reach by reach, showed that in 1917, the peak losses occurred in the Chinsurah-Dumurdaha section, 40–60 km above Kolkata but in 1955, the region of heavy losses moved down to Calcutta-Konnagar reach within 12 km of the port. This downward shift of peak energy losses was due to downward movement of effective barrier and hence to the decline of tidal propagation. Increase in the frequency of bore tides in recent years also confirmed this. He was confident that with 40,000 cusecs from the Farakka Barrage and by adopting measures, mentioned above, the Hooghly can be restored to its 1936 condition. Though the required discharge had been assessed at 46,000 cusecs, Dr. Joglekar did not consider that this reduction of available discharge would have any adverse effect, as the supplied water would be relatively silt-free.

A. C. Mitra in his report observed that under present conditions, headwater discharge of 40,000 cusecs will be necessary during the non-freshet season to neutralize the landward drift of sediment in the tidal portion. Less discharge, say of 30,000–35,000 cusecs, would reduce the total volume of accretion and hence the rate of deterioration but the zone of most significant accretion which was above Kolkata then would shift seaward and be most pronounced between Garden Reach and Babughat where the major docks, jetties and moorings were located. If deterioration in the non-freshet season can be arrested by sustained headwater discharge of 40,000 cusecs in this season, improvement that would follow from freshet flows, every year, would gradually improve the river condition. If and when improvement could be substantial and reverted the river's regime to that from 1930 to 1935, the requirement of headwater discharge to prevent deterioration of the regime in non-freshet seasons would be somewhat less. This reversion could be expedited with a discharge of 45,000 cusecs in the first few years of operation of the Feeder Canal.

View of Dr. J. J. Dronkers

Dr. J. J. Dronkers visited Kolkata in November 1968 at the invitation of Calcutta Port Commissioners, and in his report, based on prototype data, observed:

> To balance the sand movement of Garden Reach, the ratio of the flood and ebb flow must be unity. Superimposing the corresponding ebb velocity needed in the period, together with the change in the period of flood and the ebb, it is seen that a discharge of the order of 50,000 cfs (1430 m^3/sec) need to be maintained. Taking a conventional allowance of ± 10% on such computation, it would appear that for arresting the upland sand movement above Calcutta for a range of 15 feet inlet tide at the Sagar sea-face, the lowest discharge of the order of 45,000 cfs (1280 m^3/sec) would be necessary. The ebb sediment movement with upland discharge would be present in the lower ranges of the tide but the most significant landward movement need to be arrested, when the ranges of tides are between 9 feet and 18 feet;. Therefore, taking the mean significant tide for sediment movement as 14 feet;, the order of discharge on the lower limit would be 40606 cusecs (1150m^3/sec).

Prof. Hensen was again consulted in November 1971 by a team of officers of Calcutta Port, who carried with them all up-to-date data and analysis to get him ascertain the scope of reduction of the discharge, if at all. After due examination, Prof. Hensen in his report in the same month said:

> A supply of the order of somewhat higher than 40,000 cusecs is needed, throughout the year, to reverse the process of sanding up the ship route to Calcutta harbour. . .. Ship routes are ebb-tide oriented during freshets; they change to flood-side between November and May. If headwater is not maintained at 40,000 cfs in these seven months, the ship route in crossing would quickly move from ebb to flood and would stop passage of ships.

Dr. K. L. Rao's contention that the minimum requirement of the Hooghly to save Calcutta port was 40,000 cusecs, was confirmed by S. S. Dhawan, then Governor of West Bengal in a letter to Indira Gandhi on 27th August 1970. Later on, Dr. Rao changed his mind and advocated supply of head water into the Hooghly in a phased manner, varying from 40,000 to 20,000 cusecs in dry season.

Debesh Mukherjee cited a number of times that a sustained minimum flow of 40,000 cusecs, round the year, was absolutely necessary for the rejuvenation of the Hooghly.

To sum up the problems of the Bhagirathi-Hooghly, as cited by Indian and foreign experts:

a) Eastward shift of the main Ganga toward the Padma, which occurred in early 16th century, leaving the original course through the Bhagirathi. Shifting of navigation through a ship canal, or shifting the port to Canning on the Matla river, or navigation through the Jalangi and Mathabhanga, were no permanent solutions;
b) Fall in the duration of flow from the Ganga to the Bhagirathi and gradual shifting of the offtake point to downstream, leading to loss of headwater volume and of depth;
c) Uncontrolled and excess entry of sand and silt in the Bhagirathi, resulting in their deposition in the mouth and the bed;
d) Fall in the river's capacity and movement of tide-borne sand and silt upward and their subsequent deposition in the bed which further reduced the capacity;
e) Increase in tidal range and flow-tide current, intensifying bores in the port area;
f) Increase in salinity in river water, making it unfit for human consumption and damaging boilers and industrial machineries, located on the banks; ingress of salinity in ground water, causing loss of agricultural yield;
g) Siltation over the bars and low-water crossings and shifting of navigation routes, year to year, and loss of depth in navigation channels;
h) Optimum frequency and volume of dredging and non-availability of enough land for disposal of dredged spoils; and
i) Decline in movement of deep-draft ships, in handling of import and export cargo etc., affecting the economy of the country.

Remedial measures that were considered for counteracting the above were as under:

i. Shifting of navigation channel through a ship canal and of the port;
ii. Dredging of the bars and crossings and also of the river-bed;
iii. Dredging of the offtake of the Bhagirathi and the bed of the entire river;
iv. River-training works; and
v. Provision of controlled and silt-free upland discharge, round the year.

As regards (i), shifting of the navigation channel or the ports not successful and the proposal was abandoned at the initial stage.

As regards (ii), dredging could give only a temporary relief and with continuous dredging, the root cause of deterioration could not be removed, because dredging was optimum and there was not enough space ashore where dredged spoils (about 100 million cft) could be dumped, year after year.

As regards (iii), it was impossible to keep the Bhagirathi head active by dredging for prolonged supplies, round the year, as the head of the river was not stable and had shifted downward, several times, in the past. Besides, frequent changes in the

Ganga and their effect on the offtake of the Bhagirathi precluded such possibilities, as the head condition depended on the disposition of the parent river. The offtake had shifted from Dhulian to Suti and then to Geria and at present is at Raghunathpur, further down. These shifts were due to natural closure of old offtakes and creation of new, leading to gradual diminishing of head water supply, in frequency and volume, from the Ganga owing to alluviation at the head and the bed of the Bhagirathi. The angle, formed between the Ganga and the Bhagirathi at the offtake gradually changed to obtuse and finally got closed, creating a new head, downstream. It was not practicable, nor was it attempted, to peg a favourable offtake at a particular place and therefore, dredging of the offtake for facilitating entry of head water was not practicable.

As regards (iv), river-training works in the Bhagirathi and the Hooghly used to have very local effects and could not help maintain the deep navigation channel in the river course, especially when water-level in the river fell between 25 and 30 feet in the dry season. The cost of such works was also very high and the tasks were hazardous; besides, these alone could not maintain the channel, unless supplemented by head-water supply, round the year.

Regarding (v), controlled diversion of upland discharge from the Ganga was the only practical solution to resuscitate the Bhagirathi-Hooghly. This alone could reduce siltation in the bed near Calcutta port area and over bars and crossings, decrease salinity in river and ground water, bores and tidal ranges and increase navigation, the river's capacity and port activities etc. Such diversion was possible only through a barrage on the Ganga at a suitable location with provision of gates to head up water. With such discharge, it would be possible to prolong the freshet period and moderate sharp and freshet peaks which cause heavy sand movements and bank erosion. The historical background and elaborate studies by experts as well as by concerned institutions and committees across a century favoured the construction of a barrage to save Calcutta port and revive the economy of two Bengals and of India as a whole.

The need for improving head-water supply was even more urgent, considering the interception of the floods in the Damodar and the Mayurakshi by dams, constructed much earlier. Though they intercepted coarse sand and silt, flowing from above, which could otherwise intrude into the Bhagirathi-Hooghly, they substantially reduced freshet discharge, increase silt deposition and weakened tidal flows and intensified bores and sand movement with flow-tides.

Farakka Barrage Project

Although the need for a barrage at Farakka was felt for a long time, it could not be constructed by the British Indian government in Delhi. Only after Independence in 1947, the free government conceived it with the following objectives:

a) For perennial head-water supply from the Ganga into the Bhagirathi-Hooghly, particularly in the dry season, to reinforce the capacity of the ebb flow, to scour residual silt during flow-tide to revitalize Calcutta port, enable it handle more cargo and to reduce cost of dredging and port installations;

b) For restoration of the perennial navigation route between Kolkata and northern India along the Ganga-Bhagirathi-Hooghly, through a Feeder Canal between the Ganga and the Bhagirathi;
c) When the river's capacity increases, flood hazards on both banks in monsoon months would be less and relieve drainage congestion;
d) Salinity in the Hooghly water near Kolkata would return to the potable limit; this will improve water supply to the city and suburbs and save industrial machineries, using the river water as well as boost farm yields by decreasing salinity of the soil and ground water;
e) Communication between the people of the partitioned regions of the northern and southern banks of the Ganga would be restored, when a rail-cum-road bridge is constructed over the barrage.

Effects of the Partition

The Bengal Boundary Commission, constituted by the Governor-General of India in June 1947, headed by Sir Cyril Radcliffe to demarcate the boundaries of India with the newly created nation of Pakistan gave due consideration to maintaining the continuity of the Ganga-Bhagirathi-Hooghly waterway. The demarcation was done, *inter alia*, on the basis of contiguous areas of Muslims and non-Muslims. Sir Radcliffe kept in mind the need for coordination between the two countries to ensure head-water supply from the Ganga to the Hooghly. Non-Muslim members of the Commission urged Sir Radcliffe that

> It is necessary that some means, or other, should be found, by which an appreciable portion of the Ganges floods can be induced to pass through the Nadia rivers in preference to the Padma, the hydraulic conditions of which are, of course, much more efficient. In order to do this and to prevent the Hooghly from languishing altogether and reviving the health and industry of Bengal, it is absolutely necessary that the head-water of the Hooghly should be under the control of the West Bengal State

The Commission gave due importance to this plea and dealt with the following points:

i. If the city of Kolkata must be assigned to one or other of the States, what were its claims to the control of the territory, such as all, or part, of the Nadia rivers, or the Kulti rivers, upon which the life of Kolkata as a city and port depended?
ii. Could the attractions of the Ganga-Padma-Madhumati river-line displace the strong claims of the heavy concentration of Muslim majorities in the districts of Jessore and Nadia without doing too great a violence to the principle of the terms of reference?

Keeping the above in view, the Commission demarcated the boundary in such a way that the barrage, the Feeder Canal and all the head works of the project, when eventually constructed, will be within the territory of India. The award of Murshidabad to India, a Muslim-majority district, in exchange of Khulna, a Hindu majority district was made with this in view.

Construction of the Barrage and the Canal

Investigations for the barrage and the canal were launched by West Bengal government in 1948; it was taken over by the CWPC, New Delhi in 1950. Two sites were inspected for the barrage, one at Rajmahal in Bihar and the other at Farakka in West Bengal. For the sake of stability and economy of construction, Farakka was chosen as the better site. Besides topographical and geological surveys, long and cross-sections of the river, observations on the gauge and discharge, silt-load, shift of channels, explorations of foundation etc. were carried out. Necessary hydraulic model studies were made by the CWPRS, Pune and at the RRI, West Bengal. The CWPC was entrusted with designs of various components of the barrage. Another outfit, The Ganga Basin Organization, was set up under the Union Ministry of Irrigation and Power to conduct studies about the project. Another organization, the Farakka Barrage Project was also launched under the same Ministry with the headquarters initially in Kolkata and later shifted to Farakka in 1964.

Farakka had no facilities except a rail-head for passenger and goods trains, a ferry service for people and cargo to cross the Ganga and a police station. It was just a village, with no post, telegraph or telephone services. The project authorities first took up construction of staff quarters, hostels, dormitories, warehouses, power house and office premises as well as procurement of heavy machineries and construction materials. It began field surveys and set up finance and security outfits, workshop, laboratory, hospital, school, post and telegraph office, telephone exchange, market and other essential infrastructure. Engineers of various disciplines, technicians, skilled and unskilled workers were recruited to build and run a huge project. A separate organization, called the Farakka Barrage Control Board, was launched, under a central minister to oversee expenditures and execution of the project. The Calcutta Port opened a hydraulic study department for observations on the Hooghly, their study and evaluation in laboratory. The construction of a huge structure on the alluvial and mobile sand-bed was a tremendous task and by the end of 1965, the vast project was like tiny David facing the giant Goliath of an untamed mighty river. A high-level technical advisory committee was constituted in 1962, drawing experts from across India.

The specifications and the main components (also given in Fig. 7.1) were

1. The total length of the barrage was 2244.40 m, or 7363-6″ feet between abutments with 109 bays of 18.30 m, or 60 feet clear span each with a rail-cum-road bridge over it;
2. A head regulator at the canal head, having 11 bays of 12.19 m, or 40 feet clear span each;
3. A 38.30 km, or 23.80 mile, long canal with design bed-width of 150.90 m, or 495 feet taking off from the Ganga above the barrage and falling into the Bhagirathi, near Jangipur town in Murshidabad district;
4. A barrage at Jangipur, of 15 bays of 12.19 m, or 40 feet clear span each, over the Bhagirathi;

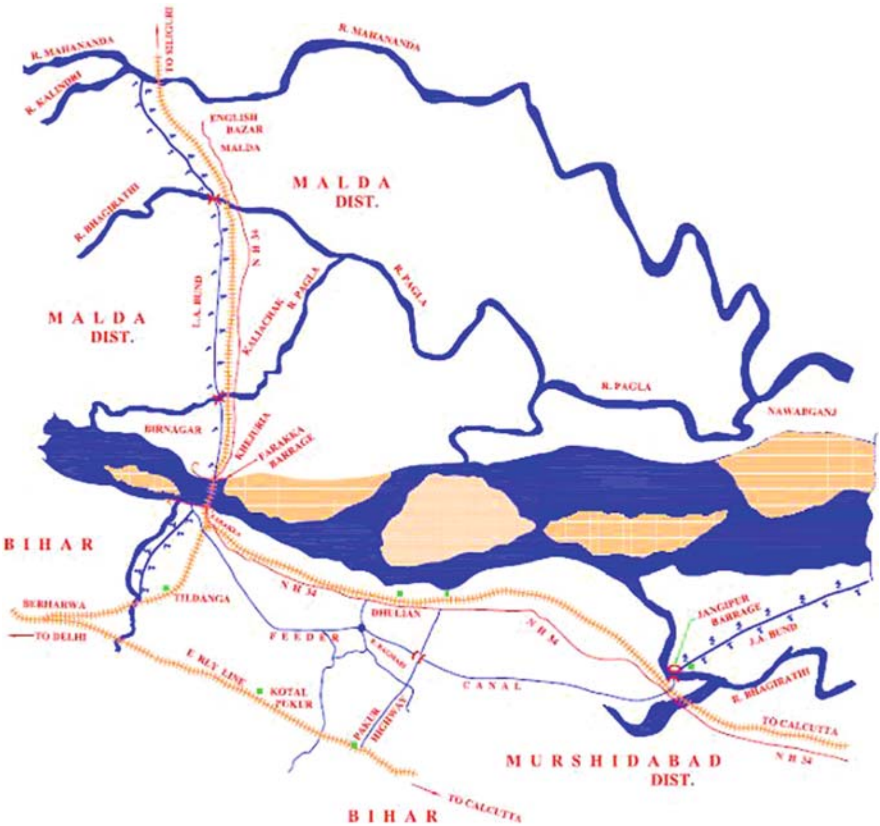


Fig. 7.1 Index plan showing some major components of Farakka Barrage complex

5. A Navigation Lock of about 24.70 m, or 81 feet width with a lock channel upstream of the barrage, connecting the Ganga with the Feeder Canal;
6. A number of cross-drainage structures, such as regulators, inlets, syphon at various places in Malda and Murshidabad districts;
7. Two navigation locks, one in Murshidabad and the other in Malda districts, for use of traffic in monsoon months; and
8. Embankments, like guide and afflux *bund*s etc.

Problems Faced and Overcome

The main difficulty in constructing the barrage was the extremely short time available in a season to complete the work. As no work was possible during monsoon and flood seasons, the foundation laying was planned from December to May every year.

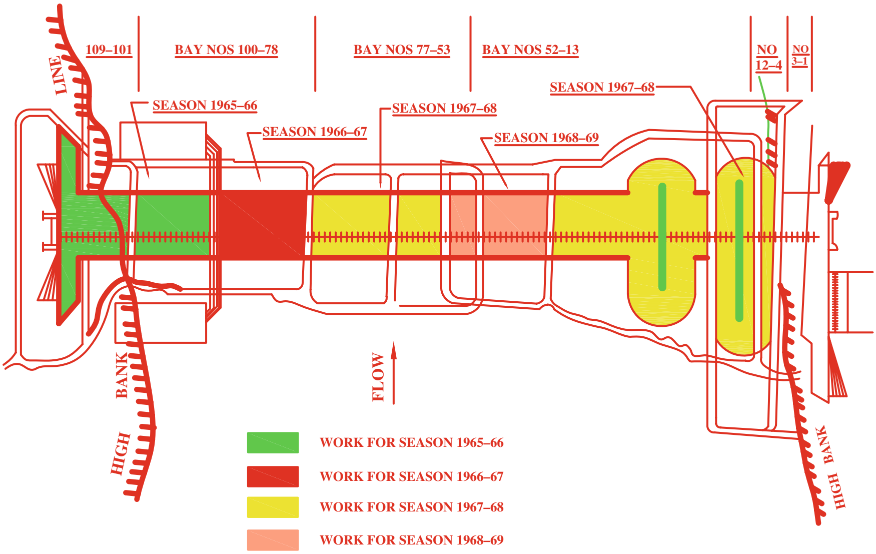
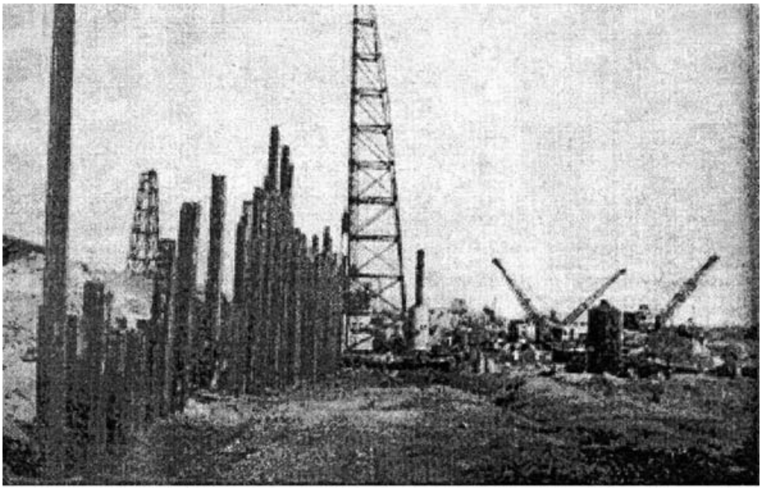


Fig. 7.2 Coffer dam enclosures of Farakka Barrage for different seasons (See also Plate 9 on page 371 in the Colour Plate Section)

The enclosure of a portion of river by coffer dam, completion of excavation, dewatering, sheet piling, foundations and other permanent works and also the removal of coffer dam prior to each flood season to allow flood water to pass through the original river course, all had to be done within the limited period of working season. Suggestion of cellular type coffer dam by foreign experts for closure of the river during construction was tried on an experiment basis, but the same proved unsuccessful after passing of one flood season over it. The method was therefore abandoned. The construction of earthen coffer dam and its maintenance during construction of the main structure was one of the most difficult works (Fig. 7.2). However, with great dedication by a team of expert engineers and workers, the work of construction of coffer dam was done for the 3–4 working seasons and the main barrage structure could be completed in time in early 1970. Photographs 7.4 and 7.5 show sheet piling works in progress and well sinking on right bank of Farakka respectively.

The construction of central bays of the barrage raft between 53rd and 77th bay posed some difficulty. The crest of the bays was constructed in two stages. In the first stage, the crest was kept lowered to allow the discharge to pass through the bays. They were raised to the design level in the second stage after flood discharges passed through the side-bays (Fig. 7.3). Photograph 7.6 shows Farakka Barrage piers under construction in 1969.

The excavation and construction of Feeder Canal, one of the biggest of the world, posed a number of problems. Experienced contractor with sufficient number of workers was difficult to find. Heavy earthmoving machineries were deployed to achieve progress satisfactorily. The rail-line and State and National Highway had



Photograph 7.4 Sheet piling in progress on the upstream line of head regulator, January 1965

Photograph 7.5 Well sinking on right bank of Farakka, March 1965

to be interrupted while excavating the canal. The rail tracks were diverted after construction of bridges over the canal at two locations, where excavation had to be slowed down. A difficult situation arose in case of the State Highway between Dhulian and Pakur, where the bridge work was slow. The earthwork below the road bridge could not be excavated as the suspended girders (3 nos.) of the central suspended span of the bridge were being cast over the ground and placing the same over the bridge piers took considerable time with high technique of lifting the heavy

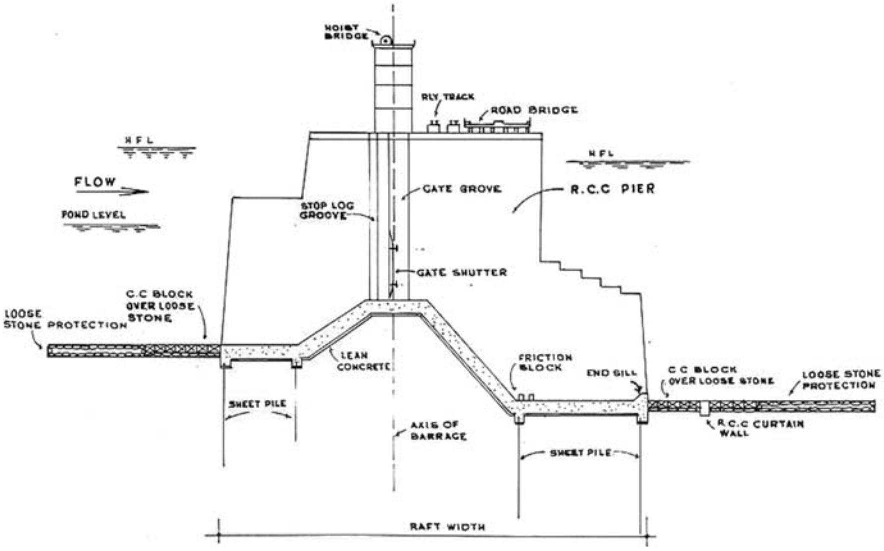
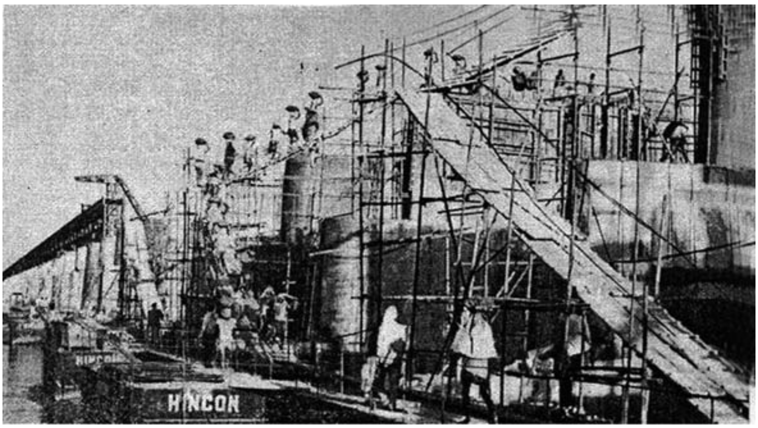


Fig. 7.3 Typical section through Barrage bays



Photograph 7.6 Farakka Barrage Piers under construction in 1969

weights (about 70 tons each) by more than 15.0 m (50.0 feet;) height. Special type of cranes, brackets and other accessories were used at site to do the job and the canal excavated thereafter (Fig. 7.4). Photographs 7.7, 7.8 and 7.9 show excavation work of Feeder Canal in progress in 1966 and 1970 and prestressed concrete girders being placed over the piers of Pakur road bridge.

Innumerable problems were also faced during construction of other ancillary structures like navigation locks, siphon below the canal bed to allow new passage of a river etc. In all the cases, problems of foundation excavation and dewatering of the

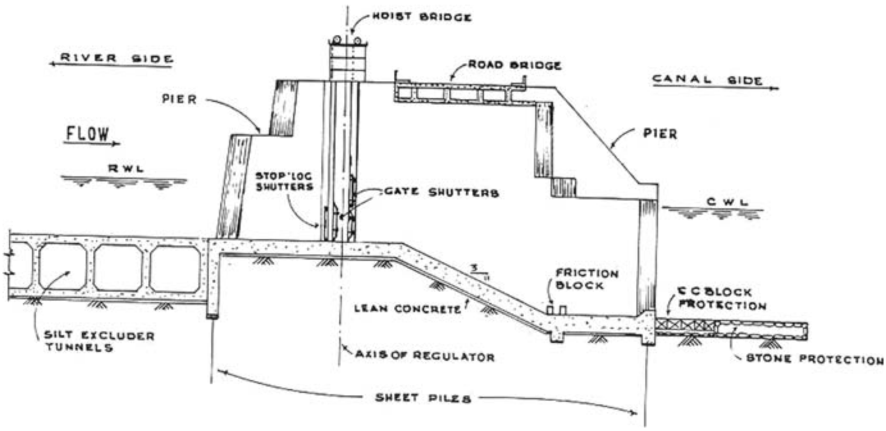


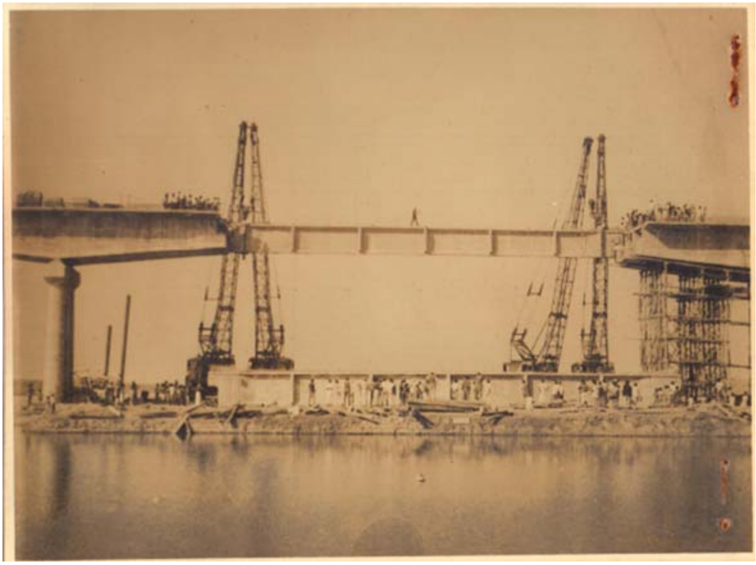
Fig. 7.4 Typical section of regulator

Photograph 7.7 Excavation of Feeder Canal in progress (1966)

working area had been successfully encountered and construction works completed in time.

Concreting works of the main barrage were completed in 1969. The steel gates and hoist structures were erected in 1970 and the rail-cum-road bridge completed in 1972. The excavation of the canal took three more years. The barrage was ready for commissioning in April 1975. The dream of Sir Arthur Cotton in 1853, the views of Indian and foreign experts, spanning more than a century, technical guidelines and advice of the German expert, Sir Walter Hensen in 1957 and tireless efforts of hundreds of engineers, technicians and workers since 1962 came to a fruition

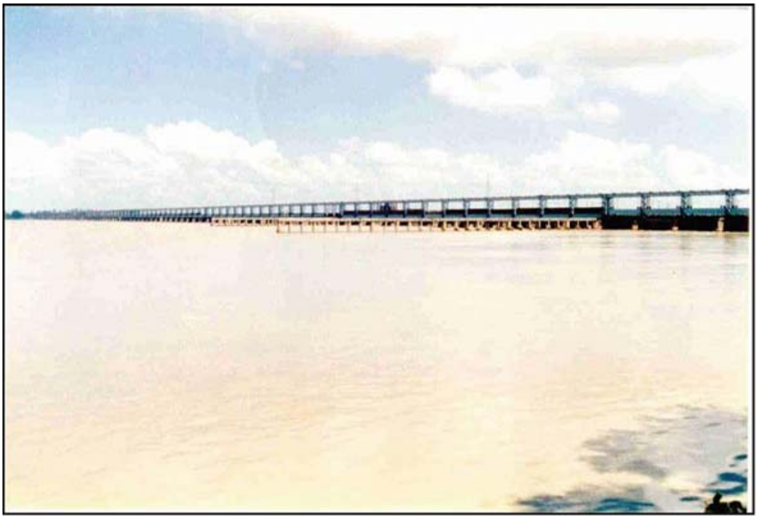
Photograph 7.8 Feeder Canal under excavation during monsoon of 1970



Photograph 7.9 Prestressed concrete girders of Pakur road bridge being placed over the piers

in early part of 1975. Photographs 7.10, 7.11, 7.12 and 7.13 show river Ganga on both upstream and downstream of Farakka Barrage and Feeder Canal flowing downstream of Head Regulator.

The Feeder Canal was commissioned on 24th April 1975 and trials started from that date. The project was formally dedicated to the nation on 21st May 1975 by Jagjivan Ram, India's Minister for Agriculture and Irrigation, in the presence, inter



Photograph 7.10 Ganga river upstream of Farakka Barrage (See also Plate 7 on page 370 in the Colour Plate Section)

alia, K. N. Singh, his deputy, Siddhartha Shankar Roy, Chief Minister of West Bengal, A. B. A. Gani Khan Chowdhury, his Minister for Irrigation and Waterways and senior Central and State officers. Bangladesh was represented in the ceremony by a team of engineers, led by B. M. Abbas, then adviser to President Ziaur Rehman on irrigation and flood control.

Photograph 7.11 Ganga river downstream of Farakka Barrage (See also Plate 8 on page 370 in the Colour Plate Section)

Photograph 7.12 Farakka Feeder Canal with head regulator

Photograph 7.13 Farakka Feeder Canal with NTPC power plant seen at a distance

India's President, Fakhruddin Ali Ahmad in his message on the occasion, expressed the hope that 'the mighty project will not only revitalize the port of Calcutta but contribute to the prosperity of West Bengal and other States of the eastern region'. Prime Minister, Indira Gandhi in her message said: 'Calcutta port is of crucial importance to the economic life of West Bengal and the entire country'. The

Farakka Barrage has been built to revitalize Calcutta port. Jagjivan Ram who inaugurated the project said in his address that it 'has become possible as a result of the understanding and cooperation between our friendly neighbour Bangladesh and our country'. Chief Minister, Siddhartha Shankar Roy in his address said, the dedication of the project to the nation on the auspicious day, 'is the redemption of a pledge given to the people to revive the dying port of Calcutta'. The project symbolized taming of Nature for benefit of people of two countries but the river had to adjust to the changed conditions and circumstances in a geological time-frame beyond human interference. The project got into the Guineas Book of Records as 'one of the largest river control, management and water resources development projects of the world'.

Chapter 8
Inconsistency, or A Conspiracy?

From the beginning to the end of the construction of the Farakka Barrage, doubts were raised, in some quarters, about the necessity of diverting 40,000 cusecs of the Ganga's upland flow to the Bhagirathi-Hooghly to resuscitate it and the Calcutta port. The Project Report, 'The Preservation of the port of Calcutta', prepared by India's Ministry of Irrigation and Power, New Delhi and sanctioned in 1961 specified optimum continuous discharges through the feeder canal into the Bhagirathi in cycle of withdrawals, as under, if these were confirmed by model tests before regularization.

	Period	Optimum releases into Feeder canal
1	1st January to mid-March	40,000 cusecs
2	Mid-March to mid-May	20,000 cusecs
3	Mid-May to mid-September	20,000 cusecs
4	Mid-September to end-December	40,000 cusecs

The report further mentioned that it would be possible to maintain continuous flow through the Bhagirathi below the Jangipur barrage with this operational pattern throughout the year.

A major input in the Report might have been the recommendations of Dr. Hensen in 1957, particularly the sequence of upland discharge from his suggested release through the River Bhagirathi. His sequence was based on very limited data made available to him in 1957. He accepted these but recommended collection of more data on the Bhagirathi-Hooghly by extensive observations. This led to the formation of a separate Hydraulic Study Department in the Calcutta Port Trust in 1962. The data that it collected were shown to Dr. Hensen when he visited Kolkata again in 1966 and 1967. Studying them, he came to the conclusion that the minimum requirement of water to stop the deterioration of the Hooghly and to gradually improve it was 40,000 cusecs. More data were collected and sent to him in West Germany in 1971 through a team of officers of the port to find out if there was any scope for reducing the upland discharge through the canal. He examined the fresh data and held that more than 40,000 cusecs was needed, round the year, to clear the ship route to Calcutta harbour and to restore the river to 1935–1936 condition.

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7_8, © Springer Science+Business Media B.V. 2010

Dr. J. J. Dronkers, an expert on tidal hydraulics in Netherlands, who was also consulted by Calcutta Port Commissioners in 1968 recommended minimum 41,000 cusecs to push accumulated sand downward, which could otherwise move upward for a mean tide range of 14 feet. For the maximum tidal range of 18–20 feet, which is normal near the port, the minimum requirement would be about 60,000 cusecs.

Many Indian experts also gave their views on the issue. Dr. D. V. Joglekar, Director of the CWPRS said in his report of 1968 that a discharge of the order of 46,000 cusecs would be necessary to restore the river to 1935–1936 condition, but considering the availability of water at Farakka, at least 40,000 cusecs were necessary.

A. C. Mitra, Chief Engineer of Uttar Pradesh Irrigation Department and Chairman of the Technical Advisory Committee of the Farakka Barrage Project held that a sustained head-water discharge of 40,000 cusecs was the minimum in the non-freshet season to neutralize the landward drift of sediments throughout the tidal portion of the river and to bring the regime back to 1930–1935 condition; however, this could be gradually reduced as per availability of water at Farakka after achieving substantial improvement.

Other eminent engineers like Dr. K. L. Rao and Mr. Debesh Mukherjee also advocated minimum head-water supply of 40,000 cusecs, round the year for rejuvenation of the Hooghly. When the Barrage was nearing completion, Dr. Rao, then India's Minister for Irrigation and Power, suddenly expressed doubts about the results of the model tests in the feeder canal that a continuous flow of 40,000 cusecs was necessary to save Calcutta port. He made a statement in Parliament on 3rd May 1973.

> The results of the model tests by the Central Water & Power Research Station, Pune show that the discharge given in the original report of 1959 is found to be satisfactory but the model tests by the Calcutta Port Commissioners indicated the requirements of higher discharges at 40,000 cusecs during the lean months. Due to the difficulties of simulation, model tests, especially for large rivers, have serious limitations in giving any precise quantitative answer to problems and can, at best, be indicative. It is difficult to quantify, precisely, at this stage, as to what is the discharge required to meet the needs of Calcutta port. The exact requirements of water are best determined by observation on prototype itself. It is, therefore, decided to adopt the following procedure for operation of the Farakka project.
>
> a) For five years, after water is let down . . . the Feeder Canal will carry the full discharge of 40,000 cusecs throughout the year, including lean months;
> b) The necessary discharge for efficient functioning of Calcutta port by continuing the improvement as a consequence of (a) will be determined by a study team by observing the effects during the first five years and subsequent two years, when the discharge will be varied;
> c) Simultaneously with the above, trench-dredging will be carried out above Howrah Bridge in varying degrees, so that the aforesaid Study Team can observe its effects on tidal prism and check any heavy movement of bed sediment on to the port area; and
> d) After the period of seven years, the entire position will be reviewed in the light of reports and observations of the aforesaid Study Team.
>
> In conclusion, it may be stated that the Government of India fully recognize the importance of maintaining the navigability of the Hooghly for the preservation of the Calcutta port as one of the topmost Indian ports and will take all necessary steps to ensure the same.

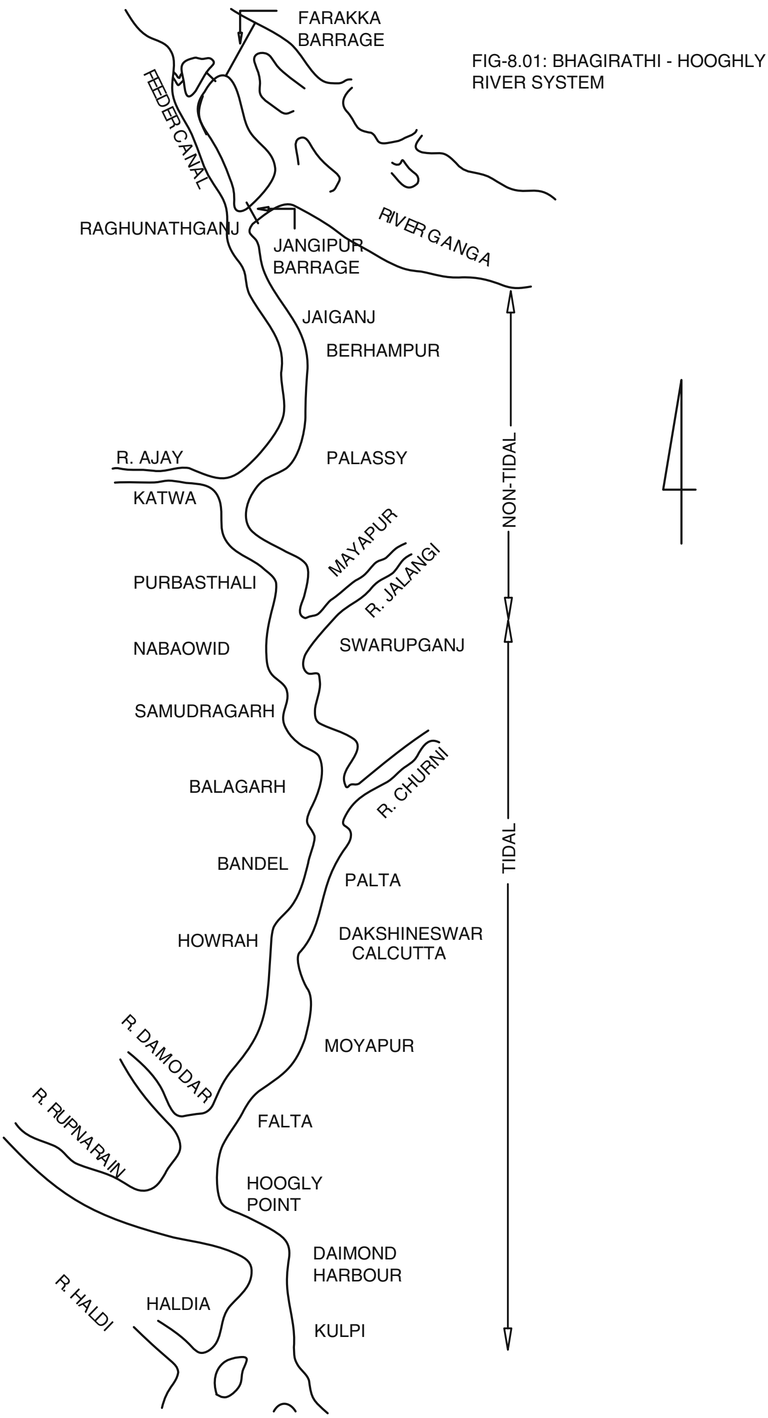


Fig. 8.1 Bhagirathi-Hooghly river system

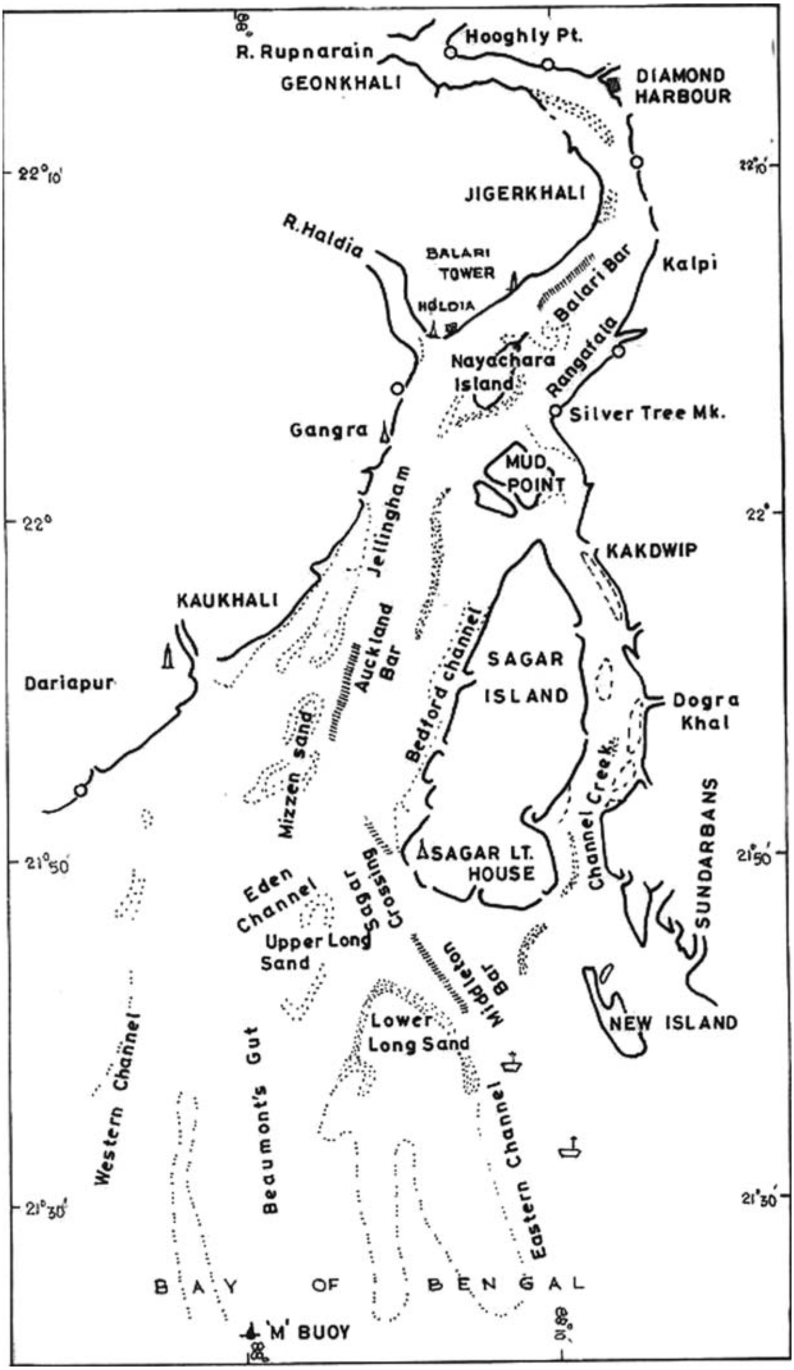


Fig. 8.2 Plan of Hooghly estuary (*lower*)

Figures 8.1 and 8.2 show the Bhagirathi-Hooghly river system and the plan of the Hooghly estuary (lower) respectively.

Dr. Rao further announced in Parliament on 3rd May 1973 that the flow of the Ganga was such that it would not be possible to release into the Bhagirathi-Hooghly more than 20,000 cusecs through Farakka Barrage from January to the first week of May. Curiously, it was Dr. Rao himself, who had advocated linking the Ganga with the Kaveri under his pet project, 'National Water Grid' so that part of the Ganga water could be diverted to the arid regions of the Deccan (South India) which has almost no perennial stream, comparable to any north Indian river. Dr. Rao did not give any clear idea about the availability of lean-season flow, or about augmentation of the Ganga flow, while formulating the Ganga-Kaveri link canal. Dr. Rao also drew another scheme to link the Ganga with the Brahmaputra under the same 'National water Grid' plan but he gave overriding priority to the Ganga-Kaveri link canal which would carry between 40,000 and 100,000 cusecs of the Ganga water to the southern river for 300 days in a year. This was an absurd idea and made questionable the role played by him during his penultimate tenure as India's Irrigation and Power minister, particularly when the construction of the Farakka Barrage was nearing completion. Work on the main barrage was almost complete and the feeder canal was in the focus.

Expectedly, this raised a hue and cry in West Bengal and within and outside India's Parliament in 1972 and 1973. Ambiguity in Dr. Rao's statements created serious uncertainties about the future of Calcutta port and its services to the city of Kolkata. The details of Dr. Rao's plan were as under:

	Period	Release through Farakka barrage
1	From 20th June to end-December	40,000 cusecs
2	January to mid-March	40,000–20,000 cusecs
3	Mid-March to mid-May	Up to 20,000 cusecs, or as available, and,
4	Mid-May to mid-June	20,000–40,000 cusecs

In monsoon months, the flows in the Bhagirathi would be far in excess of 40,000 cusecs. If the quanta of discharge, as proposed by Dr. Hensen, Dr. Rao and as outlined in the project report, are compared, the following emerge as shown in Table 8.1.

	Institute/Expert	Minimum Release through Farakka barrage
I	The River Research Institute, West Bengal	40,000 cusecs
II	Dr. D. V. Joglekar, Director, CWPRS	40,000 cusecs
III	Dr. A. C. Mitra, Chief Irrigation Engineer, UP	40,000 cusecs
IV	Dr. J. J. Dronkers, Expert from Netherlands	41,000 cusecs
V	Dr. Debesh Mukherjee, G. M. Farakka Project	40,000 cusecs

Table 8.1 Comparison of projected discharge by different experts

Sl No.	Period	Dr. Hensen (Kalna) 1957 (cusecs)	1968 (cusecs)	1971 (cusecs)	Project report 1962 (at Feeder canal) (cusec)	Dr. K. L. Rao 1962 (at Feeder canal) (cusec)
1	2	3	4	5	6	7
1)	1st January to Mid-March	40,000	Minimum 40,000	Higher than 40,000	40,000	40,000–20,000
2)	Mid-March to Mid-May	40,000–20,000	-do-	(46,000)	20,000	Up to 20,000
3)	Mid-May to Mid-June	Up to 40,000	-do-	-do-	20,000	20,000–40,000
4)	Mid-June to End of June	40,000–60,000	-do-	-do-	20,000	40,000
5)	July to Mid-September	60,000–140,000–80,000	-do-	-do-	20,000	40,000
6)	Mid-September to End of December	80,000–40,000	-do-	-do-	40,000	40,000

Other experts and specialized institutions had recommended minimum releases through Farakka Barrage as under:

Table 7.1 shows that the figures in the project report and of Dr. Rao tally with those in Dr. Hensen's proposal in 1957, though after a gap of 5 and 15 years, respectively but in 1967, Dr. Hensen had changed his figures after studying the new hydraulic and morphological data of the river and of the conditions prevailing at Calcutta port. Work on the barrage started in 1963 and went on till 1975. The discharge figures could be modified and Dr. Rao could have reviewed the fresh figures, based on the observations of Dr. Hensen in 1967 and 1971. This was not done. Moreover, the figures for the lean season were further reduced in the project report and also by Dr. Rao, against Dr. Hensen's recommendations. This was unfortunate, as the basic interests of Calcutta port were not safeguarded, while preparing the project report. Therefore, the objections by the Government of West Bengal and various individuals merit consideration.

Another point is to be noted with interest. Dr. Hensen's recommendations for discharge were for the river at Kalna, about 40 km below Nabadweep where the Bhagirathi is joined by the Jalangi, and about 310 km downstream of Farakka. It was most unlikely, therefore, that the lean-season flow at Farakka, will not reach Kalna after various losses and uses. Contributions from the tributaries within this reach in lean season will be practically nil; on the contrary, there could be back-flow to the tributaries. These were neither considered in the project report, nor by Dr. Rao in his Parliamentary statements. Moreover, most experts veered to the requirement of discharge, at least, or more than, 40,000 cusecs but the Head Regulator and the

Feeder Canal were designed to handle 40,000 cusecs only; there was no allowance for higher discharges, if needed.

Thus, the apprehension of the Government of West Bengal about the availability of minimum discharge of 40,000 cusecs of water in the River Bhagirathi was genuine. It was also expressed by bureaucrats, ministers, Members of Parliament and others on various occasions since 1968. Dr. Dharm Vir, then Governor of West Bengal in a letter dated 16th February 1969 to Prime Minister Indira Gandhi emphasized the importance of minimum head-water discharge of 40,000 cusecs and designed incapacity of the regulator to allow more discharge in the Feeder Canal. Biswanath Mukherjee, the State Minister of Irrigation and Waterways in a letter dated 19th March 1969 to Dr. K. L. Rao wrote:

> Studies made in different offices connected with the problem . . . indicate that the minimum requirement of water for the River Bhagirathi from the Farakka Barrage is 40,000 cusecs. But since anything more than that is not possible because of the limited design capacity of the regulator, we must endure that the flow does not go below 40,000 cusecs, even in the dry months. In fact, the dry period from March to May is the crucial period. It is during this period that 80% to 85% of the deterioration of the river-bed of the Hooghly takes place and hence the imperative necessity of maintaining the upland discharge of 40,000 cusecs even during this period. If that discharge were reduced during the three months from March to May, the result would be that the rate of deterioration, now noticed in the upper reaches, would be somewhat reduced, but the zone of sedimentation might be shifted downwards with various adverse effects. If this condition is allowed to continue, not only the Farakka Barrage Project will be infructuous but the Haldia port may be affected.
>
> In these circumstances, I would request you to see that the waters of the Ganga are not utilized for meeting any other demand (e.g., irrigation) without first ensuring that the Bhagirathi will receive at least 40,000 cusecs through the Feeder Canal throughout the year and even during the dry months. It is needless to remind you that the Farakka Barrage Project is meant for saving the river Hooghly for the port of Calcutta and water from the Ganga cannot be taken away for any other purpose without assuring sufficient supply to the Bhagirathi. And we firmly hold that our minimum requirement of 40,000 cusecs throughout the year including lean months should be fulfilled.

The same apprehension was voiced by the then Chief Minister of West Bengal, Ajay Mukherjee in separate letters to Dr. V. R. Gadgil, Deputy Chairman of India's Planning Commission and to Indira Gandhi, dated 21st May 1969 and 22nd April 1971, respectively. To Dr. Gadgil he wrote:

> The requirement of 40,000 cusecs of water was arrived at by internationally known technical authorities. The technical opinion in India is also for making available at least 40,000 cusecs of water. . . .Ever since we got this information, we have been trying to get details from the Ministry of Irrigation & Power, whether the proposed project is a reservoir project or a barrage project. The reason for our apprehension is that if water is diverted in the upper reaches without taking into account the immediate requirement of 40,000 cusecs for the Farakka Barrage Project, the very purpose for which the scheme was undertaken will be frustrated.. . .

To Indira Gandhi he wrote:

> . . .The State Government also wanted to know, whether any contrary opinion to the expert advice that 40,000 cusecs of water is the minimum to resuscitate the Bhagirathi has ever been expressed by any authority and if so, the details thereof may be supplied . . . it is high

> time that a categorical assurance is given to the effect that supply of water in the upper reaches will be fully controlled after keeping apart the minimum requirement of 40,000 cusecs for Farakka. A Control Board with engineers from CW&PC and the State government concerned may be set up to draw up allocation of water at different points and to supervise its implementation.

The then Governor of West Bengal, S. S. Dhawan in a letter, dated 18th April 1970 to Dr. K. L. Rao urged:

> ...West Bengal is certainly not against execution of any major irrigation project in Uttar Pradesh or Bihar. All that this State wants is that the availability of the minimum flow of 40,000 cusecs throughout the year should be assured before any project in the upper reaches is taken up. If this is not done, the Farakka Barrage Project, which is being executed at a huge cost, will become infructuous and the condition of the port of Calcutta will continue to deteriorate.

In a letter to Indira Gandhi, dated 27th August 1970, Mr. Dhawan reiterated his anxiety over the confusion. He wrote:

> ...I understand, Dr. K. L. Rao is inclined to dispute that the Calcutta port needs as much as 40,000 cusecs. ...All the experts who have examined the problem have consistently stated that the absolute minimum is 40,000 cusecs – probably a little more. We, therefore, see no reason why Dr. K. L. Rao, or the Government of India, should now take the view that somehow the Calcutta port might be able to manage with less than 40,000 cusecs, and in our view any apportionment of waters, based on this assumption, will be wrong and ultimately fatal to the Calcutta port. I must ... warn the government that Haldia too will meet the same fate as the present Calcutta port in a few years, unless the minimum water supply is assured.... I further suggest that there should be a statutory inter-State commission to regulate the withdrawal of water by the different States but subject to the proviso [that] the minimum of 40,000 cusecs must be made available to the port of Calcutta during the lean period, March to mid-June.

Others who took up the matter with the Government of India included a member of Indian Parliament, (M. P.) Samar Guha who in a letter to Indira Gandhi on 17th July 1972 wrote:

> ...The ambiguous statement made by ...Dr. K. L. Rao on the floor of the Lok Sabha on 31st May 1972 regarding the project appears to have created serious uncertainties about its principal object and great concern for the future of the Calcutta port and its subsidiary deep-draft Haldia port with its newly constructed industrial complex, along with the very fate of the Calcutta Metropolitan Area and of the entire national economy of eastern India. The Prime Minister should immediately intervene in the matter and take all necessary steps without delay to assure.... Discharge of 40,000 cusecs of Ganga water through it to flush out the Hooghly estuary so that the Port of Calcutta may be spared of the haunting spectre of an ignoble death.

Thus, it was clear that the Government of West Bengal and the Calcutta Port Commissioners did continuously object to Dr. Rao's ambiguous announcement about the quantum of head-water supply to the River Bhagirathi from the very beginning of the construction of the Farakka Barrage. They did insist on minimum discharge of 40,000 cusecs, round the year, especially during the lean season, when the sand from the sea moves upstream with flow tide to the maximum. They also emphasized the necessity of imposing restrictions of withdrawal of the Ganga water by upper riparian states without augmenting the flow by some other means, but these fell on deaf ears of powers-that-be in New Delhi. Within 2 years of the commissioning of the barrage, the River Bhagirathi, being deprived of a regular discharge of 40,000 cusecs, went lean and thin. Respective governments imposed no restrictions on reckless withdrawal of water from the Ganga, nor were any augmentation plan initiated. The Union government gave no guarantee of minimum flow of 40,000 cusecs into the River Bhagirathi either. The discharge from the barrage decreased day by day in the Ganga, as the Bhagirathi-Hooghly was continuously deprived of the minimum wanted 40,000 cusecs. The treaty, signed between Dhaka and New Delhi, further aggravated the situation.

The 3,000 million rupee project (in 1985 prices) comprising two barrages (at Farakka and Jangipur), one head and other regulators, feeder canal, guide and afflux *bund*s, cross-drainage works, bridges etc. were designed to enable the river receive, even in the driest season, at least 40,000 cusecs. The designs accorded with past hydrological data and detailed investigations, which assumed that at least around 55,000 cusecs of water would be available in the leanest season in the Ganga and after meeting the requirement of Calcutta port and of the stream from Jangipur to the sea to be resuscitated, 15,000 cusecs could flow to Bangladesh (East Pakistan before 1972). The statements by Dr. K. L. Rao meant that this huge expenditure yielded only partial result and had adverse effects on the navigation in the Bhagirathi-Hooghly and on Calcutta port.

Effects of Reduced Discharge

The effects of the reduced discharge from Farakka in the driest months from March to May, from 40,000 to 25,000, to 20,000 and even 15,000 cusecs were studied by Calcutta Port Commissioners, Government of West Bengal and others before the commissioning of the project. They predicted that

a) About 80% of silt in the port area and the upper reaches of the river owing to upward movement of sand from the sea occur from March to May. Reduction of discharge in this period of high tides would continue to push the sand and silt upstream, albeit with less intensity but their volume, thus deposited, would be in excess of that which move to the sea in other months of the year. The cumulative effects of this would continue but at a slower rate and eventual closure of the waterway for deep-sea navigation would be delayed but not averted.
b) Discharge of less than 40,000 cusecs would also reduce, though slowly, the total volume of accretion. Hence, compared to the pre-barrage condition, the zone of most significant accretion which was above Calcutta port before 1975 would shift downward and accumulate near the port area, disturbing the navigation channel, mooring facilities, jetties etc.
c) When the zone of maximum siltation shifts downstream below Calcutta, frequency of bore tides would increase in this reach and render navigation extremely hazardous.

d) Sudden reduction in discharge in the months of high tide would not leave much time to dredge the channel to enable ships come and go from Calcutta port.
e) The salinity in water in the port area would be much more than it would have been if 40,000 cusecs flowed into the river, round the year.

These adverse effects of reduced flow, as predicted by experts, Calcutta port and the Government of West Bengal before and during the construction of the barrage, have almost come true over three decades afterward. Though the deposit of silt and sand in Calcutta port area and in some stretches has reduced considerably, they have settled in the reach between Falta and Haldia and blocked the navigation channel near Haldia port. Bore tides have increased in frequency, near Kolkata and below. Water supplied to south Kolkata has turned brackish, though salinity reduced markedly soon after the upland discharge began to be diverted from the barrage in 1975. Thus, the improvement which was foreseen with 40,000 cusecs of upland flow into the Bhagirathi-Hooghly, round the year, has not been a reality because of reduced discharge.

Probable Causes of Reduction

As shown in Table 4.6, the total flow at Farakka and its distribution in the lean and monsoon periods varied from 0.248 million Mm^3 in 1992 to 0.54 million Mm^3 in 1978. Of this, the total lean-season flow, from January to June, is quite insignificant, compared to that between July and December, the ratio, ranging from 1:5.06 (1979) to 1: 12.74 (1975). From the period from July to December, four monsoon months – July to October – are separated, when the flow is about 85% of the total. Such erratic flows make it very difficult to plan and implement any water resource development project. Almost the entire monsoon flow and much of the dry-season flow go to the sea without any use. Thus, diversion of a part of the flow into the River Bhagirathi for the benefit of Calcutta port and of the people of West Bengal cannot be construed as wastage, as alleged by some people in Bangladesh.

The flow in the Ganga for 20 years between January and June, from 1975 to 1995, is charted in Table 4.6 (Chapter 4). The total available flow at Farakka and the percent share between the river downstream and the Feeder Canal is shown in Table 8.2. The average percent share of the flow in 21 years comes to 91.63 and 8.37, or 92 and 8, respectively. The average annual flow in the river between 1975 and 1996 is about 0.39 million Mm^3, against which the share of the River Bhagirathi is about 32,000 Mm^3; the remaining water flows downstream. The ratio of annual discharge, shared between the Ganga downstream and the River Bhagirathi in those 20 years, was maximum (88.1:11.9) in 1992 and minimum (94.4:5.6) in 1980, except in 1975, the year of commissioning of the barrage. The average flow ratio is about 92.8. The highest flow at Farakka was about 0.54 million Mm3 in 1978 and that in the River Bhagirathi was 34,890 Mm^3 in 1990.

The driest part of the lean season flow is segregated and analysed. This is shown in Table 8.3. The average percentage share of flow between the Ganga and the River Bhagirathi in 21 years in the lean season of March to May is 56 and 44 respectively.

Table 8.2 Percentage share between Ganga downstream and River Bhagirathi

		Share of flow		Percentage share	
Year	Total available flow (Mm^3)	Ganga downstream (Mm^3)	River Bhagirathi (Mm^3)	Ganga downstream	River Bhagirathi
1	2	3	4	5	6
1975	426,250	407,500 (E)	18,750	95.6	4.4
1976	396,300	363,770 (E)	32,530	91.8	8.2
1977	433,930	401,610 (E)	32,320	92.6	7.4
1978	539,830	507,920 (E)	31,910	94.1	5.9
1979	256,620	223,610	33,010	87.1	12.9
1980	486,370	459,220	27,150	94.4	5.6
1981	390,250	358,250	32,000	91.8	8.2
1982	375,710	342,360	33,350	91.1	8.9
1983	373,280	340,870	32,410	91.3	8.7
1984	400,500	367,460	33,040	91.7	8.3
1985	448,470	415,800	32,670	92.7	7.3
1986	375,080	340,700	34,310	90.7	9.2
1987	398,140	367,200	30,940	92.2	7.8
1988	402,580	371,320	31,260	92.2	7.8
1989	343,750	309,190	34,560	89.9	10.1
1990	435,980	401,090	34,890	92.0	8.0
1991	370,110	336,930	33,180	91.0	9.0
1992	248,240	218,740	29,500	88.1	11.9
1993	340,660	312,470	28,190	91.7	8.3
1994	389,960	356,150	33,810	91.3	8.7
1995	363,550	330,180	33,370	90.8	9.2
			Average	91.63 = 92.0	8.37 = 8.0

It may be seen from the table that though the total lean season flow (January to June) in the river varied from a minimum of 28,670 Mm^3 in 1993 to the maximum of 61,370 Mm^3 in 1984, the flow during the driest part of the lean season of March to May is substantially reduced with the minimum of 10,590 Mm^3 in 1975 and the maximum of 20,140 Mm^3 in 1979.

Distribution of Total Flow of the Ganga at Farakka

Though the total lean-season flow varied from a minimum of 28,670 mm^3 in 1984, the flow in the driest lean season, March to May, hit the minimum of 10,590 Mm^3 in 1975 and the maximum of 20,140 Mm^3 in 1979. Thus, the average lean season flow between 1975 and 1995 was about 39,103 Mm^3. The share of total flow in the lean season varied from 7% in 4 years – 1975, 1978, 1980 and 1985 – compared to the total average flow of about 9.90% between 1975 and 1995.

Table 8.3 Analysis of the driest part of the lean season flow

Year	Total flow between January and June (Mm^3)	Total flow between March and May (Mm^3)	Percent of flow	Share of flow between March and May		Percentage share between March and May	
				Ganga down-stream (Mm^3)	River Bhagirathi (Mm^3)	Ganga down-stream	River Bhagirathi
1	2	3	4	5	6	7	8
1975	31,020	10,590 (E)	30	9,500 (E)	1,090 (May only)	90	10
1976	43,500	17,460 (E)	40	9,500 (E)	7,960	54	46
1977	36,560	16,660 (E)	46	9,500 (E)	7,160	57	43
1978	49,300	17,480 (E)	35	9,500 (E)	7,980	54	46
1979	42,330	20,140	48	12,350	7,790	61	39
1980	32,500	11,400	35	7,280	4,120	64	36
1981	37,380	16,310	44	9,910	6,400	61	39
1982	46,300	18,180	39	10,910	7,270	60	40
1983	33,020	13,960	42	8,470	5,490	61	39
1984	61,370	14,400	23	8,610	5,790	60	40
1985	32,270	12,710	39	7,630	5,080	60	40
1986	40,360	16,510	41	9,900	6,610	60	40
1987	35,580	13,710	39	8,220	5,490	60	40
1988	35,740	14,110	39	8,480	5,630	60	40
1989	45,200	15,300	34	8,120	7,180	53	47
1990	40,110	16,490	41	7,980	8,510	48	52
1991	43,960	14,470	33	7,250	7,220	50	50
1992	28,870	11,230	39	4,950	6,280	44	56
1993	28,670	11,920	42	5,610	6,310	47	53
1994	33,780	12,130	36	4,510	7,620	37	63
1995	43,370	14,050	32	6,280	7,770	45	55
					Average	56	44

The total flow is being shared between the downstream Ganga and the River Bhagirathi since 1975, as shown in Table 4.6 (Chapter 4), the average flow ratio being 92:8. Of this, the flow during driest months – March to May – is quite insignificant. Leaving 1975, the flow is shared as per ratio, shown in columns 7 and 8 of Table 8.3. Dividing the total period in two parts – from 1976 to 1987 and from 1988 to 1996, the percent share in the first part ranged from 64:36 in 1980 to 54:46 in 1976 and 1978 with an average of about 59.4:40.6 and that in the second part ranged from 53.47: in 1989 to 37.63 in 1994 with an average of about 46:54. Considering the total lean-season flow, as shown in column 2 of Table 8.3, the percent flow during the three driest months varied from 23% in 1984 to 48% in 1979 with an average of about 38%, which has been shared between the two, as shown in the table.

Distribution of the total lean-season flow, as shown in Table 8.4, is about 10% of the total annual flow of the river. This flow has been between Ganga downstream

Table 8.4 The distribution of total lean season flow (January–June) between Ganga downstream and River Bhagirathi

			Share between		Percentage share	
Year	Total flow between Jan and June (Mm^3)	Percentage of total flow	Ganga downstream (Mm^3)	River Bhagirathi (Mm^3)	Ganga downstream	River Bhagirathi
1	2	3	4	5	6	7
1975	31,020	7	27,500	3,520 (May and June)	88.7	11.3
1976	43,500	11	27,430	16,070	63.1	46.9
1977	36,560	8	21,380	15,180	58.5	41.5
1978	49,300	7	33,060	16,240	67.1	32.9
1979	42,330	9	26,270	16,060	62.1	37.9
1980	32,500	7	22,000	10,500	67.7	32.3
1981	37,380	10	23,230	14,150	62.1	37.9
1982	46,300	12	31,520	14,780	68.1	31.9
1983	33,020	9	19,890	13,130	60.2	39.8
1984	61,370	15	46,870	14,500	76.4	23.6
1985	32,270	7	19,070	13,200	59.1	40.9
1986	40,350	11	24,670	15,680	61.1	38.9
1987	35,580	9	22,080	13,500	62.1	37.9
1988	35,740	9	22,670	13,070	63.4	36.6
1989	45,200	14	29,450	15,750	65.1	34.9
1990	40,110	10	23,290	16,820	58.1	41.9
1991	43,960	12	28,270	15,690	64.3	35.7
1992	28,870	12	14,480	14,390	50.1	49.9
1993	28,670	8	15,710	12,960	54.8	45.2
1994	33,780	9	17,570	16,210	52.0	48.0
1995	43,370	12	26,650	16,720	61.4	38.6

and River Bhagirathi as shown in columns 4 and 5. The percentage share is shown in columns 6 and 7 which varied from 76.4:23.6 (1984) to 50.1:49.9 (1992) with an average of about 62:38 without considering the year 1975. Thus, the flow through the downstream Ganga is only 6% and that through the River Bhagirathi is only 4%, approximately. The salient points below emerge from an analysis of the flow through the Ganga at Farakka.

i. The average annual flow through the Ganga at Farakka between 1975 and 1995 was about 0.39 million Mm^3, of which the canal carried about 32,000 Mm^3 and the remaining water flowed through the river downstream, the average ratio being about 8:92.
ii. The peak discharge at Farakka occurred on 6th September 1980; its intensity was 73,054 cumecs, or 2.58 million cusecs. That year, the discharge in the river which was above 56,635 cumecs, or 2 million cusecs, continued for a maximum period of 30 days (Table 4.6).

iii. The maximum flow was 539,830 Mm^3 in 1978 (between 1975 and 1995) and the minimum flow was 248,240 Mm^3 in 1992 (between 1995 and 1997); both are shown in Table 4.6.
iv. The flow at Farakka reduced substantially in the lean season, as against that in monsoon months, from July to December, the average ratio between the two seasons between 1975 and 1995 being 1:9.74.
v. The minimum lean-season flow of 28,670 Mm^3 occurred in 1993 and the maximum such flow of 61,370 Mm^3 occurred in 1984.
vi. The average lean-season flow was about 10% of the total annual flow and the distribution of this flow between the downstream Ganga and River Bhagirathi was 6 and 4%, respectively.
vii. The flow in the driest months, March to May, substantially reduced with a minimum of 10,590 Mm^3 in 1975 and the maximum of 20,140 Mm^3 in 1979.
viii. Between 1976 and 1988, the total flow in the driest season, as shared between the downstream river and the canal was in the ratio of about 60:40 and between 1989 and 1995, the share was in the ratio of 46:54.
ix. The average flow in the driest months from March to May was about 38% of the average lean-season flow from January to June, and about 1.5% of the total annual flow.

The flow distribution in the Ganga downstream and the Feeder Canal has been shown in schematic line-diagrams in Figs. 8.3 and 8.4.

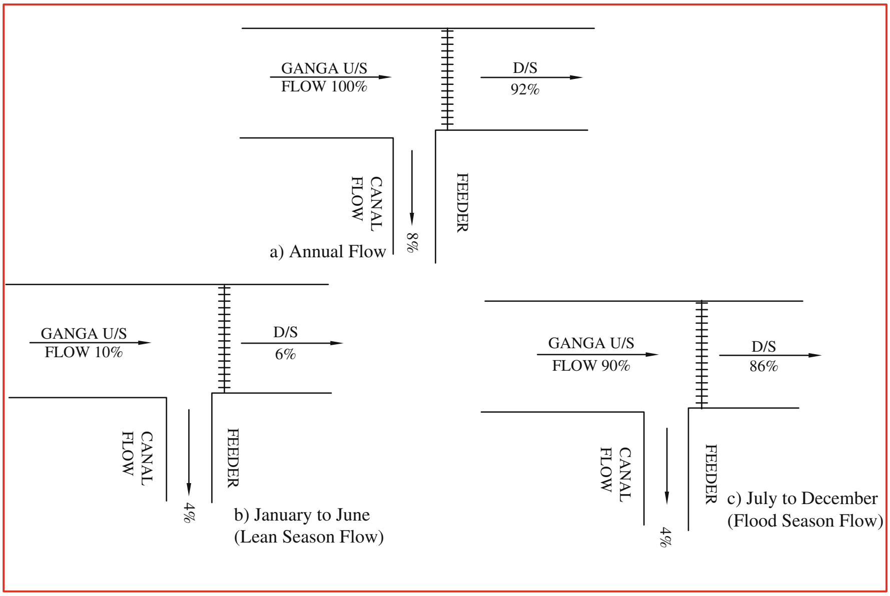


Fig. 8.3 Schematic line diagram showing the annual percentage flow distribution in Ganga and Feeder canal

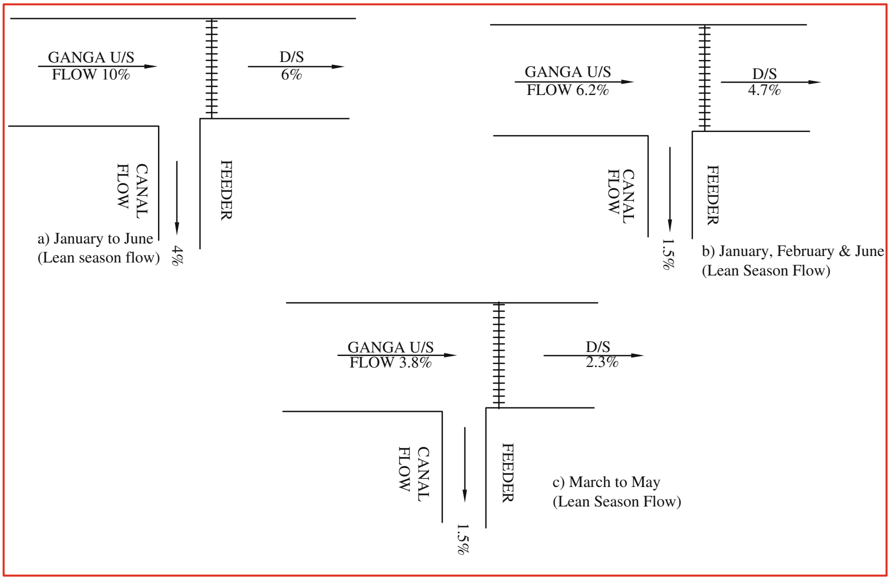


Fig. 8.4 Schematic line diagram showing the percentage lean season flow distribution in Ganga and Feeder canal

Reduction of Discharge

According to S. C. Majumdar, maximum flood discharge, as computed from the readings of the Ganga was 2.48 million cusecs at Farakka in 1913. The lowest level there was R.L. + 57.7 feet, or 17.59 m, the lowest bed-level being about + 21 feet (6.4 m) and the highest flood level at R.L. 83.2 feet (25.37 m). From available records, though the minimum flow in a very bad year might be of the order of 50,000 cusecs, or 1,416 cumecs, the average flow that should matter, even in the driest months, is much higher. After verifying records of 5 years at that time, he mentioned that the average discharge at Farakka on monthly basis varied between 299,000 and 79,000 cusecs, i.e., 8,465 and 2,237 cumecs, in the dry season, from November to May and between 1,615,000 and 175,000 cusecs, or 45,725 and 4,955 cumecs, in the monsoon months, from June to October.

Debesh Mukherjee, the Chief Engineer and later the first General Manager of the Farakka Barrage Project, is on record that in 1952 and 1953 the dry season flow of the Ganga at Farakka went down to 40,000 cusecs (1132.5 cumecs); this was the minimum there since 1948. Therefore, contrary to earlier assessments, it has been found that the lean-season flow at Farakka would be 40,000 cusecs, or even less. According to the Government of India report, ‘Preservation of the Port of Calcutta, 1961’, the lowest level, recorded at Farakka on 6th February 1958 was R.L. + 52.15 feet (15.9 m) from the gauge discharge curve at the time, the minimum discharge was 55,000 cusecs (1,557 cumecs).

Thus, although records vary about the minimum Ganga discharge at Farakka, it is clear that in 1913, the minimum was 50,000 cusecs (1,416 cumecs), which came down to 40,000 cusecs in 1952 and 1953. Those were the driest years when the Ganga flow was exceptionally low. As continuous prototype observation data at Farakka were then not available, it is difficult to establish, whether the discharge in lean season at the point was gradually reducing, or not. Development activities in the upper reaches from olden days before and after India's Independence call for a closer look to ascertain the volume of lean-season flow, utilized in such activities.

Daily discharges in a river vary from year to year. Since the commissioning of the barrage at Farakka in 1975, the highest discharge up to the 1990s, was 73,923 cumecs, or 2,610,960 cusecs, on 19th September 1987 and the minimum at 991 cumecs (35,000 cusecs) occurred on 13th April 1993. In several other years, the discharge at Farakka fell to 1,132 cumecs (40,000 cusecs), or even less, e.g., in 1980, 1983 and 1992. In 1984–1985, 1987–1989 and 1994, the minimum discharge hovered between 1,132 and 1,416 cumecs (40,000 and 50,000 cusecs). In 1980 and 1996, discharge soared to 70,793 cumecs (2,500,000 cusecs) and in 11 years, it remained above 56,635 cumecs (2,000,000 cusecs); the years were 1976 (for 13 days), 1978 (28 days), 1980 (30 days), 1982 (12 days), 1983 (4 days), 1984 (7 days), 1987 (7 days), 1988 (20 days), 1991 (13 days), 1994 (5 days) and 1996 (10 days).

An analysis of the flow data, as given in Tables 4.6, 8.2, 8.3, and 8.4, can be made to find out, whether the flow has been reducing, or maintaining uniformity since the commissioning of the barrage. Graphs have been plotted to show year-wise variation of flow (years horizontal and flows vertical), as shown in Figs. 8.5 and 8.6 for annual as well as lean season. The line drawn shows a diminishing trend of the flow. As the points are scattered and a definite trend in these years being elusive, three-yearly and five-yearly moving averages have been worked out for the annual and lean-season flows at Farakka from 1975 to 1995 and shown in Table 8.5 below.

Figures 8.7 and 8.8 show the graphs of three-yearly and five-yearly moving averages for different years. It is seen that annual and the lean-season flows in the Ganga are diminishing since 1975, i.e., after the commissioning of the barrage, which could be due to

a) Melting of less snow in the Himalayas;
b) Blockage of the natural flow and its storage at the mouths of the Ganga and its tributaries;
c) Increased evaporation loss of the Ganga water;
d) Increased under-ground storage of water;
e) Less precipitation of rains and less run-off; and
f) More withdrawal of the Ganga water in the upper reaches for irrigation, hydro-electric and thermal power generation, drinking and other domestic use and for industries.

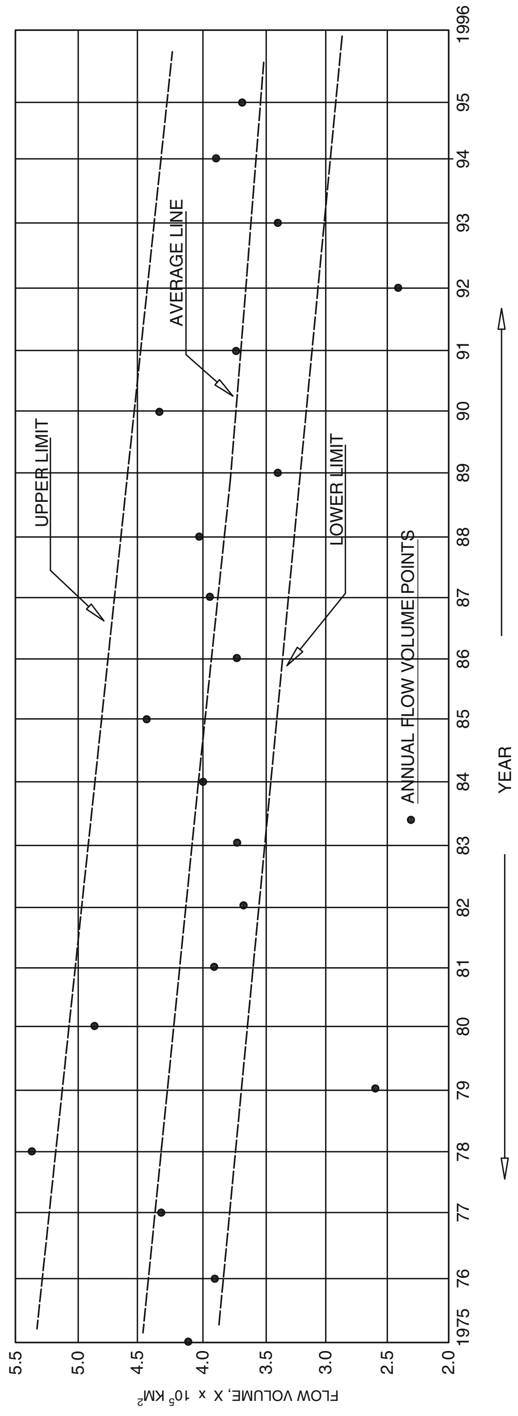


Fig. 8.5 Annual flow variation in Ganga at Farakka

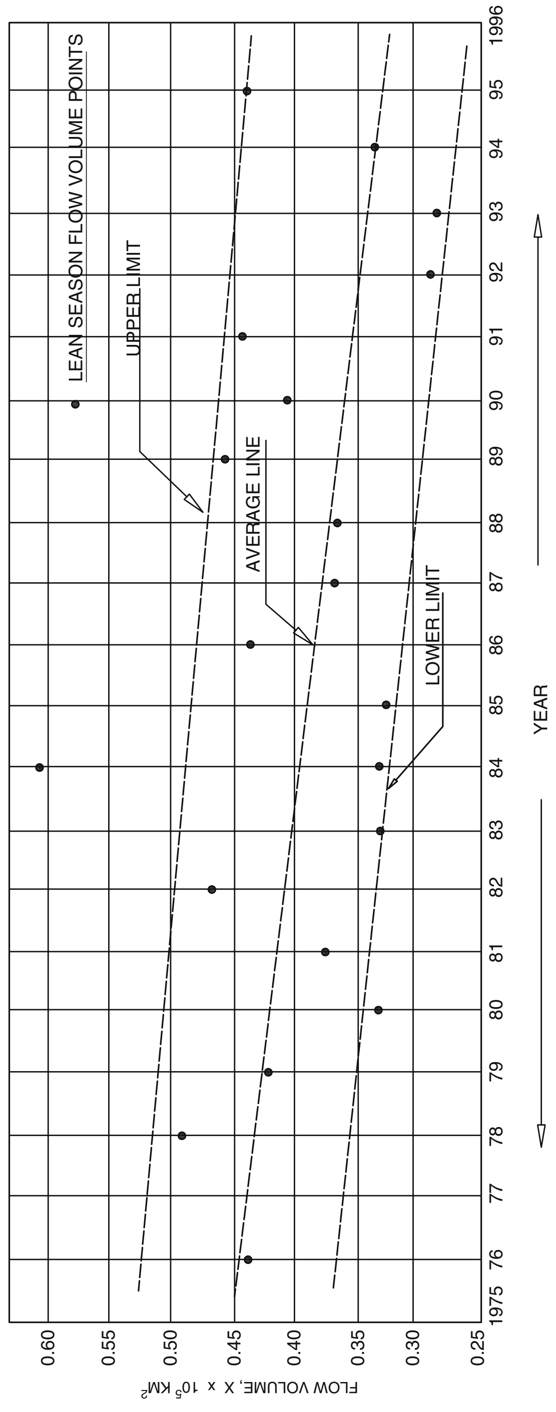


Fig. 8.6 Lean season flow variation in Ganga at Farakka

Table 8.5 Three-yearly and five-yearly moving averages for the annual flow and lean season flow of the river from 1975 to 1995

		Moving average			Moving average	
Year	Total flow	3-yearly	5-yearly	Lean season flow	3-yearly	5-yearly
1	2	3	4	5	6	7
1975	426,250	–	–	31,010	–	–
1976	396,310	–	–	43,500	–	–
1977	433,930	418,800	–	36,560	37,020	–
1978	539,830	456,690	–	49,300	43,120	–
1979	256,620	410,130	410,590	42,330	42,730	40,540
1980	486,370	427,610	422,610	32,500	41,370	40,840
1981	390,250	377,750	421,400	37,380	37,400	39,610
1982	375,710	417,440	409,760	46,300	38,720	41,560
1983	373,280	379,750	376,450	33,020	38,900	38,300
1984	400,500	383,170	405,220	61,370	46,890	42,110
1985	448,470	407,420	397,640	32,270	42,220	42,070
1986	375,080	408,020	394,610	40,350	46,670	42,660
1987	398,140	407,230	399,100	35,580	36,070	40,520
1988	402,580	391,990	404,950	35,740	37,220	41,060
1989	343,750	381,490	393,600	45,200	38,840	37,830
1990	435,980	394,100	391,110	40,110	40,350	39,400
1991	370,110	383,280	390,110	43,960	43,090	40,120
1992	248,240	351,440	360,130	28,870	37,650	38,780
1993	340,660	319,670	347,750	28,670	33,830	37,360
1994	389,960	326,270	356,990	33,780	30,440	35,080
1995	363,550	364,720	342,500	43,370	35,270	35,730

Rebuttal

I. Regarding (a) above, snow-melting reduces when the snow-line comes down with gradual decrease in its altitude, or if snow accumulates less in the mountains. Snowline also comes down if atmospheric temperature falls and the earth cools gradually, an unlikely phenomenon in times of global warming. Thus, snow-melting, cannot be a reason of fall in the volume of water in rivers.

II. As regards (b), it is true that in Uttar Pradesh and Bihar, the Ganga and many of its tributaries have been shackled by dams and barrages of various heights for storing surplus water in monsoon months and use them for water resource development projects. In the upper reaches of the Ganga, barrages have come up at Tehri Garhwal (Narora Barrage), at Bijnor (Madhya Ganga Barrage) and at Haridwar (Bhimgoda Barrage) – all in Uttar Pradesh. Construction of one more barrage at Kanpur in UP is under way. Most of the barrages were constructed before the one at Farakka but a few of them have been strengthened for more storage and head-up of water after the Farakka Barrage came up. Barrages have also been constructed before Farakka over many sub-Himalayan and sub-peninsular tributaries of the Ganga on both sides, namely (i) Wazirabad

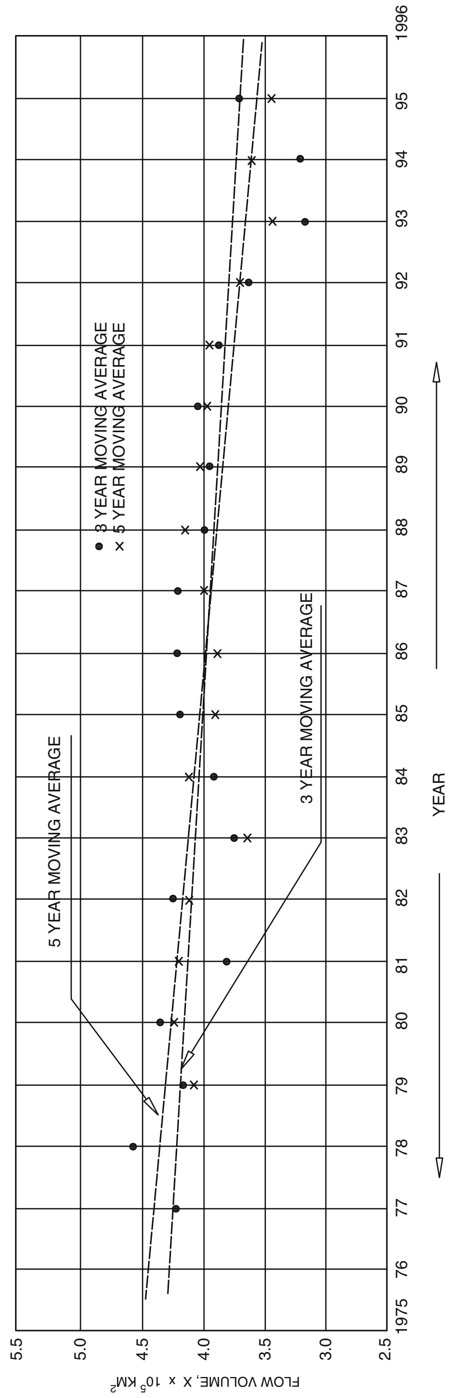


Fig. 8.7 Moving averages of annual flow distribution of Ganga at Farakka

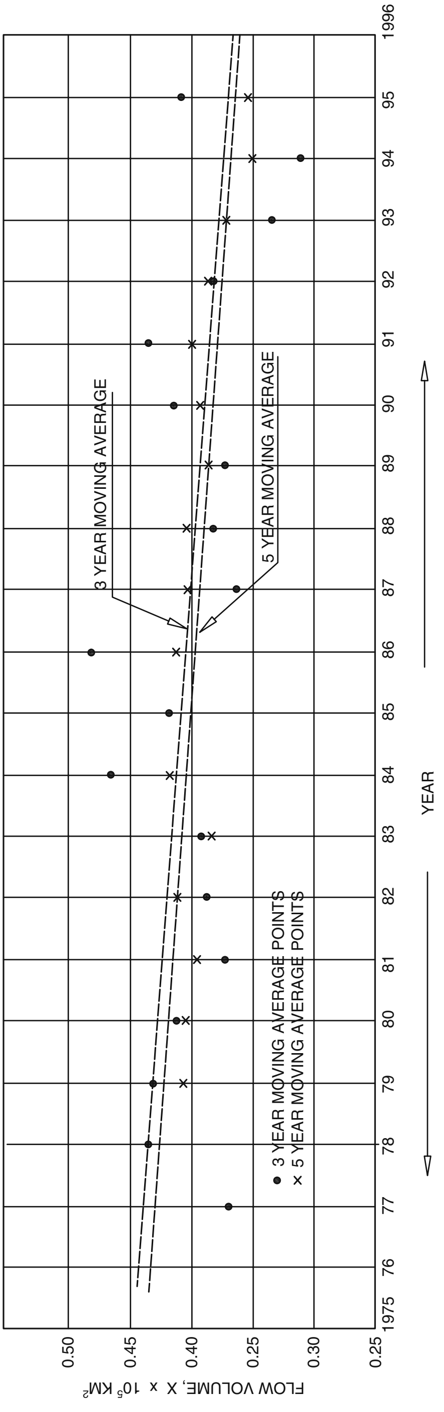


Fig. 8.8 Moving averages of lean season flow distribution of Ganga at Farakka

Barrage on the Yamuna in Delhi, (ii) Indraprastha Barrage on the river in Delhi, (iii) New Okhla Barrage on the river in Delhi, (iv)Kota Barrage on the Chambal in Rajasthan, (v) Upper Sarda Barrage over the Sarda in UP, (vi)Lower Sarda Barrage at Lakhimpur Kheri in UP,(vii) Tons Barrage over river Tons in Madhya Pradesh, (viii) Girija Barrage over the Ghagra in UP, (ix) Gandak Barrage over the Gandak in Bihar, (x) Kosi Barrage over the Kosi at Bhim Nagar (Nepal), (xi) Sone Barrage over the Sone in Bihar, and (xii) Mahammadganj Barrage over a tributary of Sone.

In addition, low-height dams, anicuts etc. have come up over many tributaries. Thus, storages that are coming up fast, reduced the volume of annual flow. Construction of high dams at the mouth of the tributaries in Nepal and India are now under consideration of the Government of India; these will also reduce flow in the Ganga.

III. Regarding (c) above, the basin area of the Ganga and its tributaries are shrinking by jacketing them with embankments and levees to avoid flood hazards in rural and urban areas and to reclaim more land for habitation and agriculture, as river-banks and *char* land are not being spared by an exploding population. At the same time, building reservoirs, excavating canals and distributaries etc. surface area of minor river-bodies has increased manifold, leading to more evaporation. Deforestation on hill-slopes and plains are also adding to evaporation loss which is rising day-by-day, depleting flows in rivers.

IV. As regards (d) above, harnessing of underground reserves for agriculture, irrigation, drinking and industries is also rising, day-by-day. Tube wells and dug-wells are being sunk in hordes for tapping ground water. This is leading to increasing natural and artificial recharge by surface water, depleting flows in rivers.

V. Regarding (e), precipitation and run-off thereafter depend on the location of the region, cloud-formation, forest-cover, geological formation, growth of vegetation, land slopes, habitation and many other factors. Forest-cover, vegetation growth, habitation etc. are man's creation. Because of a fast-breeding population, land for habitation and farming are becoming scarce, leading to deforestation and conversion of arable land. Forests at the feet and slopes of hills are being felled for firewood, furniture and timber for dwelling houses etc. All these affect precipitation and run-off in streams and rivers.

VI. As regards (f), it is well-known that the lean-season flow decreases sharply and even falls below 40,000 cusecs in some years, which mostly comes from tributaries like the Gandak, the Ghagra and the Kosi; other tributaries go dry in lean months. Even the main Ganga and the Yamuna do not contribute much, because of a number of irrigation dams and barrages on their upstream, at Haridwar, Narora, Tajewala, and Okhla (Delhi), built much before the Farakka Barrage. The Ghagra has two main tributaries – the Sarda and the Karnali; the former's water is extensively drawn for irrigation from 1927. After some years, it was found that the Sarda did not have ample water to meet rising demands of agriculture in its command area. Most of its canals went dry and needed reinforcement, as recommended by foreign and Indian engineers. A scheme was

> sanctioned in 1968 to get water from other tributaries under a project, called 'Sarda Assist'. Under it, no new canal is to be constructed except a feeder to supply water to various canals, excavated decades ago. However, the Kosi and the Gandak projects were sanctioned in 1956 and 1958, respectively, much before the Farakka project went on stream in 1975.

The importance and necessity of adequate flow of the Ganga through the feeder canal were highlighted by those associated with the Farakka project. They emphasized in their reports that water from the Farakka feeder canal should not be permitted to be used for irrigation purposes. West Bengal did not get any canal water for irrigation and not a single drop is now formally allowed from the feeder canal for any other purpose, whereas in the upper reaches, the Ganga water is diverted for major and minor irrigation schemes, sanctioned by the Government of India after the Farakka Barrage project was approved without considering, how such diversion in lean season would affect water discharge and diversion from the barrage. As reported by S. B. Sen Sharma, 1986, some 204 major and minor irrigation schemes have been sanctioned to draw water from the upper reaches of the Ganga in Uttar Pradesh and Bihar after 1975. The total volume of water, diverted to these projects, amounted, until 1995, to about 14.5 million acre feet, of which surface water component was 9.5 million acre feet. To this has to be added about one million acre feet water to industrial towns and complexes, located on the banks. A sizeable quantity is additionally drawn by unauthorized pumping from the river-bed in upstream provinces. North India claims a very major share of the Ganga water before it reaches Farakka. No scheme has ever been formulated to rationalize the share of the river water among the three riparian States, while the burden of its decay owing to reduced flow falls entirely on West Bengal and Kolkata. It is obvious that the Government of India, or of UP and Bihar, gave no over-riding priority to, and honour, the committed discharge for the Bhagirathi-Hooghly through the Farakka feeder canal. These two states should be vitally interested in saving Calcutta port, because it serves them as well as north-east India and three neighbouring countries – Nepal, Bhutan and Bangladesh. Besides, a large number of workers, employed in Calcutta port and many industries on the banks of the river hail from UP and Bihar.

Dr. K. L. Rao whose statement in the Lok Sabha on 3rd May 1973 caused this confusion and furore, contradicted himself, when in another scheme, 'National Water Grid of India', he proposed linking the Ganga with the Kaveri for diverting some 60,000 cusecs for 300 days in a year to the arid regions of Deccan (south India) which does not have a perennial river of the stature of major north Indian rivers. Dr. Rao's brain-child provoked Dr. Debesh Mukherjee to strongly criticize it. He cited Constitutional obligations and described the Grid idea as impractical and utopian. He said, the Government of India Act 1935, from which India's Constitution drew heavily, provided that a province could not do whatever it liked with the water of a river and cause injury to any province, or State, lower down. It follows, therefore, that the government of a basin State is entitled, under Indian Constitution, to use the waters of a river, flowing through its territory for irrigation, hydro power, flood control etc. but in exercising these powers, no significant injury should be caused to any other basin State. Even the US government adopted an identical policy to resolve similar conflicting claims on inter-State river waters by different States. Dr. Mukherjee posed the following questions:

i. Why is the proposed Ganga-Kaveri link given the topmost priority for a national water grid?
ii. How could the Government of India think of diverting water from the Ganga, starving the Bhagirathi-Hooghly and the entire lower reaches?
iii. Does the government consider Calcutta port as a national port and saving it from gradual death a national objective?
iv. Are the sanctions of over 200 projects, drawing water from the upper reaches, a ruse to show that there is plenty of water in the Ganga?

Dr. Mukherjee was distressed over the fact that certain projects for withdrawal of surface water from the Ganga were sanctioned against the recommendations of the Irrigation Commission, made as late as April 1972 that there was large scope for conjunctive use of surface and sub-surface water, particularly in the Ganga basin and that large tracts of the Indo-Gangetic plain are water-logged. Even in subsequent projects like the Chambal in Madhya Pradesh and Rajasthan, water-logging has become a problem. In case of the Gandak and the Kosi, the Commission felt concerned about the dangers of serious water-logging in the command areas of their projects. The high water-table, heavy rainfall and the flat terrain create serious problems in those areas. While dealing with the 'Project Assist', where large-scale draw of surface water from the Ghagra, a snow-fed tributary of the Ganga, was planned, the Irrigation Commission suggested that ground-water in the canal command should be exploited (a) for meeting inadequacies, (b) for extending irrigation, and (c) to minimize water-logging, which occurs with increase of irrigation in the area.

Ignoring these warnings by the Irrigation Commission, what Dr. K. L. Rao stated in the Lok Sabha on 16th August 1972 was just the opposite of the Commission's views. He said:

> Extensive irrigation has been developed on the Sarda since 1972. It was found later that Sarda system did not have sufficient water to supply it to the fields. Most of the canals were running empty and many foreign and Indian engineers and economists observed that the Sarda system required reinforcement. Therefore, a scheme was sanctioned in 1968 which supplies water from the other tributary of the same river and the project was named 'Sarda assist'. No new canal system is to be constructed but only a feeder canal to the various canals constructed several decades ago.

The statement hid the actual fact. The Ghagra is a tributary of the Sarda and construction of two major barrages across the Ghagra and the Sarda and construction of a diversion canal of 20,000 cusecs capacity with a future provision of a canal of another 5,000 cusecs capacity on the other bank of the Ghagra were hidden agenda. Therefore, the sanction of such a project which directly affected the earlier, much after the Farakka Barrage, was not deliberately disclosed in the Lok Sabha. Eminent MPs, like Prof. Samar Guha and others vehemently protested against such unilateral declaration of the Government of India in Parliament and brought it to the notice of Prime Minister, Indira Gandhi but without much effect.

Apart from the above, more and more projects in the upper reaches of the Ganga and its tributaries in Bihar and Uttar Pradesh were sanctioned for irrigation and industrial uses through a network of canals, lift pumps etc. The latest to be added is construction of a barrage over the Ganga at Kanpur for supply of drinking water to the city. The project is already approved by the Government of India and construction has started.

It is thus established that the various government agencies were responsible for reduction in the Ganga flow at Farakka. Genuine interests for which the barrage was constructed were overlooked and thrown over board, while sanctioning various schemes in the upper reaches. Thus, there are reasons to apprehend that many more irrigation schemes might be sanctioned in future in the upper reaches, which would further reduce the Ganga flow at Farakka and the very purpose of the project would be jeopardized.

Chapter 9
Turmoil Over Water Diversion

India's desire to get some water of the Ganga diverted into the Bhagirathi-Hooghly to save Calcutta port gave rise to a severe conflict with former East Pakistan which became Bangladesh in 1972. Dhaka even took the issue to the United Nations and other international forums to drum up sympathy and support to its causes and demands by them.

As stated, the Bhagirathi-Hooghly which was the main channel of the parent river Ganga before the 16th century flows in its penultimate course through the Indian state of West Bengal. It was not getting much of its discharge in the lean season and remained virtually dry for over nine months in a year, owing to siltation of the river mouth and the bed. Calcutta port on the eastern bank of the Hooghly was going inactive, as vessels to and from could not ply on the decreasing depth of the river. The shortage and increasing salinity of its water affected the large and densely populated city of Kolkata, the suburbs and a huge number of industries on its banks up and down stream. India constructed two barrages – one at Farakka in Murshidabad district across the Ganga and other at a place called, Ahiron, also in Murshidabad, across the Bhagirathi, a 40-km feeder canal, a number of cross-drainage structures, embankments, roads, river-training works etc., spread over 7,500 km^2 (150 × 50 km) in the districts of Murshidabad and Malda in West Bengal. The aim was to divert 40,000 cusecs of water into the Bhagirathi-Hooghly, round the year, which would gradually restore the river to 1936 condition. If it occurred, vessels of 7.9 m draft could come near the port area and ensure sweet water supply to the city of Kolkata and Howrah and their suburbs. On the basis of relevant records, it was assessed that the availability of water in the lean season at Farakka was around 55,000 cusecs. After diverting 40,000 cusecs through the feeder canal, the remaining 15,000 cusecs could be given to Bangladesh along the Padma channel. Bangladesh protested that this quantity would be woefully inadequate. Dhaka initially objected to the commissioning of the barrage at Farakka before a proper sharing of the Ganga water was agreed to by the two countries. This gave rise to a conflict with far-reaching consequences.

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History of the Conflict

The seeds of the Ganga dispute were sown when Indian sub-continent was partitioned in 1947. Britain gave up its hold on India after presiding over the division of the country into two independent States, India and Pakistan. Pakistan is comprised of two Muslim majority areas, one on the east and the other on the west, separated by a thousand miles of Indian Territory. The eastern part of Bengal, (hitherto known as East Bengal), added with Sylhet of Assam, formed the eastern wing of Pakistan, called East Pakistan. The division split the river systems in the western and the eastern sectors. As the two sovereign countries began formulating their plans for developing water resources of rivers flowing within their territories, disputes over these waters inevitably surfaced in both.

As narrated in Chapter 6, experts from abroad and across India held that the only resuscitation of the Bhagirathi-Hooghly was possible by the diversion of a part of the discharge of the Ganga into it by construction of a barrage across it at Farakka. This view dates as far back as 1853 when India was under the British colonial rule; there was no second opinion. Investigations were made by the Government of India after Independence in 1947, which also confirmed the need of a barrage at Farakka. While drawing the map of divided India before 1947, Sir Cyril Radcliffe, a British Civilian Officer, also suggested the location of the proposed barrage at Farakka in the Muslim-majority district of Murshidabad in India, which was exchanged with the Hindu-majority district of Khulna in East Pakistan. Thus, the charge of B. M. Abbas in his book, ‘The Ganga Water Dispute’ that the barrage at Farakka was constructed without proper investigation is baseless. In fact, investigations spanned over more than a century, when India and Pakistan was one country under the British.

Basically, the dispute over the Ganga water arose from the geographical location of Bangladesh which was East Bengal up to 1947 and East Pakistan thereafter until 1972 when it became Bangladesh. The 1947 Partition made East Pakistan a lower riparian State in respect of the Ganga, though more than 90% of the catchment area belongs to the upper riparian State, India. The dispute which did not exist, nor could be imagined, in united India was thus a by-product of the Partition of India. In 1972, Pakistan was compelled to give up its eastern wing and a new country, called Bangladesh emerged. Pakistan alleged that the British had neglected the eastern part of Bengal in developing river-water resources for irrigation and flood control. There was no observation station along the Ganga except at Hardinge Rail Bridge over the Padma. The East Pakistan government, therefore, had to draw up its own plan for developing water resources from the scratch after Independence but any such plan by India or by East Pakistan involving the waters of the Ganga was bound to interfere with the interest of either, or both the countries. This made Pakistan object to India’s plan of construction of a barrage at Farakka in 1951 after reports appeared in newspapers. Similarly, Pakistan’s plans of launching the Ganga-Kapotaksha (the same as Kabodak, as the British pronounced it) Irrigation Project in Kushtia and the Teesta Barrage Irrigation project in Rangpur were objected to by India.

Exchange of letters took place on the issue between Pakistan and India. The Pakistan Government sought Delhi's comments on 29th October 1951 on the newspaper report of India's plan to build a barrage across the Ganga at Farakka for diversion of the Ganga water into the Bhagirathi-Hooghly. Islamabad requested Delhi to consult Pakistan before launching any such plan, as it might affect the interests of its eastern wing. India, in its reply dated 8th March 1952, disclosed that only preliminary investigations had started and the Pakistan's concern was hypothetical. Pakistan in its letter dated 14th September 1954 informed India that the Ganga-Kapotaksha Scheme was designed to irrigate about 2 million acres of land besides creating a direct inland channel between the Bay of Bengal and the Ganga for large sea-going vessels in East Pakistan, enclosing a copy of a report. Pakistan proposed a joint survey of the upper reaches of the Ganga and the Brahmaputra which India reportedly turned down. Delhi suggested that Pakistan should consider a survey of the rivers on their side.

In March 1956, India expressed its reservations about certain articles of the Barcelona Convention and Statute of 1921 on the regime of navigable waterways of international concern, as these were detrimental to the interests of upper riparian countries, mentioning that these were superseded subsequently by the GATT. Pakistan did not agree with this contention of Delhi and correspondences followed for several years on the issue of sharing of the Ganga water. In 1957, Pakistan proposed involving the United Nations for technical and advisory services for the development of eastern river systems but this was turned down by India.

The first expert-level meeting of the two countries was held in June 1960 after the government of the two countries agreed mutually that the water resource experts of two countries should exchange data on projects of mutual interests. The meeting, headed by K. K. Framji, a Chief Engineer and a Joint Secretary of India and M. A. Hamid, Chief Engineer Advisor and a Joint Secretary of Pakistan was held in New Delhi between 28th June and 3rd July 1960. Three more meetings followed between October 1960 and January 1962 – two in Dhaka and one in Kolkata, respectively. In January 1961, India informed Pakistan that the Farakka Barrage Project work had started. Another exchange of letters started between the Indian Prime Minister Jawaharlal Nehru and Pakistan President, Field Marshal Ayub Khan on the issue, followed by exchange of data for the next four years up to 1964. This was interrupted by a war between India and Pakistan in 1965 and the stalemate continued up to 1967. The dialogue was resumed in 1968 in their fifth meeting in New Delhi. India was represented by Baleswar Nath, a Chief Engineer and a Joint Secretary of India and Pakistan by S. S. Jafri, a Secretary of Pakistan, but nothing concrete emerged. Five more meetings were held at the level of secretaries. K. P. Mathrani and V. V. Chari represented India in the first three and last two meetings respectively. Pakistan was represented by S. S. Jafri and A. G. N. Kazi in the first two and next three meetings, held between December 1969 and July 1970. The last meeting, held in New Delhi from 16th to 21st July 1970, recommended as under:

i) The point of delivery of water to Pakistan of such quantity as maybe decided will be at Farakka;

ii) A body be constituted, consisting of one representative each of the two countries to ensure delivery of agreed supplies at Farakka; and
iii) A meeting be held in three to six months at a level, to be agreed to by the two governments to consider the quantum of water to be supplied to Pakistan at Farakka and other unresolved issues relating thereto and to the eastern rivers.

It is clear from the above that though there was some advance in the talks, the main point, relating to the quantum of discharge to be shared between the two countries at Farakka was not decided. During the period there was a political change in Pakistan. President Ayub Khan was replaced by General Yahya Khan on 25th March 1969. The construction of Farakka barrage was under way and major works of the barrage were almost complete by 1970; the excavation of the feeder canal was also progressing. The Indian delegation in the fifth Secretary-level meeting, held in July 1970, complained that the data relevant for taking a decision on the volume of water which could reasonably be supplied by India out of the Ganga waters, were not obtained and agreed upon. Thus, no data on the river Ganga-Padma was available before Independence. Only after 1947, the Pakistan government started collecting hydrological data on the river but its delegates never gave to India those relating to water-levels, discharges, flow velocity, salinity, tides, erosion and sedimentation, channel patterns, bank-line shift, high floods, groundwater fluctuations, soil characteristics, crop pattern, irrigation needs, wind and wave characteristics etc. of the Ganga, the Padma, the Brahmaputra and the Meghna as well as of all their tributaries. In those days, Pakistan was planning to construct a barrage across the Ganga (the Ganga Barrage Project) in East Pakistan, which would have back-water effect on the Indian territory, whose details India wanted to know. It is well-known that there was sufficient regeneration of flow from groundwater storage, contributions from tributaries etc. between Farakka and the Hardinge Bridge, for which sufficient records were not available. As the leader of the Indian team said,

> Most important of all, is the unresolved question, how should the Pakistan project be reformulated in order that one may take a decision on the reasonable amount of water which should be supplied out of the Ganga, keeping in view the overwhelming dependence needs of Pakistan on surface irrigation in a region which is undoubtedly too wet rather than too dry.

Thus, the question of sharing the Ganga water remained unresolved in spite of prolonged meetings for years. Apparently, as author B. M. Abbas said, the Kashmir question was more important to Pakistan than the Farakka problem. India wanted a step-by-step approach in the discussions to deal with the various problems but Pakistan insisted on addressing the Kashmir question first. Therefore the Farakka problem did not get much importance in the discussions, leaving the dispute unresolved. Incidentally the demand of water from the Ganga by Pakistan did not remain fixed in negotiations from 1954 to 1970; it was ever increasing. In 1954 meeting, for example, the quantum of water demanded was 2,000 cusecs, which rose gradually to 49,000 cusecs in 1968 in just 14 years. The details figure in Table 9.1.

Table 9.1 Demand of water by Pakistan (Badal Sen, 1980)

	Demand during the years					
Details	1954	20.06.60	01.10.60	28.04.61	07.12.62	13.05.68
Quantity of water demanded (Cusecs)	2,000	3,500	18,090	29,352	32,010	49,000
Average area to be brought under cultivation (in million acres)	0.2	0.35	1.98	3.48	3.48	4.25

The Ganga-Padma basin is shared by three countries – Nepal, India and Pakistan – in the ratio of about 18.3, 81 and 0.6 respectively, China has a very small share of about 0.1 only. According to the ratio, India's contribution is 81% against Pakistan's only 0.6%, over which the water of either river flows and falls into the Ganga. The ever-increasing demand of East Pakistan from 2,000 cusecs in 1954 to 49,000 cusecs in 1968 i.e. rising by about 25 times in 14 years, was contested by India on the basis of proportionate distribution of the basin area, the population settled on it, the extent of cultivable and fallow land as well as intensity of irrigation of the two countries, pertaining to the Ganga basin. Although under the rule of proportion, East Pakistan should get only 300 cusecs of water out of the total lean-season flow of 50,000 cusecs at Farakka, i.e., only 0.6%, arithmetic should not override basic human needs of water. Some basic factors governing equitable distribution of water between co-riparian countries were considered by the International Law Association in 1966 in its 52nd meeting at Helsinki. It laid down some criteria on sharing of water between the basin countries but in the case of the Ganga water diversion, both countries stuck to their stands and no solution could be reached until 1971.

Pakistani defence forces launched an attack on the security forces and civilian population on its own territory, East Pakistan in December 1971. At the initiative of the then Prime Minister, Indira Gandhi, India gave all help for the rescue and relief of the attacked people and ultimately, the territory was liberated from Pakistan and took the name of Bangladesh on 16th December 1971. Pakistan lost its eastern wing and retained only West Pakistan. Thus, the new Bangladesh government, headed by Sheikh Mujibar Rahaman, inherited the problem of sharing the Ganga water at Farakka. He was first sworn in as the Prime Minister and thereafter as the President of Bangladesh after a constitution of the new country was adopted with the co-operation of India in the changed scenario. The Indo-Bangladesh Joint Rivers Commission (JRC) was set up in June, 1972 to resolve the dispute on sharing of water of all rivers, flowing through both the countries, including the Ganga.

Then first meeting was held between 20th and 28th January 1972 in New Delhi. India was represented by Sardar Swaran Singh, External Affairs (Foreign) Minister and Dr. K. L. Rao, Irrigation Minister. Bangladesh was represented by B. M. Abbas, Advisor to the Prime Minister on flood control, irrigation and power. Both sides laid stress more on flood control than on irrigation but did not want to involve a third party on the issue. The second meeting was held in Dhaka between 17th and 19th March 1972. This time India was led by Indira Gandhi and Bangladesh by Sheikh Mujibur Rahman. On 19th March 1972, they signed a historic Treaty of Friendship, Cooperation and Peace. Their meeting also laid down the terms of the JRC. The exciting prospect of harnessing the waters of the Brahmaputra, the Meghna and the Ganga by two countries also figured in the meeting. Thereafter, the concerned ministers of the two countries visited either sides for exchanging views and formulating future plans of development on water resources. Dr. K. L. Rao visited Dhaka between 26th and 29th April 1972, which was returned by the visit of Mr. Abbas to New Delhi between 11th and 14th September, 1972.

These meetings discussed the requirement of the Ganga water by Bangladesh for irrigation and other development activities to overcome severe food shortage in Bangladesh. It was decided that about 10,000 cusecs of the Ganga water would be sufficient for Bangladesh for irrigation. The Planning commission of Bangladesh accepted India's suggestion that what Bangladesh required for increasing its food yield was extensive use of tube-wells and low-lift pumps. The meeting virtually excluded major projects on surface water development, consistent with India's and the World Bank's views on water resources development in Bangladesh. Another meeting was held in New Delhi on 16th and 17th July, 1973 between Sardar Swaran Singh and Khondakar Mostaque Ahmed, Minister of Flood Control of Bangladesh, where they agreed that a mutually accepted solution would be arrived at before operating the Project. In these days, the Joint River Commission identified priority areas of co-operation and decided to strengthen its technical and other experts and to review its works annually.

Bangladesh premier, Sheikh Mujibur Rahaman, accompanied by Mushtaque Ahmed, and the Foreign Minister Dr. Kamal Hossain attended a summit meeting with India's representatives in New Delhi on the 12th May 1974 submit. India was represented by Prime Minister Indira Gandhi, Sardar Swaran Singh, Dr. K. L. Rao and others. In a cordial atmosphere, Sheikh Mujibar Rahman and his team were convinced about India's view on availability of lean-season flow in the Ganga and agreed that the flow at Farakka point was much less than flood discharge. They agreed with India that this little flow would have to be shared between the two countries, keeping in view the basic purpose of Farakka Barrage and the optimum requirement of Bangladesh for irrigation.

In the Joint Declaration signed by the two Prime Ministers in New Delhi on 16th May 1974, the Ganga water sharing at Farakka and the commissioning of the Farakka Barrage got prime importance. Clauses 17 and 18 which are relevant in this connection are reproduced below:

> The two Prime Ministers took note of the fact that the Farakka Barrage Project would be commissioned before the end of 1974. They recognized that during the periods of minimum flow in the Ganga, there might not be enough water to meet the needs of the Calcutta port and full requirements of Bangladesh and, therefore, the fair weather flow of the Ganga in

> the lean months would have to be augmented to meet the requirements of the two countries. It was agreed that the problems should be approached with understanding so that the interests of both the countries are reconciled and the difficulties removed in a spirit of friendship and cooperation. It was, accordingly, decided that the best means of such augmentation through optimum utilization of the water resources of the region available to the two countries should be studied by the Joint Rivers Commission. The Commission should make suitable recommendations to meet the requirements of both the countries.
> It was recognized that it would take some years to give effect to the recommendations of the commission, as accepted by the two governments. In the meantime, the two sides expressed their determination that before the Farakka project is commissioned they would arrive at a mutually acceptable allocation of the water available during the periods of minimum flow in the Ganga.

The points that emerged from the Declaration are:

(i) Both sides agreed that the Farakka Barrage project would be commissioned before the end of 1974 and that before commissioning of the barrage a mutually acceptable allocation of the water available during the periods of minimum flow in the Ganga at Farakka point would be arrived;
(ii) Both sides agreed that the fair weather flow of the Ganga in the lean months would have to be augmented to meet requirements of the two countries.
(iii) Both sides agreed that the best means of augmentation of the lean season flow of the Ganga would be through optimum utilization of the water resources of the region, available to the two countries and the studies to be conducted through Joint Rivers Commission. It was clear that the rivers flowing through the two countries- the Ganga, the Brahmaputra, the Meghna and all their tributaries- are to the explored for augmentation of the Ganga flow through the J.R.C. for benefit of the two countries. In other words, linking the Brahmaputra with the Ganga for augmentation of its flow was agreed to indirectly by the two countries.

Though the construction of barrage was completed in 1973, the excavation of the feeder canal was delayed by agitation of the local people against the loss of communication between the people of two banks of the canal and incomplete road bridge across Dhulian-Pakur State Highway. Thus, the schedule in the Joint Declaration could not be adhered to for commissioning the barrage before the end of 1974 and had to be deferred to April 1975 when both countries decided to test-run the feeder canal. In this period, certain political changes occurred in two countries. Mujibur Rahman became the President of Bangladesh in January 1975 and in India, Dr. K. L. Rao was replaced by Jagjivan Ram as the Agriculture and Irrigation Minister. A state of Internal Emergency was declared in India in May 1975, on the suggestion of Indira Gandhi to the President to control widespread chaos and lawlessness. Two ministerial-level meetings were held – one in New Delhi in February 1975 and the other in Dhaka in April 1975 to decide the modalities of test-running of the feeder canal. In the Dhaka meeting, Jagjivan Ram demanded minimum 35,000 cusecs to save Calcutta port, which Bangladesh delegates did not accept. The accord for the test-run of the feeder canal was announced on 18th April 1975 in the form of a joint press release.

> The Indian side pointed out that while discussions regarding allocation of fair weather flows of the Ganga during lean months in terms of the Prime Ministers' declaration of May, 1974 are continuing, it is essential to run the feeder canal of the Farakka barrage during the current lean-period. It is agreed that this operation may be carried out with varying discharges in ten-day periods during the months April and May 1975, as shown below ensuring the continuance of the remaining flows for Bangladesh.

Month	10-day period	Withdrawal
April, 1975	21st to 30th	11,000 Cusecs
May, 1975	1st to 10th	12,000 Cusecs
	12th to 20th	15,000 Cusecs
	21st to 31st	16,000 Cusecs

> Joint teams consisting of experts of two governments shall observe, at the appropriate places, in both the countries, the effects of the agreed withdrawals at Farakka, in Bangladesh and on the Hooghly river for the benefit of Calcutta port. A joint team will also be stationed at Farakka to record the discharges into the feeder canal and the remaining flows for Bangladesh. The teams will submit their reports to both the governments for consideration.

The full text of the Joint Press Release of 18th April, 1975 is given in Appendix – A.

The accord of April 1975 was for test-running the canal by letting 16,000 cusecs flow on its dry bed and slope to help it adjust to the regular designed discharge afterward. Any structure needs test-running with loads and stresses before the actual design loads and stresses are applied. For an unlined canal of such a big cross-section with carrying capacity of 40,000 cusecs and the bed-width of about 150 m, making it the biggest unlined canal section of the world, a test-running with less discharge and gradual increase was absolutely necessary. In the Farakka feeder canal, the discharge was gradually increased from 16,000 cusecs to the designed discharge of 40,000 cusecs in June 1975. The plea by Bangladesh that after May 1975, the feeder canal should not carry any discharge until further accord was technically unsound. A canal carrying some discharge cannot be dried up suddenly without causing bank slips and maintenance problems. Also, the Joint Declaration of May, 1974 was for the season of minimum flow, which was over on 31st May. The canal was to run during flood season which started from June.

The Farakka Barrage Project was commissioned on 21st May 1975 by Jagjivan Ram, India's irrigation Minister in the presence of Siddartha Shankar Roy, Chief Minister of West Bengal and B. M. Abbas, Adviser to the Bangladesh President Sheikh Mujibur Rahaman.

Under the 1975 accord, the places and the type of observations, to be carried out at different places at Farakka, in the river Hooghly in India and in the Ganga-Padma in Bangladesh were decided on 24th and 25th April 1975 in Kolkata by the representatives of the governments of India, Bangladesh, West Bengal and the Calcutta Port Trust. Their observations related to the gauge, discharge, tide, track shift and dredging requirement in the Hooghly, salinity, navigation channel records, rainfall data in Bangladesh and details of the Ganga – Kapotaksha pumping station in Bangladesh. Both sides agreed that the period of release of water would be too short and that the observations would not lead to any conclusion, because when the diversion began 21st April 1975, the critical period was coming to a close and the river has already begun to rise.

Meanwhile, the Joint Rivers Commission was functioning smoothly and after its 13th meeting in Dhaka in June 1975, it submitted its report to the two governments on augmentation of dry-season flow of the Ganga. It considered three aspects – availability of water at Farakka, requirement of water by both countries and the probable means of augmentation. On availability, the commission agreed that, on the basis of 75% dependability, the fair weather flow of the Ganga at Farakka in the lean months was of the order of 55,000 cusecs. It may be mentioned here that the original project report on the Farakka barrage, prepared in 1961 by the Government of India, also fixed the minimum flow to be 55,000 cusecs. As regards requirements, each side had reservations about the other's figures. The commission, therefore, adopted a working demand of 95,000 cusecs, made up of 55,000 cusecs for Bangladesh and 40,000 cusecs for India, as if the entire lean season flow of 55,000 cusecs would have hypothetically flown into Bangladesh, had the barrage not been there at Farakka. As stated, East Pakistan and its successor government of Bangladesh had gradually increased these requirement from 2000 cusecs in 1954 to 49,000 cusecs in 1968 and then to 55,000 cusecs in 1975.

On augmentation of the Ganga flow, the Commission agreed with the view that it would be feasible to increase the dry-season flow of the river by some means but the two sides gave two different schemes. India proposed augmentation of flow by diverting water from the Brahmaputra to the Ganga at Farakka by a link canal. This was in line with Clause 17 of the Joint Declaration of May 1974. Bangladesh proposed augmentation through storages in the Ganga basin in its uppermost reaches, involving Nepal as a third party. India's proposal involved excavation of about 220 mile (352 km) long canal, joining the Brahmaputra with the Ganga above the Farakka Barrage, which will pass through Assam in India, Rangpur district of Bangladesh and then through Dinajpur and Malda districts of West Bengal. It also involved construction of a barrage across the Brahmaputra at Jogigapa in Goalpara district in Assam. On the other hand, Bangladesh proposal involved construction of a number of storage dams on rivers Kosi, Gandak, Karnali etc. within Nepal and bringing down the stored water to the Ganga through the rivers of north Bengal and Bangladesh, like Kosi, Mahananda, Karatoya etc. which will also generate hydroelectricity for utilization by three countries. However, neither side could agree to the other's proposal. In this stalemate, Indian delegates proposed seeking instruction from the two governments by referring the matter to them through the JRC in the spirit of the Joint Declaration; this was also not agreed to by Bangladesh. Thus, the JRC was sharply divided. Considerable data in respect of the Farakka Barrage Project, which were sought by Pakistan since 1960, were supplied by India; these were detailed hydrological information on the Ganga and the Hooghly, Calcutta port statistics, salinity, silt and dredging data etc. India also arranged for the visit of Pakistan experts to the Farakka project site in October, 1968. They differed with

Indian experts on the gains in river supplies between Farakka and Hardinge Bridge, over and above the discharge from Farakka point, but as the observation site was shifted to Paksey where the collected data related to a short period, the two sides could not come to an agreed solution. Moreover, Bangladesh did not agree to certain basic facts about the Ganga. There are about 140 million acres of cultivable land in the Ganga basin (about 6400 km long considering Ganga and its tributaries) in India, where about 210 million people depend on the river. This area, India said, experienced periodic scarcity and drought, as only 10% area was irrigated by the Ganga and its tributaries. Apart from the agreed discharge through the Farakka barrage for revival of Calcutta port, India needed more water for irrigation of arid areas. Against this, only about 140 km of the Padma's flow go into Bangladesh, which is an insignificant contribution to the flow of the river. Yet the whole of dry-season flow is sought to be appropriated by Bangladesh for the entire four million acres of land, claimed to be under the command of the Padma, at an intensity of over 210% in a region where rainfall is abundant, and scarcity unknown. Table 9.2 illustrates this.

Table 9.2 shows that the share of water, demanded by India was quite justified. The joint potentiality of the Ganga and the Brahmaputra basins is estimated at about 980,000 Mm^3 of annual run-off, about 75% of which are contributed in five monsoon months, from June to October. The discharge in the Brahmaputra rises about three months before that in the Ganga (March in case of the Brahmaputra and June in case of the Ganga). Moreover, the minimum dry-season discharge in the Brahmaputra is more than 0.1 million cusecs. Thus, India's proposal of linking the Brahmaputra with the Ganga has a lot more sense than Bangladesh's proposal of constructing storage dams, involving Nepal, which contravenes the spirit of bilateral agreements and the Joint Declaration. Moreover, such linking and diversion of

Table 9.2 Comparative study on water requirement by India and Pakistan

	Particulars	India	Bangladesh	Remarks
1	Geographical area (Million Acres)	191	6.10	–
2	Total cultivable area (Million Acres)	140	4.90	–
3	Total cropped area (Million Acres)	125.30	1.30	–
4	Length of Ganga river (including important tributaries)	6,400 km	140 km	Excluding Bhagirathi Hooghly in India and Gorai in Bangladesh
5	Catchment area	780,000 km^2	5,700 km^2	—
6	Cultivable area (Million Acres)	154	5	—
7	Average rainfall	51–127 cm (20–25″)	140–254 cm (55–100″)	–
8	Intensity of irrigation (percent of cultivable area)	9.90	210	–
9	Population dependent on river (million)	210	12	–
10	Population per Sq. km	2,470	500	–

water could have reduced the flood havoc in the Brahmaputra basin and increase the irrigation potential in the arid regions of Assam and Bangladesh.

Widespread flood in the Ganga and the Brahmaputra basins are quite normal. About 5% of the areas within the Ganga and the Brahmaputra basins in India are flooded. In Bangladesh, more than 36% area normally goes in spate following spills in the Ganga and the Brahmaputra, every year. The most devastating floods occurred in 1986 and 1988 in Bangladesh. Almost the entire length of the rivers and their tributaries pass through the plains of both countries, making it virtually impossible to construct any big storage reservoir within the landform except perhaps in the hilly regions, encroaching on the territories of Nepal and Bhutan. Moreover, the Himalayan hills, formed by recent geological deposits, are fragile and unstable and prone to seismic and other geological problems. In spite of this, some reservoirs have already been built across some tributaries of the Ganga by India but the cumulative capacity is insignificant, hardly about 10% of the total volume, which is released in the lean season. Any big storage dam in the hilly region will, therefore, invite innumerable problems for India, Nepal and Bhutan. But the Brahmaputra has remained untapped so far. The entire flow of the river passes through the state of Assam and then enters Bangladesh with devastations every year. According to the country's own report the estimated excess design flood-flow of the country is about 239 million acre feet, of which local rainfall contributes about 32 million acre feet of water. The World Bank is of the view that Bangladesh needs outside help to mitigate incidence of flood. Seen in this context, India's proposal of linking the Brahmaputra with the Ganga for augmentation of flow was more judicious and feasible than Bangladesh's idea of constructing storage reservoirs in the hilly regions. Since the lean-season discharge of the Ganga has fallen from 55,000 cusecs in 1950 to less than 40,000 cusecs in 1995 and as the major catchment area of the Ganga falls within Indian States of Uttar Pradesh and Bihar, it was very difficult for the Government of India to embargo abstraction of water from the Ganga by these two States for irrigation and other purposes.

In spite of these facts and circumstances, the augmentation proposal of India was not accepted by Bangladesh, nor did India accept the proposal of Bangladesh. As a result, the JRC meetings used to be sharply divided. Sometimes, they were deadlocked on specific issues, like exchange of data. Though India gave all relevant records on the Ganga, Bangladesh refused to give any about the Brahmaputra. Formulation of any water augmentation scheme of the Ganga needs data of the total quantum of flow against probable total requirement of the two countries but Bangladesh did not comply; hence the bottleneck continued. Prime Minister Mujibur Rahaman, though initially reluctant, ultimately agreed to give all information about the Brahmaputra to India and accordingly, instructed his officials, but this could not materialize in his life-time, up to July 1975.

President Mujibur Rahaman was assassinated on 15th August 1975 by the country's army officers, when India was observing its 29th Independence Day. Many Indians who were associated, directly or indirectly, with the diversion of the Ganga water through the feeder canal at Farakka felt that he had to give his life for letting India continue the construction of the barrage at Farakka and for allowing diversion of water through the feeder canal to resuscitate the Calcutta port. He was killed within 3 months of the commissioning of the Farakka Barrage. There were other grounds for such apprehension. Immediately after the assassination, there was a military coup in Bangladesh and the country was in utter turmoil for several months. There were killings and arsons of people, sympathetic to Mujibar's regime and changes occurred in the government too. B. M. Abbas wrote that the Mujib era turned out to be one of an uneasy truce between Bangladesh and India.

Bangladesh remained unstable after 15th August, 1975 and false propaganda, malafide and false statements by Bangladesh media against India continued. Even there was an attempt to kidnap Indian's High Commissioner in Dhaka on 26th November 1975. Moulana Abdul Hamid Bhashani, the veteran trade union leader, threatened to destroy the barrage by bringing thousands of Bangladeshis to Farakka across the border. He arranged a long march on 16th May 1976 from Rajsahi but it stopped for unknown reasons a little ahead of the international border. The tension between the two countries mounted to its zenith in 1976, and the relation between the two countries fell to all-time low.

The test-running of the feeder canal ended on 31st May 1975, as per temporary accord. It has adjusted, by this time, to carry larger discharge. The Ganga water started rising with gradual increase in discharge. No accord beyond May 1975 existed but the canal could not remain empty once it received discharge. There was sufficient water available in the Ganga in monsoon months and beyond, up to February. After the assassination of Mujibur Rahman, there was no sincere attempt by the new Bangladesh govt. to reach further understanding with India regarding diversion of water. Therefore, India diverted water into the canal to its design capacity of 40,000 cusecs from end of June 1975. Stray protests were made by Bangladesh, alleging unilateral withdrawal of the Ganga water at Farakka. India offered to discuss it with Bangladesh before the lean season of 1976, but Bangladesh turned it down, demanding that India should stop withdrawal of water before any discussion could take place.

In 1976, Bangladesh began to seek sympathy for its cause from countries abroad. B. M. Abbas was deputed to the UN and to the USA from 19th February to 5th March. He raised the issue in the UN in a conference on development of the Ganga-Brahmaputra river basin, where Dr. K. L. Rao represented India. Mr. Abbas discussed the Farakka issue with the World Bank President, Robert Mac Namara and the member of the International Law Association, Prof. Richard Baxter of Harvard Law School. Both suggested long-term solution on the basis of long-term development of eastern rivers. Mr. Abbas gave a number of press statements in the UK and the USA in support of Bangladesh's claim on the Ganga water and condemning India's unilateral withdrawal at Farakka. Thus, instead of agreeing to India's proposal of discussion on the issue, Bangladesh tried to get foreign involvement seeking sympathy on the issue from abroad which was against the spirit of Joint Declaration. Thus, India was left with the no alternative except the so-called unilateral withdrawal of water during the whole of 1976. Moreover, India sent on its own two teams to Bangladesh – a technical delegation from 27th April to 2nd May and a ‘good-will delegation’, headed by G. Partha Sarathy, Chairman of the Policy Planning Committee of the Indian Ministry of External (Foreign) Affairs to Bangladesh from 18th to 22nd June 1976 for discussing the Ganga water-sharing at Farakka; the Bangladesh delegation was led by Rear Admiral M. H. Khan. The outcome of this meeting was practically nil, as both sides did not budge from their stands. India insisted on solving the problem within the framework of the Joint Declaration by bilateral discussions; while Bangladesh insisted on Nepal’s involvement. India suggested studying the effects on both countries of withdrawal of water at Farakka by a joint committee; to this also Bangladesh did not agree.

Mean while Bangladesh applied for inclusion of the Farakka issue in the agenda of the UN General Assembly session. This was not well taken by the Indian Prime Minister, Indira Gandhi, which was reflected when the Bangladesh team, led by M. H. Khan visited New Delhi from 7th to 10th September 1976. In the meeting with Mrs. Gandhi on 9th September 1976, there was heated exchange of words between the two sides on various issues, including sharing of the Ganga water and Dhaka’s complaint in the UN. The meeting abruptly ended with the withdrawal of Bangladesh team.

Thus, Indo-Bangladesh relationship came to the ‘breaking point’ on Farakka issue in this period, owing also to the instability in the political regime in Bangladesh. After trial operation of the feeder canal between 21st April and 31st May 1975, India wanted to reach an agreement on withdrawal of water at Farakka in the next lean season, but this fell through because of lack of response from Bangladesh. Disputes also arose on the definition of the lean season. While India proposed sharing of water from mid-March to mid-May for running the feeder canal, Bangladesh stuck to its preferred period, between November and May. India could not remain a silent spectator and let the canal remain dry, but continued to draw water at Farakka during the monsoon season of 1975 and also thereafter in 1976 and 1977 to the minimum extent of 40,000 cusecs and released the balance volume to Bangladesh. In the lean seasons of 1976 and 1977, India took less than its minimum requirement as a goodwill gesture, and gave additional water to Bangladesh. India knew the impact of such reduction in the lean season on the river and on the navigability of Calcutta port, as the river needed at least 40,000 cusecs, round the year. Bangladesh knew the extent of this reduced withdrawal by India and the increased flow, available at Farakka. In fact, Bangladesh representatives, stationed at Farakka beyond 31st May up to 7th August, 1975, saw the reduced withdrawal by India for the trial run of the feeder canal but never objected to such withdrawal. Therefore, withdrawal by India beyond 31st May, 1975 cannot be termed ‘unilateral’, as it took place in the presence of Bangladesh representatives.

This unfriendly attitude of Bangladesh leaders was anticipated, because K. Mushtaq Ahmed who succeeded the assassinated President, Sheikh Majibur Rahaman in August 1975, was noted for his ‘anti-India’ bias. Many politicians including B. M. Abbas, the noted engineer-cum-politician of Bangladesh, had displayed such attitude to India earlier and even afterward. Mrs. Khurshida Begum in her look 'Tension over the Farakka Barrage – a Techno-Political Tangle in South Asia' said:

> . . . it must not also escape our notice that being known as an 'anti-Indian' politician, he had his difficulties in maintaining relation with India. Taking a hard line course, it may be easier to prove one's sincerity towards the cause of the people, thereby to achieve quick support of the people, but it may not produce any fruitful result for the well-being of the political system. Many of the politicians in Bangladesh lack this basic political acumen. They try to exploit the Farakka barrage, a sensitive issue of vital importance to the people but they do not foresee if they are put in power, how they would adjust themselves with the geo-political realities. After assuming power, Mushtaq Ahmed also could not ignore the facts of geo-politics.

After a short spell of Mushtaq Ahmed's regime, General Zia-ur Rahman became the President of Bangladesh in late 1975. In his time too, Bangladesh approached the UN for interference on the Ganga water issue in September 1976. It was also opposed by India on the ground that it was a 'bilateral issue of purely economic nature'. Bangladesh retorted that the problem was multi-dimensional and as the hindrances to a solution were political in nature, it ought to be included not only in the General Assembly agenda, but also in that of its Special Political Committee. Bangladesh's plea for its inclusion in the special Political Committee was accepted but it did not evoke any sympathy of the international community and no debate was held on the issue in the committee's meeting on 15th November 1976 and in India's reply on the following day. However, in a meeting of the Committee on 24th November 1976, both countries agreed to a consensus text, to be worked out by a group of non-aligned countries. The important portion of the consensus statement, titled 'Situation arising out of the "Unilateral withdrawal" of the Ganges waters at Farakka' read as:

> The parties affirmed their adherence to the Declaration on Principles of International Law concerning Friendly Relations and Co-operation among States in accordance with the Charter of the United Nations and stressed in this regard their unalterable commitment to strengthen their 'bilateral relation' by applying these principles in the settlement of disputes. . . The parties undertook to give due consideration to the most appropriate ways of utilizing the capacity of the United Nations system. It is open to either party to report to the General Assembly at the thirty second session on the progress achieved in the settlement of the problem.

The statement added that the two countries would 'meet urgently at Dhaka at the ministerial-level for negotiation with a view to arriving at a fair and expeditious settlement.'

Thus, the mission of Bangladesh was not fulfilled to bring the international forum behind it on the Ganga water issue. Moreover, it had to agree that the issue was 'bilateral' and should be solved by the two countries themselves, in an atmosphere of peace and co-operation instead of hostility and non-co-operation. However, India had to accept, in an international forum, that the withdrawal of water in the lean season of 1976 was 'unilateral' and an urgent solution was necessary through mutual discussion and understanding before the next dry season.

In the September 1976 meeting between Admiral M. H. Khan of Bangladesh and Mrs. Indira Gandhi in New Delhi, Bangladesh did not show a good gesture. India wanted a solution of the problems between the two countries, if there was desire on the part of Bangladesh, instead of its attempt to include Farakka issue in the UN agenda, as these were not friendly acts.

A dialogue between the two countries followed in December 1976 at Dhaka in deference to the consensus statement at the UN in the previous month and in another discussion in January 1977. In these, the Indian side was led by Jagjivan Ram, the then Irrigation Minister and Bangladesh by Rear Admiral M. H. Khan, Member of the President's Advisory Council in charge of the Ministry of Power, Flood Control and Water Resources, but once again both sides stuck to their old positions, leading to a failure of talks. The two sides could not agree on the technical aspects of sharing the Ganga water and the quantum of share that could meet the requirements of both the countries. India offered a 50:50 sharing, i.e. India could draw 33,000 cusecs of water from the average dry season flow of 55,000 cusecs and give the remaining 22,000 cusecs, along with a regeneration of 11,000 cusecs, i.e., a total of 33,000 cusecs to Bangladesh. Dhaka dubbed the regeneration as 'highly uncertain' and held that at most it would not exceed 2,000 cusecs. India's earlier estimate of regeneration near the Hardinge Bridge was 18,000 cusecs. Bangladesh wanted the share to be as per the short-term agreement during the test-running of the feeder canal in April 1975. None of the proposals was acceptable to either side and there was an apprehension in India that Bangladesh would again try to take the issue to the next UN General Body meeting.

Thus, the political turmoil over the sharing of the Ganga water at Farakka by the two countries impeded for a while after the assassination of Sheikh Mujibur Rahman, continued up to February, 1977 in spite of sincerity and eagerness by India to reach an understanding. It was amazing that Bangladesh wanted India to stop diverting water into the feeder canal and keep it dry without considering the technical aspects and consequences that would occur to the unlined canal.

Chapter 10
Agreements & MOUs

India's parliamentary election in 1977 saw a dramatic change of power from Indira Gandhi to Morarji Desai of the Janata Party, ending a 30-year rule by the Indian National Congress, founded by a British civil servant, Alan Octavian Hume in 1885. The country's foreign policy remained, by and large, the same as formulated by the first Prime Minister after India's Independence from nearly 200 years of British colonial rule, Jawaharlal Nehru and followed by his two successors – Lal Bahadur Shastri and Indira Gandhi. Initially, the sharing of the Ganga water after the construction of Farakka Barrage in 1975 posed no problem with Bangladesh in the ambience of cordiality and friendship with the new republic, in whose emergence India played a crucial role by giving ample diplomatic and military help. Bangladesh also felt that the transfer of power from the Congress to the Janata Party in 1977 created a congenial atmosphere for coming to an understanding with India on co-sharing of the Ganga water and reconciliation of conflicting claims, leaving aside technical difficulties, as far as possible. Assuming power, the Janata government focussed on the water dispute and other bilateral issues with Bangladesh and sent Defence Minister, Jagjivan Ram who was in charge of irrigation in Indira Gandhi's cabinet, heading a delegation of officials to Dhaka on 15th April 1977 for discussions with Bangladesh government. After three days of discussions, the two governments issued a brief joint statement, as under:

> An understanding has been reached (on Farakka), details of which will be worked out at a meeting of the officials of the two governments, to be held in New Delhi, as soon as possible.

A minister-level meeting was followed by an officers' meet, next month, i.e., in May, in New Delhi and in Dhaka in July, that year. A short-term agreement was initiated at midnight of 30th September 1977 in New Delhi and finally signed on 5th November 1977 at Dhaka by S. S. Barnala, India's Minister of Agriculture and Irrigation and Rear Admiral M. H. Khan on behalf of Bangladesh. This has come to be known as the Farakka Agreement, the full text of which is given in Appendix B. Thus, a long outstanding and delicate dispute, fraught with technical, political and economic implications and hazards was solved for the time being.

The Agreement had 15 Articles, one Schedule and two side letters. It was subdivided into three major parts – A, B, and C. The period for water-sharing between

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two countries was sub-divided into 15 ten-daily periods with ratio, as shown in the Schedule. For assessing the actual quantum of release in the Ganga's downstream and in the Feeder Canal, a Joint Committee set up Observation Teams at Farakka and at Hardinge Bridge (over the Padma) in Bangladesh to record daily flows, as covered under Articles I–VII.

Articles VIII–XI related to long-term arrangements, under which Indo-Bangladesh Joint Rivers Commission was entrusted to carry out investigation and study of the schemes, relating to the augmentation of the dry-season flows, proposed, or to be proposed, by both sides to find a most economical and feasible solution. The two governments pledged to consider the scheme and take appropriate measures to implement it.

Articles XII–XV related to the review and duration of the Agreement. It could be reviewed after three years and would remain in force for five years from the date of effect. Though a short-term one, the Agreement added a new dimension to Indo-Bangladesh relations with the hope that political goodwill would overcome the difficulties which hitherto appeared insurmountable. India achieved the success of its policy of bilateralism which it had adopted in principle and focused on it to the outside world. The next United Nations General Assembly session was approaching and the signing of the Agreement before it enhanced the prestige of India in the world body which saw that a sensitive issue, like this should be resolved through bilateral dialogue.

Discussion on the Agreement

Before the Agreement was signed in November, 1977, several rounds of talks were held at officers' as well as Ministers' levels for finalizing the different articles. Discussions were also held between Morarji Desai, Prime Minister of India and General Zia-ur Rahman, President of Bangladesh in London in the middle of June, 1977 during the Commonwealth conference.' The Statesman' of 14 June 1977 reported that India renewed its offer of building a canal, linking the Brahmaputra and the Ganga to settle the dispute. It was made to the Bangladesh President by Morarji Desai in their talks in London. During the negotiation, canards spread and accusations made regarding the terms of agreement, which provoked angry protests by A. B. Vajpayee, the then External Affairs Minister of India (later a Prime Minister). Addressing a rally at Gandhi Maidan in Patna in early June 1977, he said a canard was being spread that India had been sold out in the agreement with Bangladesh and that it will completely ruin the Calcutta Port, as bulk of the Ganga water would be diverted from the Farakka barrage to Bangladesh. He said that the canard was baseless, as talks were still on with Bangladesh on the Farakka issue and no final agreement had been reached. Again, in a Rajya Sabha session in July 26, 1977, the opposition accused that the proposed meeting at Dhaka would endorse an agreement, under which India would have to be content with only half of 40,000 cusecs of water from Farakka which was needed to save Calcutta Port and that India would have to restrict the use of the Ganga water to only 10% until the plan to augment the Ganga flow was accepted. Other Indian newspapers also questioned the accord. Experts also criticized it in the meetings of the Bengal National Chamber of Commerce, Indian National Chamber of Commerce and other organizations. Debesh Mukherjee ex-General Manager of the Farakka Barrage also held that the accord would not achieve aims.

The joint declaration of May, 1974 and the agreement of April 1975 were not followed in letter and spirit before the 1977 agreement was signed. Detailed observations in respect of gauge, discharge etc. to be made in the Bhagirathi-Hooghly in India and in the Garai-Madhumati-Dhaleswar, the Bhairab-Pussar and the Padma-Meghna in Bangladesh as well as hydrographic surveys and navigation track surveys, salinity, rainfall data, exchange of information through Joint River Commission to study the effects of increased lean-season flow in the Bhagirathi-Hooghly and corresponding decrease in the Padma-Meghna and its tributaries from 1975 to 1977 were not considered before signing the 1977 agreement.

In spite of all these odds, the long-standing dispute between India and Bangladesh was somehow resolved through the Ganges Water Agreement for sharing of water in the lean season from 1st January to 31st May, each year. Both sides made substantial concessions to safeguard respective interests. For India, the Agreement was quite detrimental to the interest of Calcutta Port as the minimum requirement of 40,000 cusecs was gradually reduced to 20,500 cusecs by end-April with provision for further reduction during abnormally low-flow season, as provided in Article II. From March to May, tides in the Hooghly are quite high and the water level reaches the maximum. Enormous quanties of sand and silt move upstream with the flow tide and much of the same get deposited on the bed. As upland discharge falls in these months, the ebb flow is not strong and siltation occur. The reduced discharge does not give enough force to the ebb current and therefore, does not help scour the deposited silt which gets continuously deposited and reduce the river's capacity. Thus, the interest of Calcutta Port was not protected in the Agreement. India had to remain satisfied with the low discharge of 20,500 cusecs, which is about 49% less than the minimum requirement of 40,000 cusecs. Moreover, India's original demand of sharing water from March to May was compromised in favour of sharing the same in fully dry season from January to May. However, India's demand for a short-term agreement was met, as it was valid for five years only and could be reviewed after three years, as provided in Article XIII. Moreover, New Delhi's demand for a long-term solution to the problem by augmenting the dry-season flow of the Ganga at Farakka was safeguarded in Articles – VIII to X. Bangladesh's demand of the entire 'historic flow' of the river was not fulfilled and it had to divert 20,500 cusecs to India in the driest period. Dhaka's subsequent demand for 44,000 cusecs during negotiation was also curtailed to 34,500 cusecs in driest period, a reduction by about 22%. Moreover, its original demand of water-sharing from November to June was scarified. Its demand for a long-term agreement of 25 to 30 years validity was not accepted. In terms of legal language, the Agreement was in the nature of a '*Pactum De Contrahendo*', i.e. 'an Agreement to conclude a final agreement at a later date.'

The agreement had three parts; Part A dealt with arrangement for sharing of the Ganga water at Farakka; Part B with long-term arrangements and Part C with review and duration. In a broad sense, the agreement was unsatisfactory, as the Part A dealt with the available water resource at Farakka, without going into reasons for its gradual decrease and suggesting action and to plug loopholes, where ever possible. The realities were not considered and the development activities of the two countries were either overlooked, or side-tracked. Technical considerations were over-shadowed by political motives for achieving success in foreign affairs within a short time by both the Governments. It is a fact that the lean-season discharge in the Ganga was falling for many reasons, one of which was the increase of withdrawal by The States in the upper reaches. The understanding was reached within a year of the Janata government coming to power in Delhi by giving substantial concession to Bangladesh at the cost of India's interests. Out of these divisions, the driest period of three 10-daily periods of last two in April and first one of May, need special mention, as the concessions were maximum during this period (more than 62% to Bangladesh). National interest including that of Calcutta Port was completely overlooked at the cost of improving bilateral relations. The rigidity, followed so long by both the Governments (the Congress in India and the military rule in Bangladesh) was diluted by the Janata government. In fact, India was willing to give more concessions, according to a statement by a secretary in Indian's Finance Ministry associated with the 1977 negotiations, as quoted by 'Ben Crow'.

> The new government was willing to make more concessions. They wanted to project an image of having achieved success in foreign policy in a short time. What they did with Pakistan and Nepal amounted to getting over some mental blocks. But with Bangladesh, there was a calculated sacrifice of the national interest with a view to achieving wider purposes. We thought that if the biggest irritant was removed, the climate would change.

On the country, concession by Bangladesh was quite small. Their demand for 44,000 cusecs in dry season: was cut down to 34,500 cusecs, with a 'distress clause', which was favourable to Bangladesh. Figure 10.1 and Table 10.1 show, how concessions were allowed by India to Bangladesh against very small concessions given by the latter.

Table 10.1 shows that the percent share of India from the total available flow at Farakka varied from 42.9 in January to 37.3 in the last 10-daily in April. The percent share of Bangladesh in the corresponding period varied from 57.1 to 62.7, i.e. in the driest period of last 10-daily of April. The percent share of Bangladesh was higher than India's and also of other periods of the season. Regarding concessions by India and Bangladesh against their demands of 40,000 cusecs and 44,000 cusecs respectively, that by India, from second 10-daily in January to last 10-daily in April varied from 1.7 % to 35.4%. In the same period, Bangladesh gained from 8.1 to 2.9 in second 10-daily in January to first 10-daily in February after a concession ranging from 2.1 to 17.3. Thus India's sacrifice was more than Bangladesh's, particularly in the leanest season in end of April. Bangladesh demanded restoration of the so-called 'historic' or 'natural' flow into the Ganga without human Interference, i.e. as it was pre-barrage, but in the context of global scientific and technical advances, a developing country like India should not have remained a silent spectator to the

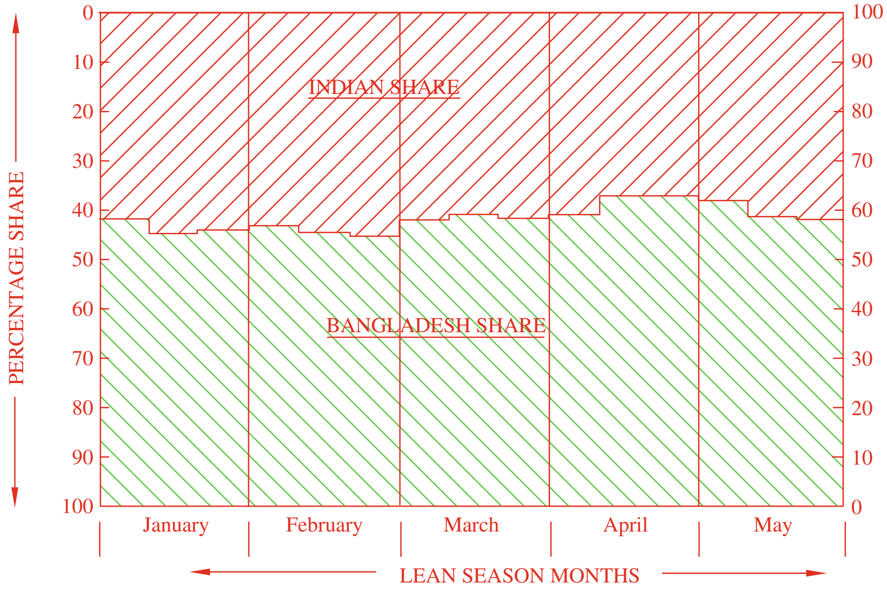

Fig. 10.1 Share of lean season flow of Ganga at Farakka between India and Bangladesh

Table 10.1 Percentage sharing of flow by India and Bangladesh at Farakka

Period	Flow reaching Farakka (Cusecs)	Percentage share and [Gain(+)/Concession(–)] given	
		India (40,000)	Bangladesh (44,000)
January: 1–10	98,500	40.6(Nil)	59.4(+14.7)
11–20	89,750	42.9(–1.7)	57.1(+8.1)
21–31	82,500	42.4(–6.1)	57.6(+4.3)
February: 1–10	79,250	41.6(–8.9)	58.4(+2.9)
11–20	74,000	42.6(–11.5)	57.4(–2.1)
21–28/29	70,000	43.9(–13.2)	56.1(–6.8)
March: 1–10	65,250	41.0(–20.3)	59.0(–8.4)
11–20	63,500	40.2(–22.8)	59.8(–9.5)
21–31	61,000	41.0(–24.6)	59.0(–13.1)
April: 1–10	59,000	40.7(–27.1)	59.3(–15.3)
11–20	55,500	37.4(–34.7)	62.6(–16.7)
21–30	55,000	37.3(–20.3)	62.7(–17.3)
May: 1–10	56,500	38.1(–32.7)	61.9(–16.0)
11–20	59,250	40.5(–27.0)	59.5(–14.8)
21–31	65,500	40.8(–20.3)	59.2(–8.0)

caprice of Nature and let its growing population to suffer. Therefore, the diversion of at least 40,000 cusecs of water into the Bhagirathi-Hooghly by blocking its natural flow by a barrage at Farakka was direly needed for the resuscitation of Calcutta Port, but the agreement did not fully provide for it. Figure 10.1 shows the disparity in the division of the water, considering the flow at Farakka.

Another point in Part A needs a special look. The agreement was drawn on the basis of past records of flow, reaching Farakka from 1948 to 1973 except for four years, from 1974 to 1977; the reasons were not mentioned anywhere. In fact, the flow reduced further in those four years, but was not reflected in the Agreement. It was based on the total volume of water to be shared. The share of India varied between 42.9% and 37.3% but not on a linear distribution. The distribution was erratic, because it was the flow likely to be available at Farakka. This left a scope for adjustments and complication in the operation of the gates of the barrage as well as of the head regulator. Had it been a linear distribution, based on actual flow at Farakka, in a ratio decided by the representatives of both countries and reflected in the Agreement, its implementation on the ground as well as the operation of the barrage and the head regulator gates could be much easier.

Both sides were convinced of the scarcity of dry-season flow to meet respective requirements which needed minimum of 84,000 (40,000+44,000) cusecs in the leanest season. They realized the need for augmentation of the flow through some other means. In fact, the Joint Rivers Commission (JRC), constituted in 1972 with representation of both the governments, aimed at augmentation of the Ganga flow through suitable schemes and actions, initiated much earlier. Thus, both sides realized the necessity of developing water resources in the Ganga basin for increasing the dry season flow.

Part B of the Agreement, dwelling on long-term arrangements provided a scope for augmenting the flow. The JRC was entrusted with taking appropriate action, proposed or to be proposed by both countries at a later date. Both had already formulated their proposals for augmentation which were under consideration of the JRC. We shall see later, how the proposals of the two countries were divergent and invited conflicts between them, leading to a deadlock.

As regards Part C, dealing with 'review and duration', the agreement was short-term with five years' validity, from the date of coming into force; it could be extended for a specified period by mutual consent, as provided in Article XV. The provision for review was made in Article XIII, after three years from the date of effect, to be made on the basis of past working, impact, implementation and progress of the arrangements, specified in Parts A and B, as mentioned in Article XIV. We shall see later how this review has become fruitless in spite of the provision for extension of the agreement for another five years.

There were two side-letters to the agreement–one from Bangladesh and the other from India, both dated 5th November 1977, confirming a point, raised by Bangladesh. It related to the proposal on augmentation and the scheme, or the schemes, for building storages in the upper reaches of the Ganga in Nepal.

In short, the dispute arose owing to the shortage of dry-season flow in the Ganga and on its sharing ratio, but the excessive initiative and hurry by the Janata Government in Delhi to improve India's relation with the new republic and compromised national interest in the agreement reflected the main motto of achieving political objective of scoring over the previous Congress regime, led by Prime Minister Indira Gandhi. It became clear, why the Congress Government was so rigid on the demands of the military rulers of Bangladesh and was dragging its feet on making an agreement on sharing of the Ganga water. The minimum period of operation of Farakka feeder canal with 40,000 cusecs throughout the year for five years after commissioning of the barrage, as was decided in the cabinet meeting had not been followed in practice, leaving no scope to study its effects on Calcutta Port and on the Bhagirathi-Hooghly and to curtail the discharge from the present 40,000 cusecs, if found harmless and not injurious to the health of Calcutta Port. In a sense, the Farakka Barrage Project was never tested in field for a reasonable period of at least five years and the huge expenditure on the project became virtually infructuous.

The Agreement had other flaws too. Part A dealt with interim sharing of water, available at Farakka, based on 75% availability from observed records between 1948 and 1973. A pre-determined flow which might be available at Farakka in the next five years was considered for sharing at a certain ratio, not fixed in different 10-daily periods between January and May, every year. The minimum flow, likely to be available in the last 10-daily period of April (21^{st} to 30^{th}) was estimated at 55,000 cusecs, out of which India would get 20,500 cusecs (about 37.3%) and Bangladesh 34,500 cusecs (about 62.7%). Another provision in Article II was of great advantage to Bangladesh. In an exceptionally low-flow season, the flow toward Bangladesh would not go below 27,600 cusecs (80% of 34,500) in the last 10-day period of April. In fact, this provision was made for any 10-daily period, specifying that the flow toward Bangladesh would not be below 80% of the flow, shown in the schedule. It meant that if the flow at Farakka came down to 40,000 cusecs in the last 10-days period of April, Bangladesh would still get 27,600 cusecs and India would get the remaining 12,400 cusecs. We shall see later, whether this actually happened at Farakka.

Under Article IV, a Joint Committee of the representatives, nominated by two governments set up teams at Farakka and Hardinge Bridge (Bangladesh) to observe and record daily flows at those places. Accordingly, the observation teams were set up, every year, since 1978. Bangladesh kept a team at Farakka and India at Hardinge Bridge; they worked in association with respective team of the other country. Observations at the two places were done jointly, from 1978 to 1982 in a cordial atmosphere.

On Part B the future of the sharing of the Ganga water primarily depended. The Agreement provided that the JRC would carry out investigation and study schemes for augmentation and will submit recommendations to the two governments for consideration within three years. This part, however, remained unresolved for the full five-year term of the Agreement. A detailed discussion on this will follow, but this much can be said here that the basic question of increasing the dry-season flow could not be addressed in five years, in spite of prolonged negotiations in the Joint Rivers Commission (JRC). Thus, the negotiations reached a stalemate by the end of 1982. To continue the discussions on this issue and also on the sharing arrangement of water, a Memorandum of Understanding (MOU) was agreed between India and Bangladesh in October 1982 which the two governments signed on 7^{th} October 1982 in New Delhi during the visit of General H. M. Ershad, President of Bangladesh. This will also be discussed afterward.

Although Part C provided review by the two governments after three years from the date of effect of the Agreement and further review within six months before its expiry, as agreed to by two governments, no worthwhile review was done; only a Memorandum Of Understanding (MOU) was signed at the end of the agreement tenure in 1982.

MOUs of 1982 and 1985

By the time the Agreement was going to expire (after the dry season of 1982), no unanimous decision on augmentation was arrived at by the Joint Rivers Commission, necessitating either to extend the validity of the 1977 Agreement, or to sign another. In October 1982, H. M. Ershad, then President of Bangladesh, visited New Delhi and discussed the matter with Indira Gandhi, then India's Prime Minister. They discussed, in the context of actual experience, gained by the two sides on the working of the 1977 agreement which was due to end on 4th November 1982. They agreed that satisfactory and durable solution on augmentation of dry season flow in the Ganga near Farakka had not emerged and that fresh efforts were necessary to clinch a solution. They also recognized that the basic problem was inadequate flow of Ganga water at Farakka in lean season for which both countries had to sacrifice much of their interests. Therefore, it was immediately necessary to arrive at an equitable formula for sharing Ganga water, available at Farakka through a Memorandum of Understanding (MOU). It was also a prime necessity that both the countries agreed unanimously for a long-term augmentation of the flow of the Ganga. Therefore, the two leaders asked their experts to expedite studies of the economic and technical feasibility of the schemes (to be discussed later), proposed by either side. It was decided that the Joint Rivers Commission would complete the pre-feasibility study and find an optimum solution within 18 months of signing of the MOU. The JRC would examine and accept the decision, after which the two governments would implement it. A sharing ratio of water available at Farakka was agreed to by the two governments in this period. Both sides further agreed that in the case of exceptionally low flows in either of the next two dry seasons, the two governments would immediately consult each other and find out ways and means to minimize the burden on either country. A copy of the MOU is enclosed at Appendix C.

The period of two dry seasons, up to which the MOU of 1982 was valid, was barren, because no unanimous decision by the JRC on the proposal for augmentation of the Ganga water at Farakka could be taken.

In 1982, India's political situation changed dramatically. Indira Gandhi returned to power, heading the Indian National Congress. Two years later, on 24th October 1984, she was assassinated and her elder son, Rajiv Gandhi took over as the Prime Minister. Mr. Gandhi and President H. M. Ershad met at Nassau, Bahamas in October, 1985 and arrived at an understanding, under which the Irrigation Ministers of two countries met at New Delhi from 18th to 22nd November 1985 to evolve the terms of reference of a joint study by the Joint Committee of Experts (JCE) of water resources, available to both countries to identify options for the water-sharing for mutual benefit, including a long-term augmentation scheme. They also agreed to sign a MOU for sharing the Ganga water at Farakka for three years, commencing from the dry season of 1986 on the same terms as of the 1982 MOU. It was further agreed that the JCE would study two aspects – (a) sharing available water resources, common to both countries; and (b) augmentation of the dry-season flows of the Ganga at Farakka. The study was to be completed in 12 months, at the end of which a summit-level meeting between the two countries would take place to approve it. It was also agreed that an interim sharing ratio would be followed for next three dry seasons (1986–1988) with the same joint observation and monitoring that in case of exceptionally low flows in any of them, the two governments would hold immediate discussion and decide how to minimize the burden to either country.

Afterwards, a Secretary-level meeting of the two countries, held on 22nd November 1985, defined the sharing ratio in the event of exceptionally low flow at Farakka. It was decided that up to, and above, 75% of the standard flow for a corresponding 10-daily period, the release to Bangladesh would be pro-rata. However, if the flow at Farakka fell below 75%, the burden will be shared by India and Bangladesh on 50–50 basis. The copy of the MOU is enclosed at Appendix D.

Discussion on MOUs

All these years, joint observations at Farakka and Hardinge Bridge continued in a cordial atmosphere, but the JRC could not arrive at a decision on augmentation of the Ganga flow at Farakka. The 1982 and 1985 MOUs were nothing but extensions of the terms of the 1977 Agreement with slight modification of sharing ratios at certain 10-daily periods in January, February, March and May, which figure in Table 10.2.

The table shows that there were some changes in release of water to both India and Bangladesh in some periods of the lean season in the MOUs of 1982 and 1985, compared to those in 1977 Agreement. However, there was no change in the MOUs of 1982 and 1985.

Thus, the modifications were the minimum, with very little effect on either side. The two MOUs were extended to give an opportunity to the JRC and experts of both countries to come to an understanding on the proposal for augmentation of flow at Farakka. Other terms and conditions remained practically the same, except in case of exceptionally low flow seasons, where the burden on India was substantially reduced. The concession, given in the MOUs gave some relief to India. The two MOUs showed the desire of both countries to come to a solution of this long-standing dispute in a spirit of 'bilateralism' and without involving any third country, but this amicability disappeared after 1988 and no further agreement, or MOU, came up until 1996, as we shall see soon.

Table 10.2 Comparative study of discharge to be shared between India and Bangladesh as per agreement, 1977, MOU, 1982 and 1985

Period	Flow reaching Farakka (Cusec)	Withdrawal by India (Cusec)			Withdrawal by Bangladesh (Cusec)		
		1977	1982	1985	1977	1982	1985
1	2	3	4	5	6	7	8
January 1–10	98,500	40,000	40,000	40,000	58,500	58,500	58,500
11–20	89,750	38,500	38,000	38,000	51,250	51,750	51,750
21–31	82,500	35,000	35,500	35,500	47,500	47,000	47,000
February1–10	79,250	33,000	33,000	33,000	46,250	46,250	46,250
11–20	74,000	31,500	31,250	31,250	42,500	42,750	42,750
21–28/29	70,000	30,750	31,000	31,000	39,250	39,000	39,000
March 1–10	65,250	26,750	26,500	26,500	38,500	38,750	38,750
11–20	63,500	25,500	25,500	25,500	38,000	38,000	38,000
21–31	61,000	25,000	25,250	25,250	36,000	35,750	35,750
April 1–10	59,000	24,000	24,000	24,000	35,000	35,000	35,000
11–20	55,500	20,750	20,750	20,750	34,750	34,750	34,750
21–30	55,000	20,500	20,500	20,500	34,500	34,500	34,500
May 1–10	56,500	21,500	21,500	21,500	35,000	35,000	35,000
11–20	59,250	24,000	24,250	24,250	35,250	35,000	35,000
21–31	65,500	26,750	26,500	26,500	38,750	39,000	39,000

Political Instability

The political situation in the two countries impinged on water-sharing agreement. On 15th August, 1975, President Mujibur Rehman was assassinated and a military junta took over in Dhaka. A new government with Khondokar Moshtaq Ahmed as the new President of Bangladesh took office. The cordiality between the people of two countries, which developed since the freedom struggle in 1971 evaporated and the governments as well as the people on both sides began to eye each other with suspicion. Moshtaq Ahmed was an anti-Indian politician and did not like friendly co-operation between the two countries in Mujib's regime. However, his tenure was short and on 7th November, 1975, following a military coup, a new ruling elite came to power in Dhaka, led by Ziaur Rehman, a senior Army officer and a former freedom fighter. The government of Bangladesh became stable thereafter for about 5½ years but instability returned after the assassination of Ziaur Rehman in May 1981, catapulting another senior Army officer, H. M. Ershad to power.

In India's March, 1977 general election, Indira Gandhi and her Congress Party were badly beaten by the Janata party, led by Morarji Desai. The new government was eager to develop and strengthen co-operation with Bangladesh on the Ganga water-sharing at Farakka and signed an agreement with Dhaka in November, 1977. The accord, reached in April 1975, was for testing the newly-constructed dry section of the feeder canal, wherein the release of water was gradually increased from 11,000 to 16,000 cusecs. More precisely, it related to the depth of the canal, which was allowed to adjust from about 3 m(10′ feet) to 3.5 m(12 feet) depth from 21 April to 31 May 1976, as against the excavated depth of 6 m. This test-running was essential for avoiding possible damage to the dry canal and therefore, the accord for maximizing release cannot be considered for future lean seasons. After 31st May 1975, the discharge in feeder canal gradually increased up to its design-capacity of 40,000 cusecs in presence of the representatives of Bangladesh. Thus, an agreement by the two countries was absolutely necessary on the sharing of the lean season discharge at Farakka.

The Indian Parliament witnessed noisy scenes in 1978, when the Congress Party, then in opposition, described the agreement of 1977 in the *Rajya Sabha* (upper house) as a sell-out of India's interest. Indira Gandhi, who was the opposition leader in the *Lok Sabha* (House of Representatives), said: 'If the Government does not ensure adequate water supply to Calcutta Port, it will affect our national interest'.

The people and the Government of West Bengal, at that time formed by a coalition of Left parties, led by Jyoti Basu of the Communist Party of India (Marxist), opposed the accord vehemently, as they felt that the interests of the State and the people were compromised. They wanted the increased flow of the Ganga water into the Bhagirathi-Hooghly and save Calcutta Port. An all-party delegation of the State MPs, led by Prabhash Chandra Roy, State Minister for Irrigation and Waterways, called on S. S. Barnala, India's Minister of Agriculture and Irrigation on 15th September 1977 and submitted a memorandum on the Farakka Barrage issue. Mr. Barnala assured them that the interest of the Calcutta Port would be kept in view. The State Congress Party also sent a delegation led by Mrs. P. Mukherjee to the Prime Minister who iterated his awareness of the problems of the port. Mr. Desai also assured Jyoti Basu that the city's interest would not be sacrificed by the Farakka Agreement.

When the Agreement was finalized, neither West Bengal Government, nor the Farakka Barrage Project Authority, nor Calcutta Port Trust was associated with it. They were kept in the dark, which gave rise to resentment in all concerned quarters and the State government. After finalization, Jyoti Basu told reporters that West Bengal would protest to the Centre against the Agreement, because Calcutta Port could not be saved, unless 40,000 cusecs of water were available from Farakka Barrage. A. B. Vajpayee, then Foreign Minister of the Janata Government (later Prime Minister from 1999 to 2004) criticized the previous Congress regime for signing two specific agreements with Bangladesh – the first in 1974 under which India was debarred from commissioning the barrage without the consent of Bangladesh and the second was the 1975 short-term agreement, under which India was committed to draw between 11,000 and 16,000 cusecs. Mr. Vajpayee added that 40,000 cusecs were India's maximum need but in lean season, when the flow went down to 55,000 cusecs, withdrawal of 40,000 cusecs would leave only 15,000 cusecs for Bangladesh and none in the world could possibly appreciate this.

The public reaction in Bangladesh was not known but expectedly, the leadership in Bangladesh was demoralized for failing to get a satisfactory solution of the water-sharing issue in an international body, like the United Nations. A much-publicized Quixotic march of thousands of Bangladeshis, led by a firebrand trade union leader, Maulana Bhasani to demolish the barrage with tongs and hammers in 1977 was cancelled at the last moment and ended in fiasco. The leaders did not know, how the interests of Bangladesh could be protected. As Khursida Begum wrote in her book, the experts of Bangladesh, failing to get the expected mediation of the international body, were in a restless state of mind, as to how to deal with India and to protect their country's interest. They felt, at least an agreement was necessary.

When the agreement was on the anvil, B. M. Abbas, a leading expert of Bangladesh expressed his view on the Farakka Agreement in a conversation with the President Ziaur Rahman:

> I was, by the time, quite anxious to get the Agreement finalized. The President at one stage, enquired, what would happen, if India did not renew the Agreement after five years. I said, who could say what would happen in future. The President did not commit himself immediately. Perhaps sensing my anxiety and to indicate his mind, he added that I need not worry; everything would be all right by the grace of Allah.

From the above, it was obvious that both sides were keen to find a workable formula for sharing the Ganga water at Farakka, even for a short period. India wanted not only to protect and further her interests but also to maintain good relation with a new country in the neighbourhood, even by sacrificing her own interests, to some extent. For this reason only, the Government of India agreed to release more than 60% of the Ganga flow in the leanest months of March and April. Bangladesh was satisfied that her interests received priority and the government was successful in signing such an agreement.

Ben Crow in his book, 'Sharing the Ganges' stated that it was the decisions of the Janata government in India that made the understanding possible.

He added that the agreement reflected the concerns of the time and defined the development of water resources of the Ganga basin solely in terms of increasing the dry-season flow. As shortage of water had caused the dispute to arise, the agreement, in its long-term arrangements of augmentation, maintained this focus. There was no provision for general regulation and development of the river's resources and little concern for floods. He further stated that even with this concentration on increasing the dry-season flow, subsequent discussions between the two governments did not materialize. Bangladesh refused to embark on feasibility studies of alternative schemes, unless Nepal was allowed to participate in the negotiations. India was unwilling to allow Nepal's participation, because the Indian government insisted that augmentation was a bilateral matter.

The political will of both the countries helped their leaders solve the long-standing problems of sharing the Ganga water at Farakka. Though it was originally technical, it turned out to be a political problem, affecting diplomatic relations between them. The goodwill gesture by India by agreeing to substantial reduction of the Ganga water to 20,500 cusecs, scaling down the original demand for 40,000 cusecs was more from political than from technical consideration. The concession by Bangladesh government by accepting 34,500 cusecs as against the original demand of 44,000 cusecs is a much lesser sacrifice, because many of their other demands were met. It has to be kept in mind that India's three joint rivers

– Bhagirathi-Hooghly, the Bhairab-Jalangi, and the Mathabhanga-Churni once carried substantial flow of the parent river, the Ganga-Padma but they were dying in the natural cycle with their mouths shut by silt. The same natural process was drying the Gorai-Madhumati of Bangladesh and could dry it more, even if the Farakka barrage was not constructed in 1975 and all its water could flow toward the sea. Therefore, the decay of these rivers was not beneficial to either country and Bangladesh cannot claim the entire water of the river for development of the Gorai-Madhumati and the region on either side. This is another justification for the construction of Farakka Barrage to develop water resources in this region.

Effects of the Agreement on India

Before the induction of upland discharge through the feeder canal into the Bhagirathi, the flow in the river was extremely irregular, quite high from mid-July to mid-September but in rest of the year, nominal, or nil. Soon afterward, the river's morphology began to change; its width, depth, cross-sectional area and cubic capacity improved up to 1977 but from next year, these began to reduce. In 2½ years – from May 1975 to December 1977, the capacity for net tonnage handling of materials in Calcutta Port got a boost. Prolonged flow from upland deepened the channel and increased navigable depths up to the estuary below, required less dredging and the salinity in water in the port area went low. The entire river complex was in a state of flux and adjusted to the new morphological parameters. This took time, natural for a mighty river, because at least five years of ceaseless flow of 40,000 cusecs through the Bhagirathi-Hooghly, as recommended by experts, could improve it in all fronts, but this was not to be owing to chinks in the Agreement. The average decade-long discharge through the Farakka feeder canal and below from May 1975 to May 1985 figures in Table 10.3.

The Table 10.3 shows that though the percentage share of water in 1976 and 1977 i.e. before the Agreement, between India (River Bhagirathi) and Bangladesh (the Ganga) for the leanest period from March to May, from 46 to 48 for India and from 52 to 54 for Bangladesh, it fell to 36 to 40 for India between 1979 and 1985 (The agreement was partly implemented in 1978). Major flow was allowed for Bangladesh in the leanest months, the percentage varying from 60 to 64. The distribution of the total flow in these years has been shown in Table 8.2 ante. After the agreement period, 1980 was the driest year and the discharge in March and April was abnormally low. The minimum discharge was 1,058 cumecs, or 37,353 cusecs on 3rd April 1980 and India's share on that day was 304 cumecs, or 10,743 cusecs, which was about 29% of the total flow only. It was below 1,132 cumecs, or 40,000 cusecs, for 11 days from 24th to 27th March and from 31st March to 6th April 1980. The average percent share in the leanest months, March to May in 1980 between India and Bangladesh was 36 and 64 and in the full lean season, January to June, it was 32 and 68, respectively. The large difference in share that year shows the extent of compromise by India under the agreement, sacrificing national interest and

Table 10.3 Average discharge through River Bhagirathi and Ganga downstream (Cumecs)

Year	Period (River Bhagirathi)				Period (Ganga downstream)				Remarks
	Jan to June		March to May		Jan to June		March to May		
1	2	3	4	5	6	7	8	9	10
1975	406	–	406	–	–	–	–	–	Pre-
1976	(May	–	–	–	–	–	–	–	Agreement
	only)	45%	–	–	–	–	–	–	period
1977	1015	45%	1001	47%	1220	55%	1160	53%	
	973		901	46%	1174	55%	1050	54%	
1978	1039	47%	1004	48%	1180	53%	1070	52%	Post
1979	1027	38%	979	39%	1685	62%	1552	61%	agreement
1980	666	32%	516	36%	1421	68%	910	64%	period
1981	928	39%	804	39%	1478	61%	1252	61%	
1982	940	32%	904	40%	2018	68%	1374	60%	
1983	839	40%	689	39%	1275	60%	1068	61%	
1984	923	24%	727	40%	2885	76%	1089	60%	
1985	845	41%	605	39%	1220	59%	960	61%	

the interest of Calcutta Port. That year, the relevant clause of distress-sharing under Article II had to be applied, as per agreement, entailing a great sacrifice for India. Naturally, the improvement which could have occurred near Calcutta Port could not take place and port facilities declined in all fronts. The actual 10-daily distributions of water against the agreement quantity in 1980 are shown in Table 10.4.

The original demands of two countries were quite high – 1,132 cumecs for India and 1,246 cumecs for Bangladesh – but as the lean-season discharge at Farakka was low, the agreement provided for less discharge in the leanest month of April. However, the actual availability in 1980 was far below the quantity, given in the Agreement. Therefore, the available quantity was further reduced which reflected in Table 10.5.

In 1981, 1983–1984, 1986 and 1988, the available discharge at Farakka in the lean season was much less than that in the agreement. Thus, it proved to be theoretical than practical, though based on 75% availability of prototype data between 1973 and 1984. It also did not envisage that either side was bound by its clauses to ensure that this quantity would be available in lean season at Farakka. However, the fact remained that the actual availability of water at Farakka between 1980 and 1989 in most of the years was much less than that in the agreement and therefore, each country had got its share of this less quantity as per the ratio fixed. This was the *fait accompli* and both countries had to share the burden.

As a result, the movement of ships to and from Calcutta port as also the draft in the Bhagirathi-Hooghly decreased since 1978. At many places on the river – Katwa, Mayapur, Kalna and Samudragarh – the water went so down that even low-draft vessels (1.5 m. or so) could not ply in March and April. New *char* lands formed, following fall in discharge in the lean season. Dredging between Calcutta and Hooghly

Table 10.4 Actual 10-daily flow distribution against agreement quantity (cumec) of 1980

Period	Agreement quantity	Actual quantity available	Distribution			
			India		Bangladesh	
			Agreement	Actual	Agreement	Actual
1	2	3	4	5	6	7
January 1–10	2789	2681(–4)	1132	1011(–11)	1656	1670(+1)
11–20	2541	2278(–10)	1091	976(–10)	1451	1302(–10)
21–31	2336	1724(–26)	991	641(–35)	1345	1083(–19)
February1–10	2244	1445(–36)	934	393(–58)	1309	1052(–20)
11–20	2095	1379(–34)	892	412(–54)	1203	967(–20)
21–28/29	1982	1369(–31)	871	481(–45)	1111	888(–20)
March 1–10	1847	1356(–27)	757	482(–36)	1090	874(–21)
11–20	1798	1288(–28)	722	433(–40)	1076	855(–21)
21–31	1727	1134(–34)	708	318(–55)	1019	816(–20)
April 1–10	1670	1117(–33)	680	322(–53)	991	795(–20)
11–20	1571	1231(–22)	587	440(–25)	984	791(–20)
21–30	1557	1254(–19)	580	458(–21)	977	796(–19)
May 1–10	1600	1568(–2)	609	609(–0)	991	959(–3)
11–20	1678	1838(+10)	680	732(+8)	998	1106(+11)
21–31	1854	2085(+12)	757	849(+12)	1097	1236(+13)

Table 10.5 Minimum quantity of water available against original demand (cumecs)

Original demand		Minimum as per agreement		Minimum as available	
India	Bangladesh	India	Bangladesh	India	Bangladesh
1132	1246	580 (37%)	977 (63%)	458 (36.5%)	796 (63.5%)

point, – which reduced substantially in post-Farakka period had to be increased from 1980.

The Calcutta Port is about 230 km from the sea face of the Hooghly. In pre-Barrage days, maintenance of this long navigation channel with 15 major sand bars was a challenging task. Of the total length, the upper reach from Calcutta to Diamond Harbour is about 75 km and the lower reach from Diamond Harbour to the Sandheads is about 155 km. There are 17 sand bars on this course, which hinder navigation. This channel required constant dredging in pre-Barrage days, as it used to shift its courses in flow and ebb tides in various alignments. The bars also changed directions in two tides in a day, as also in different flow conditions owing to seasonal changes. The alluvial river-bed as well as bank materials, coupled with unpredictable morphological changes in the estuary aggravated the problems of Calcutta Port, requiring manifold increase in the volume and cost of dredging.

The diversion of assured 40,000 cusecs in the river continuously for at least five years, as advised by Dr. K. L. Rao, India's Minister of Irrigation and other

Table 10.6 Annual quantum of dredging in the Hooghly river below Calcutta

Year	Dredging between Calcutta and Hooghly point (Mm^3)	Dredging at Balari bar (Mm^3)	Remarks
1	2	3	4
1972–1973	1.92	0.30	Pre-barrage period
1973–1974	2.20	0.62	Do
1974–1975	1.12	1.53	Do
1975–1976	1.43	1.39	Post-barrage period
1976–1977	0.88	2.03	(Water released in feeder canal from April, 1975)
1977–1978	0.84	2.48	Post-agreement Period
1978–1979	0.48	0.79	
1979–1980	0.57	2.22	
1980–1981	0.42	1.68	
1981–1982	0.46	2.62	
1982–1983	0.21	2.82	
1983–1984	0.41	2.42	
1984–1985	0.38	1.61	
1985–1986	0.36	2.66	
1986–1987	0.28	3.33	
1987–1988	0.56	1.07	

experts could not be implemented owing to the signing of the Agreement in 1977. The assured quantity of water could flow in the lean season only for two years – 1976 and 1977 – which was not sufficient to bring about anticipated morphological changes. The quantum of dredging in the Hooghly below Calcutta Port is shown in the Table 10.6.

Table 10.6 shows, how in the pre-Barrage period, the dredging between Calcutta and Hooghly Point in 1972–1973 and 1974–1975 was much more than in the lower reach over the Balari Bar, this was reversed in the post-Barrage period. Dredging below Calcutta up to the Sandheads in pre-barrage days from 1946 to 1963 constantly increased. Below the Hooghly Point, sea-going vessels from Calcutta and Haldia harbour had to negotiate six major bars (their distances from Calcutta port in brackets), namely Balari (88 km), Jellingham (108 km), Rangafalla (115 km), Aucland (130 km), Middleton (158) and Gasper (172 km).

Experts believed, the release of 40,000 cusecs of water from Farakka Barrage could clear the entire river reach up to Haldia Port area, which is about 90 km from Calcutta port. Some experts recommended 46,000–55,000 cusecs to keep a safe margin. However, induction of 40,000 cusecs of water from June, 1975 upto December, 1977 could show some increase by way of silt removal in the river and improvement in the navigation channel had started. But after the signing of agreement in 1977 and implementation of the same from 1978 lean season, the gradual improvement in the navigation channel got a setback and the silts could move downwards from port area of Calcutta up to Hooghly point (upper estuary), started dropping over the Balari bar area and also further down (lower estuary), which resulted in increase of quantum of dredging over Balari bar for maintaining the navigation channel. Thus, the full benefits of diversion of water from the Ganga could not be achieved as a result of the agreement. The ebb tide current did not become sufficiently strong enough during lean season in order to prevent the flood tide current, transporting sediment upwards.

The total length of the Bhagirathi-Hooghly is divided into five stretches through a line diagram in Fig. 10.2 to explain the position more clearly. The non-tidal reach of the Bhagirathi and the tidal reach below Nabadweep are sub-divided into two and three reaches, respectively. The flow direction and the sand movement are explained in the figure. Before the barrage came up, the mouth and the bed of the river gradually silted. The river bed which was once at the same level as that of the parent Ganga rose about 9 m, or 30 feet, in 1960. Plan and cross-section in Fig. 10.3(a, b) explain the position. Post-Barrage induction of upland discharge from 1978 reduced siltation in the lean season and pushed down the silt load from the upper reach and deposited it in the lower (non-tidal) and also in the upper (tidal) reaches. Because of tides, the silt that was pushed up with tide, moved down below Calcutta during ebb tides, but due to reduced upland flow-tide velocity, silt was deposited in the lower estuary below Diamond Harbour; the most affected reach was at Balari bar. As ships to Calcutta or Haldia ports came from the Bay of Bengal, they faced obstructions in the lower bars. Dredging over these bars had to be increased substantially in the post-Barrage days to keep the navigation channel clear. In spite of continuous efforts by Calcutta Port, the Balari bar silted up and the navigation channel from Haldia to Calcutta was completely blocked from 1988. An alternative navigation route had to be made thorough the Rangafalla channel on the eastern side of Nayachara island, as shown in Fig. 10.4. At present, ships to Calcutta port offload a bulk of the cargo either at Sagar island, or at Haldia, before entering Kolkata by taking a detour through Rangafalla channel.

Salinity reduced to a large extent in the Hooghly after the barrage came up, compared to that before 1975, when the water supplied to the city and the suburbs for drinking was quite brackish. Calcutta's drinking water is drawn from the Hooghly at Palta, about 24 km north of the city. The records of salinity in the dry season, kept from 1920 to 1967, indicated the condition of the river, as shown in Fig. 10.5. Salinity of the Hooghly water at Palta rose gradually. As salinity intrusion in the Hooghly depends on the quantity of sweet water in the river in the lean season, the volume of water fell fast in the course.

Besides the shortage and contamination of drinking water, boilers and other machineries of industrial units were heavily damaged for using saline water. The potable limit of about 0.2 ppt of salinity exceeded even at Serampore, about 50 km upstream of Calcutta, especially in lean seasons. However, landward migration of salinity could be arrested in post-Farakka period and the potable limit could be maintained even near Budge Budge, about 30 km downstream of Howrah Bridge in lean season, albeit for a short duration. Increase of salinity beyond potable limit was observed, even near Garden Reach just downstream of Calcutta, in lean seasons after 1977.

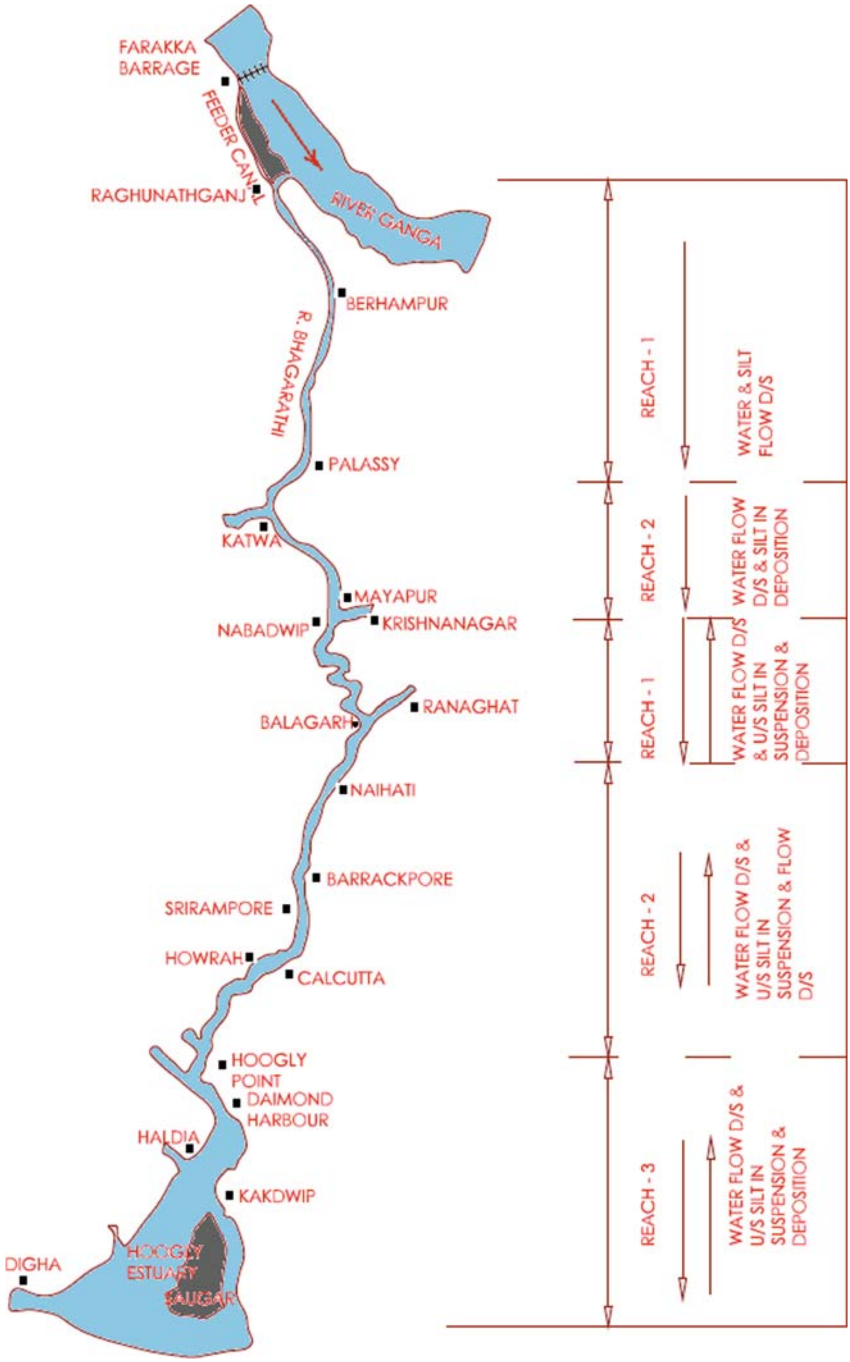

Fig. 10.2 Bhagirathi-Hooghly river system with water and silt flow in different reaches

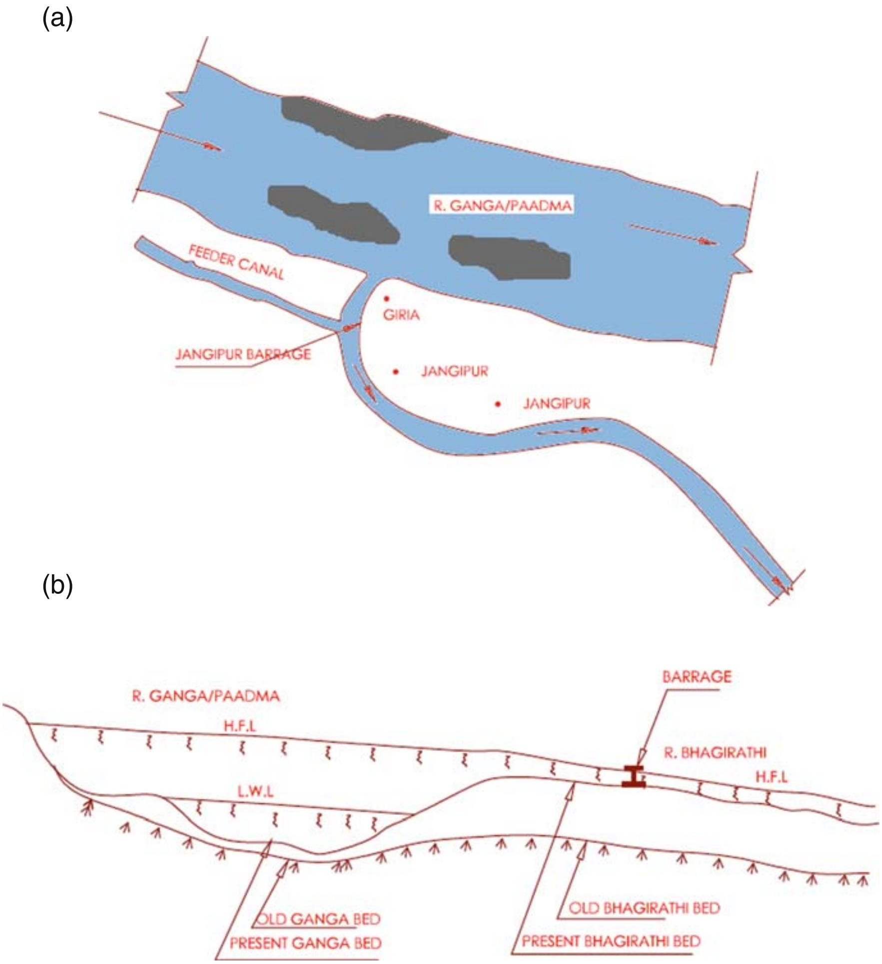

Fig. 10.3 (a) Typical plan of Bhagirathi offtake; (b) Typical cross-section near Bhagirathi offtake

Agricultural fields and orchards on both sides of the river faced severe water shortage, as the ground-water level had gone down in pre-Barrage days. Farm production came down substantially because intrusion of salinity in the soil. After the commissioning of the barrage, and owing to induction of sweet water into the river, round the year, from 1975, the ground water became saline-free and the level increased substantially which boosted farm production. However, the benefit did not last long and from 1978, after the Farakka Agreement came into effect, the discharge in the feeder canal went low in lean seasons. About 3000 km^2 on both banks in Murshidabad, Nadia, Burdwan, North and South 24-Parganas, Hooghly and Howrah districts were affected by the 1977 Agreement. The water-levels in tube and open wells went down abnormally. Low-lying areas on both sides which

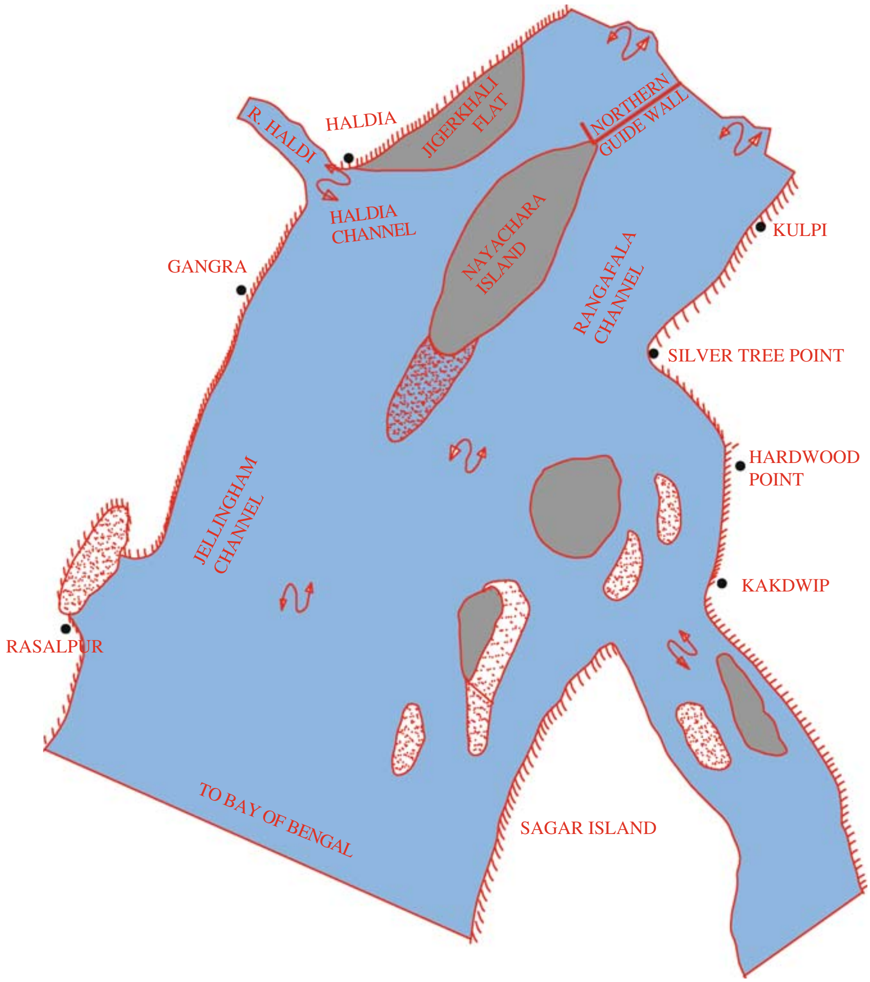

Fig. 10.4 Plan showing Haldia and channels in Hooghly estuary

remained dry before 1975 were filled by river water but afterward partly dried up in lean seasons, affecting fish and other aquatic life.

As water-level went low, the ground water table which used to be quite high in monsoon months, fell abruptly, causing erosion and bank-slips of the feeder canal as well as of the river banks. The feeder canal cross-section being unlined and artificially built with spoils of excavation gave way at many places owing to fluctuations of water-level, inside and outside the soil mass. Inspection roads on both banks were damaged at many places. The banks of the Bhagirathi-Hooghly were similarly affected at places like Jangipur, Katwa, Mayapur, Nabadweep etc. Power generation in thermal plants, located on the canal and river banks, also went down,

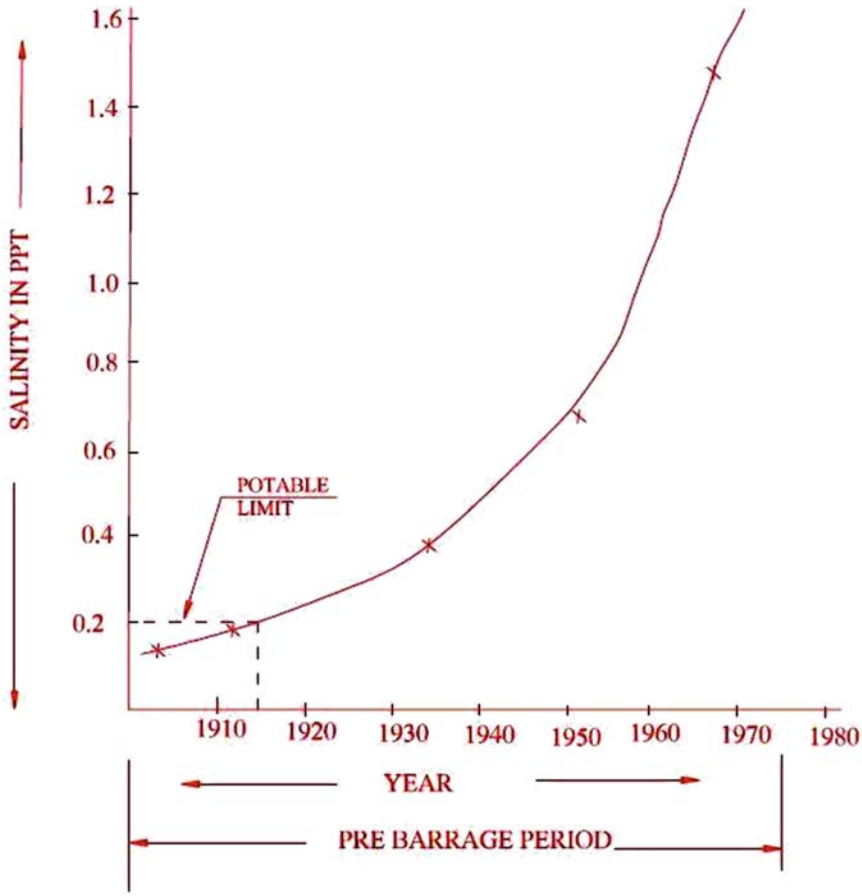

Fig. 10.5 Salinity level of Hooghly water at Palta

following decrease in water-level. The Super Thermal Plant near Farakka had to be partly shut down, every year, in March and April.

The 1977 Agreement also adversely affected the environment and ecology of the entire region. Aquatic life, commerce and transport, day and night temperature, humidity and water supply to industries etc. were all affected. Thus, the adverse effects are summarized as under:-

i) Agriculture activities hampered owing to reduced discharge and intrusion of saline water.
ii) Drinking and industrial water supply affected owing to increased salinity.
iii) Navigation hampered and trade and commerce affected owing to reduction in water level.
iv) Quantum of dredging increased substantially in the lower reach owing to siltation in the riverbed.

v) Port activities affected with reduction in cargo movement, restriction in movement of ships, delay in negotiating bars and crossings, resulting increase in port charges.
vi) Low-lying areas, e.g. ponds, nullahs, jheels (canals and lakes) etc. dried up during lean seasons affecting fish production and aquatic life.
vii) Erosion of canal and river banks increased owing to fluctuations in river and ground water.
viii) Generation of thermal power severely hampered and power plants partially shut down during lean season every year.
ix) Tube wells and open wells affected owing to decrease in water level.
x) Adverse effect on environment and ecology in the region.

Effect on Bangladesh

Like the Bhagirathi-Hooghly, other spill channels within Indian territory like Bhairab-Jalangi and Mathabhanga-Churni were heavily silted in the off-take. After closure of the Bhagirathi-Hooghly mouth in dry season, the British government in India before 1947 tried to maintain the navigation route, first through Bhairab-Jalangi and then through the Mathabhanga-Churni rivers, but both were ultimately blocked by silt at the mouths. It was obvious that the Gorai-Madhumati spill channel, passing through southern Bangladesh would have same fate as befell other channels owing to silt deposit. This was a natural phenomenon because of gradual south-eastward swing of the Ganga-Padma. The Ganga-Kapotaksha irrigation project, using high-power irrigation pumps was taken up by the then East Pakistan government at the mouth of the Gorai but faced severe siltation, even before the barrage came up at Farakka. The scheme would have irrigated the fertile alluvial soil in Kustia, Faridpur, Khulna and Jessore districts.

In spite of the above, diversion of the Ganga water into the Bhagirathi-Hooghly had adverse effects on Bangladesh. It is a riverine country; big rivers like the Padma, the Brahmaputra, and the Meghna criss-cross it and medium and small rivers as well as creeks flow through, carrying ample water for greater part of the year. It gets excessive rains, but as they occur in three to four monsoon months only, there is shortage of water in certain parts of the country in other months. The diversion of the Ganga water added to the shortage in south-western districts of Bangladesh and caused resentment and agitation in the people. The Bangladesh government protested to Delhi that reduction of the Ganga flow from 1976 caused widespread and grave damage to agriculture, industry and ecology of south-west Bangladesh. Some experts also expressed grave concern, as reflected in the views of a few of them, as reproduced below.

Amzad Hossain Khan, a water-management expert, said, Bangladesh has been losing around 5000 million taka (Bangladesh currency: 1 US$=BDT 60.00 in February 2009) annually, because of this diversion. Reduction in availability of water for irrigation affected about 60 million people. The Ganga-Kapotaksha project and many industries, like the newsprint industry in Khulna were also seriously affected after the closure of the mouth of the Garai by silt. Increase in salinity of the river water spoilt the fertility of land. Navigation on rivers and creeks also suffered for lack of required depth of water. Some 21% of shallow tube-wells-and 42% of deep tube-wells in south-western Bangladesh went defunct because of ground-water scarcity.

M. Adel Mia, an environmental scientist in a paper titled ‘Farakka Barrage: An Unprecedented Environmental Catastrophe in the Ganga Basin’, highlighted adverse effects on environment and ecology of the Ganga-Padma sub-basin. He said, before 1975, the Garai, a branch of the Ganga, which used to carry about 170 cumecs of water during four monsoon months, now carried mere 40 cumecs since 1978 and that too for three months only. Fish production has come down and certain species like veda and small prawn are going to be extinct. The fertility of soil has reduced, following loss of organic matter which could be otherwise replenished from decay of aquatic life.

Mr. Mia added that salinity intruded into 2590 km^2 area after 1975, affecting 31,078 km^2 as against its intrusion into 18,129 km^2 before. Also affected was the world’s largest mangrove area in the Sundarbans on about 5697 km^2 and about 45 million trees. Various species of animals, birds etc. in the Sundarbans were also endangered. Erosion of river banks and incidence of flood also increased and farm production substantially reduced. The Ganga-Kapotaksha irrigation project with the rated capacity of 152.82 cumecs had to be shut down in 1993 owing to non-availability of water. The paper mill at Paksey which needed 25,000 metric tonnes of sweet water for normal production stood on the brink of closure and had to be run by bringing water in barges from a distance of about 50 km. Employment opportunity of people also reduced and environmental pollution gave rise to various diseases. Mr. Mia further said, a field survey was conducted on a hundred villages on availability of water for drinking and other household purposes after diversion of the Ganga water at Farakka. The ground water table has receded below 25 feet, resulting in closure of hundreds of tube-wells. The villagers, hitherto using river water for drinking and other household activities faced hardships, as rivers and channels dried and ground-water table receded in lean season. Earth temperature also shot up, following rivers etc. going dry and sacred rituals of Hindus and other minority communities, which need holy river water, also suffered.

Other experts, like *Amjad Hossain Khan*, Ex-chairman of Bangladesh Water Development Board and an expert on Water Resources Development; *Md. Manirujjaman Mia*, Ex-Vice chancellor of Dhaka University, *Tarek Samsur Rahman*, Professor of Political Science, Jahangirnagar University, Dhaka and others also highlighted many other adverse effects.

Khurshida Begum in her Ph.D. thesis ‘Tension over the Farakka Barrage – a Techno-political Tangle in South-Asia’ said, ‘The withdrawal of a large quantity of water through the Farakka Barrage in violation of the ad-hoc Agreement 1975 for “test running the feeder canal” produced harmful effects on Bangladesh.’ This, she added, was bound to bear an impact, as it was an attempt to introduce a new ecological and environmental system against the usual course of Nature.

> A grave crisis has arisen for Bangladesh on account of India's unilateral action in diverting the waters of the Ganges at Farakka. . . ..These withdrawals amount to as much as three-fourths of the dry-season flow of the Ganga. It is difficult to find a precedent in the world, where such heavy amount of waters of an international river is appropriated unilaterally by a country at the cost of the vital interests of a neighboring country.

To counter these views, India issued a publication 'The Farakka Barrage' which said:

> The available technical and economic data, studies and observations show that the operation of the Farakka Barrage will not affect Bangladesh adversely. Some minor problems may arise, but these can be remedied without impeding the diversion of (the) Ganga water into the Hooghly.

According to Mrs. K. Begum, the Ganga along with its two main distributaries – the Gorai-Madhumati and the Arial Khan, serves about 37% of the total area of Bangladesh Of the eight districts that depend on its water, four – Rajshahi, Pabna, Kustia and Faridpur – are on the bank of the Padma and the other four – Jessore, Khulna, Barisal and Patuakhali – are in the Ganga delta. They get fresh water through its six distributaries – the Ichhamati, the Naba Ganga, the Bhairab, the Kumar, the Gorai and the Madhumati. Because of the Ganga's diversion in 1975, the minimum discharge at Hardinge Bridge came down to about 23,000 cusecs as against traditional average of 64,340 cusecs. The water and the ground-water levels came down by about five feet. The offtake of the Garai rose without any discharge through it. The affected area was about 52,000 km^2 (20,000 sq. miles), as claimed by Bangladesh.

India refuted this and held that the affected area did not exceed 2600 km^2 (1000 sq. miles) and therefore, reduction in flow of the Padma would not have any significant adverse effect. The effects on the Gorai-Madhumati reach would also be marginal and could be remedied by dredging its offtake. India also denied the fall in ground-water level, as about one-third of the Ganga's bank is within India and study of the ground-water table and functioning of tube-wells and lift-pumps by her has not noted any such adverse effect.

Salinity Intrusion

Mrs. K. Begum supported Dhaka's view that

> The most devastating effect of the diversion of the Ganga water has been generated from the marked increase in salinity, both intrusion upstream and soil moisture depletion, occasioned by depletion of ground water table. . . .Quite logically, with the decrease in the upland flows, the salinity increased and advanced . . . inland.

According to the Bangladesh government, salinity intrusion in the Bhairab was 13,600 micromhos per cm in April 1976, as against the traditional average of 500 to a very short-time extreme of 1000 micromhos per cm. The penetration was 160 km (100 miles) more, which was 270, compared to the normal 272 km (170 miles) from the coast. India refuted this, quoting the World Bank Report and stated that the withdrawal of 40,000 cusecs at Farakka would have practically no effect at all.

Irrigation Problems and Fall in Crop Yield

Mrs. Begum further quoted Dhaka's report on the dry season of 1976:

> Over 400,000 (0.4 million) acres of land were affected . . . owing to soil moisture efficiency and increase of salinity. More than 4000 low-lift pumps in the area suffered. All the shallow tube-wells . . . (and) a large number of deep tube-wells in the area were affected due to fall in the sub-soil water level. The subsidiary pumps of the G.K. Project ceased to operate, as the Ganges water-level fell below the lowest operation limit. The three main pumps faced operational difficulties. . ..It is estimated that approximately 33% of the irrigation facilities could not operate, because of the decreased availability of water.

She also added that owing to delay in cultivation of one crop, the whole pattern of due-time cultivation was disturbed, which resulted in fall of production. Yield of rice alone fell short by 236,000 tons, or 20% of Bangladesh's food imports, excluding the loss of production of second crop, owing to delay in planting the first crop.

Impact on Aquatic Life

Mrs. Begum quoted the White Paper of Bangladesh as under:

> The reduced water availability significantly reduced the landing of fish, probably because of the disturbance of the historic food chain and inability of fish to tolerate shallow depths and the unprecedented levels of salinity. At three key landing points, at Khulna, Goalanda and Chandpur, the percentage of reduction in landing of fish during February to June, 1976 compared to the corresponding period of 1975 was 75%, 34% and 46%, respectively.

There was also sharp decline in the production and catch of *hilsa*, a migratory delicious fish, very dear to the people of two Bengals and a major Bangladesh export to countries where Bengalees live. To this, India replied that the Farakka Barrage could in no way be blamed, because it did not alter the flow pattern of the Ganga in monsoon months when the yield and haul of *hilsa* were the maximum.

Effect on Navigation

Surface transport infrastructure is under-developed in Bangladesh; as a result, trade, commerce, transport and communication are mostly dependent on ferry services in the Ganga and its tributaries, especially in south Bangladesh. Mrs. Begum quoted Bangladesh government's statement in support of her view that the Agreement had affected navigation too.

> Two major ferry terminals had to shift their operations, one four miles and (another) one five miles. . . . Ninety miles of navigation routes on the Ganga (from Godagari to Archa) went out of commission, 45 miles on the Gorai and 15 miles on the Padma. . . . In addition to these, in three specific reaches, navigation throughout the entire region was hampered.

To this, India replied that navigation on the Ganga and on the tributaries of Padma was possible only in monsoon months, from June to November and impossible in lean months. Mechanized navigation in the Ganga / Padma up to the confluence of The Brahmaputra is very few only, therefore the effect of withdrawal of 40,000 cusecs on Bangladesh navigation was negligible.

Impact on Forestry

Mrs. K. Begum said, Bangladesh claimed that the forests of Sundarbans, much of which is in Bangladesh, provides raw materials to newsprint and paper mills, match and furniture factories etc. Varieties of constructive activities have been affected by increased salinity after the diversion of the Ganga water and inflicted heavy and irreparable loss, which would ultimately affect 45,000 people, living on forest products.

Impact on Industry

The salinity level in the southwest region was so high after the diversion that the Goalpara Thermal Power station had to be closed for some time and thereafter operated intermittently by bringing fresh water in barges at increased cost from long distances. The Bheramara power station could not operate, as the water level of the intake channel went below R. L. 17 feet. Khulna newsprint mill was operated at half its capacity, as the chloride content of the water, used in the mill, increased by more than 20 times. The paper mills at Paksey also suffered miserably.

Effects on Health and Ecology

Bangladesh also alleged adverse effects on health, mainly because of increased salinity in the drinking water.

> Roughly 5% of the drinking water tube-wells were rendered inoperative. Substantial parts registered high salinity. The effect of salinity on health occurs when the body is incapable of absorbing any more sodium. The manifestations is hypertension. The short-term system of disease is dysentery; in addition the propensity to fall prey to cardio logical illness is increased.

About ecology, Bangladesh said:

> . . . It is necessary to consider total eco-cycle and ecology of the region. The wild lives of the Sundarbans are already endangered species. It is hard to reconcile to this abrupt change in the balance of Nature when the awareness of the necessity for taking full account of its own eco-system, that of its neighbour, that of its region and that of the world, is ever growing in countries, all over the world.

India refuted this, saying that the region being close to the sea, the problems of salinity and its adverse effects on environment have always been there.

> Ecological and environmental problems are complex and call for a comprehensive, integrated and multi-disciplinary approach. Such problems cannot be solved on the basis of an exaggerated emphasis on only [one] factor, such as, withdrawal at Farakka, or on the problems of only one area to the exclusion of others.

Mrs. Begum ended her litany of charges, adding that Nature's equilibrium was bound to be disturbed, following the diversion at Farakka. She proposed a joint study and co-ordinated efforts to find a solution and added that unilateral withdrawal and speculation of consequences by India have brought some kind of tension and uneasy

Fig. 10.6 Affected districts of Bangladesh due to water diversion as reported by Mrs. K. Begum

feelings between the two countries. It is clear from the above that both countries wanted to safeguard their interest by over-stating (by Bangladesh) and under-stating (by India) the post-diversion situation in Bangladesh.

The affected districts of Bangladesh, as reported by Mrs. Begum are shown in Fig. 10.6.

Ben Crow's Assessment

Another assessment was made by Ben Crow, a British research scientist in his book, 'Sharing the Ganges – the Politics and Technology of River Development'. He analysed three basic documents – 'The Farakka Barrage', published by the Government of India, ‘White Paper on the Ganges Water Dispute’, published by Bangladesh government and ‘Special Studies’, published jointly by the Government of Bangladesh and a San Francisco–based firm of engineering consultants, International Engineering Company, funded by the World Bank.

Figure 10.7 shows the southwest part of Bangladesh, which was most affected by the diversion of the Ganga water at Farakka. Ben Crow said, the western part of the delta, stretching from the Bhagirathi in India across Bangladesh border, to the line of Gorai-Madhumati and Rupsa-Pussur rivers, was a moribund region before the diversion and many of the small rivers and channels were no longer tributaries of the Ganga. These channels were not having any flowing water except in the rainy season when they drained only the adjacent countryside. Though some land-building was occurring at the Meghna estuary, it was also affected by erosion, deforestation and bad farming practices. A comparison of early maps with more recent ones indicates that landforms are changing, but the total land area within the given boundaries has been roughly constant. Quoting a 1962 East Pakistan Report, Mr. Crow stated that in some periods, there had been almost no flow in the Gorai because of blocked offtake. Flows had been negligible from January to May in 1951 and at different times, an average monthly discharge of less than 1,000 cusecs was recorded for six months, from December to May. This makes it difficult to assess the effects of Farakka Barrage on Bangladesh.

Mr. Crow had no access to the records of diversion at Farakka from New Delhi. He made a tentative assessment, according to which the Ganga flow near Hardinge Bridge fell by 45% for three months, from February to April in 1976 and 1977 from those of earlier years.

On the effects of the Farakka diversion on ground-water levels in Bangladesh, the White Paper from Dhaka comments:

> The hydraulic cycle of surface and ground-water are interdependent. In 1976, the ground-water level in the highly affected area went down by five feet on an average with a range of three to eight feel below normal.

The ‘Special Studies’ report did not chime with the view of the Bangladesh government; it said:

> Ground-water conditions during recent dry season differ from conditions that existed during the dry seasons prior to 1975. Reported changes include lower water-levels in wells, increased pumping lifts, dry wells, reduced ground-water yields and increased salinity. The water levels during the dry season of 1976 were at the lowest level, ever reduced in many of the wells in the study area.

Analysing the field survey data of Bangladesh government, the Special Studies team concluded that out of 15 wells in the study area, in only five did the level in the adjacent river appear to be the determining factor. In the other 10 wells, water-levels appeared to be affected more by direct precipitation than by stream flow. The effect of fluctuations in the river-water level on the ground water reduced to 83% in a mile, 41% in 16 km (10 miles) and 16% in 32 km (20 miles) from

Fig. 10.7 South west part of Bangladesh showing the probable affected area due to water diversion

the river; it would be less in a confined, or a partly confined, aquifer. The geology of southwest Bangladesh indicates that much ground-water is stored in sandy aquifers, partly confined by lenses of silt. Moreover, the contours indicate that ground-water flows toward the Ganga, the Baral, the Gorai and the Naba Ganga etc. The team, therefore, concluded that though ground-water levels changed significantly in 1976 and 1977, its causes were difficult to establish accurately and the blame could not be laid wholly, or primarily, on diversion at Farakka. The

Bangladesh Government claimed that the increased intrusion of sea-water owing to withdrawals by India at Farakka into the rivers and canals disrupted functioning of industries.

> The increased salinity is totally explicable in the light of the increased withdrawal of the Ganga water. A large part of the affected region is subject to the tides of the Bay of Bengal. Historically, this saline intrusion was counteracted by the upland flows. Quite logically, with a decrease in the upland flows, the salinity increased and advanced . . . inland.

The Special Studies team reviewed the traditional and current salinity data, collected by Bangladesh government and analyzed them to obtain the best assessment of the extent and causes of damage. It compared salinity intrusion in 1967–1968 with that in 1976 and 1977. Of the five regions of southwest Bangladesh, in which comparisons were made and which the Bangladesh government claimed to have been affected by salinity following Farakka withdrawal, the team could identify only one in the Pussar estuary, from Rupsa-Pussar to the upper Gorai-Madhumati region which was found to have been affected by increased saline intrusion. It mentioned that major industries of Khulna are located in the region and it was there that the increased salinity in the Ganga water was most pronounced on the industries. Higher velocity of water there maintained a steep salinity gradient which, in normal years, kept salinity relatively low, adjacent to Khulna. Industrial water offtake there could, therefore, be operated, without difficulty before diversion. A small change in the Gorai flow in 1976 dramatically reduced salinity in this sensitive stretch for Bangladesh's industrial production.

Because of rise in salinity, the power station, paper mills, jute processors etc. in Khulna could not use highly saline water, or incurred damage by using it. Bangladesh government said, high salinity caused industrial losses, from December 1975 to June 1976, to almost 120 million taka, (or then 8 million US dollar). Major losses (39 million taka) were reported from Goalpara Power Station which had to use more chemicals and spend more (18 million taka) on hauling sweet water for the jute mills in Khulna, owing to power failures. Chalna Port authority incurred a whopping loss of 50 million taka to change design because of salinity intrusion. The team, however, mentioned that there might be serious consequences on industries owing to unexpectedly high salt content in cooling, or processing, of water. The estimated loss of 120 million taka was perhaps inflated, but some damage indeed took place because of increases in salinity, due perhaps to diversion of water to the Bhagirathi-Hooghly at Farakka.

On the effects of diversion on 'agriculture and forestry', Mr. Crow analyzed three documents, mentioned before. Agriculture accounted for 56% of the gross domestic product (GDP) of Bangladesh, of which rice alone contributed 30%. Jute contributed 77% of the value of commodity exports and forest-based industries contributed 5% of the GDP. In southwest, most wood came from the Sundarbans, a large mangrove forest and swamp, where the main flora was *Sundari* trees which thrive in mildly saline water.

India refuted these claims, saying that

(a) it is rainwaters that moist soil, not ground water,
(b) salinity did not affect the Padma water,
(c) no adverse effect was noticed in Indian territory below Farakka because of diversion, and
(d) the experts who visited Bangladesh did not observe any decrease in water for irrigation.

India also disagreed with the estimated loss on the ground that Bangladesh had provided no target, or base level, of production, against which such losses can be calculated. India also remarked that the quality and productivity of *Sundari* woods depended on local rainfall and on the depth and spread of the tides. 'The lean season flows in the Padma cannot reach any part of the Sundarbans and the Farakka withdrawals cannot thus have harmful effects on forestry in Bangladesh.'

The team concluded that there has indeed been some fall in farm production of the order of 0.65 million tonnes and that the forests did decline because of increased salinity. Though the team disagreed with the 'White Paper' of Dhaka on other counts, it over-estimated the loss of farm production than that given in the White Paper. The analysis of data was weak and not based on practical considerations. It was not appropriate to attribute reduced flows in the Gorai-Madhumati to that in the Ganga-Padma. Siltation in the mouth of the Gorai was a natural phenomenon which might have reduced the flow in the Gorai-Madhumati, as happened to the Bhagirathi-Hooghly, the Bhairab-Jalangi and the Mathabhanga-Churni. Therefore, both the White Paper and the Special Studies reports might have been based on weak analyses.

Ben Crow stated that as there was rise in salinity in certain areas after diversions from Farakka, farm production was bound to fall, though it was difficult to quantify it, owing to unknown factors. Similarly, the flows in the Gorai-Madhumati might have enhanced salinity in water in the Sundarbans. Therefore, the decline of the Sundarbans forests could not be due to Farakka diversions.

Regarding navigation, the Bangladesh government claimed that ferry services on the Ganga, the Gorai-Madhumati etc. were disrupted badly owing to India's withdrawals at Farakka. As a result, navigation became difficult, or even impossible, in many rivers of southwest Bangladesh and led to shifting of several ferry terminals. The 'Special Studies' team found that the affected routes were not the most important but conceded that the Farakka Barrage did have an adverse effect and that India's diversions of the Ganga water at Farakka did seriously disrupt inland navigation. Commercial navigation also suffered to the extent of 10 million tonne-miles and Bangladesh did incur a loss of three million taka, or US$ 50,000 (in February, 2009 exchange rate), because of reduced water depths in the Ganga after Farakka diversions.

Bangladesh claimed that the withdrawals reduced fish yield and haul because of disturbance of the traditional food chain and inability of fishes to breed and live in shallow depths and owing to rise in salinity. The Fishery Directorate recorded a static yearly catch until the dry season of 1975 but thereafter a sharp decline. India maintained that the main *hilsa* catch could not have been affected, because it took place in the monsoon season when all gates of the barrage are kept fully open. However, New Delhi conceded that *hilsa* catch was going down even before the withdrawals. The team observed that reduced flows could affect fish spawning and therefore, reduce breeding but statistical evidence was not sufficient and conclusive.

Bangladesh government in its White Paper argued that increased salinity affected the health of its people and the eco-system of the region, especially in the Sundarbans. Drinking water ran short in southwest Bangladesh in 1976 and 1977, as water-level receded in wells, ponds and *nulla*s (narrow canals) and bred many diseases. India argued that no adverse effect was noticed in people in the Indian part of the Sundarbans. The 'Special Studies' team had no word about ecology, except that in the region it was indeed affected in the recent years owing to the construction of Farakka Barrage.

One can see that the views of Bangladesh government and of the 'Special Studies' team were one-sided, biased and not always based on facts and circumstances and did not take into account the various causative factors. Most of these exponents over-estimated the effects of the withdrawals of the Ganga water at Farakka on Bangladesh. On the other hand, India's assessment of the effects of Farakka withdrawals on Bangladesh was based on certain assumptions, held in pre-Farakka days, and not on studies after the diversion and therefore, smacked of under-estimates.

The Special Studies team analysed the data in a neutral and realistic manner. According to it, the Gorai-Madhumati and the Rupsa-Pussar used to be moribund in the dry season, even before Farakka Barrage came up. Flows in the river were negligible in four to five months, even in 1951 and 1954. The mouth of the Garai had silted up, requiring dredging in dry season. Therefore, the diversion of water at Farakka might not have had any ill effect on reduction of discharge in the Gorai-Madhumati.

The diversion had some adverse effects on the ground-water table in Bangladesh. As the Special Studies team said, it was difficult to quantify the effect, as it depended on many other factors, like rainfall, ground slope, location of permeable strata and perched water bodies below the ground, soil stratification etc. The team added that the ground-water contour in southwest Bangladesh sloped toward the river, i.e., the flow of the ground-water of the region was toward the river only. India's claim that the Ganga below Farakka flowed through Indian territory on the right bank, for more than 100 km and that no adverse effect of Farakka withdrawals by India on ground-water has been noticed. Therefore, Dhaka's allegations of adverse effects on Bangladesh were not fully justified.

Another allegation of increased salinity intrusion in southwest Bangladesh was, however, partly true. Agriculture and industry in the Pussar estuary from Rupsa-Pussar region to that of the upper Gorai-Madhumati were indeed affected by increased salinity. Big industries at Khulna – paper mills, power station, jute-processing units etc. were affected partly by saline water but the estimated loss of 120 million taka in 1976 appeared exaggerated.

The claim of Bangladesh government that Farakka withdrawals by India had adverse effects on agriculture and forestry was exaggerated, as stated by Ben Crow. Farakka withdrawals might have enhanced salinity in the Gorai-Madhumati basin, but salinity intrusion in the Ganga-Padma because of them was negligible. Increased salinity in the Gorai-Madhumati basin might have affected farm production, but its adverse effect on the forests in the Sundarbans was doubtful. Similarly, the navigable depths in the Ganga-Padma and the Gorai-Madhumati might have reduced somewhat after diversions from Farakka which led to suspension of ferry services, reduction in trade and commerce etc. in southeast Bangladesh.

The claim of Dhaka that fish haul, especially of *hilsa*, was reduced substantially because of Farakka withdrawals, is not based on facts. Fish catch can go down owing to increase in the catch of matured fishes and of spawns and small fishes, extensive netting in rivers downstream, pollution of water by industrial and other wastes, excessive withdrawal of water etc.

Although the effect of Farakka withdrawals on the flow of the Gorai-Madhumati, increasing salinity, or harming agriculture, industry and other aspects are difficult to assess correctly, the overall impact of the diversions on the ecology and the environment of southwest Bangladesh cannot be denied. Shortage of drinking water in the dry season, spread of various diseases, decrease in fish production etc. might be the indirect results of withdrawals at Farakka.

There were other direct and indirect effects on the sedimentation pattern of the Ganga-Padma, which would eventually increase siltation and erosion of the river-bed and banks, ultimately affect the channel pattern and invite other morphological changes.

The factors responsible for these adverse effects and to what extent these were responsible for overall ecological degradation etc. of southwest Bangladesh owing to withdrawals at Farakka are summarized in Table 10.7.

Table 10.7 shows that there were many other factors for adverse effects on southwest Bangladesh. Farakka diversion did partly affect and might have accelerated the effects but other reasons were more prominent too. Had there been no diversion at Farakka, the adverse effects attributed to it would have occurred, some day, because of other factors.

Augmentation Schemes Ignored

The 1977 agreement and the two MOUs of 1982 and 1985 could only resolve the issue of sharing the Ganga flow at Farakka in the lean season between 1977 and 1988. Though these also provided for augmentation of the flow at Farakka, no solution could be found over this long period, either by the Joint Rivers Commission (JRC) or by the Joint |Committee of Experts (JCE).

The Article VIII of the 1977 Agreement, inter alia, stated:

> The two governments recognize the need to co-operate with each other in finding a solution to the long-term problem of augmenting the flows of the Ganges during the dry season.

Table 10.7 Effect of Farakka withdrawals on Bangladesh (South-Western Region)

Sl. no.	Prototype evidences	Probable factors responsible	Effect of Farakka withdrawal fully or partly
1	Reduction of *Discharge* in Gorai Madhumati	i) Siltation at the offtake-point and in river bed due to southward swing of Ganga Padma river like that of Bhagirathi-Hooghly river in Pre-diversion day ii) Farakka Diversion	Partial
2	Impact on *Ecology* and Environment	i) Increased population ii) Damage of forestry for habitation and indiscriminate felling of trees iii) More and more urbanization iv) Increase of industries v) Farakka diversion	Partial
3	Increase of *Salinity* ingression and through tributaries e.g. Gorai Madhumati etc.	i) More withdrawal of surface as well as ground wateii) Blockage of river mouths iii) Aggradation of river bed iv) Farakka diversion	Partial
4	Loss/Damage to *Industries*	i) Deterioration of labour management relationshipii) Old and obsolete machineries iii) Non-modernisation iv) Disturbance in Power Supply v) Water scarcity vi) Decrease of investment vii) More salinity in water viii) Farakka diversion	Partial
5	Lowering of *Ground Water* Table	i) More withdrawal for irrigation and domestic Purposesii) Less rainfall iii) Farakka diversion	Partial
6	Loss of *Navigation*	i) Siltation in river bed ii) Siltation in offtake point of tributaries iii) Less rainfall in catchment area iv) Farakka diversion	Partial
7	Loss of *Agricultural Production*	i) Less irrigation facility ii) Less use of fertilizer and pesticides iii) Less rainfall iv) More salinity v) No change of cropping pattern vi) Farakka diversion	Partial
8	Loss of *Forest Products*	i) Indiscriminate felling of trees by miscreants and for habitation purpose.ii) Less rainfall iii) Industrial and environmental pollution	No effects.

Under Article IX, the JRC was entrusted with studying the most economic and feasible schemes for augmentation of dry-season flow, proposed, or to be proposed, by either government and with submitting its recommendations to the two governments within three years. Accordingly, the proposals were submitted by two sides and considered by the JRC, but no consensus could be reached in spite of several exchange of data etc. and no final recommendation could be made to the governments.

The two proposals for augmentation of the discharge at Farakka made by the two governments were as under.

India's Proposal

India's proposal comprised the following:

(i) Construction of a barrage across the Brahmaputra at Jogigopa in Assam, to be about 2.40 km long, i.e., longer than Farakka Barrage;
(ii) Construction of a link canal, about 320 km long, joining the Brahmaputra, upstream of the proposed barrage at Jogigopa and the Ganga, upstream of the barrage at Farakka of a capacity of about 2,830 cumecs, or 100,000 cusecs, of the size of 2,750 metre width and 9.0 metre depth.
(iii) Construction of three dams – one across the Dihang, a tributary of the Brahmaputra in Arunachal Pradesh, and the other over the Subansiri in Assam and the third over the Barak in Mizoram.

The Indian proposal, outlined in Fig. 10.8, aimed at water transfer from the Brahmaputra basin to that of the Ganga, i.e., from a surplus to a deficit river to augment the flow of the latter in dry season. The main barrage was proposed to be constructed at Jogigopa in Assam, about 110 km downstream of Guwahati, the Assam capital, where the river is narrow and the banks are rocky and stable. The link canal was to stretch over 215 km in India, i.e., about two-thirds of its total length and over 105 km in Bangladesh, i.e., about one-third of its total length. The canal would run over about 45,000 acres of land in India and 20,000 acres in Bangladesh, to become the largest man-made canal in the world.

Indian proposal provided for augmentation of the Brahmaputra discharge in the dry season. Three storage reservoirs were proposed across three rivers in India's north-eastern provinces – Assam, Arunachal Pradesh and Mizoram. The Brahmaputra after flowing east through China for more than half of its length, takes a sharp southward turn and enters Arunachal Pradesh with a steep downward gradient of about 2.29 km out of 230 km (1:140) approximately. The proposal included construction of a rock-fill dam of about 260 mheight, across the Dihang on its right with a gross storage capacity of about 32,500 million M^3 (MCM), almost equal to that of the largest reservoir in the USA. It would augment the Brahmaputra flow in the dry season by 1,700–3,400 cumecs. A hydro-electric power station below the

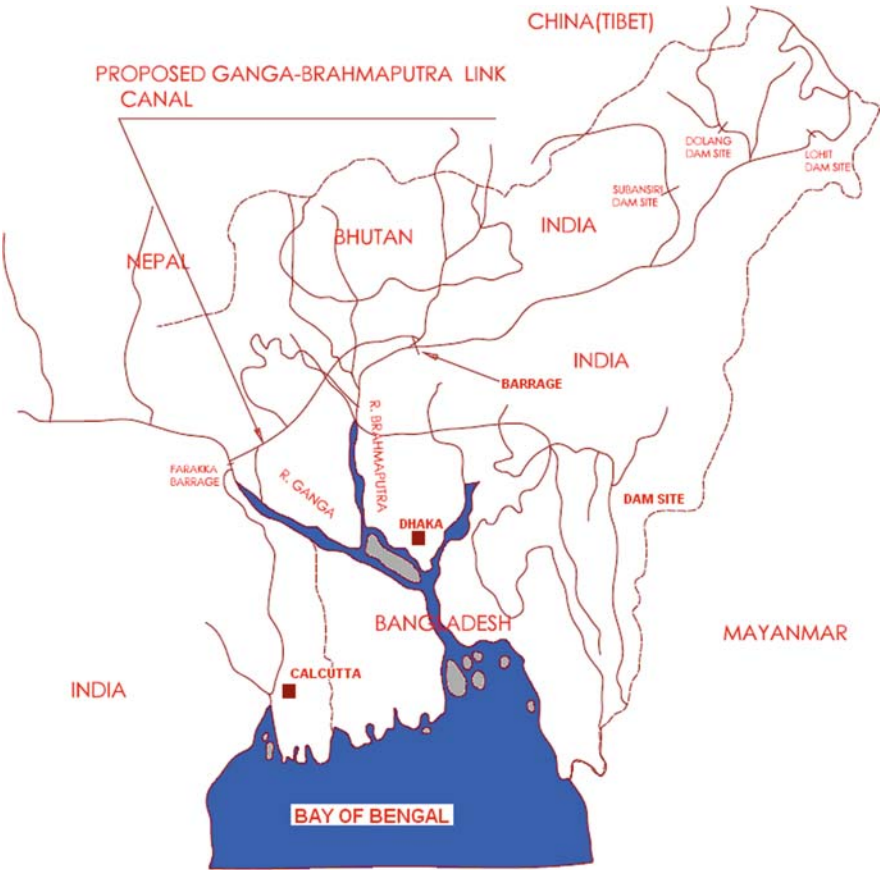

Fig. 10.8 Indian augmentation proposal

dam would generate about 7,500 MW but could submerge about 350 km^2 area, the major part of which would to be in India and the rest in China.

The proposal also included a second dam across the Subansiri, another tributary of the Brahmaputra on its right in Assam in hilly-cum-plain area. This would also be a rock-fill dam, about 240 m high, and store up to 18,000 million M^3 (MCM) to augment the dry season flow of the river by about 700 cumecs and also generate about 1,800 MW but submerge about 100 km^2 area in Assam alone. These two reservoirs would also help mitigate floods in the Brahmaputra basin and reduce the peak flood of 1.50–1 million cusecs.

A third rock-fill dam was also proposed by India, to be constructed over the Barak at a place, called Tipaimukh in Mizoram, which would directly augment the flow of the Ganga. It will have a storage capacity of 7,000 million M^3 (MCM) of water to augment the dry-season flow of the Ganga by about 300 cumecs and generate about 600 MW of hydro-electric power. It would effectively control floods in Cachar district in Assam as well as in Sylhet and Dhaka districts of Bangladesh.

The proposed 320 km long Ganga-Brahmaputra link canal would intercept a number of rivers and rivulets in India and Bangladesh, The largest one is the Teesta; the canal would cross it almost at right angle in Bangladesh. India proposed a level-crossing with four-way navigation facility in all directions. This would be a very big engineering project and the level-crossing would possibly be the largest such in the world. The estimated cost of the Indian proposal at 1983 price level was 160,000 billion rupees.

Bangladesh's Proposal

Bangladesh was totally opposed to transfer of any amount of water from the Brahmaputra basin to that of the Ganga. Dhaka believed that transfer of water from one basin to another was not the best way of augmenting the dry-season flow. Instead, it proposed that the available water of the basin should be gainfully utilized by making arrangements for storage of surplus water during monsoon months. The proposal of Bangladesh comprised the following:

a) Construction of storage dams in the upper reaches of the Ganga basin in India and Nepal for storing surplus water and its release in the dry season;
b) Construction of a canal through the Tarai region of Nepal to carry water from the Gandak and the Kosi to the Mahananda, the Karatoya and the Atreyi; and
c) Augmentation of dry-season flow by conserving a part of the river's monsoon discharge in storage dams in the upper reaches in India and Nepal to enable surplus water flow to the Ganga basin even after meeting the future needs.

New Delhi made an overall assessment of the requirement of water of Nepal, India and Bangladesh. Bangladesh proposed 83 storage dams in the upper reaches of the Ganga, of which 31 would be in Nepal and 52 in India, some of which ares shown in Fig. 10.9. It was estimated that the dry-season flow of the Ganga could be increased to about 5,100 cumecs (180,000 cusecs) by releasing water from these reservoirs in India.

The stored water in the reservoirs of Nepal could be released through natural rivers, joining the Ganga. A part of it could be diverted to the Mahananda and the Karatoya to augment their flows in West Bengal and Bangladesh respectively. The canal could also be used for navigation and be a river route of Nepal to the sea. Moreover, the storages would have high potential for generating hydro-electric power at a cheap rate to boost industries in Nepal, India and Bangladesh. Power generation as per Dhaka's estimate would be more than 10,000 MW.

The 1983 Bangladesh proposal envisaged optimum increase of surface water resources of the Ganga basin to 0.5 million cubic metre (446 million acre-feet) in a year. It also assessed the total demand in the Ganga basin for various purposes by the co-basin States as under:

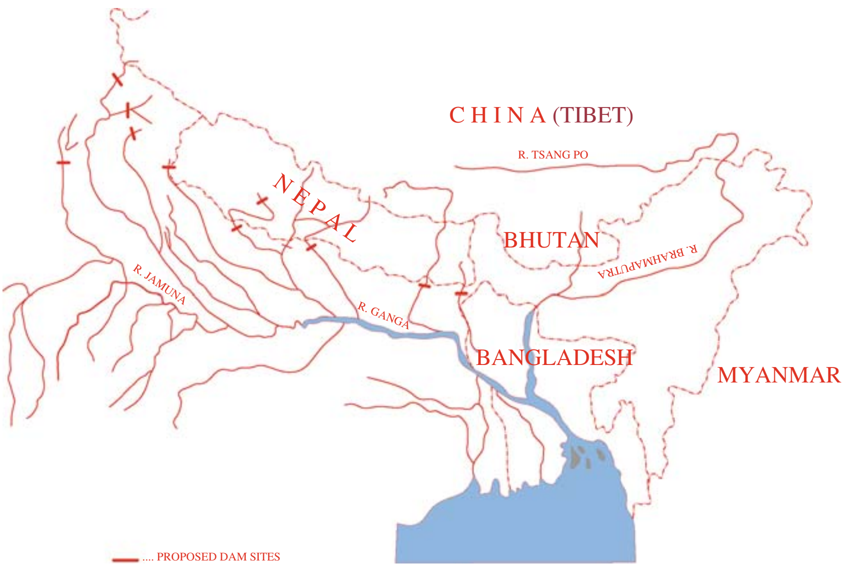

Fig. 10.9 Bangladesh augmentation proposal

i) Nepal: 0.029 million million cubic metre (23.5 million acre feet)
ii) India: 105 million million cubic metre (85 million acre feet)
iii) Bangladesh: 0.055 million million cubic metre (44.5 million acre feet)
- -
Total: 0.189 million million cubic metre (153 million acre feet)

Views of Bangladesh on India's Proposal

Bangladesh argued that India's proposal for construction of a link canal between the Brahmaputra and the Ganga to augment water in the latter violated the principles of inter-basin transfer. B. M. Abbas stated that the universally accepted basic principles in respect of transfer of water from one river basin or sub-basin to another were

a) the present and future requirements of the exporting basin must be fully met, or safeguarded, i.e. the water from the exporting basin, or region, should be surplus;
b) the requirement of the importing basin, or region, should be reduced to the minimum possible by tapping alternative sources which, except on special consideration, should be cheaper than the proposed imported water and effect savings in existing water uses, efficiently.
c) the impact of bulk transfer from exporting region, hydrological changes, ecology, environmental pollution, aesthetics and human interests in water and properties in the rights of way through which such transfers are affected to the minimum, have to be studied.

Mr. Abbas added that the present dry-season flow in the Brahmaputra is not adequate to meet the full requirements of the basin, whereas the available flow in the Ganga basin, if properly conserved, can meet them. Moreover, the impact of any transfer of water from the Brahmaputra basin to that of the Ganga in the dry-season would be severe on the economy, environment, ecology and the life of the people of Bangladesh. He also maintained that India's policy of bilateralism did not stand, because the Ganga flowed between India and Bangladesh–making them co-riparian countries; therefore, no difficulty is envisaged by associating Nepal with the scheme.

Another Bangladesh officer apprehended that India was trying to develop the whole of India with the Ganga water, because India's suggestion included watering drought areas. He anticipated that inter-basin transfers of water on the scale, implied in India's proposal would pose a threat to Bangladesh. Another officer commented.

> No sensible authority would even entertain the concept of bringing the whole of the stated 60 million hectares of land in the Indian territory under intensive irrigation at the expense of other co-basin countries.

The Bangladesh Government apprehended that construction of a link canal would uproot about 50,000 people from the thickly populated region; this made India's proposal unacceptable to Dhaka.

India's Reply

India disagreed with Bangladesh's interpretation of 'bilateralism'. New Delhi argued that as the problem is between two countries – India and Bangladesh – the issue was indeed bilateral and as per the UN guidelines, a solution has to be found by the two countries themselves. India rightly criticized Bangladesh for insisting on the participation of Nepal, because Kathmandu would obviously support Dhaka's views to get on her own proposals. Nepal also might not be interested in Bangladesh's proposal of storage dams in the Ganga basin, because these would be mostly located within Nepal and could submerge land in her territory. India maintained that Nepal could be consulted, but it cannot participate in the discussions.

India's second argument against Bangladesh was that its proposal was neither precise nor definite, but was based on probabilities and assumptions. Its layouts of storage dams, navigation canal etc. was technically unacceptable to India, as those were not based on prototype data and physical investigations. India thought, the proposal for storage dams and reservoirs which would be among the highest in the world was impractical, because it was not based on site conditions.

India added that just as the existing storages in the upper reaches of the Ganga were serving local needs, the future ones would also have to do that. As such, the proposed reservoirs in India would not help augment the flows at Farakka. The future needs of the basin State cannot be sacrificed for flow augmentation in a lower riparian country. Also, the idea of a waterway, connecting the Gandak and the Kosi along Nepal-India *terai* region for diversion of their waters to the Karatoya, the Atreyi and the Baral rivers in Bangladesh was not supported by any data. The canal, if constructed, would pass through seismically vulnerable areas and be a danger for India. Besides, construction of 83 reservoirs along the entire northern territory of India would make the whole of India and Bangladesh geo-technically and seismically unstable. India, therefore, maintained that Bangladesh proposal upheld only its own interests, ignoring the safety aspects for India and Nepal, not to speak of development of their water resources.

The Two Proposals in prism

The 1977 Agreement, signed between the two countries on sharing the Ganga water at Farakka, was in three parts.

1) Arrangements for sharing of the Ganga water at Farakka;
2) Long-term arrangement;
3) Review and duration.

The second MOU was signed on 22nd November 1985 between Rajiv Gandhi, the then Prime Minister of India and President H. M. Ershad of Bangladesh, during their meeting at Nassau, Bahamas. They recognized the gravity of the problem of inadequate flow in dry season and sharing it for mutual benefit as well as long-term solution for augmentation of the flow. They agreed to sign another MOU for three years, commencing from the dry season of 1986 on the same terms as of 1982. The Joint Committee of Experts (JCE), comprising Secretaries of the two governments and two engineering members of the commission from each side would study the schemes and identify alternatives of water sharing. This effort also came to naught and the tenure of the MOU expired after the dry season of 1988. The minutes of the two meetings are given in Appendix E.

It is clear that both sides were adamant and rigid about respective schemes and did not come to a compromise. The technocrats were hopeful about the success of their schemes and took a rigid and pessimistic view of the scheme of the other country. India contended that available water in the Ganga basin would be just sufficient for her future needs, while the quantum of available water, estimated by India for her future requirement, was unacceptable to Bangladesh; this quantum did not tally with that in Bangladesh's estimate. Dhaka did not agree with India's view that the Ganga basin would not have adequate water to meet local needs and for augmenting flows in the dry season. The assessment of water availability and its requirement, as assessed by the two countries, are given in Table 10.8.

Table 10.8 shows that there was wide variation in the estimates of demand and storage capacity, put forward by two countries. The units of water measurement, adopted by them, were also different.

Ben Crow in his book 'Sharing the Ganges' has mentioned that the Indian proposal was a carefully written, well-reasoned document, longer and more detailed than its Bangladesh counterpart and has been discussed in three parts. The proposal outlined the context in which India wished the augmenting of the Ganges flow to be

Table 10.8 Estimate of dry season water demand and storage capacity

Sl. no.	Assessment	Demand	Probable Storage
A)	**Indian's Assessment**		
a)	For Nepal	Not estimated	Not estimated
b)	For India		
	i) Irrigation (Rabi season)	320,000 (cusecs)	
	ii) Calcutta Port	40,000 (cusecs)	80,000 (cusecs)
	Total	360,000 (cusecs)	80,000 (cusecs)
c)	For Bangladesh		
	i) Irrigation	50,000 (cusecs)	
	ii) For Gorai River	5,000 (cusecs)	
	Total:	55,000 (cusecs)	
	Total (India's Assessment-excluding Nepal)	415,000 (cusecs)	80,000 (cusecs)
B)	**Bangladesh Assessment**		
	i) For Nepal	24 (MAF)	50 (MAF) 130,000 (cusecs)
	For India	150 (MAF)	54 (MAF) 180,000 (cusecs)
	iii) For Bangladesh	33 (MAF)	
	Total (Bangladesh Assessment)	207 (MAF) 614,000 (cusecs)	104 (MAF) 310,000 (cusecs)

considered, highlighting the needs of different parts of India and also the problem of flooding of both the countries. The proposal described a 'flood-drought-flood syndrome', a perennial problem for both Bangladesh and India and indicated the urgency and importance of control of floods and removal of drought, facing both the countries.

India realized that simultaneous development of the Ganga and the Brahmaputra basins would be absolutely necessary for the development of water resources in two countries, on which hinged the welfare of more than 400 million people in the two river-basins, which was nearly one-tenth of the world's population. Though the implementation of such schemes would be very expensive and need high technical expertise, large-scale development of both the countries would be possible only with such an effort. A joint venture for the development of the two basins by linking the Ganga and the Brahmaputra and facilitating inter-basin transfer of water could open up a new communication system, develop agriculture, generate hydro-electric power, increase fish breeding and catch and many other allied benefits. Scarcity of water in the Bhagirathi, the Jalangi, the Mathabhanga and the Gorai would be mitigated and Calcutta Port in India and Chalna port in Bangladesh would improve. B. G. Verghese, a renowned former editor of a major Indian newspaper and associated with a noted think-tank, the 'Centre for Policy Research' New Delhi, in a lecture delivered in New Delhi on 12th December 1977 remarked:

> The fantastic potential of the greater Ganga Basin cannot be allowed to remain grossly under-utilized for another long period of years, by which time costs will have risen greatly and population pressures will have multiplied.

Mr. Verghese added that the 1977 agreement unlocked the door, which had hitherto barred access, to the potential of the basin, but the 'fantastic potential' of the Ganga and the Brahmaputra would not be tapped easily and technical and political obstacles have to be surmounted. India's proposal of linking the Brahmaputra with the Ganga by a 320 km link canal would develop both the countries. The water from the Brahmaputra in lean season could be utilized in the drought-prone areas of northern Bangladesh and also of the upper reaches in India. A link canal could augment water to the Teesta, the Mahananda, and the Punarbhaba for the benefit of Bangladesh. Huge hydro-electric potential from the barrages and dams in the Brahmaputra and the Barak valley could also be utilized by both the countries for development of industries etc.

The Brahmaputra goes in spate about two months before the Ganga. The minimum discharge in the river is about 5,000 cumecs, i.e., 175,000 cusecs, which is normally seen in mid-February but that in the Ganga is about 1,415 cumecs, or 50,000 cusecs, normally occurring in end-April. Thus, there is a time-lag of two to three months in the minimum discharge in the two rivers. This fact can be gainfully exploited for augmenting the Ganga flow by the Brahmaputra flood water but in spite of all technical data given to Bangladesh representatives in the JRC, they did not see merit in Indian proposal. The comparative hydrographs of the Ganga at Hardinge Bridge and of the Brahmaputra at Bahadurabad for 1981 and average are shown in Fig. 10.10(a, b). The hydrograph of the Ganga at Farakka is assumed to be the same as at Hardinge Bridge.

Dhaka's charge that New Delhi was trying to develop the whole of India with the waters of the Ganga under its proposal was also ridiculous. More than 90% of the river basin as well as the course of the river lies in Indian territory. Under the relevant law, the future needs of a country should be first considered before those of its lower riparian States. The plea of Bangladesh for the transfer of the Brahmaputra water to the Ganga basin to meet the future needs of the two countries holds good about utilization of the Ganga water too for India's needs. The geographical footprint of the river should also be given due consideration.

Construction of a 320 km link canal through the two countries would displace more than 40,000 people in Bangladesh and over a 0.10 million in India. A vast land, occupied by agriculture, orchard, villages etc. would be needed for construction of the link canal, buildings, townships, colonies, diversion structures etc. and for disposal of excavated spoils. Another vast chunk of land would be needed for rehabilitation of the affected people. As population density of both the countries is among the highest in the world, loss of land would affect the economy of both. North-eastern India being seismically vulnerable, construction of barrage, dams etc. and the impounded water in the reservoirs would make the entire region prone to earthquakes.

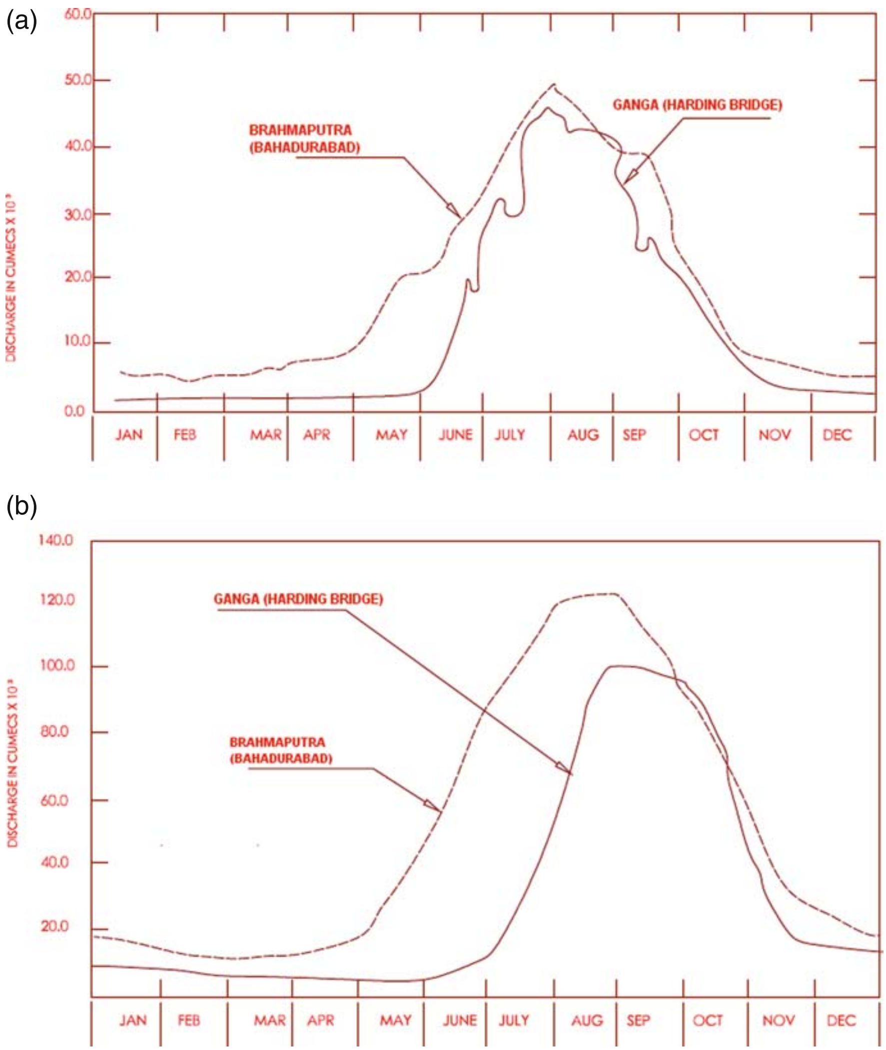

Fig. 10.10 (a) Discharge hydrograph of Ganga and Brahmaputra rivers in 1981; (b) Monthwise average discharge hydrograph of Ganga and Brahmaputra rivers

As the proposed link canal would cross a number of rivers and rivulets, a number of cross-drainage structures would be needed. One such structure would be a level-crossing for the Teesta. Bangladesh expressed doubts on the feasibility of such a structure, as the river carries huge volume of sediment. These structures including canal embankments normally cause serious drainage congestion on either side, depending on the natural ground slopes, as experienced while excavating the Farakka feeder canal. Their routine repair and maintenance of such a long canal and the drainage of its outlets would be very difficult tasks.

Bangladesh also charged that India's proposal was a threat to the sovereignty of Bangladesh, because India wanted to control the Brahmaputra water, as it was doing the Ganga water at Farakka. This was impossible, because the link canal and the cross-drainage structures on the Teesta and many other structures would be within Bangladesh. Moreover, Bangladesh being a lower riparian State and all its rivers originating from the upper reaches, should not have any suspicion on any joint water resources development programme for the benefit of two countries. Bangladesh did not give any details of their future requirement of the Brahmaputra water. Besides, the river inundates large areas, almost every year, in both countries. In view of these, India's proposal was reasonable and acceptable to both countries.

As Ben Crow had remarked:

> The Indian proposal did not refer to questions of equity of rights; it was concerned with practice and technical opinion. Enough water could not be stored within the Ganges basin for the needs of the three countries. The Indian scheme was justified, not as the most equitable way of sharing and developing the resources of the region but as the only feasible method by which all the needs (as estimated by India) could be met. The scheme was legitimized not by political value judgments, but by reference to technical expertise. Science or expertise was used in this way to authenticate one view of 'reality'. The Indian proposal was the only feasible, realistic option because the experts said so.

Bangladesh gave a very attractive picture of future storage facility by constructing reservoirs at 83 places (some are shown in Fig. 10.11) in the sub-Himalayan belt (all within India and Nepal), which would accommodate a total capacity of 104 MAF, as shown in Table 10.7 against the India's figure of only 80,000 cusecs. This looks absurd, as the Himalayan region is seismically sensitive and any major interference with Nature could cause disaster to Nepal and India. The Himalayan rocks are young, not more than 10,000 years old, friable and prone to landslides. Construction of a number of dams and reservoirs in this region could make the region unstable and trigger landslides, dam-bursts etc. following disturbance of the balance of Nature.

Bangladesh proposed a navigation canal, joining the Kosi in India with the Teesta in Bangladesh along the Himalayan foothills. The canal would be aligned east-west, against the natural north-south ground slope, which would affect the drainage system of the region. Any eventual breach of canal embankment would cause a catastrophe to the lower reaches, particularly in the Uttar Pradesh, Bihar and West Bengal. Thus, the proposal was quite absurd and India was right in not accepting it.

India's objection to Nepal's participation stemmed from her policy of bilateralism too. Since 1972, Dhaka never raised it, nor did Pakistan before. India's Treaty of Friendship with Bangladesh in 1971 was valid for 20 years, which provided for resolving all issues and disputes through bilateral discussions only. Nevertheless, India agreed to discuss the issues with Nepal before finalizing any scheme with Bangladesh but Dhaka insisted in Nepal's direct participation. New Delhi conceded that Nepal could be consulted after the scheme was approved by Bangladesh and if needed, a separate treaty could be signed with Kathmandu, later. India felt that Dhaka's insistence on involving Nepal was an attempt to influence the outcome of a study by a third country and to politicize the issue. Besides, multi-lateralism

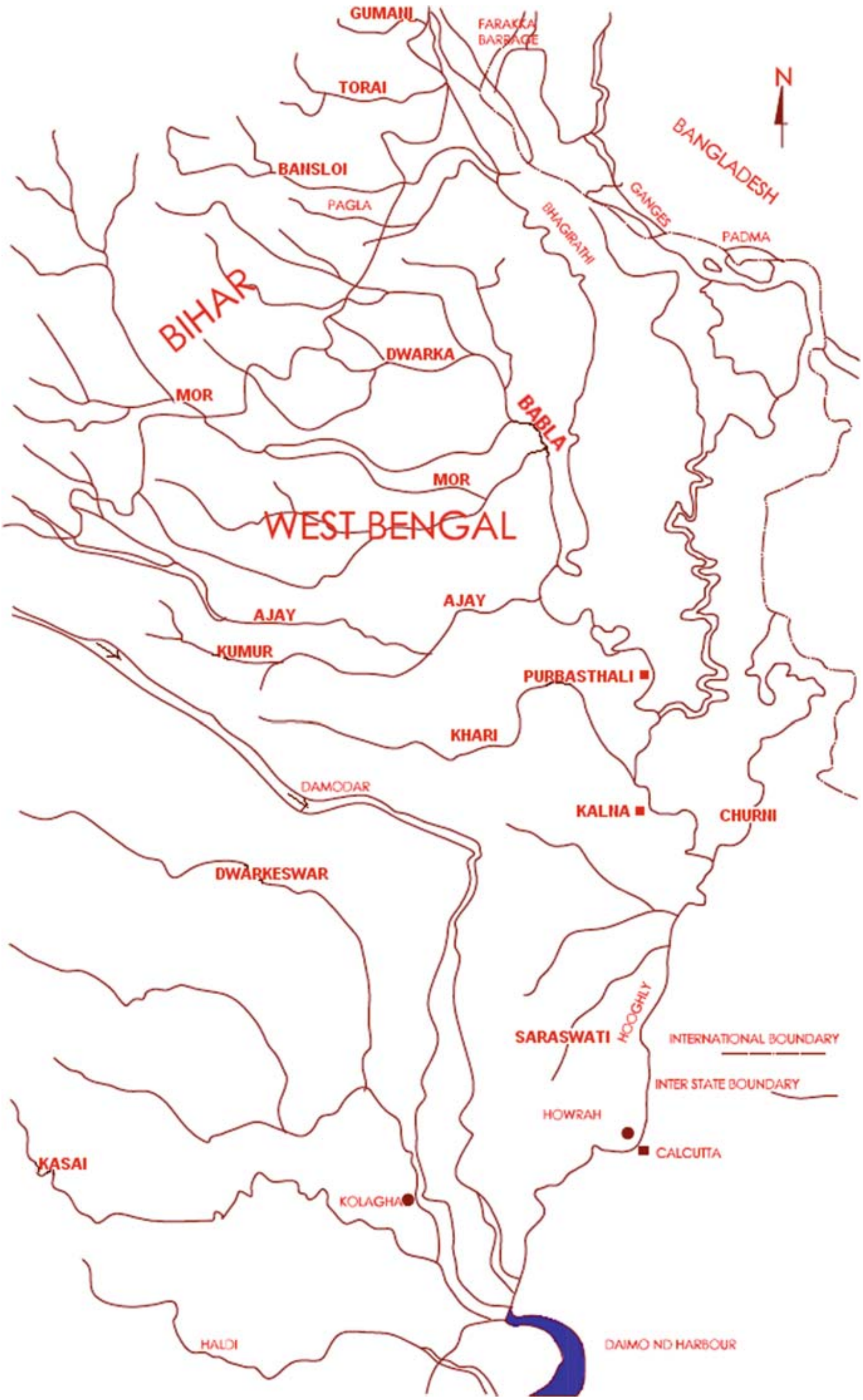

Fig. 10.11 Index map of Bhagirathi-Hooghly

could slow the progress of talks on these crucial issues, already delayed for years. New Delhi also feared that Nepal would not agree to construction of some 31 reservoirs in its territory, because they could submerge a large part of the hilly country. Curiously, Dhaka's proposal made no mention of this eventuality of submergence and displacement of people in India or Nepal but it admitted this mistake later. Besides, the scheme of Bangladesh would have least affected its own territory but done so much to India and Nepal. As all the dams and reservoirs would be in India and Nepal, they would submerge, and seismically affect, parts of these two countries only. Thus, Dhaka's scheme was biased in its favour and lacked equity and uniformity.

In short, India's proposal was based on following major considerations:

i. It was not possible to store sufficient water in the Ganges basin, which would be available for augmentation of dry season flow at Farakka after meeting future requirements of India and Nepal.
ii. Inter-basin transfer of water from the Brahmaputra to the Ganges basin would not only make available sufficient water for augmentation of the Ganges flow at Farakka during lean season, but also reduce the flood hazards of both Bangladesh and India.
iii. Sufficient water is available in the Brahmaputra river even during dry season.
iv. There is a time lag of about two-and-a-half months in the flood flow of the two rivers, the Ganges and the Brahmaputra, the floods occurring in the Brahmaputra earlier than in the Ganges.
v. The issue was purely bilateral and therefore, Nepal's inclusion in the formulation of the scheme was not necessary.
vi. The scheme was technically sound, feasible, realistic and uniform.

Bangladesh proposal was based on the following major considerations:

i. It was possible to store sufficient water in the Ganges basin itself, even after meeting the future demands of Nepal and India, which could be made available for augmentation of the Ganga flow at Farakka in the dry season to meet the requirements of both the countries.
ii. The Brahmaputra water would not be sufficient for transfer to the Ganges basin after meeting future needs of Bangladesh.
iii. As most of the tributaries of the Ganges originate from Nepal, that country should be directly involved in the augmentation scheme.

However, arguments and counter-arguments continued for and against each other's proposal for years together and ultimately, none of the proposals could be consider and therefore ultimately dropped.

Developments after 1982

The agreement of 1977, which was valid for five years, expired in 1982 but no solution was found to the issue of augmentation of dry-season flow of the Ganga at

Farakka; both sides stuck to their own stands. Two Memoranda of Understanding (MOU) were signed by India and Bangladesh – the first in October 1982 and the other in October 1985 on sharing of the available dry season flow at Farakka. The first MOU was for two years only, commencing from the dry season of 1984 and the second for three years from the dry season of 1986. In these five years, there was notable shift in the aims and objectives of the Bangladesh government. A section of Bangladesh politicians and officials realized the impracticability of their earlier stand of constructing a number of storage dams in the upper reaches of the Ganga tributaries, most of which would be in Nepal and India. However, a new thinking emerged slowly and rather secretly, to which support was meagre in all concerned quarters.

According to the new thinking, sharing of available dry-season flow of the Ganga at Farakka would be a separate issue, not to be confused with the long-term scheme of augmentation of dry season flow in the river. The thinkers favoured signing a long-term agreement with India to foreclose giving a chance to India to draw more water from the Ganga's upper reaches in dry season but they did not get much support in Bangladesh until 1996.

The new thinking was initiated by Anisul Islam Mehmud, the then Water Resources Minister; he was in favour of a long-term sharing of water of not only the Ganga but of all the 54 rivers that flow from India into Bangladesh – three big, namely, the Ganga, the Brahmaputra and the Meghna and 51 small ones. Only some technocrats of Bangladesh supported his idea. Humayun Rashid Chaudhury, the then Foreign Minister, was a staunch supporter of the 'old line' and had more influence in the cabinet.

In India too, there was a radical change in the approach to the issue. The then Prime Minister, Rajiv Gandhi wanted an early settlement of the issues but his government did not want to shift its stand, to remain consistent in its policy toward a new neighbouring country.

Anyway, the new thinking in Bangladesh along with India's eagerness for a quick and durable solution of the twin problems of sharing and augmenting the dry-season flow of the Ganga at Farakka gradually received diplomatic and technical support in Bangladesh. Dhaka realized that a short-term agreement with New Delhi of two to three years' validity would not boost overall development of its water resources, nor would it provide any security for Bangladesh to seek technical and financial support from the outside world. Other countries will not make any large investment on developing water resources in Bangladesh, unless they are assured of future availability of water in any river.

Moreover, planning and execution of a long-term scheme take much more time than a short-term arrangement. It also realized that sharing could be a bilateral issue but augmentation would not be possible without involving Nepal, or other countries, which makes the issues trilateral, or multilateral. If water from the Ganga was available to Bangladesh following a long-term treaty with India, it could plan major irrigation schemes. At the same time, an agreement on all rivers flowing from India to Bangladesh would assure huge volume of water, which India alone could utilize by constructing small dams and barrages within its own territory. This was an apprehension, because India had already started constructing barrages across some rivers, like the Gomati and the Teesta. Therefore, instead of raising only one claim of sharing and augmenting the Ganga water, Bangladesh thought it prudent to claim share of water from all rivers, flowing from India into Bangladesh. It contemplated constructing two barrages, one over the Ganga-Padma below the Hardinge Bridge and the Gorai outfall and the other over the Brahmaputra near Bahadurabad, both within Bangladesh.

Time passed but a durable solution eluded. The two-year MOU of 1982 expired after the dry season of 1984. Another MOU that was signed in November 1985 was to be in force until 1988. The so called 'old line' of Bangladesh on augmentation gave way to the new approach. Politicians as well as technocrats apprehended that the earlier proposal of augmentation by building storage reservoirs in the upper reaches of the Ganga would increase, by more than 30%, the existing water body of Nepal and submerge the scarce land of Nepal, particularly the farm land in the plains. Moreover, implementation of these schemes would take a long time, during which India's demands, or the Ganga's upper reaches would be stronger and leave no scope for increasing the dry-season flow at Farakka.

Dhaka's new approach for augmentation by joining the Brahmaputra with the Ganga within Bangladesh resembled India's proposal of 1978, which it had been rejecting so far. It had vehemently criticized it, dismissing it as India's hostility toward Bangladesh. The new thinking of Dhaka, which was similar to India's 1978 proposal was, therefore, 'betrayal and treachery' of India. The proposed scheme was under wraps and an abiding solution of sharing and augmentation issues gradually emerged. In an interview in 1987, Bangladesh Water Minister, Anisul Islam Mahmud clarified that there were two parts in this new approach – one was official and the other unofficial. The official approach had three main elements:

i) The Government of Nepal should be brought into the negotiations.
ii) Negotiations should cover all common rives, not just the Ganges; and
iii) The two issues of sharing and augmenting the dry-season flow of the Ganga should be separated and priority be given to the issue of sharing water.

However, Mr. Mahmud did not disclose the unofficial approach and kept it a secret, probably to ward off the supporters of the old approach. Circumstantial evidences and future developments clearly indicated that the demand for a tripartite understanding, or an agreement by inclusion of Nepal, gradually faded out in the unreality of the situation.

A new impetus from India under Prime Minister Rajiv Gandhi, reciprocated by Bangladesh President H. M. Ershad and his Water Resources Minister, Mr. Mahmud, brought into focus a settlement. President Ershad made Mr. Mahmud the chief Bangladesh negotiator with India, over-ruling objections by the hardliners in his country. A lot of changes had occurred by this time in the Joint Committee of Experts (JCE) in Bangladesh. B. M. Abbas, a water resources engineer, and a senior negotiator on the issue and a staunch supporter of the old line for more than two decades, was out of the government. Key diplomatic and technical positions went to strong believers of the new line. Also, by this time, funds flowed to Bangladesh from the World Bank for a pre-feasibility study of constructing a barrage over the Brahmaputra at Bahadurabad. A team of foreign engineers, who were examining alternative options, was inclined to support the new line.

The JCE and government-level discussions supported this new approach, particularly on utilization of the Brahmaputra water for augmentation of the dry-season flows of the Ganga at Farakka. India's representatives indicated three possibilities and asked Bangladesh experts to consider them, so as to place some concrete proposals before the ministerial-level meeting but the latter did not accept them. The three Indian proposals were

a) Construction of a barrage over the Brahmaputra at Jogigopa in Assam with a link canal through India, northwest Bangladesh and back to India to join the Ganga upstream of the barrage;
b) A barrage over the Brahmaputra at Bahadurbad and a link canal from upstream of barrage joining the Ganga near the Hardinge Bridge, all in Bangladesh; and
c) To utilize the waters of the Brahmaputra to meet some requirements of Bangladesh which were being met, or were to be met, from the Ganga without necessarily linking the two rivers with a canal.

When Bangladesh official put up these proposals to Mr. Mahmud, he endorsed the second which was consistent with the new approach. Ramswamy Iyer, the Secretary of the Indian Ministry of Water Resources, who led the Indian team held that the feasibility of a barrage and the gravity link canal within Bangladesh could be discussed on the condition that Bangladesh would not claim the minimum Ganga flow of 34,500 cusecs, as reflected in the 1977, 1982 and 1985 agreements / MOUs and India would not bring down to zero the flow at Farakka. He proposed about half a dozen possibilities which were accepted by Bangladesh. Mr. Mahmud proposed that his country be guaranteed a minimum dry-season flow of 25,000 cusecs from the Ganga in the last 10 days of April (21–30), 75% of the Brahmaputra flow and 50% of the flow of other common rivers, which Indian negotiators did not commit, causing a setback in the discussions.

In the ministerial-level meetings in 1986, two different attitudes surfaced. Shankaranand, India's Water Resources Minister, wanted the meeting to take up the two issues together, but Mr. Mahmud insisted on dealing with the sharing issue first. India reiterated its rejection of Dhaka's proposal for augmentation of the Ganga water by constructing storage dams in Nepal and stressed on reaching a long-term accord on the two issues but did not guarantee share of water of all common rivers, which Dhaka demanded. Bangladesh argued that sharing was an immediate bilateral problem, while augmentation was a long-term issue, requiring her co-operation with India and Nepal. Bangladesh also took the stand that it would not consider the augmentation proposal, unless India assured a definite share of the water of all common rivers. In short, India stood for sharing along with augmentation of the Ganga water but Bangladesh did not agree to go for augmentation unless New Delhi guaranteed share of the principal common rivers.

In 1986, the two countries agreed to discuss the issue with Nepal but meanwhile, Dhaka added a rider to New Delhi that discussions with Kathmandu would not be a precedent for any trilateral understanding. In October, that year, JCE delegates of two countries went to Kathmandu and called on its Water Resources and Foreign Ministry officials but the discussions yielded no solution. The delegates could not tell Nepalese leaders, how their country would be benefitted and what cost. Nepal gave no data on water-related issues but insisted on knowing 'mutual benefits' before parting with them. India and Bangladesh insisted that the data sought was needed for a preliminary study and the mutual benefits could be decided and disclosed later but Nepal stuck to its gun, rendering the meeting a waste of time and money. India's desire for involving Nepal as a party to a tripartite agreement on the augmentation issue made no headway and no approach paper, as per agenda, could be prepared.

The situation forced Bangladesh to rethink. Dhaka was convinced that building of storage dams in Nepal was a Utopian idea and could never materialize. Kathmandu would never agree to such a thing and India would not compromise on its policy of bilateralism. Mr. Mahmud veered to his new proposal, under which two barrages would be constructed over the Brahmaputra and the Ganga with a link canal, connecting the two, all within Bangladesh. Though discussions on this in 1987 were incomplete, Mr. Mahmud brought the matter to the surface for the first time.

In 1987, the relation between the two governments worsened again over mass migration of tens of thousands of Chakma refugees from the hill tracts of Bangladesh to India. They fled, following Army actions in the hilly regions of Chittagong and insurgency in the hilly tracts of Tripura, an Indian province. In the latter, Bengalees were ousting tribal people so that they could settle in their places. To sharing the Ganga water, the 'hard-liners' in Bangladesh were stiffly opposed and her Foreign Minister and Water Resources Minister appeared to be at loggerheads. President Ershad and Mr. Mahmud thought that a joint visit by teams of India and Bangladesh to Nepal could ease political pressures within Bangladesh on the 'old line' and encourage the 'new line'. Mr. Mahmud once said that he did not believe that Nepal would really provide a solution and that the Brahmaputra, not the Ganga, could ultimately meet Bangladesh's need for additional water. Ben Crow quoted an Indian official in the JCE on the situation:

> My personal view is that we could have done something, if Anisul Islam Mahmud had been backed politically and if Humayun Rashid Chaudhury had not taken a different line. I think, a long-term agreement could have been negotiated, not on Anisul Islam Mahmud's figures, but we could have compromised.

The severe floods of 1987 and 1988 in Bangladesh got a lot of international media coverage and heightened concern within and outside the country. This gave a new scope for further negotiation between the governments of India and Bangladesh. Mr. Ershad travelled to another riparian country, China to know, how they were solving their problems and to discuss regional cooperation in river development. Meanwhile, the floods were so severe in Bangladesh that the government machinery was busy tackling them. The Ganga returned to focus after 1988. The old-liners blamed India and the Farakka Barrage Authority in particular for releasing all waters from the reservoir and for creating flood havoc in Bangladesh.

Even senior politicians and government officials pursued this line of thinking, ignoring the functions of a barrage and its difference from a dam. Even engineers who should know better said in a chorus that complete flood control lay not with Bangladesh alone but with the region too with cooperation of India and Nepal. A French consortium, the United Nations Development Programme (UNDP) and the World Bank disagreed with them and advised building embankments on the Ganga and the Brahmaputra along most of their courses to prevent floods, as far as possible and to train people to live with them, as they have been used to. The UNDP recommended zoning of flood-prone plains, adopting judicious protection measures and controlled flooding in some areas as well as river training.

Discussion on flood-control measures with India continued without any effective solution. The agreement of 1985 expired after the dry season of 1988. The tenure of the JCE also expired in November of 1985 and was not extended. The new line of thinking on augmentation and dialogue on other river development issues between the two countries did not also go further.

Developments between 1988 and 1996

There had been no agreement between India and Bangladesh on lean-season sharing of the Ganga water at Farakka after 1988. Even the issue of water-sharing of all common rivers between the two countries got no further momentum because of rigidity in their approaches.

In end-1989, President Ershad visited Nepal and China and discussed the water-sharing and augmentation issue with their heads of governments but he could not make any headway either. The political situation in India and Bangladesh had also changed. Through a general election in 1989, Viswanath Pratap Singh of the Janata Party became India's Prime Minister after Rajiv Gandhi in May 1991. Mr. Gandhi was killed by a suicide bomber of the LTTE during his election campaign near Chennai. President Ershad was also overthrown in December 1990 by Begum Khaleda Zia who later became the Prime Minister of Bangladesh. Efforts made by the heads of two Governments to solve the issues were stalled again. The Joint Rivers Commission resumed the dialogues on the issues after years of gap.

In May 1991 election in India, P. V. Narasimha Rao of the Congress party became India's prime Minister. He and Begum Zia met in New Delhi and agreed to forge a comprehensive and permanent plan on developing water resources within a specified period but without exacerbating political problems in either country. In August 1991, foreign ministers of two countries met in New Delhi and discussed long-term solutions. India proposed a package on the line of the Indus Treaty, involving the Ganga, the Brahmaputra, the Meghna and the Teesta. It included use of the Brahmaputra and the Meghna waters and constructing barrages across the Ganga and the Brahmaputra, but as before, Bangladesh did not agree.

Another minister-level meeting was held in August 1992 in Dhaka, where a new Joint Committee of Experts (JCE) was formed. It met many times in New Delhi and Dhaka between 1993 and 1996, but there was tardy progress toward an understanding of the twin issues of sharing and augmentation of the Ganga water at Farakka, to which was added Dhaka's plea for sharing of water on all other common rivers by India and Bangladesh.

In the dry seasons from 1989 to 1996, without a formal agreement, India continued to release water to Bangladesh from the barrage, as before, as per a superseded sharing formula in the spirit of mutual cooperation and understanding (see Table 8.1). India also continued observing the discharges, downstream and in the feeder canal and maintained records. In 1992 and 1993, the total flow in the lean period, between January and June, was much less than in earlier years. There was acute shortage of water in those two years, both in the Ganga and the River Bhagirathi. The Hooghly's reach in the vicinity of Calcutta port was heavily silted, decreasing the depth for incoming and outgoing vessels and raising the cost on dredging. Some units of India's National Thermal Power Corporation (NTPC) at Farakka had to be shut down, as production fell to all-time low in April. The entire reach of the Bhagirathi-Hooghly from Jangipur to Diamond Harbour was also severely affected by siltation.

There was hue and cry in Bangladesh, as water became scarce in the Padma too in 1992 and 1993. Newspapers reported that the discharge recorded near the Hardinge Bridge in March 1993 was only 276 cumecs, or 9,761 cusecs, the lowest ever. The Gorai was affected too and the Ganga-Kapotaksha irrigation-cum-power project had to be closed for a few days. Khulna industrial belt on its bank as well as jute and paper mills in the region were affected and had to cut down production. Crops dried up as ground-water level went down, affecting supply of drinking water. Salinity intruded in the river and ground water of the Gorai's hinterland. Jammat-I-Islam organized a big protest rally of over 25,000 people on the dry bed of the Padma, near the Hardinge Bridge in April 1993. Bangladesh government expressed its helplessness and disappointment over the slow progress of talks in the JCE but stuck to its stand of involving Nepal.

The flow increased in the Ganga from 1994 to 1996 and discharge was sufficient at Farakka in the lean season to facilitate equitable distribution as per the earlier understanding. Public resentment in Bangladesh also disappeared and the two countries reiterated demand for a permanent solution.

Politics in India was in turmoil formal since 1996. In that year's general election, the Congress party lost again but no other party or group got absolute majority to form a government. The President called Atal Behari Vajpayee of the Bharatiya Janata Party (BJP) and its allies to form a government but after only 13 days, it fell in a trial of strength in Parliament. Some political parties came together to form a government, led by H. D. Deva Gauda of Janata Party, who became the Prime Minister with the support of the Congress in June 1996.

Bangladesh too went for poll in March 1996, in which the Awami League, led by Sheikh Hasina, daughter of Sheikh Mujibur Rahman, the founder President of Bangladesh, became the Prime Minister by defeating Sheikh Khaleda Zia's Bengal Nationalist Party.

From the beginning, both the governments revived interest in a solution, clearing the air of suspicion and mistrust. In Bangladesh, farmers were groaning for water for irrigating farm land; towns and industries on the banks of the Gorai suffered for lack of adequate water. The new government resumed dialogues on water-sharing of the Ganga and other common rivers. India took the initiative on 5th July 1996, when New Delhi sent its foreign secretary, Salman Hyder to Bangladesh to hand over a letter from the Prime Minister to Bangladesh premier on the issues. In Dhaka, he discussed the matter with Bangladesh foreign secretary and assured him of India's interest in an abiding solution before the next dry season of 1997. The JCE came up with a proposal on the subject. In October 1996, India's and Bangladesh's foreign ministers visited Dhaka and New Delhi (and Kolkata), respectively came closer in their views. Jyoti Basu, the then Chief Minister of West Bengal also visited Bangladesh on 27th November 1996 and reached an understanding with Dhaka on water-sharing issue on a permanent basis. Returning to Kolkata, Mr. Basu hinted at signing a short-term agreement with Dhaka for two to three year, but it was seen later that he was really in favour of a long-term agreement.

Thirty-Year Treaty on Water-Sharing

Accompanied with her Water Resources Minister, Abdur Razzak and senior officers, Bangladesh premier, Sheikh Hasina came to New Delhi on 10th December 1996 and met Prime Minister Deva Gauda and senior Indian officers. Jyoti Basu was called to New Delhi to meet her. A momentous 30-year Treaty was signed on 12th December 1996 between India and Bangladesh on the sharing of the Ganga water in lean season at Farakka with immediate effect. Under it, each country would receive a guaranteed flow of 35,000 cusecs (991 cumecs) in the lean season, from 11th March to 10th May. It was based on a formula that took into account average availability of water at Farakka to be 70,000 cusecs (1982), during the past 40 years, from 1949 to 1988), on 50:50 basis. If the availability went up to 75,000 cusecs, Bangladesh will get 35,000 cusecs and India 40,000 cusecs through the feeder canal. If it exceeded 75,000 cusecs, India will get 40,000 cusecs and release the balance to Bangladesh.

As provided in the earlier Agreement and the MOUs of 1977, 1982 and 1985, water-sharing under the new Treaty would be on the basis of alternating three 10-daily periods, each month in the lean season, from 1st January to 31st May, although the critical period was from 1st March to 20th May, when the discharge in the river fell to the minimum. If the discharge fell below 70,000 cusecs, each country would receive a reduced quota. The Treaty also ensured that if the flow was less, at least one side would get its guaranteed share of 35,000 cusecs in one 10-daily period.

The Treaty has 12 Articles as against 15 in 1977 agreement. The full text of the treaty is given in Appendix D. A broad indicative schedule, giving the formula of sharing is annexed as I and II. The annexure-I gives a broad indication of sharing and a detailed agreement. These imply that every effort would be made by the upper riparian States of India – Bihar and Uttar Pradesh – to keep flow of the Ganga at Farakka at the 40 years' average of 70,000 cusecs. If the flow at Farakka goes below

50,000 cusecs in any 10-daily period, the two governments would immediately consult each other to make adjustments on an emergency basis.

Under the Treaty, a joint committee was to be constituted to ensure proper implementation of various provisions. It would form suitable teams at Farakka and at Hardinge Bridge to observe and record daily flows below the barrage and in the feeder canal as well as the navigation channel of the Bhagirathi and near Hardinge Bridge on the Ganga-Padma and submit annual reports to the two governments. Whatever differences or disputes that arise, while implementing the Treaty are not resolved by the committee, would be referred to the Indo-Bangladesh Joint Rivers Commission (JRC). If any difference or dispute persists, it would be referred to the two governments which would meet urgently to resolve it by mutual discussion under Articles IV, V, VI and VII.

The Treaty also empowered the two governments to review it after five years from its coming into effect, or earlier, as felt by either country, in the spirit of equality and fairness without harming the interests of the other. It would also be open to either party to seek the first review after two years, to assess the impact and working of the sharing arrangement under Article X; this was not provided in the agreement of 1977.

Unlike the 1977 agreement, the Treaty did not give any importance to augmentation of the Ganga flow at Farakka, except that the two governments recognized the need to co-operate with each other in finding a solution to this long-term problem (Article VIII). The Treaty would remain in force for 30 years and can be renewed by mutual consent (Article XII).

Another important provision was that if the two countries agreed on adjustment after a review, as per Article X, India would release not less than 90% of Bangladesh's share, as per the formula in Article II until mutually agreed flows are decided (Article XI).

The Treaty was signed in New Delhi on 12th December 1996; the signatories were Indian Prime Minister, H. D. Deve Gouda, his Water Resources Minister, Jnaneswar Mishra, Foreign Minister, I. K. Gujral and West Bengal Chief Minister, Jyoti Basu and three associates – D. P. Ghoshal, Secretary, Irrigation and Waterways and R. N. Dey, Chief Engineer of the Irrigation and waterways department of West Bengal government and S. V. V. Char, Commissioner (ER) of Ministry of Water Resources. The signatories from Bangladesh were just two – Prime Minister Sheikh Hasina Wazed and her Minister of Water Resources, Abdur Razzak. Photograph 10.1 shows two leaders Sheikh Hasina and Jyoti Basu engaged in discussions prior to the signing of the Treaty.

To sum up the salient features of the Treaty:

a) India will release water from the Farakka Barrage in the five-month lean season, from 1st January to 31st May, every year;
b) Bangladesh will get a minimum of 35,000 cusecs, or 50% of the Ganga water at Farakka, if its volume is 70,000 cusecs, or less;
c) India and Bangladesh will get guaranteed 35,000 cusecs in three alternative 10-day periods from 1st March to 10th May;

Photograph 10.1 GOOD TIMES: Mr Jyoti Basu and Sheikh Hasina at Banga Bhavan, New Delhi, on Thursday. — The Statesman.

d) Bangladesh will get a maximum of 67,516 cusecs from 1^{st} to 10^{th} January and a minimum of 27,633 cusecs from 11^{th} to 30th April;
e) India will get a maximum of 40,000 cusecs in seven 10-day periods in January and February and from 21^{st} to 31^{st} May and a minimum of 25,992 cusecs from 21^{st} to 30^{th} April; and
f) If the flow at Farakka falls below 50,000 cusecs in any 10-day period, the two governments will discuss adjustments.

After signing the agreement, Sheikh Hasina told a crowded news conference in New Delhi:

> This is a momentous event for the people of Bangladesh, as we mark the 25^{th} anniversary of our freedom. . . .Bangladesh will firmly leave behind the atmosphere of suspicion and distrust that had blighted its ties with India. . . . it is a historic event that will usher a new era of co-operation and friendship with India. Having resolved the most difficult and outstanding issue of water-sharing, we can have legitimate pride in our achievement. For me, it's a moment of high emotion. I hope, our people will consider the signing of this treaty a fair one.

H. D. Deva Gouda, Indian Prime Minister reciprocated:

> Mrs. Wazed's visit to India is a landmark event in Indo-Bangladesh relations, which has opened the way to wider and deeper co-operation between the two countries.

Making a suo moto statement in the Lok Sabha, he said:

It was a fitting tribute to the special quality of relations between the two neighbours and the spirit of brotherhood would lead to a new era.

Other Reactions

Atal Behari Vajpayee, the leader of the opposition in Lok Sabha (a former Foreign Minister and future Prime Minister), welcoming the Treaty said 'I hope that the national interests of both countries have been safeguarded'. Jyoti Basu, Chief Minister of West Bengal, who was the architect of the Treaty, said:

> The pact which has benefited us and will no doubt benefit Bangladesh would not be without its rewards. To our advantage, the option of the use of Chittagong port by our industrialists has opened up, significantly so, in the context of the State's plans for industrial rejuvenation. No longer will we be in a state of uncertainty over the quantum of water from Farakka. . . . The guarantees (on the allocation of the Ganga water), provided for the first time in such an agreement, should resolve outstanding problems. We too had our experts and those from the Centre when the pact was finalized. For the first time, India had been assured of a minimum of 40,000 cusecs of the Ganga waters in seven of 15 ten-day periods during the loan season. Only once had the State enjoyed this privilege in the past 40 years.

Mr. Basu was particularly hopeful about the proposed Sankosh project in Bhutan, aimed at providing additional 12,000 cusecs of water daily to West Bengal. The project was to be included in India's Ninth Five-Year Plan. He regretted that though a committee of the Chief Ministers of three upper riparian States – Uttar Pradesh, Bihar and West Bengal – was set up during Rajiv Gandhi's tenure to co-ordinate the Ganga's flow, ongoing pilferage by farmers in Uttar Pradesh and Bihar reduced the quantum reaching West Bengal.

A. B. A. Gani Khan Chaudhury, the Congress MP from Malda and a former Water Resources Minister in Government of India was the first to criticize the Treaty.

> It is an unrealistic Treaty. It has not only damaged the interests of Calcutta Port, but could also worsen bilateral relations between India and Bangladesh in future. Calcutta Port Trust will be badly affected, because it needs at least 40,000 cusecs of water to remain operational. Who will measure the quantum of water required to wash out the silt, deposited in the Hooghly basin? Now that the accord has been signed, its (Bangladesh's) representatives in the joint monitoring committee will always blame us of using more water.

Some Calcutta Port Trust officials complained:

> The Port's interests have been badly compromised. They will have to think of a deep draught port, well below Haldia, for the survival of Calcutta Port.

The gloom in the port and shipping circles in India was largely because of the clauses of water-sharing. They felt that the sharing on the basis of 10-day periods, especially in the acute lean-season, between March and April, would aggravate rather than halt the progressive silting of the Hooghly and reduce its navigability.

> In the two cycles of 10-day periods in the crucial month of April, Calcutta port area will get from the Farakka Barrage between 25,000 and 28,000 cusecs, which is too low a head-water flow to flush out silt to the sea. The agreement in no way reverses the process of deterioration of the Hooghly. Heavy siltation will increase the intensity and frequency of

> tidal bores, which will seriously impede navigation. Fall in draught may render the port's 240 million rupee new container terminal inoperative in a decade.

Debesh Mukherjee, the first and former General Manager of the Farakka Barrage Project questioned the sharing formula. He remarked;

> The average data on the water-flow does not reflect the ground reality. Flow of water varies from day to day. Under the agreement, the average flow in April has been shown to be between 60,992 and 63,180 cusecs, whereas the actual average flow during the month for the past decade has been about 54,000 cusecs. It would have been somewhat proper if the average flow had been arrived at on the basis of data of the past decade rather than the past 40 years. Naturally, the basis for the sharing formula is flawed as also the quantum. Calcutta will get much less than what has been stated in the agreement, as the take-off on the upstream, especially in Uttar Pradesh and Bihar, has been growing fast in recent years.

Reactions in Bangladesh

In Bangladesh too, **r**eactions to the Treaty were varied, as in India. The leaders of the Awami League which came to power were expectedly euphoric.

> The agreement is yet another feather in Sheikh Hasina's cap. Nothing could have been more wonderful and better-timed than this. This is the best that could happen to Bangladesh.

A professor of Dhaka University, Ainun Nishat was on a different plank.

> The water available at Farakka is the residue left out, after utilization in upper reaches, [which] ... is India's own affair, provided the interests of Bangladesh did not suffer.... The water made available to Bangladesh should be utilized judiciously, for the protection of environment and its uplift.... The upper riparian country would be responsible for gradual increase of withdrawal in the upper reaches of the river". [Translated from Bengali]

Experts as well as common people felt what the manner in which Jyoti Basu and his Finance Minister, Dr. Asim Dasgupta agreed to a 30-year treaty was rather odd, because they thought, India would go in for a short-term agreement for two to three years. A dramatic change in their stance surprised them. It was also intriguing that India's Ministry of Surface Transport, Calcutta Port Trust, Central Water Commission, Central Water and Power Research Station and Farakka Barrage Project Authority as well as the provinces of Bihar and Uttar Pradesh were kept in the dark and not invited to the signing ceremony, unlike in the function of signing the short-term agreement of 1975.

In short, many people, particularly politicians in power in both the countries, welcomed the treaty but opposition parties voiced against the Treaty. India's Bharatiya Janata Party organized a huge rally of nearly a million people from West Bengal and adjacent States at Farakka.

After the Treaty (1997 to 2001)

Immediately after the signing of the Treaty, the procedures for inspection and monitoring of water-sharing, measurements of releases to Bangladesh, India's withdrawals through the feeder canal and flow arrivals at Hardinge Bridge were required to be instituted, for which the joint committee met in New Delhi on 21st December 1996. In this meeting, it was decided to set up observation teams at suitable sites near the Farakka Barrage and the Hardinge Bridge, to work out a method of functioning of the joint committee and submission of daily reports etc. It was also decided that in the lean season, joint teams would measure the discharge in the Ganga downstream and in the feeder canal from eight in the morning to 12 noon and inform the Barrage authorities about the quantum of releases to be made in two directions; they would then operate the barrage and the regulator gates as per the schedule and release water, accordingly. The records would be transmitted everyday in the prescribed format. The same procedure would be followed at the Hardinge Bridge site at Bangladesh.

The implementation of the Treaty started from 1st January 1997. A four-member first observation team from Bangladesh was stationed at Farakka from 1st January to 31st May, that year. Along with the Indian team, joint observation of the Ganga downstream and of canal started. The flows were recorded, every day and gauge observations were taken every 4 h, day and night. Water was released thereafter from 1400 to 1800 h every day in the Ganga and the feeder canal by operating the barrage gates. India's observation team, stationed at Bheramara in Bangladesh and along with the Bangladesh team, they began joint observations in the Padma, upstream of the Hardinge Bridge. Based on field observations, the discharge in the river was computed at both the places and the data were transmitted to various departments as per guidelines.

The lean season discharge, available in the Ganga in 1997 fell below 50,000 cusecs in 1st week of April, necessitating invocation of emergency clause of the Article II (iii) of the Treaty.

The matter was discussed in New Delhi and in Dhaka soon afterward. It was jointly decided that the minimum flow to either side would not go below 15,000 cusecs. Irrespective of arrivals at Farakka and that there would not be any adjustments of flows to either side on account of this arrangement except to the extent, dictated by the gate operations.

The sudden fall in discharge in the feeder canal, from 35,000 cusecs in the end of one 10-day period to 15,000 cusecs, or less, in the beginning of next 10-day period was referred to the Joint Committee. If such falling flows persisted, it would have jeopardized the safety of the unlined earthen channel by causing bank slips. India pointed out that the feeder canal, being earthen, could not be subjected to such sudden and rapid fluctuations of flow. Such low levels should be gradual, particularly at the falling stage. As a result, lesser discharge would be released to either side, in their turn of getting 35,000 cusecs. After discussions, both sides agreed to modify operation and to suitably adjust the shortfall.

Table 10.9 Variation of discharge in the dry season of 2001 in the Ganga

Year and month	Available discharge variation	Anticipated discharge as per Annexure-II (cumecs)	Approx. percentage shortfall/excess (–)/(+)
2001 January	3,270–2,490	3,040–2,550	(+)3.04
February	2,470–1,760	2,440–2,240	(–)9.62
March	2,010–1,490	2,110–1,830	(–)11.42
April	1,690–1,490	1,790–1,720	(–)9.40
May	1,610–3,450	1,910–2,320	(+)19.62

As mentioned, year 1997 was one of the driest years and the Ganga's discharge on 30th March, that year, came down as low as about 46,000 cusecs. Two 10-daily periods from 21st to 31st March and from 1st to 10th April bore the brunt of low discharge, which had to be shared by the two countries. In fact, the shortage continued for most part of the sharing period of lean season, from 1st January to 31st May. Against the anticipated flow, varying from 74,000 to 65,000 cusecs in March, the available flow varied from 66,000 to 53,000 cusecs. Similarly, against the anticipated flow, varying from 63,000 and 61,000 cusecs in April, the available flow varied from 64,000 to 50,000 cusecs.

From 1998 to 2000, the Ganga had sufficient flow at Farakka; no difficulty was faced in these three years to release water as per the sharing ratio. In those years, the available flow in March varied from 85,000 to 69,000 cusecs against the anticipated flow between 74,000 and 65,000 cusecs. These were much higher than anticipated flow for the entire lean period.

In 2001, scarcity returned, reducing the discharge rapidly from January onward. The discharge variations in lean-season months of 2001 are shown in Table 10.9.

The minimum discharge, recorded at Farakka was 1485 cumecs on 15th April 2001, against the anticipated discharge of 1,773 cumecs. However, the discharge did not fall below 50,000 cusecs (1,416 cumecs) on any day as in 1997. Nevertheless, Calcutta Port faced siltation and less of draught in the navigation channel.

The present treaty will be valid until 2026 and its overall effect is anybody's guess but as morning shows the day, its impact in five years since 1997 when it was signed, has been from bad to worse. A wide and healthy navigation channel from Farakka to Haldia and the future of Calcutta Port would be in jeopardy, unless the flow, available at Farakka, is augmented and India's due share of 40,000 cusecs is not allowed to pass through the feeder canal into the Bhagirathi-Hooghly in near future.

Diversions from Farakka Barrage

In 2009, some 32 years have passed since the commissioning of Farakka Barrage in 1977 and billions of cusecs of the Ganga water have flown through the feeder canal and the Bhagirathi. Its moribund channel and the tidal channel of the Hooghly have been somewhat rejuvenated. Calcutta Port and the city got a fresh lease of life following voluminous flow of sweet water. Much less than the required and agreed quantity of 40,000 cusecs did pass, which was not enough to restore the navigation channel to the 1935 condition. The overall effect of letting in the Ganga water into the Bhagirathi-Hooghly navigation channel from 1978 to 2000, as against that of 1975, can be seen from the records of the Calcutta Port Trust, as summed up below, in four periods.

i) Period from 1978 to 1982, covered by the 1977 agreement,
ii) Period from 1983 to 1988, covered by the MOUs of 1982 and 1985,
iii) Period from 1989 to 1996, covered by no. agreement, MOU or Treaty, and
v) Period from 1997 to 2000, under the 30-year Treaty of 1996.

The navigation channel can be divided into six parts:

i) Ahiron to Berhampur-108 km (upper reach of the Bhagirathi),
ii) Berhampur to Nabadweep-122 km (lower reach of the Bhagirathi),
iii) Nabadweep to Tribeni-82 km (upper tidal zone of the Hooghly),
iv) Triveni to Kashipur (Calcutta Port area)-63 km (lower tidal zone of the Hooghly
v) Kashipur to Hooghly Point-63 km (upper estuary of the Hooghly), and
vi) Hooghly Point to Sagar Island-84 km (lower estuary of the Hooghly).

An index plan of the Bhagirathi-Hooghly is shown in Fig. 10.11. The effect of the upland discharge on the two reaches of the Bhagirathi in terms of the average Hydraulic Mean Depth (H.M.D), its cubic capacity and the percent variation in different years from 1975 (pre-barrage period) is shown in Table 10.10.

The table shows that the effect of upland discharge on the upper reach of the Bhagirathi is far better than in the lower reach. The average depth increased by

Table 10.10 Effect of Ganga discharge on the river Bhagirathi at dominant stage level

	Upper reach (108 km) (Ahiron to Berhampore)				Lower reach (122 km) (Berhampore to Nabadwip)			
Year	HMD (average) (m)	Percentage variation (+)/(–) w.r.t.1975	Cubic capacity (post-monsoon) (10^6 m^3)	Percentage variation (+)/(–) w.r.t.1975	HMD (average) (m)	Percentage variation	Cubic capacity (post monsoon) ($10^6 m^3$)	Percentage variation (+)/(–) w.r.t. 1975
1	2	3	4	5	6	7	8	9
1975	4.37	–	98.20	–	5.10	–	187.20	–
1982	5.92	(+)35.50	114.40	(+)16.50	4.85	(–)4.90	190.00	(+)1.50
1992	5.49	(+)25.60	128.00	(+)30.30	5.07	(–)0.59	199.60	(+)6.62
1996	6.09	(+)39.40	140.90	(+)43.50	5.15	(+)1.00	192.60	(+)2.88
1998	5.63	(+)28.80	129.20	(+)31.60	5.10	0.00	194.00	(+)3.63

more than 39% up to 1996 and thereafter, fell to about 29% in 1998. The cubic capacity increased by more than 43% in 1996 and thereafter, fell to about 32% in 1998. However, in the lower reach the effect of discharge has been less. The average depth increased by about 1% up to 1996 and thereafter, remained same. The gradual reduction of depth from 1996 could be due to the effect of the Treaty, under which the flow has been fluctuating every 10-day in the lean season. The change in cubic capacity in the lower reach was not significant.

The impact of upland discharge from Farakka on the third reach of the river (upper tidal reach of the Hooghly), in terms of its cubic capacity in both high and low water level is shown in Table 10.11.

The table shows that the condition of the Hooghly reach from Nabadweep to Triveni had been deteriorating in pre-barrage days. The analysis of cubic capacity shows that it decreased from 157 to 148 million cubic meters at High Water Level (HWL) between 1974 and 1975, but in spite of induction of upland discharge of 40,000 cusecs from April 1975 and 1977, the reach did not improve. The cubic capacity showed decline by 8–10% at high and low water levels. Improvement was not expected so soon, as the silt load that was moving down, did not have enough time to move further down and get deposited in this reach. Had there been sufficient discharge of 40,000 cusecs for a longer period, the silt load could move further down gradually, leaving the Port area to the lower estuary region. This did not happen owing to fall of lean-season discharge from 1978 as per the previous year's agreement. A part of the silt load, following the scouring of the Bhagirathi bed, had also deposited in this reach. This process continued up to 1982 and thereafter, as shown in the table. Though the condition improved in 1987 and 1996 over the earlier years, it could never be even that of pre-barrage days of 1975. The improvement was due to the creation of silt-trap zones by yearly dredging of about one

Table 10.11 Effect of Ganga discharge on the upper tidal compartment of the Hooghly (Nabadwip to Triveni)

	Cubic capacity (10^6 m^3)				
Year	H.W.L.	Percentage variation w.r.t. 1975 (+)/(–)	L.W.L.	Percentage variation w.r.t 1975 (+)/(–)	Remarks
1	2	3	4	5	6
1974	157.0	–	134.0	–	Overall adverse effect on the reach.
1975	148.0	–	127.0	–	
1977	136.0	(–) 8.10	115.0	(–)9.45	
1982	124.0	(–)16.20	105.0	(–)17.30	
1987	135.0	(–)8.80	114.0	(–)10.20	
1992	133.0	(–)10.10	114.0	(–)10.20	
1996	142.0	(–)4.05	120.0	(–)5.50	
1997	133.0	(–)10.10 (–6.30)	113.0	(–)11.0 (–5.80)	Further adverse effect
1998	132.0	(–)8.10 (–7.0)	112.0	(–)11.80 (–6.70)	

million cubic metres, near Santipur and at Balagarh below Kalna between 1980 and 1987. The island in the river near Balagarh rose by more than five metres with the dredged spoil. This place has since been selected for the site of a thermal power station.

From 1997, the river's capacity in high and low water-levels deteriorated further, as the cubic capacity reduced by 6% to 8% of the 1996 capacity, in the aftermath of the Treaty.

It is seen in the above table that the upper tidal reach of the Hooghly from Nabadweep to Triveni was silting up, leading to gradual rise of the river-bed over that in pre-barrage days. The navigable depth also gradually diminished. The upland discharge from Farakka did not improve this reach.

The table also shows the effect of upland discharge on the fourth and fifth reaches, i.e., the lower tidal reach and the upper estuary of the Hooghly-Triveni to the Hooghly Point in terms of cubic capacity variation at mean-tide level (MTL), which determines navigation depths over bars in lean season, the frequency of bores round the year and salinity variation in the lean season. Table 10.12 below shows that the upland discharge from Farakka had some positive effects on the reach between Triveni and Kashipur, upstream of Calcutta Port area up to 1977 when 40,000 cusecs were diverted into the river.

From 1978 water was diverted in the lean season as per the agreement and no improvement was noticed. In fact, the cubic capacity started falling since and continued up to 1996. From 1997, the capacity fell further since the last available records up to 1999. Thus, the limited upland flow could not improve this reach of the river. No dredging has so far been done in this reach but extensive dredging with spoil

Table 10.12 Cubic capacity variation in the river Hooghly between Triveni and Hooghly point in post-monsoon period at Mean Tide Level (MTL)

	Triveni to Cossipore (Calcutta port area)		Cossipore to Hooghly point		
Year	Cubic capacity ($10^6 m^3$)	Percentage variation w.r.t. 1975 (+)/(–)	Cubic capacity ($10^6 m^3$)	Percentage variation w.r.t. 1975 (+)/(–)	Remarks
1	2	3	4	5	6
1975	152.0	–	498.0	–	Before Agreement
1976	152.0	Nil	515.0	(–)3.43	
1977	154.0	(–)1.32	521.0	(+)4.62	
1982	152.0	Nil	526.0	(+)5.62	After Agreement
1987	151.0	(–)0.70	545.0	(+)9.44	
1992	148.0	(–)2.63	533.0	(+)7.03	No Agreement
1996	150.0	(–)1.32	533.0	(+)7.03	
1997	148.0	(–)2.63	540.0	(+)8.43	After Treaty
1998	145.0	(–)4.61	558.0	(+)12.05	
1999	144.0	(–)5.26	543.0	(+)9.04	

disposal over land at suitable locations was absolutely necessary to keep the channel silt-free. If 40,000 cusecs of water were released from 1976 continuously, the reach would have improved and become silt-free. Dredging can be done, even now, to maintain the depth of the channel.

The river reach from Kashipur to the Hooghly Point in the immediate downstream vicinity of Calcutta Port area substantially improved after the induction of upland discharge from Farakka. The cubic capacity of the reach increased steadily since 1976, as can be seen from positive percent variations because of increased tidal influence added with the velocity of upland discharge in this reach. The silt-load mostly remains mobile, not getting deposited. The Port authority resorted to continuous dredging to keep the navigation channel silt-free, although its quantum has been reduced substantially from 1975, as seen in Table 10.13. The percent reduction of dredging is varying, as per requirement; still the improvement is substantial.

In some of the years, e.g. 1982–1983, 1986–1987, 1996–1997 and 1998–1999 and some other years, not mentioned in the table, dredging was nominal, or disturbed following break-down of port dredgers. Mean navigable depths over the bars in the lean season, from January to May, every year and over the crossings have increased substantially after the induction of upland discharge, as seen in Table 10.14.

The table shows the increases in mean navigable depths over six bars below Calcutta Port area in the lean season since 1975; percent increase in depth was as under:

(i) Panchpara 13–32%
(ii) Sankrail 40–101%
(iii) Lower Munikhali 47–84%
(iv) Pirsareng 5–36%

Table 10.13 Quantum of dredging in the Hooghly river from port area to Hooghly point

Year	Quantity of dredging (10^6 M^3)	Percentage variation w.r.t. 1975–1976 (+) or (–)	Year	Quantity of dredging (10^6 M^3)	Percentage variation w.r.t. 1975–1976 (+) or (–)
1	2	3	4	5	6
1972–1973	1.92	–	1986–1987	0.28	(–)75.0
1973–1974	2.02	–	1987–1988	0.56	(–)50.0
1974–1975	1.12	–	1991–1992	0.75	(–)33.0
1975–1976	1.43	–	1992–1993	0.95	(–)15.20
1976–1977	0.88	(–)21.40	1995–1996	0.32	(–)71.40
1977–1978	0.84	(–)25.0	1996–1997	0.06	(–)94.60
1981–1982	0.46	(–)58.90	1997–1998	0.30	(–)73.20
1982–1983	0.21	(–)81.30	1998–1999	0.09	(–)92.0

Table 10.14 Mean navigable depths over six different bars below Calcutta port during lean season

Year	Panchpara	Sankrail	Lower Munikhali	Pirsareng	Poojali	Moyapur
1	2	3	4	5	6	7
1974	5.20	4.99	6.11	6.27	5.52	3.91
1975	4.80	4.71	5.18	6.33	5.24	4.24
1976	5.48	5.77	6.72	6.45	6.00	4.18
1977	5.42	6.58	7.61	6.65	5.77	4.02
1982	6.33	8.27	8.64	7.69	6.68	4.38
1987	6.09	8.86	9.43	8.13	7.55	4.20
1992	6.23	8.34	9.09	7.76	5.74	4.39
1996	6.00	8.35	9.52	8.23	6.54	4.57
1997	6.27	8.68	9.32	8.06	6.13	4.55
1998	6.35	9.42	9.24	7.99	7.15	5.24
1999	6.17	9.46	9.17	8.58	6.26	5.07

(v) Poojali 10–44%, and
(vi) Moyapur 8–24%

Before 1975, all the bars below Calcutta up to the Hooghly Point needed regular, annual maintenance dredging of varying quantity, for movement of ships. In 1976 and 1977, the quantum of dredging was substantially reduced. In 1976, lower Munikhali, Pirsareng and Poojali bars did not require any dredging; from next year, Sankrail also needed no dredging. From 1978, all these bars except Moyapur did not require any dredging. The upland discharge had maximum positive effect on Sankrail and lower Munikhali bars, but compared to the year 1996, most of the bars except Sankrail have considerably deteriorated.

The mean navigable depths (MND) over other five bars up to the Hooghly Point are shown in Table 10.15.

Table 10.15 shows that none of the lower bars, except Roypur has improved much after upland discharge from Farakka, despite being dredged continuously. Instead, deterioration of Ninan and Eastern Ghat bars was faster since 1997.

The depth over the bars is utilized for calculation of draughts of ships, navigating to and from Calcutta by Calcutta Port Trust. Table 10.16 shows the governing depths, available to Calcutta Port for movement of ships, round the year. Records from November 1984 are shown in Table 10.16.

The table shows that navigable depths in the port area were falling gradually. The depth of 3.5–4 m, obtaining for more than 150 days on an average before 1989–1990 reduced thereafter and from 1995–1996, this depth was not available below Calcutta, even for a day. The navigable depths gradually reduced to less than 3 m for a long time since 1994–1995. The normal available depth below Calcutta was 3–3.5 m only.

Tidal bores in the Hooghly, especially in Calcutta Port area before 1975, was another impediment to smooth navigation. Because of shallowness and restrictions

Table 10.15 Mean navigable depths over five different bars below Calcutta up to Hooghly point during lean season

Year	Roypur	Phalta	Ninan	Nurpur	Eastern gut
1	2	3	4	5	6
1974	4.40	3.50	4.40	3.90	4.35
1975	4.70	4.40	5.35	4.25	4.15
1976	4.30	4.00	4.35	3.70	4.60
1977	4.80	3.80	4.50	4.00	4.20
1982	4.90	4.65	5.00	4.35	3.75
1987	5.00	3.90	3.85	3.35	3.50
1992	5.05	3.60	4.15	3.80	3.75
1996	4.50	4.40	5.20	4.00	3.65
1997	4.55	4.35	4.95	3.80	2.50
1998	4.90	4.15	4.50	4.70	3.50
1999	5.40	4.75	4.10	3.75	3.25

Table 10.16 Available mean depth in days for ships navigating the port area round the year

Year (July–June)	Navigable depth (m) <3.0 m	Navigable depth (m) 3.0–3.50 m	Navigable depth (m) 3.51–4.0 m
1	2	3	4
1984–1985	17	194	154
1985–1986	31	181	153
1986–1987	36	206	123
1987–1988	152	214	–
1988–1989	36	268	61
1989–1990	3	209	153
1990–1991	15	228	122
1991–1992	34	332	–
1992–1993	91	243	31
1993–1994	20	253	92
1994–1995	118	234	13
1995–1996	224	141	–
1996–1997	184	181	–
1997–1998	132	233	–
1998–1999	127	238	–

on the waterway, the tides from the sea dissipate their energy in forming a wave with a high column of water and moving upstream. In the Hooghly, they rise two to three metres high and hazard the movement of ships and damage jetties, mooring bits, sea-walls etc. Few river estuaries in the world experience such phenomena. Before the barrage came up, the Hooghly used to have tidal bores of varying intensity, throughout the year. Afterward, the frequency of bore tides came down because of continuous upland flow, as shown in Table 10.17. The percentage of their occurrence fell to five after the barrage was commissioned from 50 before it.

Table 10.17 Occurrence of Bore Tides in the Hooghly river round the year

	January to June – 181 days		July to December – 184 days	
Year	No. of days	Percentage occurrence	No. of days	Percentage occurrence
1	2	3	4	5
1974	88	49	51	28
1975	74	41	70	38
1976	90	50	61	33
1977	79	44	53	29
1982	24	13	27	15
1987	23	13	13	7
1992	33	18	25	14
1996	10	6	7	4
1997	22	12	5	3
1998	11	6	6	3
1999	9	5	–	–

The effect of upland discharge in the lower estuary of the Hooghly, i.e., between the Hooghly Point and Sagar island was minimal, as tides were quite high and the upland discharge insignificant. millions of cubic metre of water moved up and down along with huge volume of silt load, lending dynamism to the river. The discharge of 40,000 cusecs, or less, does not much affect the river morphology in this reach. The width of the river also varies from 10 km to about 25 km. Therefore, the huge volume of silt-load moving with the tides oscillates and gets deposited in the bed in a favourable environment. The upland discharge helps this process, as the silt load cannot push upland.

As sea-water is saline, flow tides push it inland, over the estuary and the hinterland. Fresh water coming downstream interacts with this saline water and enhances siltation. Sea-water, being heavier than sweet water, moves near the bed and the mingling of two waters creates some associated problems.

Before the barrage in 1975, there was no upland discharge in the lean season. The saline water from sea used to intrude up to as far as Naihati, some 50 km north of Calcutta Port. With induction of upland discharge from 1975 and a perennial flow even in lean season, saline water got mixed with the sweet water upstream and shed some salinity below Calcutta to near about Achipur, about 30 km downstream. Its movement varies from year to year, depending on availability of lean season flow and monsoon discharges from upstream. The longitudinal variation of maximum salinity in 1980, 1987, 1992, 1997 and 1999, i.e., after the barrage came up as against the situation in 1975 (pre-barrage) is shown in Fig. 10.12.

The figure shows that the potable limit of salinity (0.20 ppt) of the Hooghly water extended to about 50 km upstream of Kolkata in 1975; it came down near Budge Budge in 1980 and further down to the reach between Achipur and Moyapur from 1996 to 1999. At the Hooghly Point, the salinity is about 0.5 ppt, at Diamond Harbour about 1.5 ppt and at Haldia 10 ppt. The drafts in the Hooghly depend on

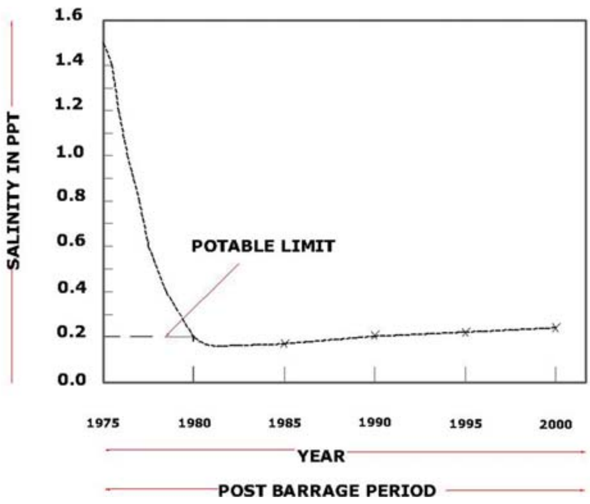

Fig. 10.12 Salinity level of Hooghly water at Palta

upland discharge, fluctuations in water-level owing to flow and ebb-tide and on the condition of the governing bars. In olden days, the river up to Calcutta Port area was navigable in the following periods.

(I) From June to October at high water springs by vessels up to 8.7 m (28.60 feet) draught and at high water neaps by vessels up to 8 m (26 feet) draught.
(II) From October to June by vessels between 6.70 m (22 feet) and 8.20 m (26.90 feet) draught.

Before the construction of the Barrage, this draught had fallen to even below 6 m in both monsoon and other months owing to siltation in the bed and governing bars. Afterward, navigability improved and even 8-m draught vessels were coming to the Port with minimum dredging of the channel. However, this situation did not last long and navigability declined since 1997. Presently, it has become difficult even for 7-m draught vessels to visit Calcutta Port in the lean season, in spite of intensive dredging at vulnerable bars and crossing up to the Sagar Island. This is mainly due to the effect of the 1996 Treaty, under the discharge has been fluctuating from as low as 10,000–15,000 and 35,000 cusecs in the lean season. Gradual decline of the navigational channel of the Bhagirathi-Hooghly was noticed from 1997 and therefore, can be attributed to the fault-lines of the 1996 Treaty.

This is another reason for lesser number of ships coming to Calcutta Port. All over the world, ships had changed enormously by the year of the Treaty. Low-draught and small capacity diesel and electric-driven ships were being replaced by electronically controlled, computer – aided ocean-going bulk-carriers of high draughts. Light cargoes were being carried in containers of various sizes and brought to riverine ports like Calcutta, obviating the need for low-draught vessels. Because of limitation of draught and difficulty of manœuvring larger ships in the narrowing waterway of the Hooghly, the Calcutta Port Trust constructed a deep-water modern dock at Haldia, a new industrial town near the outfall of the Hooghly, about 68 km below Kolkata on the right bank in East Midnapur district. The dock was opened in early 1977, where deep-draught vessels carrying bulk cargoes of oil, iron ore, coal, fertilizer etc. berth. Its index plan of Haldia dock is given in Fig. 10.13.

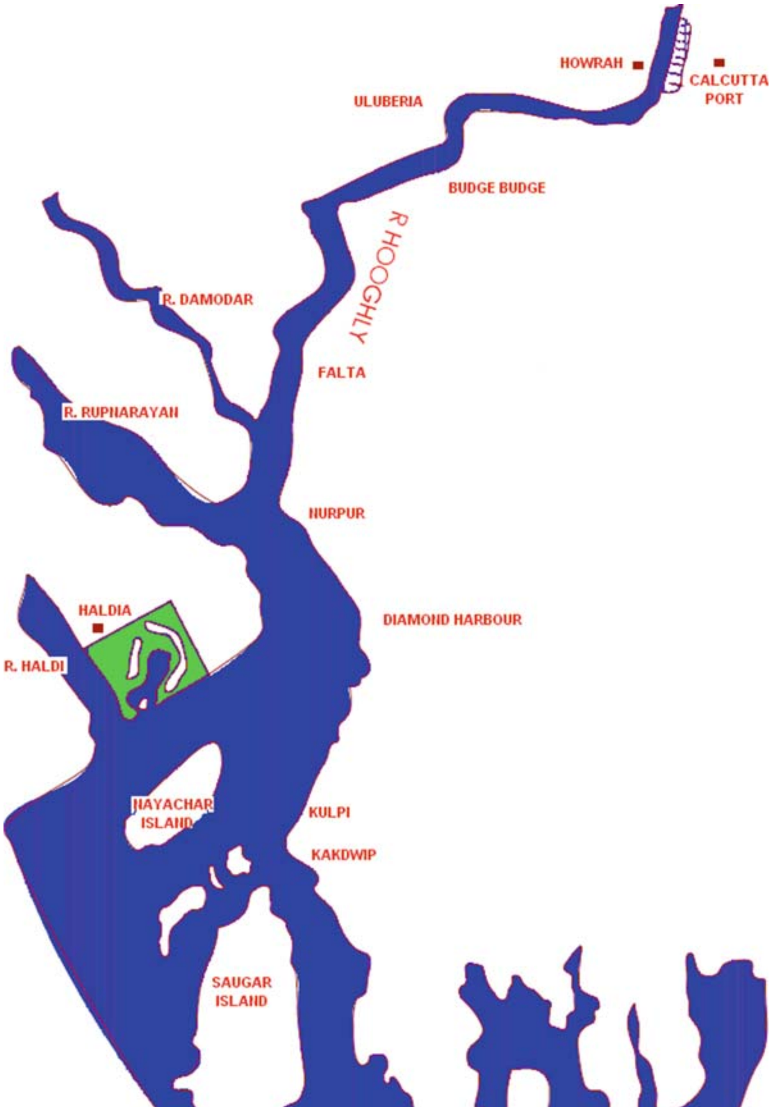

Fig. 10.13 Index plan of Haldia Dock

To facilitate movement of deep-draught, sea-going ships and prepare a scheme for improving the navigation channel, Calcutta Port Trust made certain studies. These were examined by experts in the University of Hamburg, Germany who recommended certain measures which, having been implemented, increased the navigational depth of the approach channel by 0.2–2 m (averaging 1 m) at different stretches. The scheme envisaged a number of river-regulatory measures, like construction of northern and southern guide-walls, along its two tips, supported by one at the southern tip of Nayachar island and capital dredging of the Jiggerkhali Flat and the Balari bar. Only the northern guide-wall has since been completed, but no significant improvement is noticed. Other elements of the scheme are now under way. The total number of ships handled by the Calcutta Port, before and after the Farakka Barrage is given in Table 10.18.

The volume of cargo, handled by Calcutta and Haldia docks from 1960 to 2000 is shown in the Table 10.19.

Table 10.18 Total number of ships handled by Calcutta port authority

Year	No. of ships handled at Calcutta dock	No. of ships handled at Haldia dock	Year	No. of ships handled at Calcutta dock	No. of ships handled at Haldia dock
1	2	3	1	2	3
1960–1961	1786	–	1992–1993	780	703
1964–1965	1807	–	1994–1995	782	781
1967–1968	1461	–	1995–1996	835	871
1970–1971	1070	–	1996–1997	901	1059
1974–1975	1039	–	1997–1998	1037	1365
1977–1978	963 (approx.)	30 (approx.)	1998–1999	1066	1347
1980–1981	846 (approx.)	300 (approx.)	1999–2000	983	1278
1985–1986	869	557			
1988–1989	840	591			

Table 10.19 Cargo traffic handled by Calcutta port authority (in million tons)

Year	Cargo handled at Calcutta dock	Cargo handled at Haldia dock	Year	Cargo handled at Calcutta dock	Cargo handled at Haldia dock
1	2	3	1	2	3
1960–1961	9.50	–	1992–1993	5.16	13.18
1964–1965	11.06	–	1994–1995	5.80	14.73
1967–1968	8.99	–	1995–1996	6.12	15.39
1970–1971	6.01	–	1996–1997	6.02	17.10
1974–1975	7.53	–	1997–1998	7.95	20.21
1977–1978	7.00 (approx.)	0.55 (approx.)	1998–1999	9.16	20.22
1980–1981	7.50	1.80 (approx.)	1999–2000	10.31	20.69
1985–1986	4.16	7.97			
1988–1989	4.34	9.69			

Tables 10.18 and 10.19 show that the number of ships and the volume of cargo carried by the two docks varied between 1960 and 1989, owing mainly to non-availability of sufficient upland discharge, causing siltation of the river-bed and to the global tendency to switch over to bigger and deep-draught vessels. The tables also show that the Haldia dock became very active after adoption of regulatory measures.

As stated, river regulatory measures have been partly put into effect below Diamond Harbour. The 2.8 km long northern guide-wall above Nayachar was completed in 1991–1992 to isolate the two distinct navigation channels on either side of the island and to stop inter-mixing of the tidal flow into them and prevent excessive siltation in Haldia port area. Dredging of the Jiggerkhali Fiat has also been done; but, the effect of the guide-wall was not felt and siltation in the channel continued. The flat has been extended inside the channel, blocking the channel completely. Thus, instead of giving any benefit, the northern guide-wall adversely affected the channel by creating a *cul-de-sac* and a slack zone in the Flat region. The alluvial and moving silt-load and the river-bed materials added with unpredicted geo-morphological changes in the estuary have aggravated the problem. Vessels bound for Calcutta Port are now plying on the eastern channel on the other side – the Rangafalla; those bound for Haldia port only use the western Haldia channel; this led to gradual improvement of the draft in Calcutta and Haldia port complexes, as shown in Table 10.20.

The table shows that the substantial improvement that has taken place in both Haldia and Calcutta ports has been due to fluctuations in upland discharges. Haldia port improved probably because of fluctuations in annual dredging in the estuary region.

Table 10.20 Draft available in Calcutta and Haldia port area

	Calcutta port		Haldia port	
Year	Above 7.0 m (in days)	Above 7.50 m (in days)	Above 8.0 m (in days)	Above 8.50 m (in days)
1	2	3	4	5
1960–1961	45	18	–	–
1964–1965	60	35	–	–
1972–1973	95	70	–	–
1981–1982	154	69	360	320
1984–1985	105	33	125	26
1988–1989	220	115	305	150
1992–1993	255	143	341	233
1994–1995	297	175	242	102
1995–1996	236	128	236	70
1996–1997	191	72	187	44
1997–1998	233	114	125	16
1998–1999	232	142	258	114
1999–2000	205	120	292	178

The ground-water level has risen too, benefitting agriculture on both sides of the river. Perennial flow raised surface and ground-water levels, facilitating irrigation and supply of drinking water to the population and industries on both sides. Before the barrage was built, crop yield on both sides suffered on account of water-shortage; this has changed dramatically with farmers raising multiple crops with water from the barrage.

Some envisaged secondary benefits of the Treaty have not accrued, e.g., reduction of bores and salinity, increase in the river's capacity etc. but some improvement in movement of vessels, handling of cargo in Calcutta port and reduction of bores and salinity has indeed occurred. After capital dredging of Jiggerkhali Flat, the Haldia channel is likely to reopen. When a hydro-electric project is built at Farakka, as envisaged, the project will be a complete success.

Chapter 11
What Went Wrong?

Reactions to the 1996 Treaty were diverse and both in praise and blame. Some people welcomed it and praised New Delhi and Dhaka for reaching a long-term accord at last. Others criticized it, alleging that it would harm the interests of both the countries, particularly of Calcutta Port and would not resuscitate the Hooghly-Bhagirathi, to the extent envisaged and the very purpose of the barrage would be defeated in the long run. Some questioned and suspected the role, played by Jyoti Basu and Dr. Asim Dasgupta, his Finance Minister and felt that they had sacrificed the interests of West Bengal and of India at large.

What is the truth behind these mixed and diverse reactions? In my view, there were certain questions and issues which the Treaty did not address, or did it perfunctorily; these are:

a) Were the problems of the two countries about the Ganga genuine?
b) Was it necessary to sign such a long-term (30-year) treaty in haste?
c) Were all major issues regarding the Ganga addressed in depth?
d) Were all affected parties consulted before inking the accord?
e) Was a long-term treaty really necessary?
f) Was the treaty technically sound and its implementation feasible?
g) Could national debates be held in two countries before signing the accord?

I venture to deal with these questions from my long association with the Farakka Barrage project, right from its foundation-laying to the conclusion of the 1996 Treaty and beyond (My answers below are in the same sequence, as above).

a) The unbridgeable differences between the two countries arose from (i) the stands, adopted by each; (ii) diverse opinions on the technical schemes for augmentation of the Ganga flow at Farakka; (iii) absence of stable governments in both the countries before and after the Treaty; (iv) India's policy of bilateralism toward Bangladesh; (v) India's refusal to involve Nepal as a third party to solve the augmentation problem.

New Delhi held that as the Ganga river flowed within the two countries, India and Bangladesh, both the issues of sharing of water and augmentation of flow were

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to be settled by these two countries through mutual discussions only. Bangladesh, on the other hand, wanted to involve Nepal, Bhutan and China on the issue and wanted to get moral support of those countries by pressurizing India to come to a solution in its favour on the sharing as well as augmentation issue. The proposals on augmentation of the flow also varied widely on the same ground, as India wanted to involve only the two countries between him and Bangladesh; whereas Bangladesh wanted to involve Nepal also on the issue on the ground that most of the tributaries of the Ganga on its upper reaches originated from Nepal. Both sides tried to find flaws on technical, environmental and financial aspects on other's scheme and were rigid on their respective stands. However, Bangladesh could realize the limitations of its own proposal, when the issue was discussed by both sides with Nepal at a later date, Nepal imposed certain preconditions and also expressed its reservations on the proposal of Bangladesh. Lastly, political instability during the period on each side prevented either side to come close and arrive at an agreed understanding on the issue. Bangladesh side was more disturbed and the instability in government gave rise to some sort of suspicion and mistrust amongst the common people of that country towards India.

The differences could not be resolved, as each side did not see merit in the other's stand and the necessity of the volume of water demanded. India thought, Bangladesh did not need so much water, as it had surplus run-off of rain-water as well as groundwater going waste and flowing into the sea, unused. On the contrary, Dhaka took the diversion of water from Farakka to resuscitate Calcutta Port as wastage, because this could not be achieved by diversion of the Ganga water alone. The exchange of data by either side was deemed a way of delaying a solution.

b) Both sides were indeed interested to resolve differences on the two issues and to clear the air of suspicion and mistrust that had developed after the death of Sheikh Mujibur Rahman. The excessive haste in two sides, especially of Jyoti Basu, West Bengal Chief Minister, was inexplicable by experts and observers and a mystery to common people of the State. Governments changed in both countries between March and June 1996; the Treaty was signed in December, that year. Mr. Basu took extra interest, visited Dhaka in November amid overwhelming reception (his parents had migrated from that country, when it was East Bengal) and paved the way for a return visit by Sheikh Hasina, the then premier, to New Delhi, next month to ink the Treaty. The two new governments in Dhaka and Delhi were in power for a few months only, when the Treaty was signed. Why this unseemly haste when differences persisted for years? The new governments should have gone through records of about last 50 years, proceedings, prototype data, ground reality/field condition, views of experts, concerned States, engineers and scientists who knew the problems of the affected and the beneficiaries of two countries before signing such a long-term accord. On the plea of time being short, these were not done. The issues were sensitive, had far-reaching effects and needed a thorough scrutiny. Jyoti Basu, being the Chief Minister of West Bengal since 1977 knew the problems, but the same cannot be said of Inida's Prime Minister, H. D. Deve Gowda and Bangladesh premier, Sheikh Hasina. Both appeared to have been guided by officers and inked the Treaty without understanding the implications of a 30-year accord in depth.

c) Many issues were complex, affecting the interests of two countries and therefore, deserved a closer look. For India, the major issue was resuscitation of the Bhagirathi-Hooghly channel and reactivation of Calcutta Port. The main aim of constructing barrages at Farakka and Jangipur was diversion of 40,000 cusecs of the Ganga water into the channel, which would restore it to 1935 condition. If it was fulfilled, loaded ships of 26 feet (7.93 m) draught could visit Calcutta Port, round the year, 28 feet (8.54 m) draught vessels at least 200 days and 29 feet (8.84 m) draught vessels at least 100 days, in a year. This did not come to pass because of restrictions under the 1977 agreement. Belying hopes of India, only 22-feet draught vessels could visit Calcutta Port, round the year from 1978 because of reduced water in the channel. Though the target of 40,000 cusecs was not reached, the activities of Calcutta Port could return to normal. The river was somewhat resuscitated, navigation improved with 2 m draught vessels coming to the port. As the Ganga flows through Bihar and Uttar Pradesh, much of its catchment area is spread over these two large States; therefore, their present and future needs and of West Bengal should have received priority. Those of Nepal could also not be ignored; being a land-locked country, it has every right to use water of rivers, flowing through its territory.

Other issues before India were reduction of salinity, siltation and the frequency, intensity and the height of tidal bores in the port area, of the cost of dredging of the channel and the estuary and the maintenance of a navigation channel. Urgent issues before Bangladesh were the legitimate demand of water from a long and mighty river, originating in another country but flowing partly through it. On this depended navigation and agriculture, reduction of salinity and other environmental issues. Under international law, interests of a lower riparian country are to be safeguarded, while an upper riparian country develops itself. Bangladesh indeed suffered some ill-effects of diversion from the Farakka Barrage; its navigation, irrigation and water-supply to industries were all affected and the ecology degraded. These issues were of its national interest and should have been addressed by the accord.

d) In both the countries, many other affected parties were not consulted. In India, they were the Ministries of Surface Transport, of Water Resources and of External Affairs, Calcutta Port Trust, various departments of West Bengal, Bihar and Uttar Pradesh governments, various chambers of commerce and industries. In Bangladesh too, its ministries of water resources, irrigation and waterways, agriculture, public health and of foreign affairs were concerned but were not consulted.

Questions arise, why was the Treaty signed in so much haste and why vitally concerned government departments and organisations were not taken into confidence? A solution through another agreement was indeed overdue, but did not justify such haste and marginalisation of concerned parties. National interests and objectives of both countries were sacrificed. All these strengthen a suspicion that there was a hidden motive in two governments, collective or individual interests of the signatories that compelled both sides to ink the treaty, post-haste. There was some deeper thinking which was not divulged to the people of two countries, because it was more political than pragmatic. This was to demonstrate to their people that they could solve such an intractable problem so quickly, which eluded previous governments, formed by political opponents of the new parties in power in Dhaka and New Delhi.

e) Was such a long-term accord really necessary for either or both countries? It was intriguing that such a historic long-term treaty was signed after Jyoti Basu returned from a visit to Dhaka in November 1996 and publicly announced that a short-term agreement of two to three years' validity was in the offing. Not only opposition parties but other left parties in the coalition ministry that Mr. Basu headed, were taken aback when the treaty was found to be of 30 years' validity. Prime Minister Deve Gowda met Mr. Basu in New Delhi a day before the signing ceremony and convinced him about the merits of a long-term accord. A veteran of behind-the-door diplomacy, Mr. Basu was the kingpin in bringing the two countries together to resolve the issues and everything happened as he desired. Why did he lead India to ink such a treaty of dubious benefits without detailed examination of relevant data, particularly when it had no provision of augmenting the Ganga water flow at Farakka? This was strange and Mr. Basu did not give any clarification to the people through the media.

Bangladesh required more water than it agreed to in the Treaty. Its demand was 44,000 cusecs in the lean season, but as the Treaty was silent on augmentation, it had to remain content with its share of the Ganga water at Farakka. With more water, its problems of irrigation, navigation, salinity, fall in ground-water level and overall environmental decline etc. could have eased, or been arrested.

Seeking and reaching an understanding about augmentation needed more time; if this was not available, a short-term accord of two to five years' validity could be struck, but a 30-year Treaty bypassed this major issue, entailing sacrifice of basic interests of two countries. Expectedly, the Treaty invited far-reaching adverse effects in both sides.

f) As regards technical soundness and feasibility of the augmentation scheme, both sides depended heavily on technical experts. The JRC was active for two decades and kept all records, collected since 1948 and the JCE was also looking into the issue for long. The discharge of an alluvial river depends on many factors. Some of these are characteristics of the catchment area, human habitation, forest-cover, development of water-resources through irrigation and supply of drinking water, industries, erosion and siltation etc. Because of rapid rise in population in India, the surface features of catchment areas changed fast. New houses were built and more and more land came under the plough. New towns and industries came up, raising the demand for water for sundry purposes. Forests were cleared for meeting rising demands of fire-wood, furniture and building materials; this reduced rainfall and ground-water availability, caused erosion of banks, siltation in the river-bed and affected discharges in the river. Thus, any assumption of the volume of discharge over 30 years, based on average of past 40 years is bound to be technically unsound and go wrong. The quantum of flow, supposed to be available at Farakka, as given in Annexure-II was impractical, because it may go down in future. It could be true for a short period of two to five years, but may not be so for 30 years, because a lot of changes can occur meanwhile in the catchment area and new water resources projects may come up, requiring water for various activities. Thus, discharges in the Ganga will not remain static but in all probability, go down. It was unfortunate that the technical experts of India's Ministry of Water Resources and West Bengal government's irrigation and waterways directorate, who were associated with the Treaty either did not foresee these eventualities, or their views were not sought, or given due consideration.

Calculation of average discharge for 40 years (1949–1988) should be based on the maximum and minimum discharges of a number of years. If the figures for the minimum are for 15 years in a span of 40 years, the situation can recur in the next 30 years, i.e., the period of the Treaty. The discharges will drastically go, in three decades, much below those, stipulated in the Annexure-II. How would water-sharing materialise in those years of scarcity? Will the shares of India and Bangladesh be reduced and will these reductions be proportionate? The Treaty did not clarify this, but it specifically provided that the share of Bangladesh would never go below 80% of the quantity, as laid down in the Annexure. To keep Bangladesh unaffected in such crises, India would have to suffer and sacrifice her interests. For instance, if the flow at Farakka falls to 40,000 cusecs, India will get less than 10,000 cusecs as long as it lasts. In fact, on a day in 1980, the minimum discharge did come down to about 38,000 cusecs. Since 1976, on a day each in nine years– 1980, 1983–1985, 1988, 1992–1994 and 1997; the minimum discharges were less than 45,000 cusecs. The sharing formula in Annexure-II would have been difficult to apply in those years; there was no guideline in the Treaty. Such days are bound to recur in future and perhaps more often, as upper riparian States would continue to draw more water for diverse purposes. Though the Treaty provides for mutual consultation in the event of the flow at Farakka going below 50,000 cusecs in any 10-day period, it would have been better if an automatic response by the two sides was incorporated in it, because by the time, they consult each other, the climax of fallen discharge might have passed and some harm had been done. In fact, this happened in April 1997, four months after the Treaty came into effect. The flow at Farakka went down to about 46,000 cusecs, landing field engineers in a spin for release of water from the barrage. As stated, whenever one side got 35,000 cusecs in a 10-day period, the other side was to get only about 11,000 cusecs. The treaty gave no guarantee that a similar situation would not arise in future. The Ganga is an alluvial river; its bed and banks below the barrage and the feeder canal are made of very fine silt, silty clay, sand and sandy silt deposits with little shearing resistance to sudden changes in external forces. The soil is loose, porous, non-uniform and heterogeneous, owing to uneven level between the river and the ground-waters inside the bank-soil mass. Water may either moist the soil mass, or exit non-uniformly and damage the soil. This helps erosion of banks and the bed and causes bank-slips, which are frequent in the tidal reach where water-level always changes and fluctuates. In the Hooghly, this occurs twice a day, with flow and ebb tides.

In Annexure-II, the discharges in the Ganga and the feeder canal are shown as fluctuating in March and April. The flow in the canal reduces to the minimum from one 10-day period to the next to 6,820 cusecs from 21–31 March to 1–10 April and that in the Ganga reduces to 7,366 cusecs from April 1–10 to April 11–20. Thus, the total flow during this period of March 21 to April 20 varies from 64,688 to 62,633 cusecs, but these do not tally with the figures of prototype observations in several years. In some critical years, if the flow falls to about 45,000 cusecs, minimum 35,000 cusecs are to be released to one side, as per the Treaty, the other side gets only 10,000 cusecs, bringing down the discharge, instantly, by 25,000 cusecs from one 10-day period to the next. Even if the average flow is around 50,000 cusecs, a guaranteed discharge of 35,000 cusecs would flow to one side and only 15,000 cusecs to the other side, reducing the total flow by 20,000 cusecs in the next 10-day period. This abrupt fall will severely affect the canal-bed and the banks owing to sudden fall in external water-pressure, of the tractive force of flowing water and cause bank-slips, silt deposits on the bed, rendering the canal cross-section unstable. However, the Ganga being more wide than deep, the vertical difference owing to such falls in discharge would not be much and bank-slips would not be severe. As the canal is much narrower than the Ganga, vertical fluctuations would be appreciable and bank-slips and slides would be more severe. This occurred in 1997 and affected the banks of the canal in about 30 places, following big and small slips in March and April. Sharing of the Ganga water from 1977, as per the Treaty, actually increased siltation in the river-bed. The envisaged benefits did not accrue to the extent desired. The Bhagirathi-Hooghly did not receive 40,000 cusecs, round the year, from 1978. In the lean seasonpreviously, flow-tides carried huge silt-load which could only be reduced by maximum upland discharge. After 1977, water became almost silt-free and its scouring capacity reached the maximum. Tides were quite high in the lean season and a steady flow of 40,000 cusecs, round the year for at least five years, could degrade the river-bed gradually, to the desired extent. Expected benefits of Calcutta Port after the commissioning of the barrage included up and down movement of vessels of 7.93 m, or 26 feet, draught, round the year, of 8.54 m or 28 feet draught for 200 days and of 8.84 m, or 29 feet, for 100 days, but this was not achieved. Only vessels of 6.71 m or 22 feet draught, plied round the year until 1996; vessels of 8.54 m could not come to the port, even for a single day. The salinity of water, supplied to Kolkata and Howrah regions also, was not reduced, to the desired extent. Thus, although the barrage brought some benefits to the port, they were far less than those envisaged before the construction of the barrage.

The discharges in the lean season being much less than required, navigation did not improve much and *chars* emerged, particularly below Diamond Harbour. Navigation on the Haldia channel was blocked by silt and loaded ships could not ply through the Haldia channel now. The ships now pass through the Rangafalla channel, near Kulpi. The bores during flood-tides in Kolkata region continue to occur but less frequently than before the barrage, in about 50 days as against 120 days before. Unstable flows caused erosion of banks and left a huge volume of silt on the bed, making it unstable too. It has to be admitted, however, that although some envisaged benefits eluded, some were indeed achieved.

After the signing of the 1996 Treaty, siltation, salinity, bore tides, bank erosion etc. increased because of fluctuations in flows – 10 days less and 10 days more – in the lean season, the water current also varied. The silt-load that, entering the river, moves upward with flow-tide and is deposited in the bed cannot be wholly scoured.

During ebb-tide, it moves with reduced flow of sweet water. The combined ebb-flows diminish for 10 days, raising the bed and in the long run, may revert the river to pre-barrage condition. Owing to variable flows, the banks would become unstable and cause continuous bank-slips and consequent loss of land and increase of silt and would further raise the bed. Intensive dredging to keep up the navigation channel would be required as before, with prohibitive rise of cost. For disposal of spoils, more land would be required. Salinity would intrude toward land because of variable flows and spoil farmland, ground water and water for drinking and use in industries. Bore tides in the port area will also increase. The Treaty is technically unsound. The water-sharing ratio is not consistent with the basic theory of soil mechanics; frequent forward and backward movements of flow will not keep the soil static and stable in the banks and the bed. It will always remain under-stressed with inward or outward force like a tidal reach. This unnatural situation will destabilise the feeder canal and the reach of the parent river, the Ganga downstream and the Bhagirathi-Hooghly for decades to come. The reaches will never stabilise and return to the regime condition. Siltation and erosion can return if they are not properly maintained.

Water-sharing by properly operating gates of the barrage would be quite difficult. Many of these and the regulators have to be frequently raised and downed. Discharges in the Ganga and the Bhagirathi-Hooghly via the feeder canal fell up to end-April and increased thereafter. This arrangement was technically sounder and it became easier to implement the 1977 short-term accord and the 1982 MOUs. The barrage gates and the canal regulator were operated more easily than under the Treaty.

The Treaty was technically unsound from another aspect too. The earlier accords and three Agreement/MOUs of 1977, 1982 and 1985 calculated the flows, reaching Farakka on the basis of 75% availability from the data observed for 26 years – from 1948 to 1973, keeping a latitude of 25%, presumably in view of (a) variations of flows reaching Farakka, (b) dead storage in the river, (c) utilization by upper riparian states, and (d) maximum probable years of occurrence. However, the flow data between 1974 and 1977 were not taken into account for some objections by Bangladesh. The agreement and the MOUs rightly envisaged the variations of the flows for some obvious reasons. An increasing population needs more use of water. The Farakka barrage was constructed with a raised crest-level, higher than the deepest level of the river-bed by about 2–3 m.

Like a dam in the hilly region of a river, whose design provides one, a dead storage was deemed necessary, upstream of the barrage, by experts in the Agreement and the MOUs. The experts, who drafted these, kept in view the interests of upper riparian States of India and provided for 25% of water as reserve for their withdrawal and use. However, the Treaty of 1996 arrived at the volume of flow, reaching Farakka, as the average of the total for 40 years, from 1949 to 1988; for some unknown reason, the flows of 8 years – of 1948 and from 1989 to 1996 – was not taken into account. They took the total flow of the Ganga reaching Farakka; this was a technically erroneous decision. Every river flow varies and in the case of the Ganga, it was likely to be less in future. Both dead storage and the needs of the upper States were ignored; the full flow determined the sharing ratio. This was an incorrect

Table 11.1 Comparison of flow considered in Agreement of 1977, Treaty of 1996 and actual flow available at Farakka in 1988 and 1997

Period	Anticipated flow in 1977 (75%of the availability from 1948 to 1973) (cusecs)	Anticipated flow in 1977 (considering 100% availability) (cusecs)	Anticipated flow in 1996 as per Treaty (cusecs)	Actual flow available in 1988 (cusecs)	Actual flow available in 1997 (cusecs)
1	2	3	4	5	6
January 1–10	98,500	131,333	107,516	88,029	101,976
11–20	89,750	119,667	97,673	77,605	89,672
21–31	82,500	110,000	90,154	74,195	97,542
February 1–10	79,250	105,667	86,323	66,752	85,604
11–20	74,000	98,667	82,859	61,158	81,016
21–28/29	70,000	93,333	79,106	56,894	61,920
March 1–10	65,250	87,000	74,415	56,305	66,170
11–20	63,500	84,667	68,931	55,869	56,769
21–31	61,000	81,333	64,688	55,135	53,312
April 1–10	59,000	78,667	63,180	50,848	50,331
11–20	55,500	74,000	62,633	54,734	54,526
21–30	55,000	73,333	60,922	66,530	64,052
May 1–10	56,500	75,333	67,351	70,038	66,728
11–20	59,250	79,000	73,590	73,650	65,955
21–31	65,500	87,333	81,854	82,087	66,487

decision and India's interests were sacrificed. Besides, out of 40 years, from 1949 to 1988, there might have been some years of very high and some years of very low discharges which should have been excluded from determining the average and the maximum years of occurrence of predominant discharge should have been taken into account to arrive at a reasonable volume of flow. The earlier agreement and the MOUs took note of this but the 1996 accord did not.

The Treaty did not consider increasing the Ganga flow at Farakka in future, which was falling in the lean season, especially from February to April. A comparison of the actual flows reaching Farakka with those of the schedule of water-sharing at the barrage from January to May, as per the 1977 agreement, or the MOUs of 1982 and 1985, reveals the facts, as shown in Table 11.1.

The table shows that the actual discharge at Farakka in 1988 and 1997 were far less than the anticipated flow of 1977 and 1996, as recorded in the agreement and the Treaty. For instance, the actual flow of 1988, compared to that mentioned in 1977 accord was about 11.5% less in January, 18% less in February, 12% less in March but 1.50% and 23% more in April and May, respectively. From February to April, when the demand is highest, the flow reduces. The excess flow in April 1988 was due to sudden rise in the discharge in the last 10-daily period. Similarly, the actual flow at Farakka in 1997, compared to the flow, envisaged in the 1996 Treaty, was far less than the anticipated 100% flow, reaching Farakka in 1977, round the year. The actual flow is bound to gradually diminish in future owing to rising demand for the river-water; therefore, it was necessary to provide for augmenting the flow at Farakka in the Treaty. The 1977 agreement specifically provided for finding a solution to the long-term need of augmenting the flow of the Ganga in the dry season. The JRC was entrusted with carrying out investigations and study schemes, as submitted by either government, for finding a solution, acceptable to both sides. Previous governments were also seized with the problem and made specific provisions, although these could not materialise up to 1988 because of differences of views but the fact remained that both countries understood the problem, thoroughly. The 1996 Treaty did not provide for augmentation of flow at Farakka; it merely recognised the need for cooperation to find a solution. It could have at least envisaged a definite time-frame for an agreed solution, without which both countries are now suffering.

The issue of augmentation was separately discussed by India's Prime Minister and West Bengal Chief Minister, Jyoti Basu, particularly by diverting 13,000 cusecs from Sankosh river in Bhutan at a cost of 70,000 million rupees; but they felt, it was not feasible and impractical, because the link canal from the Sankosh river to the Ganga would have to pass through dense forests, numerous tea-gardens etc. for which environmental clearance may not be available. Besides, 13,000 cusecs, required in the lean season could be elusive; only about half of it could be guaranteed. Cost-wise, they would be prohibitive; one cusec of water through this canal could cost as much as 10 million rupees.

g) These lead to the inescapable conclusion that the Treaty was not well-drafted, well-timed and well-discussed at all levels before it was signed. Because it was a 30-year treaty and renewable thereafter, national debates were necessary in both countries before it was conceived. It should also have been discussed by national-level political parties, experts, engineers and scientists in related fields, the provincial governments of riparian countries and their concerned departments, the beneficiaries and implementing authorities. These were not done, perhaps deliberately and the Treaty was executed in post-haste, ignoring the genuine interests of both countries.

Chapter 12
Chronology of Events

An account of the gradual deterioration of the Bhagirathi-Hooghly, the expert opinions as regards deterioration of this river and also the Calcutta Port activities, events leading to the disputes and misunderstandings between the two countries, India and Bangladesh (earlier East Pakistan) on the sharing of the Ganga waters from the beginning, the meetings at technical as well as political levels, the political and administrative changes in two countries and developments according to the passage of time etc. can now be brought out in statements for better understanding. The statements have been prepared on five different topics as noted below:

1. Deterioration of the Bhagirathi-Hooghly.
2. Suggestions for resuscitation of the Bhagirathi-Hooghly.
   i) Before India's Independence.
   ii) After India's Independence.
   iii) Adverse views.
3. Construction of Farakka Barrage.
4. Negotiations on the sharing and augmentation of the Ganga water.
   i) With Pakistan (1947–1971).
   ii) With Bangladesh (1971–1977).
5. On the Agreement, Memorandum of Understandings (MOUs) and Treaty.

Deterioration of the Bhagirathi-Hooghly

Individual/Agency	Month/Year	Comments
Tavernier (Italian Traveller)	January 1666	Saw the mouth of the Bhagirathi by boat, closed by sand bank.
Halwell	1756	On way to Murshidabad by boat, was detained by shallows at Shantipur below the confluence of the Bhagirathi and the Jalangi.
Renell	1781	The Cossimbazar river (i.e. Bhagirathi) is almost dry from October to May and the Jalangi (although one of its streams runs the whole year) is, in some years, non-navigable in two or three of the driest months.

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Individual/Agency	Month/Year	Comments
Colebrook	1801	The Gorai and the Chandni were the only navigable channels throughout the dry season, the Bhagirathi and the Jalangi could not be relied upon for navigation (the Chandni and the Churni may be the same river).
H. Piddington, Member, Hooghly Commission, 1853–1854	1853	Most strenuous efforts should be made and every means used and every experiment tried to ensure a copious supply of water for as many months in the year as possible at the heads and along the courses of the three main feeders of the Hooghly
The Bengal Chamber of Commerce	1853	The most difficult and dangerous state of the navigation of the Hooghly, which threatens at no distant period to render access to the port of Calcutta altogether impracticable for any vessels but those of smallest tonnage, is not far off.
Major Long	1948 and 1954	The mouths of the Bhagirathi and the Jalangi remained un-navigable.
Capt. Sherwill	1857	The Bhagirathi, the Mathabhanga and the Jalangi are not navigable. The Gorai is becoming broader every year, its fierce current is rapidly cutting its banks and in a few years, it is likely to absorb the greater portion, if not all, of the water from the Poddah (Padma).
Prestige Franklin	1861	Both the Bhagirathi and the Jalangi mouths are cut off from the parent river, the Ganga for most part of the year. The government is anxious to keep the Mathabhanga mouth open so as to have a good water communication between the Hooghly and the Ganga in all seasons of the year.
Ferguson	1863	There was a good chance that the action of the Brahmaputra would send the Ganga down the Gorai, the upper Kumar (i.e. Mathabhanga) and the Chandra (east of the Gorai).
H. Leonard (Superintending Engineer, Public works Dept.	1865	It is difficult to come to any other conclusion than that the Hooghly must deteriorate, however slowly, considering the agencies at work on the river.
G. Robertson	1872	The condition of the Hooghly has been gradually deteriorating, day by day.
Vernon Harcourt	1896	The Hooghly is a fairly stable river, undergoing indeed considerable fluctuations in depth at some places, according to the seasons and the volume of freshets but free from any general deterioration in its condition between Calcutta and the sea. Unless some unexpected change of the course of the Ganga should occur, so as to deprive the Nadia rivers of their annual supply and thereby materially reduce the discharge of the Hooghly, or unless the occurrence of some seismic, or cyclonic disturbance should alter the existing conditions unfavourably, there is every prospect that provided the two obstructions in the river can be removed and some improvements effected in the estuary, the Hooghly will provide in the future a considerably better waterway between Calcutta and the sea than it has done in the past.

Individual/Agency	Month/Year	Comments
Committee, appointed by the Port Commissioners	1902	The Bhagirathi-Hooghly has gradually deteriorated from its confluence with the river Padma to Calcutta.
Major Hirst	1914–1915	The present regime of the river is wholly insecure and the forces controlling it are so powerful that any artificial interference would be futile and that the river has deteriorated to such an extent as to be a menace to the port of Calcutta.
H. G. Reaks (River Surveyor)	1919	In spite of the trade in Calcutta Port increasing substantially since 1830 because of the replacement of sailing vessels by tugs and steamers, provision for greater facilities for navigation in the river in the way of plans, buoys, marks, good information network etc. and also greater frequency of surveys, the general deterioration of the Hooghly continued.
Man Singh Committee	1952	Condition in the Hooghly between Nabadweep and Calcutta has deteriorated.

Suggestions etc. for Resuscitation of the Bhagirathi-Hooghly

i) Before India's Independence

Organization agency/government	Year	Observations
Govt. of India	1831	Vessels coming to Calcutta Port could avoid the silting Hooghly and use a ship canal up to the head of the Matla river, as recommended of by two committees in 1853 and 1863. A new port was constructed at Canning on the Matla with railway connection with Calcutta. Construction of jetties was completed and of warehouses commenced. The port was opened and used by a few vessels but owing to various reasons, mainly financial, the scheme was abandoned in 1866.
Calcutta Port Commissioners	1860–1910	Undertook small schemes, such as, diversion of tributaries, spurs and bundelling, dredging etc. were drawn and some of them executed for increasing the draft in the Hooghly.
Sir Arthur Cotton, British Engineer	1858	If additional water is thrown into the Hooghly and kept flowing down during the dry season, it might make just the difference needed to prevent the Hooghly from silting.
Stevenson-Moore Committee	1916–1919	Headwaters of Nadia rivers were silting; this would decrease the navigability of the Hooghly. It recommended diversion of the Ganga water.

Organization agency/government	Year	Observations
H. G. Reaks	1919	The Hooghly channels are capable of considerable improvement, provided the river is kept in a healthy condition by maintaining fresh water supply from Nadia rivers and their tidal volumes; on these two factors depends the existence of a satisfactory waterway for deep-drafted vessels to and from Calcutta Port.
Sir William Willcocks, British Engineer, in 'Restoration of Ancient Irrigation of Bengal'	1928	Suggested building a barrage below the head of Boral river for heading up water and generating flow through the Bhagirathi, the Jalangi, the Mathabhanga, the Gorai and the Boral to ensure overflow irrigation in the adjoining land of Bengal.
T. M. Oag, Deputy River Surveyor, CPC	1930	Recommended additional supply of water at the head of the Hooghly to prevent silting of the bed.
A. Webster, Chief Engineer, Calcutta Port	1946	Recommended construction of a barrage across the Ganga for diversion of 10,000 cusecs of water as well as dredging and river-training in lower reaches.
M/s. Rendel, Palmer and Triton, Consulting Engineering Company	1946–1947	Proposed a ship canal to link Calcutta Port with Diamond Harbour, lower down the Hooghly. Its construction was a feasible feat and no difficulties were envisaged beyond those, normally associated with such projects.

ii) After India's Independence

Individual/Committee etc.	Year	Observation
Man Singh Committee	1952	Condition of the Hooghly river between Nabadwip and Calcutta has deteriorated. Suggested additional supply of water at the head of the Hooghly and favoured construction of a barrage at Farakka for diversion of water.
S. C. Majumder, Chief Engineer Central Water and Power Commission in 'Ganga Barrage and the Bhagirathi-Hooghly river problems'	1953	The Bhagirathi now remains cut off from the Ganga except during flood and would have remained so in normal time but for flows from the western tributaries and tidal flushing in the lower reaches, assisted by the conservancy measures of the Calcutta Port. The Ganga Barrage Project, conceived at an estimated cost of Rs. 39.87 crores (398.7 million), aims to supply water perennially from the Ganga to the order of about 20,000 cusecs through the Bhagirathi for the benefit of the Calcutta Port.

Individual/Committee etc.	Year	Observation
Dr. I. W. Hensen, German engineer, in 'A Review of the problems of the port of Calcutta'	1957	(a) Long-term inter-connected changes have taken place in the Bhagirathi and the lower Hooghly, which have adversely affected the development of tides, the capacity of the Bhagirathi and the Hooghly, salinity, bores and the like. The discharge from the Ganga has decreased with the passage of time and the scouring effect of high freshets has decreased with time and will go down even more with further reduction of flushing. (b) The best and only technical solution is construction of a barrage across the Ganga at Farakka, which would stop long-term deterioration in the Bhagirathi-Hooghly and possibly lead to gradual improvement.
K. K. Framji, Chief Engineer, Ganga Basin Organisation in 'The Farakka Barrage Project: The fulfilment of a dream'	1975	The over 100-year delay in taking up the project barrage was never on account of any doubt about its usefulness, or importance but of unreasonable fear. Sir Arthur Cotton's plan was thwarted by the then governor of Bengal, Sir George Campbell. 'I was perhaps a little afraid of once letting in Sir Arthur Cotton and his schemes, for I did not know when we should get them out again.' Similarly, baseless fears of the possible adverse consequence of the irrigation and flood control interests in the areas downstream of the barrage in the then East Pakistan led to indefinite stalling of the project since 1951.

iii) Adverse Views

Expert/Agency	Year	Comments
Kapil Bhattacharya, Superintending Engineer, I & W Directorate Govt. of W. B. in 'Silting of Calcutta Port'	1961	The deterioration of the Hooghly was caused not by a natural decline of the river's headwater but after building dams on the Damodar and the Rupnarayan, the two of its western tributaries. He said, the Farakka Barrage, proposed on the Ganga under the pressure of misguided public opinion, will cause disaster in Bihar and West Bengal, because it was the wrong river to tackle to save Calcutta Port and resuscitate the Bhagirathi-Hooghly. It is the Rupnarayan which should be tackled. In spite of my warnings, the Damodar Valley Project has been implemented without taking into consideration flood-tides and tide-borne silts into the Runarayan and the lower Hooghly. As a result, the Calcutta Port has been killed and the main drainage channel (The Hooghly) . . . choked, causing repeated flood-havoc on an ever-increasing scale. If my warnings against Farakka Barrage are not heeded, people will have to suffer consequences.

Expert/Agency	Year	Comments
Prof. Arthur T. Ippen and Clarence F. Wicker (USA), engaged by Pakistan government in 'The Hooghly River Problem'	1962	They doubted, if flushing with fresh water will be beneficent and held that at least some of the observations, made of the Hooghly suggest the opposite. They thought, the sedimentation in the Hooghly was caused by a 'crucial variable', i.e., salinity. Some of their other conclusions were as under. Fresh water diversion into the Hooghly would not remove silt but is likely to attract more. The present dredging practices were contributing to silting in the Hooghly, requiring more dredging. It is unlikely that economic benefits would justify the cost of the barrage, whether siltation improved or not. The salinity intrusion in relation to fresh-water flow increased siltation in the Hooghly. The complex of problems for the preservation of Calcutta Port has not received adequate technical investigation by model studies, simulating mixing and penetration of salinity into fresh water.
S. R. Basu and S. C. Chakravorty, Geologists	1969	We are not suggesting that Farakka Barrage will, or will not solve the basic malady of the port economy of Calcutta. We only want to emphasise that there is no objective reason to believe that a project like Farakka can at all reverse the process of decay of the Bhagirathi, or at least hold it suspended. If we wish to resuscitate the Bhagirathi, then let us do it in a civilized way by first understanding the source of ailment and then by helping it to overcome the malady in the way it is capable of doing. We cannot let the ravages of soil erosion go unabated in all the thalwegs of the right-bank tributaries while expecting the Bhagirathi to clear the bed.

Construction of Farakka Barrage

Year	Events
1947	The West Bengal Government starts investigation for the Ganga Barrage Project. Field surveys conducted and a preliminary report prepared.
1949	Investigations are taken over by the Government of India.
1952	An Expert committee, headed by Man Singh, reviews model studies and recommends a barrage project.
1952–1958	Outcry in Lok Sabha (the lower house of India's Parliament) by West Bengal MPs.
1956	A separate cell created in the Central Water and Power Commission, New Delhi for investigation, planning and design of the Farakka Barrage Complex.
1957	Dr. Walter Hensen is invited by the Government of India to review the preliminary report; after review, he recommends that India can go ahead with the project.

Year	Events
1958–1960	Long debate in Indian Parliament on the deterioration of the Bhagirathi-Hooghly, Calcutta Port activities and on the need for a barrage.
	K. K. Framji joins the Ganga Barrage organization as its head and starts a scientific study of the problem by examining the reports of the past expert investigations and the recommendations thereon. He recommends that in 1960 that the construction of the Farakka Barrage may immediately be started.
1960	Prime Minister J. L. Nehru assures Dr. B. C. Roy, Chief Minister of West Bengal that the project would be included in the ongoing Five-Year Plan. Administrative approval and financial sanction of the project for about 590 million rupees given by the Government of India and green signal given for construction of the barrage and other allied works.
	Ganga Barrage Field Investigation Circle formed and field surveys started.
1961	National Development Council includes the Farakka Barrage Project in five-year plan.
	Pakistan is informed that the work on the project has started.
	A high-power control board is formed, headed by the Union Minister of Irrigation and Power, constituted with the Government of West Bengal Minister of Irrigation and Waterways as Deputy Chairman, the Union Ministers of Railways, Transport and Finance, the Calcutta Port Commissioners as members and the Chief Engineer of the Project as Member-Secretary.
	A Technical Advisory Committee (TAC) of the Project formed with experts from all over the country as chairman and members.
	R. B. Chakravarty, an engineer of repute from the irrigation department of the Government of West Bengal appointed Chief Engineer of the project.
1962	The Calcutta Port Commissioners set up a Hydraulic Study Department to carry out investigation and improvement works in the Hooghly and its estuary.
1963	The barrage site is selected by Dr. K. L. Rao, Union Irrigation and Power Minister.
	Debesh Mukherjee joins as Chief Engineer of the project in place of R. B. Chakravarty.
	The Farakka Barrage Project office starts functioning from Kolkata.
1964	The project office is shifted to Farakka. The construction of the barrage starts.
1965–1967	Three bays, No. 1 to 3 and the head regulator on the right bank and bays No. 109 to 101 from the left bank completed.
	M/s. Hindustan Construction Company (HCC) starts work from the left bank and the National Projects Construction Corporation (NPCC) starts work from the right bank. M/s. Jessop & Company is entrusted with all structural steel works, like gates, hoists etc.
	Excavation work of the feeder canal is started by M/s. Tarapore & Company and M/s. G. S. Atwal & Company.
	Navigation lock work started by the NPCC.
1966–1967	Bays No. 100 to 78 from left bank completed.
	Navigation lock work suspended. Works on Jangipur barrage.
1967–1968	Bays No. 77 to 53 from left bank and Bays No. 4 to 12 from right bank completed.
1968–1969	Bays No. 13 to 52 completed.
1967–1970	Erection of steel gates completed.
1964–1975	Feeder canal excavation including the bridge work at RD 62 (Pakur Road bridge) completed in April 1975.
1975	On 21st May, the barrage is dedicated to the nation by Jagjivan Ram, Union Ministry for Irrigation and Power.
1987	Navigation Lock commissioned by Rajiv Gandhi, Prime Minister of India.

Negotiations on Sharing and Augmentation of the Ganga Water

i) With Pakistan (1961–1971)

Year	Events
1961	Pakistan formally told by India that the Farakka Barrage Project was going ahead.
	A meeting between Ayub Khan, President of Pakistan and J. L. Nehru, Prime Minister of India is held in London.
	The 3rd expert-level meting is held in Kolkata.
	Discussions are held in Indian Parliament about the Project. The *Lok Sabha* (Lower House) is told that the project would go ahead, in spite of objections by Pakistan.
	The 4th expert-level meeting is held in Dhaka.
1962	Pakistan proposes a meeting at the ministers' level on the Farakka barrage.
1963–1964	A joint survey is conducted for the river banks in the border area.
	Pakistan repeats proposal for a meeting at the ministers' level. J.L. Nehru, Prime Minister of India died.
1965	A war between India and Pakistan breaks out; Pakistan is defeated.
	Lal Bahadur Sastri, Prime Minister of India dies.
1967	Pakistan raises the dispute in 'Water for Peace' conference in the USA.
	Pakistan makes a request for an expert-level meeting on the Farakka Barrage.
1968	The 5th experts' meeting is held in New Delhi. Pakistan insists on a minister level meeting.
	Russia's Prime Minister, V. Kosygin writes to Indira Gandhi, urging an Indus-like settlement of the Ganga dispute.
	Pakistan raises the issue at the UN General Assembly meeting in New York.
	The 1st Secretary-level meeting is held in December in New Delhi.
1969	The 2nd Secretary-level meting at Islamabad ends in deadlock.
	The 3rd Secretary-level meeting is held in New Delhi.
	President Ayub Khan of Pakistan toppled by General Yahya Khan.
1970	The 4th Secretary-level meeting is held in Islamabad.
	Jai Prakash Narayan, a Gandhian leader and others urge an Indus-like settlement.
	The 5th Secretary-level meeting is held in New Delhi.

ii) With Bangladesh (1971–1977)

1971	Independence movement starts in East Pakistan. India intervenes in the liberation struggle. After a 14-day war, Pakistan surrenders to India at Dhaka. East Pakistan is renamed as and the Republic of Bangladesh.
	Khandakar Moshtaque Ahmed assumes power as the acting President of Bangladesh.
1972	Liberation struggle leader, Sheikh Mujibar Rahman is sworn in as the first Prime Minister of Bangladesh on 12th January.
	The Indo-Bangladesh Treaty of Friendship, Co-operation & Peace is signed in New Delhi at the end of the meeting between Indira Gandhi and Mujibar Rahman in March. The Treaty, to remain valid for 25 years, specially provides for joint studies and action in flood control, development of the river basin, generation of hydro-electric power and irrigation.

Year	Events
	A Joint Rivers Commission (JRC) is formed in April and the Water Resources Ministers of India and Bangladesh, Dr. K. L. Rao and Khondakar Moshtaque Ahmed, respectively, sign the statute of the JRC in November. It includes joint efforts in maximizing the benefits from common rivers and joint studies of flood control and irrigation projects.
	The first JRC meeting is held in June and the 2nd in December.
1973	A meeting between Sardar Swaran Singh, India's Minister of External Affairs and Khondakar Moshtaque Ahmed, President of Bangladesh in July in New Delhi decides that the final decision on the sharing of the Ganga water would be taken by the Prime Ministers of the two countries. In a press release, India promises not to operate the Farakka Barrage unilaterally, without agreement.
1974	The Foreign Secretaries of the two countries meet in Dhaka twice, in January and February.
	A tripartite meeting of India, Bangladesh and Pakistan in Simla in April resolves many sub-continental problems but not the Farakka issue. The Prime Ministers issued a joint Declaration that there would not be enough water to meet the needs of the two countries.
	The two Prime Ministers took note of the fact that the Farakka Barrage Project would be commissioned before the end of 1974. They recognized that during the periods of minimum flow, there might not be enough water to resuscitate Calcutta Port and meet the requirements of Bangladesh. Therefore, the fair weather flow of the Ganga in the lean months would have to be augmented to meet the requirements of the two countries.
	Indira Gandhi and Sheikh Mujibar Rahman meet in New Delhi in May and give a mandate to the JRC to discuss augmentation of the Ganga flow.
	Six meetings of JRC, held between June and December, discuss alternative ways of augmenting the lean-season flow in the Ganga.
1975	Jagjivan Ram, India's Minister for Agriculture and Irrigation and Abdur Rab Serniabat Bangladesh's Minister for Water and Power meet in New Delhi in February to discuss the water-sharing issue. They meet again in April and reach an interim understanding that India could divert small quantities of water for 40 days until the end of May.
	The Farakka barrage is commissioned on 21st May.
	Sheikh Mujibur Rahman is assassinated along with many of his family members on 15th August in a military coup.
	Sheikh Zia-ur-Rahman becomes the President through another coup in November.
1976	Bangladesh protests to India in its continued withdrawal of water at Farakka; exchange of protests continues. The relation between the two countries goes under strain after the assassination of Prime Minister Mujibar Rahman. The spirit of co-operation and trust which developed during Mujib's regime changes to suspicion and mistrust after the change of government in Dhaka.
	Maulana Bhasani, a peasant leader of Bangladesh, asks India to dismantle the Farakka barrage and organizes a protest march with more than a 100 thousand people within Bangladesh territory in May but withdraws it at the last moment.
	Bangladesh tries to muster international support against withdrawal of water by India through the barrage, unsuccessfully; only China and Pakistan back it.
	Bangladesh tries to raise the issue in the United Nations General Assembly in August.
	Rear Admiral M. H. Khan of Bangladesh meets Indira Gandhi in September but they reach no conclusion.
	Bangladesh places the Farakka issue in the agenda of the 31st session of the General Assembly on 21st August and again in a modified form on 8th September.

Year	Events
	No elaborate discussion on the Bangladesh allegation is held on 24th November in the General Assembly, because of lack of consensus among the members. Bangladesh and India agree to abide by a consensus text, to be worked out by a group of non-aligned countries.
	The General Assembly adopts the final text which recognizes the urgency of the situation and agrees to facilitate an atmosphere, conducive to the successful outcome of the negotiation between the two countries. It also offers to both the countries the option to again raise the issue at the 32nd session.
	The meeting between the two governments in Dhaka and New Delhi remain inconclusive.
1977	The Congress Party led by Mrs. Indira Gandhi is defeated in the General Election of India in March and Janata Party, led by Morarji Desai comes to power.
	Jagjivan Ram, Defence Minister of India and Rear Admiral M. H. Khan of Bangladesh meet in Dhaka in April, where an understanding is reached on sharing of water.
	Mutual confidence, which went low after Mujibar Rahman's death, is restored, when Morarji Desai and General Zia-ur Rahman meet in London during the Commonwealth Conference. Many outstanding bilateral disputes, including the sharing of the Ganga water are resolved.
	A draft agreement for sharing of the Ganga water is initiated in September and signed on 5th November by Surjit Singh Barnala, India's Minister for Agriculture and Irrigation and M. H. Khan of Bangladesh.

Signing of Agreement, MOUs and Treaty, 1977–2000

Year	Event
1977	An Agreement on sharing of water of the Ganga at Farakka between India and Bangladesh is signed on 5th November.
	The meeting between Morarji Desai and Zia-ur Rahman takes place in New Delhi on 19th December to discuss follow-up action on the Ganga Water Agreement.
	The JRC is upgraded to the ministerial level.
1978	Jimmy Carter, the President of the USA, while addressing Indian Parliament on 2nd January refers to the development of the waters of the eastern region and assures co-operation of the USA.
	James Callaghan, the British Prime Minister, offers his country's assistance in the development of the common rivers of India, Bangladesh and Nepal in a press conference in New Delhi on 9th January.
	The 14th meeting of the JRC held in Dhaka on 21st January, to discuss the best means of augmentation of the dry-season flow of the Ganga.
	The 15th meeting of the JRC is held in New Delhi on 5th July, attended by S. S. Barnala, India's Minister for Irrigation and Power. Bangladesh suggests associating Nepal in the augmentation scheme, which is rejected by India, as the JRC is a bilateral body.
	The 16th meeting of the JRC is held in Dhaka on 6th November and from 8th to 10th December in two sessions.

Year	Event
1979	India's Prime Minister, Morarji Desai visits Dhaka on 16th April and holds discussions on the Farakka issue and the augmentation schemes with Bangladesh authorities.
	The 17th meeting of the JRC is held in New Delhi from 8th to 12th May and in Dhaka from 16th to 20th November. India is represented by S. S. Barnala in New Delhi and by Chaudhury Brahm Prakash in Dhaka sessions and Bangladesh by Moudad Ahmed, Deputy Prime Minister. It sets up a committee to recommend formulation of draft terms of reference, jointly by the governments of India and Bangladesh to the Government of Nepal to identify specific areas where co-operation of Nepal is necessary and to recommend the method and manner of approach, keeping in view the Ganga Water Agreement of 1977.
1980	The 18th meeting of the JRC is held in New Delhi from 27th to 29th February and from 26th to 28th April. The Indian side is led by A. B. A. Gani Khan Choudhury, Minister for Energy and Irrigation and Bangladesh by Kazi Anwarul Haq, Minister for Flood Control. Jamaluddin Ahmed, Deputy Prime Minister of Bangladesh, attends the meeting in the second phase. The meeting is inconclusive.
	The 19th meeting of the JRC is held in Dhaka from 9th to 11th July. The Indian side is led by Kedar Pandey, Minister for Irrigation and Bangladesh by Kazi Anwarul Haq. This meeting is also inconclusive.
	The 20th meeting of the JRC is held in New Delhi on 30th and 31st August. The Indian side is led by Rao Birendra Singh, Minister for Irrigation and Bangladesh by Kazi Anwarul Haq. This meeting also fails to be conclusive.
	The first review meeting of 1977 agreement is held in Dhaka on 7th November where the two sides are led by Rao Birendra Singh and Kazi Anwarul Haq.
1981	The second review meeting is held in New Delhi from 7th to 9th January, led by the same ministers of two countries.
	The 3rd Review meting is held in Dhaka from 2nd to 4th April under the same leadership. The impact of the sharing of the Ganga water at Farakka on the two countries and the reasons for the JRC's inability to recommend any long-term scheme are discussed but no agreement emerges.
	President Zia-ur-Rahman of Bangladesh assassinated on 30th May in a military coup. Justice Abdus Sattar assumes the charge of President.
1982	General Ershad takes charge of President of Bangladesh.
	The validity of the water-sharing agreement of 1977 expires on 4th November after the dry season.
	Bangladesh President, H. M. Ershad visits New Delhi in October and discusses the matter with Indira Gandhi, which led to the signing of a Memorandum of Understanding (MOU) of two years' validity.
1983	India's Irrigation Minister, Ram Nivas Mridha and Obaidullah Khan, Minister of Flood Control of Bangladesh discuss the proposal for all-river permanent water-sharing accord and makes some progress.
	In December, the two governments exchange updated technical proposals on the augmentation schemes.

Year	Event
1984	The validity of the MOU on the sharing of the Ganga water in the dry season expires in June. The 26th JRC meeting is held in March in Dhaka but finds no solution of the augmentation problem. The Bangladesh side of the JRC publishes a document which candidly admits the strength of criticism to its own as well as of the India's proposals. Mrs. Indira Gandhi, Prime Minister of India assassinated on 20th October and Rajiv Gandhi takes charge. Obaidullah Khan resigns from his post and is replaced by Air Vice Marshal Aminul Islam, a hard-liner against the Indian approach on the issue. The Bangladesh government publishes 'The Ganges Water Issue' in December in a strongly-worded re-statement of its earlier positions.
1985	Ramesh Bhandari, India's Foreign Secretary, goes to Dhaka in April to break the impassé with Bangladesh and get negotiations going again. Rajiv Gandhi visits the cyclone-affected site of Urir Char in Bangladesh and meets President Ershad there; both want progress on the river-water issue. New Delhi sends Ramesh Bhandari to Dhaka again along with a special envoy, Shiv Shankar in July to proceed further of the issue. The Commonwealth Heads of State conference is held in Nassau, Bahamas in October, where India and Bangladesh work out an agreement; Prime Minister Rajiv Gandhi and President Ershad formalize it with a communiqué. The 2nd Memorandum of Understanding (MOU) is signed on 22nd November by the Ministers for Irrigation and Water Resources of both countries to be valid for three years. It follows, by and large, the same principles of sharing of the Ganga water as the first MOU in 1982. A Joint Committee of Experts (JCE) is formed with the task of completing a joint study of alternatives for sharing and augmentation of water of rivers, common to India and Bangladesh.
1986, 1987	As many as nine meetings of the JCE along with some meetings of the technical sub-committee and two ministerial review meetings are held between August 1986 and May 1987, but they remain too inconclusive. However, a new approach emerges for construction of internal barrages and gravity link canals within Bangladesh. Prime Minister Rajiv Gandhi and President H. M. Ershad agree in July 1986 that the two governments should simultaneously approach Nepal for holding a meeting to discuss the water resources issue. Delegates of both the countries from the JCE go to Kathmandu and meet a team of Nepal government's Water and Foreign Ministry officials for three days in end-October 1986. The discussions are inconclusive on the questions of how Nepal would be benefited and how the Nepalese government would be included in the discussion. The India's Foreign Minister agrees to prepare a draft position paper of Nepal's role in river development in a meeting with the Foreign Ministers of Bangladesh and Nepal, which could lay down the logic behind 'joint approach' and the true meaning of 'mutual benefit', but the position paper never comes out. Anisul Islam Mahmud, Irrigation Minister of Bangladesh wants to discuss the entire proposal before the Bangladesh cabinet on 4th January, 1987 but it concluded mid-way.

Year	Event
	The Position Paper on Nepal was discussed by Indian Secretaries in March 1987, but remains inconclusive.
	The Water Resources Ministers of both countries are changed; no further development takes place.
	Indo-Bangladesh relation deteriorates.
	The validity of the JCE expires in November, 1987.
	Severe flood in Bangladesh in monsoon months.
1988	The validity of 1985 MOU comes to an end after the lean season.
	Two countries show no initiative to make any progress on the issue.
	Severe flood occurs again in monsoon months in Bangladesh. Two severe consecutive floods compel Bangladesh government to prepare several technical reports on flood problems.
	The Government of India responds favourably to expression of concern in Bangladesh which reopens the door for negotiation on river development between the two governments.
	President H. M. Ershad visits India, Nepal, China and Bhutan to discuss cooperation on river issues and flood control with their governments.
	Bangladesh media blame India and the management of the Farakka barrage and give extensive coverage to blames and allegations by politicians and the people of Bangladesh.
	None of the technical reports, prepared by a French consortium, the US consultants and the UNDP supports construction of head-water reservoirs and dams in Bangladesh; they stress regional co-operation for solving the flood problem in Bangladesh.
1989	President H. M. Ershad meets Prime Minister Rajiv Gandhi in New Delhi in October, where they agree on raising a joint task force on flood control. He also visits Nepal and China to discuss the same issue.
	The Congress Party, led by Rajiv Gandhi defeated in election and V. P. Singh takes charge of Prime Minister of India.
	There being no further development on sharing of the Ganga water, the relations between the two countries deteriorate further.
	India continues to release Bangladesh's share of water from Farakka barrage as per 1985 MOU.
1990	The JRC meets in April after three years.
	H. M. Ershad defeated in General Election of Bangladesh and Begum Khaleda Zia takes charge of Prime Minister.
	General Election held in India and Rajiv Gandhi assassinated during election process.
	The Congress Party back in power and P. V. Narsingha Rao assumes charge of Prime Minister of India.
	India continues to release water to Bangladesh from Farakka in the lean season too.
1991	The two governments are so preoccupied with many domestic problems that they give scant attention to the issue of sharing the Ganga water.
	The Prime Ministers of India and Nepal meet New Delhi in February to set up an Indo-Nepalese task force on economic co-operation.
	India continues releasing water from Farakka to Bangladesh in the lean season.

Year	Event
1992	New Bangladesh premier, Begum Khaleda Zia and Indian Prime Minister P. V. Narasimha Rao, meeting in New Delhi, agree to evolve a comprehensive and permanent plan on developing resources in all common rivers, including sharing and augmentation of the Ganga water at Farakka within a stipulated period. Indian premier promises not to cause hardship, or pose political problems to Bangladesh. A New Joint Committee of Experts (JCE) is formed at a ministerial-level meeting at Dhaka in August. The 1st meeting of JCE is held in New Delhi in November. India continues releasing water to Bangladesh during the lean season from Farakka.
1993	The 2nd meeting of the JCE, held in Dhaka in March, also makes no progress, causing great disappointment to Bangladesh Irrigation Secretary. India's Water Resources Minister and Bangladesh's Communication Minister meet in New Delhi in May and decide to high-level talks on the issue for an early solution. Bangladesh suggests involving Nepal in the discussions. Bangladesh's Jamaat-i-Islam party organises a huge rally in the dry bed of the Ganga near Hardinge Bridge in April. In the SAARC summit, held in April in Dacca, two Prime Ministers discuss the problems of sharing the Ganga water and press for an early solution. Both want short and long-term solutions. Both sides again discuss the issue in the NAM summit in Jakarta in September. In December, the Foreign Minister of India visits Dhaka and assures Bangladesh government for an early solution of the problem. India continues releasing lean-season flow to Bangladesh from Farakka.
1994–1995	In 1994, several high-level meetings are held between the two governments, but reach no solution. Both sides remain rigid on their respective stands. In the 8th SAARC Summit, held in April, 1995, the two Prime Ministers again discuss the problem of sharing the Ganga water at Farakka. The Foreign Secretaries of the two countries hold two meetings in New Delhi and Dhaka and discuss the issue. India continues to release water to Bangladesh at Farakka during the lean season.
1996	General Election held in both the countries. In India the Congress Party is defeated and the United Front led by H. D. Deve Gowda assumes power as Prime Minister. In Bangladesh, Begum Khaleda Zia's Bengal National Party is defeated and Sheikh Hasina Wazed of Awami League assumes power as Prime Minister. India continues to release water to Bangladesh from Farakka in the lean season. Indian Foreign Secretary Salman Hyder visits Bangladesh in July and hands over a letter from the Prime Minister to Bangladesh premier. Indian Foreign Minister visits Dhaka in July and discusses the issue of water-sharing of all common rivers with the Foreign Minister of Bangladesh. Both sides want a permanent solution before the next lean season. Bangladesh Foreign Minister visits Kolkata and New Delhi in September and discusses the issues with Jyoti Basu, Chief Minister of West Bengal and with the Foreign Minister of India in New Delhi. Jyoti Basu visits Bangladesh and discusses sharing of the Ganga water at Farakka.

Year	Event
	A 30-year Treaty on sharing of the Ganga water at Farakka is signed in New Delhi by Prime Ministers H. D. Deve Gowda and Sheikh Hasina Wazed, putting an end to the strained relations between the two countries on the issue.
1997	Sharing of water as per the formula in the new treaty starts from January in the presence of two observation teams of both countries at Farakka and at Bheramara (Bangladesh).
	Very low lean-season discharge in the river results in severe bank-slips in the feeder Canal. The matter is reported to the Government of India.
	The NTPC Power plant, located at Farakka, is shut down for several days in the last week because of very low water-level in the feeder Canal.
1998–2000	Sharing of water continues as per formula in the Treaty.
	Problem of low lean season discharge plagues the functioning of the NTPC in April 1998 and 1999.
	Feeder canal bank-slips occur at some places, but no such problem is faced in the lean season of 2000, as low discharge in the river was just enough.
2001–2002	Sharing of water continues as per formula in the Treaty.
	Meetings between the two countries and exchange of information continue.
2003	Mr. Hafizuddin Ahmed, Minister for Water Resources of Bangladesh attends JRC meeting in New Delhi. He visits Kolkata and Farakka Barrage which he considers as a bone of contention between the two countries as far as water distribution is concerned.
	Sharing of water continues as per formula in the Treaty.
2004–2008	Meetings between the two countries and exchange of information continue.
	Sharing of water continues as per formula in the Treaty.

Chapter 13
The Ganga Basin Management

A river flowing through more than one country, or one province within a State, is governed by certain international laws. In olden days, rivers were the only source of water for agriculture, navigation, drinking and other purposes. Though no defined laws existed, the right to water was then universally accepted, irrespective of national identity. However, this right led to conflicts between the peoples and nations very often and weaker individuals and nations were oppressed by the stronger. Though there are many uses of water for development and the uses are varying and multiplying every day, the most important users of river water remain the farmers, industry-owners, navigators and suppliers of drinking water.

The First Law

Rivers do not care, nor have any use, for geographical or political boundaries; therefore, disputes arise among the co-riparian States. The law relating to the use of waters of rivers, flowing through several countries was first laid down by the 'Institute de Droit International' in 1911. It drew up a law on 'Utilisation of Non-Maritime International Waters (except for navigation)' in 1961, in which it developed an international law regarding utilization of such rivers, that every State has right to utilize waters of international rivers, subject to the limits, imposed by international law and particularly by co-riparian States.

Article – I says:

> The present rules and recommendations are applicable to the utilization of waters which form part of a water course, or hydrographic basin, which extends over the territory of two or more States.

Article – II reads:

> Every State has the right to utilize waters which traverse, or border its territory, subject to the limits, imposed by international law, in particular, those resulting from the provisions which follow. . .This right is limited by the right of utilization of other States, interested in the same water courses, or hydrographic basin.

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7_13,

Helsinki Rules

However, so far no clear-cut directions or conventions have emerged to deal with water disputes, in spite of many organizations including legal associations, trying to do so. The most important and effective of these are the Helsinki Rules on the uses of waters of so-called 'international' rivers, adopted by the 'International Law Association' in its 52nd session in 1966 in Helsinki. These rules have acknowledged that the international river basins should be regulated by the rule of customary international law.

Article – V states:

> Each basin State is entitled, within its territory, to a reasonable and equitable share in the beneficial uses of the waters of an international drainage basin.

What is 'a reasonable and equitable share' is to be determined in the light of all relevant factors in each particular case. The factors to be considered for share of water among co-riparian States, according to the Helsinki Rules, are:

- The geography of the basin, particularly the drainage area in each basin State;
- The hydrology of the basin including, in particular, the contribution of water by each basin State;
- The climate affecting the basin;
- Past utilization of the waters of the basin, particularly the existing utilization;
- Economic and social needs of each basin State;
- The population, dependent on the waters of the basin in each State;
- Comparative costs of alternative means of meeting economic and social needs of each basin State;
- Availability of other resources;
- Avoidance of unnecessary waste in utilization of the waters of the basin;
- Practicability of compensation to one, or more, co-basin States to adjust conflicts among users; and
- The degree to which the needs of a basin State may be satisfied without causing substantial injury to a co-basin State.

The factors are not exhaustive and gave rise to controversy and dispute, as the needs of various States in different periods varied widely from region to region. For Europe, or the USA, for example, generation of hydro-power got priority, but for under-developed countries like India and Bangladesh, irrigation overrode other needs and uses.

The Article-II of Helsinki Rules defined 'International Drainage Basin' as 'An International Drainage Basin is a geographical area, extending over two or more States determined by the watershed limits of the system of waters, including surface and underground waters, flowing into a common terminus'.

At Stockholm conference of the United Nations on the Human Environment in 1972, a principle, laid down was that,

> States have, in accordance with the Charter of the United Nations and the principles of international law, the sovereign right to exploit their own resources, pursuant to their own environmental policies, and the responsibility to ensure that activities within their jurisdiction, or control, do not cause damage to the environment of other States, or of areas beyond the limits of national jurisdiction. (Principle 21, Declaration on the Human Environment in Report of the United Nations conference on the Human Environment, 1972, UN Declaration 48/14 and Corr.-I).

International River Basin Co-operation

Subsequently, the UN General Assembly emphasized in a Resolution that '... In the exploitation and development of their natural resources, states must not produce significant harmful effects in zones, situated outside their natural jurisdiction.' (General Assembly Official Records, 27th Session supplement No. 30).

The United Nations Water Conference, held in 1977, emphasized development and management of international water resources, keeping in view eventual scarcity of global water resources. This led to a report on 'International River Basin Co-operation: The Lessons from Experience' as a supporting document for future UN water conferences. In the beginning it says,

> ... Globally, there may be potentially enough water to meet forthcoming needs; but, frustratingly, it tends to be available in the wrong places, at the wrong time, or with the wrong quality. And in one way or another, all societies are affected, however rich, however poor.

Political boundaries, dividing a river basin or an aquifer, aggravate the problem. Water flows according to physical laws, not within political boundaries; its use is governed by institutions and patterns of use, responsive to political, social and economic demands. Where national boundaries divide a river basin, which is the physical unit for assessing and allocating water resources for various purposes, the co-riparian, or co-basin, countries must engage in a co-operative endeavour to rationalize the use of the resource in terms of its capacity to meet the full range of the demands that exist.

The use of water by people of a country that shares a water resource, may determine the benefits that those of a co-riparian country can get from the same source. The use by one country without regard for the potentials and demands in co-riparian countries can easily lead to inefficient use of available water supplies and inequitable sharing of the resources of a river basin. Such action can result in ill-filling and serious political controversy.

International rivers, lakes and aquifers form a major part of the global stock of fresh water. There are over 200 continental river basins which have a direct contact with the final recipient of water, i.e. an ocean, a closed internal sea, or a lake and tributary basins and aquifers that are divided by international boundaries. In view of the critical importance of using water resources efficiently and to meet the present and prospective demands for water in agriculture, industry and domestic use for increasing world population, it is incumbent to find ways and means of best use of international water resources.

Improved management of international rivers, lakes, aquifers is not easy. Some countries may, out of economic incentive, ignore demands for basin-wide accords. Mistrust and suspicion between States can reinforce one country's incentive to act alone, or undermine mutually advantageous endeavours. Finally, some basin countries may not have the institutional and financial capability, or political interest, to make co-operative endeavours. These are difficult to overcome, but progress is possible if there is the political will.

A number of regions of the world have worked out fruitful arrangements for managing, and using, international water resources. Some of these have been summarized and assessed in 10 case studies, prepared for the UN Secretariat, which provide a basis for arriving at some conclusions about how to foster constructive actions to manage and utilize international water resources, fairly and efficiently. This statement is based on those reports. First, it seeks to (sic) the nature of the problems that must be dealt with in the management of international water resources. Secondly, by drawing on the experiences, reported in the papers listed in the annexure, it seeks to illustrate, how co-operative action has been achieved and the kinds of institutions that have facilitated co-operative action. The concluding section summarizes the kinds of measures and institutional arrangements that experience suggests, will foster the best use of international water resources.

The report mentioned the factors, governing the capability of the States for cooperation as under:

(a) The differences and similarities in the evaluative frameworks of co-riparian nations;
(b) The uncertainties that exist with regard to the possible future effects of any joint arrangement;
(c) The physical and economic characteristics of the water resource management system, as related to international boundaries;
(d) The international relations environment;
(e) Domestic factors within the co-riparian nations; and
(f) The number of nations, involved in the negotiation.

In many cases, in spite of differences of political, social and economic conditions as well as diverse cultural heritage, present and future development activities etc. some practical means of surmounting them have been found in a number of situations. The treaties on share of the water of the Rhine, the Great Lakes, the Columbia, and the Colorado etc. are cited.

Total net benefits from the water resources of a region can be increased beyond these, which can be realized through independent action by a co-riparian country by co-coordinating programmes of development of the basin. This kind of problem is found in river basins, on which countries are either upstream, or downstream, i.e., they lie in the basins of successive international rivers. Two solutions are possible:

(a) The upstream country may abstract water, or impair its quality and thus reduce the benefits for the downstream countries which cannot do the same to the upstream country. The upstream country, being under no economic compulsion to reach an accord has to have other incentives to undertake actions jointly with downstream countries.

(b) A downstream country located at the mouth of a river may not only withdraw water from the river but also pollute it, thus scoring an economic advantage over the upstream countries, in such instances, co-riparian countries have to abide by pollution control regulations, or agreements.

The report adds that co-operative action will vary greatly from situation to situation. If the concerned countries have a common cultural heritage and traditionally good relationships, reaching an agreement becomes simpler.

Information should be sought about the effects of alternative schemes of development and use on each riparian country. The World Bank recognizes that, besides goodwill, basin countries have to be committed to reach an accord and be willing to share technical and economic data. A slew of technical, economic, legal and other data is required to satisfy concerned governments, external financing or other agencies so that the solution is equitable and feasible. The Indus Treaty between India and Pakistan is a relevant example.

Possibilities within each country should be explored for providing the services from water resources that might be secured through international action. The Volta River Basin Treaty is one such example. If a country has limited ability to make technical, economic and social studies, international agencies and members of the international community, such as United Nations Development Programme (UNDP), International Development Bank (IDB), the Organization of American States (OAS) etc. should provide the needed assistance and aid in the training of professional personnel within the countries. Expertise is required to generate information on alternative scheme of development, to assess the advantages of co-operation and to proceed with the construction of the projects. If this expertise is not available for lack of experience and trained personnel for one or more of the co-basin countries, outside assistance must be sought. Actually, assistance may not elude, even if basin countries already have a relatively high professional competence in water resource management, such as, Greece and Yugoslavia had in the Varder-Axios Basin Project.

A concerted effort is necessary to forge basic agreements on the technical aspects of alternative schemes for management and use. Negotiations on substantive normative issues will be needlessly complicated and prolonged if there are disagreements on basic technical issues, which can be readily resolved by working groups of experts from the basin countries, or by a more structured joint technical committee in charge of coordinating and integrating the basic data-gathering and technical feasibility studies. To take the example of the Ganga river treaty between India and Bangladesh, although the Joint River Commission comprised technical experts from two countries, the proposal of augmentation of the Ganga flow at Farakka fell through, as the two countries did not agree on the alternative schemes, proposed by each of them.

Continuing communication and exchange of information at the technical and political levels should be encouraged to build mutual trust among co-riparian countries. Basin-wise co-operation will have to be encouraged, if communication at technical level is continued.

Imaginative ways of sharing benefits and costs to provide incentives for forging an agreement should be explored. The basic incentive for cooperation is that each country must have some gain. Sacrifices in achieving a joint objective must be more than compensation for expected benefit. The direct cash compensation, received by Pakistan from India to compensate the loss of water from the Indus tributaries that normally flowed to Pakistan, as per the Indus Basin Treaty is an example. Especially, in sequential rivers where the upstream country gets little from cooperation, a more flexible approach to encourage joint actions may be appropriate. Benefits, such as, improved trade links may induce one country to make another cooperate.

The international community should build consensus, as to what constitutes an equitable distribution of benefits and costs, resulting from the development and use of international water resources. Resolutions 21 and 22 on the States' responsibility and liability, adopted at the UN Conference on Human Environment, the Helsinki Rules, the European Convention of the Protection of International Water Courses against pollution and the Principles of Trans-frontier Pollution of the Organization for Economic Cooperation and Development (OECD) are some of the global and regional principles as well as rules of conduct which, if adhered to by basin States, can facilitate cooperation. They help reduce the issues for negotiated settlement, using the responsibilities of each country and setting out principles for equitable division.

If a country does not have financial resources to get its share of a potential joint development programme, leading inter-national institutions and the international community can contribute funds. In many basins, development will not be possible unless their governments receive outside assistance. Multilateral and bilateral financial assistance by organizations in the donor countries can bolster a basin country get its due share of a river's water. Such bilateral and multilateral assistance should be extended to basin countries, needing it and should also be coordinated and complementary. The Indus Basin and the Volta Basin treaties are examples in this respect. Under the Indus Basin Treaty, funds were made available from international organizations and the outside world. The storage works on the western rivers in Pakistan and connecting canals were constructed for diversion of water into it.

To minimize friction among countries, involved in basin development, the agreement should limit, as much as possible, the dependence of one country on continuing actions by another, so that the former gets its share of the benefits. Countries are often reluctant to forge joint arrangements, if projects vital to their economy and development are controlled by another basin country. There can be no guideline for the degree of sovereignty control over projects, because the requirements for each situation are unique. To reduce unease over potential loss of sovereignty, entailed in international cooperative arrangements, strategic works should, as much as feasible, be designed and located in such a way that each State retains as much control as possible over works, on which it is greatly dependent. A key point in solving the

Indus river controversy between Pakistan and India was to find a scheme in which Pakistan would have control over the works on which it would be most dependent.

International agreements should be as flexible as possible to adjust water use and manage unforeseen changes in conditions. Inflexibility freezes political motivations, technological possibilities and economic conditions at the time of signing. Some inflexibility is, however, unavoidable. Dams, once constructed, are a permanent commitment to one form of technology and can hardly be modified for adopting a newer technology. Nevertheless, within this limitation, flexible cooperation is possible. A treaty is a framework which sets out the principles on which joint development can proceed, with detailed planning. Implementation of projects has to be left to joint technical groups, operating under political direction. This permits a response to changing economic and technological circumstances within the terms of the agreement, obviating the need for re-negotiation of a major international undertaking.

Treaties and agreements between and among basin countries, which call for development on shared costs and benefits, should be flexible enough to maintain an equitable division of net benefits over a period of time. The exact arrangements for working out the net benefits for each country must be made in accordance with political and economic opportunities and constraints at the time of negotiation.

Where the prospects for agreement are limited because of too many riparian countries being involved, sub-dividing a water resource system into sub-systems, each involving as few countries as possible should be explored. The interest and priorities for the management and use of a river basin will vary in each country, according to their dependence on the river, the opportunities for increasing their benefits from the use of the river and their contribution to the problems, faced. What may appear critical to basin countries in one region may be of little concern to another. When many countries share a basin, the problems of differing priorities, involvement with the river along with other domestic and foreign policy issues between the basin countries complicate negotiations and reduce the prospects for basin-wise agreement. Limiting the agreement to the countries, among which mutual interest and concern prevail, is the most feasible approach. The Rhine basin is an example where several countries like Austria, Switzerland, the federal Republic of Germany, France and the Netherlands are involved.

Where an international river is expected to achieve a high degree of development and use, the basin countries should give early consideration to joint planning so as to avoid conflicting claims on the resources that may arise in the future. Disputes arise, when demands on a common resource exceed its capacity to meet them. In many cases, the basin countries can avoid such disputes, if they compare the projected demands by each country on the river water; this will reveal the incompatibility of claims. Given time, joint plans can be drawn up to regulate the flow, increase the capacity for use, apportion the waters, or to work out some other schemes to use, equitably, the shared resource without conflict. Varder-Axios project is an example where Greece and Yugoslavia exchanged information and found that the plans for developments of the resource were greater than the supply available. The incentive for co-operation was received to avoid conflict over possible future water shortages.

The problems of the river basin development and their solutions, as stated ante, are cited in the 1977 UN Report, prepared by Prof. I. K. Fox, Director of the West Water Research Centre, University of British Columbia, Canada and his colleague, Le Marquand.

International Organisations

Organizations, concerned with the development and management of international water resources, are of two categories – river basin organizations and the global and regional organisations.

River Basin Organizations

International organizations exist in many parts of the world to facilitate the management of 'international' rivers, lakes and other water-bodies. They perform many functions with varying degree of authority and effectiveness in promoting cooperative action. Some of these organizations are the International Commission for the Protection of the Rhine against Pollution, the Central Commission for the Navigation on the Rhine, the Niger Commission, the Yugoslav-Greek Commission for the Varder-Axios River, the Volta River Authority, the International Joint Commission (IJC), set up by Canada and the United States for the Colorado, the Columbia River Treaty, the International Columbia River Engineering Board, the International Boundary and Water Commission, set up by Mexico and the United States, the Mekong River Commission, set up by Lao, Thailand, Cambodia and Vietnam, the Joint Rivers Commission (JRC) set up by India and Bangladesh and the Indus River Commission set up by India and Pakistan etc.

According to the UN report by Prof. I. K. Fox, several conclusions can be drawn from the experiences of river basin organizations in various parts of the world as below.

1. Communications among national representatives through meetings of river basin organizations can build mutual trust and confidence among co-riparian countries, obviating the need for an elaborate formal organization and procedures. The organizations have to be designed in accordance with prevailing political and economic realities in the concerned basin country.
2. River basin organizations should have a limited mandate and focus on issues of mutual interest.
3. River-basin organizations have been most effective, when they have focused reaching an agreement on the technical aspects of alternative schemes and avoided efforts to resolve political issues. On the one hand, limiting an organization's responsibility to collect and exchange data does not realize the full potential of a commission. On the other hand, assigning responsibility to such an organization for resolving political issues tends to limit its capability to deal effectively with important technical matters, which need to be dealt with to

provide a basis for effective political action. Experience suggests that negotiations on political issues should be handled by national political representatives who specialize in such activities.

Global and Regional Organizations

These, according to Prof. Fox's Report, include the United Nations, its sister organizations and regional bodies, such as, the Organization of American States and the Council of Europe, which made major contributions. A report of the Secretary General on International River Basin Development to the UN Committee on Natural Resources at its fourth session gives an overview of the activities in the field of the UN and related bodies as well as several other global and regional organizations. The major contributions are as under:

- Generation and dissemination of legal and technical data: The efforts of the UN outfit in the area have varied from convening panels of experts and seminars to the publication of various documents on technical, economic, legal and institutional aspects of international water resources development. Since the first symposium on Comprehensive River Basins Development was convened by the UN at Lake Success, New York in 1949, the Secretariat has held many meetings and issued publications, related or specifically oriented, to international water resources. These provide guidelines on the technical and institutional issues, on which focus should be made, particularly in countries where the development of an international river basin is in the initial stage.
- The UN outfit has also published a number of documents, dealing specially with the legal aspects of management of shared water resources and reference material. The Food and Agriculture Organization (FAO) and the National Law Commission have reviewed bilateral and multilateral treaties and conventions, relating to the uses of international water courses and published reports which give important inputs to further legal principles for use of international river basins. The United Nations Environment Programme (UNEP) is currently carrying out work on cooperation in the field of environment, concerning natural resources, shared by two or more countries.
- Provision of technical assistance, financing and training: The UNDP has financed and assisted in various ways other UN agencies and the Secretariat, as also regional organizations, in executing development projects on a large number of international river basins. The latter include the Centre for Natural Resources, Energy and Transport of the Department of Economic and Social Affairs of the UN Secretariat, the FAO, World Meteorological Organization (WMO), the World Bank and regional organizations, such as the Organizations of American States (OAS) and the Inter-American Development Bank (IADB) which provide technical support, directly, or supervise the work done either by individual experts, or consultant firms. In addition, the UNDP assists in providing fellowships abroad and training of local personnel during the execution of projects and arranges

delivery of equipment, needed for project implementation. In several 'international' river projects, the UNDP, as the executing agency, provided technical supervision services too.

- The World Bank has a long experience in financing and assisting international river development projects. During 50 years of its existence, it has been involved in many projects, dealing directly with the development of international rivers and river basins. In addition the Bank has, on several occasions, conspicuously in the case of the Indus basin, provided its good offices to assist in resolving disputes.

To sum up, these global and regional organizations provide much-needed technical and financial assistance to international river basins, which have not only aided the cooperating States in developing the information required to plan and assess potential development schemes but also helped strengthen technical capabilities of national organizations, particularly through training of personnel to carry out these works by themselves, which is the ultimate goal of aid programmes.

There are a number of organizations in many countries for effective river basin management and development. These and other water resources agencies create conditions that enable political leaders appreciate fully the opportunities and responsibilities and the constraints of joint use for development of a national or international river basin. If an international river basin organization exists, the concerned national outfits are called upon to participate in its works. From Mr. Fox's report some important conclusions emerge.

(a) There is no substitute for the will to cooperate by the co-riparian countries in each situation, where a water resource is shared by two or more nations.
(b) Where the will to cooperate is present, it is of critical importance that each riparian country understands the existing potential management and issues as also alternative schemes and the physical, economic and social consequences and uncertainties. For this purpose, the States' own resources are to be efficient and reliable.
(c) Resolving technical differences by methodical exchange of data/records and assistance by river-basin organizations are invaluable in building mutual trust and confidence among the riparian States, which provide a solid basis for political negotiations that every agreement requires.
(d) As in many cases, an economic incentive does not exist to negotiate an efficient and equitable agreement on the management and use of 'international' water resources, a consensus has to be built on legal principles, governing the development and use of such resources. Some general principles of global applicability could be developed on the basis of experiences in reaching bilateral, multilateral and regional agreements on management of shared resources. In particular regions, a set of regional principles is needed, such as those devised by the Council of Europe to control pollution on international rivers in the region.
(e) In some situations, regional training and information centres should be created. These would meet the needs of groups of countries in specific technical fields,

which they otherwise could not independently afford to create. It might also be useful to consider promoting exchange of personnel, engaged in international water resources management, to train management staff and as a means of sharing and disseminating experience in applying the criteria and methods for collection, storage, retrieval and standardization of basic basin data.

International Organizations and Treaties

There are three kinds of international rivers in the world– the successive, the contiguous and the successive-cum-contiguous. Successive rivers flow through one country first and then enter another country, leaving the first one. The contiguous rivers flow through more than one country at a time (two banks in two countries). The successive-cum-contiguous rivers flow through one country first and then flow through two countries (one bank in one country) before finally entering a third country. Treaties have been concluded on sharing of waters etc. on La Plata (among Argentina, Bolivia, Brazil, Paraguay and Uruguay) on 23rd April 1969, on the Mekong (among Lao, Thailand, Cambodia and Vietnam), on the Columbia (between Canada and the USA), on Senegal (among Mali, Mauritania and Senegal), on the Colorado (among Canada, the USA and Mexico), on the Volta (among Ghana, Togo and Benin), on the Rhine (among Austria, Switzerland, Germany, Netherlands, France and Luxemburg), on the Vardar-Axios (between Greece and Yugoslavia), on the Nile (between Egypt and Sudan) in the 1920s, on the Danube (among Bulgaria, former Czechoslovakia, Hungary, Rumania. Yugoslavia and the former USSR) and on the Indus (between India and Pakistan). For relevance to our subject, let us have a closer look at the Indus River Treaty.

Indus River Treaty

The Indus (the *Sindhu* in ancient Hindu texts) flows through India and Pakistan. Before 1947, when there was no Pakistan, it passed through one single country, India. Afterward, it was divided between the territories of two countries. Before 1947, it irrigated Punjab, Sind, North-West Frontier Province (NWFP), Bahawalpur and Bikaner etc. but it did not have enough water to meet the demands of each State, giving rise to occasional disputes. In 1935, the then Government of British India constituted Anderson Committee to forge an agreement on some outstanding issues. The committee recommended certain modalities which the government accepted and gave effect to in 1937.

However, the government of Sind was not happy and lodged a complaint in 1941 that the withdrawal of water by Punjab upstream would affect irrigation through the inundation canals in Sind from May to October and also would create a shortage of water at Sukkur in winter. The Government of India appointed the Indus Commission with Justice B. N. Rau as Chairman and the chief engineers of Uttar Pradesh and Madras Provinces as members to look into the complaints.

The Commission's report in July 1942 said that the Punjab withdrawals are likely to cause material injury to the inundation canals, particularly in September. It recommended sharing of Indus water in the winter months, but Punjab and Sind did not accept any recommendation in spite of discussions at technical and administrative levels from 1943 to 1945. Ultimately, two governments referred the matter to his Majesty's Government in New Delhi but no final decision was taken till August, 1947, when after the Partition, eastern Punjab came within India and western Punjab and Sind went to Pakistan.

Western districts of Punjab in Pakistan were receiving water for irrigation of the Sutlej, the Beas and the Ravi belonging to be Indus system before Independence, though control structures were located in eastern Punjab in India. India continued to release water, as per an interim agreement ('Stand Still Agreement') up to the end of March 1948. As Pakistan did not show any interest in reviewing the agreement within the period, India discontinued supply of water to the Upper Bari Doab Canal which passes through Pakistan's western areas. Supply was resumed a few weeks after the signing of the 'Delhi Agreement' on 4th May 1948. In it, India assured Pakistan that it has no intention to withhold water to Pakistan, without giving it time to tap other resources. On the other hand, Pakistan recognized the genuine anxiety of India to discharge its obligation to develop areas of east Punjab where water ran short and the areas were underdeveloped, compared to West Punjab. The problem arose afterwards on the issue of availability of water, which lingered for more than three years in spite of discussions between the two governments.

In this period, David Lilenthal, ex-Chairman of the Tennessee Valley Association (TVA) who had earlier visited India and Pakistan, in an article in 1951 in an American journal, suggested that instead of dealing with the issue at the political level, it could be solved from a purely technical angle and that the World Bank might help to provide the necessary money. It was accepted and the negotiations commenced between the two countries with the good offices of the World Bank at Washington in May 1952 and the Indus Water Treaty came into effect in September 1960, after more than eight years.

The treaty was signed at Karachi by Jawaharlal Nehru, India's Prime Minister and Pakistan President, Ayub Khan. It was ratified by the two governments and the ratifications were exchanged in Delhi in January 1961; the treaty came into force with retrospective effect from 1st April 1960. Under the treaty, the waters in the Indus and its tributaries were to be diverted and those that formerly flowed into Pakistan from India were to be replaced, in part, by storage, on the western rivers in Pakistan through connecting canals. India would have unrestricted control over the waters of the Sutlej, the Ravi and the Beas, except during the transition period, 'when supplies to Pakistan would be continued by India according to the provisions of the treaty.' The period commenced on 1st April 1960 and ended ten years later on 1st March 1970. India was allowed to draw water from the two Indus tributaries – Jhelum and Chenub for irrigation of existing areas and developing 0.7 million acres of irrigation by these rivers, subject to certain conditions, as per the treaty. India would allow the rest of waters of these rivers to flow downward for use by Pakistan.

The provision of the 10-year 'transition period' was made to give Pakistan sufficient time to build engineering diversion and storage works for the substitute water supply from other sources, previously received by it from the Sutlej, the Ravi and the Beas but the agreement could not be through, as funds were not available for these works from sources outside the basin countries. The World Bank established the ‘Indus Basin Development Fund’, to which, besides Pakistan and India, Australia, Canada, the Federal Republic of Germany, New Zealand, the United Kingdom and the United States also contributed. India agreed to contribute 62 million pound sterling, in equal instalments toward the cost of these works. The agreement also made it clear that India would have no right to take part in the decisions on the system of works and also have no responsibility.

The treaty provided for regular exchange of river and canal data and for future cooperation. A permanent Indus Commission was formed by the two permanent commissioners, selected by two countries from among expert engineers, competent in hydrology, water management and use. The Commission would meet regularly, alternately in Pakistan and India and tour to both countries to clear any doubt or difficulty which might arise. It would also make cooperative arrangements to implement the treaty, submit an annual report to the two governments and resolve, by agreement, any differences concerning the interpretation, or application, of the treaty. Provisions also exist in the treaty, regarding the procedure to be followed, if the Commission could not resolve any problem by reference to a ‘Neutral Expert’ or a ‘Court of Arbitration’. A plan of Indus river basin is shown in Fig. 13.1. The

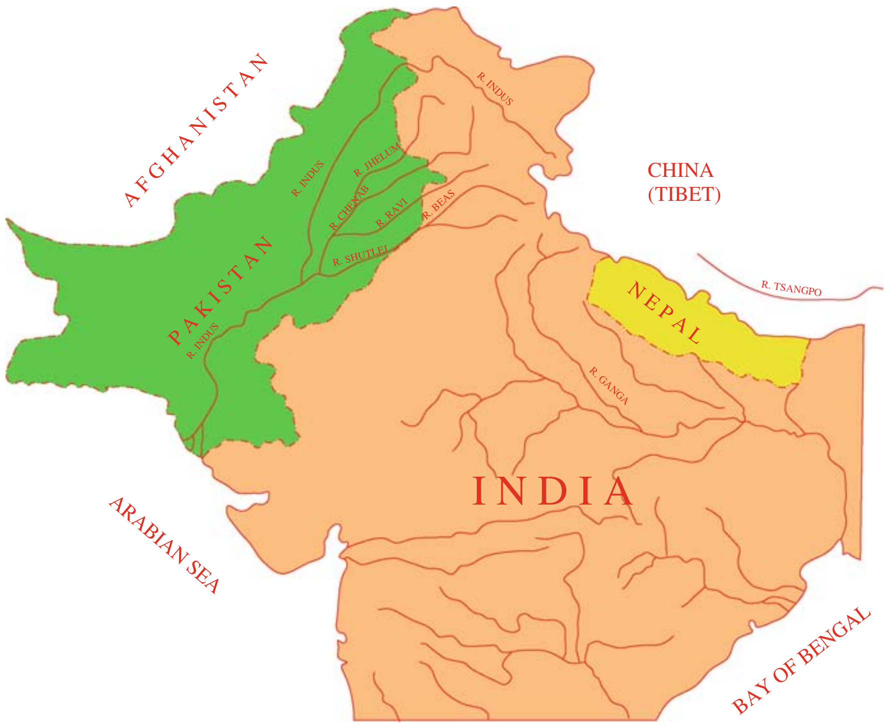

Fig. 13.1 Index plan of Indus river system

Indus treaty underlines the importance of planning and negotiation to account for the financial capability of the basin countries to undertake the required works to ensure an equitable agreement and the important role that leading international institutions play in strengthening financial capability of the basin countries.

The so-called 'international rivers', lakes and aquifers form the major global stock of freshwater. There were 214 international river basins, as per the list prepared by the United Nations Department of Economic and Social Affairs up to 1975. Out of these, the UNDP has financed, and assisted in various ways, other UN agencies and the Secretariat as well as regional organizations, in executing development projects, totalling about 30 International river basins. The World Bank has also long experience of financing and assisting 'international' river development projects. The Bank has been involved in 29 projects up to 1975 to deal directly with the development of 'international' rivers and river basins and to resolve disputes.

Inter-State River Basin Organization in India

Disputes also arise on sharing water of rivers that flow through different provinces within one country, making it difficult for a federal government to resolve them. Sometimes, they linger for years owing to political influences on the most essential technical considerations for irrigation and agriculture, drinking water, navigation, flood and erosion control, power generation etc. Many of such disputes were settled by joint discussions at the initiation of the central government and agreement reached. Some examples are cited as under:

i) *Bhakra Nangal Project*: Disputes arose between Punjab and Rajasthan on the share of the waters of the Indus tributaries-the Sutlej, the Ravi and the Beas. The Bhakra Nangal agreement was reached in 1959 and Rajasthan got its share of water through a network of canals for irrigation and drinking water.
ii) *The Krishna River Project*: The river flows through Maharashtra and Karnataka. A dam at Nagarjun Sagar in Karnataka was constructed and the issue of sharing of water was settled through a commission in 1962.
iii) *The Godavari River Project*: The river flows through five States – Maharashtra, Karnataka, Madhya Pradesh, Orissa and Andhra Pradesh. Sir Arthur Cotton, a British engineer, constructed an anicut in 1847 across the river for irrigation. It functioned nicely for about 100 years, during which the upstream of the anicut was totally silted and rendered obsolete. Another dam was constructed over the branch river to distribute water between the States. Thereafter, a barrage was constructed on the river in 1980 to transfer water through link-canals.
iv) *The Sone River Project*: The river passes through Madhya Pradesh, Uttar Pradesh and Bihar. A barrage has been constructed and an agreement signed in 1973.
v) *The Mahi River Project*: The river flows through Madhya Pradesh, Rajasthan and Gujarat. A barrage on the river has been constructed and an agreement on water-sharing has been signed in 1965.

vi) *The Chambal River Project*: The river flows through Madhya Pradesh and Rajasthan. A barrage on the river has been constructed and an agreement on water-sharing signed.

vii) *The Narmada River Project*: The river flows through Madhya Pradesh, Maharashtra and Gujarat. A commission was constituted by the Government of India, headed by A. N. Khosla, a renowned engineer. An agreement was signed in 1965, but none of the States was satisfied because of shortage of water for irrigation. A large project of dams on the tributaries with potential of hydro-power was planned and designed by the Central Water Commission, New Delhi with the consent of the three States. It was cleared by the Government of India, but the dispute lingered owing to large-scale submergence by the big reservoirs and the dire prospect of re-settlement of a large population, to be affected by it. An environmental protection group, led by Sunder Singh Bahuguna and Medha Patekar launched a movement against high dams, ecological imbalance and also widespread submergence. The Government of India constituted the Narmada Control Authority (NCA) with experts, but the problem could not be solved. Very little progress on the project has been achieved so far.

viii) *The Cauvery River Project*: The river flows through four southern States – Karnataka, Kerala, Tamilnadu and Andhra Pradesh. A dam was constructed at Almatti and an agreement reached in 1942 on sharing and distribution of water in the four States. A growing need for more water compelled these states to demand raising the height of the dam for storage of more water. The Government of India agreed to meet this demand, but Andhra Pradesh differed on the quantity of water, demanded by the other States, as this would leave much less water for it and the districts which were suffering badly for want of water for yield of cotton, maize, *bajra* etc. would be affected more. So in spite of a clear judgement of the Supreme Court about the release of specific volume of water for Andhra Pradesh, the disputes continued and the problems remained unattended.

ix) *The Damodar River Project*: The river flows through Bihar and West Bengal. Dams were constructed on the river and its tributaries – Barakar, Maithan, Panchet, Konar and Tilaiya– for irrigation and hydro-power generation for these two and other adjoining States. The Damodar Valley Corporation (DVC) was set up by the Government of India to implement schemes and remain responsible for their operation, maintenance and distribution of water. The scheme is shown in Fig. 13.2.

x) *The Mayurakshi River Project*: The river also flows through Bihar and West Bengal. A dam was constructed at Masanjore on Bihar–Bengal border for irrigation as well as power generation.

xi) *The Subarnarekha River Project*: The river flows through Bihar, Orissa and West Bengal. A scheme was conceived for storage and distribution of water for irrigation through a network of canals within the three States. The work was in progress in 2008.

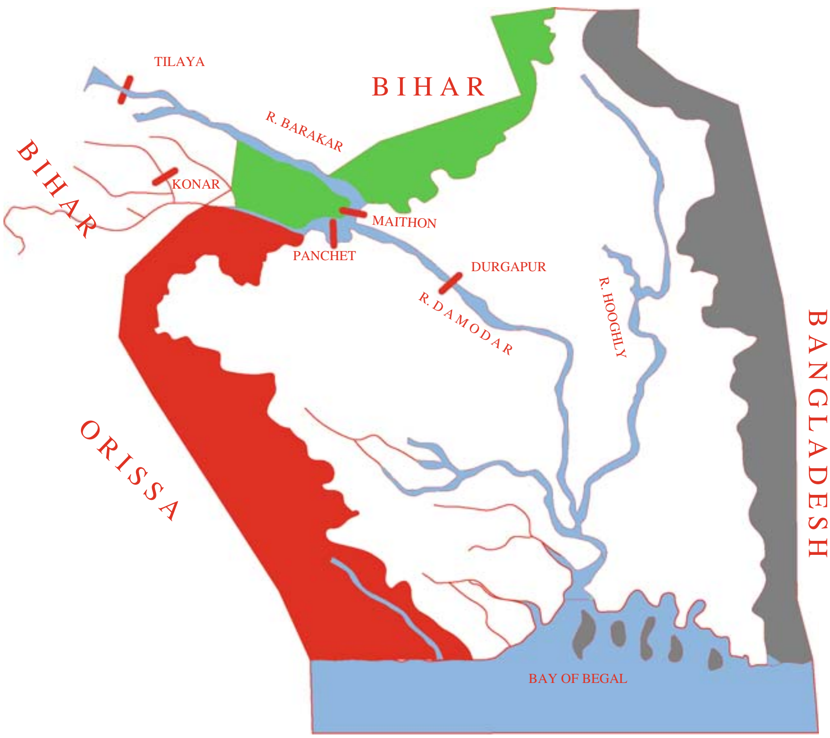

Fig. 13.2 Index plan of Damodar river

Discussion

'International' and national rivers, flowing through different countries and different provinces of a country, respectively provide sweet water for irrigation, use of human and other livestock, industries, power generation and navigation, irrespective of political or geographical boundaries. Most of the treaties have been successfully signed in Europe and America through mutual understanding and at the initiative of international organizations. The UNO has been playing a major role on these and many treaties have been signed between and among concerned countries.

Though favoured by the upper riparian countries, the 'Harman Theory' of 1896, named after a US Attorney General, that every State has absolute sovereignty over the rivers flowing through its territory was deemed totally unjust by lower riparian States. According to another theory – the 'Natural Flow Theory' – the lower riparian States are entitled to the natural flow of the river, uninterrupted by upper riparian countries. The theory was initiated by Egypt in respect of the claim on the Nile water by Sudan. Both these theories did not offer any acceptable solution to all concerned owing to conflicting interests. There is need, therefore, of a theory, safeguarding the interest of both upper and lower riparian States and of adopting a solution which would be acceptable to all parties. This can be called the 'Theory of Equitable Utilisation', according to which the entire basin of a river would be deemed as one economic unit and its water would be utilized to the best advantage of all basin countries. Development schemes would have to be planned and the works are to be executed, jointly or singly, within each territory and benefits to be shared with other countries. The USA-Canada Treaty on the development of the Columbia river basin is an example. The river originates in Canada and flows down through the USA. The scheme envisaged construction of storage dams to help control floods in the USA and generation of hydro-power for consumption by both countries. In addition, Canada would get huge financial benefits from the USA to compensate for the construction of storage dams in Canada and their operation. The index plan of the Nile river is shown in Fig. 13.3.

The Indus Treaty between India and Pakistan is another example, where interests of both countries were safeguarded. A compromise between conflicting interests is the only solution, when faced with the existing and the new, each affecting the other. Judicial decisions alone cannot resolve water-related disputes; practical considerations yield better results. The most satisfactory and abiding settlement of water disputes is possible through agreements or treaties, treating concerned countries as a single united community, undivided by political or administrative boundaries. The observations of the Rau Commission on the Indus water dispute were on above lines, which made it most relevant in the eyes of reputed international jurists. Helsinki Rules emphasize this aspect as under.

> Although certain disputes about international rivers and river basins may lead themselves to third party adjudication under established international laws, the maximum utilization of drainage basins can more effectively be secured through joint planning. The great number of variables involved the possibility of future changes in the condition of the waterway, the necessity of providing affirmative conduct by the basin States and the enormous complexity of a river basin makes comparative management of the basin greatly preferable to adjudication of each source of friction between the basin States.

Fig. 13.3 Index plan of the Nile river

The UN Conference on the Human Environment, held at Stockholm on 15th and 16th June 1972 made the following recommendations for settlement of problems arising out of sharing water resources, common to more than one jurisdiction, with particular reference to the effect of environment. These are reproduced below:

> It is recommended that governments concerned consider the creations of river basin commissions, or other appropriate machinery, for cooperation between interested States for water resources, common to more than one jurisdiction. The recommendations are

- In accordance with the UN Charter and the principles of international law, full consideration must be given to the right of permanent sovereignty of each country concerned to develop its own resources.
- The following principles should be considered by the States concerned when appropriate:
  - i) Nations agree that when major water resource activities are contemplated that may have a significant environmental effect on another country, the other country should be notified well in advance of the activity envisaged.
  - ii) The basic objective of all water resource use and developmental activities from the environmental point of view is to ensure the best use of water and to avoid its pollution in each country.
  - iii) The net benefits of hydrologic regions, common to more than one national jurisdiction are to be shared equitably by the nations affected.
- Such arrangements, when deemed appropriate by the States concerned, will permit undertaking on a regional basis, as under:
  - i) Collection, analysis and exchange of hydrologic data through some international mechanism, agreed upon by the States concerned.
  - ii) Joint data collection programmes to serve planning needs.
  - iii) Assessment of environmental effects of existing water uses.
  - iv) Joint study of the causes and symptoms of problems, related to water resources, taking into account the technical, economic and social considerations of control of water quality.
  - v) Rational use, including a programme of quality control, of the water resource as an environmental asset.
  - vi) Provisions for the judicial and administrative protection of water rights and claims.
  - vii) Prevention and settlement of disputes with reference to the management and conservation of water resources; and
  - viii) Financial and technical cooperation of a shared resource.
- Regional conferences should be organized to promote the above considerations.

These principles were further enhanced by their affirmation in two resolutions of the General Assembly, adopted immediately after the Stockholm Conference (Resolution No. 2995 [xxvii] on 15th December 1972), which emphasized that:

'... In the exploitation and development of their natural resources, States must not produce significant harmful effects in zones situated outside their natural jurisdiction.' To sum up, it can be said that although New Delhi wanted to solve the problem of sharing the Ganga water with Bangladesh through mutual cooperation and understanding, Bangladesh did not. India envisaged schemes, when it was united and undivided but could implement them only after the Partition with full knowledge of East Pakistan and later Bangladesh. Diversion of water from Farakka Barrage started in 1975 in the presence of engineers and experts of Bangladesh. In the beginning, a short-term agreement and two MOUs were executed and thereafter, a long-term treaty was signed in keeping with international guidelines but problems and dissatisfaction of the concerned countries remained.

Thus, although the Ganga River Treaty could have been another example of the two concerned countries solving the problems of an ‘international’ river, flowing through them, it remained short of this ideal owing to lack of mutual cooperation, accommodation and understanding in the part of the lower riparian country, i.e., Bangladesh in spite of sacrifices and friendliness of the upper riparian country, i.e., India.

Chapter 14
Necessity of Regional Co-operation

India's three major rivers– the Ganga, the Brahmaputra (called Yamuna in Bangladesh) and the Meghna– are common to India and Bangladesh, an undivided terrain before 1947(except from 1905 to 1911 when it was first divided by Lord Curzon).

A large delta, spread over India and Bangladesh, known as the Bengal basin, was formed by these three major rivers. Throughout the geological quaternary ages, these three rivers flowed on numerous existing and abandoned courses, leaving behind a large, low-lying, flat alluvial plain. The delta, formed by the Ganga and the Brahmaputra is the largest in the world, spread over 59,600 sq. km (23,000 sq. miles). The Ganga, primarily a meandering stream, has a maximum normal discharge of the order of 70,780 cumecs, or 2.5 million cusecs and the Brahmaputra, primarily a braided river, has that of the same volume too. The Meghna, the smallest of the three, has an approximate flood discharge of 14,170 cumecs, or 0.5 million cusecs. Thus, during floods, the Ganga and the Brahmaputra accumulate about 141,600 cumecs, or five million cusecs of water at Goalanda in Faridpur district of Bangladesh and about 155,000 cumecs or 5.5 million cusecs near Chandpur, also in Bangladesh; this combined discharge flows into the Bay of Bengal. The average annual discharge of the three rivers, which is about 42,470 cumecs or 1.5 million cusecs, is nearly the same as of the Mississippi in the USA. This huge discharge flows through Bangladesh after merging at a single point, making it the largest in the world.

The hydrological features of the three rivers are summarised below.

The Ganga

The main stream comprises the combined flow of two rivers–Alakananda and the Bhagirathi – which meet at Deva Prayag in Garhwal district of Uttarakhand, a new Indian province, carved out of Uttar Pradesh in the Himalayan range in 2002. The original course flowed southward, then easterly and finally in its lap, flowed southward again and debouched into the sea. During its eastward middle course, a number of big and small tributaries join it from the north i.e. the left bank which also originate from the Himalayan range in Nepal. Therefore, these tributaries flow from

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7_14, © Springer Science+Business Media B.V. 2010

Nepal as well as from the Indian soil on the south of Himalayan foothills. The major tributaries from the north are the Rama Ganga which joins the Ganga much above the confluence with the Yamuna at Allahabad, the Gomati, the Ghagra with its three tributaries – the Sarda, the Karnali and the Rapti, the Gandak and the Kosi with its two tributaries – the Buri Gandak and the Bagmati, the Kamala, the Sun Kosi and the Arun Kosi. The Gomati flows entirely within the Indian territory; the Sarda flows in India except a small portion in Nepal, the Karnali, the Rapti, the Gandak and the Kosi and their tributaries originate in Nepal. On the south, Yamuna joins the Ganga at Allahabad where its total annual run-off is more than that of the Ganga. The average annual run-off of the Ganga is about 0.06 trillion (10^{12}) cubic metre against 0.09 trillion (10^{12}) cubic metre for the Yamuna. Thus, the combined run-off of the Ganga below the confluence is about 0.15 trillion (10^{12}) cubic metre. With the contribution from the tributaries on both sides the average annual run-off of the Ganga at Farakka increases to about 0.4 trillion (10^{12}) cubic metre, owing to contribution of the tributaries from both sides. Out of this total run-off, the contribution from Nepal is approximately 20% only, which flow through tributaries originating in Nepal.

As stated, the catchment area of the Ganga basin between the Himalayan (northern side) and the peninsular sub-basins (southern side) is in the ratio of about 60:40, but the discharge contribution is just the reverse, i.e., about 40:60 owing to more intense rainfall in the Himalayan range and also over the foothills than that of the peninsular region. Thus, hydrologically, the Himalayan rivers contribute more to the management of water resources than the peninsular streams. Of the Himalayan streams, the Ghagra with its tributaries contribute maximum run-off – about 94,500 Mm^3 and the Gomati up to about 7,400 Mm^3 cusecs. Of the peninsular streams, the Sone contributes run-off up to 32,000 Mm^3 and the Kosi gives at least 5,000 Mm^3 run-off. The Yamuna is not a peninsular stream, as it originates in the Himalayan range, not far from the origin of the Ganga. The details of catchment area of the tributaries are shown in Table 14.1 below.

Average annual run-off of the Ganges at Farakka varies from 0.35 to 0.40 trillion (10^{12}) cubic metre.

Above the confluence with Yamuna at Allahabad-
Run-off of the Ganges — 0.053 trillion (10^{12}) m^3 — 13%
Run-off of the Yamuna — 0.098 trillion (10^{12}) m^3 — 25%
Total — 0.151 trillion (10^{12}) m^3 — 38%

Therefore, the average annual run-off between Allahabad and Farakka is (0.40 – 0.151) 0.249 trillion (10^{12}) m^3.

Now, contribution from Northern side is about 60% and that from Southern side is 40%.

Therefore, contribution from Northern side is 0.149 trillion (10^{12}) m^3.
Say, 0.150 trillion (10^{12}) m^3.

Considering 50% run-off from Nepal, contribution from Nepal is 0.075 trillion (10^{12}) m^3. This is about 19%, or say, 20% of the annual run-off available at Farakka, or about one-fifth of the average annual run-off at Farakka. A schematic diagram of the Ganges river with its tributaries on either side and of other rivers of India and the neighbouring countries is shown in Fig. 14.1.

Table 14.1 Tributaries of the Ganga river (up to Farakka)

Name of tributary	Name of sub-tributary	Country from which originated	Catchment area covering the Country	Average annual run-off (Mm^3)	Remarks
1	2	3	4	5	6
A) Northern side					
i) Ramaganga	–	India	India	15,300	–
ii) Gomati	–	India	India	7,400	–
iii) Ghagra	a) Sarda	India	India + Nepal	Total-94,500	Small contribution from Nepal
	b) Karnali	Nepal	Do		
	c) Rapti	Nepal	Do		
iv) Gandak	–	Nepal	India + Nepal	52,000	
v) Kosi	a) Buri Gandak	Nepal	India + Nepal	Total-69,000	–
	b) Bagmati	Nepal	Do		–
	c) Kamala	Nepal	Do		–
	d) Sun Kosi	Nepal	Do		–
	e) Arun Kosi	Nepal	Do		–
					–
B) Southern side					
i) Yamuna	a) Chambal	India	India	Total-98,000	–
	b) Sind				
	c) Betwa				
ii) Ken	–	India	India	11,500	–
iii) Tons	–	India	India	6,000	–
iv) Sone	–	India	India	32,000	–
v) Kiul	–	India	India	5,000	–
vi) Punpun	–	India	India	4,000	–
vii) Gumani	–	India	India	2,000	–

No dams have been constructed on any of these tributaries and the passage of water has not been fully blocked, but other types of control structures, such as barrages, anicuts etc. have been constructed across most of the tributaries and the parent river Ganga for diversion of some discharge for irrigation and other purposes.

The average monthly discharge of the Ganga river at Farakka point is shown in Table 14.2.

James M. Coleman recorded an average annual discharge of 412,000 cusecs, or 11,665 cumecs and maximum high-flood discharge of 2.585 million cusecs, or 73,190 cumecs in September 1961 near the Hardinge Bridge. The lowest flow, as he recorded, in the river as 42,000 cusecs, or 1189 cumecs. From the Table 14.3, it is observed that the average annual discharge in the river between 1979 and 1988 was 393,000 cusecs or 12,120 cumecs. The highest discharge, recorded in September 1998 was about 2,650,000 cusecs, or 75,000 cumecs and minimum discharge was about 1,050 cumecs, or 37,000 cusecs, in April 1980. In the Ganga, the flow goes down from October, hits the minimum between the last weeks of March and April, then rises from May-end, or the first part of June and hits the maximum between

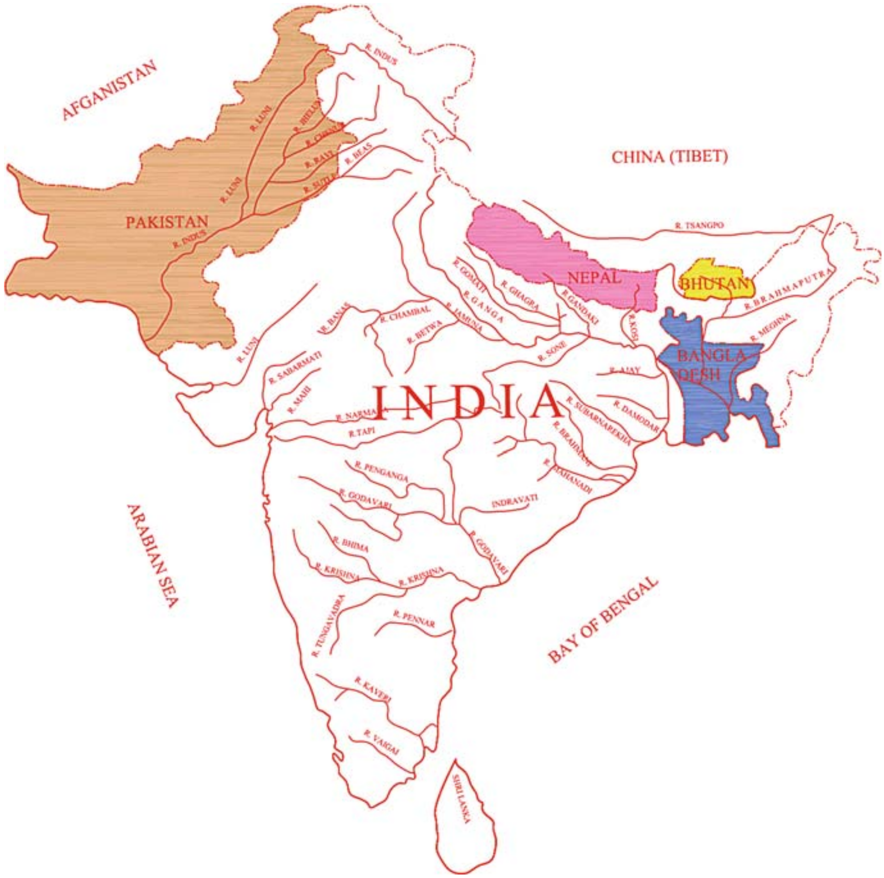

Fig. 14.1 River systems of India and neighbouring countries (See also Plate 10 on page 372 in the Colour Plate Section)

the last week of August and the first week of September. The first flood-peak occurs generally in India in July-end, or in the first week of August. Both the rising and falling stages are quite sharp, as can be seen from the Table 14.2. This is clear from the water-level hydrographs of a few years, as shown in Fig. 14.1.

The Ganga's left arm enters Bangladesh after flowing about 50 km from Farakka; the Mahananda joins it from the left. This river has its origin in India and about 10,000 sq. km of its catchment area is also in India's north-eastern States. Its average annual run-off is about 5,000 million cubic metres. A small portion of its lean-season flow has been held by barrage near Siliguri in Darjeeling district of West Bengal for irrigation purpose. Other tributaries of the Ganga-Padma in north Bangladesh are the Purnarbhaba, the Atrai (Boral) and the Karatoya which also originate in India. Their catchment area – about 20,000 sq. km – sprawls in India and Bangladesh. Taking their average annual run-off to be between 4,000 and 5,000 million cusecs,

Table 14.2 Average monthly discharge of the Ganga at Farakka (1979–1988)

Month	Discharge in cusecs	Discharge in cumecs	Remarks
January	57,430	1,630	1) Low discharge below 1132 cumecs (40,000 cusecs) recorded in 1981, 1983, 1984, 1985, 1986, 1987 and 1997.
February	46,020	1,300	2) High flood occurred in August during 1979, 1981, 1984, 1985, 1986, 1988, 1996 and 1998.
March	37,620	1,070	3) High flood occurred in September during 1980, 1982, 1983, 1987, 1996 and 1998.
April	37,330	1,060	4) In none of these years high flood crossed 56,625 cumecs (2,000,000 cusecs) for one month.
May	48,460	1,370	
June	125,000	3,560	
July	734,500	20,800	
August	1,386,000	39,250	
September	1,382,000	39,150	
October	569,800	16,130	
November	188,700	5,340	
December	97,330	2,760	
Average	392,650 Say, 393,000	11,118 Say, 11,120	

Table 14.3 Average monthly discharge of Bangladesh rivers (in 1000 cumecs)

	Ganges at Hardinge bridge (1934–1963)			Brahmaputra at Bahadurabad (1956–1962)			Meghna at Bhairab Bazaar (1957–1962)		
Month	Max	Min	Mean	Max	Min	Mean	Max	Min	Mean
January	5.10	2.29	3.11	6.60	4.36	5.21	0.65	0.51	0.59
February	4.76	1.90	2.75	4.98	3.40	4.33	0.54	0.37	0.48
March	3.60	1.61	2.35	5.97	3.77	4.67	1.10	0.51	0.62
April	2.97	1.25	2.04	8.61	5.15	7.13	1.13	0.74	0.91
May	3.14	1.39	2.12	24.04	7.98	17.81	2.49	1.39	1.93
June	9.68	2.35	4.36	38.65	26.50	32.22	5.38	3.37	4.19
July	29.59	10.76	18.09	45.36	33.55	40.15	9.12	5.69	7.28
August	52.58	23.61	39.44	55.52	30.72	44.00	9.14	6.68	7.76
September	56.03	25.03	36.64	48.50	24.35	35.33	9.51	6.43	7.73
October	42.30	8.35	17.72	32.28	14.07	21.49	8.10	5.27	6.68
November	16.53	4.39	7.19	14.98	8.49	10.59	5.01	1.78	2.77
December	6.74	2.86	4.19	9.37	5.66	6.65	1.27	0.79	0.99
Mean (Annual)	16.36	7.81	11.66	21.74	17.98	19.20	3.94	3.00	3.51

the total contribution by the Mahananda and these tributaries is about 15,000 million cusecs; about 50% of it comes from India. No control structure exists across these rivers. The total catchment areas of the Mahananda (over India and Bangladesh) and its tributaries are about 10,000 sq. km and 20,000 sq. km, respectively.

The catchment area of the Bhagirathi-Hooghly sprawls over about 60,000 sq. km but unlike the Ganga's tributaries in the upper and lower reaches, which started from the Himalayas, its tributaries have their origins in Rajmahal and Chhoto-Nagpur hills which are much lower than the Himalayas and therefore, have very little, or no discharge in dry season. Therefore, dams had to be constructed over a few of these for irrigation and generation of hydro-electricity.

Thus, the total drainage area of the Ganga-Padma for a length of about 2,515 km is about 1.03 million sq. km (their length within Bangladesh is about 380 km), out of which 450,000 or 0.45 million, sq. km is on its north and 580,000 or 0.58 million sq. km is on the south. Northern tributaries, like the Ghagra, the Gandak and the Kosi together drain about 190000, or 0.19 million sq. km in Nepal (which is about 20% of the total drainage basin of the Ganga) and 30,000 sq. km in Bangladesh. However, the total drainage area of the Ganga along the Bhagirathi-Hooghly for a length of about 2,620 km up to the Sagar island is about 1.07 million sq. km, out of which 430,000 sq. km is on the northern and eastern sides and the balance 640,000 sq. km is on the south and the west. Here, the northern and eastern catchments include the areas of two small eastern tributaries – Jalangi and the Mathabhanga (about 10,000 sq. km) and 60,000 sq. km from western tributaries on the west.

The Brahmaputra

The Brahmaputra has its origin on the northern slope of the Himalayas in Tibet, where it is called Tsan Po. It flows eastward for a length of about 1,430 km (900 miles) along the foothills of the northern Himalayas and then turns southward and enters Arunachal Pradesh, an Indian State at its north-easternmost point and flows for about 180 km (110 miles). Then it turns west and flows through other Indian State, namely, Assam – for about 650 km (400 miles) and then enters Bangladesh. At the border, the river curves southward and continues on this course for about 240 km (150 miles) to its confluence with the Ganga. After this, the combined river flows for about 100 km (60 miles) and joins the Meghna. After about another 240 km, the combined discharge joins the Bay of Bengal. The total length of the river from source to sea is about 2,840 km (1,760 miles). Within Bangladesh, the channel varies considerably in width, ranging from less than two to more than 15 km. The Brahmaputra is a braided channel, unlike the Ganga, basically a meandering channel. During low flows, it becomes a multiple channel stream with sand bars in between and the channels shifting back and forth, between the mainstream banks which are often 6 to 12 km apart an aerial view of the river shows many channels, shoals and islands, which indicate a river of low hydraulic efficiency and of heavy sediment load.

The discharge of the Brahmaputra is mostly derived from the snow-melt in Tibet on the northern side of the Himalayas until it enters Arunachal Pradesh. Rainfall is very heavy in Arunachal Pradesh, Assam and Meghalaya in India and in Dinajpur and Mymensingh districts in Bangladesh, adding substantial flows in the river. The reach between Dhubri where its leaves India and enters Bangladesh and Aricha where it joins the Ganga is popularly known as Yamuna in Bangladesh. The old Brahmaputra course which is now a distributary of the main river and joins the

Meghna near Bhairab Bazar, used to be the main Brahmaputra, once upon a time; the present course, insignificant at that time, was known as Yamuna. Further down, there is one more distributary, Dhaleswari which leaves the left bank of the Brahmaputra and joins the Meghna, south of Dhaka city.

As stated, the Tsan Po/Brahmaputra is about 2840 km, or 1760 mile, long – longer than the Ganga in any of its courses. Up to Aricha, where it merges with the Ganga, the total drainage area is about 581,000, or 0.581 million sq. km, of which 293,000 sq. km is in Tibet, 241,000 sq. km is in India and only 47,000 sq. km is in Bangladesh. The catchment area of the river above Bahadurabad is about 536,600 sq. km. The discharge observation station at Bahadurabad recorded the highest flow of 71,320 cumecs, or 2519,000 cusecs, in 1958 and the lowest of 3,280 cumecs, or 116,000 cusecs, in 1960. The average annual discharge is about 19,200 cumecs, or 678,000 cusecs, which is nearly twice that of the Ganga. The first flood-peak occurs generally in mid-June and carries huge sediment load in both monsoon and lean seasons. During floods, the channel transports nearly 5 million tonnes of sediment in a day. The annual silt run-off Bahadurabad is about 735 million tonnes.

The Meghna

The Surma-Meghna flows on the east of the Brahmaputra through Bangladesh. The Surma rises as the Barak on the southern slope of the Nagaland-Manipur watershed in India. The Barak divides into two branches within Cachar district of Assam. The northern branch is called Surma which flows through east of Bangladesh beside Sylhet town and flows southward. The southern branch is called the Kushiara which flows through India and then enters Bangladesh. At first, the northern branch joins the Meghna near Kuliarchar and then the southern branch also joins the Meghna, near Ajmiriganj. The upper Meghna up to Shaitnol is a small river, whereas the lower Meghna below Shaitnol is one of the largest rivers in the world, as it is the mouth of three long rivers – the Ganga-Padma, the Brahmaputra and the Meghna. The last receives the old Brahmaputra on its right bank at Bhairab Bazar. Its total length is about 930 km, or 580 miles. It is predominantly a meandering channel, but in several reaches, especially where small tributaries leave sediment, braiding is evident and sand islands divide the river into two or more channels.

The maximum flood discharge, recorded in the Meghna, is of the order of 12,220 cumecs, or 431,500 cusecs, in 1960; the average annual discharge is of the order of 3,510 cumecs, or 124,000 cusecs, i.e. about one-third the Ganga's. Even though the river has a lower discharge than of the Ganga and the Brahmaputra, it leaves about 0.20 million tonnes of sediment in a day during floods.

There are about 50 other small and medium-size rivers which flow through both the countries and with which the interest of both the countries are involved. However the hydrological data of most of these rivers are available. Therefore, the following discussion on regional cooperation will be confined to these three major rivers. A schematic diagram of them when they are in spate is shown in Fig. 14.2.

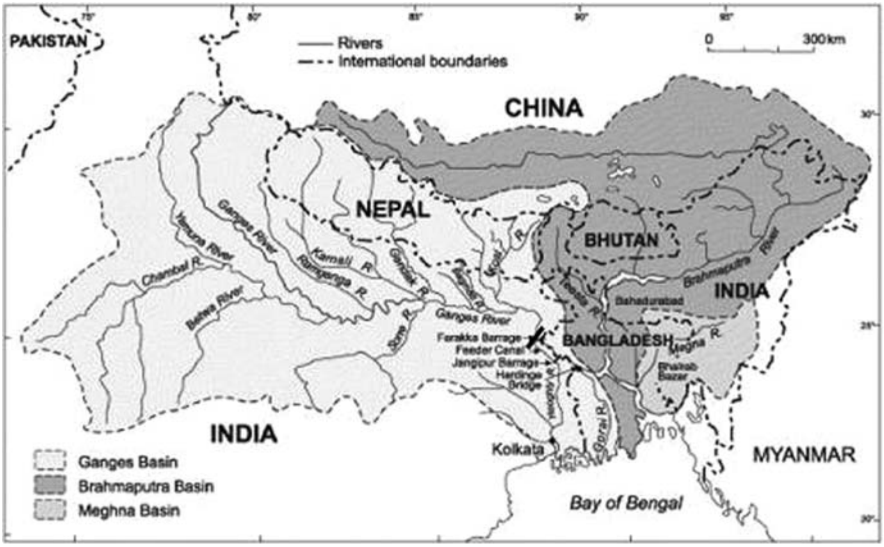

Fig. 14.2(a) GBM basin

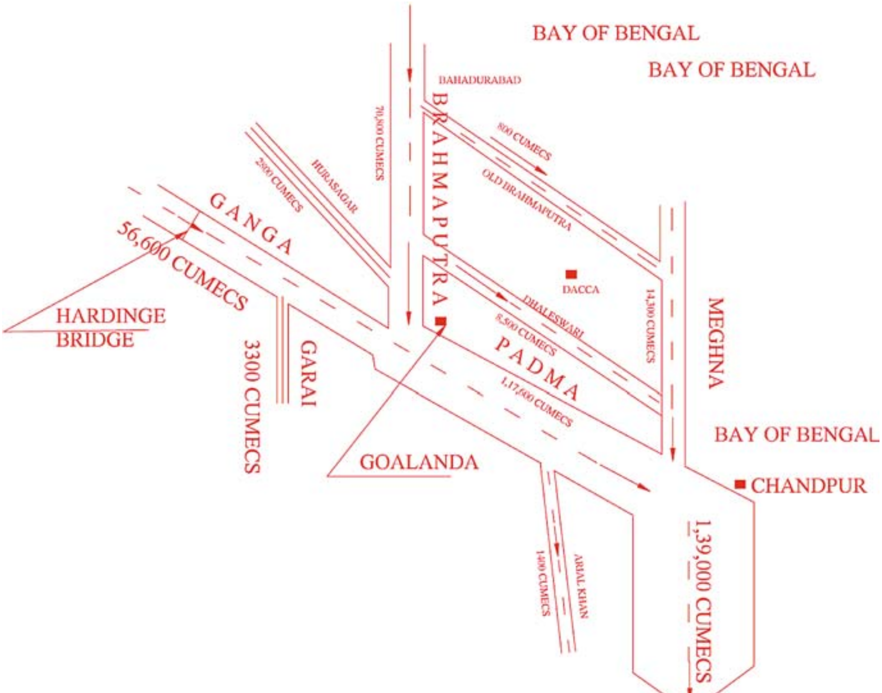

Fig. 14.2(b) Schematic line diagram of three major river system with normal flood discharge in Bangladesh

The minimum discharge of the Ganga normally falls to about 1,275 cumecs, or 45,000 cusecs, in mid-April. In the Brahmaputra, it goes down to about 3,170 cumecs, or 112,000 cusecs, and in the Meghna to about 370 cumecs, or 13,000 cusecs, in mid-February. The discharge in the Ganga rises appreciably from mid-June and falls appreciably from mid-October, every year but in the Brahmaputra and the Meghna, the flow rises appreciably from mid-April and falls from mid-September. For a comparative study of the average monthly discharge in the three rivers, the location of discharge observation sites within Bangladesh, as reported by James M Coleman in 1968 were considered. These are the Hardinge Bridge site for the Ganga, Bahadurabad for the Brahmaputra and Bhairab Bazar for the Meghna as shown in Table 14.3.

The Table 14.3 shows that whereas the Ganga starts rising from May, the Brahmaputra and the Meghna do so from March. Thus, there is a minimum time-lag of two months for flood in the Ganga and the other two rivers, the former follows the latter. Also, there is a time-lag of one month for the high flood, which comes in the Ganga in September and in the Brahmaputra in August. The minimum discharge in the Ganga, about 1,275 cumecs, occurs in April and that in the Brahmaputra, about 3,170 cumecs, about two months ahead, in February. Thus, the minimum discharge in the Ganga is over 2½ times less than that of the Brahmaputra, leaving plenty of water in the latter, even in lean season. From the schematic diagram shown in Fig. 14.3, it is seen that over 138,700 cumecs, or 4.9 million cusecs of water flow into the Bay of Bengal during floods through a single outlet of the three combined rivers, namely the Ganga, the Brahmaputra and the Meghna in Bangladesh. This is the largest in the world for a single outlet to the sea and exceeds even the Amazon by about 1½ times.

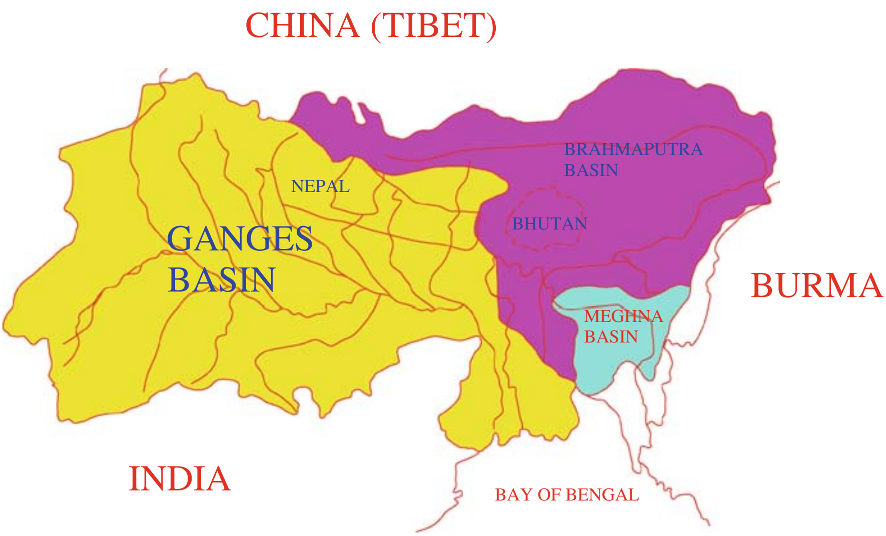

Fig. 14.3 The Ganges, Brahmaputra and Meghna basins (See also Plate 11 on page 373 in the Colour Plate Section)

Of the total volume of water, brought into Bangladesh, nearly 85% is carried by these three rivers, making them the primary causative factors for floods in Bangladesh. Flood flows of about 56,600 cumecs, or 2,000,000 cusecs, in the Ganga and the Brahmaputra and about 8,490 cumecs, or 300,000 cusecs, in the Meghna are generally sufficient to make the rivers and their tributaries/distributaries go into spate and overflow their banks. Thus, almost every year, water-levels in these rivers rise, spill over the banks and cause devastating floods. Bangladesh farm land is flooded, almost every year, plunging people in misery. Parts of Bihar and West Bengal in India are also affected in some years following the flood in the Ganga. The main characteristics (length, drainage area & discharge) of the three rivers follow in the Table 14.4.

The Table 14.5 shows that the maximum drainage area of the two rivers lay in India. The Ganga and the Brahmaputra get maximum water from the Indian soil. It is quite legitimate, therefore, for India demanding the maximum of its share for the benefit of its own soil and irrigation, drinking water, navigation and power generation. All the rivers are 'international' as they flow through more than one country. In respect of the Ganga and the Brahmaputra, India is a mid-riparian country and in that of Meghna, an upper one. Whatever may be the percentage of length, or of the drainage area in the two countries, international law dictates that the interests of the upper and the lower riparian countries have to be protected, as far as practicable.

Discussions are under way among India, Nepal and Bangladesh on issues of regional cooperation and development of water resources. Being poor and of uneven development, these South-Asian countries are considering many proposals of developing and effectively using water resources. Some of these are:

I. Storage of surface and sub-surface water for irrigation and mitigating or moderating flood;
II. Inter-basin transfer of water from India to Bangladesh and vice-versa;
III. Generation and distribution of hydro-electric power at suitable locations in Bhutan, India and Bangladesh;
IV. Improvement of navigation as well as other communication and transit facilities among Nepal, India and Bangladesh;
V. Financing and promotion of engineering expertise to secure the above; and
VI. Securing minimum guaranteed flow from India to Bangladesh.

Water resources abound in South-Asian countries, much of which flow, unutilised, into the sea. Rainfall and its distribution are not uniform in different months of the year. Therefore, judicious storage, transfer and utilization can only help their all-round development. Keeping this and proposals from various agencies in view, the potential of regional development etc. is shown in the Table 14.5 below.

These potentials for regional cooperation and exchanges cannot be achieved without mutual understanding and good neighbourly relation. Though the primary concern of each country is protection and promotion of its own interests, or the benefit of their own people, some sacrifice is necessary for regional development. Storage reservoirs may cause submergence of land and invite evacuation and resettlement

Table 14.4 Main characteristics of the rivers

River	Length (km)	Source	Drainage area (1000 sq.km)					Discharge (Cumecs)		Remarks
			China	India	Bangladesh	Nepal	Total	Max	Min	
1	2	3	4	5	6	7	8	9	10	11
Ganges	2,645 along Bhagirathi-Hooghly 2,650 along Ganga-Padma	India India	– –	880 (82%) 810 (79%)	– 30 (3%)	190 (18%) 190 (18%)	1,070 (100%) 1030 (100%)	75,000	1,275	Maximum discharge in Sept. Minimum discharge in April
Brahmaputra	2,840	China (Tibet)	293 (54%)	241 (45%)	47 (1%)	–	541 (100%)	71,320	3,170	Maximum Discharge in Aug. Minimum discharge in Feb.
Meghna	930	India	–	20 (20%)	80 (80%)	–	100 (100%)	12,220	370	Maximum discharge in Sept. Minimum Discharge in Feb.

Table 14.5 Potential for regional development

Countries involved	Potential possibilities	River basin
i) Nepal and India	a) Construction of storage reservoirs. b) Irrigation c) Hydro-power generation d) Grant of engineering expertise and finance	The Ganga and its tributaries
ii) Bhutan and India	a) Construction of storage reservoirs b) Hydropower generation c) Grant of engineering expertise and finance	Tributaries of Mahananda and Tista
iii) Bangladesh & India	a) Construction of storage reservoirs b) Flood mitigation/moderation c) Hydropower generation d) Guaranteed minimum flow e) Navigation and other transit facilities f) Inter basin transfer of water g) Granting engineering expertise and finance	Ganges, Meghna, Brahmaputra and the tributaries of Brahmaputra and Meghna
iv) Nepal and Bangladesh	a) Communication and transit facilities b) Transfer of Hydropower	Tributaries of the Ganges
v) International Organizations (in case of extreme necessity)	a) Provision for engineering expertise b) Provision for financing c) Arbitrating the disputes, if any.	–

of affected people, hydro-power has to be affordable. Inter-basin transfer of water may affect arable land. Engineering expertise and financial help may be inescapably required from other countries. All these can be sorted by detailed discussions among the concerned countries. Happily, a process is under way and following an understanding between the governments of India and Bhutan, a hydro-electric power project has been set up at Chukha in the Himalayan kingdom. The Kosi barrage project has been possible because of Indo-Nepal goodwill and joint endeavour. Negotiations are also on between Nepal and India for construction of storage reservoirs on other tributaries of the Ganga and for hydro-power generation and irrigation. The Ganga Water Treaty of 1996 between India and Bangladesh was the result of mutual understanding and cooperation on water sharing and minimum guaranteed flow to Bangladesh. However, only a few have been achieved and many more remain to be done. Though the national water policy envisages it, the water resource management of river basins as a whole has not made much headway, even in India which is the largest and more developed amongst these South Asian countries.

Negotiations for development of regional water resources should be initiated, either on its own, or bilaterally between the two countries. Most of the issues being bilateral, the government of India desires that all issues, be they on water resources, transit, transport, border dispute, or any other, are to be settled between the affected parties who are directly or indirectly involved, through discussions and with mutual trust and understanding. This is the policy, adopted by India since Independence and many problems were solved accordingly.

It is established that the combined discharge of the inter-connected river basins of the Ganga-Brahmaputra-Meghna (GBM) have enough water for the countries through which they flow and to meet their needs by optimal and integrated planning. Being land-locked and mountainous, Nepal and Bhutan have very little scope for irrigation except in some pockets but they have it amply for building reservoirs, generating hydro-power for their own use, or just for sale to India and Bangladesh. Therefore, a bilateral process is necessary between India and Bangladesh to explore the possibilities of cooperation on specific projects, involving inter-basin transfer of water for irrigation, navigation and hydro-power generation etc. However, joint discussions by India and Bangladesh with Nepal in 1986 on augmentation of the Ganga water at Farakka did not make much headway, as Nepal insisted on assurance of its benefits before exchange of information about storage facilities in its own territory. Moreover, floods in three river basins of Bangladesh occur in monsoon months, every year. In 1987–1988 and 1998, the floods were unusually severe, causing huge devastation. The Government of India, the USA, France, Japan and the UNDP rendered massive help in relief and rescue operations in 1987 and 1988 spates. Therefore, an understanding between India and Bangladesh on the vital issue of river-basin management is absolutely necessary.

The total water available from the basins of the Ganga, the Brahmaputra and the Meghna is a huge mass, much of which runs into the sea without any use. Only a miniscule of this prodigious water resource is utilized at present for irrigation, navigation and hydro-power generation etc. by the three countries. Droughts and floods have been occurring with increasing frequency and intensity all over the eastern and north-eastern parts of the subcontinent for several decades. The entire surface water irrigation of non-peninsular India, Nepal, Bhutan and Bangladesh depends on the water of these three river basins, leaving aside the huge ground-water potential of the region which is also indirectly contributed by the Himalayan rivers.

The annual available discharge of the three river basins is shown in Table 14.6 below.

As shown in the above table, the huge water mass, before coming down to the plains of India and Bangladesh, descends through steep Himalayan slopes in high falls at several places within Nepal and India. Some World Bank studies show that the hydro-power potential of the upper Ganga basin is about 13 million kw (Mkw) at 60% load factor, of which 4 Mkw are within India, 2 Mkw on the borders between Nepal and India and the rest within Nepal. Nepal's own potential for hydro-power is 83 Mkw, equivalent to the combined installed capacity of Canada, United States and Mexico. Nepal's geographical features permit massive hydro-power generation in three major sub-basins of the Ganga. According to the report of His Majesty's Government of Nepal, titled 'Hydro-power potentiality in Nepal, 1971', the Karnali basin generates 32 Mkw, the Gandak basin 21 Mkw and the Kosi basin 22 Mkw. Nepal's undulating land, covered with thick forests and numerous rivers, rivulets, creeks and Nullas(drains) has very little scope for waterway communication. Transport and communication through a network of roads and highways, or by railway, though not impossible, would be very costly as well as highly technical and time-consuming. Therefore, a viable mode of transport which is a crying need for

Table 14.6 Average monthly flow volume of three river basins (in million cusecs – Mm^3)

Month	Average monthly flow			
	Ganges at Hardinge Bridge	Brahmaputra at Bahadurabad	Meghna at Bhairabbazar	Total discharge
1	2	3	4	5
January	8,335	13,910	1,590	23,835
February	6,560	10,420	1,200	18,180
March	6,190	12,615	1,700	20,505
April	5,330	17,680	2,430	25,440
May	5,280	42,430	5,180	52,890
June	11,170	84,190	9,900	105,260
July	47,855	118,035	20,925	186,815
August	100,540	120,785	22,170	243,495
September	95,805	94,055	21,305	211,165
October	46,175	58,790	16,710	121,675
November	18,420	27,150	7,980	53,550
December	11,235	18,040	2,650	31,925
Annual	362,895	618,100	113,740	1,094,735
Say,	0.363 million Mm^3	0.618 million Mm^3	0.114 million Mm^3	1.095 million Mm^3

Nepal and Bhutan, can be a network of electrically-operated ropeway system across their mountainous territories and also with adjacent places in India and Bangladesh. As Nepal does not have high technical capability, such development is possible only if it generates and sells hydro-power to India in bulk, for which bilateral negotiations and understandings with Delhi are necessary. Trilateral or multilateral negotiations on this issue will be very difficult and may not succeed, unless a bilateral accord is reached. Already, India has stated the process with both Nepal and Bhutan and understandings on a few projects have been reached and yielded good results. The construction of barrages across the Kosi and the Gandak has been possible with such bilateral understanding between India and Nepal for the development of irrigation in two countries. Negotiations are also going on for construction of high dams in the San Kosi, the Tamur, the Kali Gandaki, the Chisapani etc., all of which would be located within Nepal. As stated, the Chukha hydro-power project would not have materialised but for technical and financial assistance by India. The work of the Tala hydro-power project is now in progress (2008) in Bhutan with also India's technical assistance.

Nepal and Bhutan suffer from enormous land erosion owing to the steep ground contour and large-scale deforestation, causing a veritable ecological disaster. Torrential rivers aggravate erosion in monsoon months, making their governments export eroded soil. If this continues unabated, Nepal will, some day, embrace ecocide, bringing in its trail widespread hunger and starvation of an increasing population. Nepal's economy was precarious for a long time because of political instability. It can never balance its trade with India unless it is able to produce and sell hydro-power to India and Bangladesh in a big way. An index plan of three river basins is shown in Fig. 14.3. On the other hand, as stated, Bangladesh has excess water, especially in monsoon months, which go waste, as it flows into the sea. High floods damage the crop and cause shortage of food and power for an exploding population and tardy industrial growth. Inter-basin transfer of water in a large scale to boost agriculture, transport and generation of hydro-power can materialize with bilateral negotiations and understanding with India. Unless this is done, Bangladesh can never achieve a balance of trade with India. The Ganga Water Treaty of 1996 was possible through such bilateralism. As it is, the Ganga basin is already developed and water available to it may not be in excess of the future requirement of India and Nepal. Therefore, the water resources of the Brahmaputra and the Meghna, which are almost untapped, can be gainfully utilized by constructing storage dams, barrages at suitable locations and also by inter-basin transfer of water from the Brahmaputra to the Ganga, as proposed by Indian representatives of the Joint River Commission (JRC) for augmenting the Ganga flow at Farakka. Construction of dams across the tributaries of the Brahmaputra, such the Subansiri, the Dihang and the Lohit in Indian soil and at Tipaimukh across the Meghna will help produce massive hydro-power for use by both countries.

The Working Group of ESCAP (earlier ECAFE) in Bangkok reported in 1968 that as the Brahmaputra during her long journey through Tibet into India goes through seven major falls and along precipitous gradients, it has potential for huge hydro-power which would have been equal to the total global production of electricity in that year. Harnessing of this massive potential would also help mitigate the flood hazards that Brahmaputra leaves on the Assam valley in India and Bangladesh, almost every year.

This would be possible through regional co-operation between India and China at the first instance and with Bangladesh, Bhutan and Nepal at a later stage, with technical and financial assistance by the USA, Japan, Russia, Canada, Britain and some international agencies under the United Nations. There has not been much progress in this direction and as it appears, Bangladesh which will benefit the most from such cooperation with India and other concerned countries is not much interested.

Augmentation of the Ganga flow at Farakka by inter-basin transfer of water from the Brahmaputra basin to that of the Ganga, as proposed by India, will not only revive Calcutta Port, improve navigability, but will be an immense source of irrigation, increase crop yield along its banks, generate ample hydro-power and mitigate flood hazards in the Brahmaputra valley in Assam and Bangladesh. The World Bank is of the view that such diversion would be a more logical and better economic solution of the problems of water scarcity in both countries, but the merits of the diversion and its timing need careful examination. Some 566 cumecs, or 20,000 cusecs to 1,132 cumecs, or 40,000 cusecs, can be transferred from the Brahmaputra to the Ganga without creating much problem in the river. The World Bank adds that there could be potentiality to use almost the entire dry-season flow of the Ganga which would boost agriculture and industry in India's upper riparian States.

On the other hand, Bangladesh held that there would be enough water in the Ganga basin for India, Nepal and Bangladesh; therefore, augmentation must be confined to the Ganga alone. It suggested 12 possible storage dams on the Karnali, the Sapta Gandaki and the Sapta Kosi, besides two more on the Arun and the Tamur (in Nepal). Together with those proposed on India's rivers, these would raise the dry-season flow of the Ganga from 1,557 cumecs, or 55,000 cusecs, to 5,096 cumecs, or 180,000 cusecs. Water stored in reservoirs in Nepal could be released to the Ganga through natural rivers. Besides, a canal constructed along the Terai in Nepal could carry water from the Gandak and the Kosi to the Mahananda, the Karatoya and the Atreyi, to augment their dry-season flow. It could also become a cross-country ('international') navigation route which Nepal, a land-locked country, needs badly. Nepal appears to be keenly interested in developing her irrigation, hydro-power and navigation facilities, but whether they have to be sorted out, bilaterally between Nepal and India, or trilaterally among Nepal, India and Bangladesh, has to be decided by Nepal. India's offer of bilateral dialogue with Nepal on these issues has merit. Being directly involved in the matter, it would be easier for them to take a quick decision. India and Nepal need almost the whole of dry-season flow of the Ganga. On the other hand, it is a fact that the water of the Brahmaputra is almost untapped and both India and Bangladesh would need huge quantity from its basin. According to a World Bank report, the total gross demand of water from the Brahmaputra basin in Bangladesh in the dry season is around about 2,265 cumecs (80,000 cusecs) and in Assam around 1,700 cumecs (60,000 cusecs) in the long run; therefore, there would be hardly any water left in the Brahmaputra for inter-basin transfer. However, much of this flow would be utilized for irrigation during the transfer also. It would thus not be difficult to transfer between 1,130 cumecs (40,000 cusecs) and 1,700 cumecs (60,000 cusecs) to the Ganga basin, even in the long run, after meeting the needs of both countries. Moreover, this volume of transferred water could be utilized by the two countries only. Seismically and in respect of other effects, the two proposals have their demerits too, which should be addressed while drawing the schemes. Thus, considering the pros and the cons, it appears that the Indian proposal has more merits but both countries should agree for overall development of the region.

The GBM basin has a diverse climate and a time-space variation of precipitation. Because of this, accommodation of the needs of the basin countries by a negotiated settlement is essential. Thus, inter-basin transfer of water from the Brahmaputra basin to that of the Ganga supports the storage of monsoon flow and its utilization for irrigation and hydro-power generation. Before going in for a multi-lateral understanding, or agreeing for it, bilateral understanding between the directly affected countries is absolutely necessary. Some progress has taken place, but it is quite slow when a vast population in the river basins suffers. There is thus a need to create public opinion in the basin countries for encouraging regional cooperation between, or among, the governments for harnessing river-water resources.

Chapter 15
My Views

During the formation of the earth, the Ganga delta might have emerged from severe dynamic and varied fluctuations of the sea-level, its changing shore-lines, upheaval of the land-mass and shifting courses of a number of rivers and birth of new streams. No mythologies about the mighty river were current during these geological processes. They were formed by experiences of primitive men. The native population lived on the river's basin until immigrant Aryans displaced them. The river was deified by them, as it was mighty, menacing and useful; its water quenched their thirst, met their other needs and nourished agriculture to feed them; its water was deemed holy and used in religious rites. It also became a medium of transportation of men and goods to near and distant land and its banks provided habitats for an increasing population and a civilisation flourished on its basin. The Ganga eventually became a part of India's ethnology, promoting commerce and agriculture, which lent sanctity to its water. From pre-historic days and the days Indus valley civilisation in the second and third millennium BC to the present day, the Ganga water has been a part of Hindu ceremonies like celebrations of birth and initiation, marriage and post-death rites and other sacred rituals. With the passage of time, the Ganga became known in the West for its might and sacredness.

The Ganga Basin

The Ganga valley was covered by forests in olden days, in early Buddhist era in the fifth and sixth century BC. Human habitation on its banks started in small groups which expanded and boosted trade and commerce. Buddhist scriptures mention traffic on its water as far east as Magadha and Champa kingdoms in Bihar. Champa was a capital city with trade connections with other great Indian cities like Tamralipta (present Tamluk) in southern tip of the Bengal delta. It was sacred to the Buddhists and Jains and was often visited by Lord Buddha and Lord Mahavira. The Ganga legend spread to Bengal where its channel shifted unpredictably, attracting silt and causing bank erosion which engulfed a series of major cities, the latest being Dhulian in Murshidabad. It is believed that the present Bengal delta once lay beneath the sea which extended up to the region of Gour, now in Malda. Gradually, the silt-load, coming down from the Himalayas with its water and eroded material

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
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of the banks, built up the land mass, criss-crossed by multiple rivers. In course of time, the silt deposits firmed and formed the region, presently spread over 11 West Bengal districts, forming the Bengal delta – Malda, Murshidabad, Nadia, Hooghly, north and south 24-Parganas and Kolkata in West Bengal as well as Jessore, Khulna, Barisal and a part of the Sundarbans in Bangladesh.

While the upper Ganga flood-plain comprises mostly older alluvial high land, through which the Ganga cut its way in diverse depths, the middle and the lower Ganga basins are composed of relatively recent alluvial deposits and characterised by extensive flood-prone plains on both sides, where the width of the river varies from 10 km to 20 km. These plains are visited by yearly floods which deposit small rocks, sand, silt and clay of varying thickness. The Ganga flood-plain belt is thus subject to various natural hazards but it has enormous economic potential. Following population explosion in India, the once marshy and desolate Ganga plains attracted people of the region and from elsewhere for habitation, agriculture, industry and pasture for cattle-grazing. The governments too were in dire need of vacant land for mass rehabilitation of refugees from two wings of Pakistan before and after the Partition in 1947. New townships, like Hastinapur in Uttar Pradesh, industries and fertile farmland have come up, especially on the upper Ganga flood-plains.

In the lower basin, the Ganga flows in two main branches – the Bhagirathi and the Padma; the former being the older channel carried the main flow on whose banks came up ancient prosperous cities. In days of yore, in the Hindu kingdoms, the Bhagirathi water, not that of the Padma, was taken to be the holy Ganga water and used in rites and rituals in the subcontinent. No great city, renowned for industries, pilgrimage or learning ever came up, or flourished, on either bank of the Padma. The Bhagirathi valley is very fertile, right from Murshidabad to the Sundarbans in the south because of silt deposited over years, but it also chokes the river and raises the river-bed which draws upward greater volumes of silt-laden saline sea-water, render the river-water unfit for drinking, household uses, navigation etc. and causes disastrous flood in monsoon months, overflowing the banks.

The Ganga basin has high density of population, said to be 8% of the global, living on the fertile farmland and industries along its banks. The high-precipitation monsoon is uneven along the Himalayan foothills, which gradually diminishes as it travels from southeast to northwest. Large seasonal time-space variations in the precipitation cause fluctuations in flow of the river. Over three-fourths of the flow occurs in three to four monsoon months. Because of lack of reservoirs and constraints of space in the Himalayan foothills and densely populated plains, this huge volume of rain water flows unused into the sea. This has given rise to demands for storage of monsoon flows in mountainous sites. Though, initially, it was aimed to mitigate flood, subsequently, ideas emerged using it for irrigation to increase crop yield, power generation, supply of water for industrial and domestic use and navigation. A burgeoning population led to increased demand for this water, but owing to limitations like lack of safety of such storage dams and lack of coordination among the affected countries, the ideas fell through.

Excessive rains on the Himalayan foothills, added with a large volume of snowmelt water generate, rather disproportionately, high volume of water to the total discharge of the Ganga. The three major trans-Himalayan tributaries – the Ghagra, the Gandak and the Saptakoshi-contribute about 71% of the natural and traditional dry-season flows and 41% of its total annual flow. These rivers also carry a large volume of fertile silt which is deposited on farmland during floods. People on the flat terrain, adjacent to the Himalayas, have learnt to live with annual inundation and make the best use of the fertile silt, left by it. For example, in the Bhutni Diara island in Malda district, on the left bank of the Ganga, opposite Rajmahal, people have learnt to live with floods by embanking both sides to contain spills. Recently, proposals have been mooted for constructing storage dams to control flood and additionally boost irrigation, urban water supply and generate hydro-electricity.

The peninsular sub-basin of the Ganga comprises the basins of its tributaries – the Chambal, the Sind, the Betwa, the Ken, the Sone etc., originating in the Aravalli hills and the central highlands, which join the Ganga from the south and the west. The ground configuration and the volume of precipitation in this sub-basin are different from those of the Himalayan rivers. Being the valley-line between these two sub-basins, the Ganga is the principal drainage channel, sloping downward from either side. The peninsular tributaries receive much less rains in their upper catchments but only in the three monsoon months – from July to September – at the same time as the rains on the Himalayan sub-basin, they causes severe drainage congestion in the catchment and the rain-water floods the basin before flowing down the lower part and then into the Ganga. The Himalayan streams add about 60% of the water in the Ganga and the peninsular rivers about 40%, though the latter cover about 60% of the basin area. This regional variation of rainfall and excess rain-water in the two sub-basins obviously gave rise to demands for its storage in the surplus areas and much wider distribution in the Ganga basin as well as for strategies for conservation and sustainable use in semi-arid conditions.

Surface water in the two alluvial sub-basins and scarcity of water in the southern and western regions are reinforced by the ground-water potential. The alluvial sub-basins of the Ganga are among the deepest sources of ground-water in the world, in quantity and quality. The annual recoverable recharge of ground-water in the Ganga basin within Indian territory is estimated at 0.15 million cubic metres. The reserve in the lower part of the basin in Bangladesh is also enormous. The main aquifer in Bangladesh is substantially recharged in every season after seasonal inundation, almost every year. On the contrary, the western and southern parts of the basin in Rajasthan, Chambal valley of Madhya Pradesh, Bundelkhand area of Uttar Pradesh, plains of south Bihar etc. have scant ground-water; this justifies and calls for inter-basin transfer westward in the Ganga basin.

The Ganga's reach between Mokama and Rajmahal and from Rajmahal to Jalangi *Bazzar* in West Bengal are being severely afflicted by bank slips in rainy months in almost every year for many decades. The construction of the Farakka Barrage caused varied and huge morphological changes in the adjustment of plan form, and cross-section, water-level, swinging course, direction of current, aggradation and degradation of the river-bed and the bed-slope, the silt movement and its deposition, formation of *char* land and alluvial plains and also bank erosion. The mighty Ganga will take a long time to adjust to these changes. Varied opening of the barrage gates, as per regulation procedure, for release of specified volumes of clean and silt-free water downstream and into the feeder canal in different seasons, throughout the river's cross-section, have made it all the more difficult and complex.

As stated, the Bhagirathi-Hooghly carried the major lean-season flow before the 17th century (see Chapter 2). The trading posts of some European merchants along its banks prospered, as their cargo-carrying sail-boats could ply on a deep navigable channel. Anchorage points of the 6th century AD gradually became major trading centres. British traders established a deep-draft inland port on the bank of the Hooghly in the heart of Kolkata and big industries came up, availing its facilities. Various morphological changes in the river altered the scenario. The off-take point of the Bhagirathi from the Ganga shifted and its mouth was choked by silt, carried in the upland discharge, gradually diminishing the flow from the parent Ganga. This made tide-borne silt move upward and get deposited in the bed, making its navigable channel shallow, reducing the width, increasing the swing of thalweg and forming silt-deposited bars and sand islands etc. The situation became so critical that the British Indian government had to look for alternatives, like shifting of the port facilities, alternative navigation routes upland and in the estuary, dredging the shipping route, stabilising banks and channelising the flow etc. under the advice of renowned experts, but there was no durable benefit. Ultimately, opinions veered to diverting a part of the flow from the Ganga through a long and wide canal by artificially heading up water at Farakka by constructing a barrage over the river. Thus, a century-old dream of successive governments, experts and concerned organisations became a reality. A quantum of 1,132 cumecs (40,000 cusecs) of water, as recommended by the experts started flowing to the Bhagirathi-Hooghly from 1975.

Necessity of the Barrage and its Effects

Although nearly all experts and government bodies recommended construction of a barrage over the Ganga for diverting its water into the Bhagirathi-Hooghly and it was constructed and commissioned at Farakka, in hindsight, the following questions arise:

- Was the diversion only viable and durable solution?
- What was the minimum requirement of water?
- What actions were taken to assess the post-diversion effects?
- What could be ideal actions? Could they be implemented?
- What were the effects of the agreement, the MOUs and the Treaty on the ground situation?

My answers to these five questions are as under, in the same sequence.

(i) Steady deterioration of the Hooghly channel, as observed by renowned experts-Indian and foreign-was self-evident. Shifting of the port, dredging of the navigation channel and many other options were considered and some even tried, but the deterioration could not be arrested. The only way to resuscitate the river and save Calcutta Port from gradual closure was to induce certain quantity of water from the Ganga, or any other river, by diversion. Figure 15.1 gives these alternatives.

Shifting of the port, excavation of short-cut canal, dredging of the navigation channel and many other palliative measures failed to resuscitate the Bhagirathi-Hooghly river and save the port from its certain extinction in near future; the only alternative left was to induce additional water from the parent river Ganga. Sir Arthur Cotton made two alternative proposals for water diversion in the Bhagirathi-Hooghly. The first one was in 1953 in which a barrage was proposed across the Ganga below the Bhagirathi offtake with a ship canal for water transport facility and the second one was in 1954 in which the barrage was proposed near Rajmahal in Bihar with a ship canal for the same purpose. The two proposals are shown in Fig. 15.2. However, the barrage was ultimately constructed near Farakka for diversion purpose.

(ii) Regarding the minimum requirement of water for flushing the Bhagirathi-Hooghly river up to the limit of port area, the general consensus earlier was to bring back the river to 1924 condition, for which the minimum requirement was about 65,000 cusecs, as per assessment made by Calcutta Port Trust (CPT). However, considering the limitations of availability of lean season flow in the Ganga, it was considered judicious to bring back the river to 1935–1936 condition, for which the minimum requirement was 40,000 cusecs as assessed by CPT and also by experts.

(iii) and (iv) In the initial stage after commissioning of the feeder canal in April 1975 in a short-term sharing agreement for one month in Dhaka, some follow-up actions were to be taken by both sides These were observations of gauge and discharge, salinity, bore tides, navigation tracks etc. in the canal, the Garai, the Madhumati, the Bhairab etc. for at least five years. The Indian team took observations from the next season and continued it, but whether Bangladesh did the same, or not, was not clear because of political turmoil after the assassination of Sheikh Mujibur Rahaman. Calcutta Port Trust is still taking observations and submits data to the study team, annually. Even before the commissioning of the canal, the following observations were to be carried out on prototype.

(a) For five years, the feeder canal would carry full discharge of 40,000 cusecs, round the year;

(b) A study team would observe the effects of varying discharges, for five years and two years thereafter; the situation was to be reviewed after seven years.

Thus, various studies of gauge, discharge and salinity were to be made in the post-barrage period, as well as of the effects of diversion of 40,000 cusecs on siltation, channel parameters, cubic capacity, changes in the river-bed, water-surface slopes, silt content etc., both upstream and downstream of Kolkata, throughout the year and thereafter, for two years, but these were continued much beyond the stipulated years and are being continued even now, when the diversion is less than 40,000 cusecs.

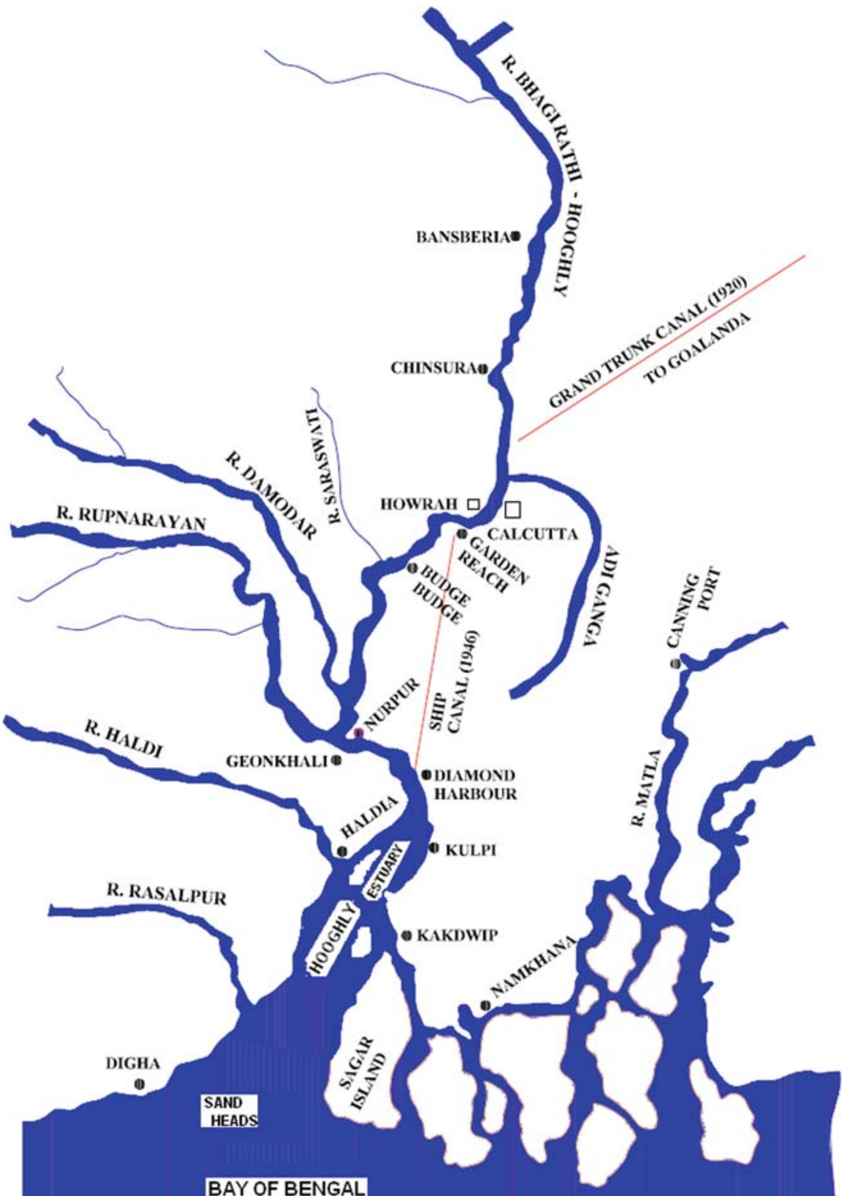


Fig. 15.1 Alternatives to barrage at Farakka

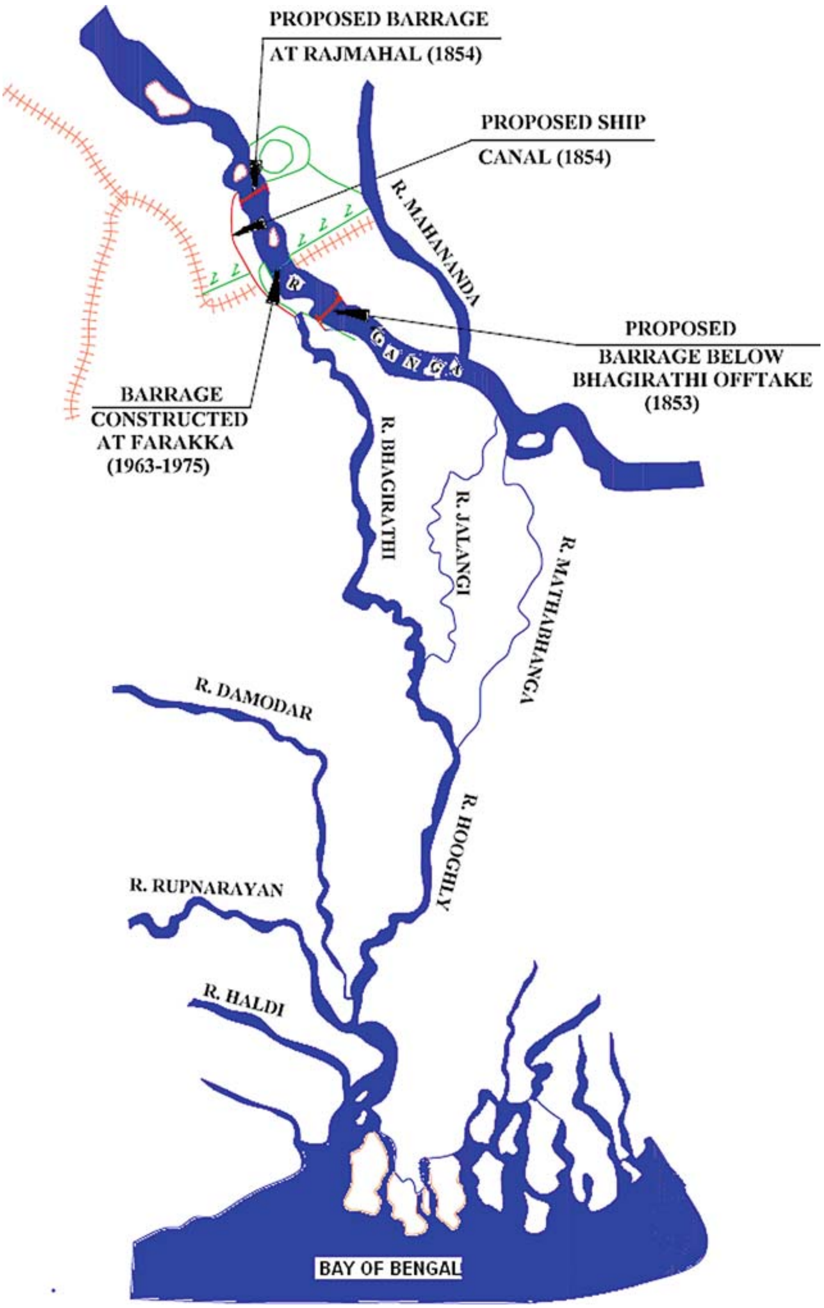


Fig. 15.2 Two proposals of Sir Arthur Cotton

(v) The feeder canal was commissioned in April 1975; the envisaged release of 40,000 cusecs into the canal was made regularly until December 1977. Thus, the effect of the recommended discharge could not be observed on prototype for five years, as stipulated. The short-type accord of November 1977 came into effect from 1st January 1978, according to which the head-water supply of 40,000 cusecs came down to 20,500 cusecs, or less, in every lean season up to mid-April and then gradually went up to 40,000 cusecs again from 1st June. The effects of discharge of less than 40,000 cusecs during the lean season would be manifold.

(a) The strong tide would continue to push the sand and silt, upstream of Calcutta Port area and above and the deposited volume would be in excess of that, which would move seaward in the lean season as well as in the rest of the year. The cumulative adverse effect continuing and ultimately blocking the navigation route cannot be ruled out.

(b) The total accretion in the river reach would increase and its zone would shift downstream and disturb port facilities, e.g. jetties, mooring buoys, slipways etc.

(c) The incidence of bore tides would increase in this reach and make navigation very difficult.

(d) In the months of strong tides, sufficient time would not be available for dredging the deposited silt; dredging volume and cost would increase.

(e) Salinity of water would gradually increase, albeit slowly.

(f) The envisaged environment changes would be affected.

These effects have actually occurred, as narrated in Chapter 10. A bar chart is shown in Fig. 15.3, which shows the improvements in the Bhagirathi-Hooghly, as envisaged and could actually be achieved in the post-barrage period?

The improvements, as shown in the bar-chart, have been noticed Calcutta Port. These may decrease in due course and it may so happen that the condition of the Bhagirathi-Hooghly may ultimately return to the situation prevailing before the construction of the barrage.

The effects of diversion of water to Bangladesh have been mixed but the adverse ones have been unduly exaggerated. A bar-chart in this respect appears in Fig. 15.4.

The sharing accord continued, uninterrupted, for 10 years up to 1987 and thereafter from 1996 and will continue till its expiry after 30 years, i.e., up to 2027. There was a gap between 1988 and 1996, when no agreement was in place, though informal sharing of water continued in the period. With rapid growth of population in India, all-round development, industrialization and urbanisation, the demand for water has been increasing. Moreover, owing to time-space limitation of the monsoon in the country, proper storage of surplus water in a particular period is difficult and cannot be properly utilised uniformly. Enormous volume of sweet waters of the Ganga-Brahmaputra-Meghna (GBM) basin flows, unused, in the sea in every monsoon season, leaving a wide gap in its demand and supply in the rest of the year. The Ganga and the Brahmaputra, being the two surplus water-carriers, into monsoon months, will need prime attention for any kind of water resources

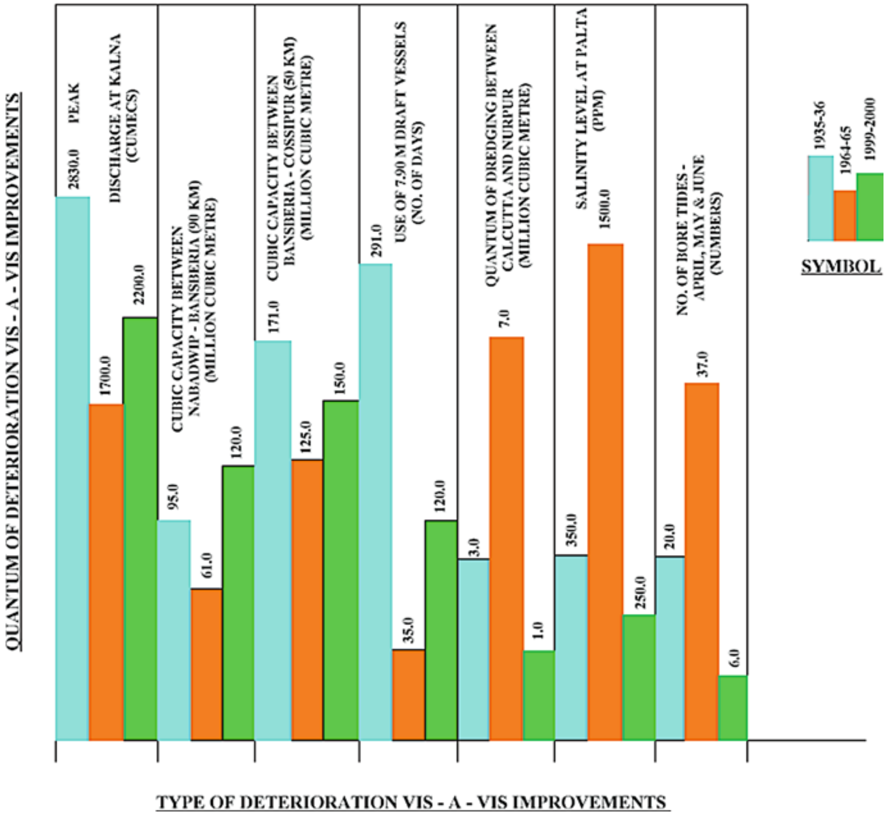


Fig. 15.3 Bar chart showing the effect of Farakka diversion on the Bhagirathi-Hooghly river (See also Plate 12 on page 374 in the Colour Plate Section)

development schemes within the basic areas of the GBM. Fortunately, one plus point in this respect is that the Brahmaputra goes in spate in March, whereas the Ganga spills its banks in May, i.e., two months ahead. This gives a scope for inter-basin transfer of water from the former to the latter, which would augment the Ganga's flow in the crisis period of March–April, each year. To make up any eventual deficit in future at Farakka, the 1977 agreement and the MOUs of 1982 and 1985 provided for augmentation schemes.

It was most unfortunate that though the Ganga discharge through the Farakka Barrage was going down, the 30-year valid 1996 treaty did not provide for augmentation of its flow. Thus, while deciding the sharing formula, the accord took account of the current availability of water at Farakka, but overlooked the probable future flow decrease, apparently intentionally. Increase of industrialization and urbanization and a virtual explosion of population in India enhanced the demand for the Ganga water, both in upper and lower reaches, in Uttar Pradesh, Bihar and West Bengal, leading to gradual fall of water in lean season. The Ganga water was diverted in the upper reaches for irrigation and other activities, requiring water for

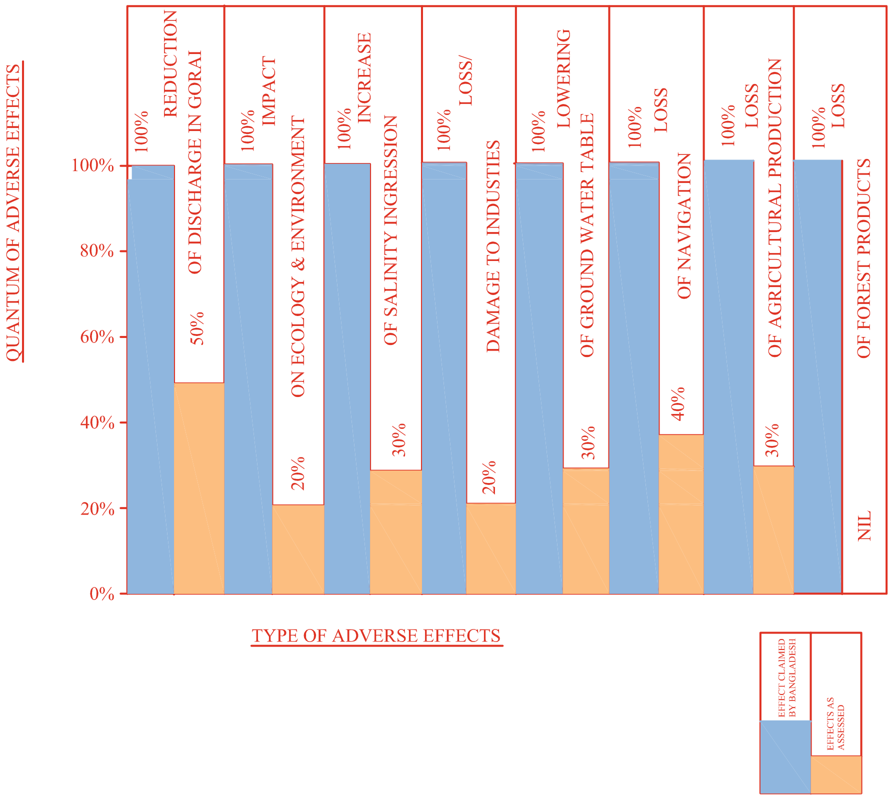


Fig. 15.4 Bar chart showing the possible adverse effects as claimed by Bangladesh and as assessed by author on Farakka diversion

a growing population, needing more food. If such diversion was restricted, as provided in the 1996 treaty, it could be tantamount to interference in the internal affairs of a State and attract legal redress. On the same analogy, the demand of the lower riparian State, Bangladesh would have increased manifold. The ticklish situation was overlooked by two governments, while inking the treaty. There is little scope for addition or alteration in a long-term treaty but it can be reviewed. It was signed in unseemly haste by two new governments, without knowledge of the past data, or consulting various government and private organisations who could be directly affected by it.

These were some of the effects of the 1996 Indo-Bangladesh Treaty, both qualitative and quantitative. Both countries have gained and lost and made sacrifices to keep up good relations. The treaty gave birth to a new outlook for the development of trade and commerce between the two countries. Additionally, India scored a diplomatic victory by solving the problem under its new foreign policy of bilateralism. The gain of Bangladesh was that it could now formulate its own programme for development of water resources in the lower Ganga basin with assured quantum of flow in the lean season. Gains of both countries were, thus, political and technical. Both countries had to be satisfied with less volume of discharge than demanded by them initially. Because of fall in discharge, the Ganga in both countries was affected by silt, salinity, reduced navigable depth and degradation of environment. India had to be content with curtailed activities of Calcutta Port.

The treaty left a few points undecided, but at least one was taken note of in the 1977 agreement and in two MOUs of 1982 and 1985. It was augmentation of the Ganga flow at Farakka in the lean season, despite the fact that the flow would be gradually reducing, leaving not enough water for mutual sharing in the lean season. Two other points, left untouched, were the mitigation of flood in the Brahmaputra in Assam (in India) and Bangladesh and sharing of the lean season flow. Its basin receives excess water which could be utilised for its development and to make up the deficit of the Ganga water at Farakka. This could form a part of the long-term transfer package. As the treaty is valid for 30 years, harnessing of excess water and power for the region, involving Nepal and Bhutan, should have been kept in view. The overall effects of Indo-Bangladesh Treaty are summed up in Fig. 15.5 which highlights the losses and gains of the two countries and its drawbacks.

Interlinking the Ganga and the Brahmaputra

To transfer water from the Brahmaputra basin to that of the Ganga, near Farakka, the following suggestions deserve consideration.

1. A barrage over the Brahmaputra near Mahimganj in Dinajpur district of Bangladesh to head up water to a certain level.
2. A 200–250 km long diversion canal could be excavated through India and Bangladesh, which would flow into the Ganga, upstream of Farakka. It could pass through four major streams – Karatoya and Atreyi in Bangladesh, Punarbhaba and Mahananda in India as well as a number of small and medium streams for regulating the flow. They could be fed partly by the diverted flow of the Brahmaputra, between 5,000 and 10,000 cusecs each, to be utilised for irrigation in two countries. The remaining water could be released into the Ganga, above the Farakka Barrage, through another regulator.
3. Taking advantage of early flood in the Brahmaputra, 70,000–80,000 cusecs from it could be diverted from February to May, every year. As the Brahmaputra goes in spate from March and the dry season water goes down to 0.1 million to 0.125 million cusecs, diversion of this volume in lean seasons may not be difficult as per the following schedule.
   (a) Karatoya regulator (Bangladesh) : 5,000 cusecs
   (b) Atreyi regulator (-do-) : 5,000 cusecs
   (c) Punarbhaba regulator (India) : 10,000 cusecs
   (d) Mahananda regulator (India) : 10,000 cusecs
   (e) Farakka Barrage regulator : 40,000 cusecs

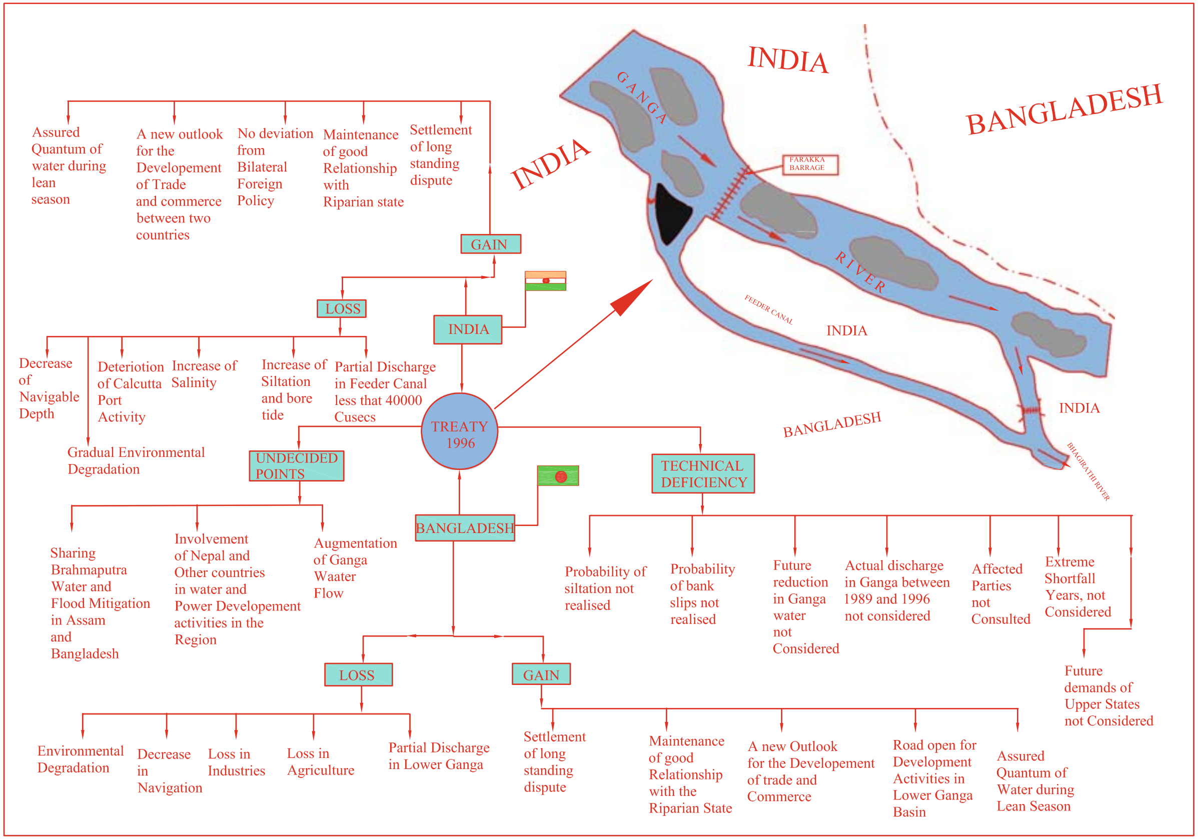


Fig. 15.5 Effects of Indo-Bangladesh Treaty, 1996 (See also Plate 13 on page 375 in the Colour Plate Section)

(f)	Seepage, evaporation and other losses in the diversion channel (approximately)	: 10,000 cusecs
	Total	: 80,000 cusecs[1]

The distribution of water will be as under:

(i)	Net withdrawal from the Brahmaputra (80,000 – 10,000)	: 70,000 cusecs
(ii)	Available lean season discharge at Farakka, likely to go down to	: 30,000 cusecs
	Total	: 1,00,000 cusecs

Diversions

(a)	To the Karatoya	: 5000 cusecs
(b)	To the Atreyi	: 5,000 cusecs
(c)	To the Punarbhaba	: 10,000 cusecs (5000 cusecs each to Bangladesh and India)
(d)	To the Mahananda	: 10,000 cusecs (-do-)
(e)	To the Ganga+ own discharge	: 40,000 cusecs to 30,000 cusecs (30,000 cusecs to Bangladesh and 40,000 cusecs to India)

Thus, the shares of discharge will be

(a)	To Bangladesh	: 5000 x 4 + 30,000 = 50,000 cusecs
(b)	To India	: 5000 x 2 + 40,000 = 50,000 cusecs

It may be noted that the original discharge of the streams will not be disturbed and the combined discharge will be shared in the ratio of 50:50

As the volumes of high-flood discharges of the Ganga and the Brahmaputra are the same – about 2.5 million cusecs, the proposed Brahmaputra barrage could be of the magnitude as that of the Ganga at Farakka (110 bays of 60 feet each). The canal head regulator has to be bigger (say, 20 bays of 40 feet each) as against that of Farakka's feeder canal (11 bays of 40 feet each). The total barrage complex including ancillary works, like guide and afflux bunds, de-siltation mechanism, navigation locks, bank protection measures, regulators, bridges, roads, township and office complexes, land acquisition, rehabilitation, environmental protection measures etc. may cost about 10 billion rupees (at 2004 prices).

For carrying 2,250 cumecs, or about 80,000 cusecs, of discharge at head reach, the canal section has to be trapezoidal of 200 $\times$ 232 $\times$ 8 m (depth) size and fully

[1] The volume of releases into the streams will depend on their capacity; they may have to be desilted for certain lengths, both up and down stream.

lined to minimise land requirement and losses. This will taper down to smaller size in lower reaches in keeping with reduced discharge. There have to be several regulators and drainage structures, bridges, roads on both banks, jetties, warehouses, navigation locks etc. besides other ancillary works, required in a barrage. The canal will be used for navigation and irrigation, inland water transport and communication and will have to be directly linked to Kolkata via Farakka in the south as well as to Dhaka and Chittagong in the north-east. The total component cost may be about 18 billion million rupees (in 2004 prices).

There has to be a network of canals to utilise the discharge from the barrage in different streams for irrigation and other purposes. Lift irrigation on the northern side of the canal can be permitted for irrigation by using limited volume of canal water with permanent pumps houses in both the countries. The total cost of the components may be about two billion rupees (in 2004 prices). The project will have enormous potential for hydro-electricity, generated by small and medium power stations; their cost can not be estimated at this stage. Thus, the total cost of the project will be about 30 billion rupees (at 2004 prices) and can be completed in about 10 years. It will have a huge, direct and indirect, employment potential and bring enormous indirect benefits, like recharge of ground-water, rise of ground-water level, ecological upgradation, generation of hydro-electricity, mitigation of floods in Bangladesh etc. and boost the economy of both the countries.

Of the total 200–250 km length of the diversion canal, about half has to be in Bangladesh and the other half in India. The cost of the total project has to be borne, proportionately, by the two countries. For implementing it, technical aid and financial support may have to be obtained from global organisations. In years of extreme water shortage in the two basins, flood water has to be harvested in small and big reservoirs in the upper reaches of the two countries and in Nepal. Also to be considered a linking of the Meghna with the Brahmaputra. A schematic diagram of the total scheme appears in Fig. 15.6

While considering such a proposal for inter-basin transfer of water, as above, the future needs of Bangladesh and Assam have to be kept in view – growth of population, of agriculture and industries, inland navigation etc., for which both surface and ground-water potential of the affected places are to be accurately assessed. Side by side, the present and future needs of water in the Ganga basin and its surface and ground-water resources will have to be kept in view, as also assessments of environmental and socio-economic impact for maintaining quality and health with minimum disruption of surplus and deficit basins, *inter-se* rights of these basins will also have to be laid down before linking the rivers. If all these are carefully done, the project will be a win-win proposition for both countries and none will be loser.

Regional Cooperation

The common issues for regional cooperation for development of water resources among the five south Asian countries – India, China, Nepal, Bhutan and Bangladesh – are the concern of their governments. Of these, development of water

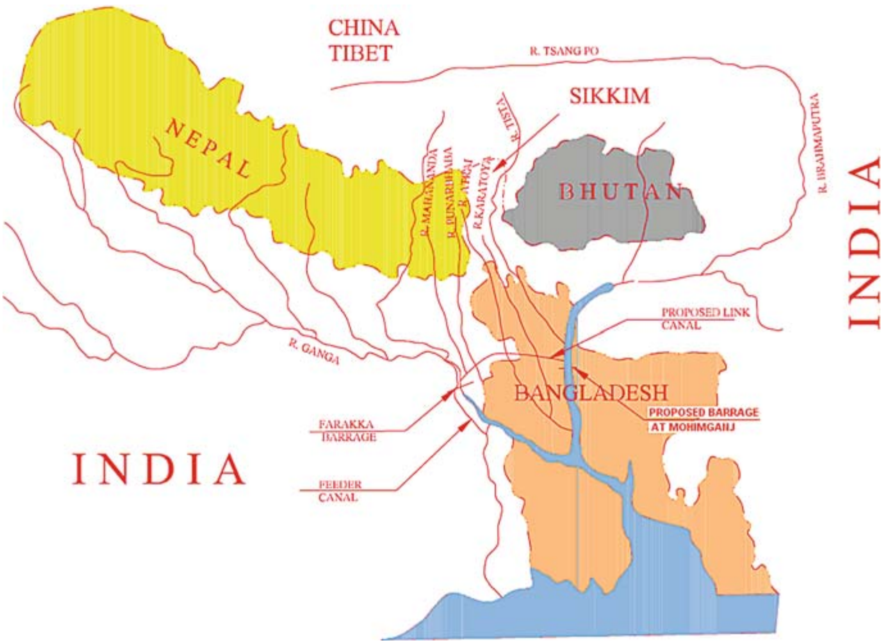


Fig. 15.6 Schematic diagram showing alternative augmentation proposal

resources should receive priority attention. The South Asia Regional Water Vision, 2025, as formulated by Global Water Partnership, envisages:

> Poverty in south Asia will be eradicated and living conditions of all people will be uplifted to sustainable levels of health and well-being, inter alia, through coordinated and integrated development and management of water resources of the region.

Keeping this in mind, the major benefits would be storage of surface and sub-surface waters for irrigation, flood-mitigation, inter-basin transfer of water to make up deficits, generation of hydro-electricity, navigation, communication and transit facilities etc. Nepal and Bhutan are land-locked with no direct access to a water body, surface and air communications are the only means of contact with outside world. A network of ropeways can facilitate transportation of cargo to India, Bangladesh and China. Huge and cheap power to run the ropeway system can be harnessed from hydro-power resources by construction of storage dams and reservoirs, taking advantage of the steep land gradient. In Nepal and Bhutan, forests are denuded by poor people, aggravating land erosion, especially in rainy months. Enormous volume of silt comes down, gets deposited on the river-bed and furthers erosion in plains. Their huge hydro-power potential, if harnessed, can boost the economy of both the countries.

Being a lower riparian country, Bangladesh is spread on the plains, except some parts of south-east. Rainfall is heavy, between 1,300 and 6,000 mm, annually and severe floods occur every year. The country is plagued by shortage of food for a fast-growing population as well as of power and industrial backwardness. Large-scale transfer of water from the surplus basins of the Brahmaputra and the Meghna to the deficit basin of the Ganga and a network of canals will boost the economy. A World Bank study observed that inter-basin transfer of water might be a logical and economic solution for both India and Bangladesh. As the bulk of the rain water in catchment areas goes into the sea, unused *en route*, a part of it can be stored and transferred to the Ganga basin, after meeting requirements of the basin population, developmental activities and preserving the ecology. The study added that the total gross demand in Bangladesh for the Brahmaputra basin alone may be about 2,265 cumecs, or about 80,000 cusecs and for Assam (in India) will be about 1,700 cumecs, or about 60,000 cusecs, in the long run. Therefore, hardly any water would be left for inter-basin transfer unless a sufficient reserve is built from the monsoon flow. Moreover, the Meghna also flows to the sea and its water remains largely unused. If the Meghna is also connected with the Brahmaputra, more water would be available and much of it could be utilised for irrigation in the two countries during transfer, meeting the demands. Thus, it would not be difficult to transfer 1,130–1,700 cumecs, or about 40,000–60,000 cusecs from the Brahmaputra basin to that of the Ganga at Farakka for use by both countries. This proposal by Indian delegates to the JRC to augment the Ganga flow had more merits than that of Bangladesh, which comprised building storage dams and reservoirs along the sub-Himalayan region of the Ganga basin.

As the Ganga basin is spread over in two countries, only bilateral understanding is necessary for a solution to the problem. Though some progress has been made, the process is slow and needs to be speeded up. Regional cooperation to harness the world's other big rivers – the Mekong, the Colombia, the Colorado, the Senegal, the Volta, the La Plata, the Indus etc. by intervention and financial assistance of the UN, the World Bank, the Asian Development Bank etc. can certainly help solve the problem of the combined Ganga-Brahmaputra-Meghna (GBM) basin in south Asia. There is need to create and mould public opinion in these basin countries to promote regional cooperation for sustainable development. The Regional Water Vision, 2025 can be achieved and poverty of the region reduced through integrated action. Additional funds for these schemes, if needed, can be obtained from external sources, on bilateral and multilateral basis, through the World Bank, ADB, UNDP, UNICEF etc.

Farakka Barrage and Bank Erosion

Erosion of the Ganga banks near the Farakka Barrage has become a serious problem. Is it, directly or indirectly, due to the construction of the barrage over the river and the feeder canal?

From the very inception, there have been doubts and disputes about the location of the barrage and its possible ill effects. These were bank erosion, land loss, siltation of the river-bed, hindrances to fish movement above and below the barrage, possibility of bypassing the main stream through the Pagla river upstream of the barrage near Gopalpur in Malda district or through the Bhagirathi-Hooghly downstream of Jangipur barrage near Fazilpur in Murshidabad district, ecological decline and many others.

Some of these doubts are genuine; the others are baseless and were not true before and after the construction of the barrage. Moreover, the benefits envisaged before it came up and those anticipated for future are much more than the ill effects, being experienced after its commissioning. The barrage was constructed in 13 years, between 1962 and 1975 and the Ganga water flowed through the feeder canal into the Bhagirathi-Hooghly since April 1975. The direct and indirect benefits that accrued from 1975 are as under:

(i) Supply of fresh water to the Bhagirathi-Hooghly reducing siltation and increased scouring of deposited silt, deepening the draft of the river-bed;
(ii) Boost to Calcutta Port activities which would facilitate visit of large-draft vessels, round-the-year, saving time and cost on dredging;
(iii) Reduction in bunching of ships in the port area;
(iv) Reduction in the volume of estuary dredging;
(v) Fall in the frequency and strength of bore tides, ensuring safety of port structures, ships etc.;
(vi) Fall in salinity of water, improving its quality for drinking and industrial use;
(vii) Facilitation of round-the-year navigation in the river and opening of the National Waterway No. 1;
(viii) Improvement of environment and ecology.
(ix) The draft of the river increased; silt and sand deposits were pushed to the sea and fresh deposits reduced;
(x) The quantum and cost of dredging in the upper and lower reaches reduced substantially;
(xi) Drainage congestion and flood hazards reduced;
(xii) Direct rail-cum-road links between the south and north Bengal established;
(xiii) Improvement in farming and fishing in the hinterland, following induction of fresh and sweet water;
(xiv) Increase in potential for industrial development following improved navigation and availability of fresh water for industrial use;
(xv) Installation of a thermal power plant on the bank of the feeder canal and ongoing construction of several other plants;
(xvi) Small streams, canals, creeks and new water-bodies formed and activated;
(xvii) Rise of surrounding ground-water level, upstream of the barrage, along the feeder canal and the Bhagirathi-Hooghly, boosting agriculture, drinking water supply etc.;
(xviii) Improvement of environment and ecology of the surrounding areas owing to increase in humidity, leading to fall in health hazards and diseases.

The quantitative benefits, so far achieved, are shown in Table 15.1.

Table 15.1 Benefits achieved after diversion of Ganga water at Farakka

Sl. no.	Type of benefits	Years 1935–1936	1964–1965	1980–1981	1999–2000	Remarks
1	2	3	4	5	6	7
1	Peak discharge at Kalna (cumecs)	2,830	1,700	2,550	2,200	–
2	Cubic capacity of river reach ($m^3 \times 10^6$)					
(a)	Nabadwip-Bansberia (90 km)	95.0	61.0	124.0	120.0	–
(b)	Bansberia-Cossipore (50 km)	171.0	125.0	152.0	150.0	–
3	Maximum discharge at Bhagirathi offtake (cumecs)	2,050	1,410	–	–	Off take is blocked by a barrage
4	Cargo handled (10^6 tonnes)	–	11.0	9.30	31.0	1999–2000 includes Haldia Port
5	7.9 m draft vessels using Calcutta Port (days)	291	35	69	120	–
6	Quantum of dredging in lower Hooghly up to Nurpur (10^6 tonnes)	3.0	7.0	0.46	1.0	–
7	Salinity level at Palta (ppm)	350	1,500	200	250	Potable limit is about 250 ppm
8	No. of bore-tides (April, May and June)	20	37	15	6	–

Many people complain about ill effects of the Farakka Barrage and allege that it has done more harm to local people as well as to West Bengal and India at large than the benefits that accrued, as summed up below:

(a) Movement of fish from downstream to upstream and vice versa has been restricted;
(b) Navigation below the barrage has been blocked, as there is no passage to upstream; riverine traffic between India and Bangladesh has been hampered;
(c) Drainage congestion on the western side of the feeder canal has increased;
(d) Submergence and water-logging in upstream of the barrage has increased, following pond-building;
(e) The ecology of the river has been disturbed;
(f) Siltation on the river-bed above and below the vicinity of the barrage has increased because of low-velocity gradient on both sides as well as sandy islands and *char* land have been formed; and

(g) Severe erosion on the left bank above the barrage and on the right bank below the barrage has extended to new places owing to obliqueness of flow.

Fish movement in the river to and fro has indeed been affected in spite of a fish-lock, provided in the barrage for facilitating passage of fish in the lean season. The lock has become ineffective and inadequate and does not function, most of the time. People of Uttar Pradesh and Bihar lament non-availability and scarcity of *hilsa* and other fish in the Ganga. A *hilsa* hatchery complex at Farakka for breeding of the delicious fish upstream has not improved availability. Separate fish passage through a bypass channel, or some other means, can make up this shortage.

Navigation has indeed improved in the Bhagirathi-Hooghly, the feeder canal and in the Ganga, upstream of the barrage, but between the upstream and the downstream and between the feeder canal and Bhagirathi downstream, navigation has been rendered impossible. The original project report provided a downstream navigation lock near the barrage and both upstream and downstream navigation locks along with bypass channels near the Jangipur barrage to access the downstream Ganga (about 106 km long in India) from all sides, but the revised report omitted these, making the downstream portion inaccessible. This posed difficulties to traders below the barrage and local fishermen. Trade and commerce between India and Bangladesh have become high-cost, as there is no direct water-route, to and fro. Vessels bound for Bangladesh ports and vice versa have to detour through the Sundarbans and Assam, plying about additional 900 km, incurring high fuel consumption and transport cost.

Drainage congestion below the barrage on both banks of the Bhagirathi comes down substantially and the drainage capacity has increased. However, because of high canal embankments, the normal drainage paths on the western side of the feeder canal have been blocked, which had otherwise direct access to the Ganga previously. Though the main drainage channels have been provided with cross-drainage structures, leading to the feeder canal, spills from neighbouring rivers and normal ground configuration might not have been taken into account, while designing the structures. As a result, their capacity has been inadequate for draining out the accumulated water to the fields after the commissioning of the canal. Flood-spills usually come down heavily from the hilly regions, heading up water, submerging fields and entailing huge loss of crops, houses, roads etc. Subsequently, a thermal power plant of the NTPC and its ash dykes further blocked the drainage basin partly. Construction of a number of hume-pipe culverts and other drainage outlets could not fully ease congestion; as a result, a vast area to the west remains water-logged for days in every season.

Because of the formation of the barrage pond, formed upstream by spills, about 160 km long and spread over about 500 km^2, all low-lying areas and water bodies, e.g. depressions, moribund spills, dead channels etc. on both banks of the river in Bihar and Jharkhand States and in Malda district of West Bengal have been acquired by the FBA before commissioning of the barrage covering 6,000 to 8,000 hectares of farmland. Although fish, aquatic animals and birds abound in these water-bodies, submergence affects crop yield. The life-cycle of aquatic fauna and flora as also the riverine floral growth have been disturbed and they will take time to adjust to the changed morphology.

Bank Erosion

Local people say, extensive erosion of river banks and submergence of vast farmland in Malda and Murshidabad districts in West Bengal are among the major ill effects of the barrage. Erosion of the Bhagirathi-Hooghly near Manikchak, Moynapur, Gopalpur, Panchanandapur, Kaliachak etc. in Malda and near Beniagram, Brahmangram, Nayansukh, Dhulian etc. in Murshidabad is occurring after the commissioning of the barrage; previously, it was not so severe and extensive.

After 1975, because of maintaining a pond-level at 72 plus feet in the lean season in the Ganga above the barrage, a part of the earlier exposed, dry bank remains below it and prevents slips owing to counter force. The barrage has obstructed the normal water-current and reduced its velocity nearby. A downward velocity gradient has been formed, causing deposits of heavier silt particles in front of the barrage. This helps formation of sandbars and *char* land, which in turn creates oblique flow-lines toward the bank, forming meander-bends and eroding banks in monsoon months. However, formation of char lands within River channels is the normal characteristic for an alluvial river and cannot be directly attributed to the barrage construction.

Because of rise of several islands in the river between Rajmahal and Farakka, i.e., above the barrage, the Ganga's course in this region has become predominantly braided with multiple channels. Before 1975, there was a meandering channel with large sand islands, as shown in Fig. 5.7 in Chapter 5. These tend to shift between the islands, or between the banks and the islands, depending on the changes in flow directions. Erosion pattern also shifts from place to place, more downstream as meandering channels tend to do. Erosion now occurs mostly on the left bank in Malda, as the deep channel now hugs the left bank after turning left from Rajmahal. It has been aggravated by the formation of a big sand island on the right, as shown in Fig. 5.8 of Chapter 5. The right channel has almost wholly shrunk and the full energy of the gradient has diverted leftward. The erosion of the left bank has been continuing for long, since even before the barrage. Official records show that between 1931 and 1978, some 14,335 hectares of land have been lost to erosion in Malda district before the barrage came up at Farakka, averaging about 300 hectares per year. The total land-loss between 1979 and 1998, i.e. after the commissioning of the barrage, has been about 2,915 hectares, averaging about 146 hectares per year, near Manikchak, Gopalpur, Panchanandapur, Charbabupur, Tofi, Simultala etc. as shown in Table 15.2.

Table 15.2 shows that bank erosion in Malda was severer before the barrage came up. Floods came in rainy months every year, as no marginal flood levee jacketed the basin in those days. Erosion of the right bank, downstream of the barrage in Murshidabad, was chronic in pre-barrage period. Records say, it was severe in different stretches since 1930. From 1945 to 1950, following a shift of the river course,

Table 15.2 Ganga bank erosion on left bank in Malda district between Rajmahal and Farakka upstream of Barrage

Sl. no.	Year	Total length affected (km)	Maximum width of erosion (m)	Approx. loss of land (Hectare)	Approx. maximum W.L. (m)	Remarks
1	2	3	4	5	6	7
1	1931–1978	–	–	14,335	–	No marginal embankment was existing upto 1972
2	1979	5.0	200	60	24.90	–
3	1980	7.0	150	105	24.80	Embankment breached
4	1981	11.0	400	260	23.70	–
5	1982	5.0	150	65	24.80	–
6	1983	5.0	200	90	24.90	–
7	1984	7.0	100	70	24.80	–
8	1985	6.0	150	90	24.30	–
9	1986	6.0	200	105	24.20	Embankment breached
10	1987	8.0	300	240	25.40	–
11	1988	7.0	100	70	25.10	Embankment breached
12	1989	100	150	150	22.90	–
13	1990	8.0	200	160	24.20	–
14	1991	11.0	150	170	25.30	–
15	1992	9.0	150	130	23.90	Embankment breached
16	1993	7.0	200	145	24.10	–
17	1994	7.0	1250	160	24.90	–
18	1995	8.0	200	145	24.0	–
19	1996	15.0	250	310	25.10	Embankment breached
20	1997	6.0	100	60	24.10	–
21	1998	10.0	900	330	25.40	Maximum discharge recorded.

about 3.2 km wide land was eroded near Dhulian. Even the embankment guarding the rail-line between Sankopara and Lohapur gave way and the old Dhulian town went into the river. Between 1968 and 1970, the banks between the old Dhulian town and Suti police station were affected. The right bank reach between Beniagram and Nimtita, below the barrage, was severely eroded from 1968 to 1978. Akhriganj, about 80 km below Farakka Barrage, was also affected, but it eroded previously between 1939 and 1968 too, threatening major establishments and the highways. Other affected areas, downstream, are Aurangabad, Fazilpur, Moya, Lalgola, Jalangi Bazzar – all in India. The details of land-loss below the barrage on the right bank

between 1931 and 1998 are given in Table 15.3 below, which shows that even before the barrage, i.e. up to 1978, annual land-loss by erosion averaged 600 hectares as against 327 hectares after the commissioning of the barrage, up to 1998.

The hydro-morphology of the Ganga between Rajmahal and Jalangi *Bazzar*, before and after the barrage, accounts for the erosion and land-loss in Malda and Murshidabad districts. While flowing on the alluvial soil-mass of the bed and the banks, its course was sinuous and swung within the narrow width, touching the two banks alternately. As it swung over the years, it eroded the banks, causing huge land-loss and forming sandbars, alternately. The deep channel meandered, as natural to an alluvial stream. The position is illustrated in Fig. 15.7 (i–viii), which also show the morphological pattern and changes in the Ganga in this stretch between 1939 and 2002. Major morphological changes occurred after the barrage came up, a massive human interference in the natural drainage; two dominant meander loops that existed on each side of the barrage, up and down stream, previously became

Table 15.3 Ganga bank erosion on right bank in Murshidabad district downstream of Barrage between Farakka and Jalangi *Bazzar*

Sl. no.	Year	Total length affected (m)	Maximum width of erosion (m)	Approx. loss of land (hectare)	Approx. maximum W.L. (W)	Remarks
1	2	3	4	5	6	7
1	1931–1978	–	–	28290	–	No afflux bund was existing. Afflux bund constructed between 1978 and 1981
2	1979	5.0	200	100	22.60	–
3	1980	6.0	250	100	24.60	–
4	1981	4.0	200	80	23.40	–
5	1982	5.0	200	90	24.30	–
6	1983	5.0	250	105	24.40	–
7	1984	22.0	700	635	24.20	–
8	1985	10.0	250	245	23.90	–
9	1986	10.0	200	180	23.70	–
10	1987	8.0	150	105	25.0	–
11	1988	9.0	300	255	24.90	–
12	1989	12.0	150	175	22.60	–
13	1990	10.0	150	120	23.80	–
14	1991	9.0	200	115	24.90	–
15	1992	6.0	200	115	23.60	–
16	1993	10.0	400	270	23.80	–
17	1994	33.0	1400	2585	24.60	Maximum erosion and land loss in 1994
18	1995	8.0	150	270	23.80	–
19	1996	10.0	1000	465	24.80	–
20	1997	4.0	100	40	23.90	–
21	1998	40.0	250	500	25.30	Maximum discharge recorded

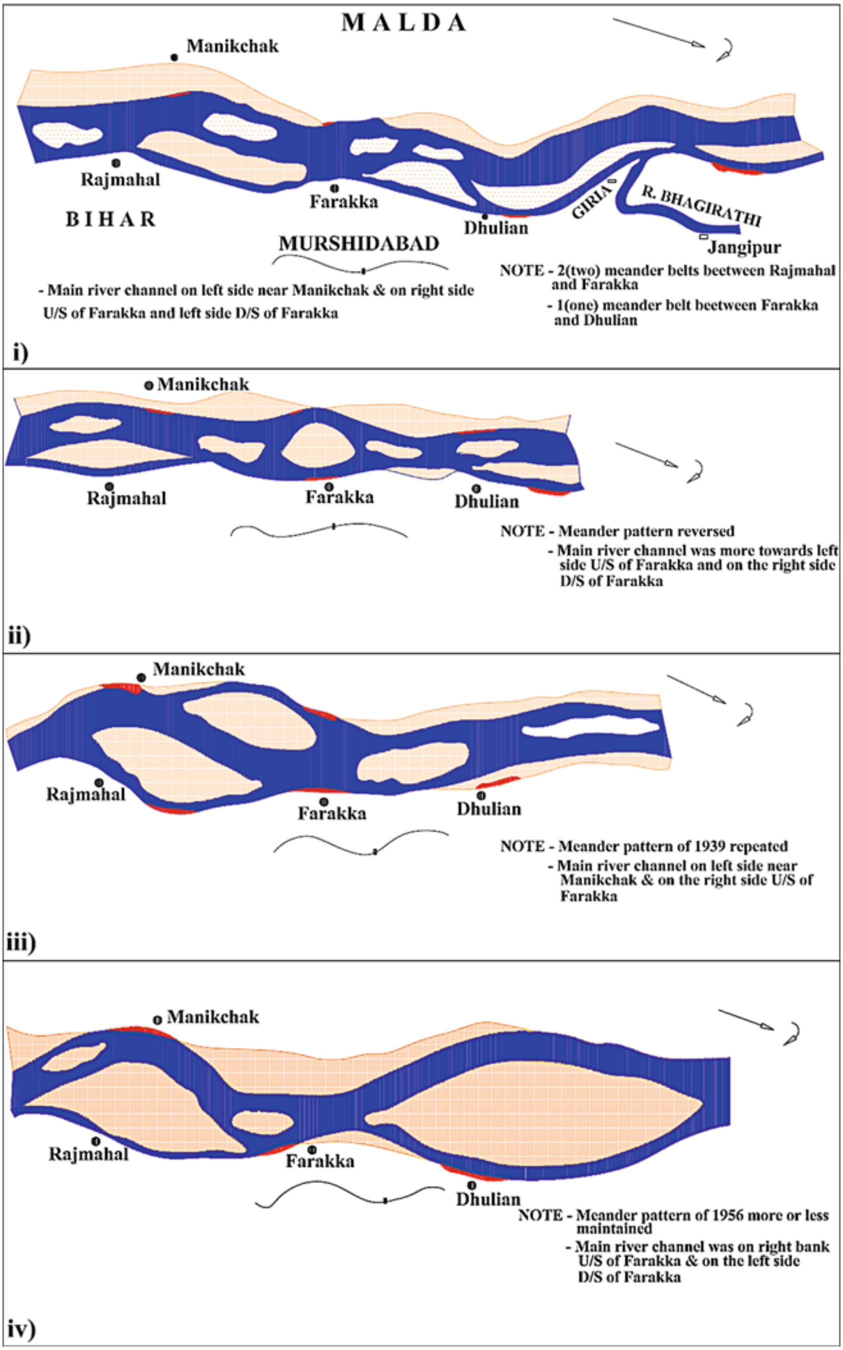


Fig. 15.7 (i) Ganga river course – 1939; (ii) Ganga river course – 1948; (iii) Ganga river course – 1956; (iv) Ganga river course – 1962; (v) Ganga river course – 1976; (vi) Ganga river course – 1986; (vii) Ganga river course – 1996; (viii) Ganga river course – 2002. Note: Erosion zones of different years are shown in red colour (See also Plate 14 on page 376 in the Colour Plate Section)

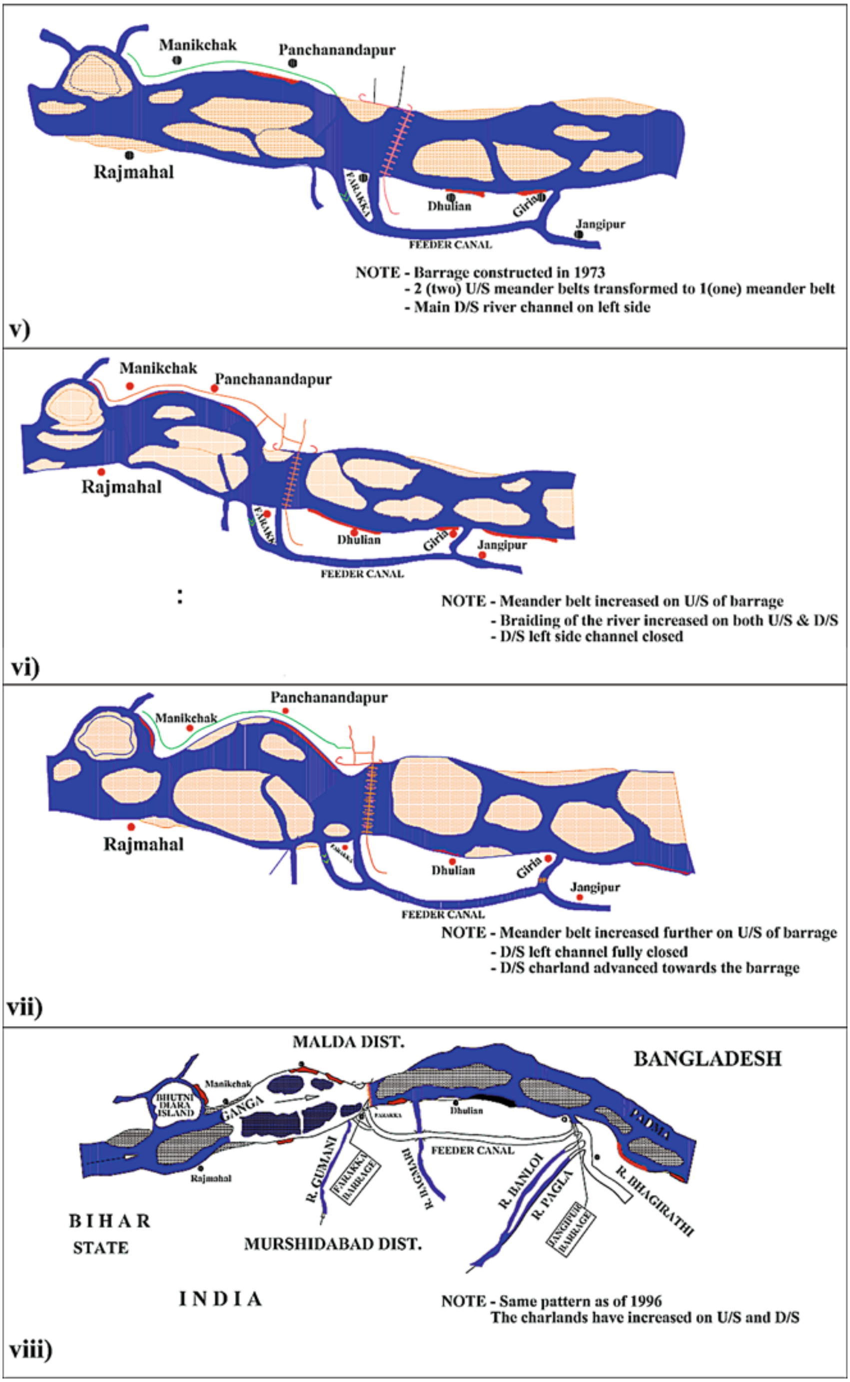


Fig. 15.7 (continued)

one – the left one, upstream and the right one downstream – as the river adjusted to the new morphology. The erosion zones shifted because of this change, above and below the barrage. The pattern of the channel, of erosion and of land-loss has been changing, shifting formation of *chars*, silt deposit on the banks and the bed. Besides, as meandering rivers tend to sometimes move downstream and sometimes upstream, the erosion zones also change. For example, the erosion of the left bank in Malda gave way from Manikchak area to Gopalpur, Panchanandapur and Birnagar – all downstream of the barrage – between 1980 and 2000 and between the third and the seventh spars, which was the most affected zone in the 1980s, but has since stabilised after adoption of protective measures. Erosion has now shifted downstream, below the third spur.

As reported in Chapter – 5, the Bhagirathi-Hooghly river banks are also affected by severe bank erosion. Location of some of these affected reaches are – Raothara, Mayapur and Palta – all on left bank and Samudragarh and Uluberia – all on right bank.

A parametric study for 160 cases was carried out to investigate the influence of various parameters on the stability of the river banks against failure under drawdown condition. Based on this study, stabillity charts and regression equations were developed, which might be used for approximate determination of factor of safety for a river bank slope with conditions similar to the Bhagirathi-Hooghly.

Siltation, Erosion and Flood

It is evident from these eight Figures – 15.7 (i) to (viii) – that before 1939, the Ganga flowed on the left only, between Rajmahal and Farakka, in one meander bend, as its concave facing the left was severely eroded. This changed gradually in two distinct meander bends between 1939 and 1956, while the main river swung from left to right in about half its length. The process reversed thereafter, as seen in the 1961–1962 course; this is the normal feature of the Ganga which swung on an alluvial bed before the barrage began to be constructed at Farakka from 1963. This swinging action led to severe erosion, alternately on the left and the right sides. As the river's banks were not high enough and the left basin was much lower than the right, floods became an annual feature in rainy months in those days on left bank. The water spilled over a large area, reducing their depth and intensity and causing damages; the affected people and their sufferings were much less. The deposited silt increased the fertility of farm land and enhanced crop yield. These benefits ceased after embankments jacketed the left bank of the river from 1972. They did control spills on the countryside and saved crops, houses and other properties, but they did some harm too. As the flood-plain was restricted, flood-water flowed within the restricted waterway between the high bank on the right and the embankment on the left. The flow velocity increased and the tremendous kinetic energy that was generated was utilised in other directions of the three-dimension flow and eroded the bed and the sides. It also resulted in deep-scour depth near the bank; loss of farm land and in the end, damaged the flood levee and inundated the countryside. As

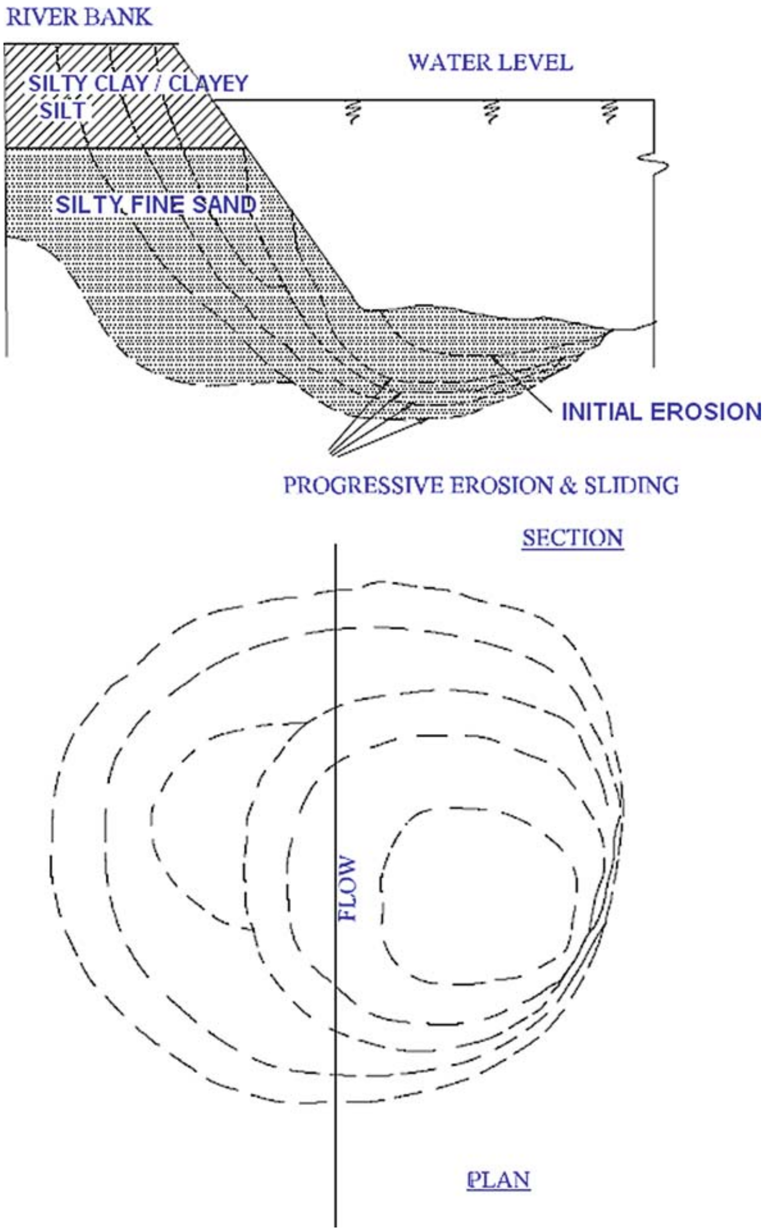


Fig. 15.8 Typical cross section of river

population increased over the years, new houses came up within the basin and over levee slopes, rendering settlers vulnerable to floods. The left bank, made of loose silt, clay and fine sand eroded easily in vertical and horizontal directions owing to water current. The toe of the bank was first affected because of high tractive force of water, eroding both the bed and the side and gradually extended to both sides, as shown in Fig. 15.8. This was a typical river-bank failure, occurring generally in the left bank. The huge soil-mass, eroded from the bed and the banks, moves with the flowing water and gets deposited where the velocity is less and the bed shallow. Thus, *char* land is formed, extending gradually to three directions until and unless the flow direction reverses for various reasons, which may erode the soil-mass on its own, or by dredging. Interference by the barrage up to the full width and depth of the river has blocked the normal passage of the silt-laden water and reduced flow velocity and increased silt-deposition in front of the barrage, when the channels are deep or shallow and deep-scour holes are formed by oblique flow. *Char* land has disrupted the channelization of the flow and made it uneven.

The intensity of bed and bank erosion has also increased at specific reaches on the left because of these and siltation zones are changing, year after year. The patterns of siltation and erosion below the barrage alter and shift because of restriction of the silt-laden flow during flow and ebb tides before and after monsoon months and of silt-load passage, through the barrage, round the year. Many barrage gates are kept above sill during very high floods of about 1.8 million cusecs and above. As the right bank, downstream of the barrage, is higher than the normal HFL (about 2 million cusecs), floods in Murshidabad district are due less to the Ganga's overflow except in low pockets and basin areas. There is no separate marginal embankment on the right bank up to the Bhagirathi offtake, except the National Highway-31 which runs almost parallel to the Ganga bank at a distance of 500 m to five km for a length of about 40 km. The afflux bund of the Jangipur barrage is below the offtake point of the Bhagirathi-Hooghly, which joins the flood levee below this barrage. The overall process of erosion and siltation, above and below the barrage, and their locations etc. have been affected due to the construction of the Farakka Barrage, though erosion and land-loss have reduced somewhat in both up and down stream after the barrage was built. The morphology of the river cannot be dynamic as long as erosion and siltation change frequently, over the years. In such a mighty alluvial river, a long-term dynamic stability is not expected too; therefore, the people have to live with these hazards, but it does not preclude taking long-term rehabilitation and damage-control measures by the concerned governments with cooperation of the people so that their sufferings can be diminished, to the extent possible.

As stated, the Ganga inclined leftward below Rajmahal, because the right bank was much higher than the left. The stretch upstream of it up to Maharajpur, about 25 km, is composed of hard hilly rocks and is held up there with a very deep channel near the bank and has been so for over a century. The left bank is low and became an alluvial flood basin, formed by fine sand on top. Down this *char* land is a river, the Mora Kosi, practically a dry sand bed which becomes a stream only in rainy months. The flow reverses, as the water-level rises, either in the Ganga, or in the countryside, after rains. On the south of this stream is an island, Bhutni Diara, encircled by a high earthen embankment and fortified with stone apron and pitching. Before 1972, this was just a *char*, within the flood-basin of the Ganga in the east, Kosi on the west, the Mora Kosi on the north and the Fulhar on the south. Because of rivers on all sides, it attracted fishermen and farmers who settled there, permanently. It was flooded in every monsoon and the settlers suffered. Farmers got bumper crop from its land, fertilised by silt and fishermen made ample catches, round the year. Its population rose to about 80,000 in 1971 when came a devastating flood which damaged houses, household properties and standing crop. Responding to the islanders' demands, the government encircled it by a ring *bund* in 1972 which prevented spills. Flood water is now passing through the right side and below Rajmahal, it has been crossing leftward near Manikchak *Ghat* in Malda. In a normal year, when the flood discharge is below two million cusecs, the river somehow accommodates it, but when it is more, it extensively erodes the left side. The huge *char* on the right side has also aggravated it. After the 1971 flood, a long embankment was constructed, next year along the left bank, above the afflux *bund* of the barrage up to the Kalindri river to protect about 350 km^2 area between the river and the *bund*. Owing to erosion in various stretches, the embankment could not be kept intact at those places. For example, near the barrage at Simultala, the embankment has been retired nine times. The 10th marginal embankment, whose frontage has been eroded, is also threatened now. The ones near Charbabupur, Panchanandapur and Manikchak breached several times. The offtake of two branch rivers on the left of the Bhagirathi and the Pagla, which was blocked by the construction of the embankment, may open shortly owing to erosion of the front land.

Some people fear that continuous erosion on the left may force the Ganga divert through these two rivers, bypassing the barrage. If this comes to pass, the basic purpose of the barrage will be defeated and Calcutta Port will dry up, but it is a remote possibility. Even if it occurs, only a small discharge will pass through these two streams, because their carrying capacity is about 10,000 cusecs only. Nevertheless, erosion in this reach needs to be arrested at any cost. Some also fear that at Fazilpur, below the Jangipur barrage, the Ganga may eventually join the Bhagirathi, as the gap between the two has been reducing after erosion of the former's right bank. In such an event, the Ganga will bypass the Bhagirathi, dealing a catastrophic blow to south Bengal and to Kolkata. The Bhagirathi may also bypass the Ganga when the water-level is favourable, making the barrage redundant. This fear is also baseless, as the carrying capacity of the Bhagirathi at HFL is 5% only of the flood discharge of the Ganga. Besides, according to survey and bank erosion data, this gap was 1.4 km in 1978. Between 1978 and 1987, about 200 m wide land was eroded. In those days, the right channel of the Ganga, flowing very close to the bank, was stronger than the left on the other side of a big *char* at the centre of the course. Thereafter, the right channel shrank and erosion stopped. The distance between the two rivers has since been maintained at 1.2 km and no further land-loss occurred since 1988; the bank is apparently stable. However, a danger can loom in future if the right channel of the Ganga gets activated and connects to the Bhagirathi, leading to flood and other catastrophe in the Bhagirathi basin. Being higher than the Ganga in the lean season, the Bhagirathi may then flow down the Ganga, whereas when it goes in spate, the Ganga will flow into the Bhagirathi, defeating the very purpose of the barrage.

Expert Committee Recommendations

For a comprehensive study of the erosion and its solution in Malda and Murshidabad districts, two expert committees were constituted – one by the Government of West Bengal in 1980 and the other by the Government of India in 1996. The State committee, named 'the Ganga River Erosion Committee', headed by Pritam Singh, a member of the CWC and with representatives of the Railways, the Survey of India, the Farakka Barrage Project and the State Irrigation and Waterways Directorate studied the past records, old maps since 1922, model study reports of the CWPRS, Pune and records available with the West Bengal government. After making extensive field visits to the affected areas, the Committee suggested

i) Construction of one or two long spurs on the left bank near Manikchak and one or two long spurs on the right bank below the barrage near village Bindugram.
ii) Maintenance and strengthening of existing bull-headed spurs upstream on the left bank.
iii) Revetment of the left bank-upstream for a length of about 10.0 km up to spur no. 7 and of the right bank entire length of 94 km downstream of barrage up to Jalangi *Bazzar*.
iv) Extension of upstream left guide *bund*.
v) Model studies to examine, whether artificial excavation can reduce shoal formation on the left bank upstream of barrage and also to examine the efficacy of the proposed upstream and downstream spurs.

However, some of these were not implemented for constraint of funds; only (b), (c) and (e) were implemented and that too partly.

After the devastating flood of 1996 in Malda and Murshidabad, the then Prime Minister of India, H. D. Deve Gowda flew over the affected areas including Malda town. The Planning Commission constituted an Expert Committee to study bank erosion of the Ganga-Padma, headed by G. R. Keskar, Member (RM) of the CWC and other members from the Ganga Flood Control Commission, Planning Commission, Farakka Barrage Project, State Irrigation and Waterways Directorate and some retired engineers. The committee went through past records and latest survey data, made extensive field and aerial visits of the river's course, examined latest satellite imagery, river configuration maps etc. and suggested some remedial measures. The suggestions were as under.

Short Term Measures

(i) Construction of two long spurs on the left bank upstream of barrage near Manikchak and two long spurs on the right bank near Beniagram downstream of barrage.

(ii) Renovation of all existing spurs on the left bank upstream and the right bank downstream.
(iii) Bank revetment at selective reaches on both upstream the left bank and downstream the right bank.
(iv) Renovation of existing damaged revetment works.
(v) Construction of two spurs at Akhrigonj and two spurs at Jalangi *Bazzar*.
(vi) Construction of fifth retired embankment (length 15 km) at Aswintola on the upstream left bank.
(vii) Essential dredging of Kosi channel and *char* lands upstream and downstream of barrage.
(viii) River behaviour studies, models, surveys and detailed investigations and updating of all requisite technical data.

Long-Term Measures

(i) Extension of Left Guide *bund* on upstream.
(ii) Bank revetment work of 10th marginal embankment on upstream left bank and remaining reach from Farakka to Jalangi Bazzar on downstream right bank.
(iii) Dredging on upstream and downstream of barrage at suitable locations.

Thus, the short-term measures, recommended by the Expert Committee were similar to those by the Pritam Singh Committee in 1980, but most of the works have not been taken up yet for constraints of fund and because of diverse views of other experts in the field.

Measures Adopted

As stated, the Government of West Bengal constructed a marginal embankment in 1972 on the left bank, starting from the left afflux *bund* up to Kalindri regulator to prevent spills on adjacent land. Previously, the North East Frontier Rail-line and the National Highway No. 34 passed through Malda. Construction of the left afflux *bund* of the Farakka Barrage was completed in 1975; it had very high crest-level, which was decided on the basis of the Highest Flood Level (HFL) at Farakka, which is much higher than the rail-line and the NH-34. The embankment breaches, every year, when the afflux *bund* holds flood water. Flood-affected people take shelter on it and many of them have built permanent shelters on the top and side-slopes.

From 1972, a number of bull-headed spurs were constructed at various places along the bank, between Kaliachak near Farakka and Manikchak, on a length of about 30 km but most of these were outflanked and erosion or breaches remained unchecked. Other protective measures, e.g., submersible and short spurs were built too, but these were also damaged and outflanked and the deep channel gradually advanced toward the countryside, eroding vast stretches of land. Seven long spurs were also constructed with earth embankments up to about 10 km from the barrage axis between 1975 and 1978 for arresting severe erosion in this reach, but these were also damaged and erosion could not be checked. After its transfer to the Farakka Barrage Authority along with Bhutni Diara island in 1980 for effective anti-erosion measures, the long spurs and the marginal embankment for a length of 10 km were strengthened and renovated; the protective measures remained stable and erosion of land, built up by siltation stopped. The embankment near the barrage, about three km long, was also protected by revetment, falling apron and short spurs at suitable intervals, which proved very effective against erosion in this reach. Unlike the upstream left bank, the right bank does not have any marginal embankment, downstream of the barrage. It is high and clayey; the National and the State Highways on the east run, more or less, parallel to it. These two highways were constructed on old embankments and act as flood levees too. The Jangipur afflux *bund* was constructed in 1975; considering the HFL at Jangipur; the crest is much higher than the highways. It has also been acting as a flood levee since 1975 and preventing spills to the other side. It has also become a permanent shelter for affected people. Between 1969–1970 and 2000–2001, more than 80 bull-headed spurs were constructed by the State irrigation department on the right bank, between Farakka and Jalangi *Bazzar* for protecting it against erosion and land-loss, but most of these have been outflanked and erosion has been persisting at several places.

In 1983, about seven km of the right bank, just below the barrage, between Farakka and Brahmangram and about 16 km of the right bank, just below the Jangipur barrage, between Ahiran and Moya, in front of the afflux bund were taken over the FBA for protection and maintenance. The first seven km was protected by revetments and bed-bars, which controlled erosion and kept the main current away and caused siltation near the bank. The 16 km length of the bank, below the Jangipur barrage was similarly protected in some critical reaches and by maintaining the bull-headed spurs at other places, where they existed. These measures had varied effects; whereas the revetment works along with the bed-bars effectively controlled erosion without much damage, the renovated spurs did not and erosion, up and down stream, continued and formed loops in the high banks. Post-monsoon surveys revealed severe damages to the spurs and outflanking of a few of them in each flood.

Reasons for Erosion

The course of a river over an alluvial bed varies from braided to meander with very few straight reaches in between. This is truer about a very wide river, like the Ganga whose discharges fluctuate from 1,100 to 76,000 cumecs. Erosion and siltation correlate in the meandering reach, the course becomes sinuous and the deep channel cuts one bank and deposits the spoils on the other, alternately. Erosion damages paddy fields, mango groves, villages, towns and other structures and installations and cause immense miseries to the people of the basin, irreversibly. *Chars*, formed in the centre of the river, or on the sides, do not give any relief to settlers on them, as they are prone to submergence. An 'international' river like the Ganga erodes land in India but benefits the people of Bangladesh by forming *chars* and giving rise to disputes between the two countries.

As stated, the reach between Rajmahal and Farakka meanders in a single channel in the left and erodes the bank during flood, but the reach below Farakka up to Jalangi *Bazzar* shows a different pattern. The portion up to Dhulian flows in a single channel on the right and thereafter, the main channel is divided by a central *char* land. This deeper channel flows in two courses, alternately and hugs the right bank in India in various zones, namely, Nimtita-Aurangabad, Raghunathpur-Giria, Moya-Sekhalipur, Akhriganj and then Jalangi *Bazzar* at the end-point of India's border before it finally enters Bangladesh. If these reaches are secured properly, land-loss will be reduced and the deep channel will move away from the bank.

Erosion of a river-bank is due to several variable factors. Natural river-banks are composed of materials, ranging from cohesive fine particles, like clay to non-cohesive coarse materials, like sand to practically non-erodible rock and a number of varieties in between. Their erodibility rate bears on the stability of the bank and its cross-section. Figure 15.8 shows a typical cross-section of a bank and the erosion pattern, caused by flowing water. Hydraulic and hydrological features, fluctuations of discharge, water-level, concentration and direction of flow, channel pattern and configuration, siltation and *char* land development etc. The ground-water table either stabilises or helps erosion, depending on its location vis-a-vis river-water. The Ganga's water-level upstream fluctuates by about 3.5 m, whereas that in downstream does by 10–12 m after the construction of the barrage. Seepage of water from the ground to the river may cause massive earth movement at a time, progressive sloughing, or flow slides and piping of the slope surface. Figure 15.8 shows the progressive sloughing of the river-bank owing to formation of small slips.

Sediment load in the river also causes erosion. Fine sediments increase the viscosity of flow by remaining suspended for a long time, enhance the tractive force, decrease bed irregularities and bed-form roughness and thus enhance the instability of the bed and bank. Coarse sediments get deposited easily in a favourable situation, block the natural passage of water, change the direction of the water-current, form the *char* land, increase bed roughness and ultimately increase erosion on the one side and deposition on the other.

Water-current and its direction also influence bank erosion. An oblique flow hits the bank directly and enhances erosion. Oblique current forms secondary current in different depths, which helps erosion of the bed and the bank. The tractive force of flowing water is more in the bed than at sides. Bed and bank materials are dislodged by the current and move down. The flow direction toward the bank accelerates the process and increases the depth along with steep slope, making it fail in shear and forming slip circle. Coarse materials resist the drag, because of their weight, but fine particles do it owing to cohesive action. When the critical value of the drag force exceeds, the particles are dislodged and move down, eroding the bed and the bank, gradually. The gravitational force over the soil particles and the formation of the secondary current also aggravate erosion. The particles move downstream and settle on the mid-channel, or on the other bank, depending on favourable velocity and direction of the current.

Waves raised by high winds can also erode banks if their direction, speed and fetch distance favour it. In monsoon months, the Ganga with high discharge becomes sea-like and the fetch distance goes up to 15 km or more. In stormy weather, the wind speed varies from 60 to 100 km/h. Once a wave height was about 2 m with a fetch distance of 25 km at Hooghly estuary, when the wind speed was 100 kmph. The wave height in the Ganga in Murshidabad and Malda region goes up to one m and this enhances bank erosion.

Furrowing of land for cultivation, grazing of cattle, house construction and increase of bank surcharge etc. also accelerate erosion.

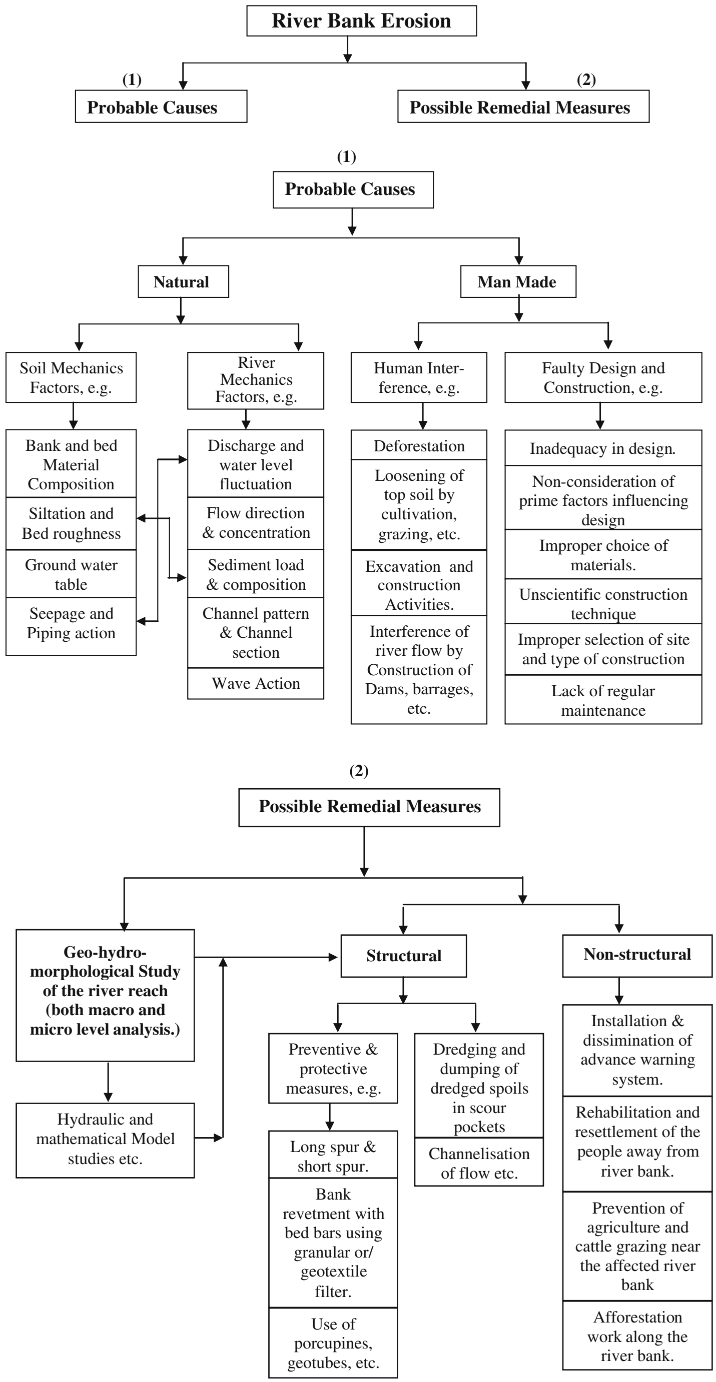
To sum up, the erosion of the Ganga banks is caused and accelerated by (i) meandering channel, (ii) hydraulic and hydrological characteristics, (iii) sediment load and siltation, (iv) heterogeneity of bed and bank material, (v) location of groundwater table, (vi) current and wave action, and (vii) human interferences. All these are variable and sometimes indeterminate too; they may not have simultaneous effect too but the worst combination of these needs is to be ascertained for finding out the actual reasons for erosion. A detailed morphological study of all these over a period of time, in both up and downstream of the reach and of the portion to be protected is necessary before taking appropriate measures. Only this way, a durable control of erosion can be found. The measures have to be both short-term (for immediate relief) and long term (for durable relief) as well as structural and non-structural to end erosion and land-loss, directly and indirectly. A flowing river is always dynamic and therefore, anti-erosion measures can never be stable for a long time; they require constant maintenance.

In an alluvial river, all that accelerate erosion, except the (vii) *ante*, i.e., 'human interference', will mostly be present in every reach. Even human interferences, mentioned *ante*, may also be present in most rivers. The reach of the Ganga between Rajmahal and Jalangi *Bazzar* is no exception. The Farakka Barrage is a massive human interference, which altered the previous flow-pattern of the river. As a result, the meandering pattern, the hydraulic and hydrological features, channel geometry, sediment load and siltation etc. changed to accelerate erosion. Therefore, bank erosion in Malda and Murshidabad districts cannot be wholly attributed to the barrage. The reasons of the Ganga bank erosion and possible remedial measures are summarised in the Tree Structure 1 and 2 below.

Measures Adopted and Their Performance

The preventive and protective measures to stop or arrest bank erosion in the vicinity of the barrage, so far adopted by the State irrigation department and the FBA are (i) long spurs, (ii) bull-headed submersible spurs and (iii) revetment of river

Tree Structure



banks. The department constructed a few long earthen spurs on the left bank in Malda, at upstream of the barrage, at one or two kilometres' gap, armoured with boulders on both slopes, protruding inside water by about 5–10 m; the countryside ends were secured by marginal embankments. Some of these near the barrage were later surrendered to the FBA for maintenance. While most of these, maintained by the department, have been outflanked and gone into the river owing to poor maintenance, those looked after by the FBA worked well. New land surfaced because of siltation in between and before the barrage owing to regular annual maintenance. A few spurs, made wholly of stone boulders, by the FBA between 1998 and 2000, also did their job. Long spurs keep the main water current away from the bank, divide the waterway and attract silt and protect long stretches of the bank from erosion. Quite a number of long spurs was needed for protecting the entire bank length at appropriate intervals. Construction inside the river was difficult and the initial and maintenance costs later were high. If not maintained well, they could be outflanked in the next monsoon. If the gap between two spurs is not appropriate, erosion below them would be heavy, following change of the flow-pattern at the nose of the spurs and eddies and secondary current are formed. Long spurs also compartmentalise the basin which helps localise the damage to the embankment and land-loss.

The bull-headed spurs are short-projecting, 5–10 m inside the river and are riveted to the bank on either side by about five m. These are generally made of loose stones and armoured with crated boulders on top and the sides, spaced at about 100-m gaps and keep the current away from the bank. If spacing is more than appropriate, the reverse flow of the river, downstream, often outflanks the structure. The spurs are severely damaged in every flood by high flow and tractive force, direction of the current and the formation of eddies. Their limited impact in a wide river attracts outflanking, if they are not properly and timely maintained. Naturally, most of the spurs in Malda and Murshidabad districts on both their banks have been damaged, or outflanked. When these are projected into the river at low height, they are partly submerged and deflect the current away from the banks, but attract silt on both sides. If they are not properly spaced, they accelerate erosion downstream, as reverse current, eddies and excess flow occur, ending in severe bank caving in both up and downstream. This has happened in the right bank, below the barrage, near Nayansukh and other villages.

Revetment is a more durable solution, if it takes care of the reasons of erosion. The surfaces of bank slopes have to be properly trimmed, as far as the banks' material strength against slip-circle failures and flow slides permit. Its design should also include toe protection with proper grip with slope, slope protection by thick and heavy material with proper filter and drainage of ground-water, without displacing the soil of the trimmed slope and adequate bed apron against probable scour depth with heavy materials without much disturbance and displacement, in the event of launching. The width and the quantity of stone and other heavy materials of the launching apron have to be chosen keeping in view the ultimate scour, depth and the size of material, depending on the drag, or tractive force that may develop at bed and sides, owing to flowing water and will try to dislodge and carry the materials, used in bed apron and side-slope pitching.

Design Criteria

The proper and stable gradient of the trimmed slide slope of the bank (factor of safety>1.0) can be determined by analysing the stability of the bank slope, using conventional method of slices, where inter-slice forces are not considered, or by using Bishop's simplified method, where equilibrium condition in respect of moments are only satisfied.

The expressions are as under:

a) Conventional method of slices:

$$\text{F.S.} = \frac{\sum \left\{c'b + (w - ub)tan\varphi'\right\}}{\sum W \sin\alpha} \tag{15.1}$$

b) Simplified Bishop's method:

$$\text{F.S.} = \frac{\left(\sum [c'b + (w - ub)\tan\varphi']^{*}\sec\alpha(1 + \tan\alpha\tan\varphi')\right)/\text{F.S.}}{\sum W \sin\alpha} \tag{15.2}$$

The data about the stability of the Bhagirathi-Hooghly river banks for a stretch of 530 km from collections and laboratory analyses of soil samples from more than 300 locations were processed in computer under various situations and applying factors that destabilise the banks. Both uniform and layered soil strata and gradual and instant draw down of the water and their effects on ground-water were examined. The factor of safety (F.S.) of the banks' was calculated as per the following equations in 1992.

a) Gradual drawdown condition:

$$\text{F.S.(GD)} = 9.13(c'/(\gamma'H)) + 1.68^{*}\tan\varphi'(h_2/h_1{}^{*}\cot\beta)^{1/3} \tag{15.3}$$

b) Instantaneous draw down condition:

$$\text{F.S./(ID)} = 10.50(c'/(\gamma'H)) + 2.0\tan\varphi'(h_2/h_1{}^{*}\cot\beta)^{1/3} - 0.55 \tag{15.4}$$

The joint correlation coefficient in both the cases varied between 0.91 and 0.92. The notations are as under:

b = Width of each slice.
w = Weight of slice.
α = Inclination of the bottom of the slice with the horizontal.
u = Pore pressure at the bottom of slice.
c', ϕ' = Effective stress shear strength parameters.

γ' = Effective specific weight of soil
β = Slope angle with the horizontal.
h_1 = Height of ground water table from river bed.
h_2 = Height of river water level from its bed.
H = Height of river bank slope.
F.S. = Factor of safety.

A typical cross-section showing bank recession through slumping and cross-section of river are shown in Fig. 15.9(a, b).

The material characteristics of the Ganga bank in Malda and Murshidabad districts are, by and large, similar to those of the Bhagirathi-Hooghly bank. Therefore, (iii) and (iv) expressions apply to the trimmed side slope angle, which will remain stable under different situations, after which appropriate measures may be adopted to counter erosion and land loss in the river.

The maximum tractive force developed in a stream of straight alignment is given by:

$$\zeta_{\text{bed}} = \gamma ds \text{ for bed} \tag{15.5}$$

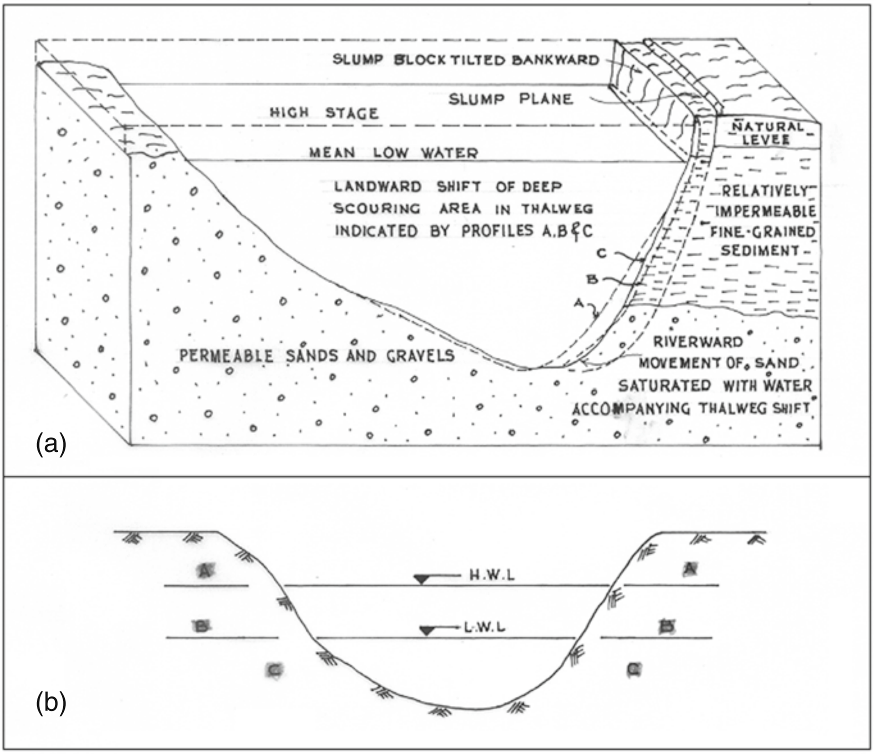


Fig. 15.9 (a) Bank recessionthrough slumping; (b) Typical cross section of river

$$\zeta_{\text{side}} = 0.8\gamma ds \text{ for side slope} \tag{15.6}$$

In the bend, the tractive force is more because of secondary current, the tractive force on the bed of a bend may be considered as suggested in CBIP 204 (1989) as under:

$$\zeta_{\text{bend}} = 3.05(R/w)^{-0.5*}\zeta_{\text{straight}} \tag{15.7}$$

The critical non-erosive tractive force would depend on the properties of soil forming the boundary. For sand bed channels subjected to turbulent flow, the critical tractive force may be considered, as suggested in CBIP 204 (1989), as under:

$$(\zeta_c)_{\text{bed}} = 99^* m \text{ gm/m}^2 \tag{15.8}$$

For cohesive material, the expression for critical tractive force may be considered, as mentioned by Vanoni A. (1975), as under:

$$(\zeta_c)_{\text{bed}} = 0.001(S_u + 180)^* \tan(30 + 1.73I_P) \tag{15.9}$$

The notations are as under:

ζ = Tractive Force.
ζ_c = Critical non-erosive Tractive Force.
d = Depth of Water.
γ = Unit Weight of Water.
S = Bed Slope.
R = Radius of curvature of bend.
W = River channel width.
m = d_{50} of bed material in mm.
S_u = undrained shear strength in lb/ft^2
I_P = Plasticity index of the material.

On the sides of the stream, the critical tractive force is less because of action of gravity on the eroding particles. The expression for critical tractive force on side is as under:

$$(\zeta_c)_{\text{side}} = \left(\cos\beta^* \left[1 - \frac{\tan^2\beta}{\tan^2\varphi}\right]^{1/2}\right)^* (\zeta_c)_{\text{bed}} \tag{15.10}$$

Where, β = side slope angle.
φ = Angle of repose of soil.

If the tractive force of the flowing water is less than the critical non-erosive tractive force, the bed will remain stable. Therefore,

$$\zeta_{\text{bed}} < \zeta_{c(\text{bed})}$$

$$\text{Or}, \gamma ds < 99m$$

$$\text{Or}, m > (\gamma ds)/99 \sim 0.01^{*}\gamma ds.$$

In other words, d_{50} of bed material > 0.01* γds.

Where the bed material is light, it is to be covered by heavier material as apron so that no scour is formed near the toe of the bank owing to flowing water. The depth of scour, the size of stones for apron and pitching, the size of filters, the quantum of stones etc. will be calculated as per provisions of BIS codes, or other well-known specifications etc. Revetment and other protective measures can be designed in this manner and adopted at site to achieve a durable solution. Protective measures need regular maintenance after the rainy season by condition surveys in order to make those structures more stable and achieve their aims. Frequent damage to the structures in Malda and Murshidabad every season owing to bank erosion may be due to design deficiency and inadequate maintenance and not related to the Farakka Barrage.

In an alluvial river, an ideal regime can never occur but damage by erosion can be lessened to some extent. Therefore, protective works should be so designed, keeping in view the factors affecting stability of the bank that even a properly sloped bank is affected by toe and bed-erosion by flowing water, making the slope steep and then causing shear failure by sliding. Thus, erosional and shear failures are inter-related and supplementary; to prevent these, proper toe protection with adequate grip and width of launching apron is necessary.

In a meandering channel, caving and deposition occur, alternately. The meander generally moves downstream with acute bend on one bank and *char* land formation on the other. This may end in a cut-off, sparing the concave face against erosion but if the *char* land formation is prevented initially by dredging, the channel will flow straight and bank-caving will be less. The dredged spoils can also be utilised in filling deep scour pockets in the concave side. Once the *char* land is allowed to form, erosion and deposition will accelerate, requiring uneconomic and voluminous dredging, rendering it difficult to maintain the dredged channel. This actually occurred in many barrages in India including Farakka.

In the Ganga, some eroding reaches have developed very high tortuosity ratio (meander length: meander width), which is likely to form a cut-off in future. In such a situation, the river's length will be shortened, the gradient will increase, the erosive power of the flowing water will be reduced at the bend and an ox-bow lake will form ultimately. Some examples in the Ganga-Padma course are Moya, Akhriganj and Jalangi *Bazzar* reaches, all in Murshidabad, where the ratios are quite high. Similarly, along the Bhagirathi-Hooghly, the affected reaches are Diara Balagachhi and Majhyampur in Murshidabad and Char Chakundi, Purvasthali and Mayapur in Nadia, where acute bends have formed and cut-offs may form also, any time, following rise of a central *char* land. In the first four places, cut-offs have already formed, the river length has reduced and ox-bow lakes have developed. The tortuosity ratio in most of these has exceeded 1:50 (assumed as critical value) and cut-offs have occurred, or are likely to occur. Though they stop bank erosion for a while, the increase of gradient concentrates flow, shifts the erosion zone downward with more vigour and affects land and other properties, downstream. This cannot be allowed and cut-offs need to be contained by adopting suitable measures. The Table 15.4 shows the details of tortuosity ratios in different reaches of the Bhagirathi-Hooghly.

Table 15.4 Tortuosity ratio of some reaches of the Ganga-Padma and the Bhagirathi-Hooghly river

					Tortuosity ratio			
Sl. no.	River reach	R (km)	W (km)	R_W	LR (km)	LV (km)	LR/LV	Remarks
1	2	3	4	5	6	7	8	9
Ganga-Padma								
1	Moya	5.50	4.50	2.25	14.0	12.50	1.12	Based on data of 1996.
2	Akhrigonj	8.0	4.75	1.90	19.0	14.75	1.30	
3	Jalangi Bazzar	5.25	5.25	1.50	16.50	11.00	1.50	
Bhagirathi-Hooghly								
4	Diara Balagachhi	0.63	3.48	0.32	7.60	4.43	1.72	Based on data of 1988.
5	Majhyanpur	0.89	2.22	0.32	5.39	3.80	1.42	Cut-off already formed at Sl-4–7.
6	Char Chakundi	1.08	6.97	0.44	16.47	3.17	5.20	Critical Ratio assumed as 1.50.
7	Purbasthali	1.20	5.51	0.44	12.35	3.17	3.90	
8	Mayapur	1.46	1.96	0.44	5.07	3.48	1.46	

Notations:
LR – Meander Length along River
LV – Meander Length along Valley
R – Radius of Curvature
R_W – Average River Width
W – Shift

Flood and Siltation

Occurrence of flood in Malda and Murshidabad owing to spill of the Ganga water in rainy months was a regular feature, every year, before and after the barrage came up, but it reduced substantially after, except when the river flowed above 67,950 cumecs (2.4 million cusecs). This might have been due to the degradation of the river-bed downstream of the barrage. There was no respite from floods in Malda, even in the post-barrage period and people living on the banks remained as affected as before.

The marginal embankments that were constructed by the State government along the left bank from the barrage to Manikchak have been breaching at several places during the monsoon since 1980 and inundating adjoining land and causing immense misery to the people. Population explosion in India makes many poor people live precariously, very close to river banks and on the embankments which they often cut for building their huts. These hapless people suffer acutely during every flood and are sometimes compelled to move away, as the flood levees are composed of loose untreated soil, a mixture of fine sand and silt. Their shear strength is low and reduces when they are saturated by rains. Strong wind, heavy rains and high waves in rainy months also take a toll of them. The enormous tractive force and direction of the current fast erode the frontage between them and the river's edge; the deep water touches the toe of embankments and breaches them. After almost every monsoon, they are retired and new ones are built behind the damaged levees, attracting erosion and damage in a vicious cycle. Scanty protective measures, adopted here and there, along the long bank, to meet local demands cannot cater to real requirements of the erosion zones at up and down stream. Thus, erosion of the Ganga banks and floods in Malda are not directly due to the coming up of the Farakka Barrage but to the inadequacy of protective measures, faulty designs and construction techniques and inappropriate construction material, time of construction and sites chosen for adopting them.

Malda and Murshidabad being in the lower reaches of the Ganga, bank erosion and flood cannot be wholly abated or prevented; the people have to live with them, as they occur like rituals every year. Other big rivers in the world like the Mississippi and the Colorado in the USA and Canada, Hoang Ho in China, the Brahmaputra in eastern India and Bangladesh also do what the Ganga does. There is no respite from the pranks of these rivers, just as there is none from earthquakes, or other natural calamities but nevertheless governments and concerned agencies have to strive to keep the damages as low as possible and do rescue and relief as fast as possible and rehabilitate displaced people.

The pattern of siltation, up and down the barrage, has changed extensively. The changes in the flow-pattern and hydro-morphology also changed the places of silt deposition and *char* land formation. Just as previous chars have been eroded, new chars have formed at many other places. Normally, erosion and siltation of banks and beds of rivers are a natural phenomenon. Silt is created by erosion of banks, deforestation, grazing and furrowing of basin land etc. Because of geographical dispositions, many major rivers originated in the densely-forested Himalayan ranges in Nepal. Deforestation in this Himalayan nation and in other northern countries as well as in India's north-eastern States has also caused frequent landslides and soil erosion. In the plains of Uttar Pradesh, Bihar and West Bengal, habitation on river basins, grazing of cattle and furrowing of land for cultivation also generate silt in the channels. Human interference with the natural flow by constructing barrages etc. reduce the velocity of water and increase siltation around the structures, degrade the river-bed near the structures and move silt further down. Increased upstream siltation helps develop multiple channels and braiding of the river. As stated, in a braided channel erosion cannot be predicted, which is maximum on the deeper side. The channel swings between the two banks and attract erosion and siltation, alternately. Below the barrages at Farakka and Ahiron, the bed of the Ganga and the Bhagirathi-Hooghly has degraded following increase of flow velocity.

In olden days, rivers spilled over banks, when flooded and submerged basin land and the silt deposited made it fertile. The silt-load does not get enough space to spread over and gets deposited on the river-bed, accelerating siltation but making the river shallow too. Jacketing the river by embankments above the barrage also results in silt deposition and formation of *char* land, here and there. Just in front of the barrage, on the right side, which was a deep channel previously, a big *char* has formed after 1985. If it was dredged and silt deposits removed in the initial stages, siltation would not have occurred. Once a huge volume of silt is deposited, a *char* forms above the HFL and grows in all dimensions, defying removal. Desiltation should be continuous and has to be done throughout a river's entire hydrological cycle. No remedy, adopted at site, can be fool-proof and dredging has to be repeated for years. This has to be both preventive and curative.

Preventive measures should stop generation of silt from landslides, reckless felling of trees on the hills and the basin and hill-slide development activities, ploughing and cattle-grazing, limit human habitation on the basin and abate erosion of banks and the bed etc. At the same time, long-term afforestation, channelization of the river-flow by proper bank protection measures and dredging have to be undertaken. Curative measures cover regular analysis of silt movement and deposition, periodic dredging and removal of silt, land reclamation, construction of embankments with compacted earth and slope protection, increase of navigational depths, storage of rain and river water in reservoirs for irrigation, water supply for drinking and industrial use, pisciculture etc.

Conclusion

After the Partition of the Indian subcontinent in 1947, the Ganga flow has been shared by three countries – India, East Pakistan (Bangladesh since 1972) and Nepal. The Himalayan cliffs through which it flows after originating from Gangotri are in India. The discharge is insignificant at its glacier source until it reaches the semi-plains near Haridwar, but it swells with flows from the tributaries up to its confluence with Yamuna in Allahabad. A number of rivers, rivulets and streams join it on the

Himalayan and peninsular plateaux and thereafter, it flows through the Indian territory. The Himalayan rivers originate in Nepal and give maximum discharge from their catchment areas and make the mainstream their chief drainage artery. Before entering present Bangladesh it bifurcates; the minor channel flows wholly through present West Bengal, which used to be the main channel before the 16th century AD and the major stream flows through Bangladesh. Thereafter, both debouch into the Bay of Bengal, a part of the Indian Ocean. In its long course of over 2,500 km, more than 2,200 km pass through India, draining more than 0.08 million sq. km area; the rest 300 km pass through Bangladesh. Before 14–15 August 1947, India and East Bengal (which was known East Pakistan up to 1971 and as Bangladesh from 1972) belonged to the same country under the British Raj. All these geographical and historical facts justify India's demand for the major share of the Ganga water. Calcutta Port was developed as an inland harbour by British and other European traders, and later by the East India Company and British government in Kolkata (up to 1912) and Delhi on the western bank of the Hooghly in view of its strategic importance and transportation facility by waterway with the rest of the country, as sufficient navigable depth was available in the river, both up and down stream. Being among the world's largest harbours, Calcutta Port serves not only India but other neighbouring countries too, like Nepal, Bhutan and Bangladesh. Its resuscitation and increase of activities also benefit these countries. As the river gradually silted, the offtake was blocked by silt, reducing port activities, because of fall in navigable depth in the estuary region and in the river. Therefore, its preservation and revival by diverting a part of the flow of the parent river was not a wrong decision, especially when all foreign and Indian experts recommended it as the only solution. In fact, the FBA should have come up much before it did, during the 190-year British rule in the sub-continent, when it would have cost much less and not seen the decline of Calcutta Port. Had the barrage been constructed at Farakka before 1947, when the sub-continent was undivided, it would not have raised such a storm of protests and rancour between the two countries and complicated the situations. The demand of due share of the river's water by Bangladesh whose geographical footprint makes it the lower riparian country in respect of the Ganga is justified too. Natural justice also dictates that Bangladesh has a right to the water on proportionate basis, lengthwise or as per the catchment area. On the other hand, international law also supports the demands of an upper riparian country, to be met on priority, while deciding any sharing ratio with the lower riparian country. The volume of discharge in the parent river is not unlimited and may, some day, reach a stage, when very little water will be available for Bangladesh in the lean season. It will then be incumbent to augment the lean-season discharge in the parent river to meet the demands of both countries. Other solutions could be harvesting of flood and rain water, tapping of ground-water and restricting the use of surface water. The governments and concerned agencies in the two countries should examine the feasibility of these suggestions and adopt the best.

As stated, to augment the Ganga flow, India proposed linking the Brahmaputra with the Ganga; on the other hand, Bangladesh proposed construction of storage reservoirs in the Himalayan foot-hills and release of stored water in the lean season. Though each of these had pros and cons, neither country accepted the other's suggestion.

Both countries recognised the scarcity of water in the Ganga, while signing the 1996 treaty but it had no provision on augmenting the flow at Farakka, owing perhaps to some hidden political and technical constraints, which have not been divulged. Long-term effect of this secrecy could be very serious for the two countries, as the Ganga's discharge at Farakka is bound to fall gradually for reasons beyond control. A grave situation could arise, when increased scarcity of water in the bed of the Bhagirathi-Hooghly would attract more silt, make it unfit for navigation and return Calcutta Port to pre-barrage days. When the Ganga downstream of Farakka dries up in the lean season, Bangladesh would be affected too.

There is still time and the situation can ameliorate in future, if both countries come closer and take sincere interest to solve the problem. Each side will have to agree to the minimum necessity in the lean season, of about 1,400 cumecs, i.e., 50,000 cusecs for the other side and supply has to be guaranteed for at least 2,800 cumecs, or 0.01 million cusecs, in the Ganga at Farakka from January to May, or to be precise, from mid-February to mid-May. Assuming that the minimum lean-season flow will be 30,000 cusecs in future, the remaining 70,000 cusecs will have to be supplemented by other sources. Keeping in view the proposals of the two countries on augmentation of the Ganga flow in the lean season, this author suggested a modified proposal on inter-linking the Ganga basin with those of the Brahmaputra and the Meghna. This, I believe, has a lot of merit and will benefit both the countries. It will have a huge potential for irrigation, navigation, flood mitigation, power generation, employment, exchange of scientific and technical expertise, financial support, transport, communication and uplift of the environment besides saving Calcutta Port and resuscitating the Bhagirathi-Hooghly in India and the Garai in Bangladesh. However, available resources of water, long-term needs of India and Bangladesh, a comprehensive environmental impact of the scheme as well as a socio-economic assessment of the two basins have to be made before proceeding with the proposal.

Cooperation among the concerned countries in this region is also necessary for the development of water resources. As the origins of the Ganga and its tributaries lie among the Himalayan hills in Nepal and Bhutan, any scheme for development in the region should be formulated with cooperation of these three countries. China could also be associated for developing the Brahmaputra and the Meghna basins. A consortium of five countries – India, China, Bangladesh, Nepal and Bhutan – can be created for the development of each one's water resources with the help of world bodies like the World Bank, Asian Development Bank, the United Nations Development Programme (UNDP) , Economic & Social Cooperation of Asia & the Pacific (ESCAP) etc. Similar efforts have succeeded in Europe, the USA, Africa and in other parts of the world and yielded good results. There is no reason, why given the same inputs, such a grandiose scheme will not fructify in Asia.

About the Author

Dr. Pranab Kumar Parua was born in West Bengal province of India in 1942 and graduated in civil engineering from Jadavpur University in Kolkata in 1963 with first class. His professional career started in 1964 in the Central Public Works Department of the Government of India in Kolkata. Next year, in January 1965, he joined the Farakka Barrage Project, then under way, as an Assistant Engineer and was associated with the design, construction and maintenance of the barrage across the Ganga at Farakka in Murshidabad district of West Bengal, about 300 kilometers north of Kolkata and later with the construction and maintenance of the Feeder Canal, a part of the project. He spent a large part of his career, over 30 years, in the project, climbing his career ladder to Superintending Engineer and General Manager (in charge) and retired in 2002. From 1985 to 1988, he worked for the Calcutta Port Trust as Engineer on Special Duty in the Hydraulic Study Department and supervised river-training work of the Hooghly estuary and its dredging operations.

While in service, Dr. Parua registered his name for Ph.D. with permission from Calcutta Port Trust and qualified for the Doctor of Philosophy (D. Phil) degree in engineering from his *alma mater*, Jadavpur University in 1992. He received many awards for excellence in his profession, like *Bharat Gaurav* ('Pride of India') from International Friendship Society, New Delhi and was adjudged as 'one of the best citizens of India', 2000 by International Publishing House, New Delhi. He figures in the 'Who's Who in Science & Engineering' of M/S Marquis, USA and also as a 'leading scientist of the world, 2005', sponsored by International Biographical Centre, Cambridge, UK. He is also associated with major engineering professional bodies of India and abroad, such as, Institute of Engineers (India), Indian Geo-technical Society, Indian Association of Hydrologists, Indian Roads Congress, American Society of Civil Engineers of India and the USA. At present, he is associated with the Asian Development Bank on water resources management and river basin management project of the Brahmaputra River Basin in north-east

P.K. Parua, *The Ganga*, Water Science and Technology Library 64,
DOI 10.1007/978-90-481-3103-7,

India. He travelled to Bangkok, Singapore and Dhaka to attend technical conferences on invitation and presented in them many papers on concrete structures, river basin management etc.

Dr. Parua is married with two sons and a daughter and lives in Kolkata.

Appendix A

(i) JOINT INDIA-BANGLADESH PRESS RELEASE

EMBARGO: Not to be Published / Broadcast / Telecast before 1700 Hrs Ist/ 1730 Hrs BST on 18th April, 1975.

DACCA/NEW DELHI : April 18:

The delegation from India led by His Excellency Sri Jagjivan Ram, Minister of Agriculture and Irrigation and the delegation from Bangladesh led by His Excellency Mr. Abdul Rab Serneabat, Minister of Flood Control, Water Resources and Power met in Dacca from the 16th to 18th April, 1975. The talks were held in a cordial atmosphere and were characterized by mutual understanding that exists between the two friendly countries.

The Indian side pointed out that while discussions regarding allocation of fair weather flows of Ganga during lean months in terms of the Prime Ministers' declaration of May, 1974 are continuing, it is essential to run the feeder canal of the Farakka Barrage during the current lean period, it is agreed that this operation may be carried out with varying discharges in ten-day periods during the months April and May, 1975 as shown below ensuring the continuance of the remaining flows for Bangladesh.

Month	Ten-day period	Withdrawal
April, 1975	21st to 30th	11,000 cusecs
May, 1975	1st to 10th	12,000 cusecs
	11th to 20th	15,000 cusecs
	21st to 31st	16,000 cusecs

Joint teams constituting of experts of two Governments shall observe at the appropriate places in both the countries the effects of the agreed withdrawals at Farakka, in Bangladesh and on the Hooghly river for the benefit of Calcutta Port. A joint team will also be stationed at Farakka to record the discharges into the feeder canal and the remaining flows for Bangladesh. The teams will submit their report to both the Governments for consideration.

Sd/- C.C. Patel Additional Secretary	Sd/- S. Z. Khan Secretary

Meetings held in Calcutta for implementing Dacca Agreement of 18th April, 1975 on 24th and 25th April, 1975 relating to withdrawal at Farakka.

The following officials participated:-

(1) Government of Bangladesh

(i) Mr. M.F.A. Siddiqui
OSD, Planning Commission.
(ii) Mr. M.L. Rasul Munsi
Superintending Engineer
(iii) Mr. M. Hossain
IWTA

(2) Government of India

(i) Shri V. N. Nagraja
Members, JRC, Department of Irrigation.
(ii) Shri R. Rangachari
Joint Commissioner (JRC)
Department of Irrigation.

(3) Calcutta Port Trust

(i) Dr. S. K. Bhattacharjee
Chief Hydraulic Engineer
(ii) Shri B. B. Deb Chaudhury
Engineer on Special Duty
(iii) Dr S. K. Nag
Deputy Chief Hydraulic Engineer
(iv) Shri G. S. Paul
Deputy River surveyor (P & R)
(v) Dr S. C. Roy
Senior Scientific Officer

(4) Government of West Bengal

(i) Shri S. P. Sen
Chief Engineer (II)
Irrigation and Waterways Department

1. Observation at Farakka

Gauge and Discharge observation to be carried out by GBWRD, Government of India.

Observation Station – Below Barrage, Feeder Canal and Barrage Pond.

2. Observation in the Hooghly

(i) Tidal gauge observation at Sagar, Haldia, Diamond Harbour, Garden Reach and Tribeni.
(ii) Continuous gauge curves for study of bores.
(iii) Inspection of day-time gauge sites.
(iv) Track survey operation
(v) Deployment of dredgers
(vi) Other information relating to salinity at different locations.
(vii) Information about Hydrographic survey charts, velocity, computed tidal influx etc. for last five years.

3. Observation by Bangladesh

(i) Salinity regime in Gorai-Madhumati-Nabaganga-Bhairab-Pasur, Garai-Madhumati-Baleswar and Padma-Meghma.
(ii) Gauge and discharge observation in the neighbourhood of tidal apex.
(iii) Available rainfall data.
(iv) Information on navigation channel, e.g. Ganga/Padma, Gorai-Madhumati and connected channels.
(v) Water levels along navigation channels.
(vi) Information regarding dredging/conservancy works, etc.
(vii) Ganga-Kobadak pumping Project—facility of access and information on water level at Paksey/Hardinge Bridge, intake channel, Padma river at Gorai off take, Gorai-Madhumati rivers above the confluence with the Brahmaputra.
(viii) Daily flow measurement at Paksey on the Ganga and Gorai-Madhumati.
(ix) C/S and L/S of intake channel and measures for its maintenance.
(x) Details of GK pumping plants, operation procedure, technical specification of pumps, daily pumping head and pump discharge, etc.
(xi) Discharge observations at head reach of the main canal and important escapes etc. (xii) Informations for the last five years.

The progress of work was regularly monitored by holding meetings in Calcutta on 28.4.75, 7.5.75, 12.5.75 and 13.5.75 and at Farakka on 10.5.75 and 11.5.75.

No further accord during monsoon of 1975. Sheikh Mujibur Rahman, President of Bangladesh was assassinated on 15th August, 1975. Relation between the two countries became strained. A Bangladesh team visited Farakka on 9th May, 1976.

Appendix B

Agreement between the Government of the People's Republic of Bangladesh and the Government of the Republic of India on Sharing of the Ganges Waters at Farakka and on Augmenting its flows.
Dated – 5th November, 1977.

THE GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH AND THE GOVERNMENT OF THE REPUBLIC OF INDIA,

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

INSPIRED by the common desire of promoting the well-being of their peoples,

BEING desirous of sharing by mutual agreement the waters of the international rivers flowing through the territories of the two countries and of making the optimum utilization of the water resources of their region by joint efforts,

RECOGNISING that the need of making an interim arrangement for sharing of the Ganges Waters at Farakka in a spirit of mutual accommodation and the need for a solution of the long term problem of augmenting the flows of the Ganges are in the mutual interests of the peoples of the two countries,

BEING desirous of finding a fair solution of the question before them, without affecting the rights and entitlements of either country other than those covered by this Agreement, or establishing any general principles of law or precedent,

HAVE AGREED AS FOLLOW:

A. Arrangements for sharing of the waters of the Ganges at Farakka

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

ARTICLE II
(i) The sharing between Bangladesh and India of the Ganges waters at Farakka from the 1st January to the 31st May every year will be with reference to the

quantum shown in column 2 of the Schedule annexed hereto which is based on 75 per cent availability calculated from the recorded flows of the Ganges at Farakka from 1948 to 1973.

(ii) India shall release to Bangladesh waters by 10-day periods in quantum shown in column 4 of the Schedule :

Provided that if the actual availability at Farakka of the Ganges waters during a 10-day period is higher or lower than the quantum shown in column 2 of the Schedule it shall be shared in the proportion applicable to the period;

Provided further that if during a particular 10-day period, the Ganges flows at Farakka come down to such a level that the share of Bangladesh is lower than 80 per cent of the value shown in column 4, the release of waters to Bangladesh during that 10-day period shall not fall below 80 per cent of the value shown in column 4.

ARTICLE III

The waters released to Bangladesh at Farakka under Article I shall not be reduced below Farakka except for reasonable uses of waters, not exceeding 200 cusecs, by India between Farakka and the point on the Ganges where both its banks are in Bangladesh.

ARTICLE IV

A Committee consisting of the representatives nominated by the two Governments (hereinafter called the Joint Committee) shall be constituted. The Joint Committee shall set up suitable teams at Farakka and Hardinge Bridge to observe and record at Farakka the daily flows below Farakka Barrage and in the Feeder Canal, as well as at Hardinge Bridge.

ARTICLE V

The Joint Committee shall decide its own procedure and method of functioning.

ARTICLE VI

The Joint Committee shall submit to the two Governments all data collected by it and shall also submit a yearly report to both the Governments.

ARTICLE VII

The Joint Committee shall be responsible for implementing the arrangements contained in this part of the Agreement and examining any difficulty arising out of the implementation of the above arrangements and of the operation of Farakka Barrage. Any difference or dispute arising in this regard, if not resolved by the Joint Committee, shall be referred to a panel of an equal number of Bangladeshi and Indian experts nominated by the two Governments. If the difference or dispute still remains unresolved, it shall be referred to the two Governments which shall meet urgently at the appropriate level to resolve it by mutual discussion and failing that by such other arrangements as they may mutually agree upon.

B. Long-Term Arrangements

ARTICLE VIII

The two Governments recognize the need to cooperate with each other in finding a solution to the long-term problem of augmenting the flows of the Ganges during the dry season.

ARTICLE IX

The Indo-Bangladesh Joint Rivers Commission established by the two Governments in 1972 shall carry out investigation and study of schemes relating to the augmentation of the dry season flows of the Ganges, proposed or to be proposed by either Government with a view to finding a solution which is economical and feasible. It shall submit its recommendations to two Governments within a period of three years.

ARTICLE X

The two Governments shall consider and agree upon a scheme or schemes, taking into account the recommendations of the Joint Rivers Commission, and take necessary measures to implement it or them as speedily as possible.

ARTICLE XI

Any difficulty, difference or dispute arising from or with regard this part of the Agreement, if not resolved by the Joint Rivers Commission, shall be referred to the two Governments which shall meet urgently at the appropriate level to resolve it by mutual discussion.

C. Review and Duration

ARTICLE XII

The provisions of this Agreement will be implemented by both parties in good faith. During the period for which the Agreement continues to be in force in accordance with Article XV of the Agreement, the quantum of waters agreed to be released to Bangladesh at Farakka in accordance with this Agreement shall not be reduced.

ARTICLE XIII

The Agreement will be reviewed by the two Governments at the expiry of three years from the date of coming into force of this Agreement. Further reviews shall take place six months before the expiry of this Agreement or as may be agreed upon between the two Governments.

ARTICLE XIV

The review or reviews referred to in Article XIII shall entail consideration of the working, impact, implementation and progress of the arrangements contained in parts A and B of this Agreement.

ARTICLE XV

This Agreement shall enter into force upon signature and shall remain in force for a period of 5 years from the date of its coming into force. It may be extended further for a specified period by mutual agreement in the light of the review or reviews referred to in Article XIII.

IN WITNESS WHEREOF the undersigned, being duly authorized thereto by the respective Governments, have signed this Agreement.

Done in duplicate at Dacca on the 5th November, 1977 in Bengali, Hindi and English languages. In the event of any conflict between the texts the English text shall prevail.

Signed/-

Rear Admiral Musharaff Hussain Khan
Chief of Naval Staff and Member,
President's Council of Advisers in-charge
Of the Ministry of Communications, Flood
Control, Water Resources and Power,
Government of the People's Republic of
Bangladesh.

FOR THE GOVERNMENT OF THE PEOPLE'S REPUBLIC OF BANGLADESH.

Signed/-

Surjit Singh Barnala
Minister of Agriculture
and Irrigation, Government
of the Republic of India.

FOR THE GOVERNMENT OF THE REPUBLIC OF INDIA.

SCHEDULE

[Vide Article II (i)]
Sharing of waters at Farakka between the 1st January and the 31st May every year.

Period	Flows reaching Farakka (based on 75% availability from observed data (1948—73)	Withdrawal by India at Farakka	Release to Bangladesh
1	2	3	4
	Cusecs	Cusecs	Cusecs
January 1—10	98,500	40,000	58,500
11—20	89,750	38,500	51,250
21—31	82,500	35,000	47,500
February 1—10	79,250	33,000	46,250
11—20	74,000	31,500	42,500
21—28/29	70,000	30,750	39,250
March 1—10	65,250	26,750	38,500
11—20	63,500	25,500	38,000
21—31	61,000	25,000	36,000
April 1—10	59,000	24,000	35,000
11—20	55,500	20,750	34,750
21—30	55,000	20,500	34,500
May 1—10	56,500	21,500	35,000
11—20	59,250	24,000	35,250
21—31	65,500	26,750	38,750

Side letter to the Agreement: 1

5th November, 1977

Excellency,

In the course of the discussions which have taken place between us in connection with the conclusion of the Agreement between Bangladesh and India on the sharing of the Ganges Waters at Farakka and on Augmenting its Flow, the two Governments has reached an understanding to the effect that the words "proposed or to be proposed by either Government", occurring in Article IX in part B of the Agreement, relate to any schemes which may have been proposed or may be proposed by Bangladesh or India and do not exclude any scheme or schemes for building storages in the upper reaches of the Ganges in Nepal. The two Governments have also agreed to take such further steps as may be necessary for the investigation and study of any scheme or schemes.

The two Governments have further agreed that the proposals designed to find a solution of the long-term problem, as mentioned in Article IX, shall be treated on an equal footing and accorded equal priority.

I shall be grateful if you will kindly confirm that the above sets out correctly the understanding reached between our two Governments. Upon receiving your reply confirming this understanding, Article IX of the Agreement shall be interpreted and applied along with the understanding embodied in this letter.

Yours sincerely,
M. H. KHAN

Side letter to the Agreement: 2

5th November, 1977

Excellency,

I have today received your letter of 5th November, 1977 which reads as follows:

"In the course of the discussions which have taken place between us in connection with the conclusion of the Agreement between Bangladesh and India on the sharing of the Ganges Waters at Farakka and on Augmenting its Flow, the two Governments has reached an understanding to the effect that the words "proposed or to be proposed by either Government", occurring in Article IX in part B of the Agreement, relate to any schemes which may have been proposed or may be proposed by Bangladesh or India and do not exclude any scheme or schemes for building storages in the upper reaches of the Ganges in Nepal. The two Governments have also agreed to take such further steps as may be necessary for the investigation and study of any scheme or schemes.

The two Governments have further agreed that all the proposals designed to find a solution of the long-term problem, as mentioned in Article IX, shall be treated on an equal footing and accorded equal priority."

On behalf of the Government of India I hereby confirm the understanding embodied in your afore-mentioned letter and agree that Article IX of the Agreement referred to in your letter shall be interpreted and applied along with the understanding embodied in the letters exchanged between us.

Yours sincerely,
S. S. BARNALA

Appendix C

INDO-BANGLADESH MEMORANDUM OF UNDERSTANDING
New Delhi, October 7, 1982.

During the visit of the Excellency Lieutenant General H.M. Ershad, ndc, psc, President of the Council of Ministers, Government of the People's Republic of Bangladesh and his meetings with Her Excellency Mrs. Indira Gandhi, Prime Minister of the Republic of India, the two leaders discussed the actual experience by the two sides on the working of the 1977 Farakka agreement, which would be coming to its end on the 4th of November, 1982. They agreed that it had not proved suitable for finding a satisfactory and durable solution and that with its termination fresh efforts were necessary to arrive at such a solution.

The two leaders recognized that the basic problem of inadequate flow of waters in the Ganga available at Farakka imposed sacrifices on both countries and that it was necessary to arrive at an equitable sharing of the waters available at Farakka. They further agreed that the long term solution lay in augmenting the flow available at Farakka and to this end directed their experts concerned to expedite studies of the economic and technical feasibility of the schemes which had been proposed by either side in order to settle upon the optimum solution for urgent implementation. It was decided that the Joint Rivers Commission would complete the pre-feasibility study and decide upon the optimum solution within 18 months of the signing of this Memorandum, at the end of which the two Governments would immediately implement the augmentation proposal agreed upon by the Joint Rivers Commission. Meanwhile, the two leaders agreed that the release for sharing the flow available at Farakka for the next two dry seasons, and the joint inspection and monitoring arrangements for this purpose, would be as in Annexure `A'. It was further agreed that in the case of exceptionally low flows during either of the next two dry seasons, the two governments would hold immediate consultations and decide how to minimize the burden to either country.

It was also agreed that a further and final sharing agreement would be reached immediately after the completion of the pre-feasibility study of augmentation, in the light of the decision on the optimum solution for augmentation that would be implemented following the pre-feasibility study.

Signed at New Delhi on the Seventh day of October Nineteen hundred and eighty two, in two originals, in English, each of which is equally authentic.

For and on behalf of the Government
Of the Republic of India.

Sd/-
P.V. Narasimha Rao
Minister of External Affairs

For and on behalf of the Government
Of the People's Republic of
Bangladesh.

Sd/-
A.R.Shams-ud Doha
Minister of Foreign Affairs

ANNEXURE-A

Sharing of Waters at Farakka between the 1st January and the 31st May

Period	Flows reaching Farakka (based on 75% availability from observed data (1948—73)	Withdrawal by India at Farakka	Release to Bangladesh
	Cusecs	Cusecs	Cusecs
January 1—10	98,500	40,000	58,500
11—20	89,750	38,000	51,750
21—31	82,500	35,500	47,000
February 1—10	79,250	33,000	46,250
11—20	74,000	31,250	42,750
21—28/29	70,000	31,000	39,000
March 1—10	65,250	26,500	38,750
11—20	63,500	25,500	38,000
21—31	61,000	25,250	35,750
April 1—10	59,000	24,000	35,000
11—20	55,500	20,750	34,750
21—30	55,000	20,500	34,500
May 1—10	56,500	21,500	35,000
11—20	59,250	24,250	35,000
21—31	65,500	26,500	39,000

Appendix D

INDO-BANGLADESH MEMORANDUM OF UNDERSTANDING
New Delhi, November 22, 1985.

In pursuance of the understanding reached between H. E. Lt. General H. M. Ershad, President of the People's Republic of Bangladesh and H.E. Shri Rajiv Gandhi, Prime Minister of the Republic of India during their recent meeting at Nassau, the Bahamas, the Irrigation Ministers of the two countries met at New Delhi from November 18 to 22, 1985 to set out the terms of Reference of a Joint study to be undertaken by experts of the two sides, of the available river water resources common to both countries, with a view to identifying alternatives for the sharing of the same to mutual benefit, including a long term scheme/schemes for augmentation of the flows of the Ganga/Ganges at Farakka and to sign a Memorandum of Understanding for the sharing of the Ganga/Ganges waters at Farakka for a period of three years commencing from the dry season of 1986 on the same terms as the 1982 Memorandum of Understanding.

2. It has already been recognized that the basic problem of inadequate flows of water in the Ganga/Ganges available at Farakka during the dry season imposes sacrifices on both countries, and that the long-term solution lies in augmenting these flows. At the same time, the need to arrive at an equitable sharing of the water available at Farakka has also been recognized.
3. Accordingly it is agreed to undertake a joint study with the following terms of reference:-

    (i). The objective of the study will be (a) to work out a long term scheme or schemes for the augmentation of the flows of the Ganga/Ganges at Farakka and (b) to identify alternatives for the sharing of the available river water resources common to both countries for mutual benefit.
    (ii). The study will be undertaken by a Joint Committee of Experts (JCE). The JCE will consist of the Secretaries concerned of the two Governments and the two Engineering Members of the Joint Rivers Commission from each side. The JCE will determine its own procedure and will take such other steps as may be necessary to ensure its completion within the time frame of 12 months.

(iii). The study will cover the following :-

(A) Sharing the available river water resources common to India and Bangladesh.

(a) Ascertaining the available river water resources common to both countries based on the collection, collation and analysis of available relevant hydro-meteorological data in both countries.
(b) Study of alternatives for sharing the available river water resources to mutual benefit.
(c) Identification of the locations of the points of sharing, where appropriate.

(B) Augmentation of the dry season flows of the Ganga/Ganges at Farakka.

Identification of scheme/schemes for the augmentation of the flows of the Ganga/Ganges at Farakka by the optimal utilization of the surface water resources of the region available to the two countries.

4. The study will start immediately and will be completed in 12 months from the date of the present Memorandum. There will be a review of the progress of joint study at the Ministerial level at the end of six months from the date of the present Memorandum of Understanding. At the end of the 12 months period, a summit level meeting between the leaders of the two countries will take place to take a decision on the scheme of augmentation of the flows of the Ganga/Ganges at Farakka and the long-term sharing of the rivers.
5. It is also agreed that on an interim basis, the release of the Ganga/Ganges water available at Farakka for the next three dry seasons and the joint inspection and monitoring arrangements and for this purpose will be as in Annexure `A'. It is further agreed that in the case of exceptionally low flows during any of the next three dry seasons, the two Governments will hold immediate consultations and decide how to minimize the burden to either country.
6. Signed at New Delhi on the twenty-second day of November Nineteen hundred and eighty-five, in two originals in English, each of which is equally authentic.

For and on behalf of the
Government of the Peoples' Republic
of Bangladesh

Sd/-
(ANISUL ISLAM MAHMUD)
MINISTER FOR IRRIGATION,
WATER DEVELOPMENT AND
FLOOD CONTROL.

For and on behalf of the
Government of the Republic of India

Sd/-
(B. SHANKARANAND)
MINISTER OF WATER
RESOURCES

ANNEXURE-A
SCHEDULE

Sharing of waters at Farakka between the 1st January and the 31st May.

Period	Flows reaching Farakka (based on 75% availability from observed data (1948–1973)	Withdrawal by India at Farakka	Release to Bangladesh
(1)	(2) Cusecs	(3) Cusecs	(4) Cusecs
January 1—10	98,500	40,000	58,500
11—20	89,750	38,000	51,750
21—31	82,500	35,500	47,000
February 1—10	79,250	33,000	46,250
11—20	74,000	31,250	42,750
21—28/29	70,000	31,000	39,000
March 1—10	65,250	26,500	38,750
11—20	63,500	25,500	38,000
21—31	61,000	25,250	35,750
April 1—10	59,000	24,000	35,000
11—20	55,500	20,750	34,750
21—30	55,000	20,500	34,500
May 1—10	56,500	21,500	35,000
11—20	59,250	24,250	35,000
21—31	65,500	26,500	39,000

1. If the actual availability of waters at Farakka during a 10-day period is higher or lower than the quantum shown in 2 of the schedule it shall be shared in the proportion applicable to that period.
2. The Joint Inspection and Monitoring of the above sharing arrangements shall be the responsibility of a Joint Committee consisting of an equal number of representatives on each side. The Joint Committee shall be constituted immediately and shall establish teams to be stationed at Farakka and Hardinge Bridge. These teams shall record at Farakka the daily flows below Farakka Barrage and in the Feeder Canal and the flows passing daily at Hardinge Bridge. The Joint Committee which shall decide its own procedures and method of functioning shall submit the data collected by it and its teams and a yearly report to both Governments.
3. The Joint Committee shall be responsible for implementing the sharing arrangement. Any difficulty arising out of the implementation of the above sharing arrangements and of the operation of the Farakka Barrage shall be examined urgently by this Joint Committee and any differences or dispsutes, if not resolved by the Committee shall be considered by a panel or an equal number of representatives of the two Governments to whom the Joint Committee shall refer the differences or dispute. If the difference of dispute remains unresolved by the panel, it shall be referred to the two Governments for urgent discussion.

Agreement on sharing of exceptionally low flows at Farakka for 1986-88.

As per Indo-Bangladesh Memorandum of Understanding of 22nd November, 1985, it was agreed that in case of exceptionally low flows during any of the next three dry seasons, the two Governments would hold immediate consultations and decide how to minimize the burden of either country.

In case of exceptionally low flows at Farakka during 1986-88 it is now being agreed that:-

(i) If the flow at Farakka is up to and above 75% of the standard flow for the corresponding ten day period, the release to Bangladesh would be pro rata release agreed to in the Memorandum of Understanding (The flow reaching Farakka for the various 10-day periods which are incorporated in the Memorandum of Understanding of 22nd November, 1985 will be termed as standard flow for the corresponding period).

(ii) If the flow at Farakka is below 75% of the standard flow for the corresponding ten-day period, release for Bangladesh would be calculated as below:-

   (a) Calculate the pro rata release for Bangladesh at 75% of the standard flow.
   (b) Calculate pro rata release for Bangladesh at the actual flow.
   (c) \`(a)' minus \`(b)' would be termed as the burden.
   (d) The burden would be shared by India and Bangladesh, on 50 : 50 basis i.e. 50% of © would be added to ©.

Signed in two originals at New Delhi on 22nd November, 1985.

Sd/-
(Mohammed Ali)
Secretary
Irrigation, Water Development
FLOOD CONTROL.
And Flood Control,
Government of Bangladesh

Sd/-
(Rammaswamy R. Iyer)
Secretary
Ministry of Water Resources,
Government of India,
New Delhi.

Appendix E

TREATY BETWEEN INDIA AND BANGLADESH SIGNED (Thursday) on 12th December, 1996. [*The Statesman*, 13.12.1996. Friday].

India and Bangladesh signed a 30-year treaty on sharing of Ganga Water at Farakka. According to the pact, each country will receive a guaranteed flow of 35000 cusecs of water during lean season between March1 and May 10. The treaty was signed by the Prime Minister of India, Mr. H.D. Deve Gowda, and the Prime Minister of Bangladesh, Sheikh Hasina Wajed (Mrs.). The treaty comes into force with immediate effect.

The sharing of water is based on a formula that takes into account the 40-year (1949—88) average availability of water at Farakka. The average availability has been around 70,000 cusecs. The formula stipulates that if the average availability remains the same, the waters are to be shared on a 50 : 50 ratio. If the availability increases from 70,000 to 75,000 cusecs, Bangladesh will still get its share of 35,000 cusecs with the excess water going to India. If the availability increases more than 75,000 cusecs, India will get 40,000 cusecs and the balance will be released to Bangladesh.

Water sharing between the two countries will be on an alternating three ten day period during the lean season. The treaty covers the water sharing arrangement between India and Bangladesh from January 1 to May 31 every year, but also takes note of the fact that the critical lean period is from March 1 to May 10. If the average availability of water at Farakka falls below 70,000 cusecs, both countries will receive reduced quota. Annexure II gives the details. The treaty ensures that even during this period each side gets its guaranteed share of 35,000 cusecs at least once in a three 10-day cycle of water release. The treaty has 12 articles:

Article I: The quantum of water, agreed to be released by India and Bangladesh will be at Farakka.

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

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

iii) In the event flow at Farakka falls below 50,000 cusecs in any 10-day period, the two governments will enter into immediate consultants to make adjustments on an emergency basis, in accordance with the principles of equality, fair play and no harm to either party.

Article III: Water released to Bangladesh at Farakka shall not be reduced below Farakka except for reasonable uses of waters, not exceeding 200 cusecs, by India between Farakka and the point on the Ganga, where both its banks are in Bangladesh.

Article IV: A joint committee will be constituted of representatives of both sides in equal numbers following the signing of this treaty. The joint committee will then set up suitable teams at Farakka and Hardinge Bridge to observe and record at Farakka the daily flows below Farakka Barrage, in the feeder canal and at the Navigation Lock, as well as at the Hardinge Bridge.

Article V: The joint committee will decide its own procedure and method of functioning.

Article VI: The joint committee shall submit to the two governments all data collected by it and shall also submit a yearly report to both the Governments. Following submission of the reports the two Governments will meet at appropriate levels to enable them to decide upon further action as may be needed.

Article VII: The Joint Committee shall be responsible for implementing the arrangements contained in the Treaty and examining any difficulty arising out of the implementation of the above arrangements and of the operation of Farakka Barrage. Any difference or dispute arising in this regard, if not resolved by the Joint Committee, shall be referred to the Indo-Bangladesh Joint Rivers Commission. If the difference or dispute still remains unresolved, it shall be referred to the two governments which shall most urgently meet at appropriate level to resolve by mutual discussion.

Article VIII: The two Governments recognize the need to cooperate with each other in finding a solution to the long term problem of augmenting the flows of the Ganga during the dry season.

Article IX: Guided by the principles of equality, fairness and no harm to either party, both the Governments agree to conclude water sharing Treaty/Agreements with regard to other common rivers.

Article X: The sharing arrangement under this treaty shall be reviewed by the two governments at five years interval or earlier, as required by either party and needed adjustments, based on principles of equality, fairness, and no harm to either party made thereto, if necessary. It would be open to either party to seek the first review after two years to assess the impact and working of the sharing arrangement as contained in this Treaty.

Article XI: For the period of this treaty, in the absence of mutual agreement on adjustment, following reviews, as mentioned in **Article X**, India shall release downstream of Farakka Barrage, water at a rate not less than 90 per cent of Bangladesh's share according to the formula referred to in Article II, until such time as mutually agreed flows are decided upon.

Article XII: The treaty shall enter into force for a period of 30 years and it shall be renewable on the basis of mutual consent.

Annexure-I of Agreement

Availability at Farakka	*Share of India*	*Share of Bangladesh*
70,000 cusecs or less	50%	50%
70,000 to 75,000 cusecs	Balance of flow	35,000 cusecs
75,000 cusecs or more	40,000 cusecs	Balance of flow

Note: Subject to the condition that India and Bangladesh each shall receive guaranteed 35,000 cusecs of water in alternate three 10-day periods during the period March 1 to May 10.

Annexure-II of Agreement

(Sharing of water at Farakka between January 01 and May 31 every year).

If actual availability corresponds to average flows of the period 1949 to 1988, the implication of the formula in Annexure-1 for the share of each side is:

Period	Average of total flow 1949-88 (cusecs)	India's share (cusecs)	Bangladesh's share (cusecs)
January 1—10	1,07,516	40,000	67,516
11—20	97,673	40,000	57,673
21—31	90,154	40,000	50,154
February 1—10	86,323	40,000	46,323
11—20	82,859	40,000	42,859
21—28/29	79,106	40,000	39,106
March 1—10	74,419	39,419	35,000
11—20	68,931	33,931	35,000*
21—31	64,688	35,000*	29,688
April 1—10	63,180	28,180	35,000*
11—20	62,633	35,000*	27,633
21—31	60,922	25,922	35,000*
May 1—10	67,351	35,000	32,351
11—20	73,590	38,590	35,000
21—31	81,854	40,000	41,854

(*Three ten-day periods during which 35,000 cusecs shall be provided).

Delegates present during signing of Treaty at New Delhi on 12.12.1996

Indian side:

1. Mr. H. D. Deve Gowda
   Prime Minister
2. Mr. Janeshwar Mishra — **Signatory of agreement**
   Union Water Resources Minister
3. Mr. I. K. Gujral
   Foreign Minister
4. Mr. Jyoti Basu
   Chief Minister, West Bengal

Associates

1. Mr. D. P. Ghosal
   Secretary, I & WD/GOWB
2. Mr. R. N. Dey
   Chief Engineer, R & D
   I & WD/GOWB.
3. Mr. S.V.V. Char
   Commissioner (ER)
   MOWR/GOI

Bangladesh Side

1. Sheikh Hasina Wajed
   Prime Minister
   And Others.
2. Mr. Abdur Razzak **Signatory of Agreement**
   Minister for Water Resources.

Glossary

Acumen Keen discernment.

Acute angle angle less than one right angle.

Aeon Age of the Universe.

Afflux Bund Embankment against the flooding of countryside due to heading up of water from a human interference across a river or a stream.

Aggradation General and progressive build up of the longitudinal profile of a channel bed due to sediment deposition.

Agni Fire (God of Fire in Hindu Mythology).

Airabat Elephant of white colour on which God Indra rides (Hindu Mythology).

Angle of obliquity Angular flow of water towards the bank in a stream or river.

Albeit Although it be that.

Alluvial Pertaining to or composed of materials deposited by a stream or running water.

Alluvium A general term of clay, silt, sand, gravel, or similar unconsolidated detrital material deposited by a stream flow or other body of running water during a comparatively recent geologic time in the bed of the stream or its floodplain or delta.

Alluvial channel Channel wholly in alluvium; no bedrock is exposed in channel at low flow or likely to be exposed by erosion.

Alluvial Fan A fan-shaped deposit of material at a place where a stream comes out from a narrow valley of high slope onto a plain or broad valley of low slope.

Alluvial stream A stream which has formed its channel in cohesive or non-cohesive materials that have been and can be transported by a stream.

Alluvium Deposition of alluvial materials.

Ambiguous Inconsistent.

Armour Surfacing of channel bed, banks or embankment slope to resist erosion or scour.

Apron Protective material placed on a stream bed to resist scour.

Augment To increase.

Augmentation Increase of flow of river by artificial means.

Avulsion A sudden cutting off or separation of land by a flood or by an abrupt change in the course of a stream.

Bank revetment Erosion-resistant materials placed directly on a stream bank to protect the bank material from erosion.

Bar An elongated deposit of alluvium within a channel, not permanently vegetated.

Bhagirath Ancestor of King Sagar (Hindu Mythology).

Bhima Son of King Pandu and elder brother of Arjuna in Hindu epic, Mahabharat.

Bhisma Son of King Santanu and Grand-father of Kauravas and Pandavas (Mahabharat).

Bilateral Between the two countries.

Billion One thousand million.

Bore Wall height of water during flow tide rushing towards the hinterland of the estuary.

Boulder A rock fragment whose diameter is greater than 250 mm.

Braid Division of main channel of a stream or river by smaller ones due to formation of bars in between them.

Braided stream A stream whose flow is divided at normal stage by small mid-channel bars or small islands.

Burgeoning Beginning to grow.

Centrifugal Rotational force towards the centre of a circle.

Chandimangal A Hindu epic.

Channel pattern The geography of a stream in plan view.

Confluence The junction of two small streams.

Comprehensive Satisfactory.

Concave bank Inside face of a curved river bank.

Consensus Agreed by all parties.

Coriolis force The inertial force caused by the Earth's rotation that deflects a moving body to the right of the Northern Hemisphere.

Critical shear stress The minimum amount of shear stress required to initiate soil particle in motion.

Cut-off A direct channel, either natural or artificial, connecting two points on a stream, thereby shortening the original length of the channel and increasing its slope; it also means a natural or artificial channel which develops across the neck of a meander loop or across a point bar (chute cut-off).

Delta The low and flat alluvial tract of land deposited at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area enclosed and/or crossed by many distribution of the main river.

Debris Floating or submerged material, such as logs, vegetation, or trash, transported by a stream.

Degradation A general and progressive lowering of the channel bed due to erosion, over a relatively long channel length.

Dike A relatively long and linear impermeable structure for the control and prevention of overbank flow.

Diurnal flow Tides with an approximate tidal period of 24 h.

Drainage basin A catchment or watershed area confined by drainage divisions often having one outlet for discharge.

Deterioration Bad situation.

Debouche Discharge into a greater waterbody.

Diminution Reduction.

Draught Draft; the depth of water below the keel of a ship.

Drought Scarcity of rains; dry situation.

Ebb-flux Height of water during ebb tide.

Ebb-tide Flow of water from the bay or estuary to the ocean.

Ecology Life style of plants and animals in relation to environment.

Eddy current A vortex-type motion of a fluid flowing contrary to the main current, such as the circular water movement that occurs when the main flow becomes separated from the bank.

Ephemeral A stream or reach of a stream that does not flow for part of the year.

Erosion Displacement of soil particles due to water or wind action.

Estuary Tidal reach at the mouth of a river.

Evolution Gradual development.

Feeble Very small, not prominent.

Fetch The unobstructed area in which waves are generated by wind.

Filter A layer of fabric (geotextile) or granular material (sand, gravel or graded rock) placed between protection material and bank/bed material.

Flood tide Flow of water from the ocean to the bay on estuary.

Flood Plain A nearly flat, alluvial low land bordering a stream, that is subject to frequent inundation by floods.

Flow flux Rise of water level during flood tide.

Flow slide Saturated soil materials which behave more like a liquid than a solid. A flow slide on a channel bank can result in a bank failure.

Fluvial The matter relating to or pertaining to the stream or river and produced by river action.

Fragile Easily breakable.

Freshet Flood season.

Friable Fragmentation of rock or mineral that crumbles naturally or is easily broken, pulverized or reduced to small pieces.

GBM Ganga-Brahmaputra-Meghna

Geomorphology The science that deals with the form of Earth, the general configuration of its surface, and the changes that take place due to erosion and deposition.

Geo textile Textile cloth made of chemical fibres.

Glaciation Ice formation, frozen.

Goutama The childhood name of Lord Buddha.

Guide bank A dike extending both upstream or downstream along the river bank on both sides of the bridge or barrage.

Hydraulics The applied science concerned with the behaviour and flow of liquids, especially in pipes, channels, structures and the ground.

Hydraulic model A small-scale physical or mathematical representation of a prosituation.

Hydrograph The graph of stage or discharge against time.

Hydrology The science concerned with the occurrence, distribution and circulation of water on Earth.

Impedence Obstruction.

Indra The king of Gods in Heaven according to Hindu mythology.

Intrusion Forcible entrance.

Industrialization Growth of industries in a locality.

Jahnu A sage mentioned in Hindu mythology, Mahabharata.

Jheel A water body like lake.

Kapil A sage mentioned in Hindu mythology, Mahabharata.

Kartikeya Supreme commander of Gods in Heaven according to Hindu mythology.

Kauravas Sons of King Dhritarashtra of Hastinapur mentioned in Hindu mythology.

Levee An embankment, generally landward on top of river bank, that confines flow during high-water periods which prevents overflow into lowlands.

Leeward Other side of the wind direction.

Mahabharata Hindu mythology.

Mahavira The Founder of Jain Religion.

Marginal embankment Embankment along the river bank to restrict overflow of flood water on the countryside.

Maneouvering Moving around.

Mathematical model A numerical representation of flow situation using mathematical equations (also computer model).

Meander Two consecutive loops of a river, one flowing clockwise and the other anti-clockwise.

Menoka A beautiful Goddess dancer of Heaven.

Migration Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank.

Mind-boggling Memorable, Eventful.

Mooring Fastening by a cable or anchor.

Moribund The dying stage of a river without any flow.

Morphology The structural arrangement of landform, rivers, river basins etc. of Earth's surface.

Obtensive Critical.

Obtuse angle Angle greater than a right angle.

Perennial stream Stream carrying flow round the year.

Persistant Continuous.

Planation Plan formation.

Plateau Table-land.

Point-bar Formation of sand-deposit island within the river bed.

Potable Fit for drinking.

Predominate To surpass the strength or authority.

Prestressed Stressed in advance.

Probability The qualification of risk; risk assessment.

Propagation Reproduction.

Prototype Original type or model from which anything is copied.

Puranic Copied from Puran, a Hindu epic.

Ramayana A Hindu epic.

Rampur Bauleah Name of a place.

Regime The condition of a stream or its channel with regard to stability. A stream is said to be in regime stage if its channel has reached an equilibrium form as a result of its flow characteristics.

Regulator A control structure across a stream or river.

Rejuvenation Getting young or growing again.

Rehabilitation Reinstatement to earlier privileges.

Restoration Reinstatement.

Resuscitation Revival.

Riverine Pertaining to or formed by a river.

Reversion Bringing back to original.

Revitalisation Restoration.

Riparian Pertaining to anything connected with or adjacent to the banks of a stream (vegetation, corridor, landmass etc.).

Runoff That part of precipitation which appears on land surface and moves down towards the stream and low lands either in perennial or intermittent form.

Sagar Name of a king of Hastinapur in Hindu epic, Mahabharata. Also name of an island in Hooghly estuary. Also the word means sea.

Sandheads A place at the outer point of the Hooghly estuary.

Santanu Name of a King of Hastinapur in Hindu epic, Mahabharata.

Scaled Rusted.

Sediment load Amount of silt load carried by a stream.

Seepage The slow movement of water through small cracks and pores of the bank material.

Semi-diurnal Tides with an approximate tidal period of 12 h.

Shiva Name of one God in Hindu religion.

Shear-stress The force or drag developed at the channel by the flowing water.

Shoal A relatively shallow landform or bar occasionally submerged in a body of water.

Silty Mixed with silt load.

Simulation Assumption of a similar but false appearance.

Sinuosity The ratio between the deep channel length and the valley length of a stream.

Slack zone Ponded zone of a stream, zone where there is no velocity of flow.

Sloughing Sliding or collapse of overlying material.

Slump A sudden slip or collapse of a bank, generally in the vertical direction and confined to a short distance.

Spur A permeable or impermeable linear structure that projects into a channel from the bank.

Subsidence Settled, sinking down.

Swamp Low spongy land.

Terrace Raised level bank.

Thalweg The line extending down a channel that flows the lowest elevation of the bed.

Tidal prism Volume of water contained in a tidal bay, inlet or estuary between low and high tide levels.

Tidal propagation Movement or distribution of tide.

Toe of bank That portion of a stream cross-section where the lower bank terminates and the channel bottom or the opposite lower bank begins.

Tractive force The drag or shear on a stream bed or bank caused by passing water which tends to move soil particles along with the stream flow.

Trough A narrow strip of low depression. A depression between two wave-crests.

Turbulent Disturbed, unruly.

Turmoil Commotion.

Uma Another name of Goddess Durga, the symbol of strength.

Urbanisation Conversion to town or city area.

Valmiki A sage who had written the Hindu epic, Ramayana.

Vishma the Son of King Santanu and Grand-father of Kauravas and Pandavas in the Hindu epic, Mahabharata.

Vortex turbulent eddy in the flow generally caused by an obstruction, such as, bridge pier or abutment.

Warehouse a covered godown for storage purpose.

Weightage Gravity.

Wash load Suspended material of very small size (generally clay or colloid particles) originating primarily from erosion of land slopes of drainage area.

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Colour Plates

Plate 1 Bank erosion near Panchnandapur in Malda district (See also Photograph 5.1 on page 49)

Plate 2 Breach of marginal embankment upstream of Farakka Barrage in Malda district during floods of 1998 (See also Photograph 5.2 on page 51)

Plate 3 Flood affected people taking shelter over marginal embankment (See also Photograph 5.3 on page 52)

Plate 4 Bank erosion of Bhagirathi near Palasi (See also Photograph 5.4 on page 58)

Plate 5 Bank slip of Nayachara island near Haldia (See also Photograph 5.5 on page 58)

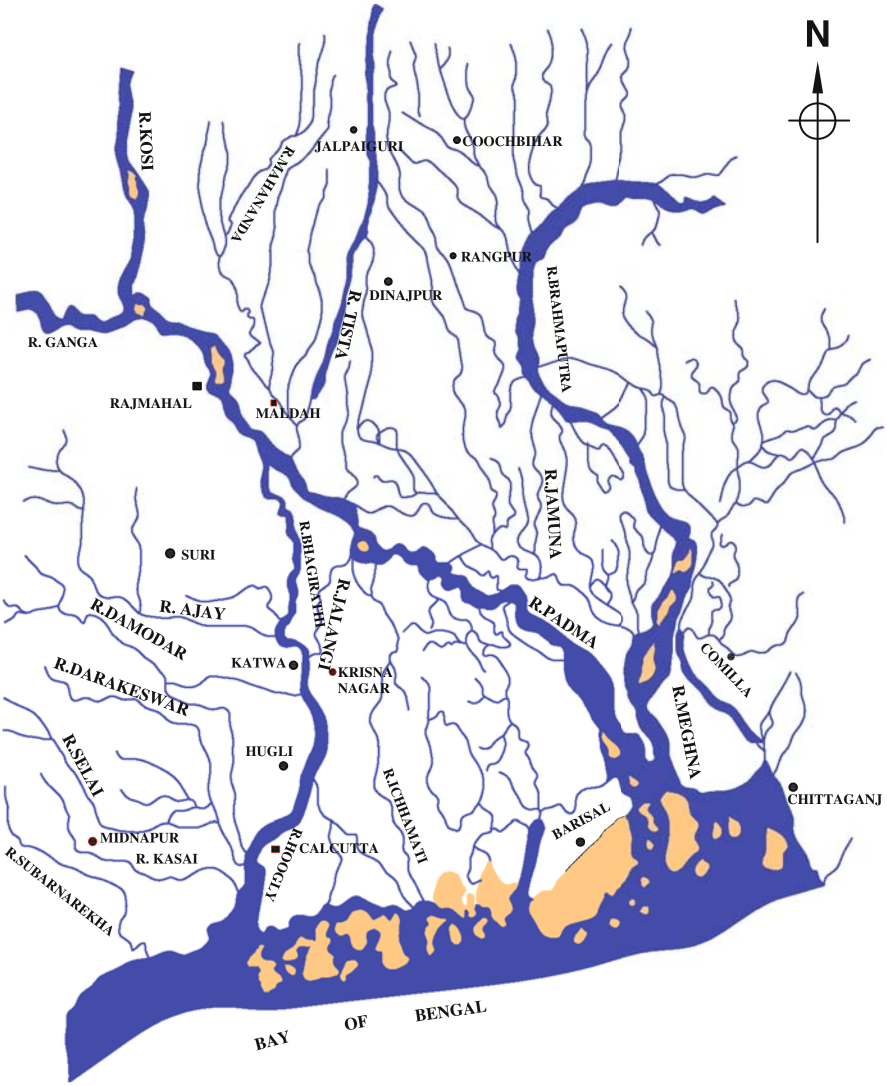

Plate 6 Bengal rivers in 1764–1776 (Rennel's map) (See also Fig. 6.1 on page 64)

Plate 7 Ganga river upstream of Farakka Barrage (See also Photograph 7.10 on page 104)

Plate 8 Ganga river downstream of Farakka Barrage (See also Photograph 7.11 on page 104)

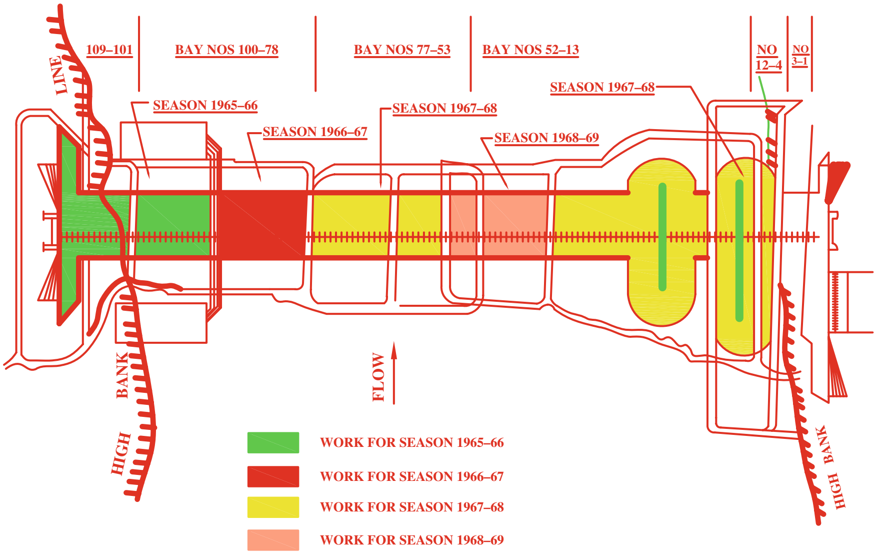

Plate 9 Coffer dam enclosures of Farakka Barrage for different seasons (See also Fig. 7.2 on page 99)

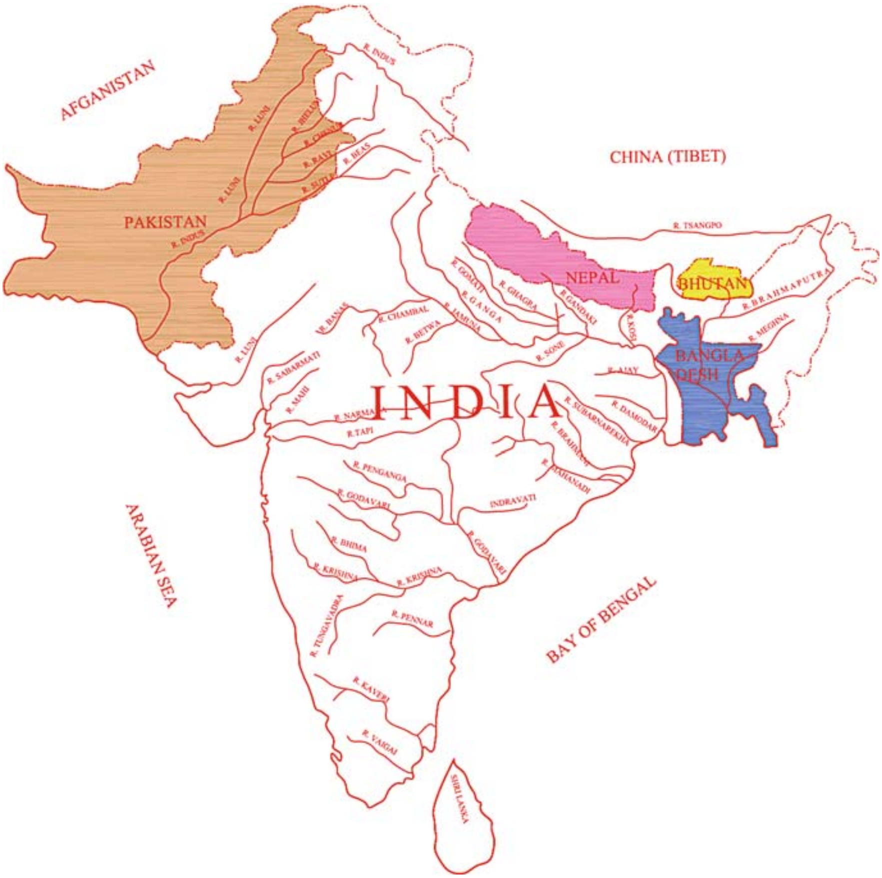

Plate 10 River systems of India and neighbouring countries (See also Fig. 14.1 on page 270)

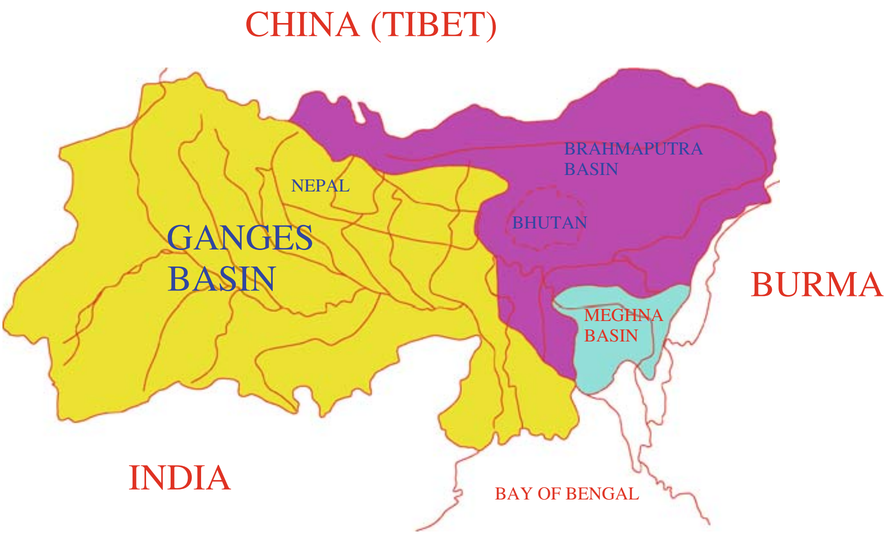

Plate 11 The Ganges, Brahmaputra and Meghna basins (See also Fig. 14.3 on page 275)

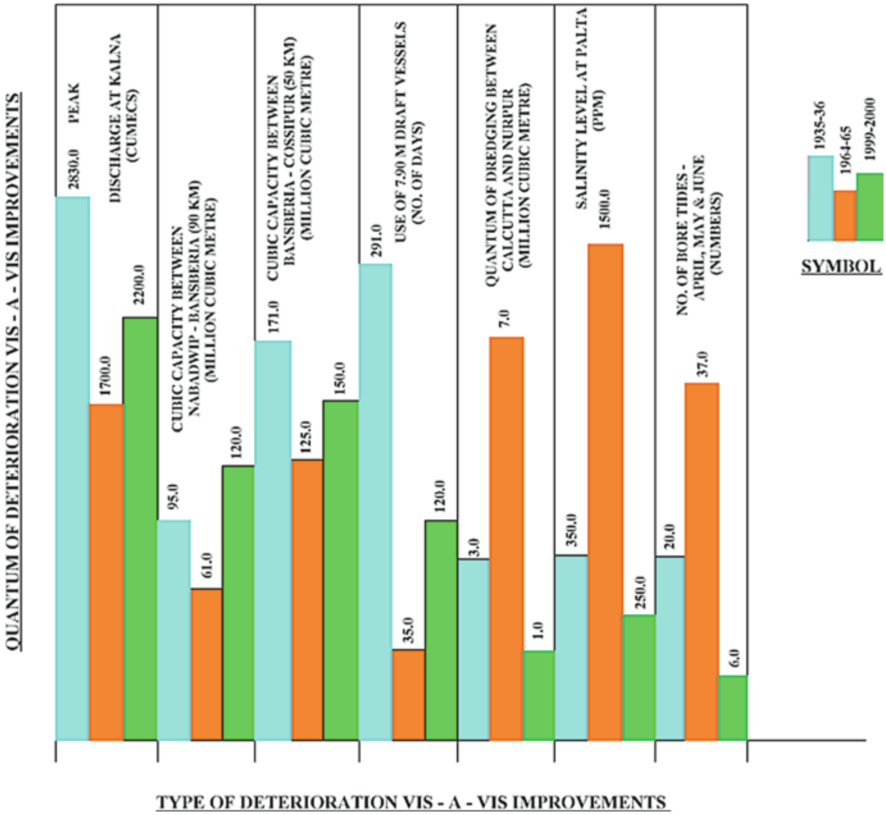

Plate 12 Bar chart showing the effect of Farakka diversion on the Bhagirathi-Hooghly river (See also Fig. 15.3 on page 291)

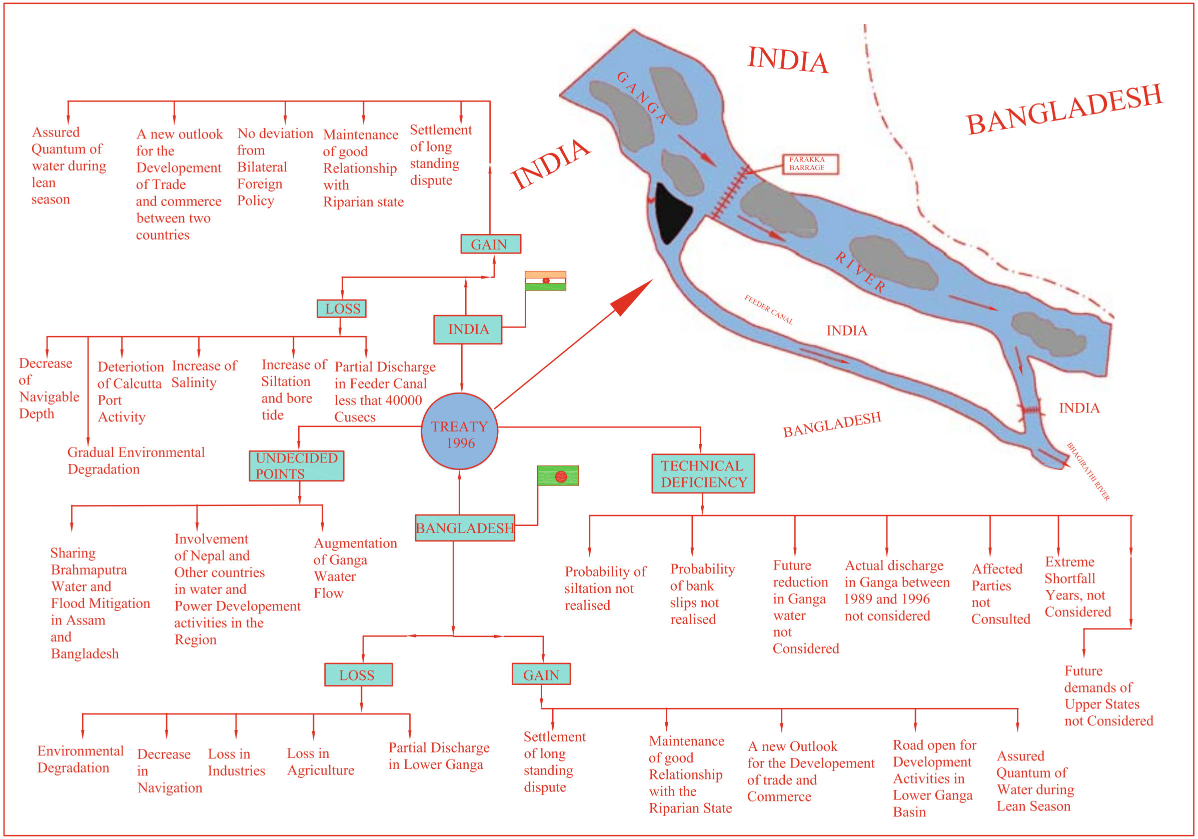

Plate 13 Effects of Indo-Bangladesh Treaty, 1996 (See also Fig. 15.5 on page 294)

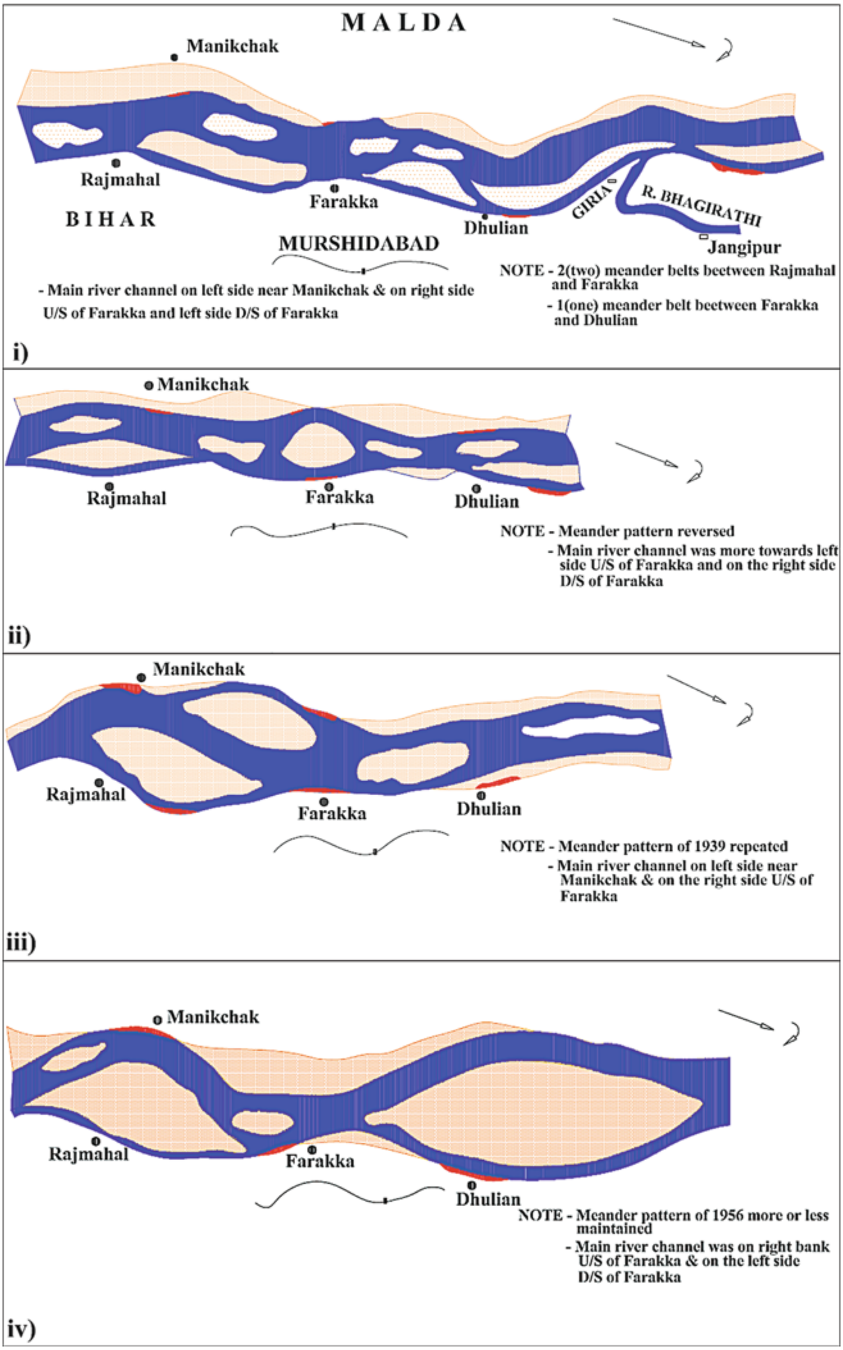

Plate 14 (i) Ganga river course – 1939; (ii) Ganga river course – 1948; (iii) Ganga river course – 1956; (iv) Ganga river course – 1962; (v) Ganga river course – 1976; (vi) Ganga river course – 1986; (vii) Ganga river course – 1996; (viii) Ganga river course – 2002. Note: Erosion zones of different years are shown in red colour (See also Fig. 15.7 on page 305)

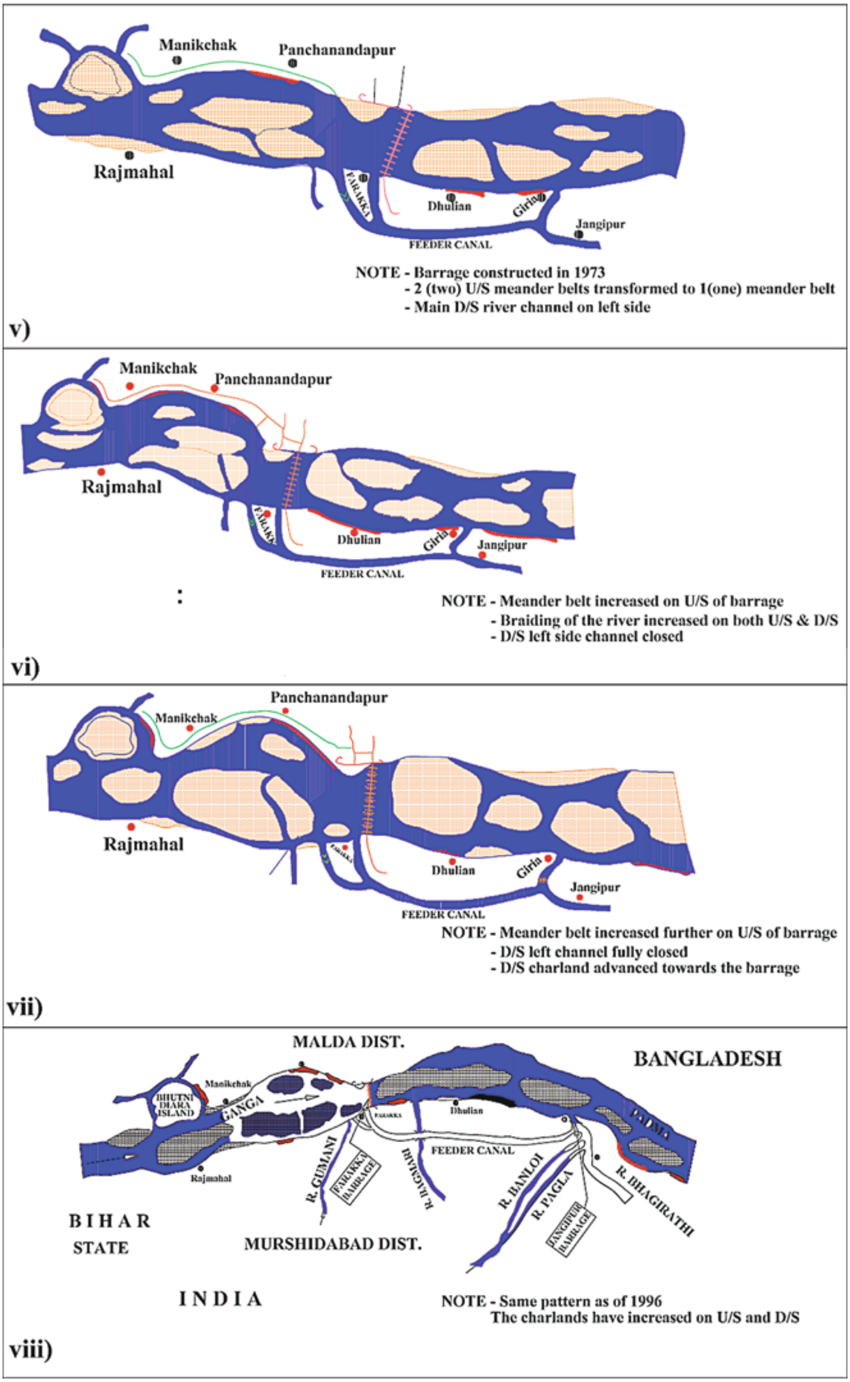

Plate 14 (continued)

Maps


N
Major Rivers
INDIA
JAMMU & KASHMIR
Indus
Jhelum.
Chenab
Ravi
Beas
PAKISTAN
HIMACHAL PRADESH
Satluj
CHINA (TIBET)
PUNJAB
CHANDIGARH
UTTARANCHAL
Slang
Lonit
Satluj
HARYANA
DELHI
Gandak
NEPAL
ARUNACHAL PRADESH
RAJASTHAN
Yamuna
Ganges
SIKKIM
BHUTAN
Kosi
Brahmaputra
Luni
Chambal
UTTAR PRADESH
Ganges
ASSAM
NAGALAND
MEGHALAYA
BIHAR
MANIPUR
GUJARAT
Saraswati
Narmada
TRIPURA
MIZORAM
MADHYA PRADESH
JHARKHAND
WEST BENGAL
Mahanadi
Tapi
CHHATTISGARH
MYANMAR
DIU
DAMAN
DADARA & NAGAR HAVELI
ORISSA
BANGLADESH
Godavari
MAHARASHTRA
Bhima
Krishna
ANDHRA PRADESH
BAY OF BENGAL
ARABIAN SEA
Krishna
YANAM (Pondicherry)
GOA
KARNATAKA
Payaswani
LAKSHADWEEP
Kaveri
PONDICHERRY (Puduchchery)
MAHE (Pondicherry)
TAMILNADU
KARAIKAL (Pondicherry)
ANDMAN & NICOBAR ISLANDS
KERALA
State Boundary
Rivers
Map not to Scale
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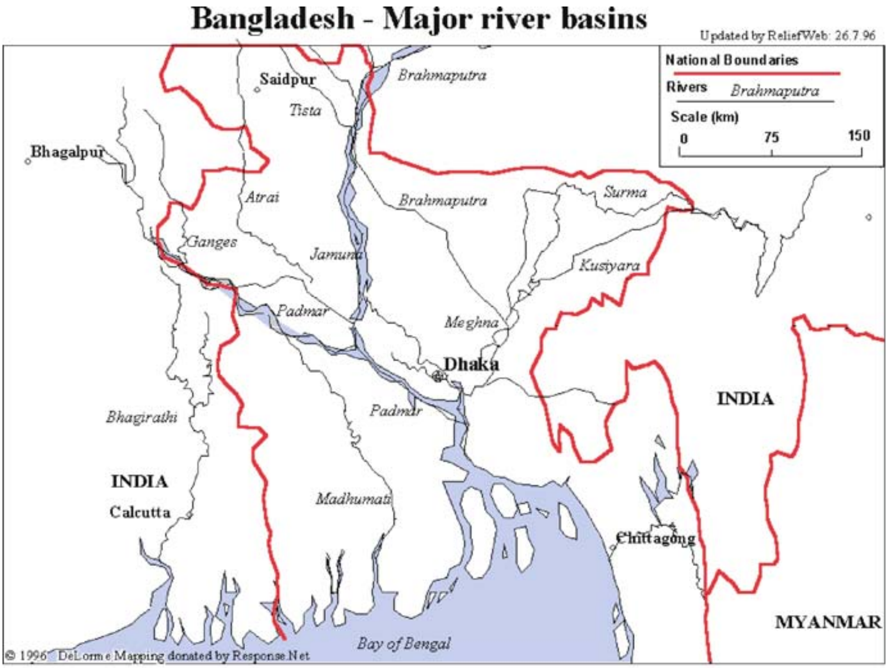

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WEST BENGAL
Physical
SIKKIM
BHUTAN
N
NEPAL
Tiger Hills
Darjeeling Hills
Western Duars
Eastern Shiwalik
Jalpaiguri Plain
Konkai
Mahananda
Amo
Tista
ASOM
Sapi Kosi
BIHAR
Kosi
Karcha
Ghugri
Ganga
Balurghat Plain
Barind Plain
INDIA
Badua
JHARKHAND
Gaur Plain
BANGLADESH
Batakar
Ajay
Mayurakshi Plain
East Bhagirathi Plain
Maithon Reservoir
Panchot Reservoir
West Bhagirathi Plain
Lower Ddamodar Plain
Damodar
Purulia Upland
Susunia Upland
Rupnarayan Plain
Silai
Rarh Plain
Subarnarekha
ORISSA
Kangsabeti Valley
Kasai
Medinipur Plain
Physical Altitude Scale
3000 m
1800m
900 m
600 m
300 m
150 m
0 Sea Level
150 m
Kanthi Coastal Plain
Hugli River
BAY OF BENGAL
Map not to Scale
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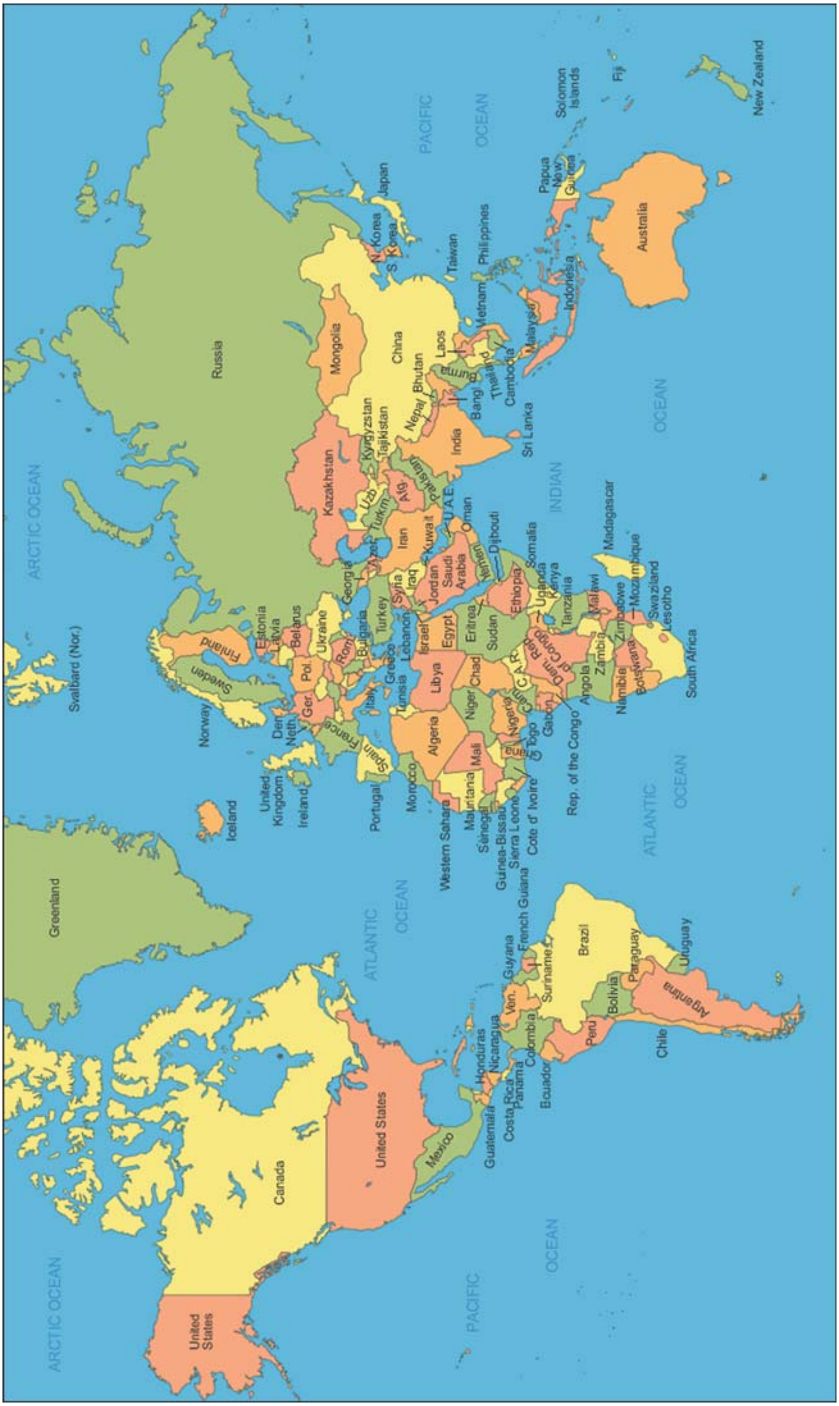
ARCTIC OCEAN
ARCTIC OCEAN
PACIFIC OCEAN
PACIFIC OCEAN
ATLANTIC OCEAN
ATLANTIC OCEAN
INDIAN OCEAN
United States
Canada
United States
Mexico
Guatemala
Honduras
Nicaragua
Costa Rica
Panama
Colombia
Ecuador
Ven.
Guyana
Suriname
French Guiana
Peru
Brazil
Bolivia
Paraguay
Chile
Argentina
Uruguay
Greenland
Iceland
Svalbard (Nor.)
Norway
Sweden
Finland
Estonia
Latvia
Belarus
Ukraine
United Kingdom
Ireland
Den.
Neth.
Ger.
Pol.
France
Spain
Portugal
Italy
Rom.
Bulgaria
Greece
Turkey
Georgia
Azer.
Russia
Kazakhstan
Mongolia
China
Uzb.
Turkm.
Kyrgyzstan
Tajikistan
Afg.
Pakistan
Iran
Iraq
Syria
Lebanon
Israel
Jordan
Kuwait
Saudi Arabia
U.A.E.
Oman
Yemen
Nepal
Bhutan
India
Bang.
Sri Lanka
Burma
Laos
Thailand
Cambodia
Vietnam
Malaysia
Indonesia
Philippines
Taiwan
N. Korea
S. Korea
Japan
Papua New Guinea
Solomon Islands
Fiji
Australia
New Zealand
Morocco
Western Sahara
Algeria
Tunisia
Libya
Egypt
Mauritania
Mali
Niger
Chad
Sudan
Eritrea
Djibouti
Ethiopia
Somalia
Senegal
Guinea-Bissau
Sierra Leone
Cote d' Ivoire
Ghana
Togo
Nigeria
Cam.
C.A.R.
Gabon
Rep. of the Congo
Dem. Rep. of Congo
Uganda
Kenya
Tanzania
Angola
Zambia
Malawi
Zimbabwe
Mozambique
Namibia
Botswana
Swaziland
Lesotho
South Africa
Madagascar

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