Chapter 3
Flood and Water Resource Management in the Controlled Tropical River Damodar

Abstract The Damodar River, a subsystem of the mighty Ganga system, has always been notorious as a calamitous river like the Hwang Ho of China and the Kosi of India. People as well as governments throughout the centuries have dealt with the caprices of these vital water resources using different strategies. In the case of the Damodar, heavy embankments were used in its lower sector to reduce flood hazard in the Rarh plain. When the Damodar Valley Corporation (DVC) was first conceived and modeled after the Tennessee Valley Authority (TVA) of USA in 1948, the river was again controlled, this time through the construction of sophisticated engineering structures. This chapter focuses on the hydrogeomorphic consequences of lateral control structures. The riverbed has been raised, soil composition in the adjacent riparian tract has been changed, cross sections have been increased, and a number of spill channels have been opened on the right bank. In addition, shifting of banklines and bank erosion are observed on the left bank.

Keywords Bank erosion · Bank lines · Cross sections · Damodar valley corporation · Embankment · Riparian community · Riverbed · Tennessee valley authority

3.1 Tropicality of the Lower Damodar Environment

The Damodar is referred to as a tropical river as it flows through a tropical environment. Tropicality of environment is assessed in terms of specific conditions and not by mere latitudinal location. The tropicality of environment is primarily a product of thermal criteria. Further classification is based on amount and seasonality of precipitation.

The basic tropical climatic characteristics of the drainage basin are the following:

i. The temperature of the coolest month (December) is 19.15 and 19.85°C at Asansol and Barddhaman, respectively (Tables 3.1 and 3.2)
ii. The average seasonal ranges are 13.95°C (May and December) and 11.85°C (May and December) for Asansol and Barddhaman respectively

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Table 3.1 Climatological table of Asansol (based on observation from 1931–1960)

	Temperature in °C			Wet Bulb temperature				
Month	Highest	Lowest	Mean	in °C	in °F	Relative humidity	Total rainfall	No. of rainy days
Jan	29.5	08.5	19.00	14.45	58.01	56.0	16.6	1.3
Feb	33.1	10.3	21.70	16.10	60.98	50.5	24.3	2.2
Mar	39.1	14.9	27.00	18.70	65.66	37.0	17.3	1.8
Apr	42.8	18.9	30.85	21.85	71.33	38.0	23.9	1.3
May	44.5	21.7	33.10	24.95	76.91	52.0	73.0	4.8
June	42.6	22.9	32.75	25.80	78.44	69.5	192.4	7.3
July	35.3	23.6	29.45	26.40	79.52	82.0	344.4	18.2
Aug	34.4	23.7	29.05	26.35	79.43	84.5	335.3	17.6
Sep	34.7	23.1	28.90	26.05	78.89	81.5	234.8	11.4
Oct	34.1	17.6	25.85	23.50	74.30	73.0	112.9	5.4
Nov	31.7	12.1	21.90	18.10	64.58	61.0	14.8	1.0
Dec	29.2	9.1	19.15	14.90	58.82	57.5	2.5	0.2

Source: IMD Climatological Tables of Observatories in India (1931–1960).

iii. The average daily range of temperature is greater than seasonal range of temperature
iv. Monthly rainfall varies from 2.5 mm (December) to 344.4 mm (July), 4.3 mm (December) to 314.4 mm (July), and 3.2 mm (December) to 331.9 mm (August) for Asansol, Barddhaman and Hooghly respectively (Tables 3.1 and 3.2)
v. The Lower Damodar Basin has an annual rainfall of 1,321 mm (western upland area) to 1,600 mm (eastern and south eastern part), Fig. 3.1
vi. There is a definite dry period from November to May
vii. There are five rainy months, from June to October, which account for more than 80% of the total annual rainfall
viii. Relative humidity is more than 80% in July–September, and only 50% or less than 40% in March and April
ix. The number of rainy days increases from June to August
x. The annual rainfall is variable, the co-efficient of variability being 106.07%.

The above conditions conform to the requisite conditions for a tropical climate as defined by Thronthwaite in 1931, 1933, 1948, Köppen in 1931, 1936 and also by Trewartha (1968), Barry and Chorley (1978) and Nieuwolt (1977).

The monsoon tropicality of the environment is reflected on the hydrographs (Fig. 3.2). The hydrograph is leptokartic in nature. Peak discharge is generally found in the months of July–September. Discharge is low between January and May and again between November and December.

Table 3.2 Climatological table of Barddhaman (based on observation from 1931–1960)

	Temperature in °C			Wet Bulb temperature				
Month	Highest	Lowest	Mean	in °C	in °F	Relative humidity	Total rainfall	No. of rainy days
Jan	30.1	09.3	19.70	14.45	58.01	59.5	11.2	0.9
Feb	33.5	10.6	22.05	16.10	60.98	54.5	24.6	1.8
Mar	38.5	15.1	26.80	18.70	65.66	49.5	25.0	1.7
Apr	41.4	20.1	30.75	21.85	71.33	53.5	46.1	3.0
May	42.1	21.5	31.80	24.95	76.91	64.5	114.8	6.5
June	39.7	23.0	31.35	25.80	78.44	76.0	196.0	10.6
July	34.7	23.7	29.20	26.40	79.52	83.5	314.4	15.9
Aug	34.5	24.0	29.20	26.35	79.42	83.0	301.2	16.3
Sep	34.5	23.4	28.95	26.05	78.89	81.5	236.5	11.5
Oct	34.1	19.7	26.90	23.05	74.30	75.5	106.8	5.2
Nov	31.8	14.1	22.95	18.10	64.58	69.0	23.0	1.1
Dec	29.3	10.4	19.85	14.90	58.82	64.0	4.3	0.2

Source: IMD Climatological Tables of Observatories in India (1931–1960).

The tropicality of the Lower Damodar basin can also be assessed from the floristic composition. Original climax vegetation was tropical deciduous with Sal (*Shorea robusta*) predominating. Extension of coal mining activity, construction of roads,

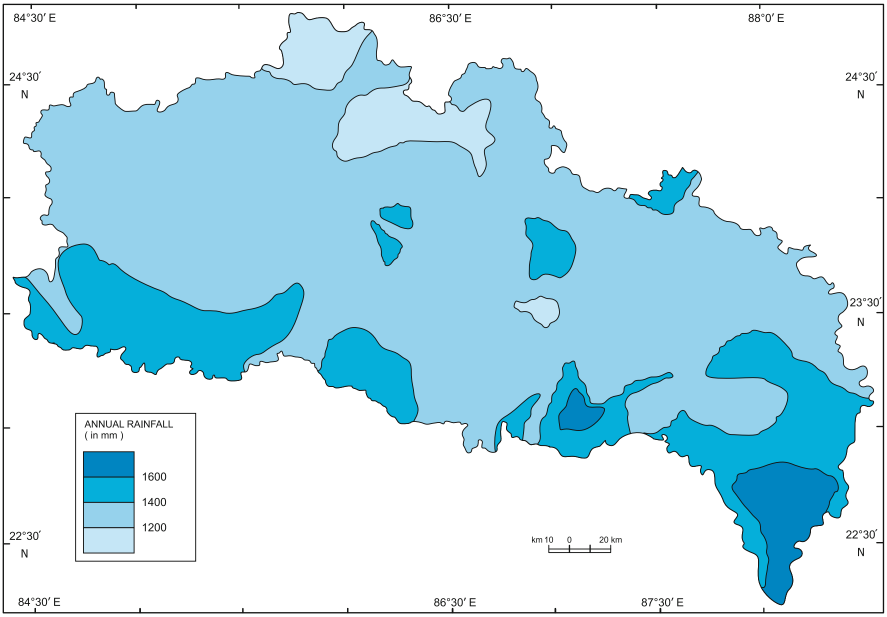

Fig. 3.1 Rainfall map of Damodar valley region. Source: Chatterjee (1969)

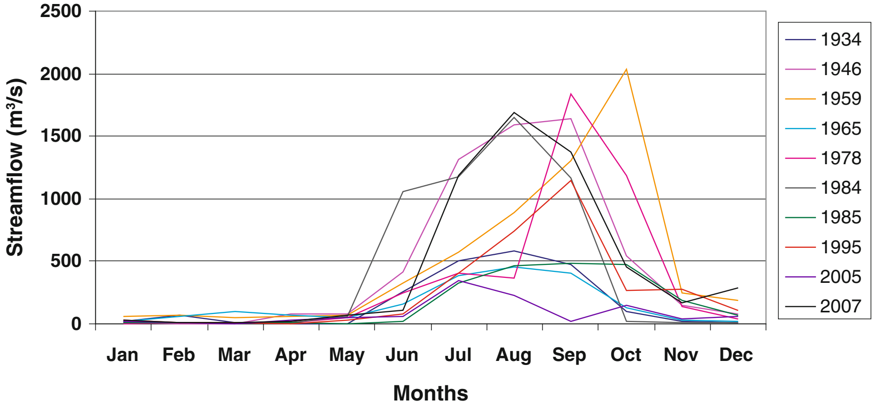

Fig. 3.2 Hydrographs of the Damodar River at Rhondia. Data source: Damodar Canals No. 11, Subdivision–Rhondia, Barddhaman

railways, barrages and reservoirs, and growth and development of urban industrial towns in the upper part of the Lower Damodar has necessitated removal of this climax vegetation. Now there are mostly open forests with coppiced Sal (Dhara and Basu 1988). By virtue of its position, the rest of the Lower Damodar basin must have been forested in the historical past. The forests were cleared long ago for agriculture. An expensive afforestation scheme has been initiated under the territorial forestry and social forestry schemes. Tropical energy plant species such as Akashmoni (*Acacia monilisormis*) and Subabul (*Leucaena leucocephala*) have been planted almost everywhere. The tropicality of the environment can also be recognized from soil characteristics.

Tropicality is also reflected in the economic activities of the region. In the entire Damodar drainage basin, human occupation varies from rock quarrying, forestry, mining, and agriculture to industrial urban activities. Agricultural land use characteristics are closely associated or adjusted with the flood-prone micro-environment. Crop selection and crop calendars strictly follow the tropical climatic regime and will be discussed in later sections. Economic activities such as open-pit mining and sand quarrying are greatly affected by heavy rain during monsoon. Transport facilities in the Lower Damodar valley area are extremely inadequate as the Grand Trunk Road, which links Kolkata (Calcutta) with Upper India, is the only important all-weather long distance road in the valley. The village roads are seasonal and almost impassable during the monsoon period using any modern conveyance. Unmetalled roads are motorable only in the dry season i.e., from November to May. Seasonal rivers are fordable during the dry season as ferry service is rendered during the monsoon period. There are state and district highways but surface conditions deteriorate during the rainy season. All these activities, however, are not controlled by the tropical environment but are influenced, to some extent, by climatic characteristics. Jarrett (1977) also refers to the human background of the tropics while defining the tropical region.

3.2 Background of the Population Group

The studied section of the controlled Lower Damodar is inhabited by several distinct communities: local Bengalis and migrated Bengalis; migrated people from Bihar and Jharkhand; Bangladeshi refugees; and Bihari and Uttar Pradesh (UP) people with refugee status. The Biharis came from the Chhotanagpur plateau to work in the coal mines of the Ranigunj coalfields. The labor freed from disused collieries was absorbed later in the agricultural sector. People from Uttar Pradesh were originally fishermen or boatmen. Before independence, they used to ply the rivers from UP to the present Bangladesh. They probably left the former East Pakistan after 1947. The Bengali Hindus (Bangladeshi) came to India after 1947 and again after 1970. There was step migration from East Pakistan or Bangladesh. They came to the districts of Nadia and 24 Parganas first and from there they moved to the Barddhaman and Bankura districts. Biharis and local Bengalis include Muslims. The total population in the studied section is about fifty thousand approximately. All these groups are undifferentiated in one characteristic: the level of education is very low everywhere.

3.3 The Damodar – A Flood-Prone River

A flood is a high flow of water, which overtops either the natural or the artificial banks of a river channel (Smith 2001). Under pre-dam conditions, the hydrologic processes of the fluvial system create and maintain stream channels with channel maintenance maximized during bankfull discharge. Whenever streamflow exceeds bankfull capacity, and river spills over onto an adjacent floodplain, the river visits a flood stage. All rivers work in the same way suggesting that flooding is a natural behavior of a river system. Floods become hazards when these events disrupt an established routine of life, inflicting suffering and death on many who occupy hazard zones (Bhattacharyya 1991). The Damodar River is very small and is not comparable to the large rivers of the world. However, it shares notoriety with the Hwang Ho (Yellow River) of China and the Kosi of India as far as floods are concerned (Bhattacharyya 2002).

Floods have been a concern for people from time immemorial and are still significant events in developing and as well as in developed countries, although with different modes of production. Floods and flood-related issues are addressed by various disciplines such as engineering sciences, hydrology, meteorology, economics, and sociology. In geography, flood is viewed from a spatial standpoint. It is included within the province of pure or theoretical geomorphology and applied geomorphology as well. This inclusion in both fields is justifiable from somewhat different perspectives. In theoretical geomorphology, floods, flood-borne materials and flood-built features are fundamental entities, whereas in applied geomorphology they are treated as a resource or a hazard or both, depending on the combination of physical environmental parameters and socio-economic factors. Thus, they become functional entities in theoretical as well as in applied research (Bhattacharyya 1998, 2009).

Flood control structures can be seen as effective indicators of progress and development of a community or a society. Transfer of flood water from surplus regions to deficit regions and from surplus seasons to deficit seasons through control structures are in fact associated with hydraulic civilizations. In other words, the rational use of flood water can be considered one of the factors behind the progress of civilization. From documents ranging from the ancient Puranas (religious stories) and to recent government reports, it is evident that the Lower Damodar is an endemic flood-prone tropical river. Flood propensity of the river is also reflected in old maps (Bhattacharyya 1998, 2002).

Investigation of the controlled Lower Damodar begins with the flood problems that necessitated adopting flood control measures from embankments to multipurpose reservoirs. Control structures are the effects and flood is the cause. In this chapter both causes and effects are considered with equal weight. The objectives of this section are three-fold: to trace the changing courses of the Lower Damodar which lead to flooding; to trace the flood history of the Lower Damodar; and to trace the evolution of control structures both chronologically and chorologically, as well as to assess the impacts of lateral control structures. In brief, this chapter reviews the state and community level efforts in managing river resources through ages.

A flood is a hydro-geomorphological process controlled by hydro-meteorological factors in a physical environment where physical laws dictate all phenomena. However, flood control measures are taken on the basis of cultural practices and socio-economic situations that are always location-specific. Therefore, research methods here are necessarily ideographic. This does not imply that the physical parameters of flood phenomena are ignored. In fact, hydro-geomorphological information is applied to solve flood-related socio-economic problems. At flood stage, a river crosses its normal boundary inundating a large part of its valley floor and expanding spatially. The spatial scale of the Lower Damodar has varied in different flood years and this variable spatial scale must be considered when floods and flood-related issues are examined.

The flood history of the Damodar has been traced for a time span of 342 years from 1665 to 2007, although recorded flood history dates back from 1730. Embankments, the first control structures on the Lower Damodar, were mentioned in the government report of 1852 (Ricketts 1853; Voorduin 1947; Bhattacharyya 1998, 1999–2000a). This report states that the embankments are a century old, indicating that the embankments were in existence from 1752. The Rangamatia dyke or dam, the last control structure in the studied section, is 14 years old. Therefore, the time span between the first control structure and the last control structure is 244 years. Although most of the data is obtained from government reports and records, data has also been generated and inferences drawn from old maps. The first recorded information on the Damodar embankment is available from 1846 onwards (Sage et al. 1846; Bhattacharyya 1998, 2008b). For later years, data from the DVC has been used. There is, more or less, a continuity of data on control structures and other hydrological information from 1933 onwards.

3.4 Changing Courses of the Lower Damodar

The Lower Damodar had an extensive delta formation which was older than the Ganges-Brahmaputra-Meghna delta. The changing courses of the Lower Damodar exemplify the shifting of rivers in an unstable deltaic environment. Shifting of channels, needless to say, is always associated with avulsion and floods (Bhattacharyya 1998).

The early maps of Jao De Barros, 1550; Bleav, 1645; Vanden Broucke, 1660; Rennell, 1779–1781 and maps and charts of other unknown cartographers provide cognizable evidence of the changing courses of the Lower Damodar (Fig. 2.5). Superimposing the present river system on the river shown in the Rennell's map (1779–1781), some trend lines can be obtained. One course bifurcates from Selimabad and flows in a south-easterly direction and then in a north-easterly direction before entering into the River Bhagirathi near Noaserai above Tribani. The main flow is found in a southerly direction, passing through the Amta channel and falling into the Hooghly River. Another old course, which can approximately be identified with the present Gangur River (Sen 1962), flows in an easterly direction below Barddhaman, meeting the Bhagirathi River near Kalna.

According to De Barros (1550), the main flow of the Damodar in the sixteenth century was restricted to the present Kana Damodar channel taking off below Selimabad and meeting the River Hooghly at Uluberia. Vanden Broucke's map from 1660 shows the main channel of the Damodar flowing through the Moja Damodar and meeting the River Rupnarayan near the present Bakshi Khal. At the same time, a large branch used to flow through Barddhaman, apparently along the line of the present course of the Gangur and Behula River, falling into the River Bhagirathi near Kalna. In the Bengali folk story "Manashar Bhasan" (1640), it is stated that the dead body of Lakhindar, the hero of the epic, was taken by his wife Behula in a boat along this river. This story reveals that in that period (1640), a great volume of the Damodar water used to pass through this route (Das K and Das K 1885). In the same period (1660), a smaller branch of the main Damodar used to flow through the Amta channel falling into the Hooghly River opposite Falta and was known as the Mondal Ghat River. This was shown as a small creek in a chart from 1690. Shortly after 1660, the Damodar deserted the Gangur–Behula branch and the Kana Damodar became the main channel. Subsequently, another branch opened along the Kana and Kuntinadi. The Kana Damodar in that period entered Noaserai, 4.81 km above Tribeni and 62.76 km above Howrah. It showed deterioration owing to the diversion of its supply to Kana Nadi. In the maps and accounts of the seventeenth century and the beginning of the eighteenth century, the Kana Damodar was called the Jan Perdo River, i.e. a river for large ships (Census 1961), and its importance is still attested to by the long marshes and populous villages along its bank. This Kana Damodar is represented as an insignificant creek in Ritchie and Lacam's chart of 1785 (Stevenson et al. 1919; Sen 1962; Bhattacharyya 1998, 2002).

Meanwhile, changes had taken place in the Kana and Kunti Nadi which were flowing in an unnatural direction i.e., from south-south east to north-north east. This is evident from the fact that the Saraswati River, which left the Hooghly River at

Tribeni, would have been flowing in a generally parallel but reverse direction to the Kunti Nadi. The latter must, therefore, when the Hooghly level was high, have acted as an effluent (owing to the Hooghly River backing up into it) and changed into an affluent when the periodic flood came down the Damodar (Stevenson et al. 1919; Bhattacharyya 1998, 2002).

People of the adjacent countryside, we may presume, tried to maintain the channel by constructing marginal embankments and thus giving the river an artificial and precarious existence for a period. An additional supply from the Kana Damodar was diverted into this river and the bed level rose, particularly in the Kunti Nadi which could not accommodate the supply. As a result, the volume of the main river was diverted from it (Stevenson et al. 1919). Rennell, during his survey around 1760, referred to the Kana and Kunti as the old Damodar (Sen 1962).

Although it is not recorded, tradition has it that the Damodar, which formerly flowed into the Hooghly at Noaserai, burst its embankment around 1762 (Sherwill 1858). From all this evidence of the changing courses of the Lower Damodar, we can conclude that the entire tract between Noaserai and Mundeswari was inundation-prone in the historical past (Bhattacharyya 1998, 2002). At present the Amta channel is chained with embankments restricting further shifting of the lowest part of the Lower Damodar.

3.5 Flood History of the Lower Damodar River

In old records the Damodar has always been referred to as a river of sorrow. Hunter in 1876 writes that, during floods, the rainwater used to pour off the hills through hundreds of channels with such suddenness that water heaped up to form dangerous head waves known as "hurpaban". These were of great breadth and appeared like a wall of water, sometimes 1.5 m high, causing irreparable damage to land, property and people (Hunter 1876; Bhattacharyya 1998, 2002). The flood rose and subsided rapidly within one to 3 days. Long before Hunter, however, an anonymous poet had referred to the Damodar flood of 1665 (Mitra 1946). The first recorded flood was in 1730 (Voorduin 1947). Since then, floods of different magnitudes have occurred every 8–10 years. Floods with peak flow of 8,496 m^3/s or more occurred 37 times between the years 1823 and 2007. The records for the period between 1878 and 1912 are not complete, but floods were reported to have occurred also in 1882, 1890, 1898, 1901, 1902, 1903, 1905, and 1907. The floods of 1823, 1840, 1913, 1935, 1941, 1958, 1959, and 1978 had peaks of more than 16,992 m^3/s. A peak flow of about 18,678 m^3/s has been recorded 3 times: in August 1913, 1935 and October 1941 (DVC 1995; Bhattacharyya 1998).

The 1913 flood originated from a mean rainfall of 30.23 cm over the basin whereas a mean rainfall of 23.29 cm in 3 days caused the 1935 flood. The 1943 flood, with a comparatively low peak flow (9,911 m^3/s), resulted from a mean rainfall of 21.34 cm over the catchment. Despite low peak flow, the damage caused by this flood was the highest on record assessed on the basis of 1951 prices (DVC

1995). In the month of September 1958, heavy rainfall for 3 days at a stretch caused flooding in the Damodar and the Barakar Rivers with peak flow greater than any recorded in the past. Had there been no dams, the maximum observed peak flow at Durgapur would have been of the order of 18,537 m^3/s. The DVC reservoirs succeeded in moderating this flood to only 5,802 m^3/s. Similarly, from the 1st to the 3rd of October 1959, the Damodar and Barakar Rivers experienced another record-breaking peak flow. Without the intervention of the dams, the peak flow at Durgapur would have been of the order of 22,923 m^3/s but was actually moderated to only 9,905 m^3/s. The 1978 flood can be considered the greatest disaster of the twentieth century. The cyclonic rainstorms between the 27th and the 29th of September followed by a secondary peak between the 2nd and the 4th of October caused heavy rainfall above 500 mm in the Damodar catchment. The highest combined inflow at Maithon and Panchet was recorded as 21,070 m^3/s on September 27, 1978. This huge inflow was moderated by the dams to a combined outflow of 4,616 m^3/s. It was further augmented to 9,345 m^3/s at Durgapur and 10,919 m^3/s at Rhondia, causing widespread flooding in the Lower Bengal (DVC 1978; Sen 1985b). In 1995, and again in 2000 and 2006, the lower valley witnessed a normal flood with flows of 6,522, 6,387 and 7,035 m^3/s respectively at Rhondia. Lastly, in 2007, an abnormal flood with a peak flow of 8,883 m^3/s at Rhondia visited the lower Damodar valley. Therefore, recorded history of the endemic flood prone areas of the Damodar can be traced from 1730 onwards.

Inundations have occurred several times between 1730 and 1816, with an average interval of 13 years and with the next inundation occurring after 7 years i.e., in 1823. The next flood surfaced in 1834 after an interval of 11 years with another one following in 1840 after 6 years. Subsequent intervals were further shortened. Severe floods occurred in 1841, 1844 and 1845. Hence, within the time span of 115 years, 13 severe inundations took place, out of which 7 occurred in the first 85 years and 6 in the last 30 years (Sage et al. 1846; Bhattacharyya 1998, 1999). This increase in flooding may be attributed to the fact that, in the earlier period, overflow irrigation from the Damodar was considered beneficial for agriculture and people built and maintained canals to carry flood water to their fields. Egyptian engineer Sir William Willcocks, in his lectures delivered at the Calcutta University in 1930, stated that he considered the soils of the Lower Damodar valley one of the richest soils in the world. He further stated that travellers in 1660 used to consider central Bengal as rich as Egypt. In 1815 Hamilton passed through the districts of Burdwan (present Barddhaman), Hooghly and Howrah and described the tract as the most productive agricultural land in entire Hindustan (undivided India) (Willcocks 1930). From 1815 onwards, however, landlords and tenants of central Bengal started to neglect the irrigation canal systems. The negligence probably began in the undivided Bengal during the Maratha–Afghan war (1803–1818) and later in Barddhaman in the later half of the eighteenth century. These waterways remained neglected and unused after the wars. The British thought these waterways were for navigation only and left them as they were. As these deteriorating waterways or canals took in less amounts of water, more and more water remained in the Damodar and it grew as a menace to the riparian tract (Willcocks 1930; Bhattacharyya 1998). Eventually the entire riverine regime of Bengal, Bihar and Orissa was transformed from a flood-enriched agrarian area into a landscape vulnerable to devastation by floods (D'Souza 2006).

The flood history during the period 1857–1917 can be traced from the EL Glass report submitted to the then Bengal Government as observed at Raniganj, a few kilometers upstream of Durgapur (Sen 1962). Corresponding data for the period between 1933 and 1956 and 1959 and 2007 at Rhondia, are given in Table 3.3. During the period 1857–1917 the number of floods (between 5,664 and 8,496 m^3/s) was 33, which was reduced in later periods to 11 (1935–1956) and 5 (1959–2007) respectively. In the post-dam situation only three high floods have occurred: October 1959, September–October 1978, and September 2007.

The 1978 flood merits special mention as the most destructive flood of the twentieth century in south Bengal. The huge amount of sand deposited by the Damodar can still be seen in the adjacent villages near Gaitanpur, Panchpara and elsewhere. The riverine sand bars still exhibit sand heaps deposited during this flood. The floods of 1995, 2000, 2006 and 2007 are not insignificant compared to many other floods that have occurred in the historical past but in magnitude they cannot compare with the 1978 flood. Following Collier et al. (1996) we can say that two or three preceding flood-free decades may have been traded for this devastating flood.

Table 3.3 Flood history of the Lower Damodar River

At Raniganj (during 61 years (1857–1917) – A	
No. of extremely abnormal floods (above 12,744 m^3/s)	1
No. of abnormal floods (above 8,496 m^3/s)	12
No. of normal floods (between 5,664 and 8,496 m^3/s)	33
No. of subnormal floods (below 5,664 m^3/s)	15
At Rhondia (during 23 years (1933–1956) – B	
No. of extremely abnormal floods (above 12,744 m^3/s)	2
No. of abnormal floods (above 8,496 m^3/s)	7
No. of normal floods (between 5,664 and 8,496 m^3/s)	11
No. of subnormal floods (between 2,472 and 5,664 m^3/s)	4
At Rhondia (during 50 years (1959–2007) – C	
No. of extremely abnormal floods (above 12,744 m^3/s)	0
No. of abnormal floods (above 8,496 m^3/s)	3
No. of normal floods (between 5,664 and 8,496 m^3/s)	5
No. of subnormal floods (between 2,472 and 5,664 m^3/s)	25

After Bhattacharyya (1999).
Data source: Flood history at Raniganj during 61 years (1857–1917) has been drawn from the report of EL Glass, submitted to the then Bengal Government, cited in Sen (1962).
The annual peak discharge data for the River Damodar at Rhondia is available from 1823 to 1933 as a discontinuous series in published form from the National Commission of Flood, Vol. 2. The same data for 1934–1960 is available in published form from the UNESCO, Vol. 11, 1971 and for 1960–2007 from the Damodar Canals No. 11, Subdivision–Rhondia, Barddhaman.

3.6 Policy Recommendation by National Commission on Floods

The National Commission on Floods submitted its report (1980) after the devastating flood of 1978. The Commission made 207 recommendations in all for a comprehensive dynamic and flexible approach to the problem of floods as part of a comprehensive approach for the utilization of land and water resources. It recommended the development of prioritized measures to modify the susceptibility of life and property to flood damage. Equally important were the recommendations by the National Commission for Integrated Water Resources Development and Management Plan, 1999 regarding flood management. It was noted that the country must shift its strategy towards efficient management of flood plains, flood proofing, flood forecasting, and flood insurance. The National Water Policy of India, formulated in 1987 and then reviewed and revised in 2002, mandates an integrated and multi-disciplinary approach to the planning, formulation, clearance and implementation of projects, including catchment area treatment, environmental and ecological aspects, the rehabilitation of affected people and command area development. While physical flood protection like embankment and dykes will continue to be necessary, increased emphasis should be laid on non-structural measures for minimization of losses, and reduction of recurring expenditure on flood relief (DVC Interin Report 2008, personal communication with Ray C, February 15, 2008).

3.7 Phases of Controlling the Lower Damodar

The flood-prone Damodar River has necessitated construction of control structures from very ancient times: "In uninhabited regions the rivers are wayward and restless, ever shifting from place to place within the bounds of the valleys that are theirs to sprawl across at will . . . But as soon as a country acquires a settled population this unstable habit of running water is corrected. For many reasons, human interests demand that a stream shall have a fixed course" (Lamplugh 1914, p. 651). The validity of this statement with regard to the Damodar cannot be denied as rivers were also restless over the Rarh plain which was populated even in the distant historical past by a highly civilized community known as Gangarides, or Gangaridaes (Basu 1989). Since agricultural prosperity in the region has continued for centuries, it is fair to presume that flood control measures in the Lower Damodar were taken long ago, one of the earliest control measures being embankments. It is most likely that those ancient embankments were non-engineered earthen embankments that have been totally destroyed due to shifting of rivers. A geomorphological map prepared by Niyogi (1978) shows the palaeo-channels and old levees. It is unfortunate that the literature has discussed the shifting courses of the Lower Damodar but has remained silent about embankments. Therefore, the discussion on control structures begins with embankments that have been mentioned or shown in government reports or in old maps.

3.7.1 Embankments

The origin of embankments constructed on the Lower Bengal Rivers is difficult to trace. The embankments along the Damodar River were most probably constructed by local landlords to protect their land and property from floods (Gastrell 1863; Bhattacharyya 1998; 1999–2000a). These embankments were intended to save the paddy crop, the main crop of Bengal, as well as to protect the towns and villages (Sengupta 1951). According to Kapil Bhattacharyya (1959), a hydraulic engineer, these embankments are 4,000 years old.

3.7.1.1 Zamindary Period

It is difficult to trace exactly when and where flood disaster abatement measures were first adopted. It is clear, however, that these embankments date to a period before the British rule (O'Malley and Chakravarti 1909; Bhattacharyya 1998, 1999–2000a). Earlier papers refer mainly to the condition and management of the embankments which, in January 1852, were said to have existed for a century (Voorduin 1947). In 1760, the districts of Barddhaman and Medinipur were ceded to the East India Company. They already contained embankments at that time, the most important being those within the Burdwan Raj Estate i.e., within the present Barddhaman, Hooghly and Howrah districts (O'Malley and Chakravarti 1912). This system of embankments was never very extensive along the river bordering the Bankura district as the main channel here was quite broad and shallow and sufficed to carry off most of the flood waters (Gastrell 1863). It was the duty of the local landlords to secure their lands from inundation by renovating or repairing the embankments, locally known as *pulbandi* measures. Detailed quantified information about these zamindary embankments is not available but it may be assumed that a uniform system of bunding the river had never been thought of. The report of the embankment committee formed in 1846 states that these embankments were irregular and levels were uncertain. If one portion of the embankments was 0.91 m above the highest flood rise, the adjoining one was low enough to be overtopped or breached during floods. Initially these embankments were not even continuous, resulting in devastating floods when the floodwaters of the Damodar rushed in through the gaps between them. The maintenance of embankments was inefficient and neglected (O'Malley and Chakravarti 1912; Bhattacharyya 1998, 1999–2000a) and breaching of embankments was a regular phenomenon. The cost of repair was realized by the zamindars from the tenants concerned.

3.7.1.2 British Period

It is difficult to distinguish the government embankments from the zamindari embankments until 1833. In 1836 the embankment question was taken up seriously by the British Government. In 1840 the town of Barddhaman was submerged under water three times in a single year due to breaching of the left bank embankments in 113 places. Willcocks stated that these were all secret breaches by farmers to take flood water into their fields (Willcocks 1930). In 1845 about 89 masonry sluices were constructed in lieu of cuts that were formerly made by people or landlords. In 1846 the general question of embanking the rivers was reviewed by an expert committee. The committee report began with the statement that all the rivers should be kept unconfined. The committee further recommended the total removal of embankments (Sage et al. 1846). Concern was expressed about the role of embankments in gradual shallowing of the river thus augmenting flood propensity in the lower reach. There were correlated fiscal issues regarding maintenance of embankments. Questions were also raised about the neighboring flood basin being deprived of fertile silt (Sage et al. 1846) due to embankments. The land between the embankments and the river were considered valuable and landlords sometimes moved the embankments a mile off the river. The owners of the land left outside the embankments, despite gradual deterioration of the land, had to pay a higher rent (Ricketts 1853). Several committees were formed to investigate issues such as increased sedimentation on the riverbed making the river shallower, increase in flood propensity due to shallowing of the riverbed, unhappiness of landlords about cost of maintenance of embankments, restriction of lateral spread of flood water thus depriving the adjacent plain from flood-borne fertile silt, reluctance of landlords to pay higher rent for these silt-deprived so-called protected lands, and removal of embankments as the solution to these problems.

It is noteworthy that all of these problems had a very strong applied connotation. Embankments were constructed for the benefit of flood-affected communities. It is ironic that, on the basis of observations on embankments, river discharge, and river bed sedimentation, several proposals were made to remove embankments for the benefit of the same riparian communities (Bhattacharyya 1998).

Proposal for Removing the Right Bank Embankments

Beadle, a secretary of the then Military Board in 1852, proposed that the right bank embankments of the River Damodar be removed in order to relieve the works on the left bank. He observed that, on the right bank, the land rises a short distance from the river and slopes down towards its junction with the Hooghly River. Therefore considerable space on the left side would be inundated if the embankments were removed from both sides (Ricketts 1853; Bhattacharyya 1998). Baker (1852), a consulting engineer of the then railway department, commented that the channel between the embankments was quite inadequate for discharging enormous quantities of floodwater. During floods, 18,275 m^3 of water per second had to be disposed off at an average velocity of 0.91 m/s, and for that a channel with 3.2 km width and 6.1 m depth was required. But nowhere was the river 3.2 km wide. These earthen embankments were not strong enough to keep such a flood within the channel. Barker also proposed the maintenance of embankments on the left side but removal of embankments on the right side, wherever necessary, to admit a free efflux for floods in that direction. Goodwyn, a superintending engineer of the then South East Province, based his conclusion on the assumed power of water to scour out and deepen the channel when it was contracted laterally. In his support he quoted the

Italian engineer Guliemini: “if we restrict river’s bed by art, we cause it to deepen its bed, while if the bed is too wide, or divided into several branches, its bottom will be raised in proportion” (Goodwyn 1854, p. 47). He referred to the features of the country as being unfavorable to the project of removing the embankments on the right bank of the Damodar and deprecated any such measure as unnecessary and fraught with dire consequences to the country. Dickens (1853), an assistant secretary of the then Military Board, pointed out that the capacity of the Damodar was deteriorating from about 25.6 km west of Barddhaman to Amta. It could not carry one-eighth of the flood discharge received from the upstream reach. He mentioned that the breaching of embankments in 1840 in 113 places was due to the diminution in the capacity of the channel from Sungutgolah, a few kilometers west of Barddhaman to Amta. He added that no breach had occurred above Sungutgolah in 1840. Passing through the sandstone-rich Gondwana sedimentaries with high rate of declivity and in a district liable to heavy falls of rain after long intervening periods of dry weather, the Damodar is subject to heavy floods and brings down an enormous quantity of sand upon the plains. The river does not improve by closure with embankments as sufficient velocity cannot be obtained by that means to transfer excess water and sediment downstream. Any complete and permanent measures for securing the country on both banks from inundation were not possible. An observation was then made on the effect of removing the bunds from the right bank and it appeared that though the tract on both sides would be liable to heavy floods, floods would be less severe than before and the flood level of the River from about 8 km west of Barddhaman downwards would be reduced by from 2.44 to 1.22 m rendering the embankments on the left bank comparatively safe (Dickens 1853; Bhattacharyya 1998). It was finally concluded that the removal of the right embankment for about 32.2 km would provide complete security to the left bank. Colonel Garstin (1854), the then officiating chief engineer, pointed out that the system of embankments in this part of the country was not satisfactory and this system should never have been adopted. But he realized that the abolition of the vicious system which had been allowed to grow and extend itself was not an easy matter and many points must be considered and different interest groups consulted before any viable recommendation could be made. Garstin did not realize that it would injure the railways if the bunds were abolished on both banks of the Damodar. He ultimately recommended abandonment of the bunds on the right bank of the Damodar as the best measure. The opinions expressed by different technical experts on the embankment issue reveal that all of them had doubts about the efficiency of the ill-defined and mal-constructed embankments as viable flood control measures. In addition, they were particularly vocal on the issue of removal of the right bank embankments.

Removal of the Right Bank Embankments

The Bengal Government recommended the adoption of Colonel Garstin’s view. In May 1855 orders were received from the supreme government for the demolition of 32.19 km of the right bank embankment from Sungutgolah down to Begua (Figs. 3.3

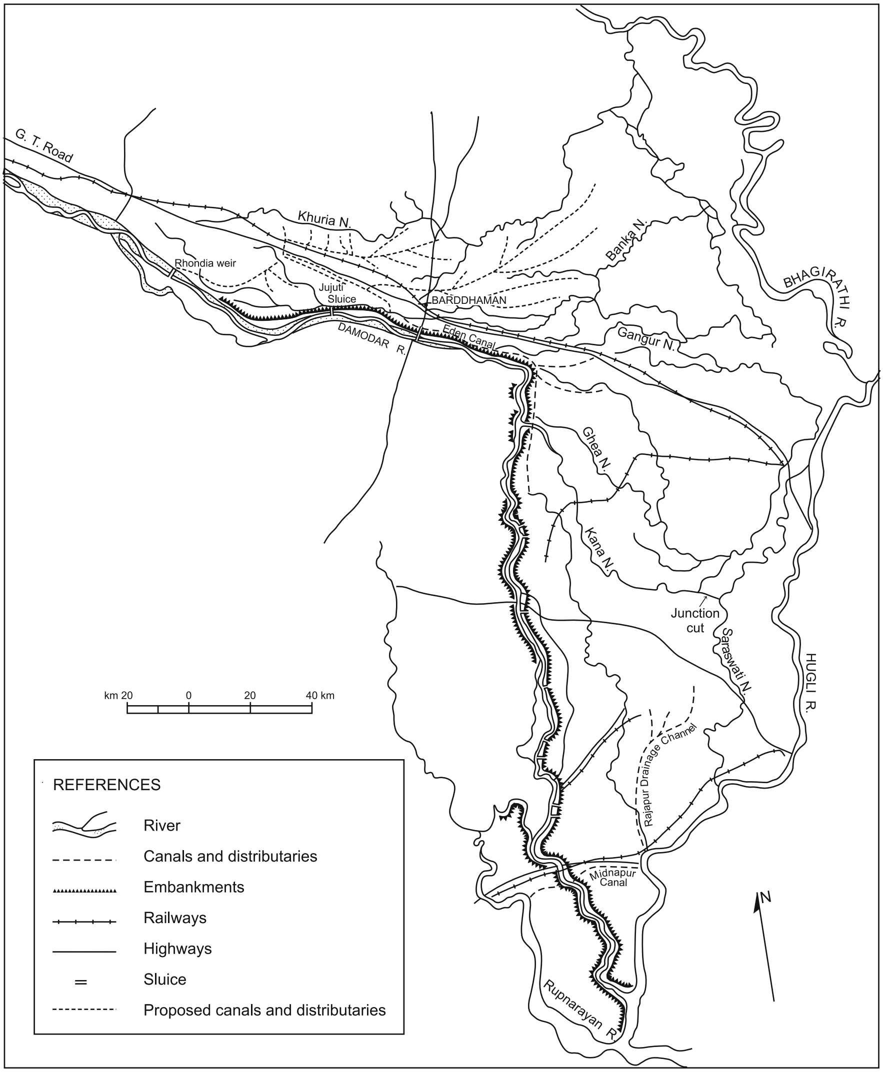

Fig. 3.3 Phases of controlling the Damodar River (British period, 1908–1946). Source: Bhattacharyya (1998, 1999–2000a)

and 3.4) for flood control and for the safety of the continuous line of left bank embankments which afforded complete security to the town of Barddhaman, the East India railway line, and the populous districts of Hooghly and Barddhaman. Before the flood season of 1959, 32.19 km of the right bank embankments from Sungutgolah down to Begua were removed. Only the embankments parallel to the river were removed whereas embankments at shoulder angles or those where the banks were low or of loose formation were left in place. In some cases embankments were strengthened and put in order. On the right bank, with the exception of a

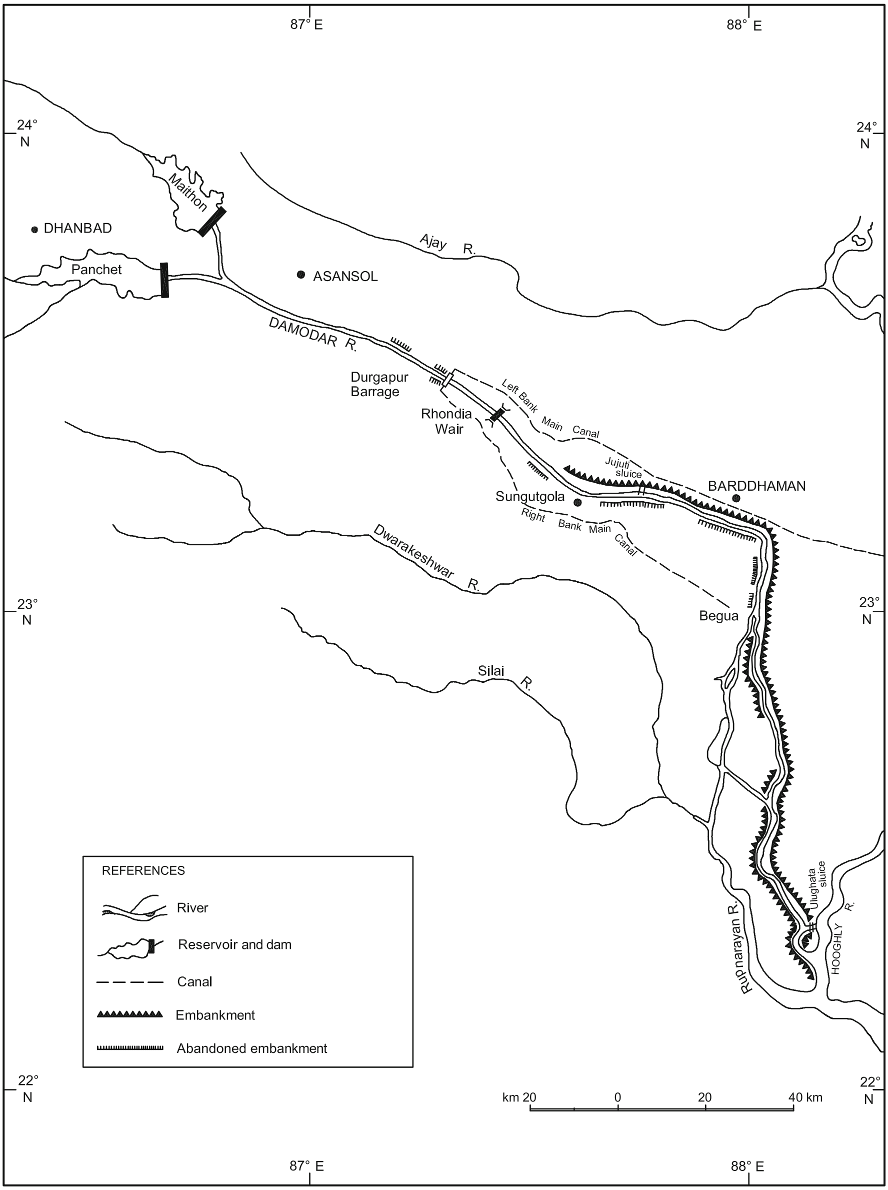

Fig. 3.4 Phases of controlling the Damodar (post British period). Source: Bhattacharyya (1998, 1999–2000a)

continuous line of 28.8 km from the Begua breach to the villages of Deboorsoot and a few detached short lengths of no importance, the embankments were completely removed. In 1889 another 16.1 km of the right bank embankments were removed (Voorduin 1947; Bhattacharyya 1998, 1999–2000a).

Proposal for Remodeling the Left Bank Embankments

There were several recommendations on remodeling the left bank embankments and some of the recommendations were translated into action. Between 1856 and 1860, the zamindars' embankments along the left bank of the river were realigned and reinforced. The left bank embankments were made continuous for 176.87 km and were provided with many sluices (Biswas and Bardhan 1975; Bhattacharyya 1999). The great Damodar floods affected the river levels at Calcutta (present Kolkata) due to cross-country spill from Barddhaman and flow from the Kana nadi. The Kana nadi was first closed at its head in 1853 by the construction of the left bank embankment that breached in 1856, and was left open until 1863, when once again it was completely closed by a bund over which the metalled road from Memari was laid (Stevenson et al. 1919).

At present, there are double embankments at Amirpur, Gaitanpur, Jujuti and areas above Paikpara. Due to severe bank erosion at these places, the embankments are being eroded. Therefore, these flood jacketting measures have been taken. Embankments have also been constructed on the left bank above the Durgapur Barrage near Andal due to excessive bank erosion. Initially the embankments were made of locally available mud and had little vegetal cover. Now, however, they are protected by laterite and basalt slabs on the inward side in many places. Strip plantation on the embankments has provided further protection and the embankments are also covered with morums. The embankments are not only important landforms in an otherwise monotonous landscape but are also a significant part of the rural resource base. People take shelter on the embankments during floods. They use the flat surface of the embankment for drying paddy and other cereals. Embankments form important transport links between villages although these are motorable only in the dry season. Embankments are lined with energy plants such as Eucalyptus and Akasmoni. In a way embankments have become an important resource base in the rural economy.

3.8 Weirs, Sluices and Canals

The bed of the Damodar River is considerably higher than the water level of the Hooghly and there are several natural water courses draining the country between the Damodar and the Hooghly into the latter. Sluice gates of a type that takes off only the top water of the Damodar during floods were fixed to the embankments near the upper reaches of these water courses. The left bank embankment has been provided with many sluices. The most notable one is at Kamarul constructed in 1883–1884. A channel inside the sluices was excavated in 1889–1890. Attempts were also made to transfer excess water from the Damodar River to some of the decaying distributaries through the Eden canal in 1881. In 1873, the first step towards the construction of the canal was taken up by opening the head of the Kana nadi. In 1874, cuts were made connecting the channel with the Kana Damodar River and the Saraswati River. The complete scheme consists of a head sluice at Jujuti to admit water from the

Damodar River to the Banka nala, the abandoned channel of the Damodar. Water flows along the Banka nala for 11.27 km up to Kanchannagore weir and then is admitted into the Eden canal by an anicut. Therefore, the canal runs parallel to the left bank of the Damodar River for about 32.2 km, diverting the water into the Kana Damodar at Jamalpur where a head regulator was built in 1874. There was also a cut connecting the Kana nadi with the Saraswati near Gopalnagore (O'Malley and Chakravarti 1912). In 1933, the Damodar canal system was opened. Water from the main river was admitted into the canal with the help of a weir at Rhondia near Panagarh of Barddhaman district. It is known as the Anderson weir and has a length of 1,143 m. The main Damodar canal is 42.55 km with a branch canal of 34.51 km and a network of distributaries and village channels totaling a length of 344.78 km.

3.9 Post-British Period

A full century before dam closure, Dickens (1853) looked into the possibility of storing instead of trying perennially to build defences against floods in the Damodar. He was supported by Garnault in 1864, by Horn in 1902, by Addams Williams in 1814 and by Glass in 1918–1919. The foresight of these Bengal engineers was remarkable (Hart 1956). In order to alleviate the distress which was caused to the inhabitants by the removal of the right bank embankments, a proposal for storage reservoirs in the upper reaches of the Damodar and the Barakar was considered between 1864 and 1866 (Horn 1902), but measures for control of floods in the Damodar Valley received top priority only after the devastating flood of 1943. A medium flood with a peak flow of only 9,912 m^3/s breached the Damodar left bank embankment near Amirpur, a few kilometers downstream of Barddhaman, on the night of 16/17 July 1943. The river forced its way through the breach as the slope was much more favourable. Water passed through an old and abandoned course of the river and flooded the country on its way towards the Bhagirathi near Kalna. Water levels rose up from 1.83 to 2.13 m and the entire rail, road and telecommunication system was totally disrupted (Hart 1956; Mookerjea 1992). The Second World War was then at its height and the INA (Indian National Army) under the leadership of Netaji Subhas Chandra Bose was advancing towards India from Burma (presently Myanmar) during 1943 with active support and help from the Japanese Government. Because of the disruption of the rail, road, and communication facilities from North India, all the army installations at Kolkata and in eastern India were isolated having lost all logistics support. The situation was so critical that the British Government had to adopt a "scorched earth" policy and retreat from Kolkata towards the Panagarh base and ultimately to Ranchi, the headquarters of the Eastern Command. The then Bengal Government had also set up the Damodar flood Enquiry Committee to advice on permanent measures to control floods in the Damodar (Mookerjea 1992).

3.9.1 Damodar Flood Enquiry of 1944: Conception of the DVC

The Damodar flood enquiry committee met for the first time on 17th January 1944 and submitted its final recommendation by March 10, 1944. The committee, under the chairmanship of Maharajadhiraj Bahadur Uday Chand Mahtab, king of Barddhaman, did magnificent work during the period of 3 months and paved the way to the creation of the DVC, a corporate body for the solution of river basin problems affecting two states, Bihar (present Jharkhand) and West Bengal. During this time, the Tennessee Valley Authority (TVA) had been set up for taming of the wayward River Tennessee in the USA and had produced a model of an integrated river basin development project for the world showing how rivers with more or less similar features could be controlled with the help of different types of engineering works constructed in the river basin. It also demonstrated the need and utility of soil conservation measures, including erosion control and afforestation in the catchment to arrest depletion of soil and retention of run-off in the river catchment. In fact, the TVA model later became the standard engineering practice for the moderation of floods (Report 1944; Mookerjea 1992; Bhattacharyya 1998). There are numerous examples of projects that followed the TVA model in developing countries including the Damodar Valley in India, the Volta River Project in Nigeria, and the Aswan Dam on the River Nile in Egypt (Hey 1997).

The Damodar flood enquiry committee gave definite and positive recommendations regarding the construction of dams, barrages, hydro-power stations, construction of water conveyance systems for extending irrigation facilities in the Lower Damodar Valley, conservation of the Lower Damodar Valley by occasional flushing, setting up meteorological and flood forecasting stations in the upper catchment, and introduction of soil conservation and land management measures in the upper catchment through the Government of Bihar (present Jharkhand) (Report 1944; Mookerjea 1992; Bhattacharyya 1998). The Government of India then commissioned the central technical power board to study the proposal and invited W. L. Voorduin, a senior engineer of the TVA, to study the problem of the Damodar and to make his recommendation for its comprehensive development. Accordingly, in 1945 Voorduin submitted his preliminary memorandum on the unified development of the Damodar River system. He proposed construction of 7 multipurpose dams and low diversion dams on the Damodar and its main tributaries with a total storage of 5,733 million m^3 for flood control, irrigation, and power generation. The project had originally envisaged the construction of dams at Tilaiya, Maithon and Balpahari on the Barakar River, Bokaro on the Bokaro River, Konar on the Konar River, and the Panchet, the Aiyar and the Bermo diversion dams on the main Damodar River. The planner estimated a design flood of 28,321 m^3/s with a 100-year frequency. To protect the Lower Valley, it was estimated that the design flood be moderated to 7,080 m^3/s, which was the total capacity of the Lower Damodar. However, due to financial and other constraints, the participating governments of West Bengal, Bihar (present Jharkhand), and the central government approved the construction of only 4 multipurpose dams (Voorduin 1947; Bhattacharyya 1998).

3.10 Post-Independence Period

A high diversity organization known as the Damodar Valley Corporation (DVC) came into existence on 7th July 1948 as a River Basin Organization (RBO) (Chandra 2003) in India (Table 3.4) and proposed four multipurpose dams. The DVC constructed Tilaiya and Maithon dams on the Barakar River, a tributary of Damodar, in 1952 and 1957 respectively, Konar dam on the Konar tributary in 1955 and the Panchet dam on the Damodar River itself in 1959 (Tables 3.5 and 3.6).

Table 3.4 Example of RBO in India: The Damodar Valley Corporation

Inception	July 1948 by an act of the Constituent Assembly
Objectives	Irrigation and drainage; water supply; generation, transmission and distribution of electricity from hydroelectric and thermal sources; flood control; navigation; forestation and prevention of soil erosion
Integrated operation management	Damodar Valley Reservoir Regulation Committee (DVRRC) headed by Member (River Management), Central Water Commission (CWC) with representatives from DVC, Jharkhand, West Bengal
Functions of DVRRC	Develop principles for the effective regulation of reservoirs; resolve conflicts between stakeholders

Source: CWC (2001a), Chandra (2003) and Pangare et al. (2009).

Table 3.5 DVC infrastructure – at a glance

DVC Command area	24,235 km^2
Power management	
Total installed capacity	2,796.5 MW
Thermal power stations	4, Capacity: 2,570 MW
Hydel power stations	3, Capacity: 147.2 MW
Gas Turbine station	1, Capacity: 82.5 MW
Sub-stations and receiving stations	At 220 KV- 11 At 132 KV- 33
Transmission lines	At 220 KV – 1,342 Circuit km At 132 KV – 3,419 Circuit km
Water management	
Major Dams and Barrages	Tilaiya, Konar, Maithon, Panchet Dams and Durgapur Barrage
Irrigation command area (gross)	5.69 lakh ha
Irrigation potential created	3.64 lakh ha
Flood reserve capacity	1,292 million m^3
Canals	2,494 km
Soil conservation	
Forest, farms, upland and wasteland treatment	4 lakh ha (approximately)
Check dams	16,000 (approximately)

Source: DVC, Kolkata

Table 3.6 DVC power plants – at a glance

Name	Location	Existing capacity	Commissioning
Hydel			
Tilaiya	River – Barakar Dist – Hazaribagh State – Jharkhand	4 MW (2×2 MW)	U-I Feb 1953 U-II July 1953
Maithon	River – Barakar Dist. – Barddhaman State – West Bengal	63.2 MW (2×20 MW + 1×23.2 MW)	U-I Oct 1957 U-II Mar 1958 U-III Dec 1958
Panchet	River – Damodar Dist. – Dhanbad State – Jharkhand	80 MW (2 × 40 MW)	U-I Dec 1959 U-II Mar 1991
Total hydel		**147.2 MW**	
Thermal			
Bokaro "B"	Dist. – Bokaro State – Jharkhand	630 MW (3 × 210 MW)	U-I Mar 1986 U-II Nov 1990 U-III Aug 1993
Chandrapura	Dist. – Bokaro State – Jharkhand	750 MW (3 × 130 MW) + (3 × 120 MW)	U-I Oct 1964 U-II May 1965 U-III July1968 U-IV Mar 1974 U-V Mar 1975 U-VI Mar 1979
Durgapur	Dist. – Barddhaman State – West Bengal	350 MW (1 × 140 MW) + (1 × 210 MW)	U-III Dec 1966 U-IV Sep 1982
Mejia	Dist. – Bankura State – West Bengal	840 MW (4 ×210 MW)	U-1 Mar 1996 U II Mar 1998 U III Sept 1999 U-IV Feb 2005
Total thermal		2,570 MW	
Gas turbine			
Maithon	Dist. – Dhanbad State – West Bengal	82.5 MW (3× 27.5 MW)	U-I Oct 1989 U-II Oct 1989 U-III Oct1989
Grand total		2,799.7 MW	

Source: DVC, Kolkata.

The Maithon and Panchet act as control reservoirs and are located about 8 km above the confluence point of the Barakar and the Damodar. The construction of a barrage at Durgapur was started in 1952 and inaugurated in 1955 and subsidiary structures were completed by 1958 (Fig. 3.5). The barrage is about 692.20 m long. The main canal on the left bank is 137 km and the main canal on the right bank is 89 km in length. Branch and minor canals, distributaries, and drainage channels are about 2,270 km in length.

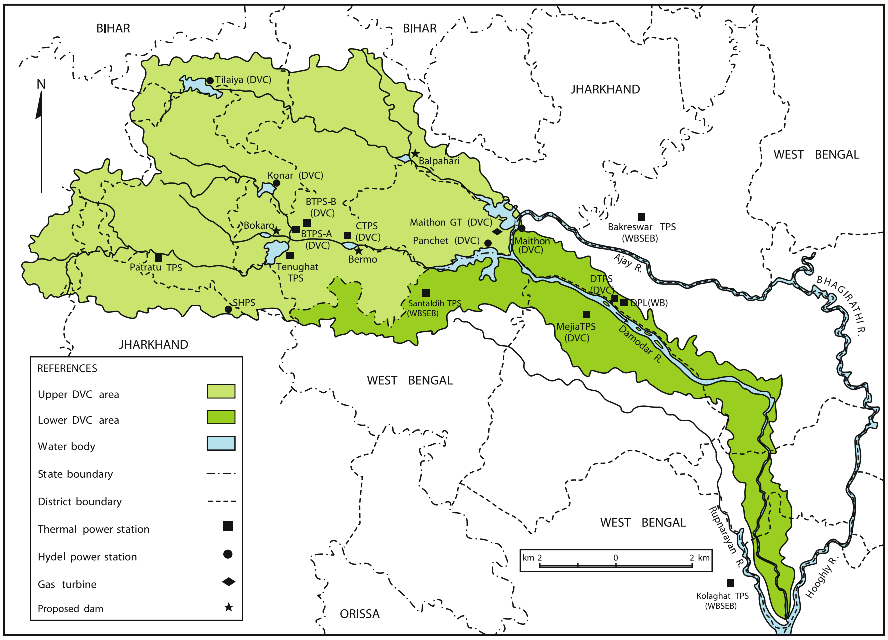

Fig. 3.5 Damodar valley region. Source: DVC Kolkata

One more dam, the Tenughat, was constructed by the Government of Jharkhand in 1978 on the Damodar River and designed primarily for industrial and municipal water supply uses as well as for irrigation through the Tenu-Bokaro Canal. Due to non-acquisition of land upto the design level, the dam is not meant to have any flood management component and has remained out of the control of the DVC. All five dams now fall under the territory of Jharkhand state and, except for Tenughat, which is under the control of Jharkhand, and the Durgapur barrage, which is controlled by West Bengal, the rest of the dams are operated by the DVC. The integrated operation of all structures upstream of the Durgapur barrage is managed by the Damodar Valley Reservoir Regulation Committee (DVRRC) which is headed by Member (River Management), and the Central Water Commission (CWC), with representatives from DVC and also from the states of West Bengal and Jharkhand. The main functions of the committee (DVRRC) are to discuss and lay down the principles for effective regulation of the reservoirs. The committee directs storage and releases from the DVC reservoirs on a day-to-day basis and distributes stored water to DVC and the Government of West Bengal for generating power, irrigation, and the industrial/domestic uses. A reservoir regulation manual prepared by CWC (2001a) is utilized for integrated regulation of the reservoirs for the principal benefits of flood management, irrigation, industrial and domestic water supply, and power generation.

3.10.1 Lower Damodar Scheme

To mitigate the flood problem and water logging of the lower part of the Lower Damodar Valley, the West Bengal Government developed a scheme known as the Lower Damodar scheme. It aimed to remove flood hazards and improve the drainage condition of a vast tract of the trans-Damodar area in the districts of Barddhaman, Hooghly and Howrah. This scheme was sanctioned in 1971. It envisaged jacketing of the Mundeswari River from Begua Hana to allow a discharge of 7,080 m^3/s of flood water. The work started but was stopped when a large number of people living between the embankments and the proposed jacket vehemently objected to it. They apprehended perpetual flooding of the area. The human problem played a vital role in this regard. Subsequently, the Ram Ballav Chakraborty Committee was set up to find an acceptable solution (Halder 1992; Bhattacharyya 2002). A new scheme was drawn up. It suggested re-sectioning of the original main Damodar channel to carry 708–849.6 m^3/s of flood water below the Begua Hana to the Rupnarayan River from Thalia, a place downstream from Amta of Howrah district. The work started but met the same fate as the earlier scheme. Ultimately a 58-vented outfall sluice was constructed during 1975–1976 (Halder 1992; Bhattacharyya 1998; Fig. 3.4) at Ulughata, near Garchumukh of Uluberia. As a result, the inflow of any appreciable quantity of floodwater in the Amta Channel was allowed proper exit to the Hooghly River. Tidal water from the Hooghly River also flows through the Ulughata sluice into the Damodar for irrigation purposes. A canal was cut between the Hooghly and the Damodar to carry excess water from the Damodar to the Hooghly and to carry tidal water from the Hooghly to the Damodar for irrigation. The Ulughata sluice was completed during 1975/1976. From the years between 1984 and 1985, however, the lower Damodar at the upstream of the sluice started acting as a feeder channel in summer months for growing Boro (summer) paddy in the region. The sluice at present is opened to allow the water of the Hooghly River at high tide. On the issue of flood mitigation, it was noted that at times, even while blocking tidal ingress in monsoon months by closing the sluice, the adjoining areas of lower Damodar could not reap any substantial relief from flood. So another scheme was drawn up to divert 849.6 m^3/s (30,000 cusec) of flood water entering the present Lower Damodar to the Rupnarayan by a channel connecting these two rivers. After studying all relevant geo-physical data, this channel alignment was finalized and excavation started and completed by the year 2005–2006. The channel takes off at a place about 50 km upstream of the Ulughata Sluice and joins the Rupnarayan at a place called Baxi. Incidentally, there was already a drainage channel at this place. The channel from the lower Damodar was routed through this channel after some alteration (personal communication with Chandan Ray Jan 25, 2009). The last control structure is the indigenous cross dykes or dams at Rangamatia, locally known as the Rangamatia dykes. The main purpose of these dykes is to divert the flow coming from the Durgapur barrage.

River training is ongoing in the Damodar River. Processes such as closing of the Jujuti sluice by sand bags and spill channels and remodeling of the left bank embankment by boulder pitching continue. In many places flow of the Damodar is obstructed by sand bags. Temporary bridges have been constructed in order to take sand from riverbed sand quarries. Thus the Lower Damodar, as a result of human interference to the river system through longitudinal and transverse dykes, has now become a controlled river with little natural behavior left (Fig. 2.1, Plate 2.1). The Lower Damodar has transformed from a natural channel to a "reservoir channel" (Bhattacharyya 2002, 2008a).

3.11 Impacts of Lateral Control Structures

Culturally defined, the Lower Damodar, with a multitude of control structures, now demands reasoned and exemplified answers to the following questions:

i. What are the hydro-geomorphological consequences of control structures?
ii. What is the socio-economic relevance of such control measures on the adjacent riparian tract and on the riverbed itself?

When local landlords decided to construct embankments, their decisions were influenced by immediate gain i.e., to protect the riparian tract from flood hazards. The side effects of such measures and wider physical consequences were never considered. The Environmental Impact Assessment (EIA) movement was far ahead in the future when the TVA was conceptualized in 1933 and when the DVC followed the TVA model in 1948. A series of reservoirs and barrages have come up as a consequence of planning decisions taken by engineers, planners and politicians to tame the Damodar but no attempt has been taken yet either by the DVC itself or by any other non-government agency to analyze the physical consequences of such control measures in a systematic manner. This project attempts to fill the gap while acknowledging that, for such impact analysis, not only is an inter-disciplinary approach desirable but teamwork is a necessary pre-requisite.

In the previous section control measures in the Lower Damodar were treated as effect and flood was considered the cause. In this section and in the following chapter control measures are treated as causes behind consequent hydro-geomorphic changes in the riverbed and in the adjacent riparian tract; in other words, the very status of control structure has changed from "effect" to "cause". While acknowledging that the impacts of embankments cannot be severed from those of reservoirs or dams, they have been separated for the convenience of discussion. This section discusses the impacts of lateral control structures and Chapter 4 examines the impact of dams.

In river training programs, quantified data on hydro-geomorphological parameters of the river are of paramount importance but socio-economic demands of the communities are prioritized in planning programs. Similarly to examine the hydro-geomorphological consequences of control measures, a set of quantified data is required which helps a researcher take a much desirable nomothetic method. In the case of the river under consideration, the Lower Damodar, quantified data on the embankments are available partly. Mostly qualified archival data have been used. So, the nomothetic method has been selected partly for reviewing the impacts of embankments on selected hydro-geomorphological conditions. In the next chapter where the impacts of transverse control structures have been examined and quantified data are available, a nomothetic method has been selected. Because of this particular methodological problem, the impact of transverse control structures has been treated in a separate chapter. Following King (1967) it may be said that the method of analysis is inductive too. It is most probably justifiable if it can be stated that a historical method has been applied, as the database is historical database.

During floods, like any other river, the Damodar used to cross its normal boundary in pre-embankment days. Part of the valley is still inundated in its unconfined sector and when embankments are breached or over-topped the river is extended. This extension of the river during floods needs to be considered when dealing with the spatial scale of inquiry. For impact analysis of the embankments, the total time span is 155 years i.e., from 1852 to 2007.

It is already mentioned above that the database is mostly historical. Qualified data from old maps, government reports and records have been generated. With this passive data, active field data have been used. Techniques adopted are interpretation of historical data and field survey technique. Old maps, as the basic tools, have also been consulted.

3.12 Impacts of Embankments

An embankment is a cultural feature, which becomes a viable component of a historically conditioned geomorphic landscape. How an embankment disrupts the physical process is discussed below. In the course of discussion the area outside the embankments has also been ventured on to strengthen some of the arguments.

3.12.1 Rising Riverbed

Like any other embankment, the Lower Damodar embankments have interfered with the physical process of sediment transfer and deposition. The Damodar bed load is rich in sands as it flows through a quartz-rich gneissic terrain in its upstream sector and sandstone-rich Gondwana sedimentaries in the lower reach of the upstream sector. “It is very hard to measure the bed load, or even to estimate it very closely” (Morisawa 1968, p. 46). But from the bed load characteristics it can be inferred that in the pre-embankment days the river became a wide shallow river with braided channels. As the river was extremely floodable, sizable portions of the bed load used to be deposited in the immediate flood plain during floods. In the post-embankment phase, flood discharge of the wide and braided Damodar is unable to spill and deposition takes place on the riverbed itself. The most probable consequence, therefore, is the gradual rising of the riverbed. Guliemini, an Italian Engineer, stated in a report by Goodwyn (1854) that a river is deepened due to restriction but where the bed is wide and divided into branches, its bottom will be raised. This assertion is applicable to the Damodar. The river cannot be kept in a state of regime, neither can it be deepened owing to the sandy and unstable nature of its bed (Bannerjee 1943). The 1854 map of Dickens shows the Damodar with a large number of sand bars. R.A. Marston and others have similar observations on the Ain River, France, where embankments prevent lateral reworking of flood-plain alluvium and sediments are stored within a channel (Marston et al. 1995).

3.12.2 Changes in Soil Composition in the Adjacent Riparian Tracts

In the report of the Embankment Committee of 1846, there are some remarks on the produce of the land outside and within embankments. Landlords had a feeling that land protected by embankments were deprived of the fertilizing effects of the Damodar floods, whereas in the unprotected tract, in addition to the usual varieties of rice, mulberry, sugarcane, brinjal, Bengal hemp (*Crotolaria-juncca*), *chorchorn-capsularis* (cultivated for its fibre), *Eeschynomine connbina* etc., could be raised. About 32.2 km below Barddhaman, rice was the only crop within embankments whereas outside the embankment Arum, Crotolaria juncca and cotton could be cultivated (Sage et al. 1846). Embankments provide full protection up to a certain stage and they may be breached or over-topped or collapsed due to piping action near the toe of embankment (Ward 1978). In the historical past, long before the construction of reservoirs, the Lower Damodar breached its embankments in 1770, 1787, 1789, 1823, 1835, 1840, and 1845. At least 25 breaches occurred in 1847, 14 in 1849, 56 in 1850, 45 in 1852 and 28 in 1854 (O'Mally and Chakravarti 1912; Bhattacharyya 1998, 1999–2000a). Although these breaches are generally interpreted as natural consequences of unusual floods, it is not unlikely that these were secret breaches made by the villagers for irrigation purposes. The common people used to believe that had there been no embankments, river water would have had free ingress in the rice land and the adjacent riparian tract would have benefited from deposits of the Damodar silt (Sage et al. 1846). From the above discussion one has to conclude that soil composition in the tract protected by embankments changed due to entrainment of sediments in the riverbed and lack of annual replenishment in the adjacent tract. Additional deposits of sediments on the riverbed ultimately become socio-economically significant (Bhattacharyya 1998, 1999–2000a).

3.13 Consequences of the Removal of the Right Bank Embankment

Before the flood season of 1959, a full extent of 32.19 km of the right bank embankments were removed in order to control Damodar floods and for the safety of the continuous line of left bank embankments. In the following sections, the situations in the embankment pre-removal and post-removal periods will be compared.

3.13.1 Changes in Fertility Status on the Right Bank

Prior to the removal of the right bank embankment it was reported that 762 villages with a total of 619.13 km^2 would be vulnerable to floods if the embankments were removed. Of these, 64.95 km^2 were unculturable lands. But approximately 35.30 km^2 of uncultivated land would be benefited by flood-borne sediments and 222.71 km^2 of cultivable lands would be injured, i.e., as a whole, only 40% of the land would be rendered more or less unfit for cultivation (Young 1861; Bhattacharyya 1998, 1999–2000a). Removal of these right bank embankments initially created problems for adjacent villages. Loss due to periodic inundation of an appreciable amount of paddy land was assessed at ₹5 million. This was calculated on the basis of price behavior prevailing in 1951 (DVC 1995). Such periodic floods, on the other hand, resulted in the deposition of silt which enriched agricultural lands facilitating production of splendid crops of rabi (winter crops, harvested in spring) and thus compensated for the loss of summer paddy crops (Sengupta 1951). Thus, ultimately, cultivators benefited from the removal of the right bank embankments (Bhattacharyya 1998, 1999–2000a).

3.13.2 Changing Cross Profile

The right bank embankments were demolished in 1859. The DVC (1957b, Vol. II) report states that this arrangement gave relief for a certain number of years. The removal of the right bank embankments led to an enormous increase in the cross section of flow and a corresponding lowering of the level of high flow. But at the same time the velocity of flow was considerably reduced, thereby increasing the rate of silt deposition in the bed and raising its level more rapidly than before. This issue raised some controversy at that time.

3.13.3 An Increase in Cross Section

The cross sections of the channel at different points increased enormously between 1881 and 1943 (Fig. 3.6) and there was a corresponding lowering of the level of high flow. In some places the cross sections are characterized by pronounced flood plains between embankments or between embankments and river levees. When these get inundated, velocities on the flood plains are lower than those in the thalweg itself. This causes the effective cross-sectional area in the river to become smaller than the actual geometrical cross section (CWC Interim Report 1983). The width of the river has increased considerably in many places; it has narrowed in some places and a few areas remain constant (Table 3.7).

3.13.4 *Opening Up of* Hana *or Spill Channels on the Right Bank*

A chain of *hanas*, or spill channels, opened up by breaching natural levees on the right bank. These breaches or spill channels are locally known as hana. A chain

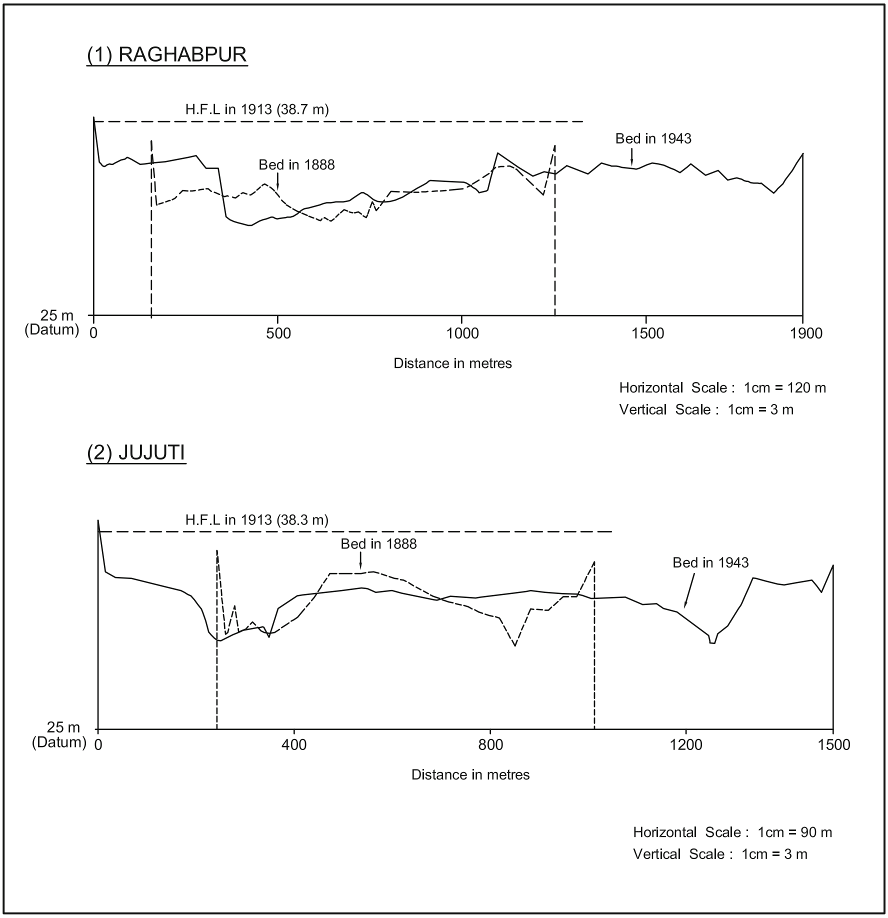

Fig. 3.6 Cross sections of Damodar River at selected sites. Source: After I & WD, WB

of spill channels serves as a spillway for flood waters of the Lower Damodar to overflow into the low land through which run the Debkhal and its ramifications. Entire low-lying areas become a sheet of yellow water moving eastward and then southwards during the rainy season. Thus the flood water, unable to pass through the restricted channel of the main river, finds its way into the Deb khal (Bose 1948; Fig. 3.7). In 1956 maximum discharge at Rhondia (at 24 h) on 26th September was 8,694 m^3/s and maximum discharge at Jamalpur on 27th September was 3,002 m^3/s. On the same day maximum discharge was 7,307 m^3/s at Muchi hana and 708 m^3/s at Champadanga. Thus, it appears that a discharge of about 5,692 m^3/s passed over the right bank in the reach between Silna and Jamalpur (DVC 1978). Due to such spilling over the right bank, the left bank embankments were not breached during major floods of 1959 and 1978 (Bhattacharyya 1998, 1999–2000a).

Table 3.7 Width of the Damodar River at different places between 1881 and 1943 (in meters)

Stations	1888	1913	1918	1943
Raghabpore	1,097.28	2,072.64	2,072.64	1,928.34
Jujuti	987.552	1,298.45	1,310.64	1,524
Edilpur	1,248.68	1,245.41	1,245.41	1,127.76
Becharhat	1,126.82	1,164.92	1,280.16	1,173.48
Manikhati	853.44	853.44	835.15	1,066.8
Salalpur	987.552	966.22	987.55	920.50
Palla	897.62	882.40	897.65	893.07
Serangpur	615.69	621.79	621.79	502.92
Jamalpur	396.24	345.34	345.34	403.56
Dhapdhara	386.24	384.05	396.24	365.76

Source: Sen (1962).

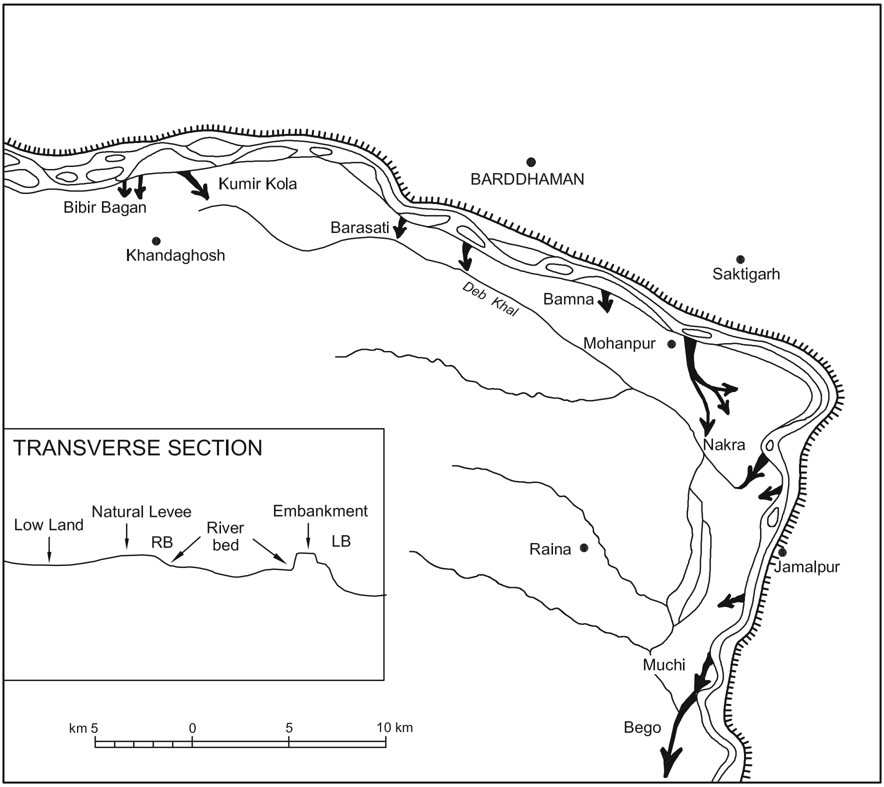

Fig. 3.7 Hana or spill channel on the Damodar River. Source: Bhattacharyya (1998, 1999–2000a)

This spilling over the right bank has decreased now as the river has formed a natural levee and most of the spill channels on the right bank are either closed or take lesser amount of water and leave sediments to be deposited within the channel itself. As a consequence, the riverbed and the flood level have risen considerably. Previously the Damodar used to open up flood channels towards the north east or south east. As the left bank is protected by embankment, spill channels in the historical past have opened up on the right side.

3.13.4.1 Origin of the Begua and the Muchi Hana and Deterioration of the Amta Channel

A natural flood channel known as Begua hana was probably opened up in 1865. The river below Harogobindapur had already formed an acute bend that affected the left banks embankments. By 1856, a well-defined spill channel had formed on the right bank of the Damodar to relieve the pressure on the left bank embankments. In an old map, mentioned in the DVC report of 1957a (Vol. I), it appears that in 1857 a dyke was put up across the Damodar below this spill channel. This dyke probably helped in the development of the Begua hana. Later on a cut-off known as the Muchi-hana or khal was affected by joining the neck of the loop formed by the Begua hana at Muidipur under the Jamalpur police station. Locals believe that this artificial measure was taken to protect the settlements and the railway line on the left bank. Floods below the Muchi spill channel are now attributed to this artificially cut spill channel (Ghosh 1993; Bhattacharyya 1998, 1999–2000a, Fig. 3.8). Bird (1980) observes similar phenomenon in the Lang Lang River, Victoria, Australia, where an artificial neck cut-off has made for straightening the channel.

Around 1865 a great Begua breach occurred on the Lower Damodar and scoured out a channel parallel to the main Damodar known as the Kanki that eventually joins the Mundeswari River (DVC 1957a, Vol. 1; Fig. 3.8). The combined stream falls into the Rupnarayan River. At this bifurcation point, formation of a high sand bank completely shuts off the flow of water into the Damodar known as the Amta channel below this bifurcation point. A newly scoured bed of the Muchi-hana is lower than the sand filled bed of the main Damodar (Bose 1948; DVC 1957a, V-1), which is now used for cultivation in the non-monsoon period.

The Amta channel i.e., the lowermost part of the Lower Damodar, gets water through the Begua hana and this channel. It has shrunk perceptively in size and volume due to reduced discharge as the downstream discharge in the lower reaches below bifurcation point into the Kanki-Mundeswari and the Amta channel is in the 4:1 ratio (DVC 1995; Bhattacharyya 1999–2000a). The Kanki-Mundeswari channel hydrologically formed a much shorter route than the Amta channel route via Uluberia. Under these circumstances the old Damodar i.e., the Amta channel, gradually deteriorated not only because of its longer hydraulic length but also because of its absence of spill area due to embankments on both sides, as well as gradual encroachment on the riverbed (DVC 1995; Bhattacharyya 1999–2000a). Bankfull capacity of the Mundeswari is hardly 2,832 m^3/s, and the Amta channel has silted up so much that hardly 5–10% of the discharge passes through it at present. The

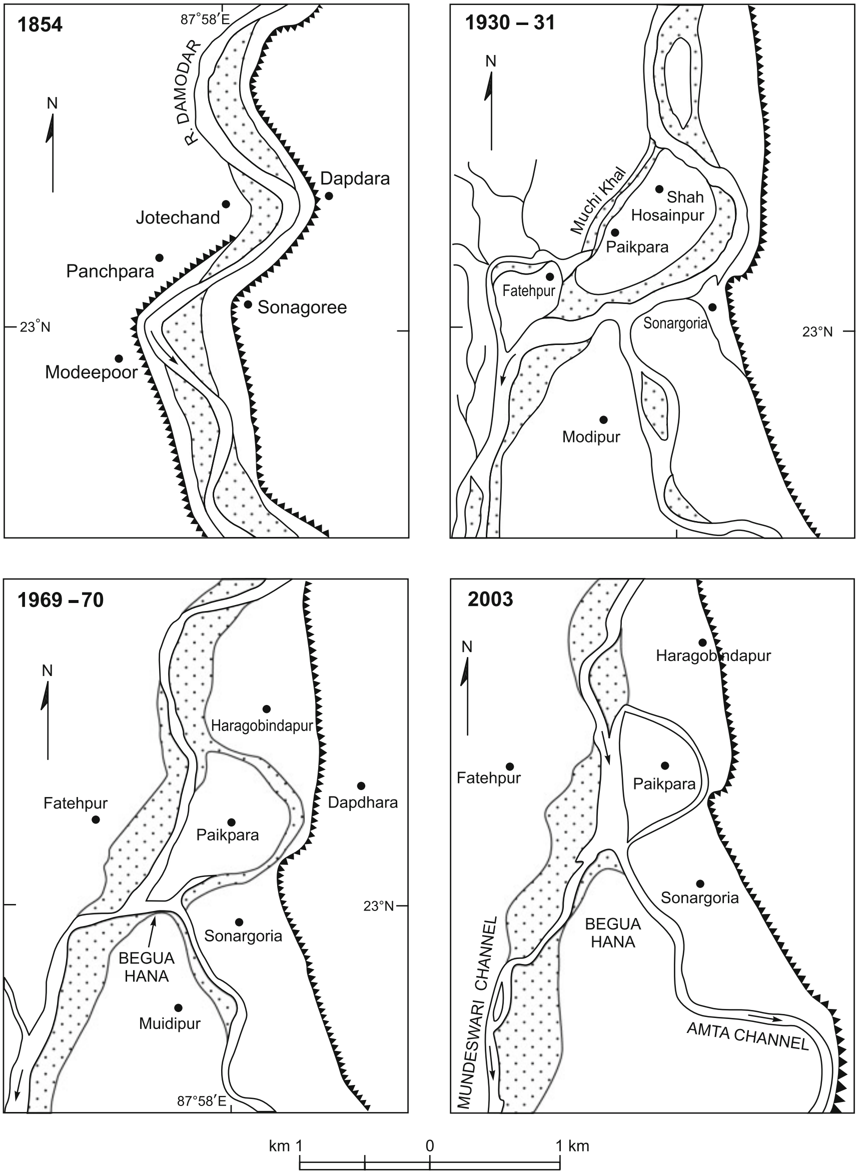

Fig. 3.8 Opening of Begua or Muchi hana on the Damodar River. Source: Bhattacharyya (1998, 1999–2000a)

actual carrying capacity of the Amta channel is only 849 m^3/s even after revival through the Lower Damodar areas improvement scheme (CWC 2001a). From 2003 LISS-3 scenes taken by an IRS-ID satellite (Fig. 3.8) it is evident that a small sand-bar has been formed in the Mundeswari River, so that, during low water periods, the

Amta channel gets more water than the volume flowing through the Mundeswari River. At present, the downstream discharge between the Mundeswari and Amta channel is divided in the ratio 7:3.

3.14 Impact of the Left Bank Embankment

To save the town of Barddhaman, the Grand Trunk Road, and the railway line from flood havoc,, the left bank embankment was not only strengthened but disjointed portions were connected and a second line of embankments was constructed in places. The consequences often became hazardous. Changes have been observed in the regional slope.

3.14.1 Drainage Congestion

The district of Barddhaman is bounded by the Ajay to the north and the Damodar to the south. The watershed is ill-defined particularly in the east. The Khari (Khuria) and Banka drain this area (Fig. 2.3). Previously much of the Damodar flood water used to pass through these two rivers, but roads, railways and embankments have severed these rivers from the mother stream. As a natural consequence both the rivers have deteriorated and have become flood-prone. Secondly, the water that used to flow into the Damodar now creates water-logging in this low inter-stream area. This drainage congestion has been reported by Haig (1873), by Biswas and Bardhan (1975) and by Akhtar et al. (2010). Water-logging is conducive to breeding of mosquitoes and the region for decades has suffered from Barddhaman fever, a kind of malaria. Its water-logged condition affected agriculture and the region had to face fever, famine and depopulation between 1850 and 1925 (Biswas and Bardhan 1975). Although drainage conditions have improved in recent years, a few pockets still suffer from drainage congestion and its consequences. The area discussed above falls outside the study area but occasional trespassing becomes necessary to fortify some of the arguments against the unplanned chaining of the river. In the Kaliaghai River of West Bengal, riparian communities applied indigenous technological innovations and helped in the functional management of seasonally waterlogged area (Bhattacharyya 1994).

3.14.2 Reversal of Slope

In earlier times the regional slope was from the Barddhaman side towards Bankura i.e., from north to south. Since the southern bank is not protected, there is continuous siltation in the flood plain of the south bank or right bank. As a consequence, the right bank flood plain has become higher and it forces the thalweg to move northward, creating pressure on the left bank embankment. This reverse slope (Fig. 3.9) is a noticeable consequence of the removal of embankments on the right and the presence of the embankment on the left. In the 1995 and 2007 floods, some of the

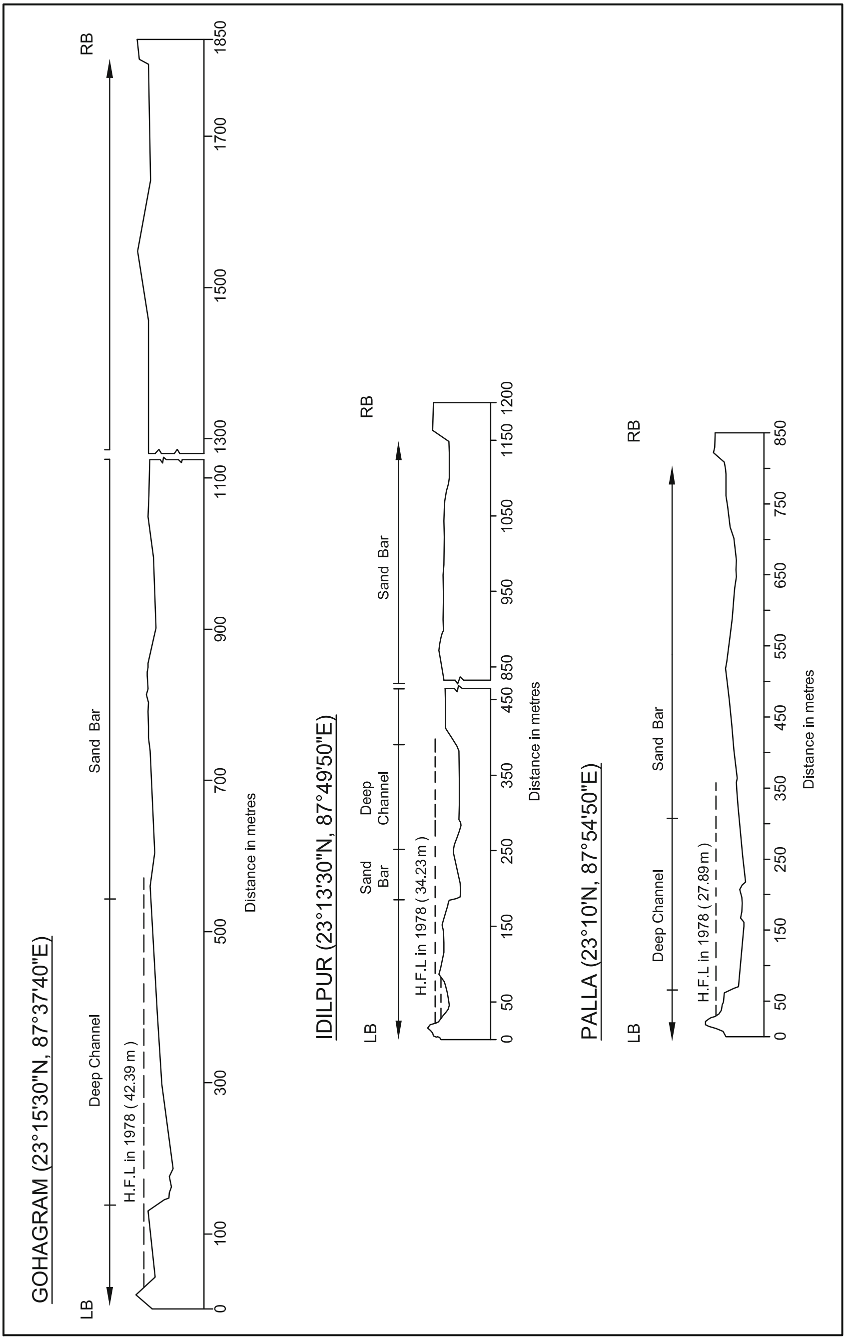

Fig. 3.9 Cross profiles of Damodar River at selected sites. Source: After I & WD, WB

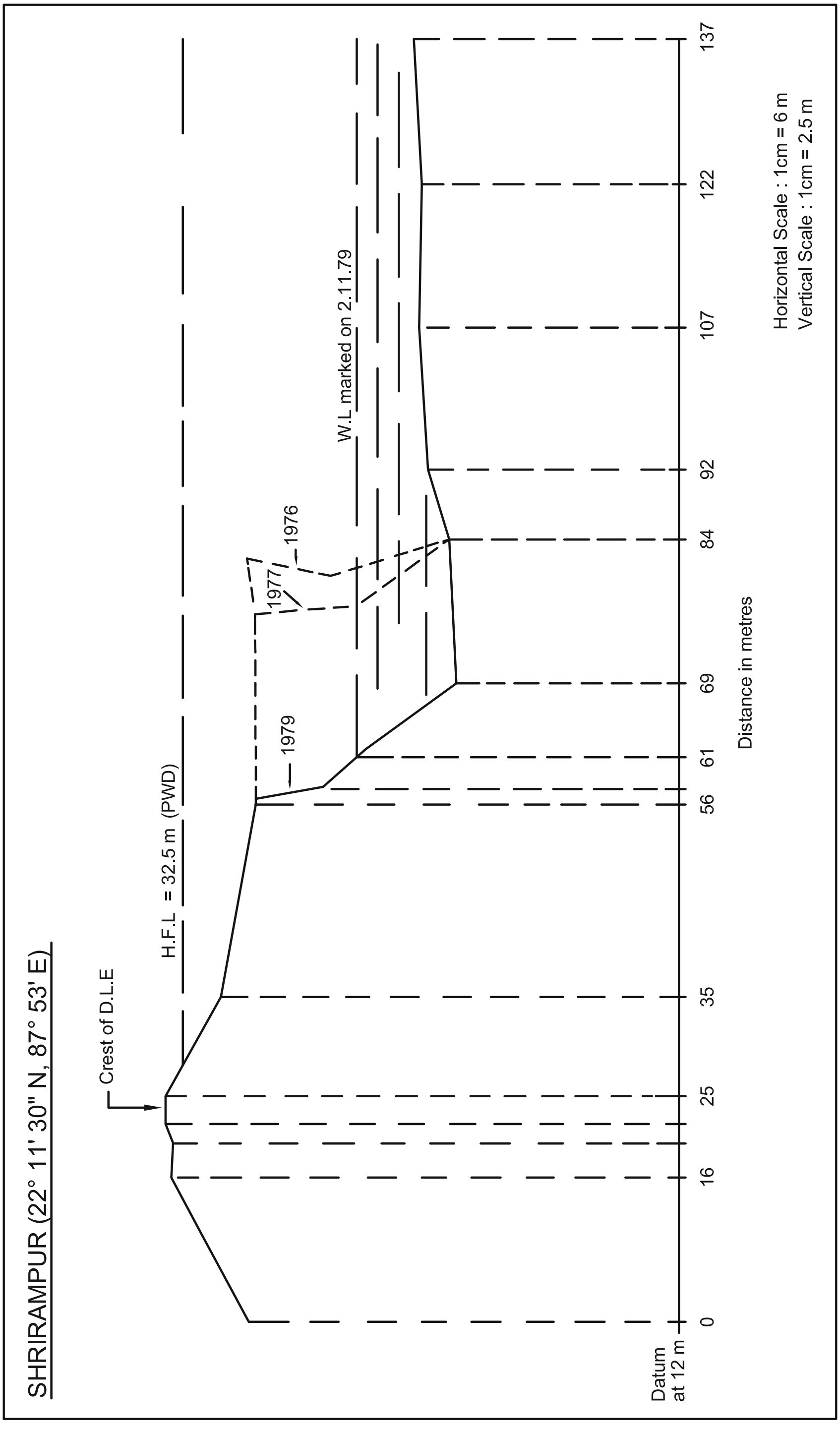

Fig. 3.10 Shifting of left bank of the Damodar River. Source: After I & WD, WB

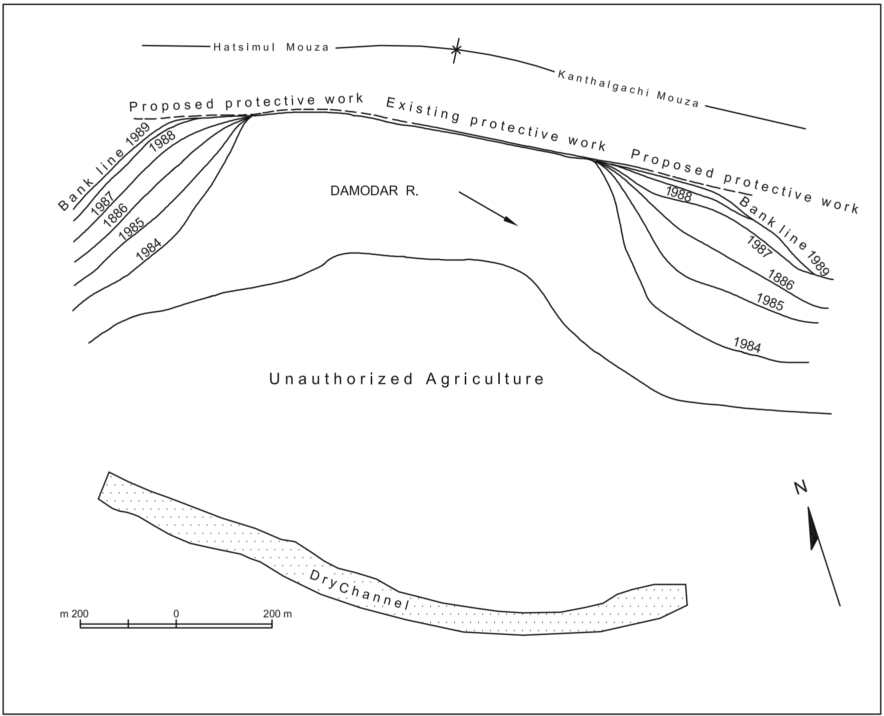

Fig. 3.11 Shifting of bankline (Hatsimul Mouza to Kanthalghachi Mouza). Source: After I & WD, WB

abandoned flood channels on the left were re-activated and the left bank embankment has breached in several places. The left bank is thus becoming vulnerable. Shifting of bank line is prevalent between Shrirampur and Kalinagar (Figs. 3.10, 3.11 and 3.12) near Palla village (Bhattacharyya 1999–2000a). Channel migration in the middle Ganga (Philip et al. 1989), migrations of bank lines and consequent problems in the Lower Ganga in India and in the Brahmaputra in Bangladesh have been noted by Bandyopadhyay (1994, 2002) and Goswami (1988) and Thorne et al. (1993) respectively. The shfting trend and changing geomorphology of the Kosi River has been studied by Ansari (1987) and Bose et al. (2009).

3.15 Summary

The Lower Damodar has always been a flood-prone river. It has changed its main flow several times in the historical past and its shifting courses can be identified if we collate archival maps. Recorded flood history, however, dates back only from 1730. Since 1730, floods of different magnitudes have occurred every 8–10 years.

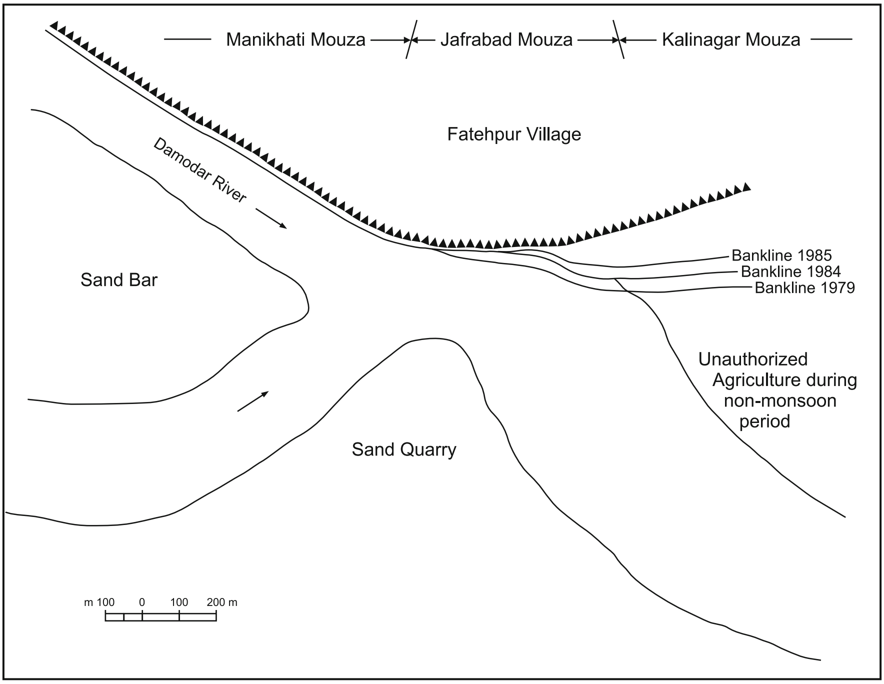

Fig. 3.12 Shifting of bankline (Manikhati Mouza to Kalinagar Mouza). Source: After I & WD, WB

In the twentieth century, the September flood of 1978 is interpreted as the greatest disaster in South Bengal within a 100-year period.

Embankments were obviously the first control measures on the Lower Damodar. These were constructed by local landlords but the need for embankments was extensively examined during the colonial regime. The right bank embankments were removed and the left bank embankments were raised and fortified. This resulted in a gradual rise of the riverbed, changes in soil characteristics in the adjacent riparian tract, widening of the river between embankments, and opening of spill channels on the unprotected right bank. Other consequences include opening of the Begua and the Muchi spill channels on the right, drainage diversion through the Kanki-Mundeswari, deterioration of the Amta channel, drainage congestion to the north of the left bank embankment resulting in increased incidence of Barddhaman fever, shifting of the thalweg towards Barddhaman side due to reversal of slope, and shifting of bank lines on the left bank. The left bank embankments have also been provided with many sluices, the Jujuti sluice being one of them, but due to lack of maintenance some of the sluices do not operate properly. Canals were dug to divert excess water from the river and to revive some of the decaying distributaries of the Damodar through water transfer from the canal to the river. The Eden canal was constructed for this purpose in 1881.

The most important control structures on the Lower Damodar are the Maithon and the Panchet reservoirs which are outcomes of the DVC and began functioning properly from 1957 and 1959 respectively. Despite several control measures taken by the DVC, the lowermost part of the Lower Damodar, the Amta channel, is deteriorating. To address this problem, a 58-vented outfall sluice was constructed at Ulughata in 1975–1976 as a program of the Lower Damodar Scheme. The last mention-worthy control structure is the Rangamatia cross dyke, locally referred to as the Rangamatia dam at Rangamatia sandbar.

The River control process is an ongoing process that includes strengthening of embankments, closure of spill channels, and drainage diversion as components. But the process itself is an anthropogenic process which has given rise to several cultural features such as embankments, weirs, sluices, barrage and reservoirs. These cultural features are the indicators for identifying the characteristics of the Lower Damodar. The stretch between the Maithon and Panchet reservoirs to the Falta outfall is thus culturally defined. This places a particular responsibility on us to take a long-term and holistic view of the entire river system and deal with it in a way that ensures its ecological health while meeting the diverse needs of people.

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