Chapter V: Flood Hazards in Jalpaiguri

5.1 Introduction

Throughout the human history, floods have been part of his destiny. They are widely discussed today as a result of increased public awareness and greater destruction caused by them. Perhaps, flood is one of the most dramatic interactions between man and his environment, emphasizing both the shear force of natural events and man's inadequate efforts to control them. The holy bible has an account of the greatest flood to ever happen. The following chapters out of Genesis tell how God explained to Noah to build the ark before the great flood. God said to Noah, *Seven days from now I will send rain to the earth for forty days and forty nights, and I will wipe from the face of the earth every living creature I have made* (GENESIS, 7:4,7).

Defining a flood is difficult, partly because floods are complex phenomena and partly because they are viewed differently by different society, people and government. For most practical purposes and certainly in popular usage a meaningful flood definition should incorporate the notions of damage and inundation. Chow (1956) defines *a flood is a relatively high flow which overtaxes the natural channel provided for run-off.* Ward (1987) provided the most comprehensive definition that: *a flood is a body of water which rises to overflow land which is not normally submerged.*

The sub-Himalayan West Bengal being situated not far from the Himalayan margin and cris-crossed by the sub-Himalayan rivers has always been liable to floods. The reasons for high floods are excessive rainfall within small duration in small catchments and continuous rainfall of several days in bigger catchments. The simultaneous melting of snow accumulated on high mountains and rainfall in lower reaches often caused floods of devastating nature. These along with sudden bursting of water storage in the upper catchment caused by heavy landslide that blocked river channel released unbelievable volume of water through the river Tista in 1968 and caused unprecedented devastation (Kusari, A.M. et al. 1981; Ramaswamy C., 1987; Sarkar S., 2004b; Sanyal, C.C, 1969, 1970 and Sen S., 1968).

North Bengal is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of flood and problem of extensive and regular bank erosion, course shifting, renders thousands of homeless during the rainy season. The majority of the rivers of *Terai* and *Duars* originate in the Himalayas and enter from a north to northwesterly direction and flows south to southeasterly direction. The lateral gap between the two major rivers is in between 3 to 30 kilometer i.e., Torsa – Jaldhaka and Gadadhar – Raidak respectively. As many of the rivers originate at the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The catchment of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the rivers. Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon. These often add more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone. As a result, the river-bed is rising at some sections in the plains, resulting in the lessening of cross-sectional areas which being incapable of arresting the unusual monsoon discharge and allow water to spill, causing floods. Moreover, the narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behavior of the rivers. This often cause accelerated deposition at the bottom of the bridge and thereby, narrowing the outlets of the rivers gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and firm lands (Sarkar S., 2007).

5.2 History of occurrences of major floods

The first recorded disastrous flood of this region occurred in 1787. It caused dramatic changes to the river Tista, which used to flow into the Ganga, deserted its channel and emptied itself into the Brahmaputra through an ancient spill channel. Numerous deserted riverbeds of the Tista, Torsa, Sankosh, Raidak and Jaldhaka bear the testimony to the fact that the river changed its course at ease often in consequence of heavy rains in the following years.

Historical documents on the floods and flood-induced evolution of the sub-Himalayan rivers viz., Bolt, 1772: Buchanan-Hamilton,1810; Dash, A. J., 1947; Furgusson,1770-79; Hunter,1787; Sunder, D. H. E. 1985; Gruning, J.F. 1911; Rennel,1779; Mitra,1964; Sanyal,1969 etc are numerous and fascinating. Record reveals that up to 1787, the river Tista and Karotoya were the same river that flowed through the Atrai-Punarbhaba into the Ganga. Neo-tectonic activity coupled with high intensity rainfall induced flash-flood caused massive shifting of the river. The so-called whale backed subsurface ridge of the Baikanthapur-Fulbari became active and the Tista migrated eastwards bifurcating the river Karotoya.

Table 5.1

History of Flood Occurrences in Jalpaiguri district

Year	Magnitude	Triggered by	Affected areas
1787	V	Earthquake, landslide followed by heavy rainfall	Jalpaiguri, Koch Bihar and parts of Darjeeling district; the Tista river shifted from the Ganga to Brahmaputra
1840	IV	Heavy rainfall in the catchment area	Jalpaiguri, Koch Bihar and part of Darjeeling district; the river Torsa and Sankosh shifted their courses.
1881	III	Heavy rainfall in Darjeeling Sikkim and Bhutan hills	Jalpaiguri and part of Koch Bihar districts.
1892	III	High rainfall in the Catchment areas	Jalpaiguri and Koch Bihar districts, river Jaldhaka shifted its course.
1902	IV	Incessant rain in Sikkim and Darjeeling hills	Jalpaiguri and Darjeeling districts caused heavy damages to land and property.
1906	III	Heavy rainfall in North Bengal Plains amounting over 1000mm in 72 hours	Parts of Jalpaiguri district and most part of Koch Bihar district were affected caused heavy damage to land and properties.
1922	II	Heavy rains in Sikkim	Parts of Darjeeling and Jalpaiguri districts
1948	II	Heavy rains in the North Bengal Plain	Parts of Jalpaiguri and Koch Bihar districts
1950	IV	High intensity rain in upper catchments of the Tista, Jaldhaka, Mahananda rivers and landslides in hill slopes	Heavy damage to land and properties in entire North Bengal particularly communication lines. Heavy damage to human and animal life was also reported
1968	V	Cloud-burst over large parts of Sub-Himalayan West Bengal, 1200mm rainfall recorded at Himalayan margin caused landslides & damming of river	Jalpaiguri was worst affected, also affecting Darjeeling and Koch Bihar districts, heavy damage to lives, land and properties; massive deposition was taken place in many parts of North Bengal
1969	II	Heavy local rainfall	Jalpaiguri district
1972	II	Heavy rainfall in the catcment	Parts of Jalpaiguri and KochBihar districts
1980	II	Incessant rains in the catchment areas	Jalpaiguri, Koch Bihar and parts of Darjeeling districts

1993	IV	Cloud-burst over the Lower Bhutan-Darjeeling Himalaya Hasimara recorded 850mm/ 24 hours	Alipurduar sub-division of Jalpaiguri district was devastated, massive fluvial transformation were taken place.
1998	IV	Cloud-burst over the lower Bhutan hills, 1250mm in 72 hours, massive landslide & debris flow in Bhutan hills	Foothill area was devastated, shifting of river courses, destruction of forest, tea garden, settlement, communication lines and deposition of course sediments.
2000	III	Heavy rainfall in the catchment area followed by drainage congestion	Koch Bihar and part of Jalpaiguri and Darjeeling districts were affected.
2002	II	Heavy rainfall in the catchment area along with the local drainage congestion	Malbazar, Kalchini, Madarihat Blocks in Jalpaiguri district and many parts of Koch Bihar district.
2003	III	Heavy rainfall in catchment area on July 1 i.e., Jalpaiguri 182, Banarhat 221, Malbazar 175 and Hasimara 189 mm in 24 hours.	30000 people are affected in Jalpaiguri , 70m embankment of I&W Dept. damaged
2003	III	High intensity rainfall in Duars on August 7, causes flood i.e., Central Duars TG 424,Hasimara200,Malbazar19 8 and Banarhat recorded 264 mm in 24 hours	215 m long embankment washed away, 500 acre of Tea Garden land destroyed. Massive bank erosion takes place in Pana, Gabur Basra and Reti rivers.
2004	II	Cloud burst in Lish-Gish catchment cause flush flood along Lish valley, Bagrakote GP of Mal block.	At Ramnagar basti, Bagrakote river Lish breach her left embankment for 200 meter destroying 200 homesteads and others, 1000 people remains homeless.
2005	II	Heavy rainfall in catchment area on 10^{th} May i.e., Jalpaiguri 178, Alipurduar 152 in 24 hours.	Large scale destruction of crops from Jalpaiguri district was reported.
2007	III	Very heavy rainfall in Jalpaiguri on August 16 (350 mm in 24 hours).	Over 25000 families affected, 6500 homestead destroyed and 4500 hectare of arable land affected.
2008	II	Heavy rainfall in catchment area on 20^{th} June in Jalpaiguri district causes large scale flood in Mal area.	Railway bridge over Gish river near Odlabari was destroyed.
2009	I	Heavy rainfall in catchment area on 20-21 August in Jalpaiguri district causes large scale flood in Mal area.	2 died in Jalpaiguri in flood. 25000 family affected in Jalpaiguri sadar and Maynaguri.
2010	I	Heavy rainfall in catchment area on 19^{th} August in Jalpaiguri.	414 families affected in Falakata.

The occurrences of floods during the following 224 years along with their estimated magnitude, triggering mechanism and effects are tabulated in table 5.1. The characteristic features of some of the major floods of Jalpaiguri district is given below:

The floods of 1922

The flood of 1922 during 23rd to 28th September was caused by cyclonic rainfall of practically unprecedented magnitude. The rainfall in the central area in one week was about 10 times the normal weekly precipitation, which was nearly three times the normal precipitation for the month of September, and approached the normal rainfall for the whole of three months of July, August and September. In other words, the flooded area received in one week practically as much rain as it would have received in certain years during the whole monsoon period. The railway embankment in Jalpaiguri district hampered quick draining away of the flood-water, and thus served to prolong the duration of the flood. However, with such a heavy rainfall, a flood of practically the same magnitude was bound to occur, had there been no railway line in existence. Though no records are available with regard to flood damages, it was classified as very severe and extensive flood with huge loss of property. It affected the parts of Jalpaiguri district.

The floods of 1968

The rivers in North Bengal, particularly in the western half, from Jaldhaka to Mechi witnessed an unprecedented flood, during 3rd October to 5th October 1968 which caused number of breaches in many embankments and damage to anti-erosion works, revetments and spurs. The damages caused due to the river Tista were unprecedented in magnitude. The Jalpaiguri town protection embankment was breached at eleven places. Embankment on both the banks of the river Tista were breached and washed away, two numbers solid spurs was outflanked and thirty numbers permeable spurs of Jalpaiguri embankment were washed away.

The floods of 1993

In the year 1993, the damages to flood protective structures on different rivers were very high. The damages by the river Kaljani were maximum at the Alipurduar Town where the Alipurduar Town Protective embankments were breached by overtopping due to its highest recorded discharge. During the period from 18.7.1993 to 21.7.1993, there was very intensive rainfall in Jalpaiguri district and the lower catchments of the river Kaljani. In the upper catchments, the rainfall recorded at Hasimara within the adjacent catchment of Torsa on 19.7.1993, 20.7.1993 and 21.7.1993 were 220 mm, 368 mm and 790.60 mm respectively. Such incessant heavy rainfall in the entire catchment caused heavy floods in the river Kaljani and its tributaries. It is seen from the records of the North Bengal Flood Control Commission that the design discharge adopted for the river Kaljani at Alipurduar is 112480 cusec (3468 cumec) in respect of all the flood protective works (NBFCC, 1965; WAPCOS, 2003). From the recorded rainfall of July 1993 and considering other relevant factors, it has been calculated that the peak discharge through the river Kaljani on 20.7.1993 was 140237 cusec (3971 cumec).

The floods of 1999

In 1999, the State of West Bengal suffered from cyclone and high precipitation during monsoon months i.e. between June to October. In the last week of August the district experienced high rainfall varying between 100 cm in 24 hours for about three days. This resulted heavy discharge passing through the rivers of the district. It caused widespread inundation and bank erosion including damage to spurs, revetment works and existing embankments in the Jalpaiguri district.

There was heavy rainfall during August 1999. On 9.7.1999, the rainfall at Jalpaiguri was 474 mm which was a record rainfall crossing the previous record of 390 mm on 8th July 1892. This year the rainfall up to 13.10.1999 was about 1100 mm. Because of this heavy rain and flood, heavy damages occurred to the embankment structures. Out of total existing length of embankment of 434.00 km in the district, 1.75 km was breached, 10.46 km was severely damaged, 20.44 km was partially damaged and 8.65 km revetment works were damaged.

The floods of 2000

Due to concentration of heavy rainfall during the months of June 2000, earlier part of July 2000 and first week of August, 2000 in the hilly areas of Darjeeling, Sikkim and Bhutan, Synchronised with heavy rainfall in the Duars area of Jalpaiguri and Alipurduar, the river

Sankosh, Raidak-I, Raidak-II, Kaljani, Torsa, Mujnai, Basra, Pana, Diana, Jaldhaka, Tista, and other tributaries were in high spate and the water levels of these rivers crossed even extreme danger levels. The heavy concentration of flood with high velocity and thrust leading to rise in water levels caused several breaches in the embankments specially in the foothill zones under Alipurduar Sub-Division. It also caused severe damages to the structures, embankments, spurs due to erosion and scour.

The unique feature of the flood during the first week of August, 2000 was that, though there was less rainfall at Jalpaiguri but heavy and incessant rains occurred in the Bhutan and adjacent foothills amounting to more than 500 mm on 2nd and 3rd August, 2000. Thrust of the rainfall and eventual discharge was such that the rain gauge station at Chukka on Raidak river was washed out and there were heavy landslides in the Bhutan territory leading to deposition of boulders and debris in rivers in Alipurduar.

5.3. Flood hydrographs

Flood hydrograph is the plot of discharge or water-surface elevation against time during a flood event and defines the slope of the flood wave at the location of the gauging station. Hydrographs at successive locations can be used to define the changing slope of the flood wave as it moves down wards. In the study area the flood hydrograph is mostly depend on the high intensity rainfall and catchment characteristics.

The flood hydrograph is an important guide to flood characteristics it gives the information of peak discharge and water level, the duration of flooding, time taken to attain peak condition and the total volume of the flood water. The rate of discharge provides the basis for most methods of predicting flood magnitude and frequency. However, the other dimensions of flooding the velocity of flood water, water depth and area of inundation.

5.3.1 Factors affecting flood hydrograph

The factors that affect the shape of the hydrograph can be broadly grouped into climatic factors and physiographic factors. Each of these two groups contains a host of factors and the important ones are listed in table 5.2. Generally, the climatic factors control the rising limbs and the recession limb is independent of storm characteristics, being determined by catchment characteristics only. Many of the factors listed in table 5.2 are interdependent. Further, their effects are very varied and complicated. As such only important effects are listed below in qualitative terms only.

Table No- 5.2 Factors affecting flood hydrograph

Physiographic Factors	***Climatic Factors***
Basin characteristics : Shape Size Slope Nature of Valley Elevation Drainage Density *Infiltration characteristics:* Land use and cover Soil type and geological condition Lakes, swamps and other storage *Channel Characteristics:* Cross-section, roughness and storage capacity	Storm, characteristicPrecipitations, intensity, duration, magnitude and movement of storm. Initial loss Evapotranspiration

(Based on Subramanya, 1994)

5.3.2 Components of hydrographs

As indicated earlier, the essential components of a hydrographs are: (i) the rising limb, (ii) the crest segment, and (iii) the recession limb. A few salient features of these components are described below:

The rising limb of a hydrograph, also known as concentration curve represents the increase in discharge due to the gradual building up of storage in channels and over the catchment surface. The initial losses and high infiltration losses during the early period of a storm cause the discharge to rise rather slowly in the initial period. As the storm continues, more and more flow from distant parts reach the basin outlet. Simultaneously the infiltration losses also decrease with time. Thus under a uniform storm over the catchment, the runoff increases rapidly with time. As indicated earlier, the basin and storm characteristics control the shape of the rising limb of a hydrograph.

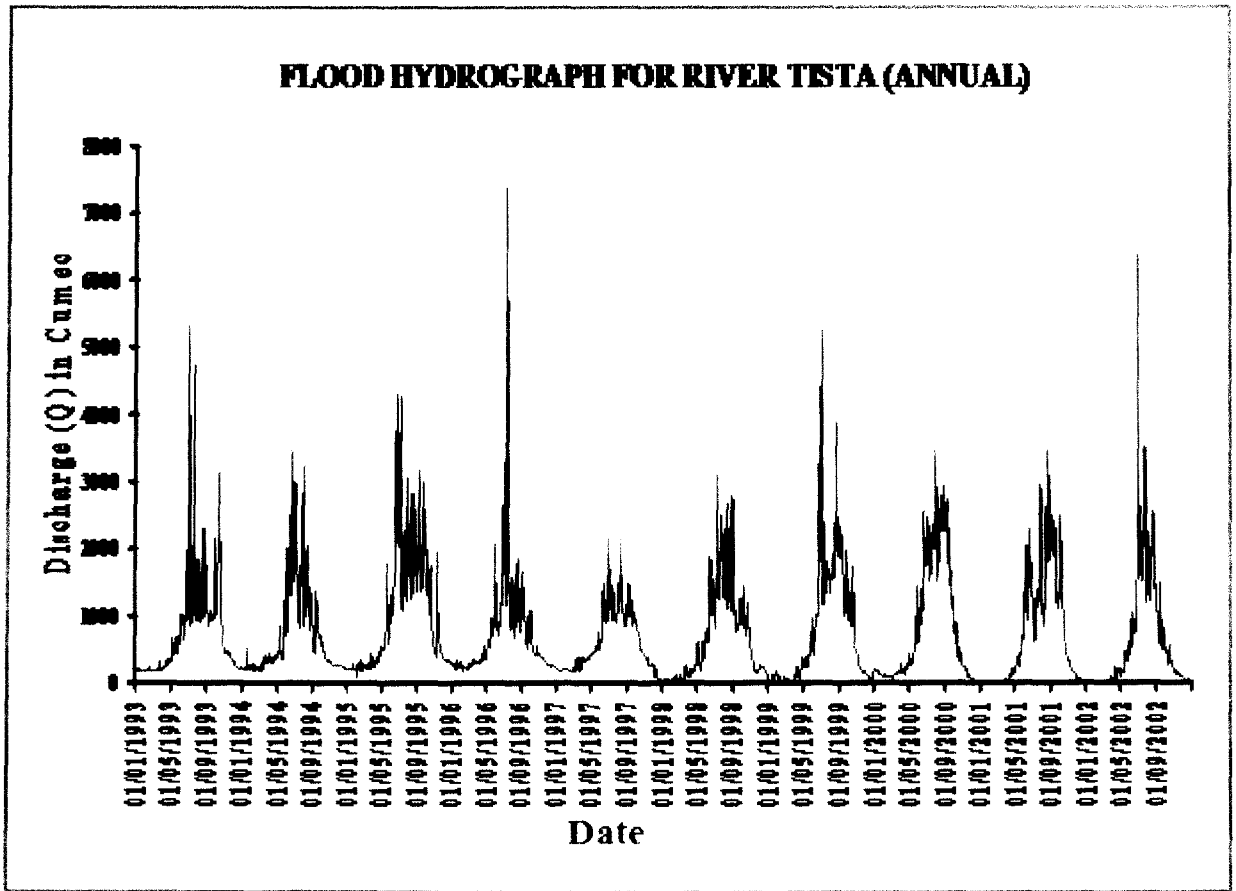
The crest segment is one of the most important parts of a hydrograph as it contains the peak flow. The peak flow occurs when the runoff from various parts of the catchment simultaneously contribute to the maximum amount of flow at the basin outlet. Generally the large catchments, the peak flow occurs after the cessation of rainfall, the time interval from the centre of mass of rainfall to the peak being essentially controlled by basin and storm characteristics. Multiple-peaked complex hydrographs in a basin can occur when two or more storms occur in close succession.

The recession limb which extends from the point of inflection at the end of the crest segment to the commencement of the natural ground water flow represents the withdrawal of water from the storage built up in the basin during the earlier phases of the hydrograph. The starting point of the recession limb, i.e., the point of inflection represents the condition of maximum storage. Since the depletion of storage takes place after the cessation of rainfall, the shape of this part of the hydrograph is independent of storm characteristics and depends entirely on the basin characteristics.

5.3.3 Characteristics of flood hydrographs for rivers under study

The shape of the basin influences the time taken for water from the remote part of the catchment to arrive at the outlet. Thus occurrence of the peak and hence the shape of the hydrograph are affected by the basin shape. Fan-shaped , i.e. nearly semi-circular shape catchments give high peak and narrow hydrographs while elongated catchments give broad- and low peaked hydrographs. Multi-peaked complex hydrograph is produced by a catchment of composite shape. Moreover, multi-peaked hydrographs may be produced, if the next rainfall occurs before the direct runoff of the previous rainfall ceases (Mukherjee, 2008).

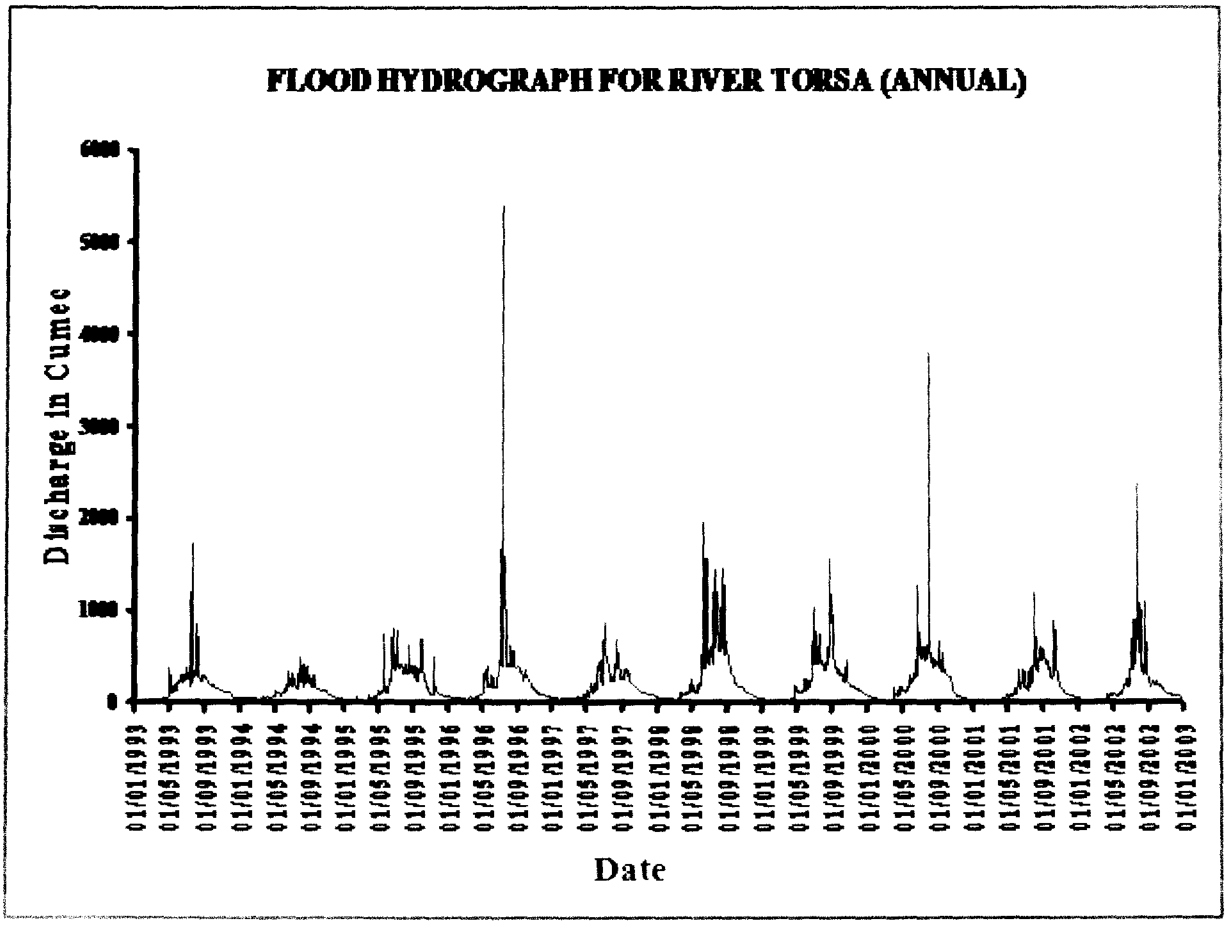
In case of river Tista (figure 5.1), flood hydrographs have been constructed for consecutive ten years (i.e., from 1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the direct runoff of the previous rainfall ceases. Moreover, it has been pointed out that the flood hydrographs for the years of 1993, 1994, 1995,1996,1998,1999 and 2002, are skewed to the left which indicates that the peak occurs relatively quickly. Again, the flood hydrographs for the years of 2000 and 2001 are skewed to the right which indicates that the peak occurring with a relatively longer lag. But, only for the year 1997, peak occurs at an intermediate time, neither very quickly nor at a longer lag.



Based on Mukherjee, M, 2008

Figure 5.1 Flood hydrograph of the river Tista.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 6.267 cumec to a maximum value of 173 cumec. Hence, it can be interpreted that river Tista is a perennial river where there is always some flow above the river bed level. Moreover, the base-flow contribution is more significant up to the year 1997 and decreased thereafter.

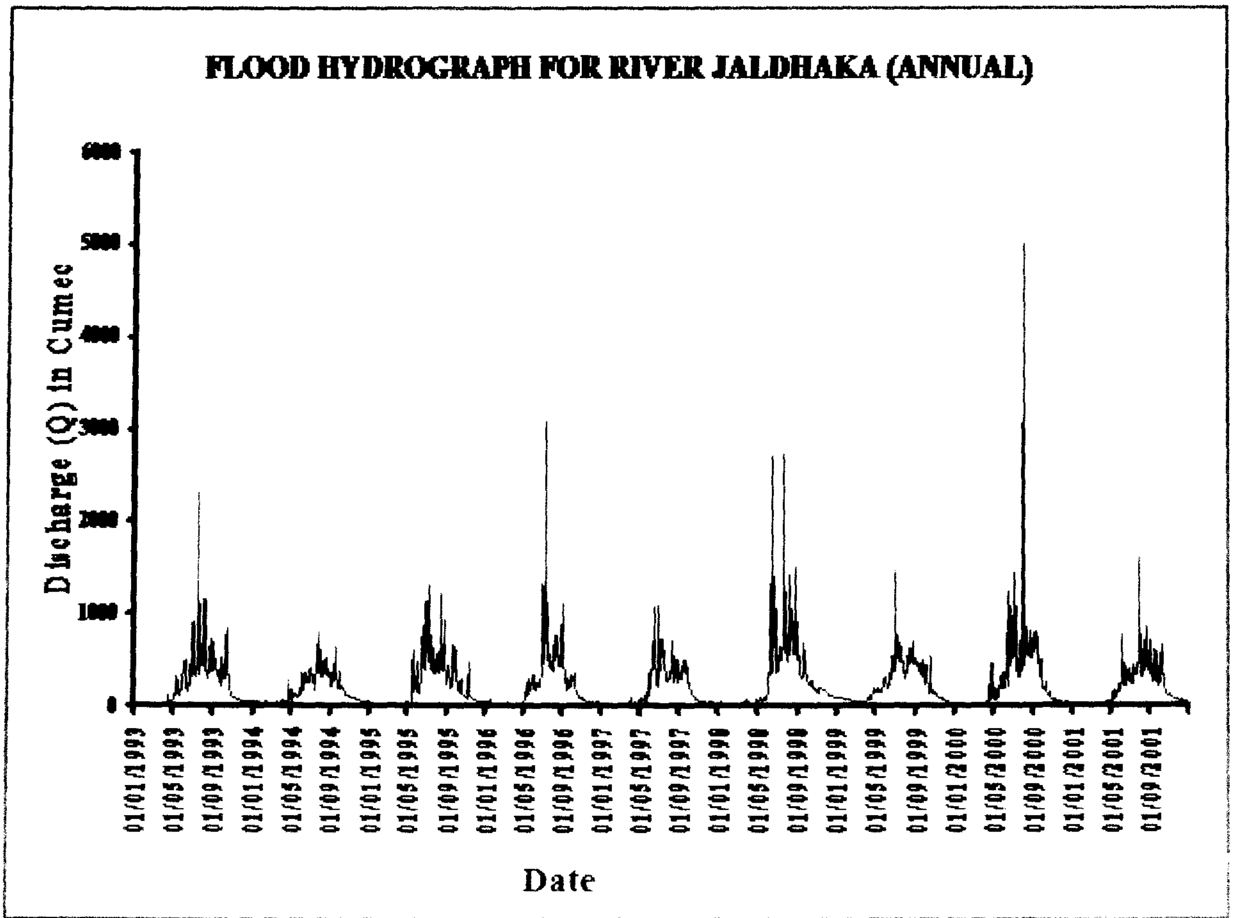


Based on Mukherjee M 2008

Figure 5.2 Flood hydrograph of the river Torsa

In case of river Torsa (figure 5.2), flood hydrographs have been constructed for consecutive ten years (i.e., from 1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1995, 1996, 1997, 1998, 2001 and 2002 are skewed to the left, which indicate that the peaks occur relatively quickly. For the years 1999 and 2000 the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, only for the year 1994, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 18.96 cumec to a maximum value of 36.02 cumec. Hence, it can be interpreted that river Torsa is a perennial river, where always there is significant flow above the river bed level.

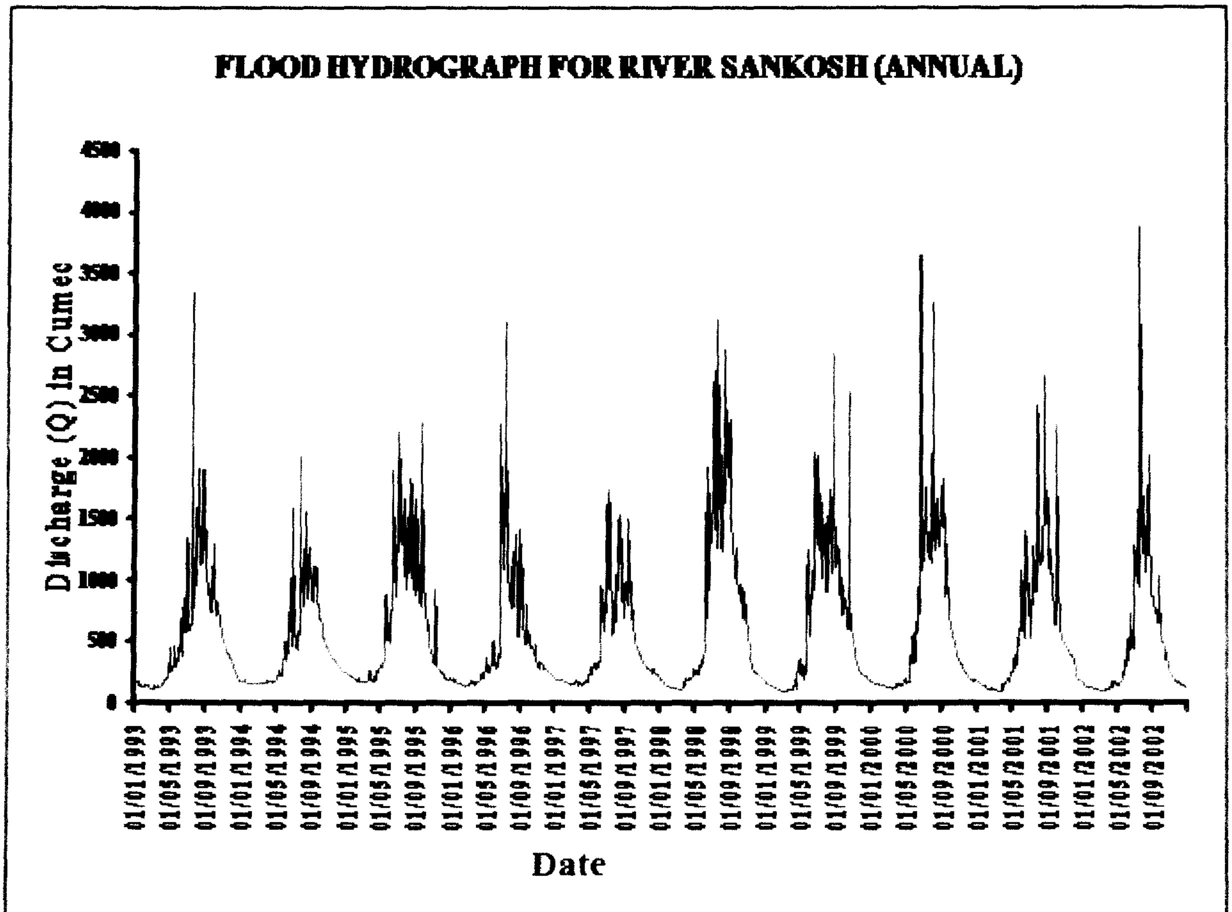


Based on Mukherjee M 2008

Figure 5.3 Flood hydrograph of the river Jaldhaka

In case of river Jaldhaka (figure 5.3) flood hydrographs have been constructed for consecutive nine years (i.e., from1993 to 2001) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the nine years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1995, 1996, 1997, 1998 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1999 and 2001, the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, only for the year 1994, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the nine years duration under consideration is varying from a minimum value of 11.17 cumec to a maximum value of 28.07 cumec. Hence, it can be interpreted that the river Jaldhaka is a perennial river, where always there is some flow above the river bed level. So, river Jaldhaka can be classified as perennial.



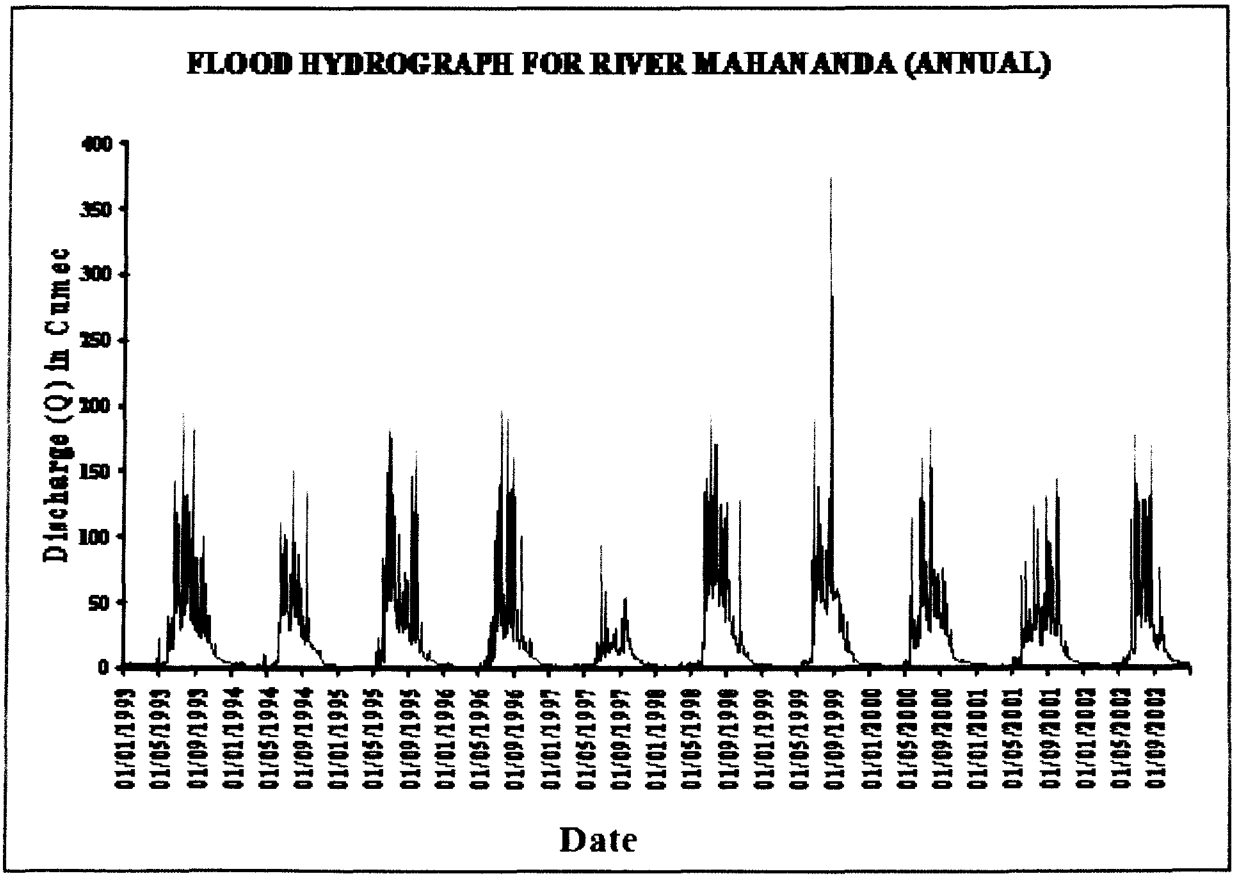
Based on Mukherjee M. 2008

Figure 5.4 Flood hydrograph of the river Sankosh

In case of river Sankosh (figure 5.4), flood hydrographs have been constructed for consecutive ten years (i.e., from1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years 1993, 1994, 1996 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1998, 1999, 2001 and 2002, the flood hydrographs are skewed to the right.

which indicates peak occurring with a relatively longer lag. But, for the year 1995 and 1997 peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 90 cumec to a maximum value of 164.6 cumec. Hence, it can be interpreted that river Sankosh is a perennial river where there is always some flow above the river bed level. Moreover, the base-flow contribution is more significant up to the year 2000. Then the base-flow is throughout more or less steady for the period under consideration.



Based on Mukherjee, M, 2008

Figure 5.5 Flood hydrograph of the river Mahananda

In case of river Mahananda (figure 5.5), flood hydrographs have been constructed for consecutive ten years (i.e., from1993 to 2002) from the available data. From the constructed flood hydrographs, it has been observed that in case of all the ten years under consideration, the flood hydrographs are multi-peaked. So, it can be inferred that rainfall occurs before the run-off of the previous rainfall ceases. Again, the flood hydrographs for the years

1993,1995,1996,1998 and 2000 are skewed to the left, which indicates that the peak occurs relatively quickly. For the years 1994 and 2001, the flood hydrographs are skewed to the right, which indicates peak occurring with a relatively longer lag. But, for the year 1997, 1999 and 2002, peak occurs at an intermediate time, neither very quickly not at a longer time.

It has also been observed from the plotted hydrographs that there is always a base-flow component throughout the ten years duration under consideration is varying from a minimum value of 0.504 cumec to a maximum value of 2.228 cumec. Moreover, it has been observed that base-flow contribution is very small for all the ten years under study. Hence, like other rivers under consideration, river Mahananda cannot be classified as perennial river. It is better to classify as intermittent river, particularly when the base-flow is negligible, around 0.5 cumec.

It has been observed from the above constructed flood hydrographs shown in figures 5.1, 5.2, 5.3, 5.4 and 5.5, that two main features are there which are common for all the rivers under study i.e., Tista, Torsa, Jaldhaka, Sankosh of the Brahamputra basin and Mahananda of the Ganga basin. In all the cases the flood hydrographs are multi-peaked, so it can be inferred that rainfall occurs before the direct runoff of the previous rainfall ceases. Except the river Mahananda, remaining all the rivers may be classified as perennial rivers having significant base flow contribution throughout the year. While, the river Mahananda may be classified as intermittent river. This has been corroborated from the findings furnished from the constructed hydrographs.

The flood hydrographs which have been constructed from consecutive ten years (i.e from 1993-2002) from the available data reveals that in majority of the cases the peaks are skewed to the left and in some cases are skewed to the right. The fact reveals that the peak occurs relatively quickly when the hydrographs are skewed to the left and the peak occurring with a relatively longer lag when the hydrographs are skewed to the right.

5.4 Causes of flood

Jalpaiguri district is endowed with an intensive network of river systems. Most of the rivers are considered to be highly notorious for their unpredictable nature, letting loose fury of floods and problem of extensive and regular bank erosion, course shifting and rendering thousands of people homeless during the rainy reason. The majority of the rivers of Terai and Duars originate in the Himalayas and enter from north to northwesterly direction and flow south to southeasterly direction. The lateral gap between the two major rivers is in between 3 to 30 km. i.e., Torsa – Jaldhaka and Gadadhar – Raidak respectively. As many of the rivers originate from the same hill, flood often occurs simultaneously in many rivers and the rivers coalesce to form a single vast sheet of water.

The catchment area of these rivers has mostly been deforested and the clearings of the steep slopes have been used for the extension of settlement, agriculture, plantation and communication, disrupting the overall hill slope hydrological balance. As a result, during heavy and concentrated rainfall, innumerable landslides are caused transporting huge amount of sediment to the rivers (photo 5.3 & 5.4). Most of such landslides have never been treated scientifically with proper protective measures and as such those are in the habit of expanding their territories during monsoon (photo 5.1 & 5.2). This often added more and more silt to the rivers, which are incapable of transporting the loads efficiently under the existing hydrological conditions, especially areas beyond the foothill zone (Sarkar, S., 1996; Sarkar S., 2008).

There are many causes of floods in the district as a whole. All the causes create huge flood condition in the study area. Some causes are similar to the floods of different places of India and West Bengal. But few causes are highly local which is predominant in the district of Jalpaiguri. Such causes are foothill situation of the area, lateral gap of the rivers are thin, high intensity of the rainfall in the district and avulsion etc.

5.4.1 Transient causes

Among the transient causes of flood, heavy and concentrated rainfall in the upper catchment is noteworthy (Starkel, L., Sarkar, S., Soja, R., Prokop, P. 2008). Records reveal that the floods of 1906, 1968 and 1993 caused by the high intensity incessant rainfall in Darjeeling and Sikkim Himalaya. Heavy and incessant local rainfall also caused large-scale inundation and flooding at Jalpaiguri district in 1902, 1906, 1950, 1952, 1968, 1972, 1980 and 1998 (table 5.1).

Photo 5.1Deforested catchment in the Hills

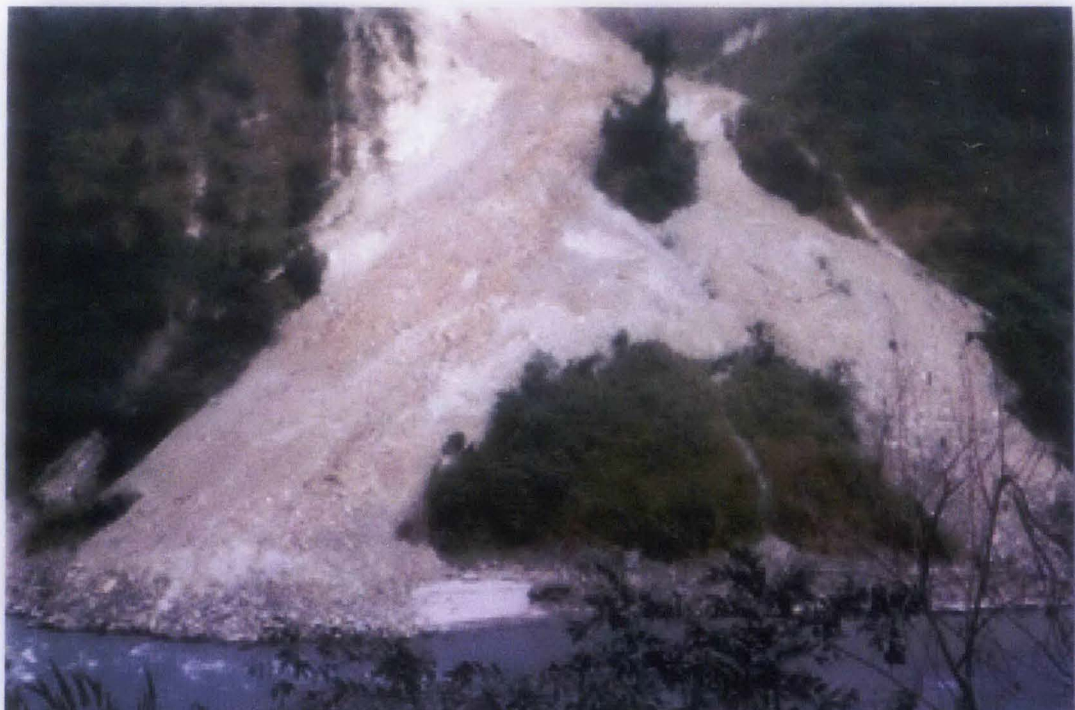


Photo 5.2 Landslide along the Tista Valley

5.4.1.1 Grazing

Grazing rights, privileges, and concessions for forest produce. Minor timber etc, are generous and vary from state to state. Forest regulations admit such rights. Tribal people in state have their free rights to grazing and extracting minor forest produce. Overloading degrades the watershed. Sediment discharge and overland flow volume increase from such degraded catchments. The situation becomes more acute in places where livestock population is very high. Some areas are having this problem of the district and the upper catchments of the main rivers of the Jalpaiguri district facing the problem.

5.4.1.2 Forest fire

Forest department have a practice of administering regulated fire in moist regions for encouraging natural regeneration of teak (*Tectona grandis*), sal (*Shorea rebusta*), deodar (*Cedras deodars*) etc. This is mostly done to check the growth of evergreen tree, shrubs and woods, reduce depth of leaf litter and create a conductive site for the germination and establishment of seedlings. However, the unregulated wild fires are fraught with danger for defecating watershed conditions. Such incidences are numerous. They damage the soil and rob the forest of its productive and protective capacity hence, the normal hydrological functioning of the forest watershed gets upset.

5.4.1.3 Surface mining

Large scale surface mining of minerals for manufacturing of cement and especially for the extraction of dolomites in the Bhutan hills make radical change in river behaviour of the Jalpaiguri district. It is noticed that spilling and massive sand and debris deposition in the multi-cropped agricultural field. This has caused national loss in term of the agricultural and tea productivity and also has adverse effects to the people residing in the adjacent area. Buxa-Jainti area is the worst affected by this problem followed by Chamurchi-Reti-Pagli-Makrapara-Lankapara area (Starkel, L & Sarkar, S, 2002). The details indicating the cause and nature of silt-deposition of some of the vital locations are given in table 5.3.

Photo 5.3 Deep seated landslides along Bhutanese border caused massive deposition in Pana-Gabur Basra valley.

Photo 5.4 Parminder landslide in Lish catchment caused huge deposits in the valley

5.4.1.4 Deforestation

Deforestation has several environmental affects like air pollution, soil pollution, climatic change and soil erosion etc. But flood occurrences are very prominent due to the deforestation in the upper and lower catchments of the river basin in the recent years. Jalpaiguri district is famous for the vast forest tracks and for their luxuriant growth of natural vegetation is facing the problem of large scale deforestation or forest clearings due to the expansion of agricultural lands, tea gardens, roadways, railways, rapid urban isotones or settlements etc. these causes landslides, sheet erosion, slope failure and top soil erosion in the upper catchment areas of the leading river of the district, which enhance the debris flow and large scale sedimentation in the riverbeds of all the rivers of the district and acute the flood problem of the district. This reckless deforestation also affects the climate of the study area.

Table 5.3
Causes and nature/extent of silt deposition along the river beds

Location	River	Down-stream	Siltation (m/year)	Causes	Results
Pagli Bhutan	Pagli	Tulsipara, Lankapara	1.0	Extraction of dolomite and deforestation in the Bhutan hills caused landslides and siltation downstream.	The embankment on the left bank of river Pagli is being breached almost every year and raising of embankment necessary every year.
Madarihat Totopara Road	Titi Bangri	Madarihat Totopara	1.0	Extraction of dolomite from the Bhutan hills and deforestation in Bhutan causing excessive landslides and siltation at the downstream	Left bank and the road between Madarihat & Totopara gets cut-off even during normal flood. Spilling is a recurrent problem in this area affecting the lands and properties.
Chamurchi	Rehti Sukriti	Chamurchi Binanguri Army Cantonment	0.45	Quarrying and blasting in Bhutan hills aggravating the problem of landslides and other problems	The situation is aggravating gradually in downstream area and structures are likely to be affected.
Jaigaon	Hasimara Jhora	Jaigaon	1.0	Excessive deforestation in Bhutan hills and landslides therefrom	The road connecting Jaigaon to Phuntsholling gets delinked frequently, areas on both banks get inundated.

Based on field observations

5.4.1.5 Landslides

The mountainous upper catchments experience landslides which contribute substantial amount of silt to stream flow. Compared to the mountains in the Deccan plateau or central

India, the Himalayan ranges experience serious landslides. No systematic or reliable data are available on the extent of the problem and the amount of sit contributed from this source. With the increasing activities of road construction in the Himalayan region, road engineers annually face the land slide problems for clearing the debris and keeping the roads open (Sarkar, S., 1991;Starkel L et. al., 2000). Therefore, the volume of debris contributed by the slides along the Himalayan roads may furnish a first approximation of the silt estimates contributed from this source, though numerous landslides occurring in inaccessible areas will remain beyond any possible estimation. Under the circumstances, an effort may be made to give a partial view of the serious problem of land slide infesting the entire stretch of the upper catchments of the flood prone rivers of the Brahmaputra river systems. Due to its characteristic geological formations and being in the seismic region, the problem in the upper catchments is, however, quite complex. The contributory factors for the land slides in the region may be summarised as follows:

(i) The stresses set up in the rocks by the fold the thrust movements leading to deformation of original physical character as well as in jointing and shearing.

(ii) Erosion and chemical weathering which loosen up such strained rocks along the fracture and joint planes and gradually widen gaps between the planes.

(iii) High rainfall and lack of proper drainage condition which reduce the frictional resistance to sliding of the loose and firmer rocks alike, thereby increasing the chances of land slides.

(iv) Increasing deforestation and shifting cultivation (Jhum & un-terraced cultivation on steep slopes) cause intensive erosion of top spills.

(v) In a metamorphic country, there is often an alternation of hard compact strata such as quartzite and marble with slates and phylites. When such strata have steep dip, they offer suitable condition for rock slides and the harder strata slides over the softer rocks lubricated by moisture.

The eastern Duars is mostly spread over the areas situated at the foot of Bhutan hills, where bed-slopes of rivers and jhoras coming down from hills are flattened considerably all of a sudden. Naturally, such sudden flattening of bed-slopes causes normal deposition of silts and reduces discharge-carrying capacity of the river resulting change of rivers-courses as well as spilling over banks due to inadequate and reduced waterways. However, this process of normal siltation takes place slowly and the results are visible after lapse of a number of years.

Since slopes of Bhutan hills in this region are unstable, landslides occur frequently at different places. The situation is aggravated further when green cover of hill slopes is removed artificially by the inhabitants. The process of mining associated with blasting further reinforces and boosts up the possibility of occurrence of massive and frequent landslides. These land masses come down and cause considerable rising of river beds, due to accumulation of huge debris and silts, especially at the transition zone where steep slopes are flattened and at other upstream reaches.

5.4.1.6 Rapid urbanisation

Rapid urbanisation in the Jalpaiguri district is experienced since long back. Jalpaiguri town is a divisional town from the British period and the district as a whole is well connected with Bangladesh before partition. After independence the district witnessed huge infiltration from Bangladesh, it is most important factor for the rapid urbanisation in the district. The towns of the district is also very closely spaced like Jalpaiguri, Maynaguri, Dhupguri, Falakata, Birpara, Malbazar, Hasimara, Nagrakata, Goirkata, Binnaguri, Madarihat, Jaigaon and Alipurduar etc. other important factors are huge potential of tourism in the Duars region, development of Tea Gardens, bordering areas of Bhutan and Assam, normal population growth, and air force and army bases make rapid growth of urbanisation of the district.

This urbanisation process leads large scale deforestation because forest lands are been encroached by the people which enhance the soil erosion, bank erosion and other problems and ultimately encourage the flood problem. People also encroaches the flood plains and during normal floods the situation became vulnerable.

5.4.1.7 Shifting of river courses or avulsion

This is the most significant hazard of the district. Avulsion is often found in the foot hills and Duars area of Jalpaiguri district. Avulsion not only causes the floods of severe nature but also defoliates the flood situation and flood havocs of the district significantly. Shifting of river courses in the Jalpaiguri district is so often due to the rise of river bed levels, high deposition of silts and coarse materials in the river beds, soil erosion and landslides in the upper catchment of the rivers and bank erosion. Rivers are very closely spaced in the district, so the lateral gap of the rivers of the foothill areas is very small and the river coalesces makes the shifting quite normal. Shifting of the rivers creates prolonged flood condition and gave birth of the high magnitude of flooding and havocs. River Tista, Jaldhaka. Sankosh, Torsa and many other rivers shifted their channels in the past.

5.4.1.8 High intensity rainfall

High intensity rainfall is the mother of all problems particularly the flooding of the Jalpaiguri district. Sudden maximum downpour creates the situation of flood in the district. The nature of the flood is mainly flash flood. Cloud burst or maximum rainfall in a short span always aggravate the situation of flooding in the district since long past. The flood history of the district gives no clean conception of the cause that is high intensity rainfall or cloud burst is the main cause behind the major floods of the district. Floods of 1922 is due cyclonic rainfall in one week was about 10 times of the normal rainfall. Major floods of 1954, 1968, 1993, 1999 and 2000 all are caused due to unprecedented high intensive rainfall. Occurrences and distribution of high intensity rainfall has already been discussed in chapter III.

5.4.1.9 Construction of road and railway bridges

This is also a factor for the flooding in the district. The narrow road and railway bridges, spanning the rivers as well as the pillars supporting them, are always considered to be the barriers, interrupting natural load movement behaviour of the rivers. This often cause accelerated deposition at the bottom of the bridges and thereby, narrowing the outlets of the river gradually. Such constrictions, sometimes due more to the entanglement of uprooted trees to the voluminous flows of the flood, often multiply its effects many times damaging the bridges, human habitations and farm lands.

5.4.1.10 Continuous encroachment by the people

Huge encroachment of the forest land and flood plains mainly vulnerable areas of the district causes huge damage in the floods by the people day by day due to the increase in population, development purposes, infrastructural needs, tourism and for defense purposes huge encroachment is noticed. Encroachment of the forest land degrading the situation of soil erosion and large scale debris flow and encroachment in the flood plains restricts the river flow of the region. Sometimes in the monsoon period normal discharge causes flood because rivers are not hampering the habitation but the habitation disturbing the normal river flows.

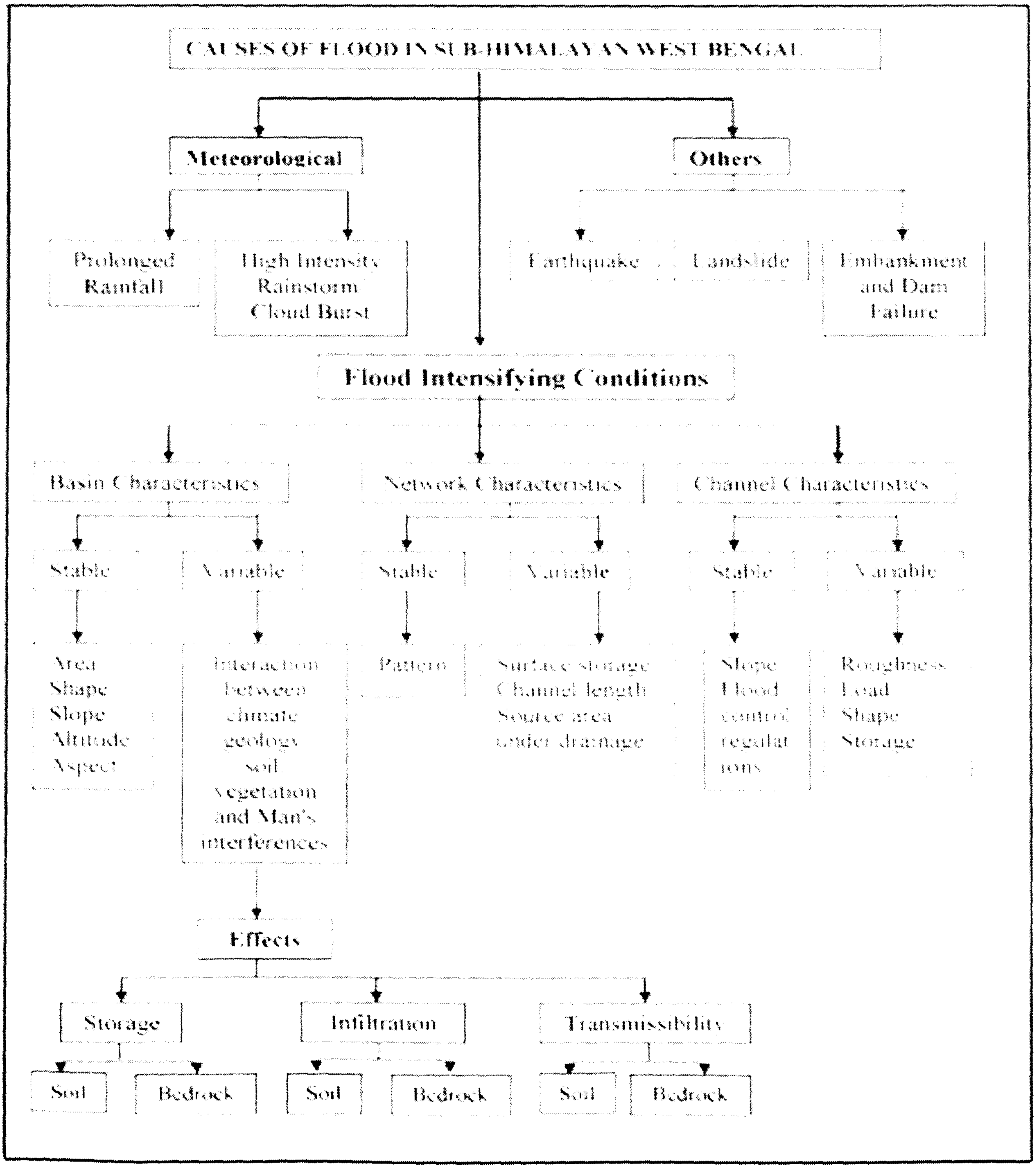


Figure 5.6 Causes of flood in sub-Himalayan Jalpaiguri district (Based on Sarkar, 2008)

5.4.1.11 High siltation process in the river beds

The entire study area is come under the periphery of hills, foot hills, alluvial fans and piedmont plains. It is the area where rivers are entering the plains from mountainous course, therefore high amount of silts and other bed materials are deposited by all the rivers of the district. As most of us know that rise in river beds decreases the river depth which ultimately leads to the spilling of the river banks at the time of high discharge mainly in monsoon season. This siltation process is very common and normal process of this region because most of the rivers enter in the plains in this district. After entering in the plains the velocity of the rivers decrease many fold for the flattened nature of the topography leads to the huge sedimentation of coarse variety is often found and sometime landslides in the upper catchments brings huge flow of the earth materials and these materials sometime block the channels like dams. When these dams are breached at the time of peak discharge causes floods in the surroundings. Siltation process is also responsible for the avulsion or silting of the river courses because large scale deposition of the debris in the river beds blocked the channels and increase the altitude of the river beds, mostly the rivers are carries world's highest sediment flow in the study area and channels find another route which causes avulsion and inundation of a new area.

5.4.2 Permanent causes

Among the permanent causes of flood at Jalpaiguri, environmental set-up of the catchment area, size and shape of drainage basins, fluvial dynamics of the rivers, stream networks and geometry of the channels etc. are more important. These along with the lag-time behavior of the rivers control the flood patterns of Jalpaiguri.

5.4.2.1 Topographical situation

Maximum altitude of the Jalpaiguri district is 1925 metre and minimum altitude is 41 meter the relative relief is 1884 meter. Maximum slope is 39.5^0 and minimum slope is 0.6^0 and average slope of this district is 19.78^0. And the altitude decreases sharply southward in the piedmont region of the district. The entire northern part of the district lies in the foot hills of the Himalayan range. This topographical nature is an ideal situation for the heavy sedimentation in the piedmont plains, flash floods in the high rainfall period and some water logging situation in the southern part of the district. Most of the rivers of the district are of high velocity and vulnerable for bank erosion, floods and sedimentation. So, the floods are so often and unpredictable in this district.

5.4.2.2 Drainage congestion

Here the network of the drainage is very high and the lateral gap between the two rivers is very less in this region. Only 3 to 30 kms are the lateral gap of the rivers in this district. So, rivers are very closely spaced which may create a problem of the river coalesces in the floods or heavy discharge in the rainy season.

5.4.2.3 Low lying or water logging areas

Low lying and water logging situation mainly in the southern part of the district cause prolong floods in this area. Here the slope and altitude are both minimum. So, the ideal situation of water logging is found in the southern part of the district.

5.5. Flood producing processes & impact of flood

The major rivers of sub-Himalayan North Bengal originated from Sikkim, Bhutan and Darjeeling hills (except Torsa which rises from Tibet). The rainfall is very copious being of the order of about 350 cm. on the average in a year ranging between 100 cm to 600 cm. The area lies in the seismic belt which was, by and large, undisturbed in the past. A condition of equilibrium was maintained in the area and the rivers were generally in regime state and hence, stable except in some years of exceptionally high floods. Very heavy precipitation for long duration in the catchment, synchronized with heavy local rainfall, causes enormous flood discharge in the rivers.

Landslides and floods are the major problems of the North Bengal situated in sub-Himalayan area. All major disasters have occurred due to abnormal rains in this area causing landslides in the gorges, through which the major rivers follow their course. These gorges are very deep and narrow. These consist of soft rocks which can't withstand high velocity during the rains. As a result, erosion occurs throughout the length of all these rivers and land occur fairly frequently. Due to these land slips, large quantities of detritus come down into the river, thus silting up the river bed in lower reaches. These land slips some time assume such magnitude as to block the waterway of the channel completely, forming temporary lakes. Ultimately the dam caused by these land slips, is itself pushed down, increasing the intensity of flood many times, by simultaneous release of water stored in the temporary lakes along with the storm water in the catchment areas of the rivers.

In the upper terrain, the rivers flow through the narrow gorges with high velocity carrying high silt load. In the plains, the rivers intend to accommodate the discharge as the longitudinal slope and the velocity of flood decreases to a great extent. This sudden reduction of velocity does not allow the heavy boulders, silt etc. to flow downwards resulting in the increase of river bed levels near one of its banks and tracing another course through a relatively deeper portion. This phenomenon is largely responsible for the change in the river course over a period of time.

With the increase of population and with improved communication facilities, there has been continuous encroachment of forest land. In additional there has been large scale deforestation, cultivation on steep slopes, uncontrolled grazing of cattle, extraction of forest produce by dragging on slopes causing aggravation of land slope and surface erosion. The wiping away of high river bank also causes overflow of banks even at low water levels and thereby diversion of flow through neighbouring deep water. In this process, channel happens to abandon the old course entirely.

The problems in the hills, where river flows in gorges so erosion of soil cover and land slips causing loss of agricultural area and forests. But the problem in the plains is extremely acute being erosion, avulsion and inundation of valuable agricultural lands, tea gardens, villages and towns. The inundation not only damages the crops for a particular season but also leaves behind large deposits of coarse sand making such land unfit for cultivation for quite long time. The large scale dislocation of vital communication links such as railway, national highways connecting Assam with rest of India, running East-west, is caused in almost all years due to flooding and avulsion of the rivers flowing north to south (Sarkar S., 2004).

Contributory factors for reduction in carrying capacity of rivers, thereby resulting floods and erosion are:-

i) Intensive top soil erosion and landslides in hills.

ii) Each year enormous quantity of silt and detritus coming down into the rivers in hilly areas are further carried down into the lower reaches and get deposited into the river bed in the plains, thereby constantly reducing the waterway of river. This deposition into the bed in plains is due to sudden reduction of velocity where the gradient of river bed suddenly drops from 40 m/km in hills to 0.70 m/km in plains.

iii) Due to reduction of velocity, the rivers, in turn, try to make up the waterway by eroding the banks. The rivers also widen with formation of shoals and braided channels.

iv) Human occupancy in the dry bed of river and in flood plain obstructs the free spilling and natural flow of river which elevates the river level.

v) Rapid urbanisation without scientific planning also cuts off the free spilling area.

vi) Waterway provided to some existing bridges of PWD and railway Dept. is quite inadequate to cope with the maximum flood discharge. This causes abnormal high afflux on the upstream of bridge and, as such, multiplies the flood problems to a great extent. The PWD bridge at Alipurduar has been found responsible for aggravating the flood havoc in 1993.

vii) Avulsion of one river into another one or even a tendency to avulse by way of erosion of banks and by wiping out vast tract of land with structures thereon also poses serious problems.

viii) Increasing indiscriminate deforestation creates ecological imbalance and multiplies the flood problems.

5.6 Flood prediction

Flood prediction is also known as flood estimation. Prediction using the information of meteorological, hydrological, and catchment to estimate extreme flooding condition of a particular river. Estimation of the flood is very much necessary for the design of structure such as flood embankments, dams, resources, bridges and culverts. This is also an essential input to the design of channel improvement schemes, aimed of increasing the flood carrying capacity of channels and to attempts to plan and mange land use in order to minimise flood risk and flood damage. Sometimes one can confuse with flood estimation and flood forecasting, the latter is essentially carried out in real time often of a very precise nature on the magnitude, depth, timing and duration of the forthcoming flood event. And flood forecasts are normally associated with appropriate tracing and evacuation procedure.

Flood prediction will depend on the rainfall data, discharge capacity and gauge levels. Flood prediction often helps in designing the protective measures and also largely influences the land use planning of the district.

5.7. Flood forecasting

Flood forecasting means prediction of how high a river or stream is likely to rise at a specific location and time. For issuing flood forecasts, the observation and collection of hydrological and hydro-meteorological data, flood meteorological data regarding general meteorological situation, rainfall quantity for the past 24 hours and heavy rainfall warning for the next 24 hours. The data transmission is done on real time basis from the hydrological and meteorological stations to flood forecasting stations through VHF/HF wireless sets at the data collection stations.

For real time issue of flood forecasts, telemetry based has been successfully installed by CWC in Mahanadi and Chambal rivers. In telemetry, the probe is located where the event to be measured is taking place. This differentiates telemetry from remote sensing whereas the probe is also located at a distance i.e., a radio reporting rain gauge is in the domain of telemetry where as a rainfall sensing radar is in the domain of remote sensing.

Recent advances in electronics have now made it possible to install a system which can collect data over a large area in the catchment and transmit this data accurately and quickly to a control station where the data is stored and analysed. Using only the rainfall data in the catchment, it is possible to operate a conceptual rainfall-runoff model to forecast the runoff at the site of interest.

In practice, runoff (or gauge) observations at number of key location will also be required to divide the catchment into convenient sized sub-catchments, and to correct the model status periodically. A telemetry based flood forecasting system consists of four main components:

FLOOD FORECASTING MODEL

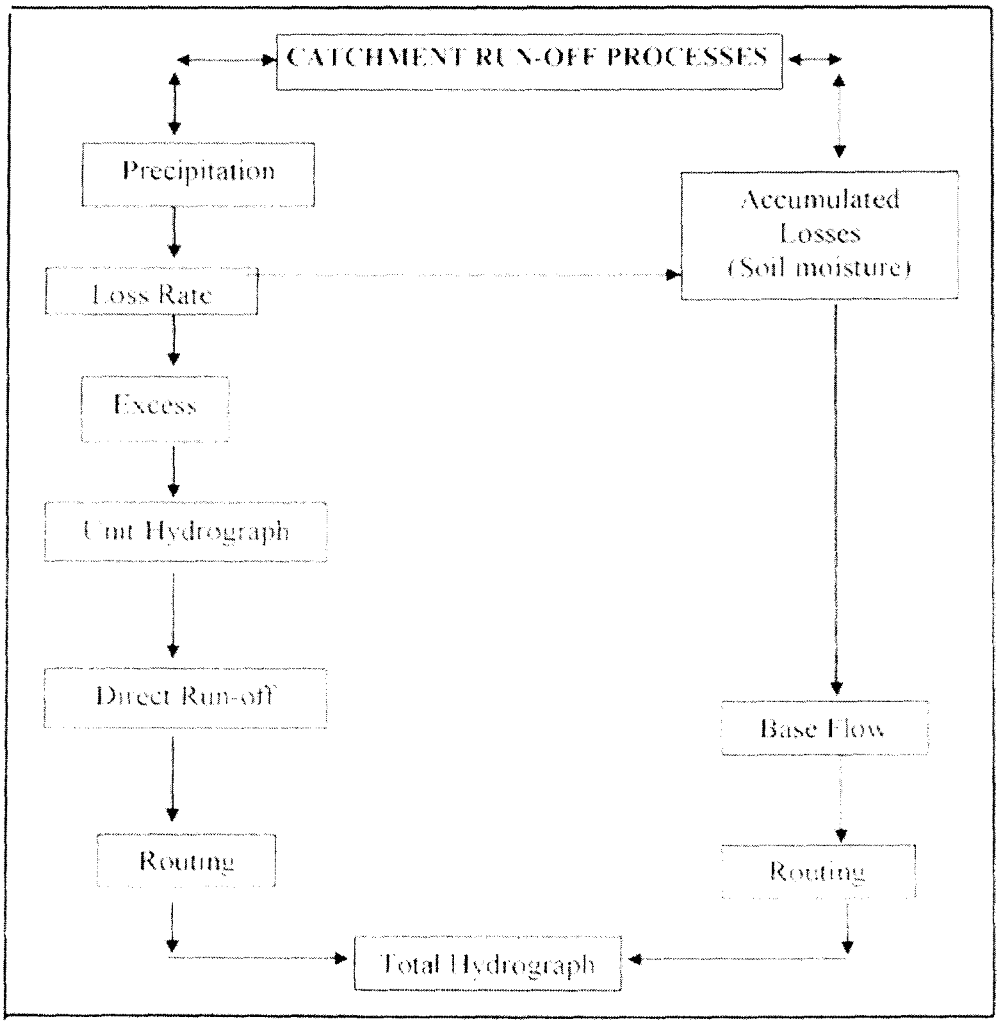


Figure 5.7 Flood forecasting model

Sensors and data loggers for data collection

- Wireless communication system for data transmission
- Computers for data storage and analysis
- Computer software for mathematical modeling

Data is sensed by sensors located in the field (Remote Stations) and temporarily stored in a data logger, also located in the field. A wireless communication device connected to the data logger transmits the data to the Master Control Station (MCS) where it is received in a computer and transmitted to concerned flood forecasting Front End Computer (FEC). The FEC makes a rough check on the data and detects whether the data as transmitted has been received correctly without any error. Then it makes further checks to determine whether the data is within reasonable limits with respect to time of the years, data received from that station a little time earlier and with respect to data received from other nearby stations. This process is called data validation. If the data does not pass the various tests, then the sending stations is requested to send it again. If acceptable data is not received after a reasonable number of attempts, then that particular data field is tagged as 'missing data'. The data so obtained by the FEC is sent to another computer for storage and analysis. In rare instances when the data is not received correctly, statistical procedures are used to fill missing data. The final data, received or computed is then stored in a permanent data base.

A mathematical model uses this data to compute runoff, flood levels etc. at various locations on the river. The model can also assist in reservoir regulation, canal regulation and general decision making which is largely a matter of software selection which can be easily upgraded from one level to other (figure 5.7).

5.8 Conclusion

Deforestation via-a-vis environmental degradation in the watersheds of the sub-Himalayan river indeed plays the decisive role in contemporary increased frequency and magnitude of hazards. Vicious cycle of degradation has already been established in the sub-Himalayan watersheds. Perhaps, the only possibility to save the habitable environment lies into the pro-active watershed management. It is thus, our imperative duty to inform the people living in threshold areas within the watersheds (prohibitive/restrictive zone) categorically about the hard reality of possible hardship during the different stages of watershed management processes.

Let us tell our people living in threshold areas (prohibitive/restrictive zone) categorically that you are living in an unsafe area and it is not possible to provide you security against possible flood. The land use pattern, house type must be suitable to cope up the possible threat. The traditional art and life style of ***living with flood*** must be adhered to. However, the life both human and animal along with movable property must be protected through the construction of Flood Shelter nearby preferably within the radius of 5 km (Sarkar, S. 2007).

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