RN-22

EFFECT OF CHANNEL PROCESES ON FLOOD ROUTING

SATISH CHANDRA
DIRECTOR

STUDY GROUP
A B PALANIAPPAN
S M SETH

NATIONAL INSTITUTE OF HYDROLOGY
JAL VIGYAN BHAWAN
ROORKEE-247667(UP)
INDIA

1985-86

CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Although a river occupies a small portion of the catchment, its role in shaping the landscape is enormous. The river and the adjoining plains and as a matter of fact, the whole catchment undergoes changes with time. Some of the changes are man induced. As a result, the same flood volume(caused by similar precipitation) occurred in the past does not behave today in the same manner as it did earlier. The planform might gets changed and severe aggradation/degradation might take place. These in turn change the nature of the flood flow. No systematic study on these aspects of flood movement in natural rivers could be found in the available literature.

In this study, three important aspects have been identified and the literature has been surveyed to review the effect of channel processes on flood flow and routing. They are: (1) resistance to flood flow, (2) general aggradation or degradation, causing the flood water level to change, and (3) Planform modifying the characteristics.

The stage-discharge relationships are important for discharge computations and some flood routing methods like Kalinin-Milyukov method using rating curves. The shape of the hydrograph also gets affected by channel processes. Both these aspects have been discussed in the report.

The Muskingum method of flood routing is used in many countries. This method uses the past flow records to arrive at values of two parameters. These parameters reflect only the river system existed at time of observation in the past

and as such cannot account for the changes that occurred/ would occur to the river due to various channel processes. Certain other hydrologic flood routing methods take the geometry of the river for establishing the parameters. For instance, the Muskingum- Cunge method account the plan area of submergence during floods and slope, the Kalinin-Milyukov method takes care of the volume of river reach involved in flood movement. These methods can be used to route the floods taking the effect of channel geometry into consideration to some extent. Hydraulic flood routing explicitly accounts for the channel geometry and hence may be preferred. However, available methods of computing the changes in geometry due to various channel processes are inadequate.

After studying specific cases of river changes the following main conclusions have been arrived. The river environment undergoes changes at various rates. The change might be seen in 10 years to 30 years. A single flood event could change the river drastically as seen in Rupicon river. In any case flood routing should take into account the effects in the parameters. Alluvial river models could provide a practical solution to this problem.

1.0 INTRODUCTION

A river channel at any single location reflects the geology, geomorphology, biology, climate and hydrology of a drainage basin (Allen,1985). They undergo continuous changes due to channel processes. The word process normally includes all of natural actions that produce the river system. The magnitude and frequency of runoff events can be a major factor determining the character of a river channel. For example, river channels characterized by high peak discharge can be very different from those characterized by a relatively uniform flow although both rivers may have the same mean discharge. All effects of climatic differences therefore should reflect in the changes of erosional and depositional processes. A comparison of geometry of perennial streams of humid and sub-humid regions with that of ephemeral streams of semiarid region demonstrate that significant differences exist. But these studies (Leopold et al,1964) are only qualitative. Tectonic effects are found in Iraq where Diyala River, a tributary of the Tigrus near Baghdad was altered. Modern flood and river control problems in Brahmaputra river are enhanced by these tectonic movements(Coleman, 1969). The following aspects are considered in this report:

1. Resistance to flood flow caused by bed forms
2. General aggradation or degradation causing flood water level to change in a river.
3. Plan form, which modifies the flood characteristics.

4. Stage-discharge relations, used in flood studies
5. Shape of the hydrograph

Hydrologic flood routing methods and hydraulic flood routing methods have been found in the literature. The adequacy of these models are also described in the section 8.

2.0 RESISTANCE TO FLOOD FLOW

An alluvial boundary is formed in cohesive or non-cohesive materials that have been and can be transported by the stream. The non-cohesive material generally consists of silt(0.004-0.062 mm), sand (0.062-2.0 mm) or any combination of these. An alluvial boundary can be moulded into many configurations by the flow as shown by Gilbert(1914). The movable alluvial boundary increases the complexity of analysis. Systematic study on resistance to flow was undertaken in U.S.Geological Survey by D.B.Simon, and E.V.Richardson(1962,1963). A complete documentation and description of all basic data collected from 1956-1961 by the USGS is available in their professional paper 462-L(1966). As a result of the above study, the following classification of bed configuration were made:-

1. Plane bed without sediment movement
2. Ripples
3. Ripples on dunes
4. Dunes
5. Plane bed with sediment movement
6. Anti dunes
7. Chutes and pools

In their original classification, they suggested 8 types of bed forms. These bed configurations are listed in their order of increasing stream power, which is expressed as the product of shear stress and velocity. This sequence is applicable for bed materials having d_{50} less than 0.6 mm For

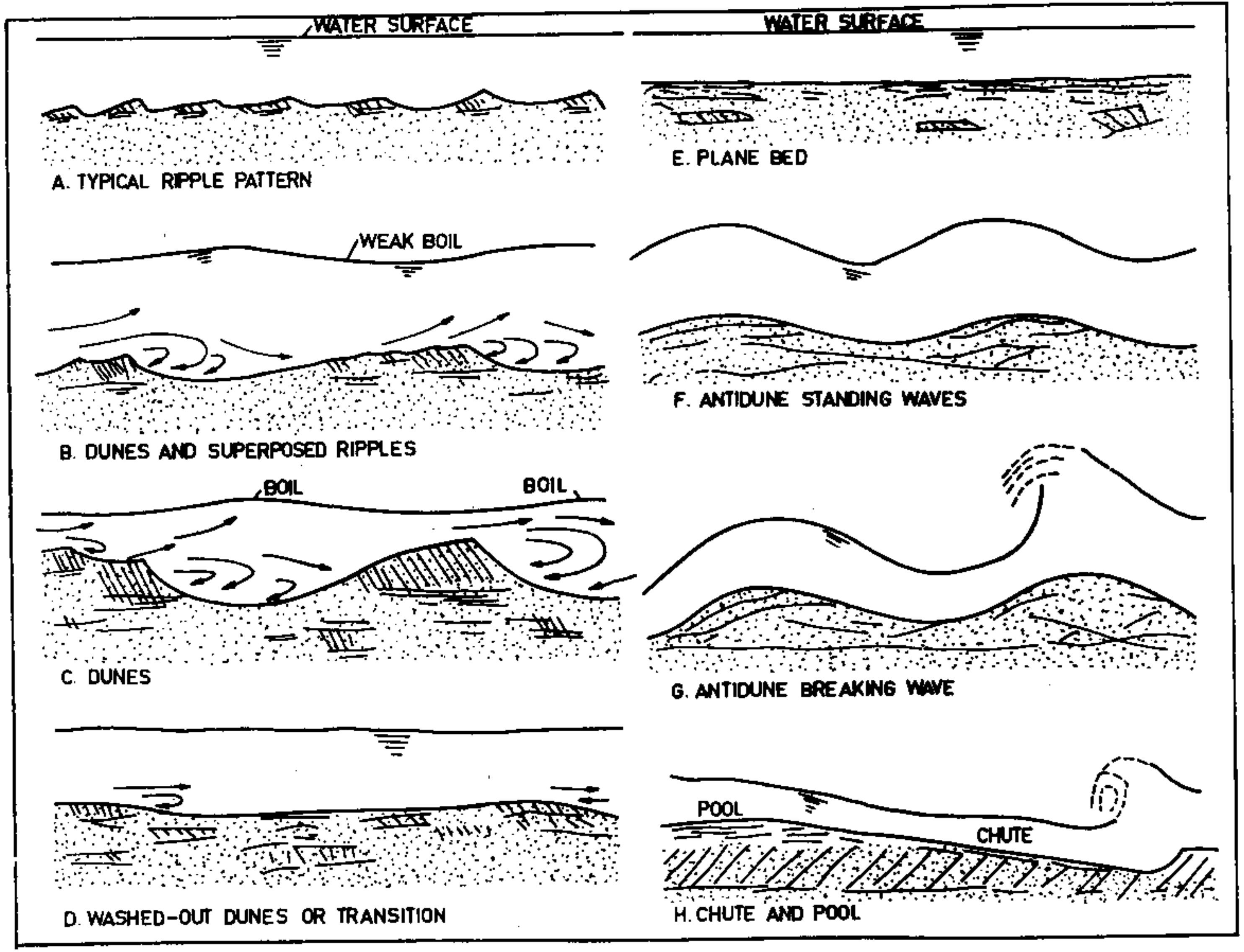

Figure 1 - Idealised bed forms of Alluvial Streams

material coarser than these ripples will not form. These forms are shown in Figure 1.

2.1 Plane Bed

Prior to the beginning of motion i.e. flow on a plane alluvial bed, the problem of resistance to flow can be successfully treated as one of rigid bed hydraulics. The beginning of motion is described adequately by Shield's diagram,although some deviations are noticed in the case of non-uniform sediment materials. The Manning's 'n' for no bed material movement appropriately lies between 0.012 to 0.014.

2.2 Ripples

These are small triangle shaped elements having gentle upstream slope and steep down stream slopes. Resistance to flow is larger and the Manning's 'n' is found to lie between 0.018 to 0.03.

2.3 Dunes

These are larger sized elements similar to ripples. The height of the dune varies between 6 cm to 30 cm and the length between 60 cm to 300 cm. (corresponding dimensions observed in the natural rivers are given in section 2.7). Manning's 'n' in this case varies from 0.02 to 0.04.

2.4 Plane Bed with Motion

With subsequent increase in stream power dunes might get washed and plane bed may result. However, for certain sizes of bed material this may not occur. In the case of plane bed there is a considerable material movement. The Manning's 'n' drops down and varies between 0.015 to 0.018.

2.5 Antidunes

These are defined as a strain of symmetrical sand waves which are in phase with a corresponding train of symmetrical water surface waves. Wave breaking can be noticed. Based on observations at the glass-walled section of the flume, Simon et al.(1961) mentioned that when antidunes broke, the water in the crest moved upstream, the water close to the bed almost ceased to move till they vanished and shortly thereafter, normal flow was resorted. The Manning's 'n' ranged from 0.010 to 0.013.

2.6 Chutes and pools

At very steep slopes, alluvial channel flow changes to what has been called Chutes and pools. Resistance to flow is very large. The Manning's 'n' varies between 0.02 to 0.04.

In view of the above classifications the flow in alluvial channels can be divided into two distinct flow regimes with a transition zone, viz., lower flow regime and upper flow regime.

Bed forms have several important effects. First bed forms locally distort the vertical velocity profile and reverse flow in the separation. Secondly, bed roughness is controlled by dune size rather than grain size. The form roughness affects energy loss and as a result also affects velocity and depth of flow. It has been noticed that ripples have an effect of doubling of channel length in the River Jizera in Czechoslovakia (Martinec,1972).

2.7 Field Observations

It has been observed that in the fall of the year the average stage of Missouri river between Sioux city, Iowa and Omaha decreased by about two feet (60 cm) and averaged depth by about one feet (30 cm). This change in depth occurred without a decrease in discharge. The only noticeable change was temperature. Sonic sounding of the bed profile showed that the bed configuration was changing dunes to plane. These observations are in good agreement with that of USGS experimental studies.

The storage of water caused by the breaking of antidune as mentioned in the section 2.5 could be seen as ruging of dis charge is alluvial streams with steep slopes. That is, with antidunes water is stored and released in the upper reaches of the stream in a random haphazard manner. But in some cases a systematic pattern of surges, as antidunes break, is also noticed.

3.0 DETERIORATION OF BED AND BANK

Lane(1955) includes an impressive list of examples of degradation or aggradation in natural streams. In many of the cited cases, the causes was induced by man. Very typical is the increase of sediment load due to hydraulic mining. The Sevendah river in Malaya, where the river bed rose 21 feet in the years 1922-1933 due to addition of sediment from the hydraulic mining of tin. The degradation of Colorado river downstream of Hoover dam is worth mentioning. The bed dropped by an average of about 15 feet in the vicinity of the dam. Livesey (1963) points out that tremendous difficulties are encountered in the field in predicting the rate of degradation as well as total degradation.

3.1 Accretion of River Beds

The rivers in Pakistan bring enormous quantities of debries from hills since ages and deposited the same in their basins. This continuous deposition has deteriorated the river channel due to accretion, resulting in higher flood levels and greater flood damages. The following table 1 provides some relevant extract as obtained from Choudry (1976).

Table 1: Average Annual Rate of Accretion

River	Station	Annual Rate of accretion (mm)
Indus	Kalabagh	16.46
	Mithankot	59.44

	Sukkur	46.94
	Kotri	18.59
Jhelum	Jhelum bridge	6.09
	Trimmu	58.52
Chenab	Alexandra bridge	20.12
	Rivaz bridge	41.45
Ravi	Shahdara	24.99
	Sidhnai	15.24
Sutlej	Islam	42.67

The Rio Grande at Albuquerque, New Mexico(Richardson, 1976) has aggraded its bed which is at present several feet above the old town streets. This aggradation is attributed to the decrease in peak discharge during spring runoff. The decrease is caused by irrigation development upstream. The smaller peak flows will not transport the sediments brought in by the tributaries.

The town Niebrara,Nebraska(Richardson,1976) had to be moved on to higher ground because the river bed has aggraded, flooding low areas. The aggradation was caused by backwater from Gavins point Dams on the Missouri river (U.S.A.). The backwater caused decrease in river slope, velocity and the transport capacity of the flow.

3.2 Degradation

The Nile river (Richardson,1976) as a result of high Aswan dam is undergoing changes. The degradation downstream is controlled by three diversion dams between high dam and

Cairo. There is ,however, a tendency for the Nile to establish a new meander pattern as the result of the change in discharge hydrographs.

Clear water diversion into South Boulder Creek in Colorado is another classical example. Originally South Boulder Creek was a small mountain stream. Water was diverted from western slope through tunnel to South Boulder Creek, increasing the flow by a factor 4 to 5. The additional water eroded the banks and degraded the channel. Degradation was as great as 15 to 20 feet before measures were taken to stabilize the Creek (Richaardson,1976).

Streams transporting little bed material load are relatively narrow, deep and sinuous. Low sinuosity streams have a gradient very near that of the valley slope and these streams have a low percentage of silt and clay in their channels. Depending on the type of rocks exposed within a drainage basin, the load of a river might change from gravel and sand to silt, clay etc. Rivers draining areas of relatively coarse or sandy sediment load and continued to flow on a slope which is today essentially that of the valley itself. An increase in sinuosity and the accompanying decrease in stream gradient reflect the need to dissipate the energy. The rivers with sandy channels have low sinuosity and the rivers with high silt-clay channels have high sinuousity. There are some exceptions to this conclusion. For example, streams draining the mountain meadows of South Park,Colorado are meandering although their bed composed of cobbles. Bed armouring is said to be the cause of such meandering(Schumm, 1971).

Changes in discharge and sediment load in a river may change the planform also. For example the highly sinuous relatively narrow and deep Cimarron river of Kansas(U.S.A.) was destroyed by the major flood of 1914. Between 1914 and 1939, the river widened from an average of 50 feet to 1200 feet and the entire floodplain was destroyed. Large floods moved considerable sand and caused this transformation. The precipitation data indicate that the years 1916-41 were generally a period of below average precipitation. Thus, during years of low runoff and high flood peaks, the Cimarron river was converted from a narrow sinuous channel characterized by low sediment transport to a very wide, straight river with large bed load. These changes were apparently the result of climatic fluctuations. Agricultural activities within the basin may have increased the flood peak and the sediment loads by destruction of natural vegetation.Towl (1935) reported that the length of the Missouri river from the mouth of the Big Siour river to the mouth of the Platte river was about 400 km. in 1804. In 1935, the length between these two tributaries was about 240 km. which is 40% shorter. Towl attributed this change to the cutting of timber on the flood plain and the great flood of 1881. Apparently, this and the subsequent floods straightened and widened the river. This transition caused 40% increase of gradient since over the shorted course the level difference remained constant.

3.3 Bank Erosion

The river bank is divided into two parts according to

United Nation's publication(1953). They are the upper part which is subjected to relatively strong currents and the lower bank which is foundation of the upper bank. The lower bank erosion is known as toe failure (Planiappan,1984). The banks are not subjected to erosion in all phases of different flood stages. Usually some portion remains unaffected by erosion and this portion is carved only during high or exceptional floods. As a result the upper bank has been divided into two zones by Sen(1966). They are : (1) free board zone which is affected only at high and serious floods,(ii) Fore shore zone which is covered by water by usual floods as shown in figure 2.

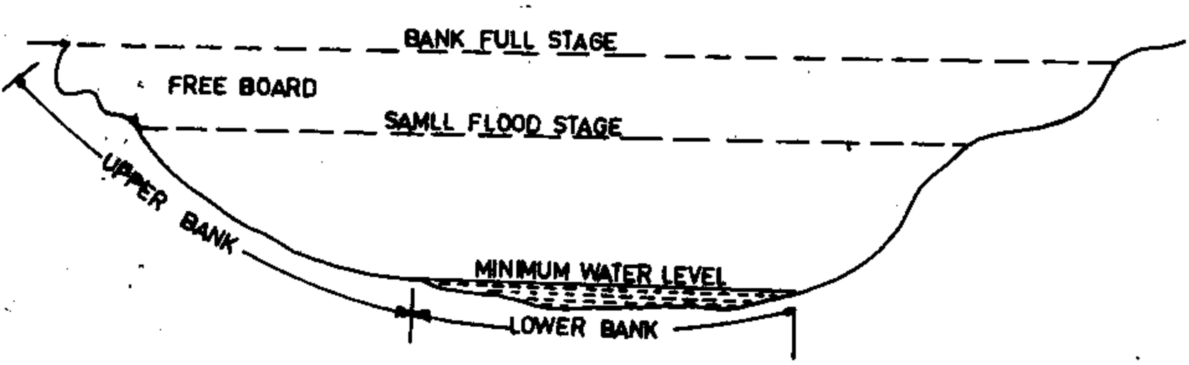

Figure 2 - River Bank Details

As far as lower bank is concerned toe erosion takes place at the minimum water level.

. It is observed that maximum flow velocity occurred close to the concave side of the meander curve during falling flood stage and the maximum velocity shifts towards the centre of the channel during the rising flood stages. Bank erosion is maximum during falling stages Mathes(1941). There are six causes of bank recession as per United Nations(1953). They are: (i) Removal of soil particles by currents or waves,(ii) Sliding erosion due to increase in slope,(iii) The collapse of upper bank material by toe erosion caused by eddies,(iv) sloughing when saturated with water (v) Sliding due to seepage flowing back into the river after the flood recession, and (vi) Piping in a sub-layer which removes sufficient material due to the movement of groundwater to the river. A study on the field observation on the river Bhagirathi can be seen in Sen (1966) and briefly discussed in section 7.5.

4.0 PLAN FORM

4.1 Braided Channel

A braided river is wide with multiple channel divisions as shown in figure 3 by islands or bars. Braiding is one of the way that alluvial rivers achieve equilibrium among the variable of discharge sediment characteristics and slope. Lane(1957) concluded that generally the two primary causes that may be responsible for braiding are: (1) the stream may be supplied with more sediment than it can carry resulting in deposition of part of the load, and (2) steep slope which produce a wide shallow channel where bars and islands from. Either of these factors alone or both could be responsible for a braided pattern. If the channel is overloaded with sediment, deposition occurs the bed aggrades and the slope of channel increases in an effort to maintain an equilibrium. As a result, velocity increase, multiple channel develop and cause the overall channel system to widen.

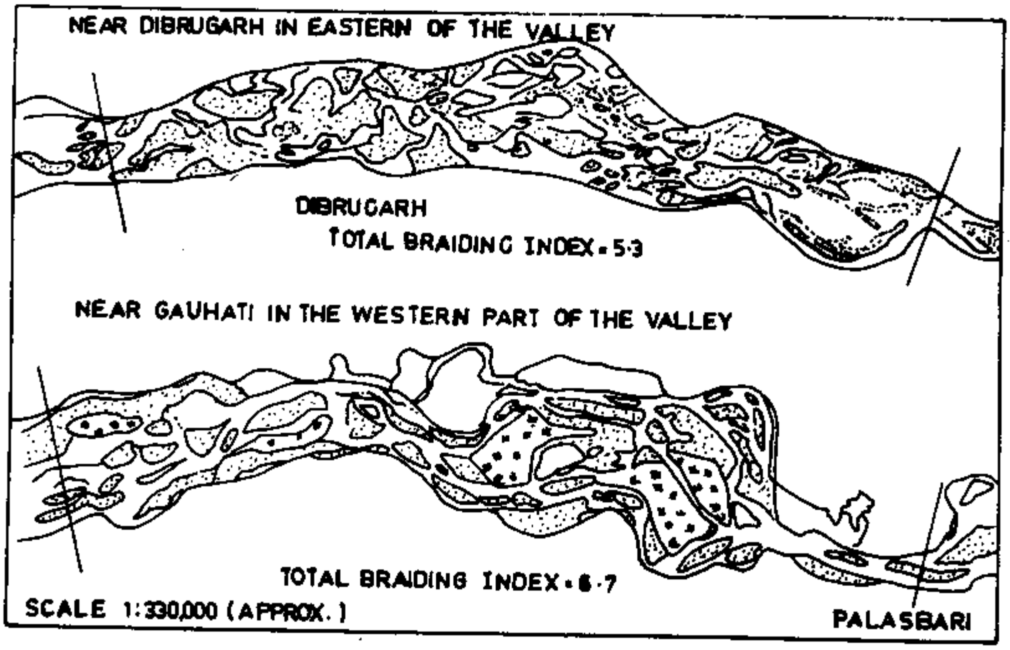

Figure 3 -Braided River

The multiple channels which form when bars of sediment accumulate within the main channel, are generally unstable and change position with both time and stage.

Another cause of braiding is easily eroded banks. If the stream banks are eroded, channel widening takes place together with islands. The braided stream is difficult to work with because it is unstable. It changes alingment rapidly. Even large flood would be shallow and unpredictable

4.2 The Meandering Process

Alluvial channels of all types deviate from a straight alignment. The thalweg oscillates transversely and initiates the formation of bends. The secondary currents, thalweg shifting, sloughing of the banks, non-uniform depsotion of bed load, debris such as trees etc. are causes for meandering of streams. As the meandering progress, the meander loops moves at an unequal rate because of unequal erodibility of the banks.

The word'meander'originates from the Meander river of South-west Turkey which clearly shows the winding course characteristics of a meandering river. The ratio between the channel length and valley length is known as 'sinuousity(r)'. In practice, a meandering river will not have a single sinuousity or follow a sine function. However, Inglis (1947) found the various wave length λ , as shown in figure 4 is proportional to the square root of the bankful discharge.

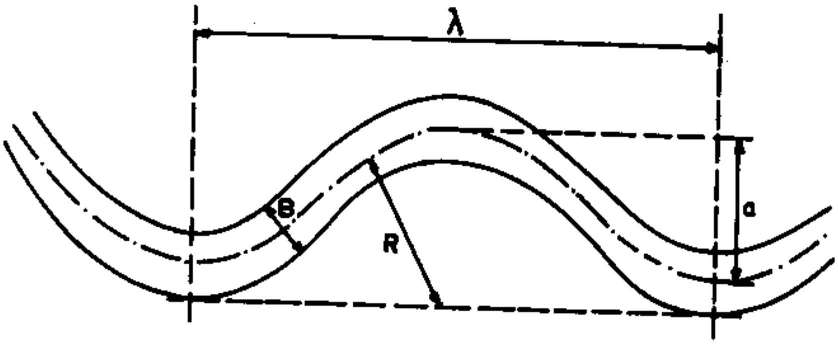

Figure 4 - Meandering River

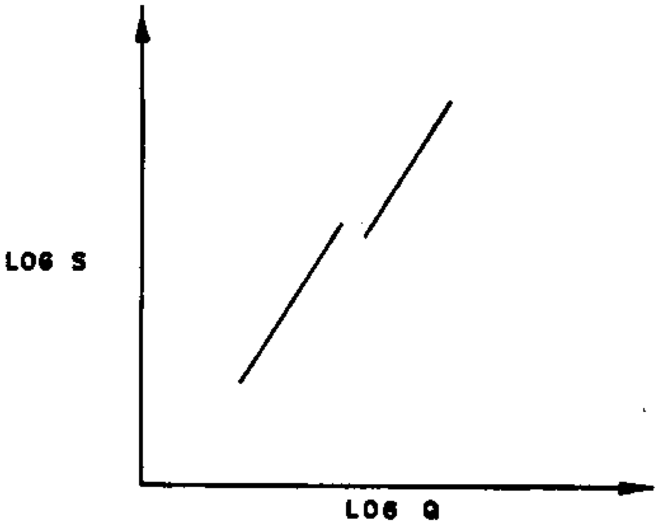

Figure 5 - Discontinuous State-discharge Relations

5.0 EFFECT OF STAGE-DISCHARGE RELATIONSHIPS

Computation of discharges for a given stage hydrograph is an important aspect in flood routing. This is because systematic stream gauging produces continuous stage measurements at high frequency that is suitable for flood routing. In order to convert them to discharge hydrograph, a stage-discharge relationship is adopted. In this section the effect of channel processes on the above relationship is given. The usual methods of determining discharges by such relationships fail to account underlying relation in alluvial streams. This is because in alluvial streams neither the bottom nor the sides of the channel are fixed.

Discontinuities occur in state-discharge relations, as shown in figures 5, as dunes are washed away (Dawdy, 1961). Bedforms in rivers with varying discharge are often out of equilibrium with prevailing flow. For example during the rising of flood peak, development of dunes lag behind the fast rising discharge and large dunes belonging to peak discharges may even occur on the falling limb. The dune steepness (height/length of the dunes or ripples) appear to adjust in such a way that they offer maximum resistance to flow

(Yalin(1977))and thus serve as an efficient energy dissipation mechanism.

Hence when rating curves are used for computation of discharge the discontinuities should be noted and incorporated properly in flood studies. Sometimes rating curves are used for establishing routing parameters for flood routing techniques like Kalinin-Milyukov method. It is important to know the discontinuity that occur due to channel processes while establishing the mean rating curve for use in flood routing.

6.0 EFFECT ON HYDROGRAPH SHAPE

The flood at a site is represented as a hydrograph of flow. This hydrograph, when routed through a river reach will get its shape shifted along the time scale and may get distorted involving reduction in magnitude of peak without violating the continuity of flow. The flood routing is done by means of certain mathematical formulae or algorithms. Physically this changes in the shape of the hydrograph are caused by different channel characteristics like flood plains, slope etc. In this section the effect of flood plains, meander etc. have been briefly discussed.

A flood hydrograph can be divided into three parts: the rising limb, the peak, and the falling limb.

6.1 The Rising Limb

This portion of hydrograph suggests that the drainage basin has a steep slope and a narrow flood plain which may be unvegetated. A uniform rise in the rising limb indicates uniform intensity of the rain over the catchment. For the same discharge the rising limb of the hydrograph corresponds to a larger sediment load, a higher velocity and a smaller depth of flow than that in case of falling limb(Morisawa,1968). A flat rise of the hydrograph indicates a flatter drainage basin slope or a dense growth of the vegetation in the basin or a broad flood plain, or a combination of these. A very flat, slow and uniform rise may indicate that the channel is fed mainly from ground water sources.

6.2 The Falling Limb

This part of the hydrograph is the result of withdrawal of water in excess of the inflow to the channel. This portion is less dependent on the time variations in the precipitation or infiltration, but largely dependent on physical features of the channel alone. High sinuousity of the channel slows down the process of recession because of low water velocity in such channels. A low rate of recession also indicates a high resistance to flow and low sediment discharge.

6.3 The Peak

A steep rise and a steep fall are associated with a very sharp peak. A slow rise and flatter recession are generally associated with a broader peak. Ground water fed channels may have broad peaks.

The shape of the routed hydrograph can be related to the characteristics like sinuousity etc. But their relation to the routing parameters are not yet known. Considerable research studies are needed still.

7.0 EFFECT OF FLOODS UPON STREAMS

The following examples illustrate the changing river environment due to flood. The examples are not intended to present a complete study on the changes caused. More extensive documentation can be seen from the different references cited therein.

7.1 Changes on the Eel River and Rubicon River

The climatic characteristics of the Eel river basin are highly conducive to fluvial erosion. Most precipitation and runoff occurs during winters months when evaporation is insignificant and the erosive power of the stream is maximum. The effect of floods upon streams channels and sediment source in this river basin has been well documented by Waananen et al. (1971). In December 1964, the Eel river experienced a flood with a return period greater than 100 years. Precipitation in some location exceeded 510 mm in 48 hr. period. This caused the river stages to rise by as much as 4.6 m above previously recorded stages. Stream bank erosion, land slides and sheet flow erosion produced tremendous sediment yields. For a 3 day period beginning on 22nd December,1964, the suspended sediment discharge on the Eel at Scotia,California was found to be 105.2×10^9 Kg. This exceeded the yield of 85.3×10^9 Kg. for the previous 8 years. Hickey(1969) found that as a result of the flood sediment disposition, the stream bed elevation raised to 1.8-2.4 m the vicinity of the confluence of the

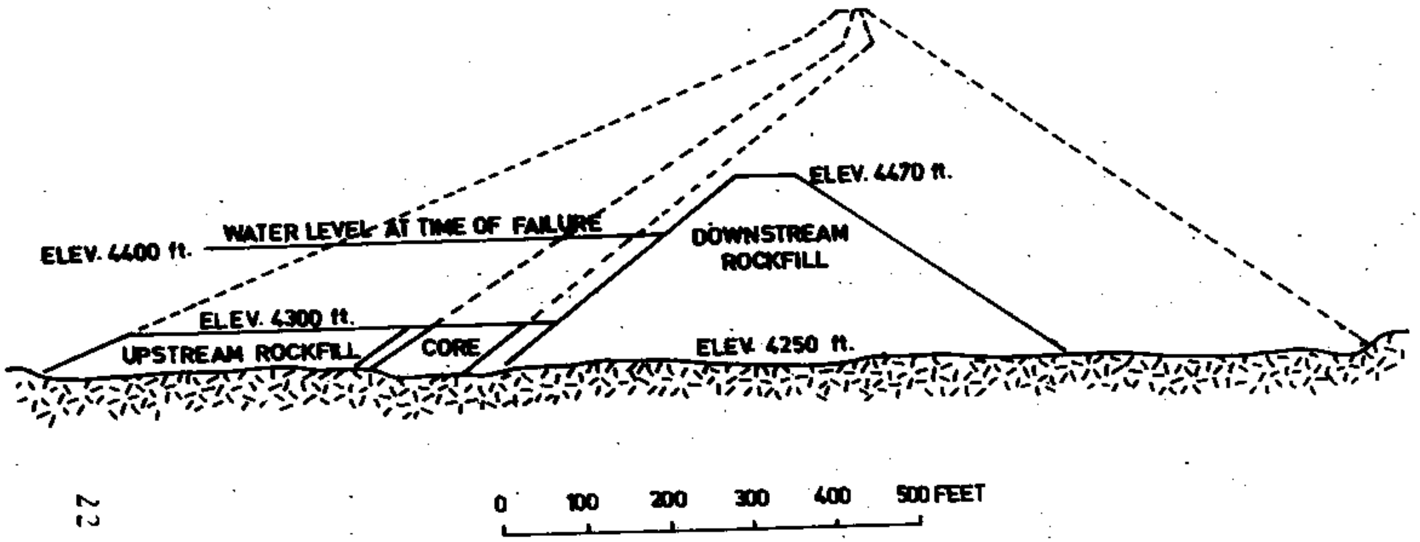

Figure 6 - Earth and Rockfill Dam on the Rubicon River

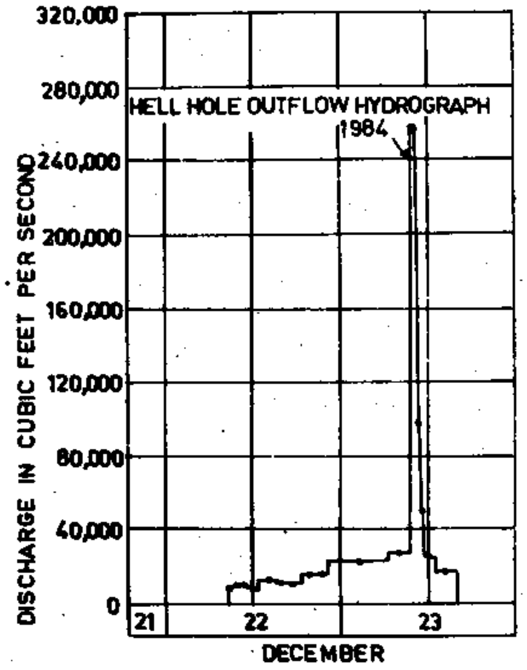

Figure 7 - Flood Wave experienced in Rubicon River

Middle Fork of the Eel and Black Butte river. He also noted that the deposition also continued during the next water year.

The Rubicon and American rivers drain a part of the western flank of the Sierra Nevada in California. The Rubicon rises north east of Pyramid Peak in Eel Dorado county at an elevation of 8700 feet above mean sea level. A torrential rainfall of 22 inches in 5 days occurred in December,1984. There were no meteorological indication that such an unusual storm would occur. All precipitation occurred in the form of rain. This caused heavy runoff from storms of late December. The rainfall in the month of November maintained high soil moisture providing a rapid runoff. Further, the low temperatures of the winter caused freezing of the ground at the higher elevations. The Rubicon river experienced such a huge flood third time in 9 years. There are no concurrent hydrographs for any of the three major floods at successive gauging stations on the Rubicon river main stream and hence no flood routing procedure was used to compute hydrographs(Scott,1968).

The Hell Hole dam situated on this river is a rockfill dam as shown in Figure 6.

Once overtopped the loose rockfill was rapidly reduced and the surge was expelled in 1 hour at an average flow of 7300 C.mecs. A massive surge as shown in Figure 7 begain its passage through uninhabited canyon.

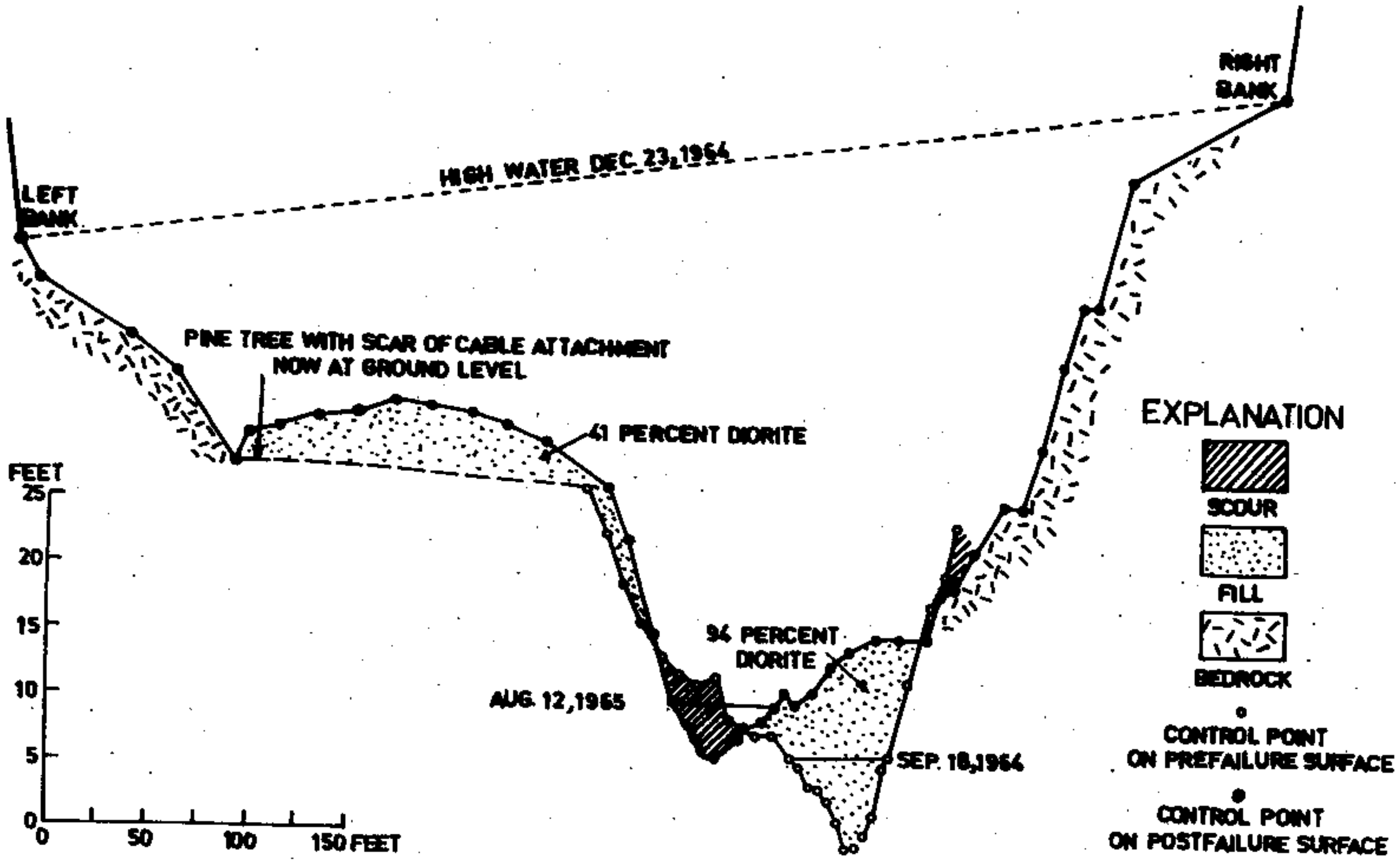

Figure 8 - Cross-sectional change after the flood in Rubicon river

It has been reported that a slow initial rise followed by a terrific amount of debris followed by the wave rising at about 60 cm per minute occurred. Four of the 5 downstream bridges collapsed. Average velocity of the wave was 6.7 meters per second over the entire route sedimentaty deposits in and along the channel were severely eroded by the surge.

Erosion of terrace gravel was mainly due to lateral cutting than scour. Only a minor amount of bed rock removal occurred. Most of the seciment material was derived locally with slumping of boundary terrace deposits. These were introduced apparently into the flow on the receding stage when competency was continuously decreasing. Therefore, for more material was supplied than the channel could transport. Much of the extremely coarse material supplied from the sides of the channel was either not moved or moved only short distances. Thus the chief effect of this surge is to introduce coarse sediments to the active stream channel with a net aggradation in the thalweg. A 'V' shaped channel was modified to a 'U' shaped channel as shown in Figure 8.

Nearly flat topped berm occurred continuously on both sides of the channel in the upper most reaches but downstream they are confined to protected areas behind bed rock projections or inner banks of the bends. Berms composed of rockfill derived at the dam site were seen until 15 km from the dam site. The berm surface usually slopes gently towards the present channel and where berms are present on both sides of the channel they occurred at approximately the same level. It is also noticed that the coarsest detritus at or near the surface. This reverse grading of deposits relates to the depositional dynamics possibly to the dispersive stress forcing large particles to the surface during movement, rather than coarser particles remaining a lag deposit after removal of fines.

In the reach immediately downstream from the dam, coarsest debris occurs in the center of the channel. Through the middle of the area of berm formation, the pool-riffle pattern becomes more pronounced. The terrace like berms are analogous to common alluvial terraces formed by channel aggradation followed by incision of a lower channel. The terrace like berms were formed by a single flood event and that the bed material is almost entirely of boulder size. Thus once deposited, the berm would be unlikely to be eroded at a lower water level. This acts as an armour layer. Macroturbulent conditions transported boulders in suspension well above the berm surface. The material composing the berms however was deposited from the bed load, which locally moved as thick subaqueous debris flows or a series of gravel waves. The top of the continuous berms may represent the approximate level of bed load flow or wave movement attained in the main channel rather than any static aggradational surface. The berm surface was continuous across the channel at one period during the surge. Bed load movement may have been continuous in the center of the channel and, as the material moved out of the reach, the present low water channel could have been left as basically a depositional rather than an erosional feature. On vegetated banks, downstream, discontinuous ridges of sand formed in areas of low velocity. Further downstream the surge caused terrace like berms with normal alluvial gravel.

The sequence of berms suggest that the movement of bed material was episodic in response to a single flood wave length the failure of the structure was gradual and continuous.

The single flood event has resulted in the drastic change in bed and the shape of the river. This gravel/boulder bed effect is very different from the earlier bed to the floods. Bed sediment movement of the river would reduce drastically at these locations. These are to be taken into account while routing the floods in the future.

7.2 The Kankai River

With the assistance of the Asian Development Kankai project has been implemented in Nepal in 1979. Because of the interaction of floods and channel processes the river bed degraded and the banks erosion took place. The hydraulic structure failed. Some studies on design aspects have been carried out by Nippon Koei Co.,Japan. However, the complex interactions showing the effect of channel processes have not been studied.

7.3 The River Kosi

The Kosi is well known for its shifting and the flood problems. Since 1731 when it was said to be flowing close to Purnea, it has shifted westwards through a distance of 110 km. to its present position. The attention to its fast changing course was first drawn by Holmes (1965).

The river rises in Tibet and after traversing through Nepal and India for about 725 km. distance it joins the river

Ganga at Kursela in North Bihar as shown in Figure 9

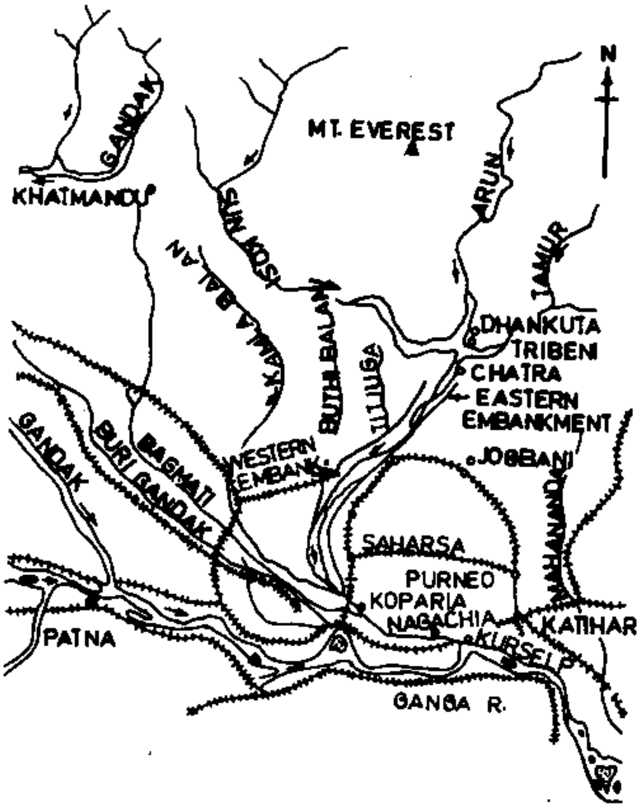

Figure 9 - The Kosi River Basin

The catchment area of the Kosi is approximately 59,300 sq.km. The maximum and minimum discharge are 26,300 cumecs and 283 cumecs respectively. The annual sediment load is 95 million m^3 The Kosi river bed is bouldery in the Himalayas. Further downstream, the bed is sandy. During floods (S.V.Chitale, 1984) the river occupies the entire width and forms a very wide and shallow section. The Kosi is known to have shifted 110 km in about 250 years. In order to keep the river confined embankments were constructed. The barrages have also been constructed to provide relief. However, because of the excessive sediment load the river bed aggradation is inevitable. Barrages however reduced aggradation to some extent but caused the same at

Table 2 : Rise of River Bed Level to Achieve Stable Slope and Period required for the Kosi River

No. of Reach	From To	Length of reach in Km.	Present High Flood level(HFL)	High Flood Level According to stable slope of 0.45m per km.	Rise in (m)required to come upto stable slope of 0.45 m per Km.	Average rise over the reach in (m)	Rate of rise experienced between 1963 and 1974 in mm per year	Number of years required for river bed to come upto final stable slope of 0.45 m per Km.
	Dagmara		62.00	81.72	44.50			
IV		34				31.3	18.6	1680
	Supaul		48.35	66.47	18.07			
V		40				13.1	63.5	203
	Mahesi		40.35	48.47	8.12			
VI		25				4.1	120.3	34
	Koparia		37.22	37.22	0.0			

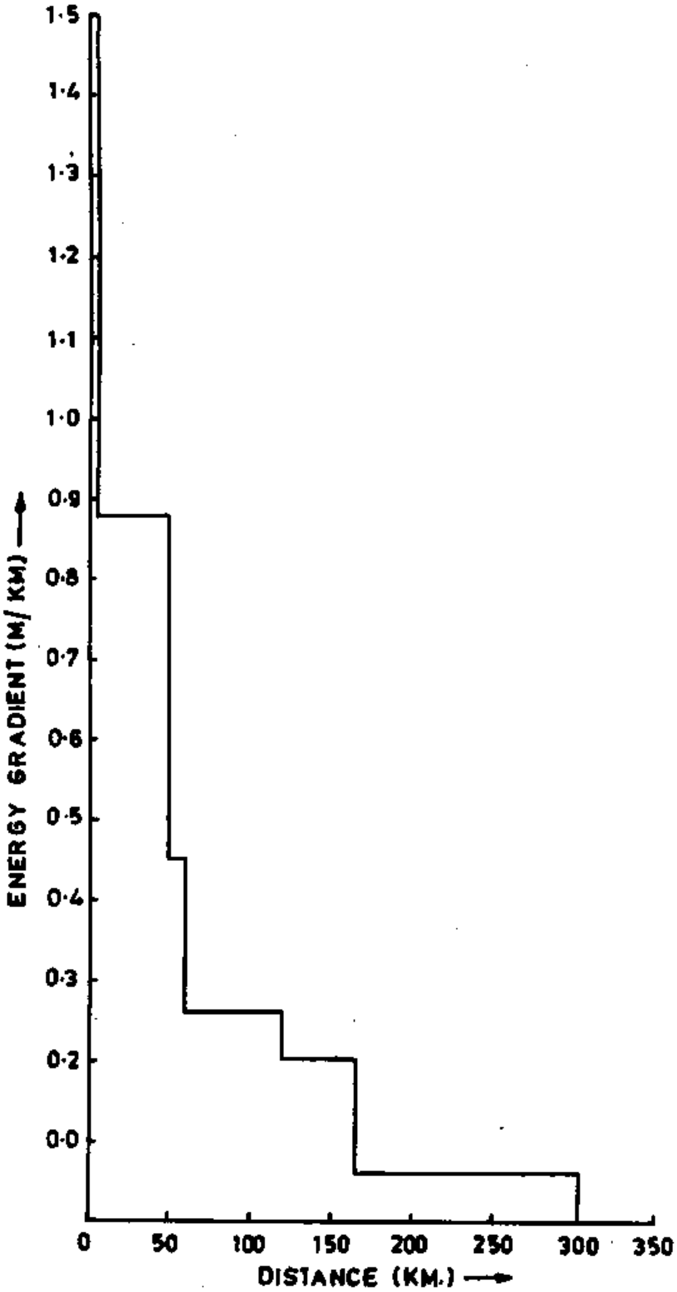

Figure 10 - Flood Slope of River Kosi

upstream. The continuous rise of bed levels cause rise in the high flood level endangering the embankment. The Table 2 gives the estimates of the bed levels and flood water level as provided by S.V.Chitale(1984).

The river Kosi has a steep gradient of about 1.5 m per km. in the gorge upstream of Chatra. From Chatra to Bhimnagar' where a barrage has been constructed' under Kosi project the river has an average flood gradient of 0.873 m per km.(Sanyal, 1980) in a 42 km. reach. Downstream of the barrage the flood slope considerably flattens to 0.455 m per km. Flood slope of the river Kosi corresponding to 4000 m^3/s as given by Sanyal is shown in Figure 10. This rapid change in the gradient of flood slope in a comparatively short distance is attributed by Sanyal to the special characteristics of Kosi.

Due to these special aspects of Kosi the usual flood routing methods can only be a gross approximation and will not be suitable. Mathematical models for alluvial rivers are to be taken into consideration. But yet as on today no model available in the literature can solve the problem. Since floods with a breach of embankment would be disasterous, solution to these problems is an urgent need of the country.

7.4 The Brahmaputra River

This river originates in a great glacier mass in the Kailas range of the Himalayas in South West Tibet at an elevation of 5300 m and flows through China, India and Bangladesh for a distance of 2880 km before draining into the Bay of Bengal. The Brahmaputra covers an area of 5,80,000 Km^2. In Assam, the

Brahmaputra flows in a highly braided channel characterized by the presence of numerous bars and island as shown in figure 3. Most of the bars are transient in nture and changes their location and also changes their shape. They are submerged during high flows in the summer. The hydrologic regime of the river responds to the seasonal rhythm of the monsoons and to the freeze, thaw cycle of the Himalayan snow. Nearly 80% of the annual flow occurs in the rainy season (May through October). The river carried heavy sediment load. The banks of the river are highly fraiable. Coleman(1969) observed the bed forms ranged from few centimeters to 15 m in their height. Aggradation after earthquake was severe. The flood discharge spills and inundates large area since flood level rises with aggradation. As a consequence stream bank erosion is also noticed.

With the present days technology the floods in this river can not be routed taking into account the various channel processes.

7.5 The River Bhagirathi

This is an important distributary of the Ganga. It is an old river and is a right arm of the river Ganga and flows towards south into West Bengal. This river joins with Jalangi and gets the name Hooghly.

The lower Bhagirithi has been studied by Sen (1966) and Basu et al.(1970). The details of the field survey etc. are available with the River Research Institute, West Bengal. The valley is nearly rectangular as shown in Figure 11 and has an area of 466 km^2. Flood water can move easily towards east of the river

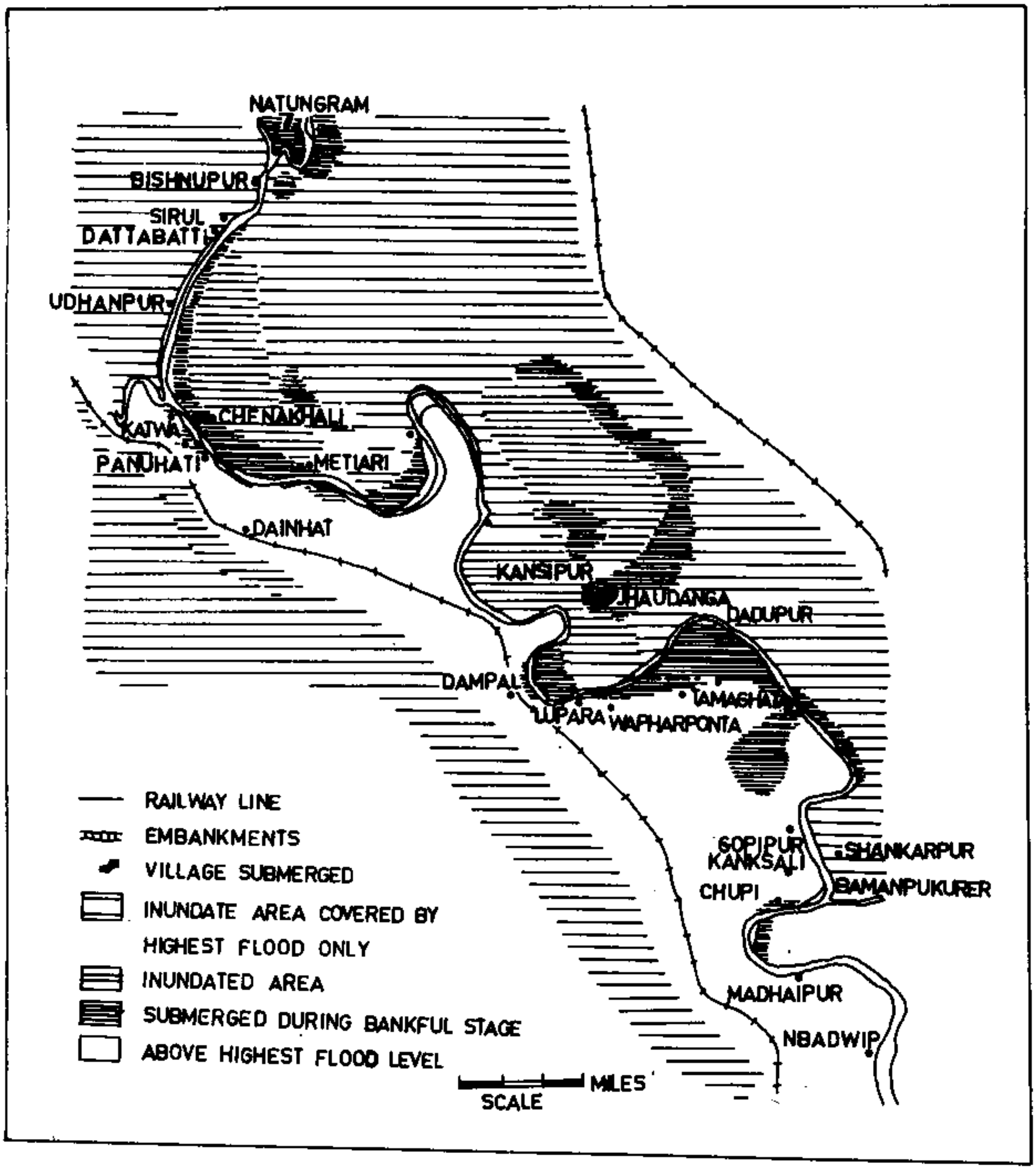

Figure 11 - Lower Bhagirathi River

than the west. However, at large floods the entire region is submerged. In the olden days the discharge of the river Bhagirathi in different months of the year were much more than those of recent years. The single important cause behind this reduction in the amount of discharge is the gradual reduction of carrying capacity of the river. At the offtake the sand deposits acts as a barrier to the usual supply from parent river Ganga.

The general tendency of the river is to shift towards west. The magnitude of meander was said (Sen,1966) to be normal in the past and this was probably because of high discharge. But later meanders became severe. Because of human interference like embankments changed the river course unnaturally as shown in figure 11.

Because of the special changes in the river characteristics the model calibrated with the earlier floods could not be used.

7.6 The River Manali

This river rises in the Western Ghats in Kerala. After meandering about 40 km. it joins Kurmali river to from Karuvannoor river and finally drains into the back waters. The river is ephemeral. During June to September heavy rains of south west monsoon the river is flooded every year. The river has a dam at Peechi which is about 20 km. from Trichur, and the river is used for navigation and other purposes. Due to the meandering characteristics the flood routing parameters needs up dating every time.

8.0 FLOOD ROUTING METHODS

Flood routing is recognized as a procedure used to determine the hydrograph at one point on a stream from the known hydrograph at an upstream point. The hydraulic methods, the hydrologic methods are two major class of routing methods. The hydraulic methods are based on solution of the basic differential equation for unsteady flow. The hydrologic methods make approximations to these equations.

Numerous hydrologic methods of flood routing have been delveloped. For details any standard text book on hydrology may be referred. The Muskingum method is popular. This method uses past flow records and determines the routing parameter based on the observed hydrograph. These parameters are satisfactory for the floods observed in the river environment in which they have been observed. But the river continously undergo changes and hence they do not provide adequate ways of accounting the changes in the flood routing. Certain other hydrologic methods take the channel geometry into consideration to establish the parameters. The Muskingum-Cunge method uses information on plan area of submergence during flood movement and the bed-slope. The Kalinin-Kilyukov method account for the volume of water in the river reach and the rating curve alongwith bed slope. These methods may be preferred to Muskingum methods.

Hydraulic methods directly uses the channel geometry where as the former methods try to reflect them in the routing parameters. Hence they can account for the changed river environment while routing.

In either case the determination of changes caused due to channel processes is necessary. The methods for the above are still inadequate.

9.0 CONCLUSIONS

Natural processes and man made changes alter the river environment affecting the flood flow. Large and rare floods also bring in a total change in the river bed and planforms as seen in Rubicon river. These changes may take place in a short spell of time or over a long period. The model parameters calibrated using past flow records cannot be used if appreciable changes in the river is noticed.

The resistance to flow increases as the bed form height increases. The bed forms are seen to vary from plane bed to ripple and then dunes before being washed away by the flow. The variation in the Manning's 'n' is enormous that flood routing model cannot have a constant roughness factor. This can be solved by using a water and sediment routing model with variable roughness factors.

The planform is linked to the total sediment that the river carries. The planform changes affect both travel time and attenuations. But their effect on routing parameter is yet to be studied.

In some flood routing methods like the Kalinin-Milyukov method rating curves are directly used for establishing the routing parameters. The stage-discharge relationship in a river is affected due to loose boundary of the channel. It affects flood flow computations and needs an attenuation.

The shape of the flood hydrograph has been discussed with special reference to channel processes.

It has been seen that hydrologic methods like

Muskingum-Cunge,Kalinin-Milyukov methods may be preferred to Muskingum method. The former methods can take the information on channel geometry. The hydrolgic methods try to reflect the effect of channel geometry through the routing parameters. But hydraulic methods uses the information on the geometry of the river directly and hence may be preferred to hydrologic methods, while routing floods.

However, the methods for the determination of the changes caused due to channel processes are at present inadequate. They need further studies. Each of the aspects described in this report needs further research alongwith field observations and studies for evolving better flood routing methods accounting the channel processes.

REFERENCES

1. Allen,J.R.L.(1985),' Principle of physical sedimentology', George Allen and Unwin,London.

2. Basu,S.R. and Kar,N.R.(1970),' Meandering,migration and alluvial terraces in lower Bhagirathi valley,West Bengal', in Indian Journal of Power and River Valley Development, Jan.,pp.29-39.

3. Bruk,St.,(1973),' Variation of river plan forms(braiding meandering,alluvial fans)', in Int.Seminar on Hyd. of alluvial streams , New Delhi,CBIP,Vol.1,Lect.No.8.

4. Chitale,C.V.(1984),' Kosi-The problem river of North Bihar',J.Irri. and Power,CBIP,Apl.pp.197-202.

5. Choudry,W.M. and S.M.Ayood,' Flood control in the province of the Punjab(Pakistan)', Symp. on Inland Waterways for navigation,Flood control and Water Diversion,Vol.II, ASCE,pp.1071-1093.

6. Coleman,J.M.(1969),' Brahmaputra River: Channel processes and sedimentation', sedimentary Geol.3(213),pp.129-239.

7. Dawdy,D.R.(1961),' Depth discharge relations of alluvial streams-discontinuous rating curves', USGS,Prop.paper No. 1498-C,Washington D.C.

8. Gilbert,G.K.(1914),' The transporation of debris by running water', U.S.Govt. Printing Office, Washington D.C.

9. Gowswami,D.C.,(1985),' Brahmaputra river,Assam, India: Physiography,basin denudation and channel aggradation', Wat.Reso.Res.Vol.21,No.7,Pages 959-978.

10. Hickey,J.J.(1969),' Variation in low-water stream bed elevations at selected streams gauging stations in north western California', Water supply papers 1879-E,USGS Washington,D.C.

11. Holmes,A.(1965),' Principle of physical geology', English book Society and Nelson,London.

12. Inglis,C.C.(1947),' Meanders and their bearing on river training', Inst.Civil Engr.Maritime and Waterways,paper No.7.

13. Lane,E.W.(1955),' The importance of fluvial morphology in hydraulic engineering',Jour.Hy.Dn.,ASCE,Proc.Vol.81.

14. Lane,E.W.(1957),' A study of the shape of channels formed by natural streams flowing in erodible material', U.S. Army Dn., Missouri River Corps of Engr.Omaha,Neb.MRD, Sediment Series No.9.

15. Leopold,L.B., M.G.Wolman and J.P.Miller(1964),' Fluvial processes in geomorphology',Edit.Freeman San Francisco/ London.

16. Livesey,R.H.(1963),' Channel armouring below Fort Randoll Dam', Federal Interagency sedimentation conference,Jackson, Mississippi.

17. Mathes,G.H.(1941),' Basic aspects of meanders',Trans.Am. Geo.Union,1941,22,p.632.

18. Madan,M.G.(1972),' River classification by photos and maps', thesis submitted in partial fulfilment of the degree of Master of Science,Colorado State University,Fortcollins.

19. Morisawa,M.(1968),' Streams: Their Dynamics and Morphology', McGraw Hill Book Company,New York.

20. Martinec,J.(1972),' Comment on the paper on river meander', by Ch.T.Yang,Journal of Hydrology,15,249-251.

21. Richardson,E.V. and D.B.Simon(1976),' River response to development', symposium on Inland Waterways for Navigation Flood Control and Water Diversions,Vol.II,pp.1285-1300.

22. Sanyal,N.(1980),' Effect of embankment of river Kosi', Proc. of the Inter.Workshop on alluvial river problems, held at Roorkee,p.5-55 to 5-62.

23. Schumm,S.A.(1972),' River Morphology', Dowden Hutchinson and Ross Inc., Stroudsbur Penn.(Bench Mark paper in Geology).

24. Schumm,S.A.(1971),' Fluvial Geomorphology: The historical perspective', in River Mechanics,Vol.I,pp.4.1 to 4.29 Edt.by H.W.Shen,Fort Collins,Colorado;U.S.A.

25. Scott,K.M.(1968),' Flood surge on the Rubicon river, California-hydrology,hydraulics and boulder transport, USGS,Prof.paper 422-m.

26. Sen,S.(1966),' River curves and their forms II Bank Erosion', In Indian Jour. Power and River Valley development Sept.p.23-26.

27. Simon,D.B. and E.V.Richardson(1961),' Forms of bed roughness in alluvial channels', Proc.ASCE,87,HY3,paper 2816, 87-105.

28. Towl,R.N.(1953),' The behaviour history of the Big Muddy', Eng.News Record,Vol.115,p.262-264.

29. United Nation(1953),' River Training and Bank protection - A flood control series No.4.

30. Waananen,A.O.,D.D.Harris and R.C.Williams (1971),'Floods of December 1964 and January 1965 in the far western states', Water supply paper 1866, Washington,D.C.

31. Yalin,M.S.(1977),' Mechanics of Sediment Transport', Pergamon Press,Oxford.