

## Chapter 2

# Channel Forms and Patterns

**Abstract** *Channel forms and patterns* are important determinants of ease of movement of water and sediment and immediate clearance of materials from up slope. *Twenty five (25) cross-sections* have been drawn along the lower reach of the Rupnarayan River, by measuring river depth using *Echo Sounder* and collecting staff readings using leveling instrument, to understand the channel forms and patterns. Most of the cross-sections, except two (at Kolaghat-AA' and Geonkhali-YY') are *asymmetrical* in nature. Depth is more near Kolaghat (maximum 10.5 m) and Geonkhali (maximum 11.5 m) than the middle of these two extremes (<8 m). Most of the portions near two banks and around the *mid channel bar* have the depth less than 2 m. *Width-depth ratio* is less near Kolaghat (38.09) and Geonkhali (130.43), but in the middle portion width-depth ratios are more than 300 and becomes 1111.10 in cross-section QQ'. Sudden expansion and widening of the channel near Kolaghat (width is 400 m at AA', 1650 m at BB', 2900 m at CC') leads to *flow separation*, reduction of energy and deposition of sediment (during low tide) and near Geonkhali sudden constriction (bottle neck shape) of the channel (width-depth ratio—130.43) hinders free draining of ebb tide water leading to ponding effect and reduction of velocity and stream energy to drain the sediments and initiates sedimentation.

**Keywords** Channel forms and patterns • Asymmetry of channel • Width-Depth ratio • Flow separation • Sedimentation

### 2.1 Introduction

*Channel forms and patterns* are important determinants of ease of movement of water and sediment and immediate clearance of materials from up slope. Both the magnitude of discharge and character of the flow regime influence channel form (Harvey 1969; Stevens et al. 1975). Leopold and Maddock (1953) described the *morphology of river channels* in terms of the relationships between discharge (Q), width (W), depth (D) and velocity (V) and their rate of changes. Dury (1974), Wolman and Miller (1960) studied the relationship between discharge and channel

morphology. Schumm (1974) studied the relationship between channel patterns and sediment load and gradient in a flume. Generally width increases faster than depth and velocity in a downstream direction. Parker's (1978) model and Bagnold's (1980) equation imply that for a given discharge and slope, a larger sediment load requires a wide channel. Bagnold (1966) postulated a link between stream power and sediment transport capacity by suggesting that stream power provided an integrative parameter for relating sediment transport to channel hydraulics. Leopold and Maddock (1953) explained the concavity of the longitudinal profile in terms of the downstream decrease of sediment load in relation to discharge. Keller (1972) proposed a five stages model of the development of pools and riffles in an alluvial river. Both meander bends and pool-riffle sequences are repetitive, meander wave length and amplitude, as well as pool-riffle spacing are related to channel width and pools are associated with meander bends while cross-over with riffles. Langbein and Leopold (1966) hypothesized that the *meandering pattern* represents a least work tendency and an equalization of power expenditure. Lewin (1977) classified meanders pattern changes as autogenic or allogenic. Autogenic changes are those inherent in river regime, including changes made by channel migration, crevassing, neck cutoffs etc. Allogenic changes are those taking place in response to some outside influence such as climatic fluctuations or human activities etc.

## 2.2 Field Monitoring and Applied Methodology

A total number of *twenty five (25) cross-sections* (Fig. 2.1) have been drawn all along the lower reach of the Rupnarayan River to understand the nature of channel forms and patterns. In this regard, depth of river is measured by *Echo Sounder* interfaced with position fixing system (Fig. 2.2a). Staff readings have been collected using leveling instrument considering several numbers of change points (Fig. 2.2b). The *bench mark* of 6.5 m near Kolaghat Thermal Power Project has been used as standard for the calculation of reduced levels at all the stations. Then, all the cross profiles have been drawn using these reduced levels. The long profile is drawn with the help of the *thalweg positions* of all the cross profiles. The spatial distributions of depth and *shoaled up area* along the river are also done by this methods along with the data collected by G.P.S. receiver. Cross-sectional area and width-depth relation have been estimated by the collected data in the field.

Slope of the river bed is calculated by the equation-

$$\theta = \tan^{-1} \frac{r}{h} \quad (2.1)$$

where,  $\theta$  = the river bed slope,  $r$  = difference of reduced level at the first and last points and  $h$  = the horizontal distance between same two points.

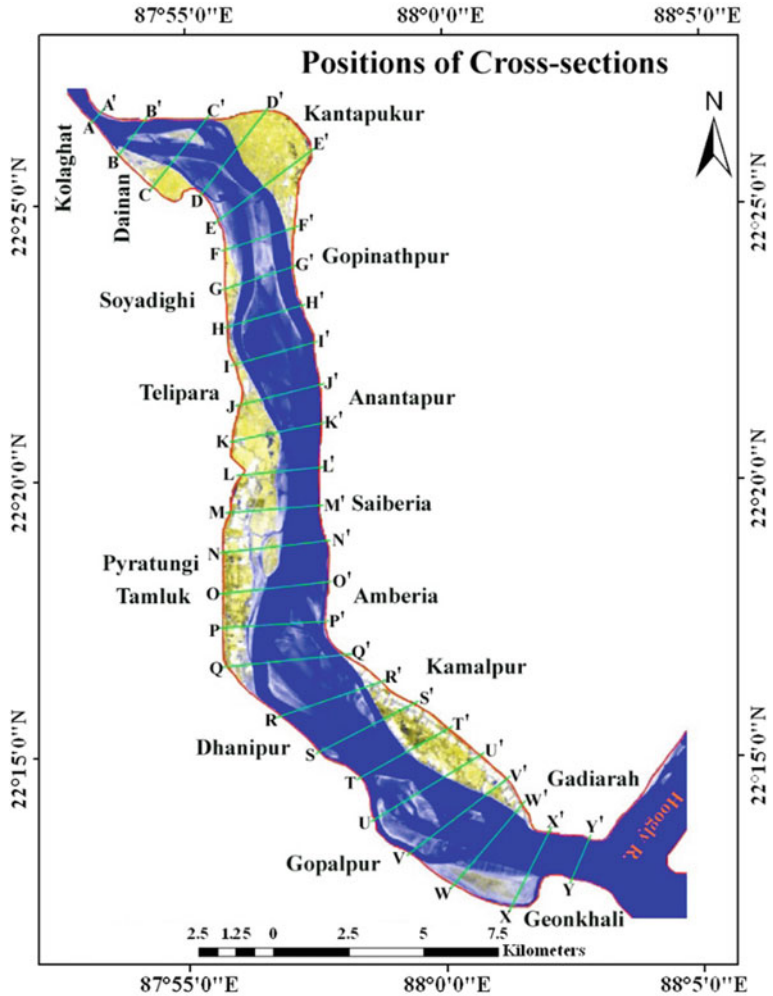


**Fig. 2.1** Location of cross-sections drawn in the study area

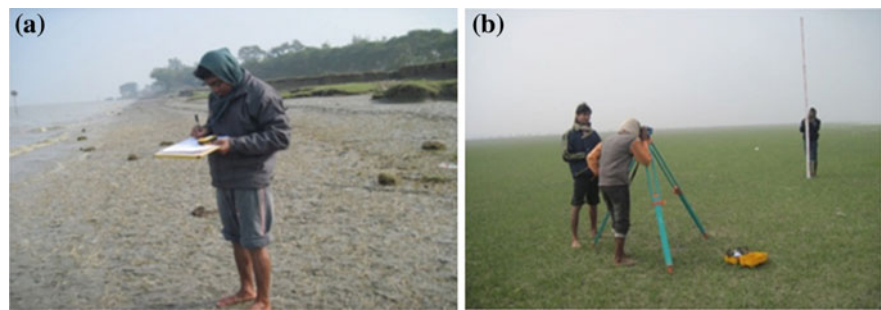


**Fig. 2.2** Collection of primary data by G.P.S. receiver (a) and leveling instrument (b)

*Sinuosity Index (SI)* is calculated following the equations-

$$SI = \frac{\text{Thalweg Length}}{\text{Valley Length}} \quad (2.2)$$

(Leopold and Wolman 1957).

$$SI = \frac{\text{Length of Channel}}{\text{Length of Meander belt axis}} \quad (2.3)$$

(Brice 1964).

## 2.3 Nature of Cross-Sections

Cross-sectional form of natural channels is characteristically irregular in outline, locally variable and is roughly parabolic in shape. The shape of cross-section of a river channel is a function of the flow, the quantity and character of the sediment and the composition of the materials making up the bed and banks of the channel (Knighton 1981). Width, mean depth, cross-sectional area, wetted perimeter, hydraulic radius, maximum depth, bed width, width-depth ratio etc. are the important parameters commonly used to describe channel form (Fahnestock 1963; Knighton 1981). In the study area only two cross-sections (one at Kolaghat-AA' and another at Geonkhali-YY') are symmetrical (the slope, length and configuration of both the sides of the cross-sections are same from the thalweg position) and remaining cross-sections are *asymmetric in nature* (Fig. 2.4). As the study area is facing the problem of rapid rate of sedimentation that's why the development and *shifting of shoal area*, re-distribution of sediments and *shifting of thalweg* position etc. are causing the cross-sections to be asymmetrical in nature. Spatial variation of erosion and deposition, river meandering are also contributing to make the channel asymmetrical (Middleton and Southard 1978). Asymmetry in the cross-profile is very common in areas of gently sloping beds (Knighton 1981).

### 2.3.1 Cross-Sections and Velocity Distribution

The *distribution of velocity* varies according to the shape of the channel (Morisawa 1963). Where the channel is wide and shallow the velocity gradients are higher near the bed than at the banks. If the channel is narrow and deep, isovels (lines joining points of equal velocity) will be crowded near the banks and farther apart along the bed. Shear will then be greater at the banks than at the bed. These concepts are important in considering erosion of the channel and sediment transport through the reach (Hubbell and Matejka 1959). Where the channel is asymmetric, velocity

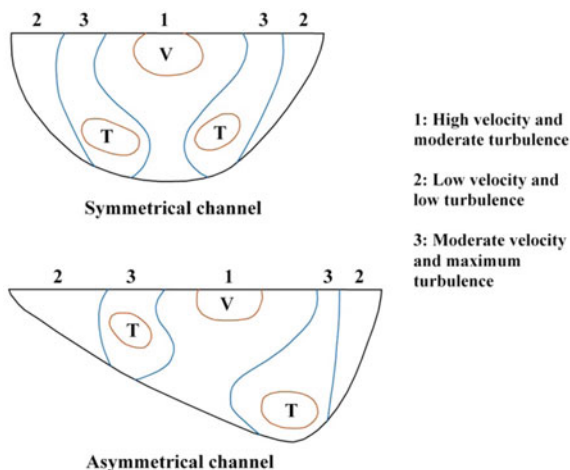
distribution is skewed and, indeed, may be separated into two or more cells (Morisawa 1985). In the study area most of the cross-sections are asymmetrical in shape that leads to *flow separation*, *velocity separation* and reduction of velocity towards the shallower section. This results in sedimentation, whereas in deeper portion scouring is dominant (Maity and Maiti 2012). But, if the channel is symmetric the highest velocity is in the middle of the channel just below the surface (Knighton 1988).

### 2.3.2 Cross-Sections and Turbulence

The mechanics of river flow are greatly influenced by turbulence, i.e., the superposition of secondary movements on predominant downstream flow of water (Morisawa 1963). Leighley (1934) related *regions of turbulence* in a river cross-section to *realms of velocity*. He divided the transverse section into three parts-(1) An inner axial region of high velocity and moderate turbulence. (2) An outer realm of low velocity and low turbulence. (3) An area between the other two regions where turbulence is maximum and velocity is moderate (Fig. 2.3).

The size of the belts and zones of turbulence shift laterally and vertically with cross-section shape. In symmetrical form zone-1 is located at the middle of the cross-section and zone-2 and zone-3 are on both sides of it with same areal extension. But in asymmetric cross-section all the three zones are shifted towards one side (deeper portion) of it, with zone-2 and zone-3 on both sides of zone-1

**Fig. 2.3** Relation between channel shape, velocity and turbulence (After Leighley 1934)



(Fig. 2.3). Here, the areal extension of zone-2 and zone-3 is more towards the shallower portion than the deeper portion of the cross-section (Leighley 1934).

As most of the cross-sections in the study area are asymmetrical, the *zone of low velocity and low turbulence* (zone-2) is wider towards the shallower section than the deeper section and creates favorable environments for sediment deposition. Sudden widening of the channel near Kolaghat leads to *flow separation*, reduction of energy and deposition of sediment (during low tide) and near Geonkhali the flow getting obstructed due to constriction of channel, causing reduction of flow velocity and stream energy and deposition of sediments (during low tide). In the middle portion, the sediments are redistributed during two phases of tide and deposited during low tide as low tide is longer and weaker (Maity and Maiti 2012).

## 2.4 Longitudinal Profile and Thalweg Profile of the Channel

*Long profile* of the stream bed is irregular because of variations in bed material size and shape, riffle-pool spacing, and other variables (Knighton 1984; Leopold 1992). The long profile of the study area represents that at two extreme ends (one at Kolaghat and another at Geonkhali) the width of the river is 400 m and 1500 m respectively but the maximum depth is 8.5 m and 11.5 m respectively (Fig. 2.4). In between these two extremes, the channel is wide enough with respect to the depth. Longitudinal profiles are important for identifying the general trends of down cutting and aggradations (Bernhardt et al. 2005). The slope of the longitudinal profile determines the energy of the water flow and provides a link between the long profile and the capacity for a reach to transport sediments (Brookes and Sear 1996).

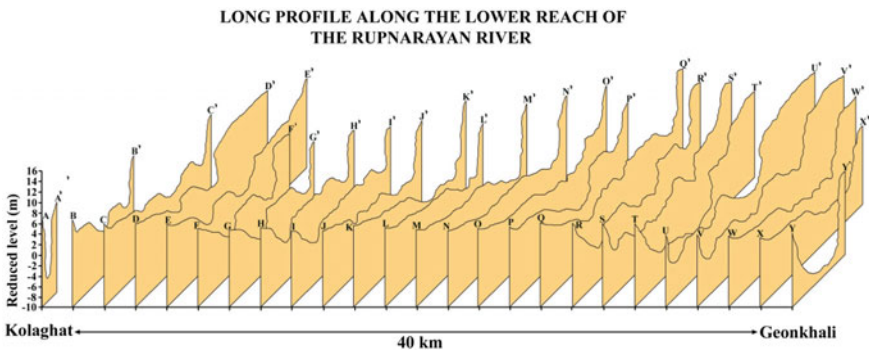


Fig. 2.4 Long profile of the lower reach of the Rupnarayan River. (Source Field measurement)

Average gradient of the thalweg profile (between Kolaghat and Geonkhali) is 0.0000105, indicating very gentle slope of the region.

## 2.5 Depth Distribution along the Lower Reach

*Channel shape* depends on the distribution of depth across and along the channel. Distribution of depth across the channel depends largely on channel width, which depends on discharge. The mean depth of a stream varies greatly from reach to reach (along the river) depending on channel width, slope, volume of discharge and riffle-pool spacing etc. With an increase of volume of water discharge through a channel the depth will increase (Leopold and Maddock 1953). In the study area the longitudinal distribution of depth is highly dynamic in nature. Near Kolaghat and Geonkhali the depth is more compared to the middle section of the reach. Maximum depth (>10 m) is observed at the thalweg of the cross-sections (symmetrical valley) at Kolaghat and Geonkhali (Fig. 2.5). In the middle of these two extremes the depth is mainly <8 m. There are some scattered zones where scouring and shoaling on river bed lead to the formation of *irregularity in cross-section*. Most of the portions near two banks and around the *mid channel bar* have the depth less than 2 m (Fig. 2.5). Generally the thalweg line lies along the middle of the channel, except at Soyadighi and Gopinathpur, where the development of a mid-channel bar, the *diversion of the flow* is observed (Fig. 2.5).

### 2.5.1 Seasonal Variation of Depth Distribution

Distribution of depth along the lower reach is the result of the interaction between *upstream discharge* and *tidal discharge* in different seasons (Maity and Maiti 2012). The river discharge is impounded during flood period and released during ebb period. When the material carried by littoral drift reaches a river mouth during ebb period, it is picked up by the tidal current and is carried into the river channel by the flood current. The incoming high tide brings a lot of sediments from seaward side and deposits it on the bed of Rupnarayan River in absence of any upland discharge during the non-monsoon months (Rhodes 1950). As a result of continuous sedimentation the depth of river is decreased to a great extent. During Pre-monsoon and Post-monsoon, the maximum depth near Kolaghat region are 10.1 m and 10.5 m respectively and near Geonkhali the depth are 11.3 m and 11.5 m respectively. In the middle portion, all the places have maximum depth of <10 m. During freshet condition (July-September) the impact of high tide is felt to be reduced due to discharge of large volume of water from the upland area of the

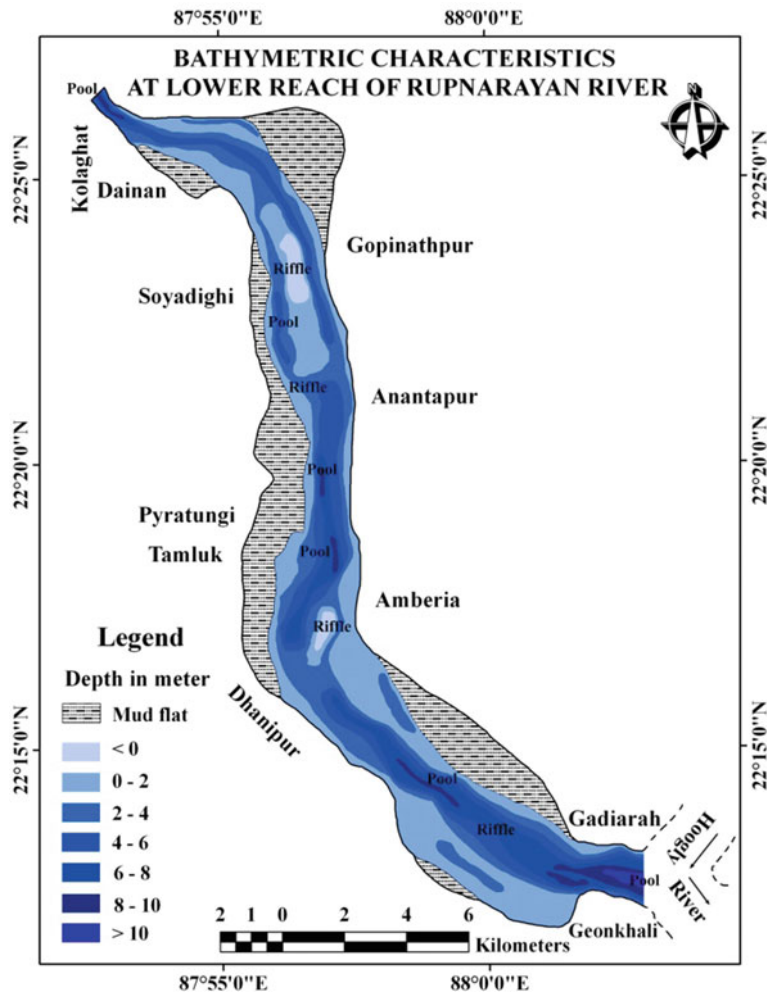


**Fig. 2.5** Distribution of depth along the lower reach of the Rupnarayan River. (Source Field measurement)

river. During monsoonal period scouring of river bed is more compared to the shoaling and so, the depth of river is increased (Maity and Maiti 2012). Maximum depth near Kolaghat and Geonkhali are 13.2 m and 14.9 m respectively in monsoon and in between these two extremes most of the places have maximum depth of more than 10 m (Table 2.1).

**Table 2.1** Seasonal variation of Depth distribution and Width-depth ratio

| Cross-section | Maximum Depth (m) |         |              | Average Width-depth ratio |
|---------------|-------------------|---------|--------------|---------------------------|
|               | Pre-monsoon       | Monsoon | Post-monsoon |                           |
| AA'           | 10.1              | 13.2    | 10.5         | 38.09                     |
| BB'           | 5.1               | 7.6     | 4.5          | 366.66                    |
| CC'           | 4.8               | 7.8     | 5.4          | 659.09                    |
| DD'           | 5.1               | 8.2     | 5.4          | 666.66                    |
| EE'           | 5.0               | 7.3     | 4.2          | 916.66                    |
| FF'           | 6.1               | 7.5     | 4.6          | 543.47                    |
| GG'           | 5.5               | 8.7     | 5.6          | 419.64                    |
| HH'           | 7.1               | 8.8     | 5.9          | 440.47                    |
| II'           | 5.3               | 6.4     | 3.8          | 723.68                    |
| JJ'           | 6.2               | 8.0     | 5.2          | 528.84                    |
| KK'           | 6.1               | 8.3     | 5.9          | 525.42                    |
| LL'           | 8.8               | 11.7    | 8.5          | 323.52                    |
| MM'           | 7.3               | 9.3     | 6.8          | 455.88                    |
| NN'           | 8.1               | 10.5    | 8.6          | 389.53                    |
| OO'           | 5.7               | 9.3     | 6.1          | 590.16                    |
| PP'           | 6.6               | 10.7    | 7.5          | 446.66                    |
| QQ'           | 4.1               | 7.8     | 3.6          | 1111.10                   |
| RR'           | 7.1               | 9.8     | 7.3          | 495.89                    |
| SS'           | 7.4               | 9.6     | 7.5          | 480                       |
| TT'           | 6.1               | 10.4    | 6.1          | 410.97                    |
| UU'           | 4.7               | 10.8    | 6.5          | 500                       |
| VV'           | 6.8               | 10.4    | 6.7          | 572.22                    |
| WW'           | 8.2               | 11.5    | 7.8          | 461.53                    |
| XX'           | 8.2               | 11.8    | 9.4          | 305.31                    |
| YY'           | 11.3              | 14.9    | 11.5         | 130.43                    |

(Source Field measurement)

## 2.6 Width-Depth Ratio

*Width-depth ratio* is one of the important parameter to understand the channel form. Relatively narrow and deep river with lower width-depth ratio is capable of moving more suspended sediment by turbulence and velocity of flowing water, but shallow wider channel, having large width-depth ratio, is more efficient to transport bed load by shear on the bottom of the stream (Coleman 1969). In the study area width-depth ratio is less near Kolaghat and Geonkhali (38.09 and 130.43 respectively), but in the middle portion width-depth ratios are more than 300. It becomes 1111.10 in the cross-section of QQ' (Table 2.1). The width-depth ratio changes continuously to adjust with the discharge, load type and slope of the bed. River discharge, rock type, slope, type of load being transported, type of sediment at the channel's perimeter, and rock uplift rate have all been shown to control river width and

width-depth ratio (Schumm 1960). Channel perimeters with a high amount of coarse grained materials tend to be wide and shallow (Schumm 1960).

2.7 Channel Widening, Flow Separation and Diversification

There is a sudden *expansion and widening of the channel* near Kolaghat region which leads to flow separation and diversion of flow. The width of the cross-section AA' is 400 m, but it suddenly increased to 1650 m at cross-section BB' and again increased to 2900 m at CC' at downstream of the Kolaghat (Figs. 2.1, 2.6 and 2.7a). In spite of this one, there are another two diversion and flow separation in between the region of Pyratungi and Dhanipur and Dhanipur and Geonkhali (Figs. 2.1, 2.6

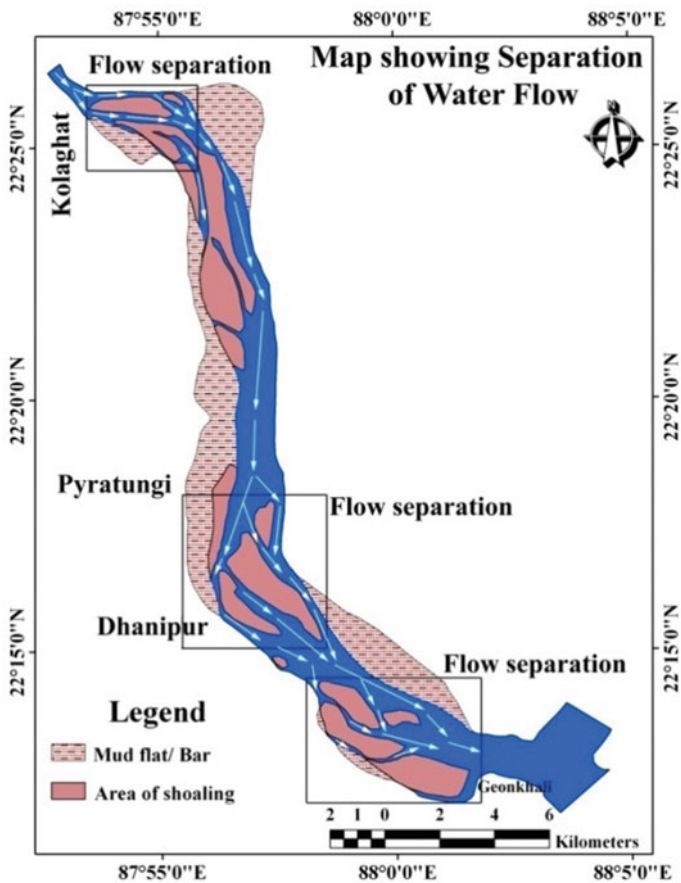


Fig. 2.6 Separation of flow at lower reach of the Rupnarayan River

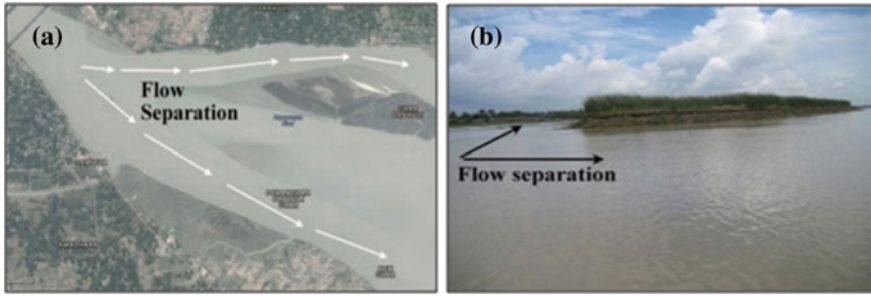


**Fig. 2.7** Flow separation near Kolaghat (a) and Pyratungi (b)

and 2.7b). Flow separation and diversion of channel is caused where channel widens, gradient declines or discharge decreases (Naden and Brayshaw 1987). Smith (1974) mentioned that abrupt expansion of channel banks is important cause of flow separation.

### 2.7.1 *Flow Separation, Velocity Reduction and Sedimentation*

*Channel widening* and associated *flow separation* is important cause of reduction of flow velocity, reduction of stream energy and sedimentation on river bed. Bagnold (1966) noted that stream power is expressed as the ability of the water flow to do work within a channel in a particular instant of time and that rate of work indicates the availability of energy in a stream to transport the sediments. The rate of doing work by the available energy or the cross-sectional total stream power ( $\Omega$ ), can be expressed as the combined effect of the specific weight of the fluid ( $\gamma$ ), the discharge of water ( $Q$ ) and the energy slope or the slope of the channel bed ( $S$ ):

$$\Omega = \gamma QS$$

If there is any change in the magnitude of water flow, due to any reason (single diversion for example), the total available stream power will be changed. In case of river diversion and separation of flow the available stream power is reduced, causing the reduction of the ability of the flow of doing work at a certain rate, i.e., the *reduction of sediment transport power* (Letter Jr et al. 2008). Watson et al. (1999) pointed out that though the bed slope and sediment particle size remain constant but the water flow will decrease because of channel diversion and flow separation. It will reduce the sediment transport capacity of the river resulting into the sedimentation and aggradation on the river bed. Near Geonkhali region sudden constriction (bottle neck shape) of the channel (width-depth ratio—130.43) hinders the free draining of ebb tide water leading to ponding effect and velocity reduction

that leads to sudden reduction of energy to drain the sediments. Again, during flood tide sudden widening at upstream of Geonkhali (width-depth ratio-130.43 at YY', 305.31 at XX', 461.53 at WW' and 572.22 at VV') leads to flow separation and energy reduction that also incapacitates the stream to favour *sedimentation*.

## 2.8 Stream Meandering

Channel pattern is usually represented by the ratio of stream length to valley length (stream sinuosity). As the asymmetry increases, flow impinges on the banks and erodes them to form sinuous pattern (Schumm 1963). The value of Sinuosity Index (SI = 1.35) between the reach Kolaghat and Gopinathpur represents the braided nature of the channel (the channel is divided by bars and small islands), whereas the channel is of Sinuous pattern (SI = 1.08) between Gopinathpur and Dhanipur reach. Between Dhanipur and Geonkhali, the channel is braided in nature (SI = 1.38). For the entire lower reach of the Rupnarayan River, the Sinuosity Index (SI = 1.31) indicates the *braided pattern* of the channel. The gradient of the river bed is very gentle to almost flat (0.0000105) and the mean grain size is fine sand to coarse silt in nature, which have an impact to control channel pattern. Generally speaking, as gradient and particle size decreases, there is a corresponding increase in sinuosity. Braided pattern of the channel leads to flow separation, reduction of stream energy, shifting of the area of scouring and shoaling and changing of the river course.

## References

- Bagnold RA (1966) An approach to the sediment transport problem from general physics. US Geol Survey Prof Paper, 422:37
- Bagnold RA (1980) An empirical co-relation of bed load transport rates in flumes and natural rivers. Proc R Soc 372A:453–473
- Bernhardt ES, Palmer MA, Allan JD et al (2005) Synthesizing U.S. river restoration efforts. Science 308:636–637
- Brice JC (1964) Channel patterns and terraces of the Loup River in Nebraska. US Geol Survey Prof Paper, 422D
- Brookes A, Sear DA (1996) Geomorphological principles for restoring channels. In: Brookes A, Shields J (eds) River channel restoration: guiding principles for sustainable projects. Wiley, Chichester, pp 75–101
- Coleman JM (1969) Brahmaputra River: channel process and sedimentation. Sediment Geol 3:129–139
- Dury GH (1974) Magnitude—frequency analysis and channel morphometry. In: Morisawa ME (ed) Fluvial geomorphology. SUNY-Binghamton, New York, pp 9–21
- Fahnestock RK (1963) Morphology and hydrology of a glacial stream-White River, Mount Rainier, Washington. US Geol Surv Prof Pap, 422A
- Harvey AM (1969) Channel capacity and the adjustment of streams to hydrologic regime. J Hydrol 8:82–98

- Hubbell DW, Matejka DQ (1959) Investigations of sediment transportation Middle Loup River at Dunning, Nebraska. US Geol Surv Water Suppl Pap 1476:123
- Keller EA (1972) Development of alluvial stream channels: a five stage model. Bull Geol Soc Amer 83:1531–1536
- Knighton AD (1981) Local variations of cross-sectional form in a small gravel bed stream. J Hydrol (New Zealand) 20:131–146
- Knighton AD (1984) Indices of flow asymmetry in natural streams: definition and performance. J Hydrol 73:1–19
- Knighton AD (1988) The impact of the Parangana Dam on the River Mersey, Tasmania. Geomorphology 1:221–237
- Langbein WB, Leopold LB (1966) River meanders—theory of minimum variance. US Geol Surv Prof Pap 422:1–15
- Leighly JB (1934) Turbulence and the transportation of rock debris by streams. Geogr Rev 24:453–464
- Leopold L (1992) Sediment size that determines channel morphology. Dynamics of Gravel Bed Rivers. Wiley, New York, p 15
- Leopold LB, Maddock T (1953) The hydraulic geometry of stream channels and some physiographic implications. US Geol Surv Prof pap, p 252
- Leopold LB, Wolman MG (1957) River channel patterns-braided, meandering and straight. US Geol Surv Prof pap 282B:39–85
- Letter Jr JV, Pinkard Jr CF, Raphelt NK (2008) River diversion and shoaling. Coastal and Hydraulic Engineering Technical Note, ERDC/CHL CHETN-VII-9, Vicksburg, MS: US Army Engineer Research and Development Center
- Lewin J (1977) Channel pattern changes. In: Gregory KJ (ed) River channel changes. Wiley, New York, pp 167–184
- Maity SK, Maiti RK (2012) Impact of sedimentation on development and shifting of shoal area, pools and riffles and thalweg position at lower reach of Rupnarayan River-A case study. Indian J Power River Val Dev 24:46–54
- Middleton GV, Southard JB (1978) Mechanics of sediment transport. SEPM Short Course No 3, Binghamton, New York, p 248
- Morisawa ME (1963) Distribution of stream-flow direction in drainage patterns. J Geol 71(4):528–529
- Morisawa M (1985) Rivers: forms and process. Longman Inc, New York
- Naden PS, Brayshaw AC (1987) Small and medium scale bed forms in gravel-bed Rivers. In: Richards KS (ed) River channels: environment and process. Blackwell, Oxford, pp 249–271
- Parker G (1978) Self-formed straight rivers with equilibrium banks and mobile bed. Part 1: the sand-silt river. J Fluid Mech 89(1):109–125
- Rhodes RF (1950) Effects of salinity on current velocities, US Corps of Engineers, Committees Tidal Hydraulics, report No 1, p 94
- Schumm SA (1960) The shape of alluvial channels in relation to sediment type. US Geol Surv Prof Pap, 352-D
- Schumm SA (1963) A tentative classification of alluvial river channels. US Geol Survey Circular, p 477
- Schumm SA (1974) Geomorphic thresholds and complex response of drainage systems. In: Morisawa ME (ed) Geomorphology. SUNY, Binghamton, pp 299–310
- Smith KG (1974) Erosional processes and landforms in Badland national monument, South Dakota. Geol Soc Amer Bull 69:975–1008
- Stevens MA et al (1975) Non-equilibrium river form. J Hydr Div, ASCE 101:557–566
- Watson CC, Biedenharn DS, Scott SH (1999) Channel rehabilitation: processes, design and implementation. Workshop proceedings, US Army Engineer Research and Development Center, Coastal and Hydraulics Laboratory, July 1999
- Wolman MG, Miller J (1960) Magnitude and frequency of forces in geomorphic processes. J Geol 68:54–74

Sedimentation in the Rupnarayan River

Volume 1: Hydrodynamic Processes Under a Tidal  
System

Maity, S.K.; Maiti, R.

2018, XVII, 100 p. 35 illus., 29 illus. in color., Softcover

ISBN: 978-3-319-62303-0