Sedimentation Problems in Rivers and Reservoirs

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Slide-1: INTRODUCTION

- Sedimentation continues to be one of the most important threats to river eco-systems around the world
- World's 145 major rivers with long term sediment records show that about 50 %. of the rivers have downward flow trend due to sedimentation (Walling and Fang, 2003).
- Sumi and Hirose (2009) reported that the global reservoir gross storage capacity is about 6000 km3 and annual reservoir sedimentation rates are about 31 km3 (0.52 %).
- At this sedimentation rate, the global reservoir storage capacity will be reduced to 50 % by year 2100
- International Sediment Initiative (ISI) addresses the wide-ranging social, economic and environmental impacts of erosion, sediment transport and sedimentation processes

Slide-2: River Morphology-Lane's Theory

- The shape of rivers and streams changes through time as erosion, deposition, and transport of sediment continue
- As per Lane (1955),Rivers maintain a dynamic equilibrium between discharge(Q), slope (S), sediment transport (Q_s), and sediment size(D_{50})
- Processes of aggradation and degradation of river bed can be explained by Lane's balance theory:

  Lane's Balance Theory: $Q.S_e\ \bar{\alpha}\ Q_sD_{50}$
- Long-term shifts in equilibrium observed in the landscape result from climate change, tectonic uplift and subsidence, local base-level changes due to landslides and damming including GLOF .
- River stability is affected by human activities e.g. dams for water storage, barrages for flow diversion, transportation, irrigation, power generation, embankments for flood protection etc.

Slide-3: River Morphology-Aggradation (Fig.1)

Fig.1 Aggradation Due To Landslides in 2013 Flood in Uttarakhand

Slide-4: Devastation due to GLOF in 2013 in Kedar Valley, Uttarkhand (Fig.2)

Fig.2 Devstation of Kedarnath Town (a) Before GLOF (b)After GOLF

Slide-5: River Morphology-Plan Forms (Schum, 1981)

- Inter-relation between River plan form, hydraulic and sediment parameters and relative stability of a river is illustrated in Fig. 3 (Schum, 1981)

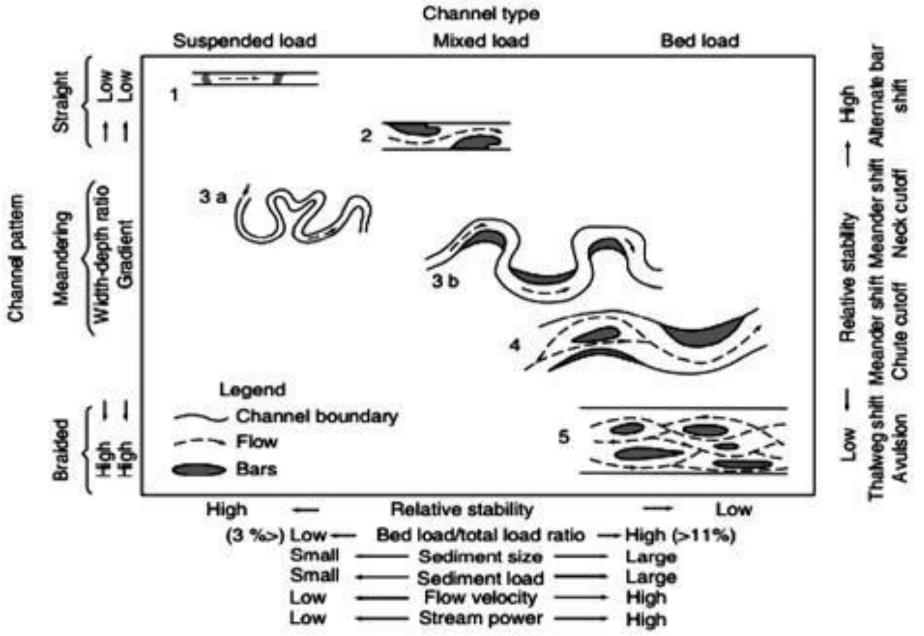


Fig.3 Schum's Diagram Showing Different Plan forms of Rivers

Slide-6: Brown-Einstein Bed Load Equation, 1942

- Using 1942 bed load equation of Einstein (H.A. Einstein-1942), following relation known as Brown-Einstein formula was derived:

$\varphi=40/\psi^3$ where $\psi<5.5$ and

$\varphi=e^{-0.39\,\psi}$ when $\psi>5.5$

Here, $\varphi=[q_B/(\gamma_s.F)][g\{(\rho_s/\rho_f-1)\}d^3]^{0.5}$ –bed load function

and $\psi=\{(\gamma_s-\gamma_f)/\tau_0\}d$ - bed shear stress function

and F is Ruby's fall velocity given by the frelation:

$F=[(2/3)+36\upsilon^2/\{gd^3(\rho_s/\rho_f)-1\}]-[36\upsilon^{2/}/\{gd^3(\rho_s/\rho_f)-1\}$

Where, q_B is bed load transport rate per unit width, γ_s and γ_f are unit weight of sediments and water respectively, ρ_s and ρ_f are the densities of water and sediments respectively,d is size of sediments, τ_0 is bed shear stress and υ is kinematic viscosity of water.

Slide-7: Brown-Einstein Bed Load Equation, 1942)-Its Application

Brown – Einstein equation can be used to explain why a river sheds its bed load and forms a delta like structure **(Fig.4)** when it enters a flood plain and expands after its hill journey as shown in **Fig. 4**

Fig.4 Elwah River Delta

Slide-8: Prediction of River Regime

(FIG.5) illustrates quantitative relationships between channel beds slope (So) and mean flow (Q)

- As per Lane (1957), non-cohesive stream bed composed of silts and sands is predicted to meander when

  $S_o\, Q^{0.25} > 0.00070$

  and braided when

  $S_o\, Q^{.25} > 0.0041$

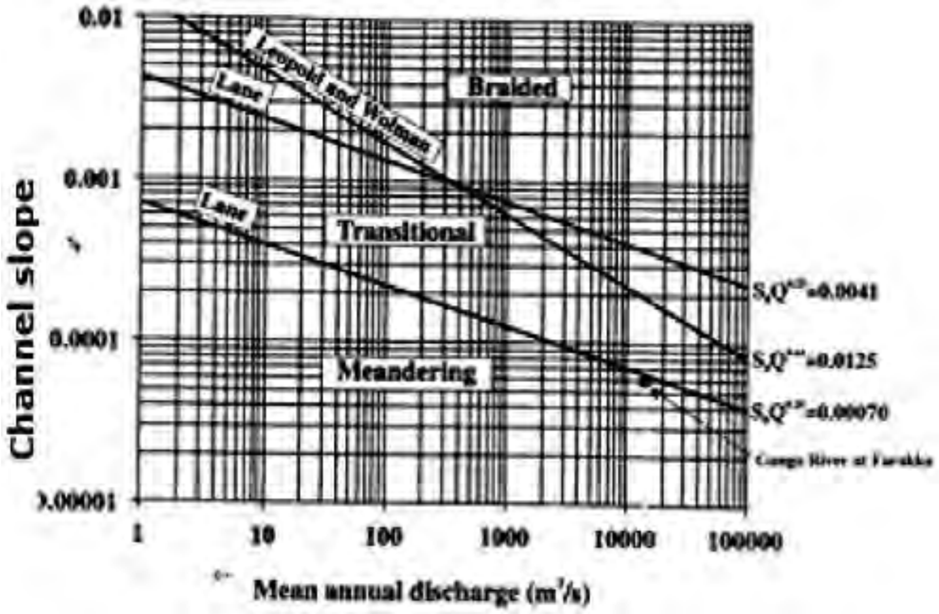


Fig.5 River Regime Lane’s (1957) Criteria

Slide-9: Research on River Meandering/Bends

- A lot of research work on meandering river have been carried out by eminent river scientist like Rozovsky (1957), Zimmerman and Kennedy (1978), Engueland (1973), Oddgard (1986), Wang (1994), Yalin (1999), Chitale (1981), Garde and Raju (2000).
- Wang (1992) developed a mathematical model of the meandering process to prove that the typical cross slope developed in a meander with lower bed elevation on the outer side of bend (due to erosion) and higher elevation on the inner bank side (due to sediment deposition) arising out of secondary current provides stability to the meandering River
- Hickin and Nanson (1984) described the lateral migration rate (M) of a meander by the functional relation

  $$M = f(\Omega, b, G, h, \tau_b)$$

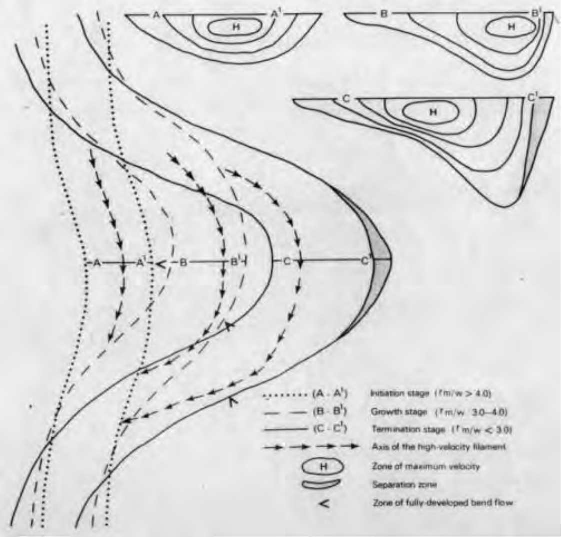
  Hickin concluded that the migration rate is maximum when meander stabilizes at an approximate value of r/w =2.5 and got the relation

  $$M_{2.5}\ (\text{m/year}) = \rho g\ QS / \tau_b.h$$

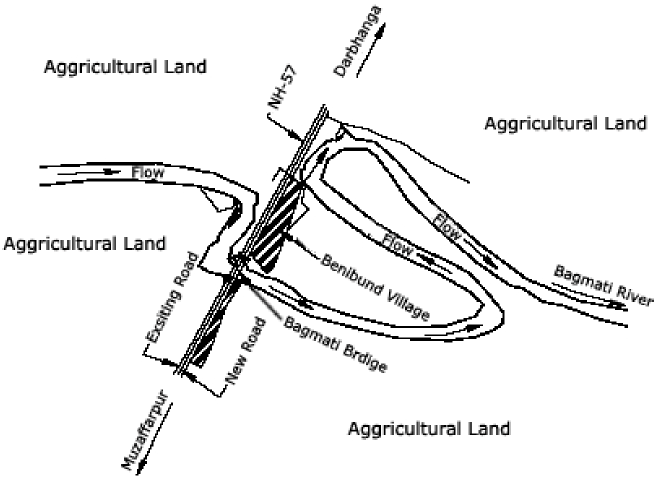
Slide-10: Meandering Process/Cut off Formation

- Development of lateral instability associated with deposition and erosion on alternate river banks give rise to thalweg pattern.
- Uncontrolled deposition and erosion ultimately give rise to meander formation as illustrated in fig. 6.
- Mazumder (2010) proved that Critical Shear stress in a meandering bend may be zero, depending on strength of secondary current causing scour on the outer side of bend.
- Uncontrolled meandering may lead to outflanking of hydraulic structures and flow avulsion when river shifts its course and may join other low lying rivers as observed in both Farakka and Kosi barrages in India (Mazumder)

Slide-11: Meandering Processes



(a)

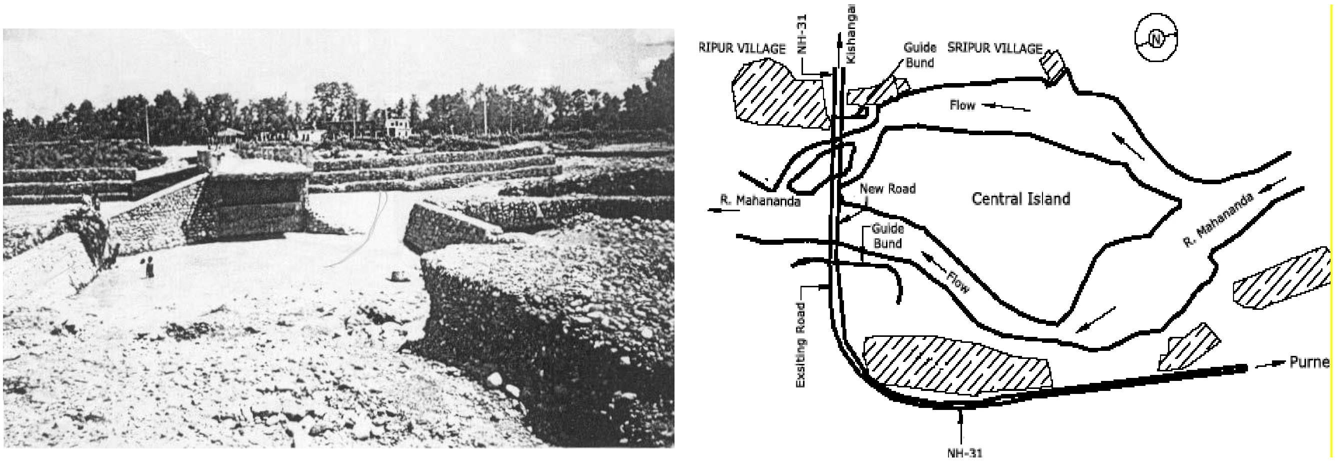


(b)

Fig.6 River Meandering Process (a) Lateral progress and Change in River Cross-Section (b) Severe Meander of River Bagmati Damaging NH-57 in MP in India

Slide-12: Effect of Hydraulic Works on Rivers –Bridges

- The construction of hydraulic works such as dams, weirs, bridges, levees etc. has played a key role in the development and utilization of water resources
- However, the development of hydraulic works within a river system has the capacity to both affect and be affected by the sediment regime of a river system.
- There are a numerous of examples of how the individual river systems are affected due to manmade works.



(a) **(b)**

Fig.7 (a) Outflanking of a Bridge on River Danabkhola in Nepal (b) Anabraching of a Bridge on River Mahananda in India

Slide-13: Effect of Hydraulic Works on Rivers –Bridges

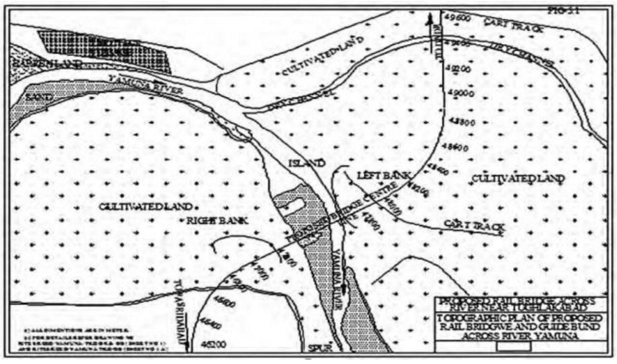


Fig. 8: (a) A Bridge on Meandering Yamuna Flood Plain near Delhi

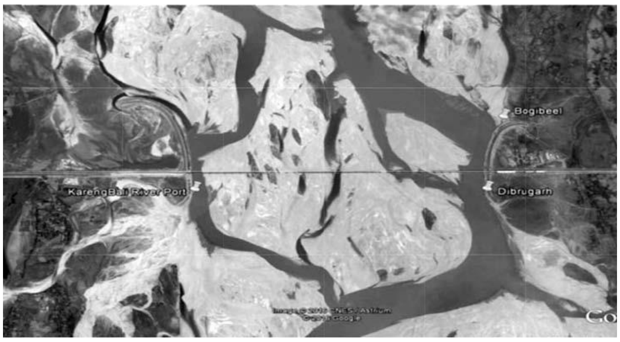


Fig. 8 (b) Bogibeel Bridge on Braided River Brahmaputra

Slide-13: Impacts of Dams and Barrages

- Construction of dam and barrages cause backwater effect and cause damage to ecology and the function of river systems.
- Dam/barrage/Bridge construction can result in changes to sediment transport, aquatic ecosystems, and migratory fish species
- The capture of sediment behind dams, barrages and Bridges can have profound impacts on the River morphology and state of the river downstream of these structures.
- The water released below these structures has been termed "hungry water" because the "hungry water" consumes the bed and banks of the river below the structures resulting in entrenchment and armouring of the bed.
- Fig.9 illustrates sediment Deposition in Lewis and Clerk Reservoir in Gravin Point Dam in Missouri River
- Aswan High Dam traps vast quantities of sediment which both reduces the storage capacity of Lake Nasser and results in problems downstream of the dam,
- There is need for increased fertiliser application to offset the loss of fertile silt formerly deposited by the annual flood, erosion of farmland on the river banks, erosion of the coastline and degradation of the Nile Delta

Slide-14: Impacts of Dams and Barrages-case Study

Fig. 9 Sediment Deposit in Lewis and Clark Lake - reservoir created by Gavins Point Dam on the Missouri River. It's 30 percent full of sediment and could be half full by 2045

Slide-15: **Boreland Milar**

Curves

- **-Trap Efficiency**
- **-Type of reservoir**
- **-C/I Ratio**
- **-Size and Distribution of Sediments**
- **-Area-incremental Method**
- **-Area Reduction Method**
- **-Satellite Imageries**

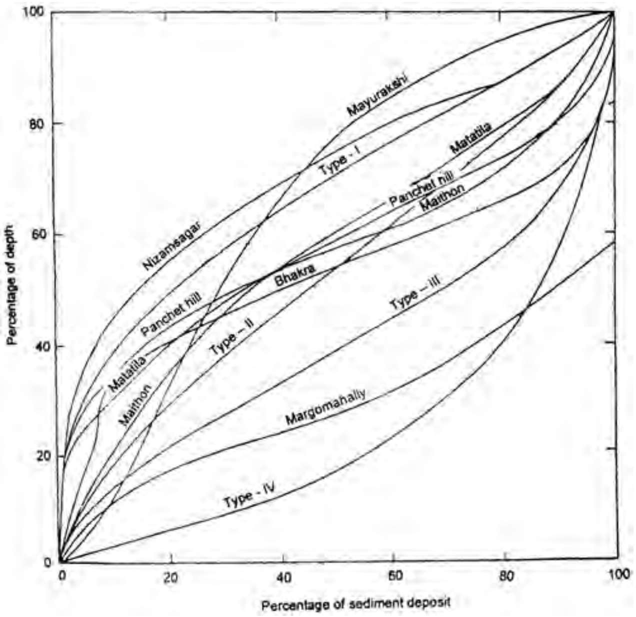


Fig. 10 Boreland- Milar Curve Snolwing Sediment Distribution within Reservoir

Slide-16 MEASURES AGAINST RESERVOIR SEDIMENTATION

(a) In the reservoir:

Fig. 11 Sediment Flushing from Xiaolangdi Dam on Yellow River in China

- Dredging Dead storage
- Flushing
- Hydro suction
- Air lift
- Avoiding settling of fine sediments
- Controlling the turbidity currents

Slide-17 MEASURES AGAINST RESERVOIR SEDIMENTATION
b) At the dam:

- Sluicing
- Turbidity current venting
- Turbining suspended sediments
- Dam heightening

(c) In the catchment area:

Soil conservation

- Setting basins
- Slope and bank protection
- Bypassing structure
- Off-stream storage reservoir