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Numerical Simulation-Optimization for Channelization of River Kosi

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Abstract : ***Kosi is highly braided river and notorious for its vagaries. During its last two hundred years, it has been shifting laterally towards western direction. It has shifted across a width of over 100 km. The river Kosi has been provided with levees along the banks, at a width ranging from 6 km to 16 km to minimize further shifting of river. The general bed level at many places has risen by 0.1 to 3 m over a period of 50 years due to inadequate velocities in the river for carrying out the sediment. For the minimizing the silting and lateral shifting, it is desirable to explore the possibility of channelizing the river Kosi, which is thought to be one of the method by which the velocities in the river could be increased thereby increasing the sediment carrying capacity of the river. This paper presents the analysis of hydraulic aspects of channelizing the river by using 1D mathematical model HEC-RAS 4.1. Various channelization widths ranging from 800 m to 2000 m were examined keeping the bed profile unchanged and it is found that the channelization width of 1100 m would minimize aggradations and degradation of the river.***

KEYWORDS: **Channelization, Water way, Aggradations, Degradation, Sediment load**

1 Introduction

Although flow in natural rivers is three-dimensional (3D), however, one (1D)-or two (2D)-dimensional models are often used in engineering practice for shallow open channel flow. In particular, when simulating a very long river of multichannel in cross section for a long period, 1D models (e.g., HEC-RAS) are more cost effective than 2D or 3D models, however, they are unable to simulate momentum exchange between main channel and floodplain, turbulence around engineering structures (e.g., bridges piers, spur dikes), and flow in highly sinuous channels (Duan et al, 2001.; Duan and Julien 2005). To overcome these limitations, engineers commonly enhance 1D model with empirical formulas to approximate energy losses attributable to in-stream structures or meandering bends. The site of the present study is the Kosi River, a reach consisting of braided, transitional, and meandering channels with levees and dikes, and highly overloaded sediment supply, which requires an improved 1D model to simulate the hydraulic aspects of channelizing the river.The river Kosi is well known for its abundant sediment supply and insufficient flow which leads persistent sediment deposition and continuous rising flood levels. The river Kosi carries about 187 million metric tons of sediment, which is coming from Himalaya, out of total quantity of sediment 70% of sediment is settling between two embankment/levees and the balance sediment is flowing to the river Ganga (Burele et al., 2012).

2 Historical Perspective Of Kosi River

Kosi is the third largest Himalayan River originating from the snowy peaks in the Central Himalayas. The three main tributaries are the Sun Kosi rising east of Kathmandu, the Arun Kosi rising north of the Mount Everest in Tibet and the Tamur Kosi rising west of Mount Kanchanjunga. These three tributaries join at Tribeni in Nepal and thereafter the river is known as Kosi. The river Kosi, after flowing for a length of about 10 km through a deep gorge, debouches into the plains at Chatra. From this point, the river runs in a sandy alluvial plain through Nepal upto Bhimnagar for a distance of 42 km and further it flows through North Bihar eventually joins river Ganga near Kursela. The total distance from Bhimnagar to its outfall into river Ganga is about 260 km. The important tributaries that join Kosi in this reach are Trijuga, Bhutahi Balan, Kamla Balan and Bagmati. River Kosi has a steep gradient of about 1.5 m/km in the gorge portion upstream of Chatra. The slope at Chatra is about 0.95 m/km but it flattens to 0.03 m/km in the tail reach at Kursela as shown in Fig.1.

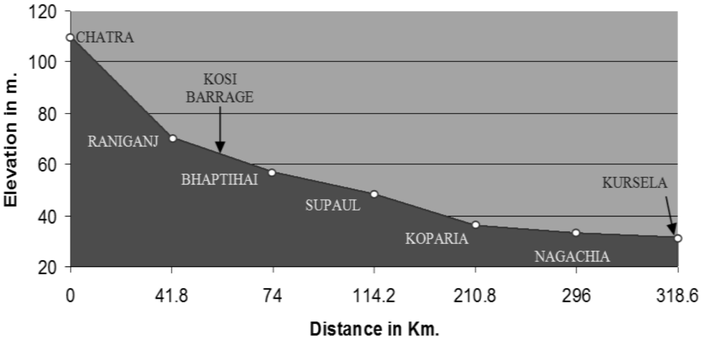

Figure 1: Bed slope of river Kosi from Chatra to Kursela

The Kosi River is notorious for its capricious nature. It carries with it an enormous load of sediment, which it is unable to transport. Emerging from the young Himalayan Mountain, the river carries an estimated sediment load of about 187 million tonne per year. Of the total sediment load, approximately 50% is contributed by the Sun Kosi and 25% each by the river Arun and Tamur. As it traverses through the plains, the velocities are reduced from about 5 m/s at Chatra gorge to values as low as 1.25 m/s in the plains depending on the slope and depth of flow resulting in deposition of 130 million tons of sediment load between Chatra and Kursela. The drastic reduction in bed slope results in marked reduction of sediment transport capacity and causes significant aggradation. Due to deposit of such a large quantity of sediment charge, the river has been shifting its course from times immemorial. As illustrated in Fig. 2, the river has shifted by about 112 km to the west from Purnea to Supaul in 223 years (year 1731 to 1954) bringing death and devastation in about 7680 sq. km area.

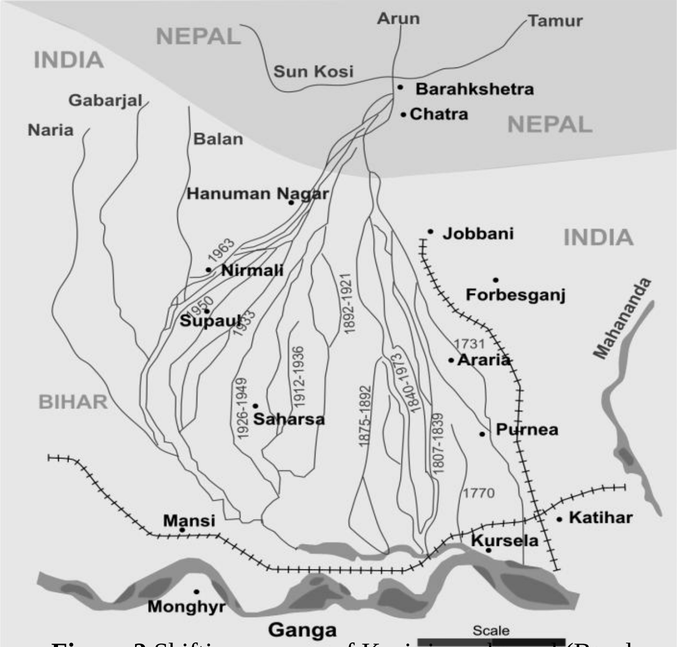

Figure 2 Shifting courses of Kosi river channel (Burele et al., 2012).

To control further shifting of the river, a scheme was prepared in the year 1954 consisting of

a) A barrage across the river at Bhimnagar, with canals on either side with a potential for irrigating 1.1 million hectare area.

b) upstream afflux bunds extending to 13 km on western side and 32 km on eastern side of the barrage.

c) flood embankments (stop banks or levees) below the barrage extending to about 100 km on the western side and 124.5 km on the eastern side.

The work of construction of levees on either banks was completed in the year 1959 and the river was diverted through the barrage in 1963. However, the levees were constructed at a distance of around 6 km to 16 km and the river was allowed to take its own course in this width. As the flood wave gets reduced due to less longitudinal river slope, the velocities reduce and river gets braided. In few cases the river Kosi is flowing between the stop banks at a relative bed level above the general ground level in the area. In view of this, it is felt that the river may be constricted to such an extent and given a particular cross-section whereby it will have self cleaning velocities so that the river carries all its sediments downstream. This could be achieved by the well known procedure called the channelization. Channelization of a waterway by straightening it prevents the water from changing directions randomly, and net erosion / deposition is greatly reduced (Harding et al., 2007). Channelization includes those methods of engineering (resectioning, straightening, construction of levees, diversions, etc.) that modify existing river channels or create new channels, often changing the relationship between river channels and floodplains. The most common purposes of channelization are flood control, land drainage improvement, creation of new spaces for urbanization or agriculture, maintenance or improvement of navigation, and reduction of bank erosion. Channelization is carried out both on very large rivers and small streams; it is widespread in lowland rivers, but also many upland (mountain) rivers have experienced this type of human intervention. Human impact on rivers has a long history. For instance, the Yellow River, in China, has been regulated for at least 4000 yr and most alluvial rivers in Europe have been channelized during the last 2000 yr. (Surian et al., 2003)

This paper present a conceptual study that was conducted using a mathematical model to assess the effectiveness of constriction of waterway in development of a regime river course with minimum aggradation and degradation for channelization purpose.

3 Study Areas

The study consider for channelization of river Kosi are from Chatra to Nirmali. The River Kosi meanders between Eastern and Western embankment with a bed load consisting of unconsolidated fine sand and silt. The river is approximately 720 km in length from source to where it joint to river Ganga at Kursela. Out 720 km. length of river, about 200 km. length river flows in plain. From Chatra to Kosi barrage, the distance is 42 km. and from Kosi barrage to its 47 km downstream near Nirmali reach is considered for study (Fig. 3).

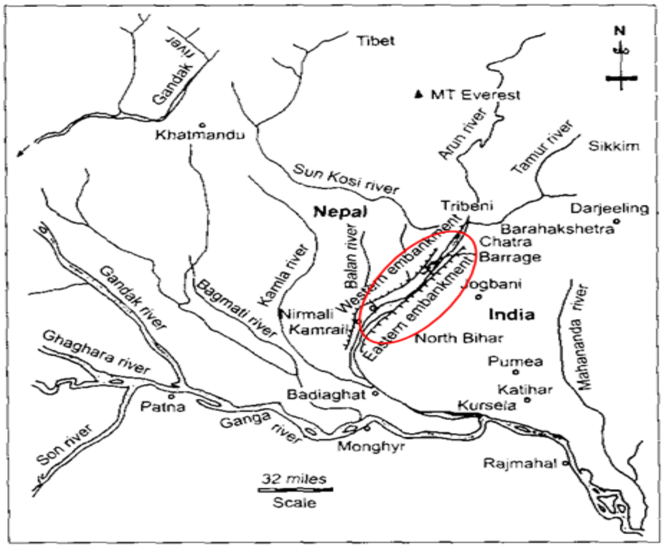

Figure 3 Plan showing study area (Burele et al., 2010).

4 Available Data

The data of River cross-section post 2002 flood at 1 km interval for the reach from 42 km upstream to about 47 km downstream of Kosi Barrage was collected (Fig. 4,5 & 6).

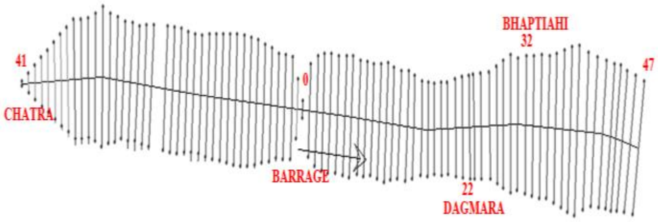

Figure 4: Plan showing cross-section

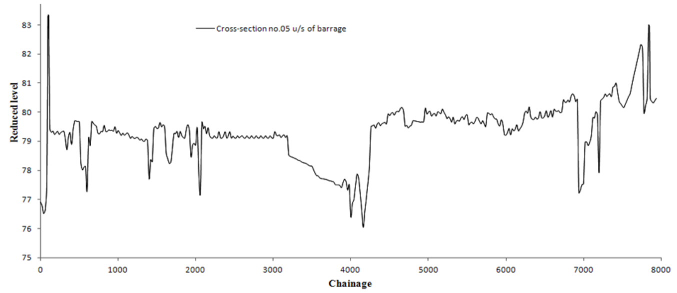

Figure 5: Typical Cross-section (c/s no. 05 u/s of barrage)

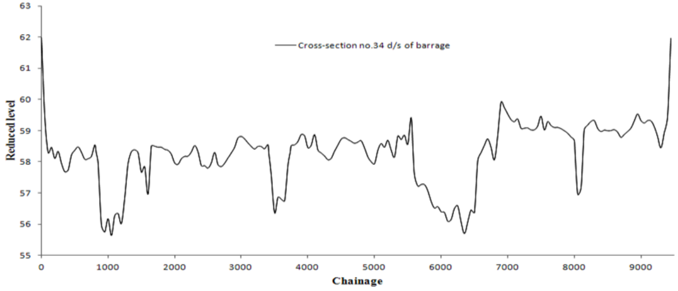

Figure 6: Typical Cross-section (c/s no. 34 d/s of barrage)

Two gauges one at Dagmara (22 km downstream of barrage) and another at Bhaptiahi (32 km downstream of barrage) were established in May 2002. The data of water level at these gauge sites were recorded at an interval of six hours during the period from June to December 2002.

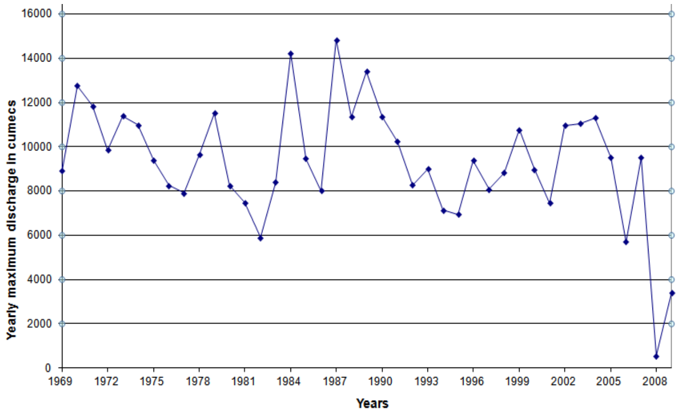

Figure 7: Annual peak flood discharge

It is established that the 100 year and 500 year return period flood discharges are 22375 m^3/s and 26900 m^3/s, respectively. Figure 7 for annual flood frequency analysis indicates that from last 40 years the annual flood frequency does not exceed 15590 m^3/s cusecs, so, for this model study same is considered.

The riverbed material samples at three locations along the river width including the deep channel portion and foot of Eastern and Western embankments were collected in May 2002. The typical grain size distribution curves for a sample are shown in Fig. 8. It could be seen that the river bed material is composed of medium and fine sands with mean diameter (D_{50}) of 0.23 mm

Sediment in the river can be classified as fine sand with no or little clay content and has a D_{50} of 0.23 mm. The discharge and sediment data were collected daily and recorded at the barrage for a period of June 2001 to April 2003. Similarly, inflow hydrograph at Kosi barrage for the period 01May 2002 to 1 January 2009 was available.

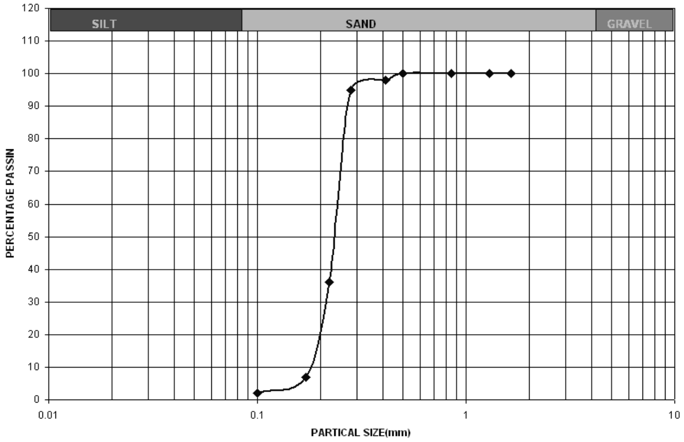

Figure 8: Grain size distribution curve

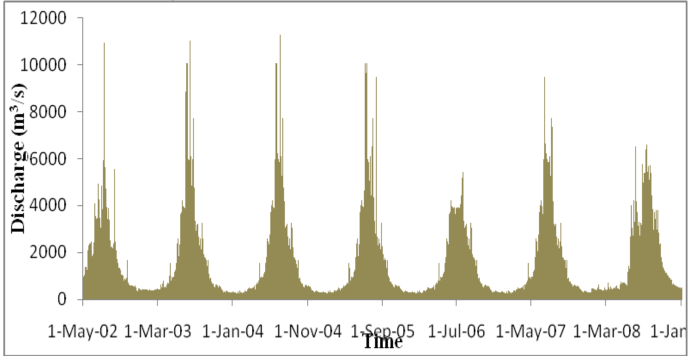

Figure 9: Inflow Hydrograph at Kosi barrage

5 Model Developments

5. a) Development of sediment rating curve

The discharge and sediment concentration data collected during the period of June 2001 to April 2003 at Kosi barrage was used for the study. A relationship between water discharge Q and the sediment discharge Q_s was evolved using this data and is plotted on log graph. This is presented in Fig. 10. A best fit relation was developed and is used in mathematical model HEC-RAS.

$$Q_s = a*Q^b$$

Where- Q = water discharge (m^3/s), Q_s = Sediment discharge (million ton/day), a = proportionately constant = 0.0104 and b = 2.283

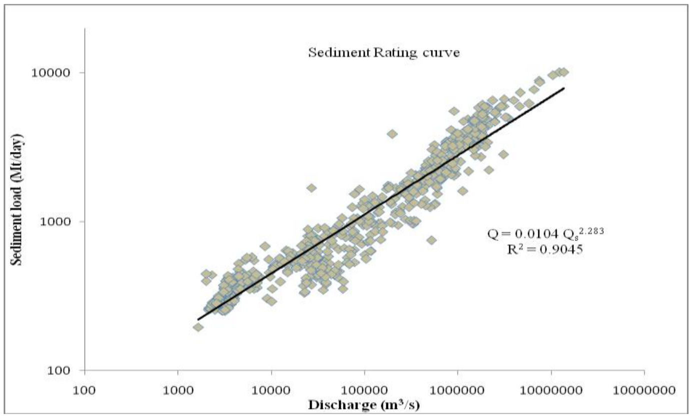

Figure 10: Rating curve for sediment load

5. b) Numerical Model

b.1 Governing Equations

The numerical models (HEC RAS) solves the De Saint Venant equations describing unsteady flow in open channel and the continuity equation for the conservation of the sediment mass.

Continuity equation:

$$\frac{\partial h}{\partial t}+\frac{\partial q}{\partial x}=0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Momentum equation for water:

$$\frac{\partial q}{\partial t}+\frac{\partial}{\partial x}\left[\frac{q^2}{h}+\frac{gh^2}{2}\right]+gh\frac{\partial z}{\partial x}+ghS_f=0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Continuity equation for sediment:

$$\frac{\partial}{\partial t}\left[(1-\rho)z+\frac{q_s h}{q}\right]+\frac{\partial q_s}{\partial x}=0 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Evolution of the bed elevation and sediment erosion relationship

$$\frac{\partial z}{\partial t}=\frac{\varepsilon}{\rho_s} \qquad \varepsilon=\varepsilon_m\left\{\frac{\tau_b-\tau_{cr}}{\tau_{cr}}\right\}^{\alpha} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

in which h is the flow depth; q the water discharge per unit width; z the bed elevation; q_s the unit sediment discharge; S_f the friction factor; x the distance along the channel; t the time; ρ the porosity of the bed level; ρ_s the sediment density; ε_m and α two parameters; τ_b the bottom shear stress; τ_{cr} the critical bottom shear stress.

The friction slope S_f is evaluated using the Chezy – Manning relation:

$$S_f=\frac{q^2n^2}{h^2R^{\frac{4}{3}}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

with R the hydraulic radius and n the Manning roughness coefficient which is evaluated by the Einstein relation, taking into different roughness values on the wetted perimeter P:

$$n=\left(\frac{P_{sw}n_{sw}^{3/2}+P_b n_b^{3/2}}{P}\right)^{2/3} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

$$\tau_b=\rho_w gRS_f\left\{\frac{n_b}{n}\right\}^{3/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

in which ρ_w is the water density.

6 Calibration Of Model

6.1 Conformity of Manning's "n" values

Proving studies were carried out for verifying the conformity between mathematical model and observed data in respect of water surface profile in Kosi river by varying values of Manning's 'n'. The discharge and water level data of Kosi river recorded during monsoon of year 2002 were utilized for this purpose. The maximum discharge recorded at Kosi barrage during this period was 10960 m^3/s. For this discharge at Kosi barrage, the corresponding water levels recorded at Dagmara and Bhaptiahi were 64.3 m and 60.2 m respectively. The village Dagmara and Bhaptiahi are situated at c/s no. 22 and 32 downstream of the barrage. The values of Manning's 'n' were varied for discharge of 10960 m^3/s and the water level computed by using mathematical model at Dagmara and Bhaptiahi were compared with the actual observed values. It was found that Manning's n value of 0.022 gives better comparison and is used for further studies. The results of these proving studies are presented in Table-1

Table-1

Gauge site	Gauge levels		
	As observed during 2002 flood	Mathematical model result	
		n = 0.025	n = 0.022
Dagmara	64.30 m	64.79 m	64.67 m
Bhaptiahi	60.20 m	60.21 m	60.11 m

6.2 Model Proving Studies

Cross-sections of the river were measured in April/May 2002. The cross-section data shows the water levels recorded along these cross-sections during the survey, while the river carried a discharge of 2000 m^3/s. The cross-section data as above along with Manning's 'n' value as 0.022 were used as input data for the mathematical model. The results of this study were compared with the water surface elevation recorded all along the cross-sections and are presented in Fig. 11. The comparison is found to be satisfactory; hence the use of Manning's 'n' value as 0.022 is justified.

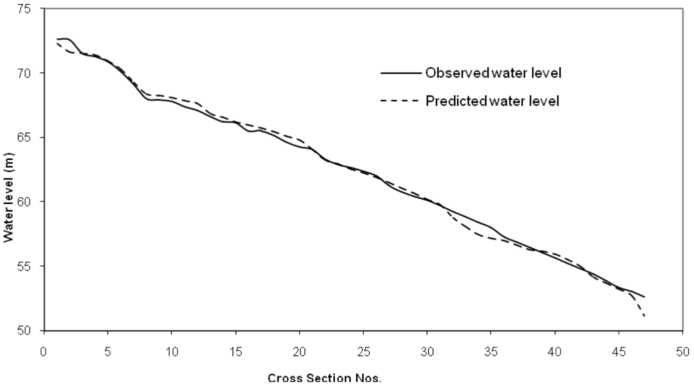

Figure 11: Comparison of prototype water surface profile with mathematical model results for Q = 2000 m^3/s

7 Morphological Changes

The change in river bed profile and the course occur due to several years of flows and long term simulations are necessary for predicting these changes. The topographical data in the form of river cross sections is required to simulate river flows. The water level and discharge data at boundaries and two or three locations within model reach are required for specifying boundary conditions.

The required river cross sectional data was available in the month of May 2002. The cross sections of the river within the embankment were at a regular interval of 1.0 km, from 41 km upstream of Kosi barrage to 47 km downstream. Data pertaining to sediment and discharges (Figs.10), recorded at the Kosi barrage were also used for the present studies.

Mathematical model (HEC-RAS) was run with the input data as discussed above for a discharge variation as shown in Fig. 7. The water way computed using Lacey's formulae $W = 4.83\sqrt{Q}$ (for Q = 26900 m^3/s maximum flood) is 800 m. The waterway provided at the Kosi barrage is 1100 m. These two waterway were adopted for computation along with a waterway of 2000 m and without any constriction i.e. river flowing between the existing levees. The aggradation / degradation in the bed profile for various waterway widths are presented in Fig.12.

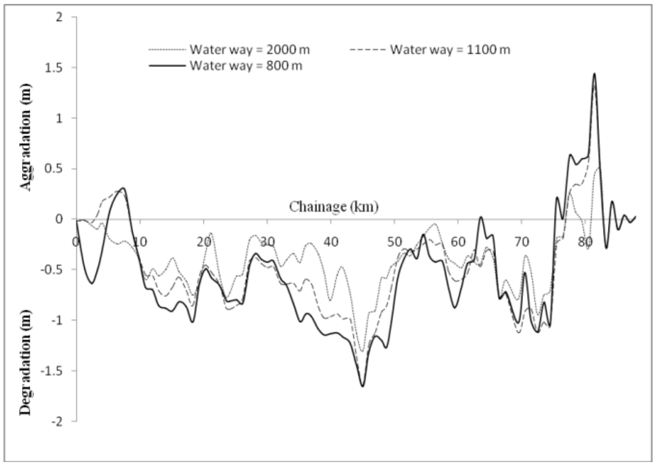

Figure 12: Morphological changes of bed level with respect to river bed level of year 2002

It can be observed by these results that the river bed is aggrading by about 0.1 m to 0.25 m on an average in a year without any constriction. It is estimated based on survey data that the Kosi river bed is aggrading by about 3 to 9 m in 50 years. The results of mathematical model agree well with this prototype measurement data. The river bed is observed to aggrade even when the waterway is 2000 m, while it is observed that the bed level is degrading when the waterway provided is 800 m equivalent to Lacey's waterway. However, the river bed aggradation / degradation is minimum when the waterway provided is 1100 m. The mathematical model shows degradation during the initial 2 year periods only (Fig. 12 to 17). However, the river bed remained unchanged indicating regime channel. The average velocities in the river without any constriction ranged about 1 m/s. However the average velocity were 2.2, 2,7 and 3.3 m/s for 2000 m, 1100 and 800 m water way respectively (Fig. 13). It is also observed in the vicinity of Kosi barrage that, the sedimentation near the spillway portion has not affected the operation of the barrage over nearly 50 years. The barrage has a waterway of 1100 m. The river Kosi reach constricted to 1100 m width would result in a regime channel which will not be either degradation or aggradation.

It is seen from the figure 21, that many a places level of water overtops embankment, if one of the either bank consider as leeves then top level of that bank is to be raised and also has to strengthen or a new leeves to be constucted.

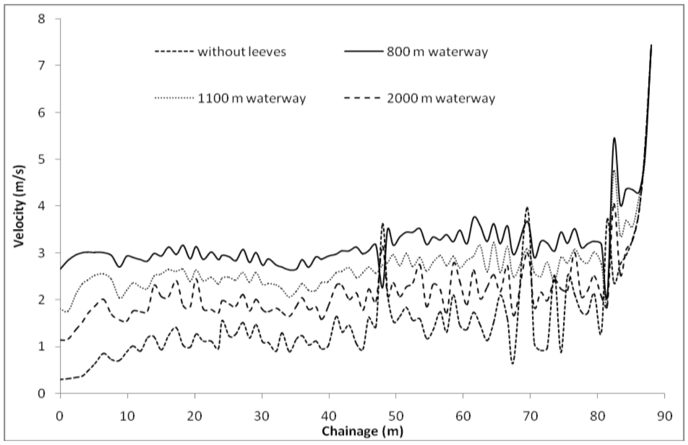

Figure 13: Velocity distribution longitudinally for various channelization width

EXAMPLE - 1

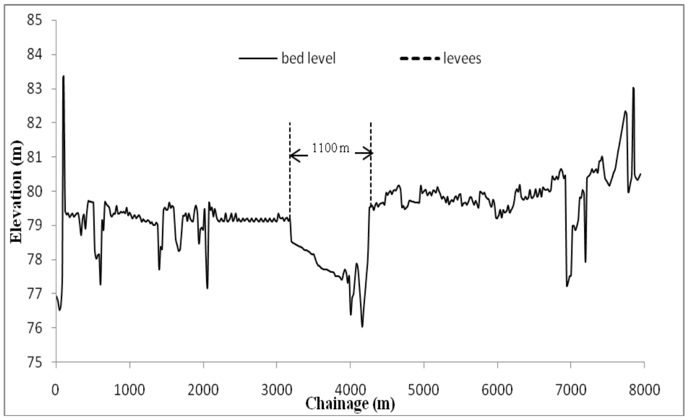

Figure 14: Cross-section no. 05(u/s) showing position of leeves

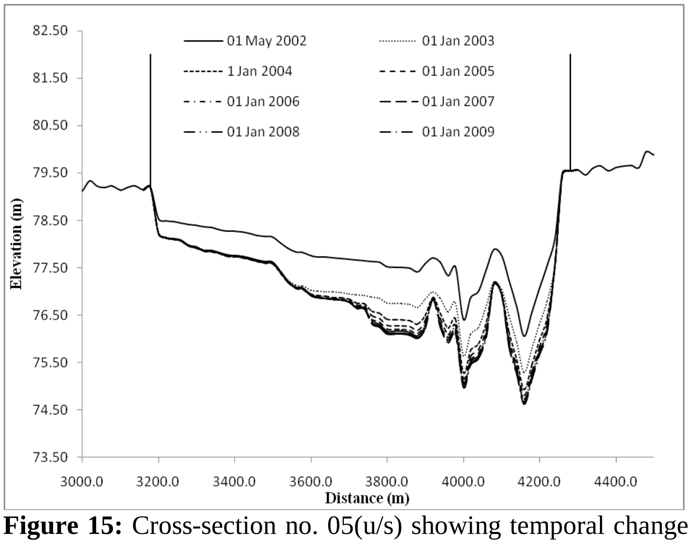

Figure 15: Cross-section no. 05(u/s) showing temporal changes in bed level for consticted waterway = 1100 m

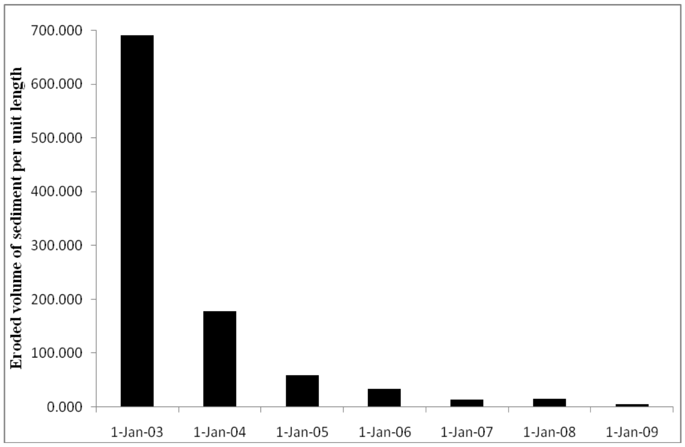

Figure 16: Temporal variation of eroded volume of sediment per unit length at cross-section no. 05(u/s)

EXAMPLE – 2

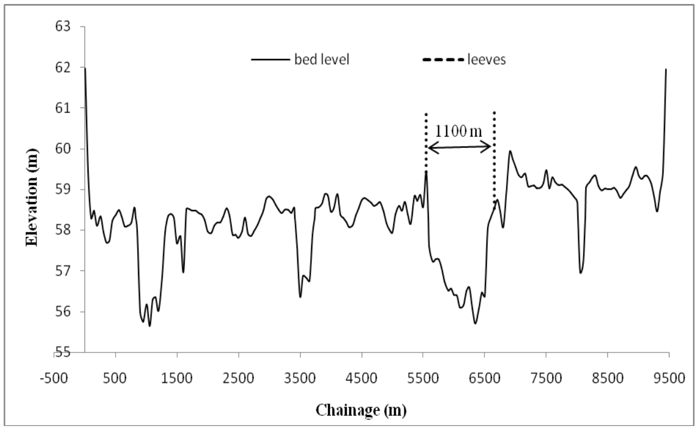

Figure 17: Cross-section no. 34(d/s) showing position of leeves

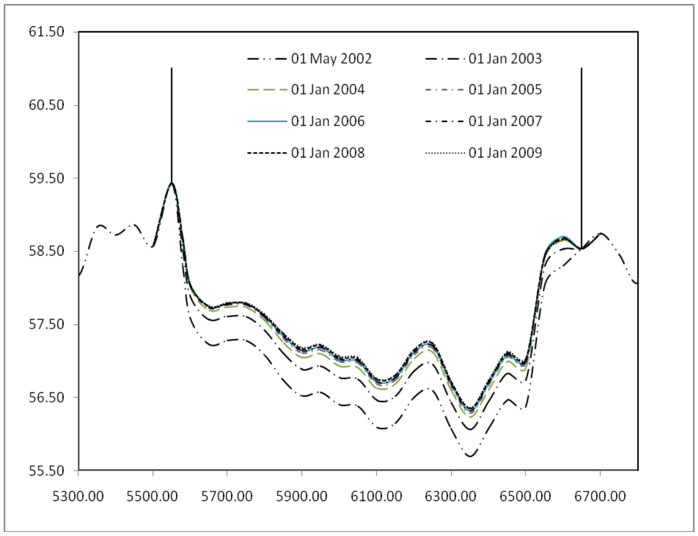

Figure 18: Cross-section no. 34(d/s) showing change in bed level due to constriction of waterway

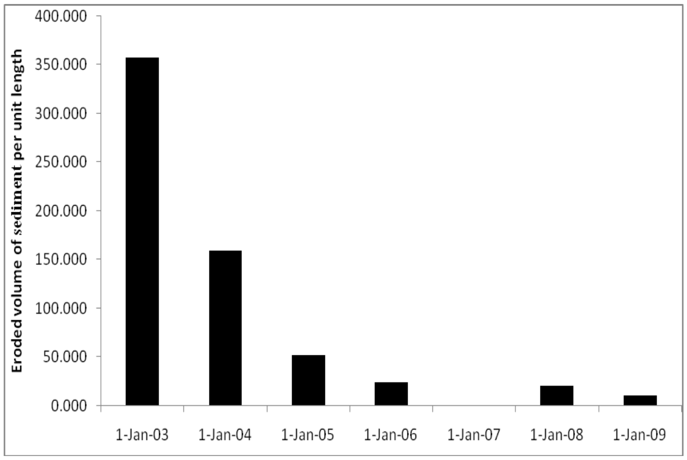

Figure 19: Temporal variation of eroded volume of sediment per unit length atcross-section no. 05(d/s)

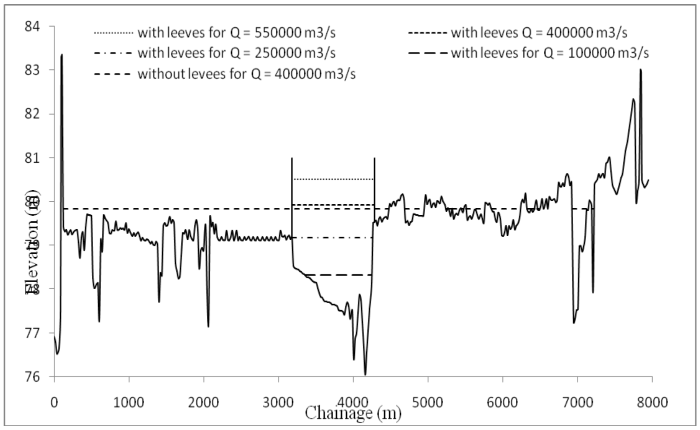

Figure 20: Typical cross-section showing watel level of 1100 m waterway

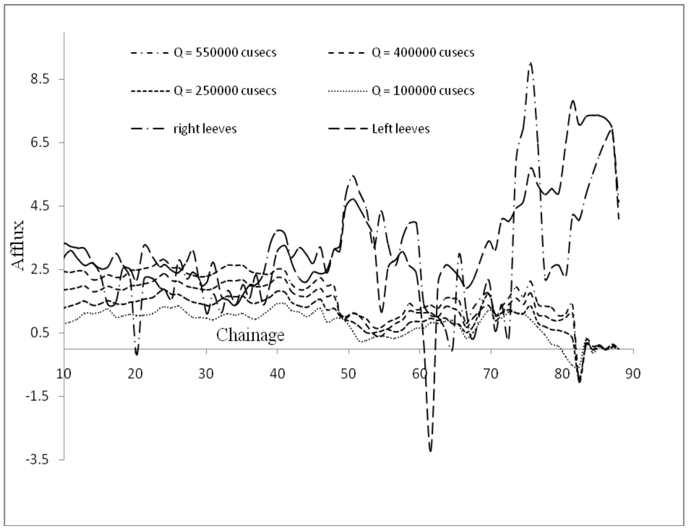

Figure 21: Afflux for waterway 1100m

8 Conclusion

The mathematical model studies was conducted for the channelization of river Kosi. Various waterways were considered including the Lacey's waterway. The study indicates that the river did not aggrade/degrade for a waterway of 1100 m which is also equivalent waterway provided at the Kosi barrage. The Kosi barrage has not been affected by the sediment for the last 50 years and it is seen that there is no aggradations / degradation in the vicinity of the barrage portion. This along with the mathematical model studies indicate that the River Kosi would be in regime without aggradations or degradation with the waterway of 1100 m.

HEC-RAS being a 1D mathematical model, so it is not possible to reproduce the structures like spur, guide bunds of barrage etc. Attempt has been made for channelizing river Kosi considering limited hydraulic aspects. Further, detailed studies need to be carried out using physical and 2D mathematical models with additional field data.

9 Acknowledgements

We wish to express our deep sense of gratitude to Shri. Shanmugam Govindan, Director, Shri. M. N. Singh, Joint Director and Dr. R. G. Patil, CRO, CWPRS for constant encouragement and valuable suggestions during the course of this study.

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