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Impact of River Valley Shape on Flow Characteristics in Case of Flooding

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Abstract

The properties of a river flow strongly depend on the shape of river valley. Especially the magnitude of flooding downstream a dam significantly changes with respect to the shape of downstream river valley. There are different shape parameters of the river valley which could affect the flow through a river. This paper focuses on the impact of valley slope and width on main flow characteristics (discharge and water level) in case of flooding. As a basis for systematic hydraulic analysis, the Jhelum river valley downstream of Mangla dam in Pakistan has been considered. First the Jhelum river valley has been classified according to the available river classification systems and then artificial new valley shapes have been produced by making different changes in valley slope and width with respect to the available guidelines. For all valley shapes, unsteady flow modeling has been carried out by using the model MIKE 11 for different flooding scenarios. The changes in flood routing results of different valley shapes have been analyzed. This study would guide in assessing the behavior of other river valleys in the world with respect to the severity and extension of flooding. The results of this study would also be helpful in planning structural and non-structural flood safety measures for river valleys in Pakistan as well as in other parts of the world.

Key Words: Valley shape, River classification, Flooding, Unsteady flow modeling, Jhelum river valley

1. Introduction

The flow pattern in a river changes according to the geometry of river valley. In case of high flooding in a river valley, the extent of flooding also changes with respect to the typical shape of the river valley. For different rivers, the response of the river valley to flood water would certainly be different. There are many parameters of river geometry which are responsible for the conveyance of regular river flows and floods. This paper discusses the impact of valley slope and width on flow properties (discharge and water level) in case of flooding. For this purpose, the Jhelum river valley downstream of Mangla dam in Pakistan has been taken into consideration. The project reach is about 329 km long downstream of Mangla dam with different hydraulic structures as shown in Figure 1. In order to analyze the impact of valley shape on flow characteristics, the Jhelum river valley has been first classified by different available systems of river classification. Then different changes in the Jhelum river valley with respect to valley slope and width have been made to develop new valley shapes for analysis [1].

Depending on available data, one dimensional hydrodynamic modeling for unsteady flow conditions has been carried out for different valley shapes by using the tool MIKE 11. Different scenarios of high flooding (with and without dam failure) were considered for the unsteady flow simulations of produced valley shapes. The results of flood routing for different scenarios of valley shapes have been analyzed. This study is intended to provide useful guidelines for the estimation of intensity and expansion of flooding along a river valley with respect to its particular valley shape.

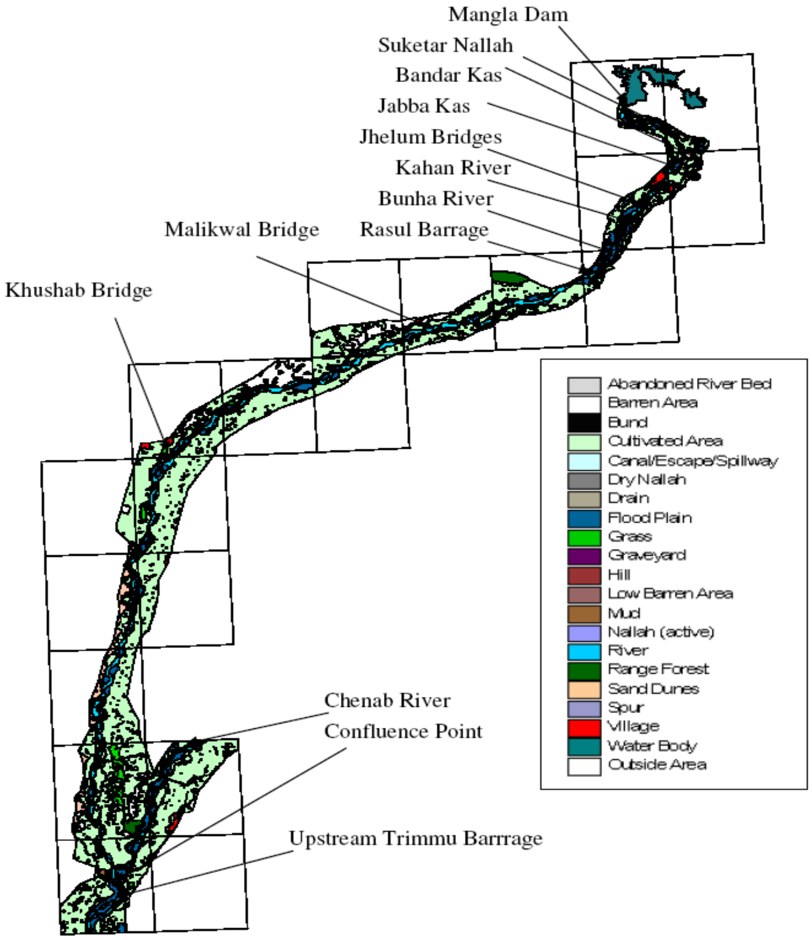

Figure 1: Jhelum river valley downstream of Mangla dam [1]

2. River Classification

In this research, different river classification systems have been studied to classify the Jhelum river valley downstream of Mangla dam. River classification systems are very important for knowing the features of a river valley. They provide useful guidelines for understanding the geometry of river cross-sections. Different important parameters of the river valley can also be calculated according to these classification systems.

2.1 *River Classification System*

Different classification schemes have been developed based on different purposes. The categorization of river systems by channel morphology is justified in order to achieve to some

- Predict the behavior of a river from its appearance
- Develop specific hydraulic and sediment relations for a given morphological channel type and state
- Provide a mechanism to extrapolate site-specific data collected on a given stream reach to those of similar character
- Provide a reliable frame of reference of communication for those working with river systems in a variety of professional disciplines in the following, two main classification systems of rivers have been briefly discussed.

1. *Rosgen Classification System*

The Rosgen classification system is based on a hierarchical approach. The benefit of hierarchical assessment is that it provides the physical, hydrologic and geomorphic context for linking the driving forces and response variables at all scales of inquiry [3]. The hierarchical approach is a process-based procedure. It was developed by formulating morphological process relationships at the reach level and then determining how to extrapolate these relationships to a larger scale [3]. The hierarchical system has four levels of assessment. These levels start at a broad geomorphic scale and progress down to a detailed-specific description and assessment. The level of required data collection and analysis increases as the resolution improves through the levels. Different levels of Rosgen Classification are illustrated in Figure 2. [2], [3], [4].

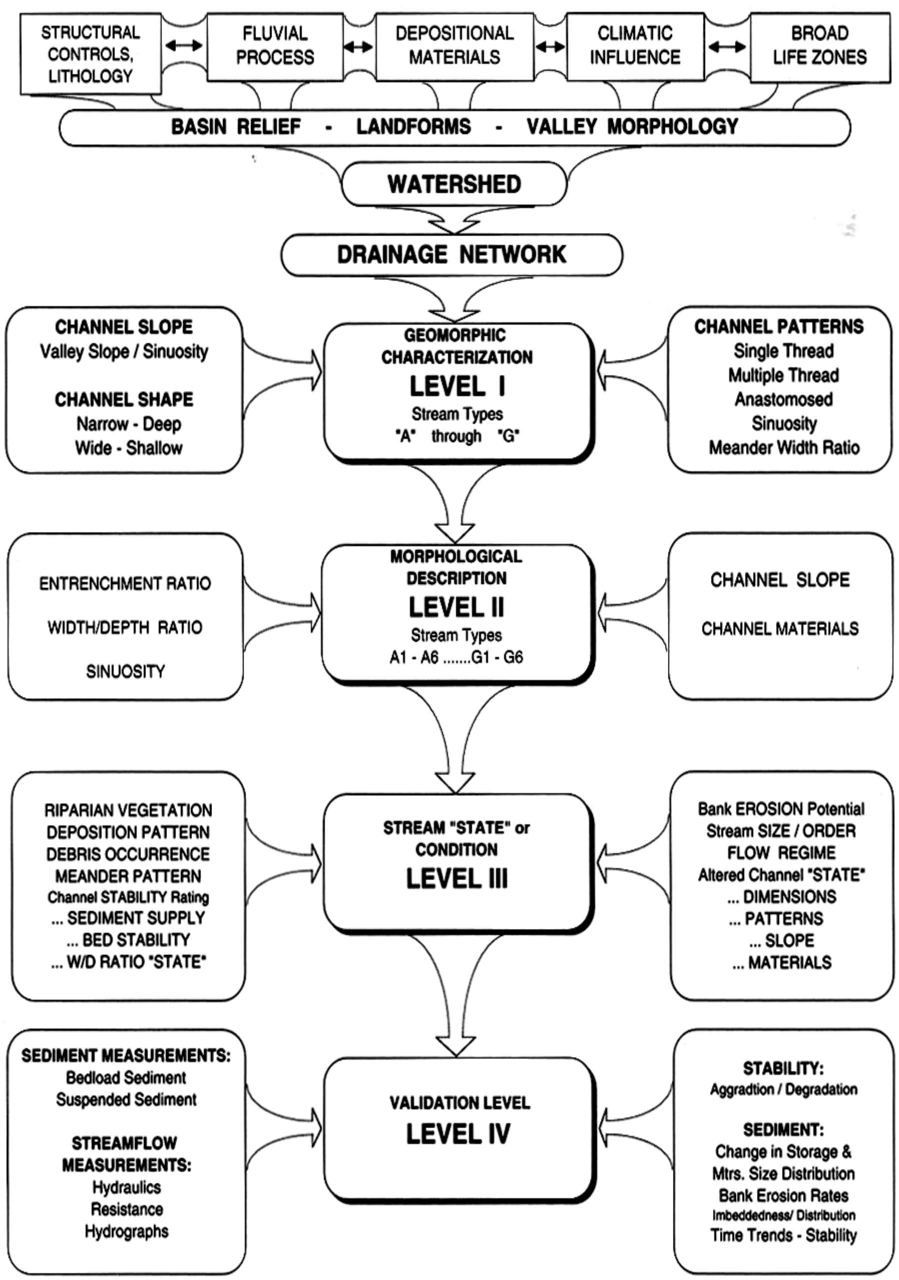

Figure 2: Rosgen Hierarchy [3]

2. *Montgomery and Buffington Classification System*

The Montgomery and Buffington classification system is a classification of landscape and channel form that gives a base for interpreting channel morphology, assessing channel condition and predicting response to natural and anthropologic disturbance. Channel types are defined based on channel morphology, sediment transport processes and sediment flux characteristics as controlled by hydraulic discharge and sediment supply. It uses maps and aerial photos to classify reach boundaries by estimating stream gradients, degree of valley confinement, channel meander patterns and significant changes in predominant rock types. Montgomery and Buffington channel classification includes a range of scales over which various factors affect channel characteristics. A natural division of scales that shows differences in processes and controls channel morphology is given by geomorphic province, watershed, valley segment, channel reach and channel unit scales. [4], [5]

Figure 3 shows an idealized stream showing the general distribution of channel types from the hilltop down through the channel network [5].

In order to classify the Jhelum river valley, different guidelines from both classification systems have been used with respect to the available data of the Jhelum river valley downstream of Mangla dam.

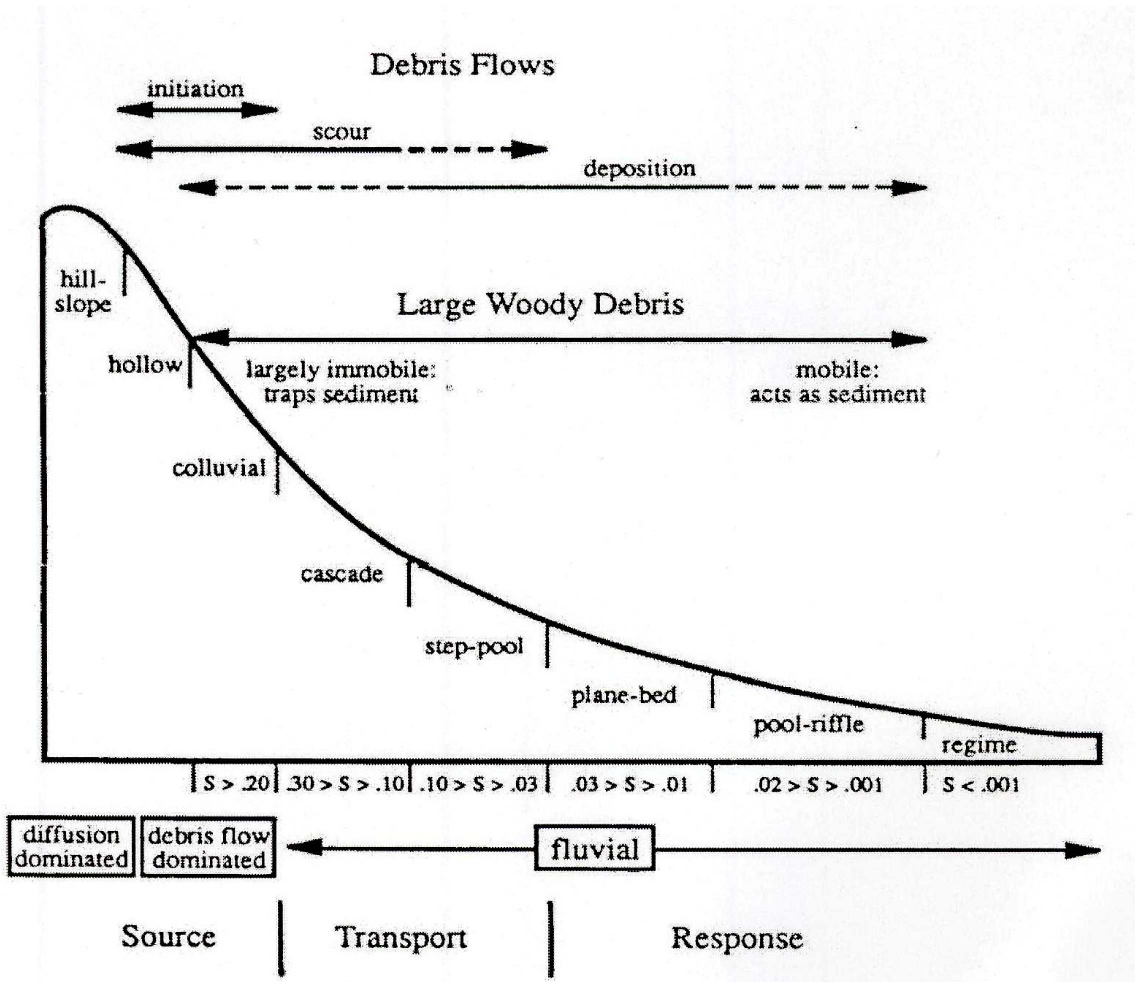

Figure 3: Idealized stream showing the general distribution of channel types [5]

2.2 *Classification of Jhelum River Valley*

Depending on the available data, the Jhelum river valley downstream of Mangla dam has been classified with respect to following parameters. [1]

- Sinuosity
- Slope
- Width

Sinuosity

Sinuosity is the ratio of stream length to valley length. It shows the meandering behavior of a river. According to the available data, the sinuosity of Jhelum river valley has been computed to be 1.27 which comes into the category of moderate sinuosity according to Rosgen [2].

Slope

Slope or gradient is the ratio of vertical distance to horizontal distance. Channel slope is a measure of how far the channel drops over a horizontal distance. Channel slope is one of the important factors that influence the flow velocity in the channel. For Jhelum river valley downstream of Mangla dam, slope has been computed at all locations (between the consecutive cross-sections). The mean slope of the Jhelum river valley is about 0.0004. It comes into the category of 'regime' with slope<0.001 according to Figure 3 [5].

Width

Width is also an important parameter in a river valley. It has been considered in the following two ways, [1], [2], [3]

- Width/Depth ratio (with respect to bank full discharge)
- Entrenchment ratio

According to the computed width/depth ratios at downstream cross-sections, the Jhelum river valley has been classified as *'very broad and shallow valley'*. By definition, the entrenchment ratio is the ratio of the width of flood-prone area to bank full surface width of the channel [2], [3]. The flood prone width is defined as the width measured at an elevation that is twice the maximum bank full water depth. This flood prone elevation has also been related to a frequent flood (50 years or less return period) by field observations [2], [3]. Figure 4 clearly represents the bank full width and flood prone width. Different entrenchment categories are mentioned in section 3.2.

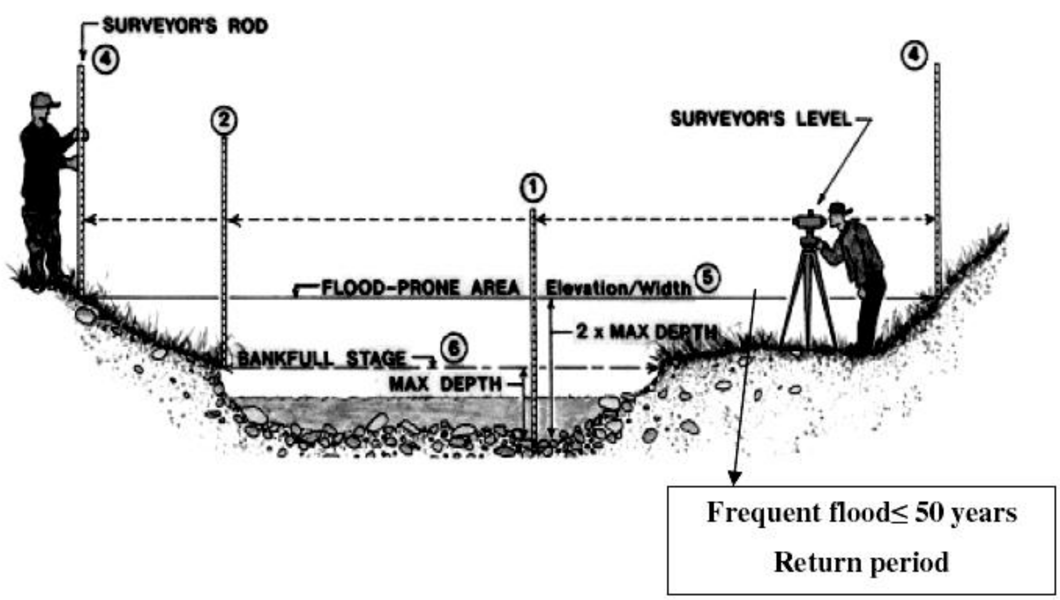

Figure 4: Computation of entrenchment ratio [3]

According to the available data of cross-sections, it was not possible to measure the flood prone width at an elevation that is twice the maximum bank full depth. As the elevation at twice the bank full depth was exceeding the maximum cross-section limits for most of the cross-sections due to broadness and shallowness of the Jhelum river valley as illustrated in Figure 5 [1].

In this case, the available definition of flood prone elevation with respect to a frequent flood (50 years or less return period) has been considered. The criteria of entrenchment by Rosgen [2] were developed for natural streams and small rivers. For such natural streams and small rivers the flood of 50 years or less return period can be a frequent flood. But this definition of frequent flood is usually not applicable to large river valleys like Jhelum river valley. For large river valleys, it is considered that a flood of 5-15 years return period would have significant impact [1]. Depending on available data, the results of 1997 flood (8 years return period) have been considered for the computation of entrenchment ratio [1]. With respect to the entrenchment ratio, the Jhelum river valley has been classified as *'moderately entrenched'* and *'slightly entrenched'* by Figure 2 [3].

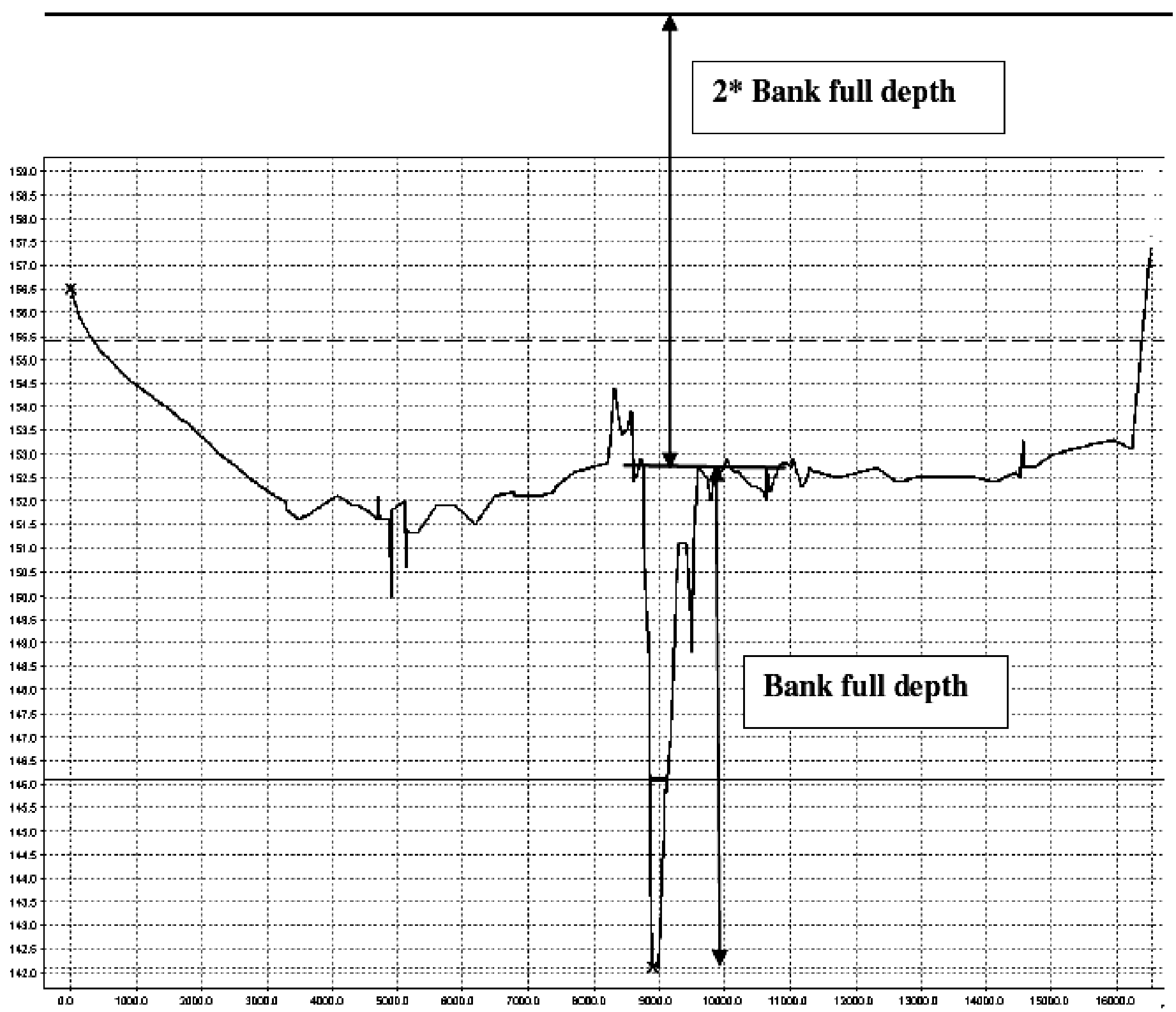

Figure 5: Flood prone elevation exceeding the maximum cross-section limits

3. Development of New Valley Shapes

Considering the available data and above discussion, following changes in the Jhelum river valley have been suggested in order to produce new valley shapes for further analysis.

- Changes in valley slope
- Changes in valley width

Both parameters are very important in a river valley. They influence the flooding quite significantly.

3.1 Changes in Valley Slope

The Jhelum river valley is very broad and shallow with a mean gentle slope of 0.0004. According to figure 3, this mean slope comes into the category of 'regime' with slope<0.001 [5]. For such very broad and shallow rivers, valley is usually not so steep [6]. In order to analyze the effect of valley slope on flow characteristics in case of high flooding, different valley shapes have been produced with the following suggested valley slopes. Different slope values have been considered up to 0.001 starting from the mean value of 0.0004. Additionally, a higher slope of 0.0015 has also been considered in order to have an example of the pool-riffle category (0.02<S>0.001) as shown in figure 3 [1], [5].

Considered Valley Slopes were 0.0004, 0.0007, 0.0009, 0.001 and 0.0015.

For each valley shape, the elevations of the consecutive cross-sections were changed according to the considered slope and the same slope was maintained throughout the reach length. In this way, different valley shapes with respect to the considered valley slopes were developed. All other parameters have been kept the same for these valley shapes. Figure 6 shows the bed levels of cross-sections for suggested valley slopes and the original valley slope downstream of Mangla dam.

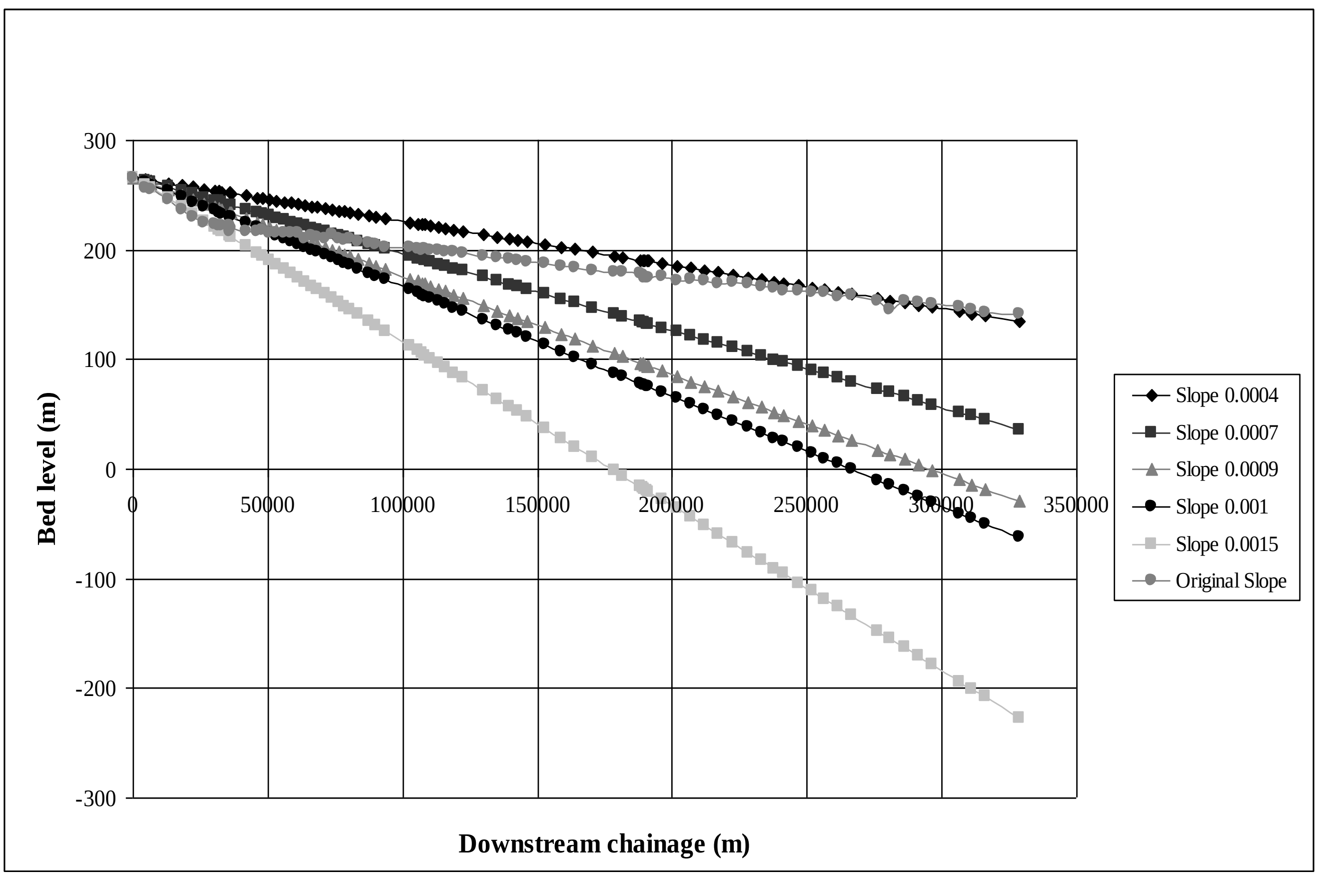

Figure 6: Bed levels of downstream cross-sections for different valley slopes

Depending on the data availability, different changes in the width of valley have been suggested in terms of entrenchment ratio. The entrenchment ratio has been categorized in the following way as illustrated in Figure 2 [2], [3].

1 – 1.4	entrenched
1.41 – 2.2	moderately entrenched
> 2.2	slightly entrenched (well-developed flood plain)

The Jhelum river valley has been classified as *'moderately entrenched'* and *'slightly entrenched'*. For this research, different valley shapes have also been produced with the following suggested entrenchment ratios (for 97-flood of 8 years return period) in order to analyze their impact on flow properties.

Considered Valley Widths were 1.4, 1.8, 2.2 and 2.6.

For different valley shapes the entrenchment ratios have been kept the same for all downstream cross-sections. The bank full width has not been changed. Only the flood prone width of cross-sections has been changed accordingly to have respective entrenchment ratios for different valley shapes. As an example a typical cross-section of Jhelum river with different entrenchment ratios is shown in Figures 7 and 8.

4. Unsteady Flow Modeling

For new valley shapes with the different suggested changes, one dimensional hydrodynamic modeling for unsteady flow conditions has been carried out by using the program MIKE 11. One dimensional flood routing in MIKE 11 is based on an implicit finite difference scheme developed by Abbott [7]. MIKE 11 is capable of using kinematic, diffusive or dynamic and vertically integrated equations of conservation of continuity and momentum (the 'de Saint Venant' equations), as required by the user [8], [9]. The basic equations are derived considering the conservation of mass and conservation of momentum [8].

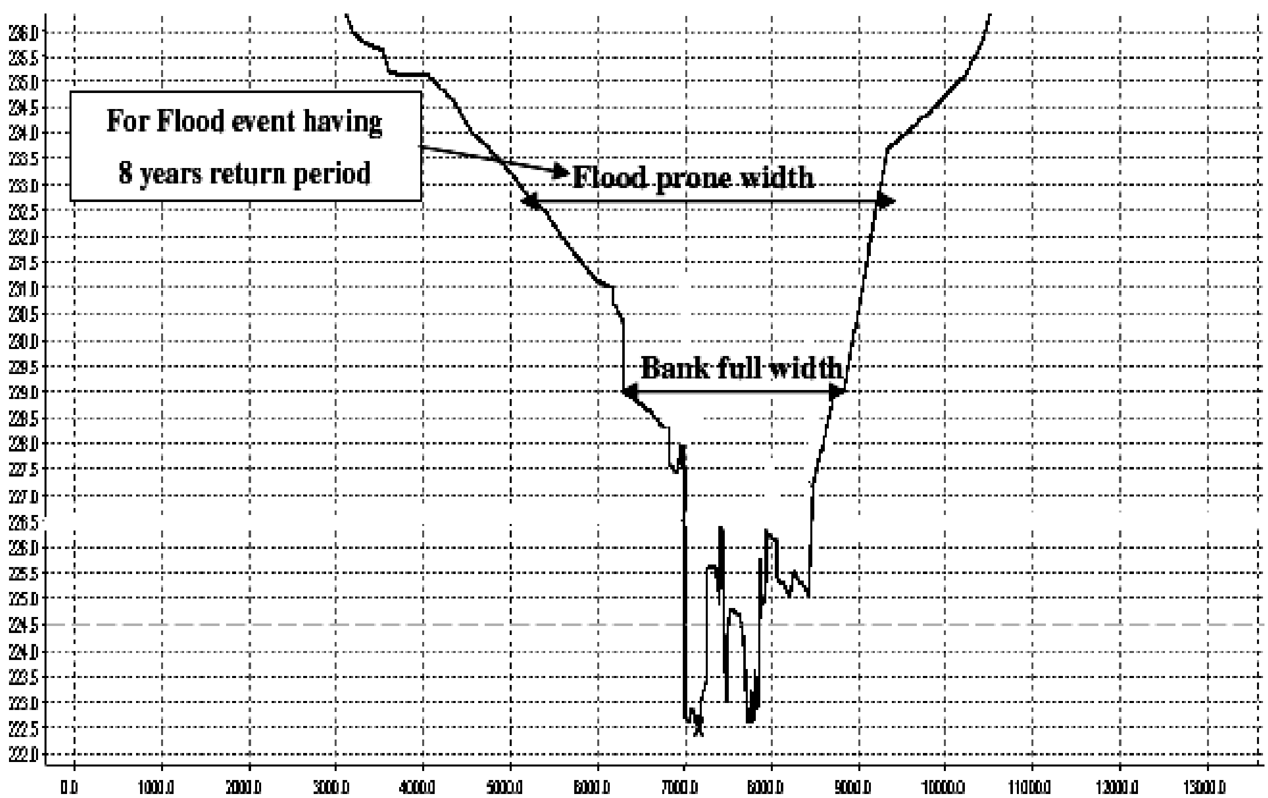

Figure 7: Typical cross-section with entrenchment ratio 1.4 for Jhelum river

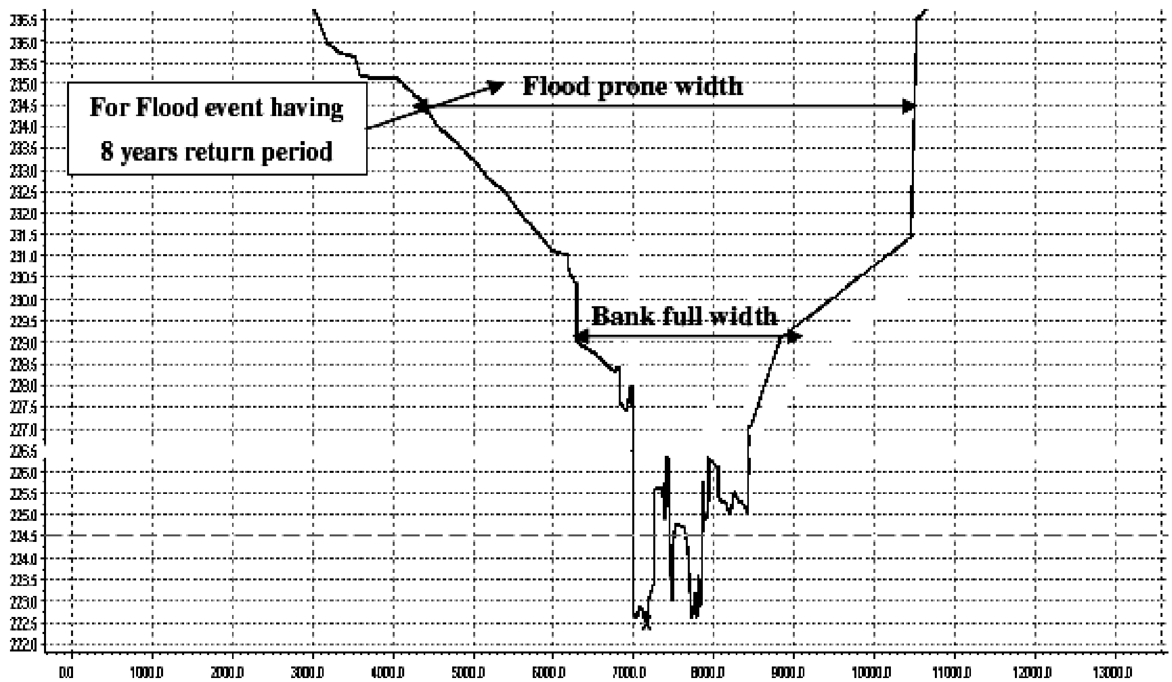

Figure 8: Typical cross-section with entrenchment ratio 2.2 for Jhelum river

instabilities due to the changing position of hydraulic structures with respect to the changes in valley shape, hydraulic structures (weirs and bridges) have not been considered in all modeling scenarios. After calibration and validation, model was run for different flooding scenarios with and without dam failure. Depending on the requirement, necessary extrapolation of cross-sections has also been done. The maximum outflow for the worst case of dam failure is more than 300,000 m^3/s which could be the highest possible discharge after the failure of Mangla dam [1], [10]. The computed failure outflow hydrographs from dam break modeling and other flood hydrographs have been considered for the upstream boundary in different flood routing scenarios of valley slopes and widths. The downstream water level boundary changes with respect to change in elevation in case of varying valley slope. While in varying valley width, the downstream boundary remains the same.

4.1 *Flood Routing Results for Different Valley Slopes*

The unsteady flow simulations were run for different scenarios of slope changes. For all modeling characteristics. In Figures 9 and 10, the results of discharge and water level have been shown for the worst case of dam failure flooding. The maximum discharge decreases along the river valley due to the retention of upstream hydrograph with respect to the geometry of cross-sections. It is quite clear from the results that with the increase in valley slope, discharge increases and the water level decreases at all river locations (cross-sections). In other words, it can be said that the steeper the valley, the higher the discharges and vice versa. Moreover, the steeper the valley the lower the water levels and vice versa. With an increase in valley slope the flowing water accelerates due to increase in elevation (between river cross-sections). Because of this fast flow and increase in elevation, water does not accumulate itself to increase water levels. The water levels for different valley slopes have been relatively represented with respect to the corresponding bed levels of cross-sections (Figure 6). The differences in the results at downstream locations are very significant for different slope cases. The overall flood severity in the river valley would increase and flood travel times would decrease (due to fast flooding) with the increase in valley slope.

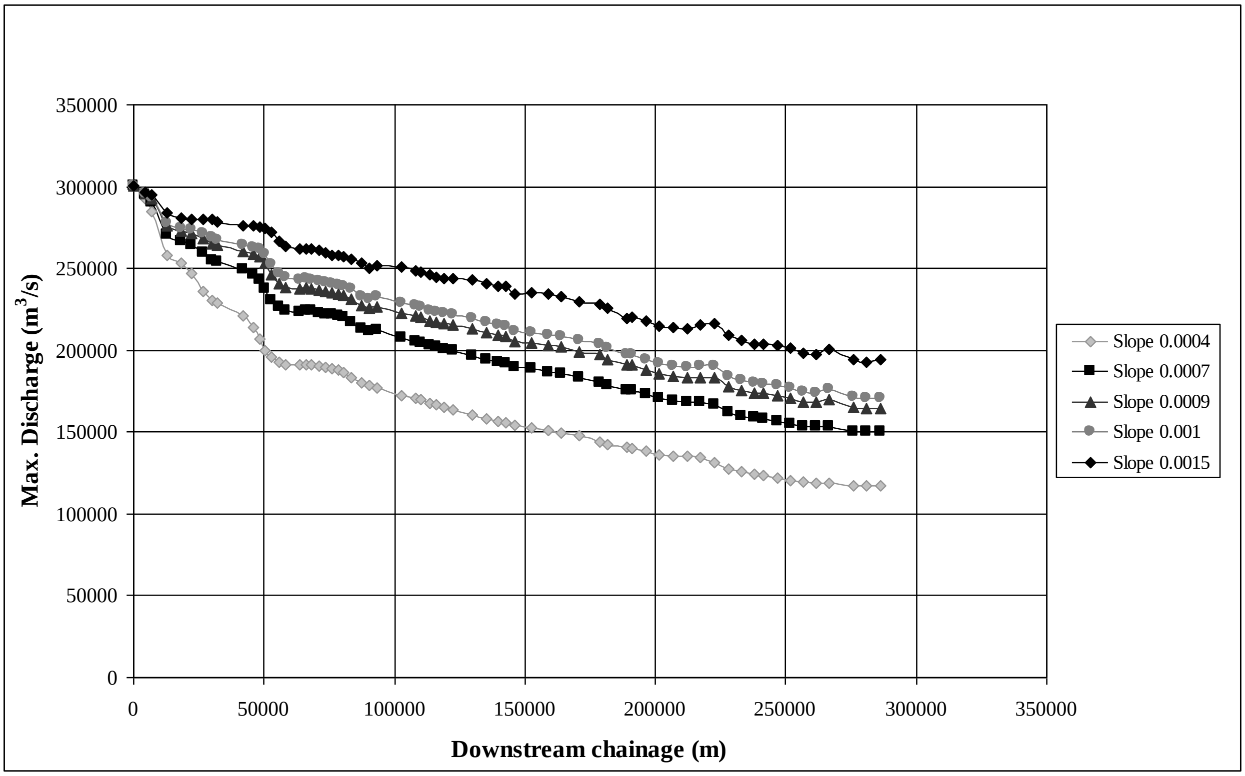

Figure 9: Impact of valley slopes on discharge

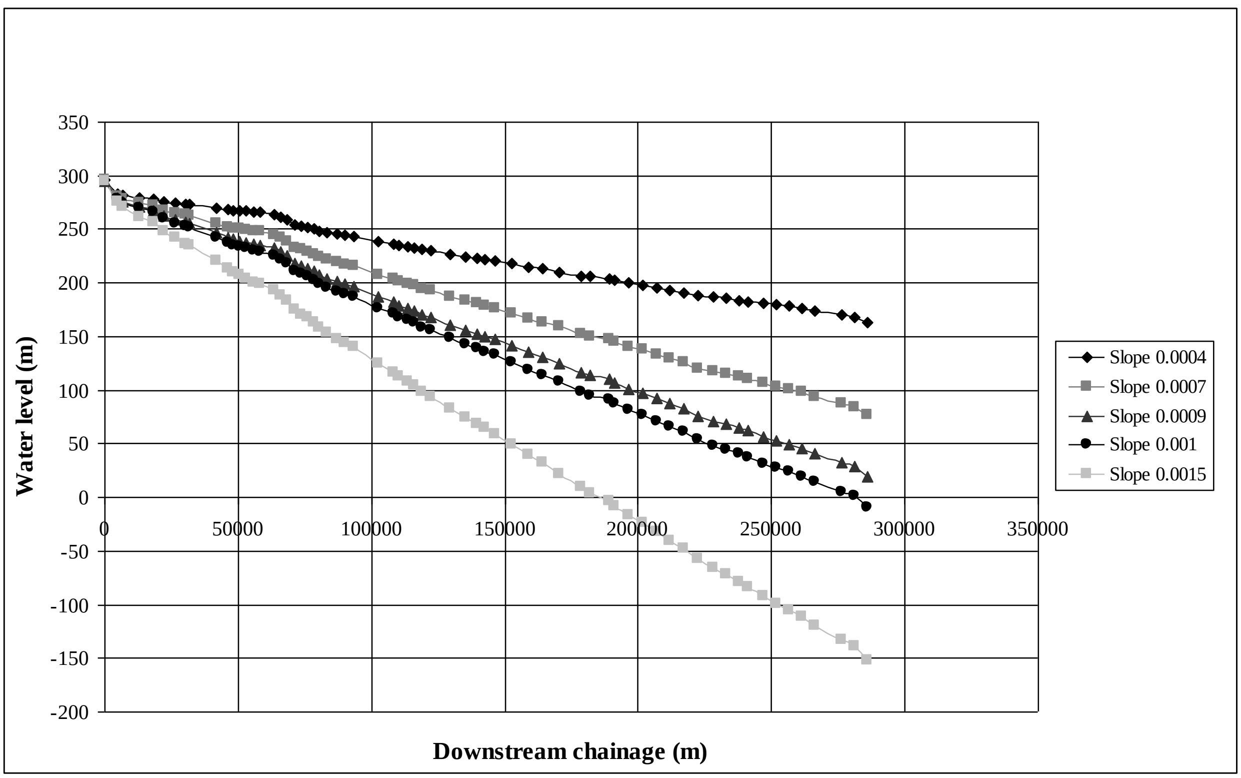

Figure 10: Impact of valley slopes on water level

4.2 Flood Routing Results for Different Valley Widths

For different valley widths (entrenchment ratios), model runs were made for unsteady flow conditions. The results of all flooding scenarios represent the same character. The differences in the results for different valley width cases are not as big and significant as in the case of valley slopes. But they show the impact of change in valley width on discharges and water levels. In order to have a clear understanding, the closer views of results for a part of the project reach have been shown in Figures 11 and 12 for the worst case of dam failure flooding. It is obvious from the results that both the discharge and water level decrease with the increase in valley width (entrenchment ratio) and vice versa. In other words, the broader the valley the lower the discharge and water level and vice versa. Due to increase in the width of a river cross-section the flowing water extends more along the flood plains to accommodate itself. This process decelerates the flowing water and also reduces the water level. The overall flood severity in the river valley would decrease and flood travel times would increase (due to comparatively slow flooding) with the increase in valley width (entrenchment ratio).

5. Conclusions

This paper emphasizes the impact of the river valley shape on typical flow characteristics in case of flooding. The impact of valley slope and width on flow properties (discharge and water level) has been separately analyzed for different flooding scenarios. The changes in the flood routing results are more significant in different valley slope cases as compared to the valley width cases. It was found that with the increase in valley slope, discharge increases and the water level decreases. On the other hand, with the increase in valley width (in terms of entrenchment ratio) both discharge and water level decrease. It is also concluded that with an increase in valley slope, the overall flood severity in a river valley would increase due to fast flooding. But in case of increase in valley width (entrenchment ratio), the overall flood severity in a river valley would reduce due to comparatively slow flooding. The outputs of this study would guide for the estimation of possible flood extension and flood severity in different river valleys in the world with respect to their specific valley shapes. This study is also intended to help in planning flood protection measures (structural and non-structural) for river valleys in Pakistan as well as in other parts of the world.

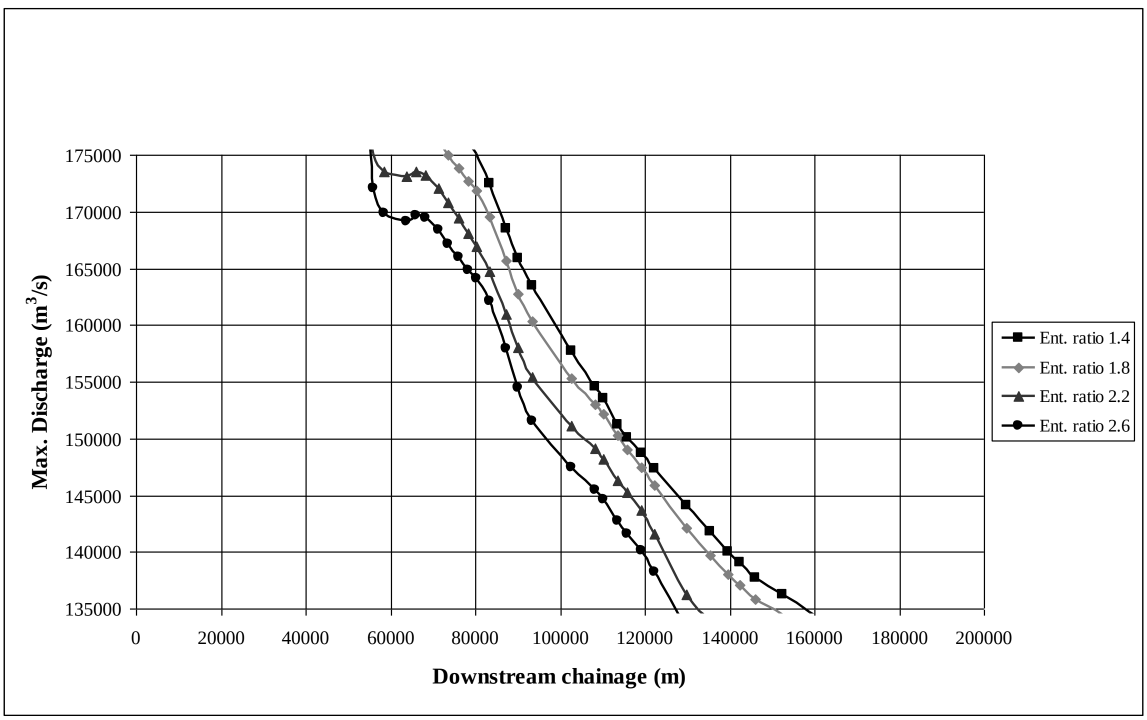

Figure 11: Impact of valley widths on discharge

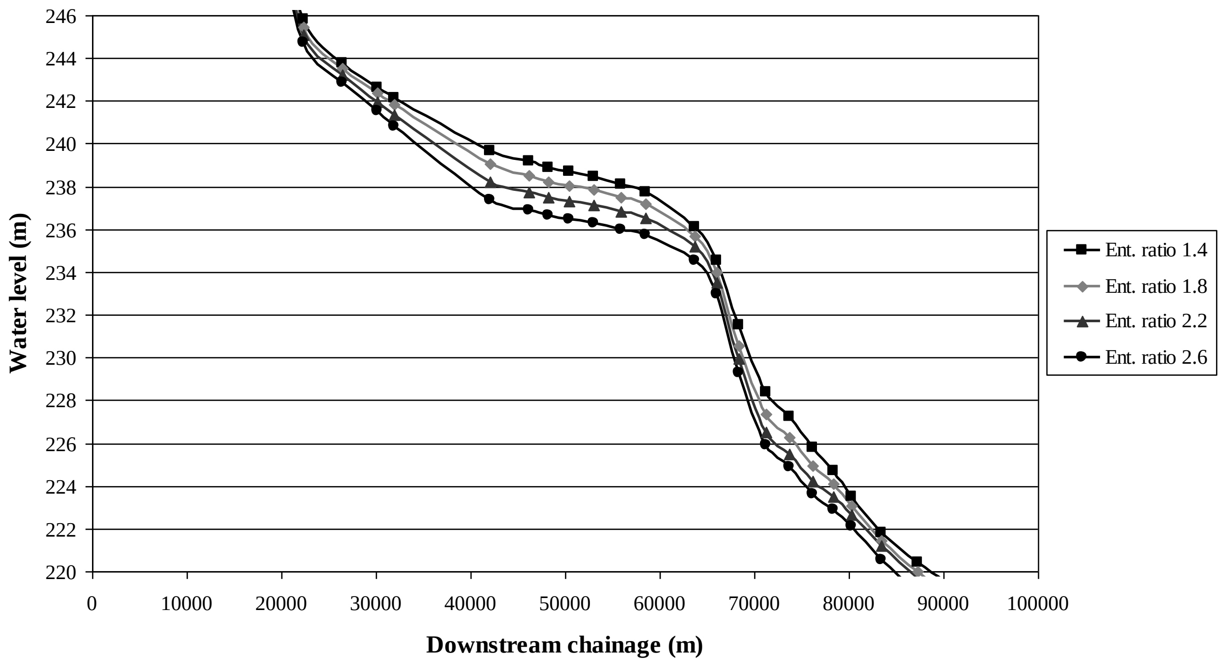

Figure 12: Impact of valley widths on water level

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REFERENCES

[1] Ehsan, S.; (2009). Evaluation of Life Safety Risks Related to Severe Flooding, Dissertation Book, Institut fuer Wasserbau, Universitaet Stuttgart, 180, ISBN: 978-3-933761-84-2.

[2] Rosgen, D.L.; (1994). *A Classification of natural rivers*, *Catena, Elsevier Science B.V.*, 22, 169-199.

[3] Rosgen, D.L.; (1996). Applied River Morphology, ISBN: 0-9653289-0-2.

[4] Patterson, L.; (2003). *Examination of stream and habitat classification systems to aid in computer habitat modeling*, Master's Thesis, Institut für Wasserbau, Universitaet Stuttgart, Germany, Ch-3.

[5] Montgomery, D.R. and Buffington, J.; (1993). *Channel classification, Prediction of channel response and Assessment of channel condition*, Report FW-SH10-93-002, SHAMW committee of Washington state timber-fish-wildlife Agreement.

[6] Schumm, S.A.; (1977). The Fluvial system, John Wiley and Sons, New York.

[7] Abbott, M.B. and Ionescu, F.; (1967). *On the numerical computation of nearly-horizontal* flows, *Journal of Hydraulic Research*, 5, 97-117.

[8] Reference Manual MIKE 11 (2004). A modeling system for rivers and channels.

[9] User Guide MIKE 11 (2004). A modeling system for rivers and channels.

[10] Ehsan, S., Marx, W. and Wieprecht, S.; (2008). *Precise estimation of Warning times for downstream areas in case of catastrophic flooding due to Dam failure*, 9. Forum Katastrprohenvorsorge (Disaster reduction), Deutscher Wetterdienst , Offenbach, Germany, ISBN: 978-3-933181-43-5.