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Safe Passage of Riverine Flood from Highly Urbanized City: A Case Study of Lahore City in Pakistan

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Abstract

Unplanned urban spawn in developing countries have resulted in spring of settlements within floodplain of the rivers. Lahore City of Pakistan depicts such an example. In past 100 years, two exceptionally high floods in Ravi River created havoc in the Lahore City, resulting in huge loss of properties and lives. To assess current flood hazards, the researchers analyzed present hydraulic capacity of Ravi River along Lahore City using HEC-RAS software. Digital Elevation Model of 1 m × 1 m, river cross-sectional survey at an interval of 300 m and geometry of structures were used for modeling and analysis of river in HEC-RAS. To safely pass a flood corresponding to 100 years return period, the researchers designed a channel, from Ravi Siphon to Korotana Reserve Forest. Channelization has been proposed in six reaches. Every reach has a unique geometry, based on constraints, presence of bridge, existing settlements or presence of any historic monument. Manning's equation was used for the design of each reach and analysis was performed on HEC-RAS to verify the hydraulic capacity of the designed channel. Results indicate that the potential consequences of a large flood are disastrous, but the proposed channel can safely pass a flood of 100 years return period, with minimum disturbance to existing infrastructure. The technique used in the research is globally applicable to other sites facing similar problem.

Keywords: Flood; Gumbel; River training; Channelization

Introduction

Presence of a water body has been the most important factor in establishment of human settlement. For this reason, almost all historical cities of the world lie on the bank of a river. Alexandria (Egypt) lies with Nile River, Baghdad (Iraq) lies with Tigris River, Berlin (Germany) lies with Spree & Havel Rivers, Cairo (Egypt) lies with Nile River, Damascus (Syria) lies with Barada River, Delhi (India) lies with Yamuna River, Hong Kong (China) lies with Pearl River, Jakarta (Indonesia) lies with Liwung River, London (England) lies with Thames River, Madrid (Spain) lies with Manzanares River, Melbourne (Australia) lies with Yarra River, Tokyo (Japan) lies with Sumida River, and similarly Lahore (Pakistan) lies with Ravi River.

The increase in population resulted in expansion of metropolitan areas and hence encroachment in floodplain of the rivers. This resulted in occasional flooding of areas along the river. On the other hand, the rivers with high sediment concentration gradually changed their course and shifted towards the settlements on either of both banks. An addition to these factors is the construction of dams. A country on downstream end of a transboundary river will have increased vulnerability, if the countries on upstream end have a dam on the river.

During a flood, the aforementioned factors accumulate into a huge loss of properties and lives. Hazards of floods are particularly notable in developing countries, with poor metropolitan planning and limited resources to carry out river training works. The Developed countries, however, are also not entirely safe.

The same threats are being faced by Lahore, the second biggest city of Pakistan. Historically, Lahore City was built along the Ravi River. The catchment of Ravi River lies in Monsoon region, which is associated with heavy rainfalls during summer, yielding torrential runoff [1]. For this reason, Lahore had been subjected to extreme floods in past due to high discharge in Ravi River during monsoon season. The flood of 1955 is the second highest on record flood for the Ravi River, with peak discharges of 14,932 cumecs at Shahdara. It breached flood embankments of the Bambanwala–Ravi–Bedian–Dipalpur Link Canal, upstream from Ravi Siphon, and at Shahdara Bridge. The Punjab

Irrigation Department estimated that flood discharges of 7,334 m³/s passed through the breaches at Ravi Siphon and 8,495 m³/s through the breaches at Shahdara Bridge. The flood of 1988, with magnitude of 16,309 cumecs (575,941 cusecs) at Shahdara, was the worst flood of 20th century to hit Lahore City. The flood claimed 731 lives and displaced 1,250,000 people. The Shahdara Distributary bund was breached, causing heavy flooding of the area between Shahdara and Kala Shah Kaku. Downstream, the Balloki and Sidhnai head works were subjected to discharges far in excess of their design capacities, and embankments were breached to save the structures.

According to Indus Basin Treaty in 1960, right of Ravi River belong India. India uses the water of Ravi for the purpose of Irrigation and generation of electricity. Before entering into Pakistan, Madhopur Headwork is present in India, with spillway capacity of 17,750 cumecs, further 24 km upstream is the Ranjit Sagar Dam (Thein Dam), having spillway capacity of 20,678 cumecs (CWC India). The Ranjit Sagar Dam was put into operation in 2011. This massive storage, if released at the rate of maximum spillway capacity, can create a huge flood. To safely pass any flood, it is mandatory to leave maximum width for the river flow; which is now absent for Ravi River along Lahore.

Due to change in temporal flow pattern, spatial river course [2], urban development [3], increase in river pollution [4] and frequent flooding (World Bank 2010), the connection between Ravi River and planned metropolitan area of Lahore City have lost. Bund roads on both sides of the river are meant to keep the city and river segregated. Although the unplanned urban spawn, increase in industrialization and

decrease in average flows have resulted in increase in unplanned and unapproved settlements around the river, there is no effective planning to integrate the river as a part of the city.

With the advent in hydraulics engineering, many sophisticated methods have been developed to save developed areas from flood inundation and keep a healthy connection between city and the river. Some of these methods include (i) Storing of excessive water and gradual release by construction of dams, retention basins or reservoirs; (ii) Confining flood water to a flood way by construction of levees or floodwalls (iii) Watershed treatment, which can be employed to help the soil on slopes to become more absorbent of rainfall until flood heights have receded. (iv) Channel improvements, which include, straightening to remove undesirable bends, deepening and widening to increase size of waterways; clearing to remove brush, trees and other obstructions or lining with concrete to increase efficiency.

Since 19th century, engineers and planners have come up with an interactive solution of river channelization to mitigate flood as well as use the same water to enhance quality of urban areas, increase standard of living and add aesthetics to the city. In recent years, river channelization is being excessively used in combination with construction of upstream retaining structures to allow urbanization around channelized river. This kind of schematics is called a waterfront. During last 40 years, extensive channelization of natural streams has occurred around heavily populated and advanced cities. Generally, the channelization is done to maximize the value and area of developable land by reducing flood hazards. The conventional design methods used for flood control channels were developed mainly based on research carried out between 1900 and 1950.

River channelization also poses risks to the surrounding environment by imposing negative effect on habitats, the aquatic ecosystem, and the natural function of floodplains. Sometimes, the environmental destruction is to such a great extent, that the channelization had to be reversed [5]. Main reason of such results lies in the way they are planned. The major considerations while planning a river channel has been to create a waterfront for human development and use it for recreation, commercialization or a center of urban development. As the study area has already suffered a great loss of loss of habitat in recent years [6], it is important to keep provision for sustenance of bio-diversity in any river training work.

Study Area

The Ravi River originates in the Himalayas in the Multhan tehsil of Kangra district of Himachal Pradesh, India and is mostly fed by snow melt. Many tributaries join Ravi River downstream of its source. It then flows along the Indo–Pak border for 80 kilometres before entering Pakistan and flows past one of the major cities in Pakistan, i.e., Lahore. A number of nallahs and drains also join the river within boundary of Pakistan. Most important drains are Bein and Basanter Drains.

Flows in the river have a great temporal variation, which results from structural interventions from Indian side and Rainfall pattern. The flow in Ravi River is measured by gauging station installed on Railway Bridge near Shahdara. Monthly averages flows from October to March are very less. The average flow in these six months is 46.4 cumecs. The maximum average flow occurs in the months of July, which is 546 cumecs. While minimum average flow is in December, which is 40.4 cumecs.

Lahore City is located in North East of Punjab Province and is the second biggest city of Pakistan. Currently population of Lahore is 9.3 million people. Owing to increase in population, industry and migration from other parts of the country, the area of Lahore has almost

doubled in the last 12 to 14 years. The development around the river lacks proper planning and government interest due to floods during high flow seasons and unhygienic conditions during low flow seasons in the Ravi River.

Focus of this research was on the part of Ravi River, around Lahore City. The selected portion extends from Ravi Siphon to Korotana Reserve Forest (Figure 1). This part is surrounded by unplanned population, which is expected to increase (Figure 2). The first step of planned urbanization in this area will be confinement of river and improvement in its aesthetics.

As reported by Punjab Irrigation Department, Ravi Siphon has a discharge capacity of 12,740 cumecs. Along Lahore City, five bridges are present of Ravi River; namely, Railway Bridge, Old Shahdara Bridge, New Shahdara Brudge, Saghian Bridge and Motorway Bridge. These bridges are designed for capacities of 7078 cumecs, 7078 cumesc, 9909 cumecs, 12,740 cumecs and 12,740 cumecs respectively.

According to Flood Fighting Plan [7] of Lahore Division, a flood of only 5100 cumecs (180,000 cusecs) is considered exceptionally high flood at Shahdara. It should also be noted that flood of 2590 cumecs was observed in 2014, which was in High Flood category.

Research Methodology

Data collection

Annual peak discharge data, at Shahdara Gauging Station, was obtained from Punjab Irrigation Department from year 1922 to 2013. The river cross sections at an average interval of 300 m were obtained from Lahore Development Authority. The cross sections were recorded in year 2013, covering the wet portion during normal flow period. A digital Elevation Model (1 m × 1 m) of the river and surrounding area was also obtained from Lahore Development Authority [8]. The DEM was obtained in year 2014 by Digital Globe. Geometry of bridges was also obtained from Punjab Irrigation Department.
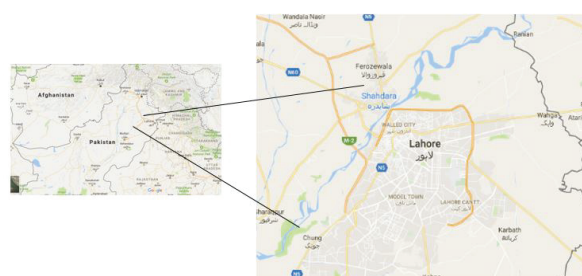

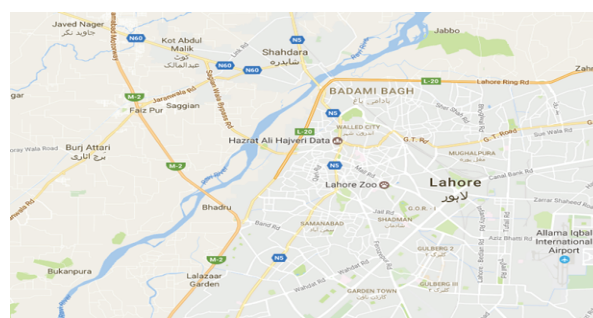**Figure 1:** Location of study area (Source: Google maps).

Figure 2: Settlements around Ravi River (Source: Google maps).

Flood frequency analysis

Flood Frequency analysis was performed on annual instantaneous maximum discharges, observed from 1922 – 2014 (93 years). Gumbel Extreme Value Type-1 method was used, in accordance with practice of Punjab Irrigation Department. The Gumbel equation is given as under:

$$Q_T = \overline{Q} + K * \sigma_{n-1} \qquad (1)$$

Where Q_T is the flood discharge corresponding to 'T' years return period, K is the frequency factor and σ_{n-1} is the standard deviation of sample size 'N'.

Standard deviation 'σ_{n-1}' is computed using following formula:

$$\sigma_{n-1} = \sqrt{\frac{\sum \left(Q - \overline{Q}\right)^2}{N-1}} \qquad (2)$$

Computation of frequency factor 'K' is done using below equation:

$$K = \frac{y_T - \overline{y}_n}{S_n} \qquad (3)$$

y_T is reduced variate. Equation of y_T is given below

$$y_T = -\ln\left[ln\frac{T}{T-1}\right] \qquad (4)$$

$\overline{y}_n$ and S_n are reduced mean and reduced standard deviation respectively. Both variables are functions of sample size 'N'. They are computed using tables.

Analysis of existing river

Hydraulic analysis of existing river was performed to assess the present hydraulics capacity of river and potential threats against different floods. This, in turn, helped to assess the threat of inundation of adjoining areas of Ravi River and hence the justification for any intervention.

Following parameters were required to develop HEC-RAS [9] model for assessment of hydraulic capacity of the river:

1. Geometry of river
2. Manning's n-value
3. Hydraulic Structures
4. Boundary condition(s)
5. Flood magnitude

As described earlier, the cross sections only extend to the width of river during normal flow season. However, for flood analysis, cross sections should be wide enough to cover the whole floodplain. On the other hand, the digital elevation model (DEM) does not represent the true river bed in wet portion of the river. To overcome both problems, the river cross sections were transformed into DEM, using GIS tools. A wider river geometry was then created by merging river bed surface and DEM (1 m × 1 m) of surrounding area. During this process, the river bed surface was prioritized. This resulted in a DEM of true ground surface of required extent.

River alignment was drawn on Google earth. The river in the project area was treated as unbraided river. The cross sections were extracted from modified DEM. The distance between cross sections was selected based on meandering and presence of hydraulic structure. Cross sections, along with the consecutive distances were exported from GIS tool and imported in HEC-RAS.

To assign Manning's 'n' values initially, the cross sections extracted from DEM surface were also exported to Google Earth. Based on different physical parameters, the manning's n values were assigned. These values were later calibrated.

The hydraulic structures, their geometry and present capacities were obtained from Punjab Irrigation Department. As the river is continuing downstream of the study area, without any obstruction or fall, the boundary condition is selected as the downstream slope. Referring to the DEM, the downstream slope is 0.00016.

The flood of 2014 was used for calibration of model and flood of 1988 [10] was used for validation. After calibration, the model was analyzed against different flows. The minimum flow which can pass from the river, without causing any structural damage to any bridge or overtopping any bund was noted as current hydraulic capacity of the river. It is to be noted here that Punjab Irrigation Department reports the capacities of bridges after leaving a free board whereas in this research, the capacities of bridges correspond to the maximum flow which can pass from the river, without causing any structural damage to any bridge or overtopping any bund. Therefore, the value reported by Punjab Irrigation Department is expected to be lesser than the value computed in this research.

Design of modified channel

Constraints: The following constraints are Present, which were required to be overcome.

1. The settlements around the river have grown to a great extent. Much of the settlements include industries which are nearly impossible to relocate.

2. Capacities of bridges are significantly low. The lowest designed capacity in study area is of Railway Bridge, which is 7100 cumecs (250,000 cusecs).

3. Shahdara Branch Canal runs parallel to the river, on the western side. The canal cannot be disturbed, as it will disturb the command area.

4. The river channel also includes Kamran's Tomb (Kamran ki Baradari) which is a historic monument and required to be preserved.

5. Tomb of Jahangir and a Cricket Stadium are present on right bank of the river, just upstream of Railway Bridge. These structures are also required to be preserved.

6. The bio-diversity of the river has already suffered to a great extent.

Design methodology

As the river passes downstream, the constraints vary. Therefore, the river was divided into multiple reaches. A few meters upstream of a new for all reaches, known parameters are design discharge (Q = 10,428 cumecs), manning's roughness (n) and depth of channel (d = 7.5 m). In every reach, either of the parameters 'cross-sectional shape', 'width' or 'slope' is varied to overcome constraints as well as enable the channel to pass the design flood. In accordance with practice of Punjab Irrigation

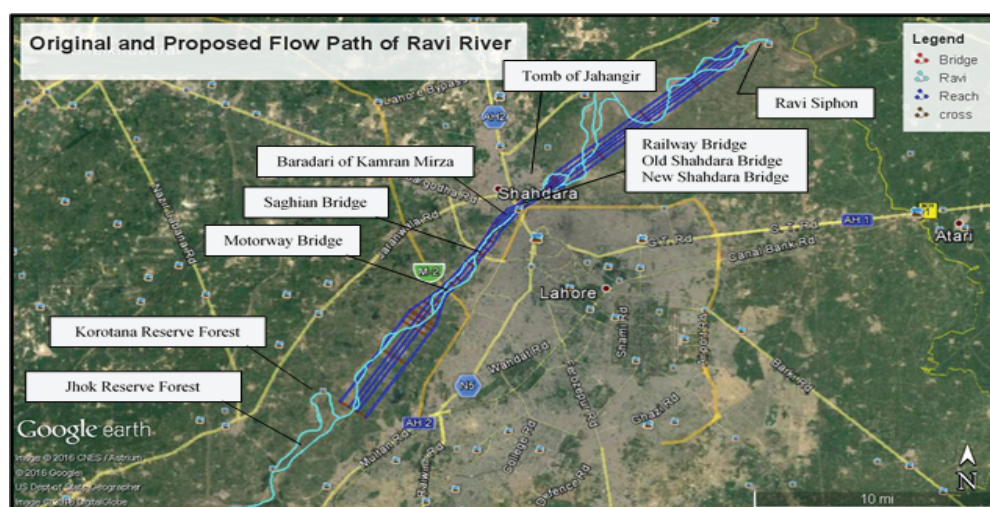**Figure 3:** Flood frequency using Gumbel extreme value, Type – 1.

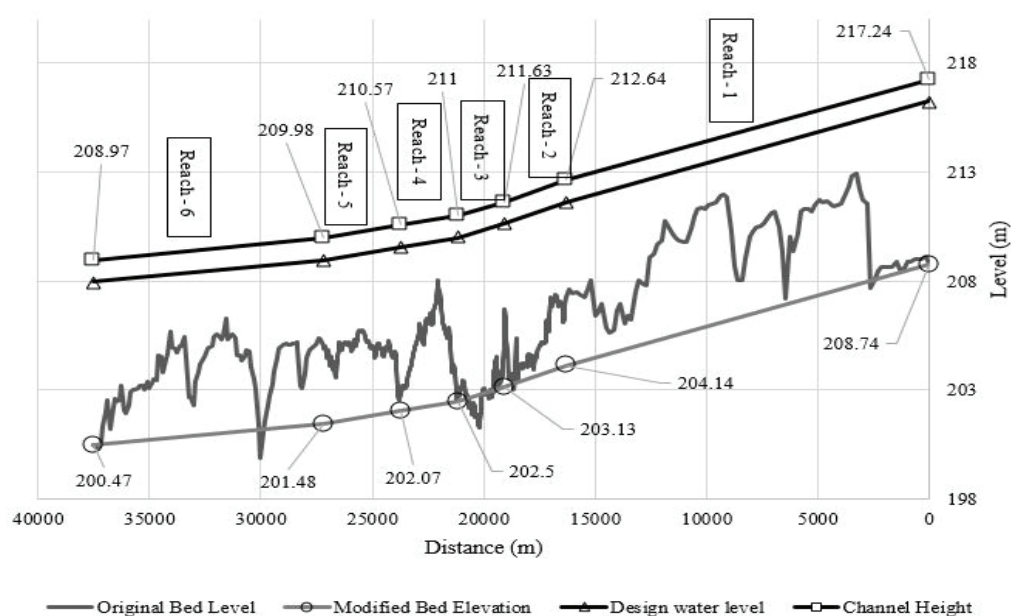**Figure 4:** Top view of original and modified of river channel (Source: Google maps).

Figure 5: Original vs. modified bed of river channel (longitudinal view).
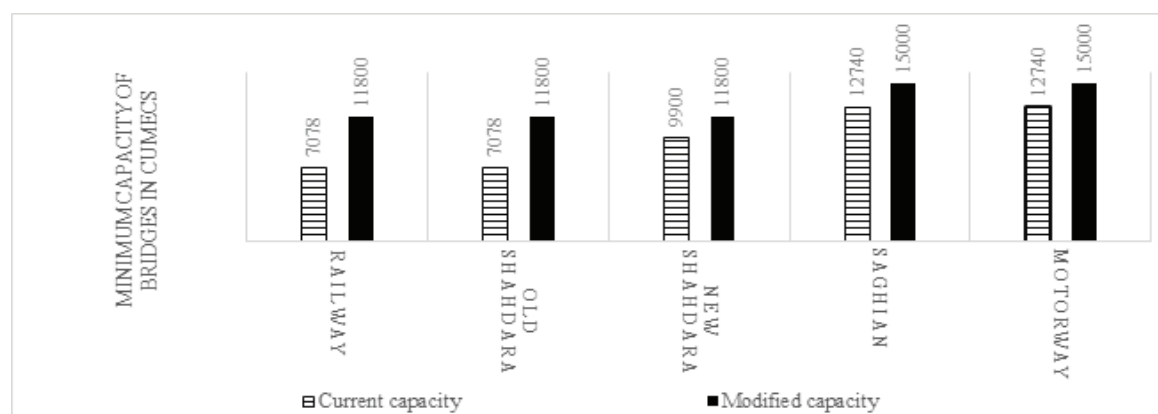
Figure 6: Increase in capacity of bridges by modification in channel.

Reach	Cross sectional Shape	Length	Slope	Width of lower cross-section	Height of lower cross-section	Bottom Width of upper cross-section	Top Width of upper cross-section	Height of upper cross-section
1	Double stage, Lower stage, Rectangular, Upper Stage, Trapezoidal with side slopes of 1:3	16329	0.0002817	442	3.75	1140	1162.5	4.75
2	Single stage rectangular	2722	0.0003728	442	8.5	-	-	-
3	Single stage rectangular	2226 2077	0.0002815 0.0003017	250 250	8.5	-	-	-
4	Single stage rectangular	2574	0.0001673	655	8.5	-	-	-
5	Single stage rectangular	3506	0.00017	655	8.5	-	-	-
6	Double stage, Lower stage, Rectangular Upper Stage, Trapezoidal with side slopes of 1:3	10295	0.0000973	655	3.75	2040	2062.5	4.75

Table 1: Geometry of designed reaches.

Department, the Manning's equation was used, as given below:

$$Q = \frac{A}{n} S^{1/2} R^{2/3} \qquad (5)$$

Where 'Q' is the discharge capacity, 'A' is the cross-sectional area of flow, 'n' is Manning's roughness co-efficient, 'S' is the friction slope and 'R' is hydraulic radius of each reach.

After detailed assessment, the proposed channel was divided into six reaches. The first reach extends from 1.7 km downstream of Ravi Siphon to Shahdara Cricket Stadium. The upstream side of proposed modified channel was kept considerably downstream of Ravi-BRB Siphon to allow construction of intake structure at later stages and allow accumulation of water for the intake structure. Second reach extends from Cricket stadium to just upstream of Kamran's Baradari. As this reach passes through a series of bridges and the width is restricted, it was proposed that this channel be built as rectangular channel having concrete walls. Third reach extends around Kamran's Baradari, a historical monument. As the baradari is directly within the flow of water, the reach was divided into two branches to save Kamran's Baradari. Fourth reach starts from downstream of Kamran's Baradari and ends downstream of Saghian Bridge. This reach was also designed as a rectangular channel. Fifth reach start from downstream of Saghian Bridge to downstream of Motorway Bridge. This reach

too is rectangular and sixth reach extends from end of fifth reach to just upstream of Korotana Reserve Forest, 9 km upstream of Hudiara Drain. During the alignment stage, it was ensured that the alignment do not pass from any major existing settlement.

Due to presence of bridges, width is a major constraint in reaches 2, 3, 4 and 5. Rather than widening of bridges, it was proposed to pass the design flood from available clear width. The rectangular cross-section is most optimum option for these reaches. A side slope will only reduce total cross sectional area, which will result in reduction of discharge carrying capacity. Vertical walls also allow the river channel to be transformed into a riverfront.

The reaches 1 and 6 were designed as two stage channels. Lower stage is rectangular and will carry average flows. Upper stage will be trapezoidal, with side slopes of 1:3. This stage allows passage of flood water. As the flooding may occur once in every few years, this area can be used for provision of temporary development such as amusement park, walk way, sports facility or for landscaping.

The actual clear height between deck of bridge and river bed was observed to be 8.5 m. The channel is designed for 7.5 m and 1 m is later added as free board.

Reaches 2, 3, 4 and 5 were solved for 'slope', required to pass the Design discharge. Reaches 1 and 6 were solved for 'width'. The reaches were designed in order of 2, 3, 4, 5, 1, and then 6. This is in order to fix slopes and geometry of reaches with constraints first and design other

reaches in compatibility with these reaches. Total drop of scheme was noted by noting the available depth of proposed reach at upstream side and available depth at downstream side. After calculating drop requirement for adequate slope for reaches 2-5, remaining drop was calculated by (total available drop – sum of drop for reaches 2-5). The available drop was initially divided between reach 1 and reach 6 in proportion to their lengths and HEC-RAS analysis was performed. After a number of trials, the most optimum division of drops between reach 1 and 6 was selected.

Hydraulic analysis of proposed channel: After computing the coordinates and elevations of nodes from above mentioned process, the alignment, in the form of a 3D surface was drawn using GIS tools. The cross sections were extracted from the 3D surface. Geometry was built in HEC-RAS by importing cross sections, assigning 'n' values and entering downstream lengths. Boundary conditions were entered as upstream slope of 0.0003 and downstream slope of 0.00016. The slopes were computed from DEM. Multiple flow values were entered to check the threshold value for which the flood water passes from the entire reach, without causing threat to any hydraulic structure. The analysis was run and results were computed.

Results and Discussion

Flood frequency analysis

The average annual peak ($\bar{Q}$) was calculated to be 2455 cumecs. Standard deviation ($\bar{y}_n$) was computed as 83796 cumecs. The value of $\bar{y}_n$ and S$_n$ are 0.5591 and 1.2026 respectively, for a sample size of 93 years.

The results of Flood frequency analysis are given in the Figure 3. The general criteria for selection of design flood for urban development is the flood corresponding to 100 years return period [11]. The same was adopted to be design discharge for design of the channel. Refer to the figure, the flood corresponding to 100 years return period is 10428 cumecs. This discharge was also compared with flow computed by the consultants in "Second Flood Protection Sector Project – Package C [12] and remodeled capacity of Balloki Barrage. The difference between the values is less than 5%.

Hydraulic analysis of existing river

After construction of model in HEC-RAS, calibration was done using flood [13,14] (2588 cumecs). Level obtained at Railway Bridge after calibration was equal to 208.05 m, while actual level observed was 208.08 m. Validation of the model was done using flood of 1988. Level obtained after calibration was 211.19 m, while actual level observed was 211.73 m.

Analysis confirms that capacities of Railway Bridge and Old Shahdara Bridge are significantly low. After a discharge of 7000 cumecs, the water level on the upstream of bridge starts rising. As the right bund is lower in height, as compared to left bund, such flood shall pose an extreme threat to the Shahdara and its surrounding areas. It was understood that the model cannot account for the strength of bridge, which in reality, can fail during high floods, if no breaching is done. Such failure will also limit the flood relief operations [15].

The researchers also observed that if the breaching section on Kala Khatai Road is operated, a vast metropolitan area will be inundated, before the water will join the river again. Considering that Lahore City is the industrial center of Punjab Province, such inundation will be a huge blow to economy of whole country.

The exceptionally high flood value is checked for return period,

using flood frequency analysis graph. It was observed that the return period for exceptionally flood (5100 cumecs) corresponds to only 7 years return period. Whereas, the flow for which structure is completely inundated (7078 cumecs) corresponds to less than 20 years return period.

Design of river channel

The river channel was divided into six reaches as discussed in section 3.4.2. Most settlements are present around reaches 2, 4 and 5. As all the bridges also lie in these reaches, the widths were kept equal to widths of bridges in the respective reaches. By allocating maximum slope to these reaches, the river was confined to very narrow widths (Table 1). Most of the settlements, including industries will not be required to be relocated. Furthermore, no bridge will require an increase in width or other structural alteration [16-21].

The Reach-3 passes around the Kamran's Tomb. Dividing this reach in two parallel Reaches (Reach 3-1 and Reach 3-2) will enable safe passage of flood, safety of the monument itself and enhancement of aesthetics. The Tomb of Jahangir and Shahdara Cricket Stadium lie on western bank of Reach 2 and through channelization, are also safe from floods [22,23]. There are relatively less settlements in the vicinity of Reach-1 and Reach-6. The availability of land enabled allocation of wider area for river in the design. As discussed earlier, these Reaches are designed as two stage channels. The lower stage will be used to carry average flows, while flood will be accommodated in upper stage. To enhance sustenance of bio-diversity in the region, the upper stage can be used for forestation and landscaping [24,25]. Other possible use includes temporary recreational facilities.

The final alignment does not interfere with Shahdara Branch Canal. Figure 4 shows path of original and proposed modified river channel on Google Earth. Figure 5 compares longitudinal profiles of modified bed with current levels at the center of reaches in the same path. It can be noted in Figure 5 that most of the channel will require excavation. Reason of original levels being higher than modified bed is that the river path was straightened to decrease cost of construction and increase in slope. The straightened path does not necessarily pass from existing river. The geometrical measurements of all reaches are summarized in Table 1.

Hydraulic analysis of proposed channel

HEC-RAS analysis confirms that the designed channel is safe for the designed discharge. After addition of freeboard, the channel is safe to carry a flood corresponding to 200 years return period (11,800 cumecs). In both Reaches 1 and 6, the upper stages start inundating at a flood of ten years return period. Significant increase in bridges capacities were also noted and presented in Figure 6.

Conclusion

The researchers analyzed present hydraulic capacity of Ravi River along Lahore City, using HEC-RAS. As the hydraulic capacity is very less and large catastrophe is expected during high floods, the researchers proposed an alternative to pass a flood of 100 years return period. It was found that the current capacity of Ravi is extremely low. A flood of magnitude greater than 7078 cumecs (less than 20 years return period) can create havoc in surroundings of Lahore. Shahdara, on right bank of the river, is most vulnerable settlement. Furthermore, the magnitude of 'Exceptionally high flood' as defined by Punjab Irrigation Department is 5100 cumecs; corresponds to only 7 years return period. For safe passage of flood and to reduce complications of resettlement or structural interventions in existing infrastructure, the

researchers have proposed to channelize Ravi River from Ravi Siphon to Korotana Reserve Forest. The channelization has been proposed in six reaches. Every reach has a unique geometry based on constraints, presence of bridges, existing settlements or presence of historic monuments. Reaches 1 and 6 have compound cross sections. Lower stage is rectangular, while upper stage is trapezoidal. Reaches 2, 3, 4 and 5 are single stage rectangular channels. The channel was designed for flood corresponding to 100 years return period. Provisions were also given for urban development, recreational facilities and sustenance of bio-diversity around the channelized river. HEC-RAS analysis showed that the proposed channel can safely pass flood upto 11,800 cumecs (200 years return period).

Acknowledgements

References

1. World Bank (2013) The Indus Basin of Pakistan.

2. Thomas A, Sharma PK (1998) The shift of Ravi River and the geomorphological features along its course in Amritsar and Gurdaspur districts of Punjab. J Indian Soc Remote 26: 57-68.

3. Ahmad K, Ali W (1998) Variations in Ravi River water quality, 24th WEDC Conference Islamabad, Pakistan.

4. Shakir HA, Qazi JI (2013) Impact of industrial and municipal discharges on growth coefficient and condition factor of major carps from Lahore stretch of Ravi River. J Anim Plant Sci 23: 167-173.

5. Otto B, McCormick K, Leccese M (2004) Ecological Riverfront design: Restoring rivers, connecting communities. Planning Advisory Service Report Number 518-519.

6. Iqbal M, Saleem I, Ali Z, Khan M, Akhtar M (2011) Bird ecology from the Ravi River of Lahore: Habitat degradation. J Anim Plant Sci 21: 817-821.

7. Punjab Irrigation Department (2014) Flood fighting plan for Lahore Zone. Lahore Drainage Division, Punjab Irrigation Department, Lahore, Pakistan.

8. Lahore Development Authority (2014) Feasibility report of Ravi Riverfront Urban Development Project, Meinhardt.

9. Gary W (2010) User Manual for HEC-RAS (Hydraulic Engineering Centre – River Analysis System), US Army Corps of Engineers, Davis, CA, USA.

10. World Bank (1988) Flood Damage restoration Project. Report No: 11850

11. Bueno I, Castillo-Rodrˊ J, Zechner S, Jobstl C, Perales-Momparler S, et al. (2012) A quantitative flood risk analysis methodology for urban areas with integration of social research data. Nat Hazards Earth Syst Sci 12: 2843–2863

12. Nespak Delft Hydraulics (2008) Second Flood Protection Sector Project – Package C, Volume – III, flood forecasting model – Ravi River.

13. Sabarmati River Front Development Corporation Limited (SRFDCL).

14. Garg S (2007) Irrigation engineering and hydraulic structures.

15. Japan International Cooperation Agency (2002) Technical Standards and Guidelines for Planning and Design, Department of Public Works and Highways, Volume I: Flood Control.

16. Cui B, Wang C, Tao W, You Z (2009) River channel network design for drought and flood control: A case study of Xiaoqinghe River basin, Jinan City, China. J Environ Manage 90: 3675–3686

17. Jason S, Richard C, Reed W (2012) A brief history and summary of the effects of river engineering and dams on the Mississippi River System and delta. U.S. Department of State, Circular: 1375.

18. JICA (2003) Manual on Flood Control Planning. Department of Public Works and Highways, Japan International Cooperation Agency, Japan.

19. Nakamura K, Tockner K, Amano K (2006) Rivers and wetland restoration: Lessons from Japan. BioScience 56: 419-426s

20. Rambaud M, Combroux I, Haury J, Moret J, Machon N, et al. (2009) Relationships between channelization structures, environmental characteristics, and plant communities in four French streams in the Seine–Normandy catchment. J N Amer Benthol Soc 28: 596-610.

21. United States Department of Agriculture (2007) Stream restoration design. National Engineering Handbook 654.

22. Wang Z, Tian S, Yi Y, Yu G (2007) Principles of river training and management, Int J Sediment Res 22: 247-262.

23. Watson C, Biedenharn D, Scott S (1999) Channel rehabilitation: Processes, design, and implementation. U.S. Army Engineer Research and Development Center Vicksburg, Mississippi.

24. William P, Swanson M (1989) A new approach to flood protection design and riparian management. USDA Forest Service. Gen Tech Rep pp: 40-46.

25. Wongsa S, Shimizu Y (2003) Modelling pre-channelization and their impact on flood and sediment yield in Ishikari River Basin. Proceedings of Hydraulic Engineering 47: 223-228.