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Investigation of Existing Flood Protection Measures Upstream of Rasul Barrage

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ABSTRACT

Floods in Pakistan have caused a huge loss of life and property. Use of HEC-RAS computer simulation model can help to improve flood protection measures to minimize flood damages. This study was conducted from downstream of Mangla Dam to the upstream of Rasul Barrage. This particular reach has populated towns and villages on both sides of the bank that can be inundated in case of high flood. The measured data for the reach was location and height of the existing flood protection measures on both banks of the river and the geometric data of the reach. This data set was collected from NESPAK Hydrological Division. The obstruction of the reach was Jhelum Rail cum Road Bridge and its geometric data was entered in the model. The flow data of 1997 flood was used for calibration and the 1992 flood data was used for validation. Simulations of discharge closely matched observed data showing model efficiency. The existing flood protection measures were evaluated for the floods of 1992 and Maximum Design Flood (MDF) discharge for Mangla Dam of 61977cumecs. The model simulations identified four locations within this reach that have insufficient embankment height. These results indicate that the embankment height at these locations must be increased to make these specific areas safe against flood. Also this study serves as a guideline for modelling complete length of River Jhelum for future researchers to investigate the existing flood protection measures.

KEYWORDS

Flood Protection Measures, Jhelum River Valley, Rasul Barrage, HEC-RAS.

INTRODUCTION

Flood is the submerging with water of a normally dry area or Flood is state of high water level along the river channel or on the coast that leads to inundation of land, which is not usually submerged. Floods are one of the world's prime environmental hazards and they continue to be devastating despite the advancement in flood forecasting and flood protection facilities throughout the world. Since 1947 there have been twenty one major flooding events. The cumulative financial loss due to all the floods that include the structural losses, rehabilitation and property damages have been around 38 billion dollars, more than one hundred thousand villages have been effected and about fifteen thousand people have lost their lives. (Memon & Malevolent, 2014), (Flood Impact Assessment 2011-12)

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Tab.1. Historical flood events and the losses due to flood events in Pakistan (Flood Impact Assessment 2011-12)

Duration	Flood events	Lives lost	Population Impacted	Financial Loss (US Dollars)
1950-1959	6	3691	N/A	N/A
1960-1969	2	32	225000	3300000
1970-1979	5	2,066	13.4 million	1.2 billion
1980-1989	7	519	302000	N/A
1990-1999	14	4180	15.1 million	1.1 billion
2000-2009	33	2265	9.6 million	700 million
2010-2011	4	2113	20.3 million	9.5 billion
63 years	71	14866	59 million	12.5 billion

This study focuses on the existing flood protection measures from downstream of Mangla Dam to the upstream of Rasul Barrage and there adequacy for different flooding scenarios. The flood protection works in this specific reach consist of spurs and embankments. Spurs are constructed perpendicular to the direction of flow. Flood protection is provided by the interaction betweennumber of spurs which direct the flow away from the banks. Properly constructed spurs also help in rapid sediment deposition and inhibit vegetation growth to reinforce embankments (Nut, 2013). Spurs may be built from reinforced concrete, rock boulders, stones, gabions, timber sheet piles or bed material. (Khan, 2013), Embankments are aligned in the direction of flow. They are a continuous structure producing a less turbulent flow along the face of the wall. They provide better flood protection as compared to spurs and preferred for weir sites. But they are much more expensive than spurs and are used for the most sensitive sites or where the construction of spurs is less feasible like weir sites, narrow or a steep section. (Flood Protection Works Inspection Guide, 2000).The Provincial Irrigation Departments (PIDs) are responsible of maintaining flood protection embankments and spurs those lie in their respective provinces along the rivers. Punjab has 496 spurs and 3334km length of embankments and total of 6807 km of embankments and 1410 number of spurs throughout the country. (Annual Flood Report, 2013), (Memon & Malevolent, 2014)

Hydrological Engineering Centre's River Analysis System HEC-RAS is developed by US Army Corps of Engineers. This numerical model has a capability to perform numerous functions like one dimensional steady flow analysis, unsteady flow calculations, sediment transport computations and water temperature modeling (HEC-RAS River Analysis System, User's Manual 2010). Many numerical models are unable to incorporate the obstructions to flow like the bridges, culverts but HEC-RAS uses these values accurately. The ability to incorporate the structures of the river makes it close to the existing features of the study area. Moreover it has the capability of storing data in different formats and the data can be then exported to other numerical models for further use. The general reviews about HEC-RAS by hydrological experts are favorable for river and flood modeling. (Mehta et al., 2014)

OBJECTIVES OF THE STUDY

- To assess the adequacy of existing flood protection measures (FPM) on River Jhelum for a reach from Mangla Dam to upstream of Rasul Barrage using HEC-RAS numerical model.
- To identify vulnerable areas along the project reach

MATERIALS AND METHODS

Geographical Location of the Study Area:

The study area lies between the Mangla Dam and the Rasul barrage mainly in the Punjab province of Pakistan and has a reach length of 69Km. Many important towns and villages lie on both sides of the river and that is the reason this specific reach is selected as the project area.

Mangla Dam is located at Mangla in the Mirpur district of Azad Kashmir at the co-ordinates 33.1420N and 73.6450E. It is the 9th largest dam in the world. The crest length of the main dam is about 2561m (Ehsan, 2009). The original catchment area of the reservoir is about 33360 km2& water surface area (at conservation level) is about 253 km2 (Ehsan, 2009).It was completed in 1967 at a cost of 1.473 billion US Dollars by financial assistance from World Bank and the ADB. Design consultants for Mangla Dam were Binnie& Partners of London.

Rasul Barrage is located between Jhelum District and Mandi Bahauddin District in Punjab Pakistan. Its co-ordinates are 32040'49''N and 73031'15''E. It is about 69Km downstream of Mangla Dam. It was completed in 1968 and has a length of 975m, width of 17m and has a fall of 6m. It generates a power of 22MW.

The reach length starts from Mangla Dam up till the upstream of Rasul Barrage. The reach has important cities, town and Villages/Mosas that are susceptible to flooding in case heavy rainfall. This is the main reason of selecting this specific reach. This reach contains the outskirts of Jhelum city, Jhelum Cantt, Sarai Alamgir and Rasul both on the right and left Bank of the River Jhelum.

Model Setup:

The available geometric and hydraulic data was inserted in HEC-RAS for the project reach of 68304m.The step by step description is given below.

Geometric Data:

This specific reach has a length of 68.3km. Geometric Data consisting of cross sections of River Jhelum is collected from NESPAK Hydraulics Division. This surveyed topographical data of the reach consists of 25 cross sections. Each cross section gives a detailed description of the width and depth of the river at the specific location.

In the cross section editor first the stations and their respective elevations have to be entered for the whole width of the cross-sections. The average width of the River Jhelum cross sections is around 2000 meters but some channel sections are as wide as 5000 meters and some are only 800m. Also the downstream length from that specific channel to the next available channel has to be entered which gives the distance between the two specific channels.Other important function is the main channel bank stations.

This is a parameter in HEC-RAS that needs to be defined which shows the main channel of the cross section. The cross-section can be of a large width but depending upon the channel geometry the main channel flow area can be of less width. This must be defined in HEC-RAS. In the above channel right main channel bank lies at 1347.05m and the left main channel bank lies at 2279.16m. Lastly the expansion or contraction coefficient value for the specific cross section both of these due to energy losses during the flow and must be specified for the cross section. This depends upon the changes in the cross section. From downstream of Mangla Dam to upstream of Rasul barrage there are five tributaries that augment the river flow. They are Suketar, Bandar, JabbaKas, Kahan River and Bunha River as shown in Table 2. The discharge from Suketar and Bandar are less and they lie in close vicinity so they are taken in combination.

Tab.2. Location of tributaries

Tributaries	Chainage(m)
Suketar and Bandar	26479
JabbaKas	30203
Kahan River	42118
Bunha River	63654

In HEC-RAS tributaries are added as lateral inflow in the main river reach. The two important factors of the tributaries are their location in the reach and the inflows. For the location of the tributaries in relation to the main river reach it is entered just above the cross section which lies in the vicinity of the tributaries. Suketar and Bandar tributaries lie just below the cross section 7 so it is entered in the lateral inflow window. JabbaKas tributary lie just below the cross section 8, Kahan River tributary lie just below the cross section 15, Bunha River tributary lie just below the cross section 23 and is entered.

Bridges Along the Reach:

The main obstructions in this reach are the two bridges namely Jhelum rail cum road bridge, Jhelum new road bridge. The data available from NESPAK was only for the Jhelum Rail cum Road Bridge. Entering bridge in the HEC-RAS was a very tedious process. Because of the obstructions in the flow there are energy losses in the flow. The program adopts a different approach to calculate these losses. Contraction of flow occurs upstream of the bridge and expansion downstream. The program requires to enter four cross sections for the bridge.

Tab.3. Geometric details of Jhelum Rail cum Road Bridge (Harza Engineering Company International 1976)

Description	Units (ft)
Width of Waterway	1377
Highest flood level recorded	231.3
Bottom of girder	234.5

Existing Flood Protection Measures:

The structures that are erected on the banks of the river with the purpose of containing the water in the river channel and protecting the adjacent areas from flood inundation during high floods are called Flood Protection Measures. The Jhelum River which has a large areas vulnerable to flooding that have been tried to make safe from the floods by the relevant authorities. The flood protection map for the total length of the Jhelum River was developed by NESPAK in collaboration of DELTARS Netherland. The portion of map up to Rasul Barrage is shown in Figure 1.

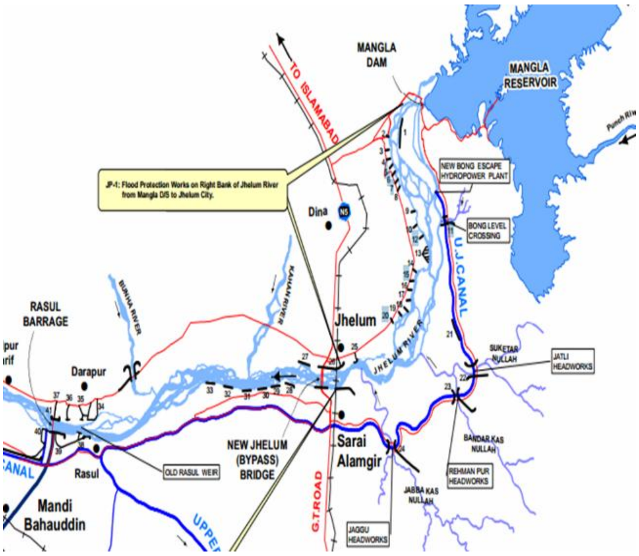

Fig.1. Different locations of levees/Dykes along Jhelum River up to Rasul Barrage (NESPAK)

The existing flood protection measures are of two types. First are the embankments or levees. They are the form of vertical wall of a certain height and specific length. They are provided along the direction of flow at important locations to safeguard the adjoining areas from flooding. Second type of flood protection measures are studs or spurs. They are provided in the lateral direction to the flow and have specific length and height. The existing flood protection measures in the project reach are a combination of both. For the purpose of this study both the protection measures were taken as embankments.

Calibration of the Model:

After entering the geometric data in HEC-RAS next step was entering the flow data for unsteady flow analysis. In the unsteady flow data window first of all upstream boundary condition was to be defined.

In this case the upstream boundary condition is the outflow hydrograph of the 1997 flood downstream of Mangla dam. The flood of the 1997 was used for the model calibration. For calibration 1997 flood data was used because the 1997 flood was a mild flood as compared to 1992 flood which was a heavy flood or the 2010 flood which was a low flood. The flood hydrograph of 1997 started from September 15, 1997 at 6:00 pm to October 16, 1997 at 4:00 am. The peak discharge occurred at September 27, 1997 at 7:00 pm. The flood data had been obtained from NESPAK Hydraulics division. The peak discharge was 12798m3/s.

Reliable data for the downstream boundary condition was unavailable so the option of normal depth in HEC-RAS was used which indicates that the downstream boundary condition of any specific reach depends upon the channel bed slope. The bed level of the first channel and the bed level of the last channel divided by the total reach length gives the downstream boundary condition which comes out to be 0.0015.

The tributaries augment the flow in the main river as discussed in the geometric data section. The flow hydrographs of the tributaries were obtained from NESPAK Hydraulics Division. For the 1997 flood used for model calibration the hydrographs were inserted for 25 year return period.

The already existing data used for calibration was that discharge value for 1997 flood at the upstream of Rasul barrage was 15563m3/s (Ehsan 2009). Now to calibrate the model correctly a correct value of Manning's n must be specified according to the channel bed. Because of the unavailability of reliable n value for the channel different values were used to calibrate the model correctly. After trying various value of n such as 0.075, 0.045, 0.03 the calibration value was not achieved. Finally the model was calibrated by using n value of 0.04.

The maximum discharge value at the cross-section just above the Rasul Barrage is 14988.97 m3/s. It is near to the actual value of 15563m3/s (Ehsan, 2009). Also the maximum water level at the Rasul barrage section is 221.3m which is quite comparable to the maximum water surface value of the already available data.

The difference between the values can be due to many factors.Firstly the unavailability of accurate value of Manning's coefficient. Secondly the exact downstream boundary conditions are unknown.

Validation of the model:

For the validation of the calibrated model the 1992 flood was used. For the upstream boundary condition the outflow hydrograph of the 1992 flood downstream of Mangla dam was used. The hydrograph started from August 18, 1992 at 6:00pm and ended on September 29, 1992 at 6:00 pm. The peak value occurred at September 10 and the value was 26293m3/s.

The flow data in the tributarieswas entered as in the case of 1997 flood. The difference was that the data in this case was entered for 50 year return period because the flow data for 1992 flood was greater than 1997 flow data. The downstream boundary condition for 1992 flow data was used as normal depth option which was the bed slope of the project reach. The value was 0.0015 as in case of calibration.

After running the unsteady flow analysis of the river for the entered flow data of 1992 flood the obtained results were close to the already carried study for the whole of the Jhelum River (Ehsan, 2009). The discharge value at the last cross section comes 24912m3/s which was reasonably close.

The discharge value keep on decreasing downstream of the Jhelum Rail cum Road bridge because of the river geometry.The values at upstream of upstream of Rasul Barrage at close hence validating the result of the model. Now the model was ready to be used for different flooding scenarios. The maximum discharge along the reach for 92 flood is shown in Figure 2.

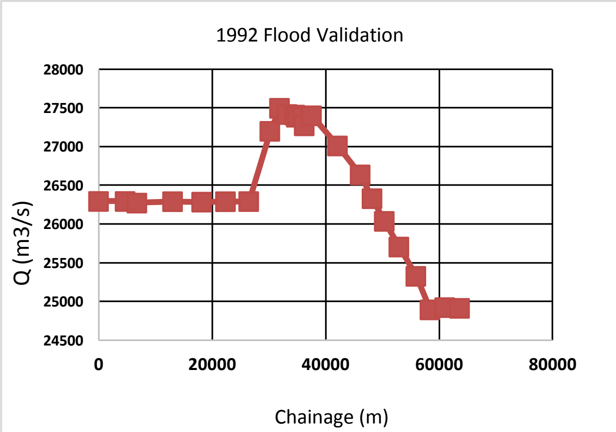

Fig.2.Peak discharge from Mangla to Rasul Barrage for 1992 Flood

RESULTS AND DISCUSSIONS

After careful calibration and validation of the model, the model was used to find discharges and water levels for different flooding situations. The flood of 1992 and MDF discharge were modelled and the results were analyzed.

Flood of 1992 as 1$_{st}$ scenario:

Firstly the results of the 1992 flood were presented and discussed. The 1992 flood was one of the highest floods in Pakistan. In Jhelum River it was the highest recorded flood during which all the spillway gates of the Mangla Dam were opened to their maximum capacity. After the model run different cross sections were observed where the water level exceeded the main channel of the river. After inputting all the required flow data, the model was run for unsteady flow analysis. The vulnerable cross-sections for this flood have been mentioned in Table 4.

Tab.4.Results of the flood modeling for 1992flood

Cross-section	Chainage (m)	Depth of flooding (m)	River Bank	FPM's existing or absent
5	13050	0.8	Right	Insufficient height
9	31904	0.5	Left	Absent
11	34869	1.9	Left	Insufficient height
13	36266	2.6	Left	Insufficient height
14	42118	2.2	Left	Insufficient height
23	46130	3.1	Right	Insufficient height
		3.1	Left	
24	48225	2.7	Left	Insufficient height
		2.7	Right	

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The upstream of the Jhelum rail cum Road Bridge there was a sufficient length for the outskirts of the Jhelum city on the right bank of the river had an absence of embankments. Embankment has been provided for a reasonable length and height before this specific section but its length had to be increased.

For the cross sections of 11, 13, 14 (Table 4) the results show that the FPM's provided were insufficient in height. The adjoining areas are villages and mosas of khambi, Kastilla, KhanpurKamb. Not only the population was at risk of flooding but there were large agricultural lands that is the livelihood of the population also at the risk of damaging.

Water level variation throughout the project reach was also an important factor and dictates the extent of flooding and the depth of flooding. This is an important factor for the identification of the vulnerable areas. Areas with insufficient embankment heights would be have a higher difference between the top level of the embankment height and the water level. The water level of flood also gives information about the extent of flooding which shows that a certain quantity of discharge will be carried to a certain distance.

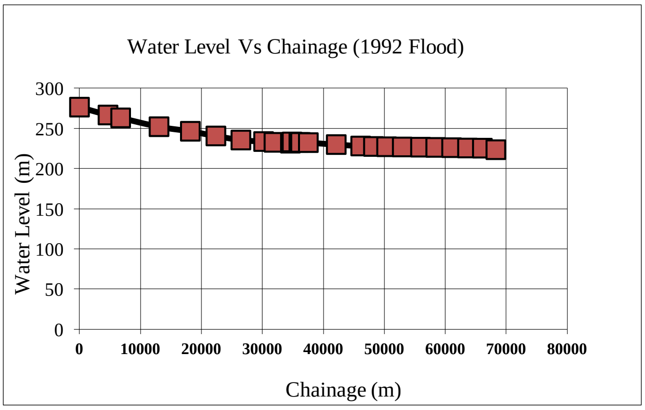

Fig.3.Water levels for 1992 flood

MDF Flood of 61977m3/s as 2ndScenario:

The maximum design flood MDF for Mangla dam was 61977m3/s and it is based on 1000 years return period flood. The hydrograph of the MDF flow was obtained from NESPAK hydraulics division is a five hour unit hydrograph.

The flow data of the tributaries was entered for 100 year return period in this case. The downstream boundary condition for MDF flow data was used as normal depth option which is the bed slope of the project reach.

After inputting all the required flow data, the model was run for unsteady flow analysis. The results were observed and at numerous locations the water level exceeded the cross-section. To make the results reliable those cross sections were extrapolated beyond their actual dimension and again the model was run and the results were formulated by the model.

The results obtained of the unsteady flow analysis were shown for the areas where the water flows beyond the flood plain are there were vulnerable areas of flooding with danger of loss of life and property as shown in Table 5.

Tab.5. Results of flood modelling for MDF flooding scenario

Cross-section	Chainage (m)	Depth of flooding (m)	River Bank	FPM's existing or absent
3	6754	2.1	Right	Insufficient height
5	13050	3.6	Right	Insufficient height
9	31904	1.8	Left	Absent
11	34869	5.9	Left	Insufficient height
13	36266	4.7	Left	Insufficient height
14	42118	4.1	Left	Insufficient height
23	46130	5.9	Right	Insufficient height
		5.9	Left	
24	48225	4.3	Left	Insufficient height
		4.3	Right	

This is quite clear from the results that flood depths at vulnerable cross-sections are considerably higher as compared to the flood depths of 92 flood. For MDF discharge there was an increase in the maximum water level for all cross ons and the demand of embankment height also increases. For the cross section 3 (Table 5) the existing FPM's were insufficient because of the increased water height and the population of Mangla Hamlet on the left bank and Barala on the right are now more vulnerable to flooding as the depth of flooding has increased to 2.1m.

For cross section 9, upstream of the Jhelum Rail cum Road bridge and in its vicinity the outskirts of the Jhelum city the depth of flooding increases to 1.8m. This makes the specific location very vulnerable as there is a huge population in the vicinity of this location because the embankment length provided here is not sufficient and on this specific location the FPM's are absent.

For the cross sections of 11, 13, 14 the results showed that the FPM's provided were insufficient in height for the MDF scenario. The increase in flooding depth shows that they are vulnerable to severe flood losses in terms of life and property for the flood of this magnitude. The adjoining areas are villages and mosas of khambi, Kastilla, KhanpurKamb. Population and agricultural lands are at a risk of flooding. Lastly the FPM's upstream of the Rasul Barrage for the cross- sections 23 and 24 are also insufficient on both right and left banks.

The MDF scenario had an increased value of discharge and water level. The discharge throughout the project reach is shown with respect to chainage in Figure 4.

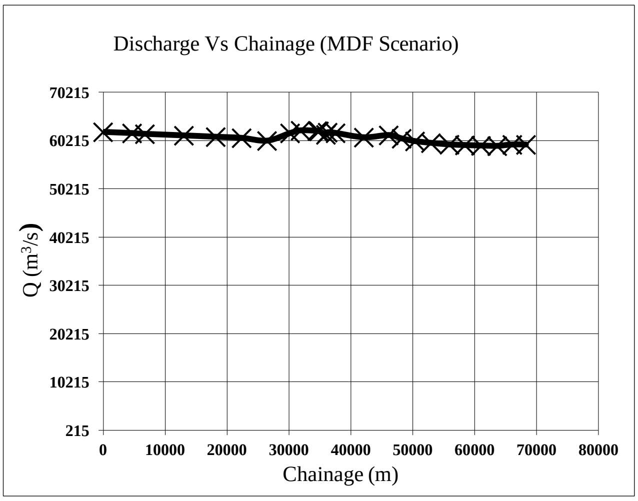

Fig.4.Discharge MDF Scenario

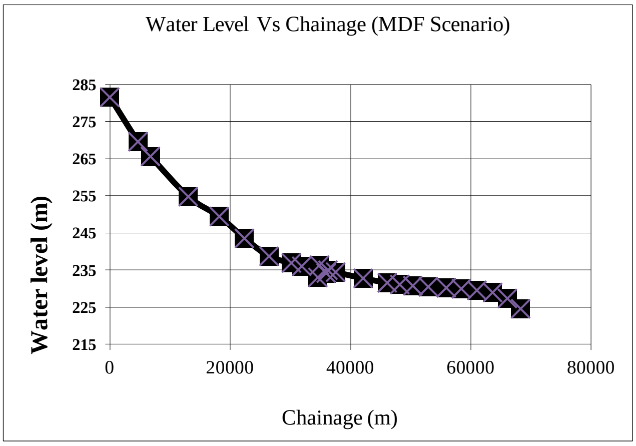

Fig.5.Water levels for MDF Scenario

Suggestions:

Keeping in view the results of both flooding scenarios it is recommended that the FPM's of insufficient height for Mangla Hamlet be increased by at least 1.2m immediately. For 1992 flood scenario it is sufficient and for MDF discharge it is insufficient by 2.1m as MDF is a very high level of food and the embankment raising is expensive, so for saving the life and property of the people it should be increased by at least 1.2m so that it can be sufficient for a flooding scenario greater than the 1992 magnitude.

For the cross section 9 (at 31904m downstream of Mangla dam) that is upstream of the Jhelum Rail cum Road Bridge and has outskirts of the Jhelum city it is recommended that embankment length be increased and also its height should be increased by at least 1m to make it safe for the flood of magnitude that is greater than 1992 flood. For 1992 flood the embankment height is insufficient by 0.5m and for MDF discharge embankment height is inefficient by 1.8m so recommended height is 1m. The absence of embankment for sufficient length makes this area more vulnerable to flooding.

For the cross sections 11,13 and 14 (from 34869m to 42118m downstream of Mangla dam) that have villages Khambi, Kastilla and KhanpurKamb on the left bank of river Jhelum it is recommended that the height is insufficient and it should be increased by at least 4m so that a flood of magnitude greater than 1992 can be withstood. For 1992 flood the embankment height is insufficient by 2.6m and for MDF discharge embankment height is insufficient by 5.9m so recommended height is 4m.

Lastly for Rasul village on the left bank and Darapur village on the right bank of the river have insufficient height. On the left bank as the channel section is such that it can contain a large portion of the flood so the levee height can be increased to a lesser value of 2m. But on the right bank the embankment height must be increased by 3.5m to make it safe against flooding of a flood greater than the 1992 flood magnitude.

The recommendations made for the increase in embankment height are realistic as it is advised that the height can be less than the height required for MDF discharge. The reason is that MDF discharge is based on a 1000 year return period and the cost of increasing the height will be very high. But the 1992 flood is a flood that has been occurred in the past. Any embankment that cannot withstand this magnitude of flood is insufficient and must be reviewed and its height be increased. The recommendations made are increased heights of the embankments for the 1992 flood data. This study would be helpful in enhancing the existing flood protection measures along Jhelum river as well as other rivers in Pakistan and other parts of the world.

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