Paper No. 282

FLOOD 2010 IN PAKISTAN AND ITS DAMAGES

Ch. Ghulam Qadir

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Abstract:

It is a historical fact that most of the ancient civilizations were developed along the river banks on account of easy access to water for agriculture, transport and daily uses. The rivers on one hand, provided life line for the people. Whereas, on the other hand, some-times the rivers inflicted disaster to their infrastructure on account of high floods. A number of unprecedented damages due to the river floods are on the record and those damages amount to billions of dollars in terms of financial losses and unforgettable losses to the social setup. A similar flood disaster is inflicted by Indus River during recent flood of 2010. At the initial stage, a low monsoon depression developed in the Bay of Bengal and proceeded towards the catchment area of Indus River. It caused a heavy and long duration of rainfall in the catchment area of Indus River. Simultaneously, another monsoon low depression developed in the Arabian Sea, which caused heavy rain in the catchment area of Kabul River in Afghanistan.

Unfortunately, peaks of both the rivers coincided at the confluence point of Kabul and Indus Rivers. Moreover, the other tributaries joining these rivers also contributed their share to aggravate the flood situation. This phenomenon of flood from the natural streams resulted in a heavy flood of long duration in Kabul and Indus Rivers, which inflicted heavy damage to the infrastructure existing along their passages.

The detail of damages caused by Kabul and Indus Rivers has been elaborated in this paper. This flood of Indus River has also been evaluated in the perspective view of historical floods occurred in the Indus and its tributaries previously. The author has tried his best to quantify the financial as well as social damages of the recent flood as compared to the past floods. As the recent flood of Indus is unprecedented, the river engineers have started thinking to devise ways and means to mitigate such floods and to avoid heavy damages inflicted by the floods. Moreover, the author has also enunciated a few suggestions for better control of floods in rivers to avoid such extensive damages of infrastructure.

River System:

Rivers are natural channels which carry a huge quantity of water drained from their catchments as run-off. They take off from mountains, flow through plains and finally join the sea or an ocean. The discharge in a river increases as it flows from the mountains to the sea because the catchment area increases and a large number of streams and tributaries join it. The rivers provide water for various purposes. It is therefore, not surprising that early civilizations developed along the banks of the rivers. Even modern cities and towns are generally situated on the river banks or at places where water is available in plenty. Similar situation prevails in the sub-continent where rivers are classified into two groups (i) Himalayan Rivers (ii) Non-Himalayan Rivers. The main Himalayan Rivers are the Indus, the Ganges and the Brahamputra. These rivers have a large number of tributaries. The main tributaries of the Indus are Sutlej, Beas, Ravi, Chenab and Jhelum rivers which are shown in **Figure-1** and are focus of our discussion. It is worth mentioning here that water of eastern rivers viz the Ravi and the Sutlej have been allocated for exclusive use of India under the Indus Basin Treaty signed by

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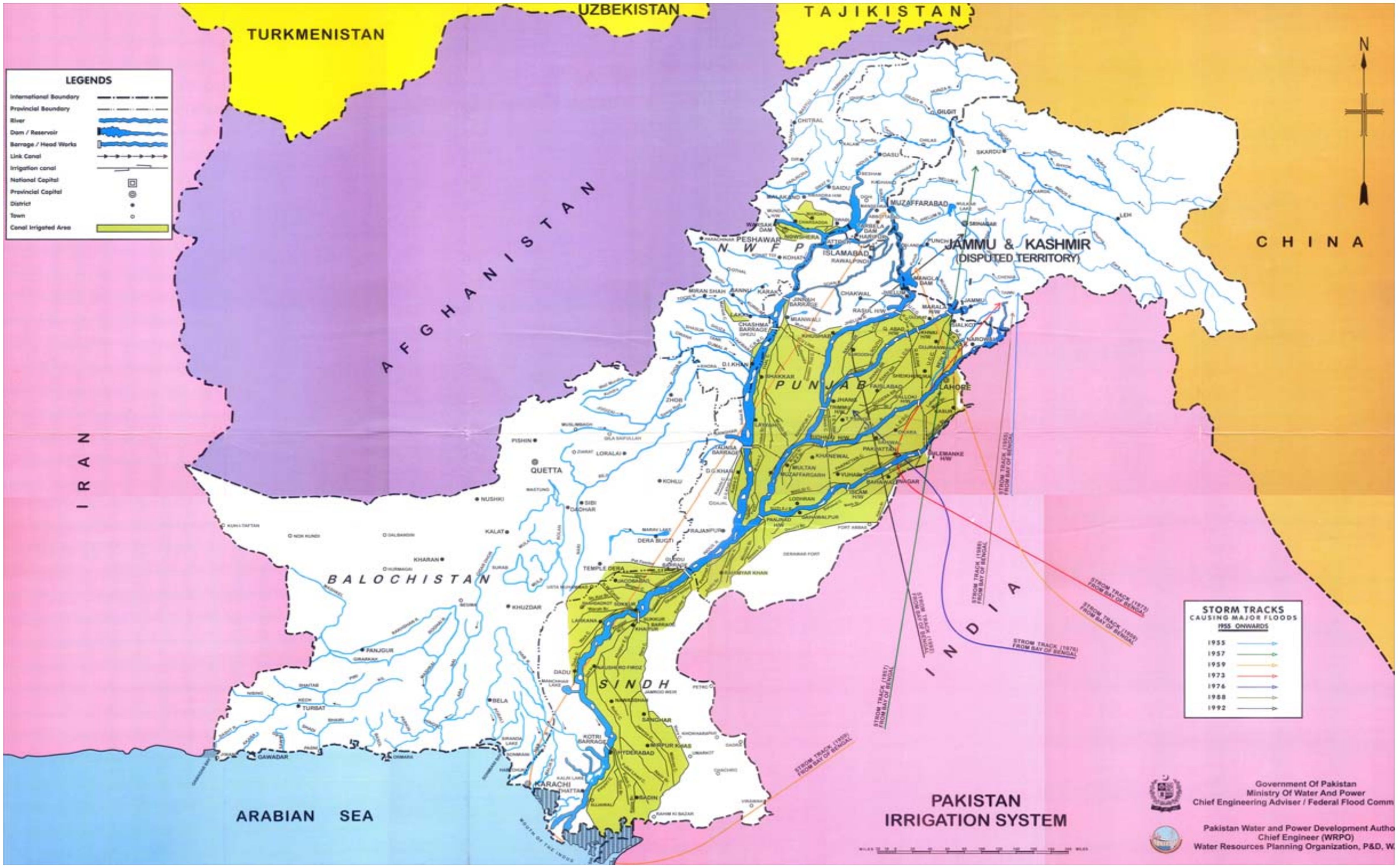
both the countries in 1960. Therefore, any chance of severe flood from these rivers has ceased to exist in territory Pakistan.

Morphological profiles of these alluvial rivers have been plotted along with major structures existing over them in **Figures 2 & 3**. Further details of these rivers are available in **Table-1**. From these rivers available annual supplies amount to 142 million acres feet (MAF) and a number of barrages have been constructed over them at suitable sites. Dozens of canals are emanating from these barrages and diverting 105 MAF water through 42 main canals for irrigation of agriculture land of about 42 million acres. In addition to the above benefits, several run of river reservoirs are under consideration for construction at suitable sites for power generation purposes whereas two major Dams viz Tarbela and Mangla exist on Indus and Jhelum rivers respectively. These Dams also augment the irrigation supplies of the canals under their commands along with power generation.

Large Historical Floods And Damages:

All the main rivers in Pakistan are perennial. The discharges vary from a few hundreds of cusecs in the winter season to hundreds of thousands of cusecs during flood season. This trait of the rivers, amongst other things, makes it almost impossible to control and harness them completely. Due to limited storages in the upper catchment, there is a rapid build up of flood peaks. The flood period is mainly from mid June to mid September in all these rivers. The floods are thus a normal feature of these rivers. The floods occur almost every year to varying extent.


TURKMENISTAN
UZBEKISTAN
TAJIKISTAN
AFGHANISTAN
IRAN
CHINA
INDIA
JAMMU & KASHMIR
(DISPUTED TERRITORY)
N W F P
PUNJAB
SINDH
BALOCHISTAN
ARABIAN SEA
LEGENDS
International Boundary
Provincial Boundary
River
Dam / Reservoir
Barrage / Head Works
Link Canal
Irrigation canal
National Capital
Provincial Capital
District
Town
Canal Irrigated Area
STORM TRACKS
CAUSING MAJOR FLOODS
1955 ONWARDS
1955
1957
1959
1973
1976
1988
1992
PESHAWAR
ISLAMABAD
RAWALPINDI
MUZAFFARABAD
GILGIT
SKARDU
SRINAGAR
LAHORE
QUETTA
KARACHI
HYDERABAD
PAKISTAN
IRRIGATION SYSTEM
Government Of Pakistan
Ministry Of Water And Power
Chief Engineering Adviser / Federal Flood Comm
Pakistan Water and Power Development Autho
Chief Engineer (WRPO)
Water Resources Planning Organization, P&D, W.

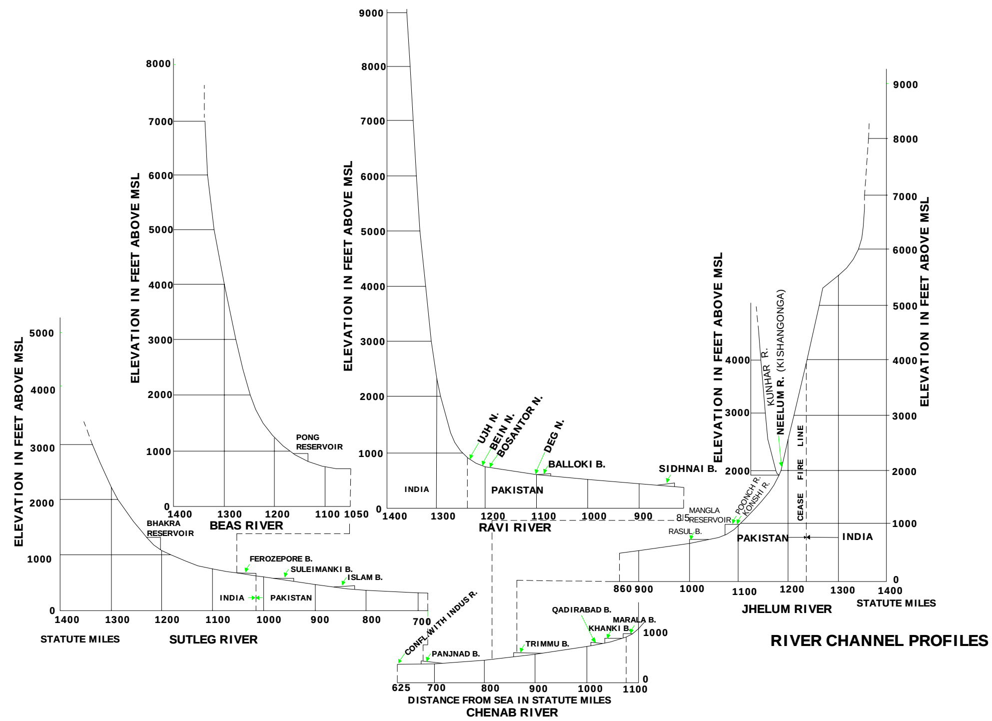


FIG-2: Profiles of Tributaries of Indus River

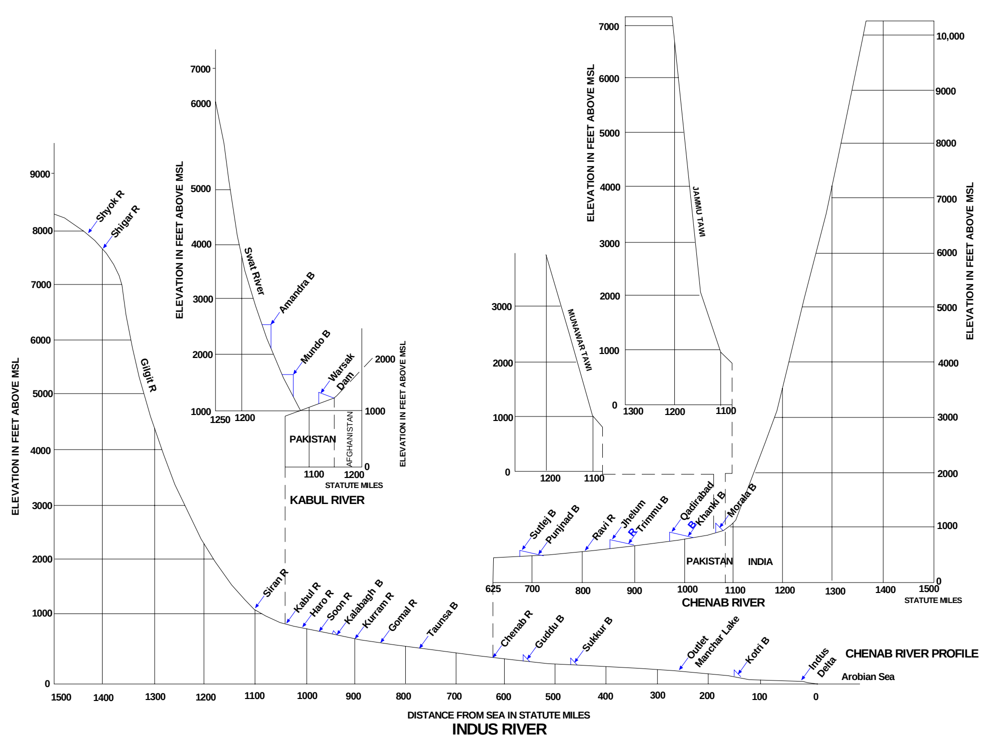


FIG-3: Profiles of Indus River and its Tributaries

Based on the catchment areas of the rivers, their average flows and regime capacity within the Khadir (effective river width), river engineers in the sub-continent have over the years categorized the floods into 5 types viz; Low, Medium, High, Very High and Exceptionally High (Super Flood) flood as given in **Table - 1**.

Table – 1: Design capacity and flood limits of barrages at different locations on various Rivers in Pakistan

River	Site of Barrage or Bridge	Designed Capacity	Flood Limits				
			Low	Medium	High	Very High	Exceptionally High
Indus	Attock Bridge	.--	2.50	3.75	5.00	6.50	8.00
	Kalabagh Barrage	9.50	2.50	3.75	5.00	6.50	8.00
	Chashma Barrage	10.00	2.50	3.75	5.00	6.50	8.00
	Taunsa Barrage	10.00	2.50	3.75	5.00	6.50	8.00
	Guddu Barrage	12.00	2.00	3.50	5.00	7.00	9.00
	Sukkur Barrage	9.00	2.00	4.50	5.50	7.00	9.00
	Kotri Barrage	8.75	2.50	4.00	5.50	6.50	8.00
Jhelum	Kohala Bridge	.--	1.00	1.50	2.00	3.00	4.00
	Mangla Dam	9.00+2.12	0.75	1.10	1.50	2.25	3.00
	Rasual Barrage	8.50	0.75	1.10	1.50	2.25	3.00
Chenab	Marala Barrage	11.00	1.00	1.50	2.00	4.00	6.00
	Khanki Headworks	8.50	1.00	1.50	2.00	4.00	6.00
	Qadirabad Barrage	9.00	1.00	1.50	2.00	4.00	6.00
	Trimmu Barrage	6.50	1.50	2.00	3.00	4.50	6.00
	Punjnad Barrage	7.00	1.50	2.00	3.00	4.50	6.00
Ravi	Jassar Bridge	2.75	0.50	0.75	1.00	1.50	2.00
	Shahdara Bridge	2.50	0.40	0.65	0.90	1.35	1.80
	Balloki Headworks	2.25	0.40	0.65	0.90	1.35	1.80
	Sidhnai Headworks	1.75	0.30	0.45	0.60	0.90	1.20
Sutlej	Suleimanki Barrage	3.25	0.50	0.80	1.20	1.75	2.25
	Islam Headworks	3.00	0.50	0.80	1.20	1.75	2.25
	Mailsi Syphon	4.00	0.75	1.10	1.50	2.25	N.A.

It is noted that Ravi River, having the lowest catchment area, has the lowest flood limits and super flood is over 1,80,000 cfs only. Super floods which are the most devastating, do not occur every year. Details of main rivers and years of occurrence of super floods are given in **Table-2**.

Table – 2: Super floods of different years in Pakistan

RIVER	CATCHMENT AREA IN THE MOUNTAINS (SQ. MILES)	TOTAL LENGTH (MILES)	EXCEPTIONALLY HIGH FLOODS		OBSERVATION STARTED SINCE YEAR
			LIMIT ABOVE (cfs)	YEARS OF OCCURRENCE	
Indus Main	1,18,400	1958	8,00,000	1929, 1942, 1950. Post Tarbela 1992	1928 (Kalabagh Barrage)
Jhelum	12,445	528	3,00,000	1928, 1950, 1954, 1959, 1960 &1992.	1922 (Rasul Barrage)
Chenab	11,399	807	6,00,000	1928, 1929, 1950, 1954, 1957, 1959, 1960, 1966, 1973, 1976, 1988 & 1992	1922 (Khanki weir)
Ravi	3,562	626	1,80,000	1947, 1950, 1955, 1957, 1959, 1966, 1973, 1976 & 1988	1922 (Balloki Barrage)
Sutlej (Including Beas)	30,550	964	2,25,000	1942, 1947, 1950, 1955 & 1988	1928 (Sulemanki Barrage)

Discharge data is available since 1922 for Ravi, Chenab and Jhelum Rivers and from 1928 for Indus and Sutlej Rivers. It is worth mentioning here that data for Indus River at Attock Bridge is available from 1868 when Railway Bridge was constructed during British regime. But in any case, before the construction of the Barrages & Headworks for supply of water to irrigation system, no super flood greater than 8,00,000 cfs was reported at the bridge site.

Salient data of main rivers and years of occurrence of super floods is plotted in **Figures 4, 5** & **6** for Indus, Jhelum and Chenab rivers.

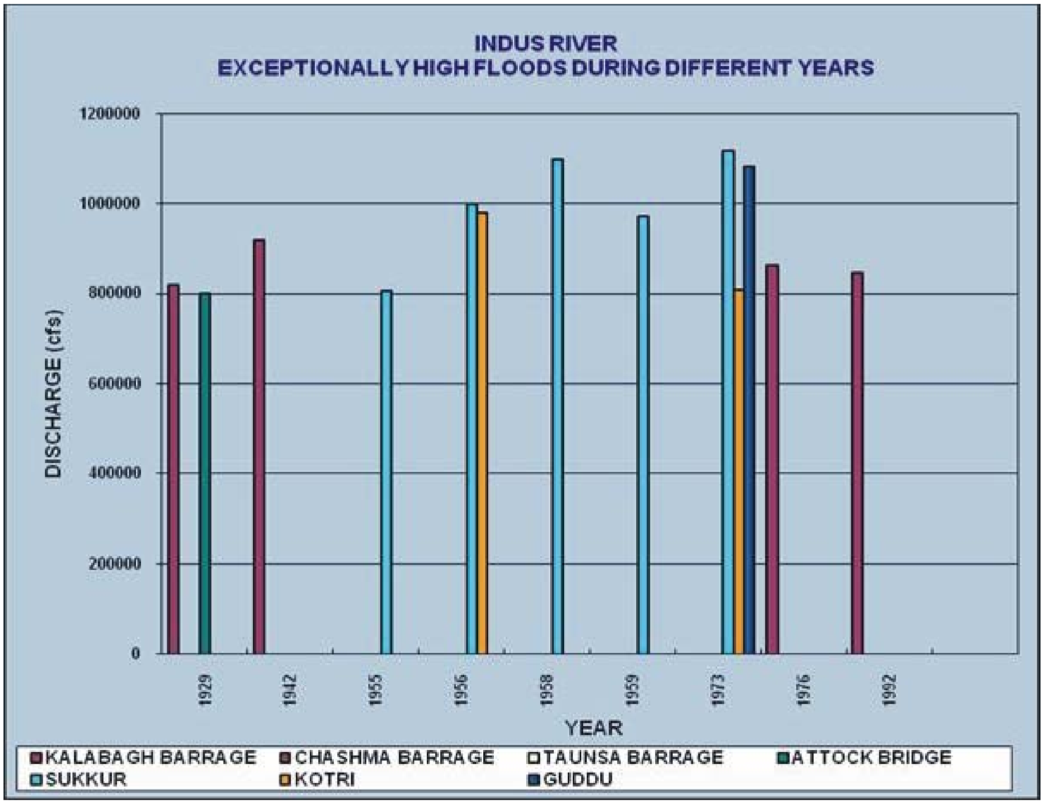


Figure 4: Indus river

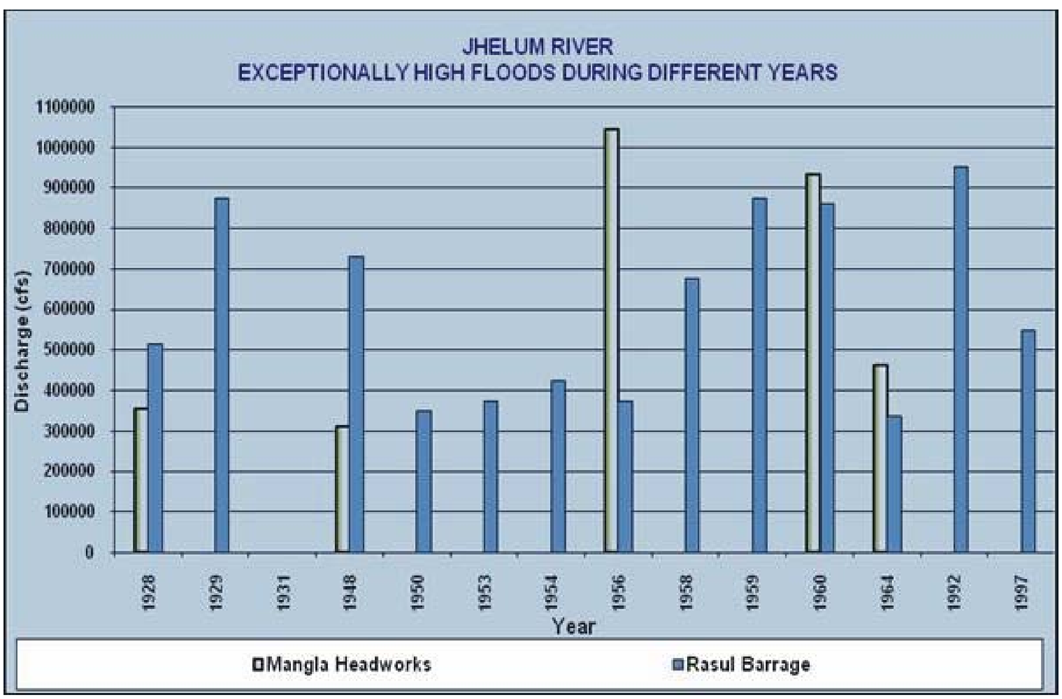


Figure 5: Jhelum river

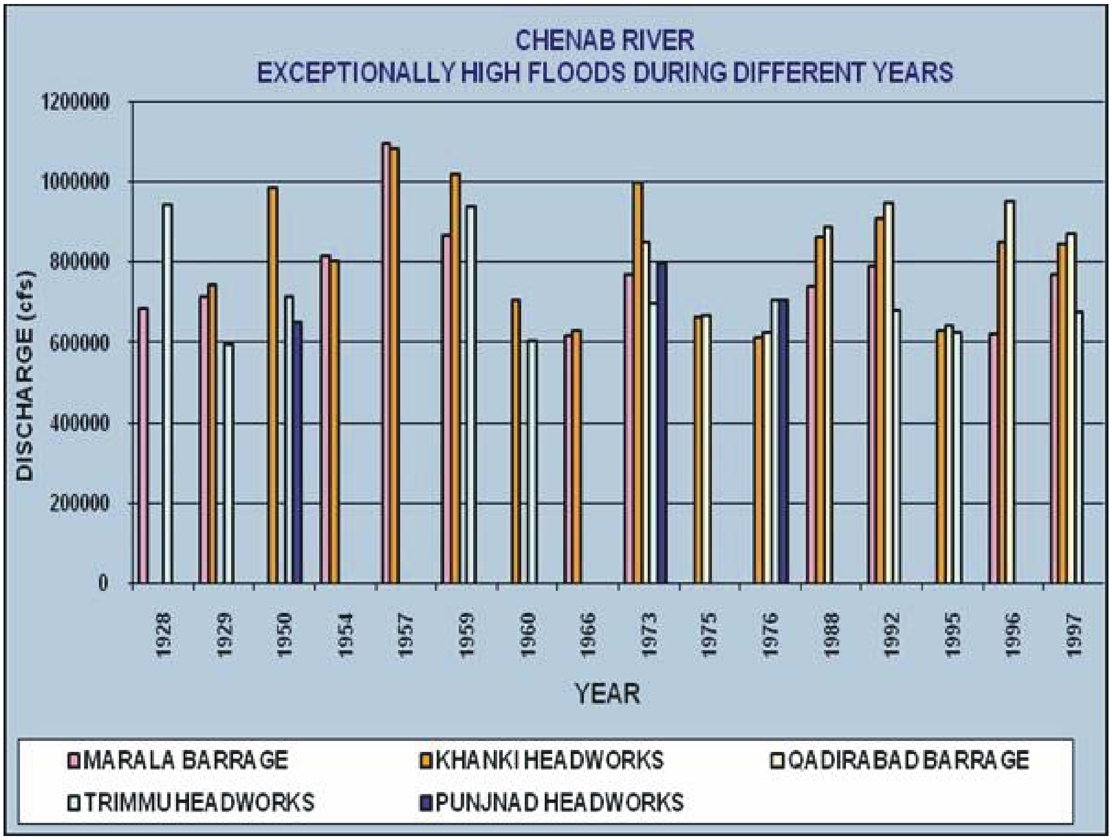


Figure 6: Chenab river

During the 88 years since the discharge data is available at some barrages continuously, super floods occurred only 16 times. Generally 2 to 3 rivers were flooded, in the same year except in 1950 when all the rivers had passed super floods; the Jhelum and the Indus in August, and the Sutlej, the Ravi and the Chenab in September. Fortunately due to the topographical divisions of the catchment area in between the various mountain arêtes, the floods in the rivers did not synchronize. If this ever happens, that will be the deluge. Due to non-synchronization along with the larger capacity of Indus river valley storage, super floods downstream of Mithankot occurred only 5 times whereas it occurred 15 times upstream of Mithankot. For example, the 1988 flood was characterized by the fact that it affected only Chenab, Ravi and Sutlej rivers. This flood event was mainly confined to Punjab where it caused very heavy damage. This pattern was repeated in 1992. It is noted that the worst hitting rivers which also pass through the most heavily populated areas and intensive agriculture cropped lands in Pakistan are Chenab and Ravi Rivers which passed super floods 12 times and 9 times respectively during the period of 88 years.

As far as the matter of damages is concerned, floods cause misery to millions of people and loss of human life. Tremendous damages to public and private property occur during major floods. Crops are lost not only during the year of floods but also for the years to come. It is impossible to estimate exactly the total direct and indirect losses. However, the total losses estimated by independent sources that occurred during the years of significant damages by floods since 1950 are given in **Table – 3**.

Table – 3: Damages caused by historical floods

YEAR	DIRECT LOSSES ($ MILLION) ADJUSTED TO 1988 PRICE LEVEL	LIVES LOST	INTANGIBLE LOSSES	
			VILLAGE AFFECTED	FLOODED AREA (SQUARE MILES)
1950	162	2,910	10,000	7,000
1955	126	679	6,945	8,000
1956	106	160	11,609	29,065
1957	100	83	4,498	6,251
1958	35	90	2,459	6,863
1959	78	88	3,902	4,072
1973	1706	474	9,719	16,200
1975	227	126	8,628	13,645
1976	1,158	425	18,390	32,000
1977	112	349	2,186	1,819
1978	740	214	9,199	11,952
1980	45	75	862	744
1981	99	82	2,071	1,637
1982	6	41	283	101
1983	45	39	643	735
1984	25	42	251	427
1985	5	30	171	89
1988	285	508	tbd	2,400
1992	2,400	1,300	13,208	15,140

In this way, Pakistan faced 19 severe floods and these floods victimized about 8,000 lives, affected more than 1,00,000 villages and towns. The land eroded by these floods amounts to 101 million acres. The total financial loss during the floods mentioned above was estimated as $11 billions.

Super Flood 2010:

Main cause of floods in the Indus Basin is exceptionally heavy and wide spread monsoon rains. A significant low depression of monsoon rains developed over northwest Bay of Bengal on 24th July 2010. Initially it adopted northwesterly course and reached over western parts of Madhya Pradesh (India) on 25th July. From there it started to move northwesterly direction and reached over north Madhya Pradesh India on 27th, then it moved to the western direction and was located over Gujarat and then merged into seasonal low depression. After occurrence of the above phenomenon, it changed its characteristics and the seasonal low depression became well marked resulting in influx of strong moist currents from Arabian sea in the upper catchments of Indus River. At the same time, a trough of westerly wave over Afghanistan started to affect the upper catchments of Kabul and Indus Rivers. A strong jet storm was the third factor to lift the moisture up to 15 Km from mean sea level. Under the influence of above mentioned factors, a very heavy rainfall was recorded in the upper catchments of Kabul and Indus Rivers. Meteorological analysis during and before the spell of heavy rain is shown in **Figure-7**.

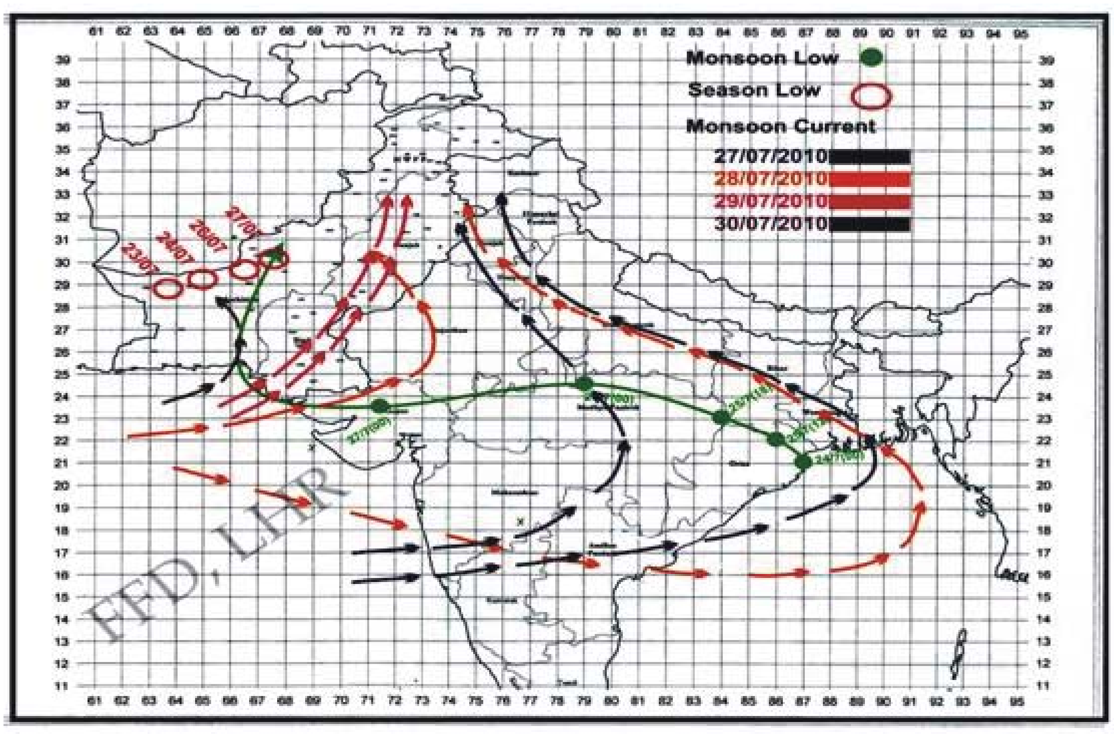


Figure 7: Tracks of monsoon Low super flood 2010, moisture incursion and position of seasonal low

Due to meteorological factors discussed above, a very heavy rainfall was recorded over the upper catchments of the rivers. Formation of clouds is also shown in the following satellite Image, **Figure-8**.

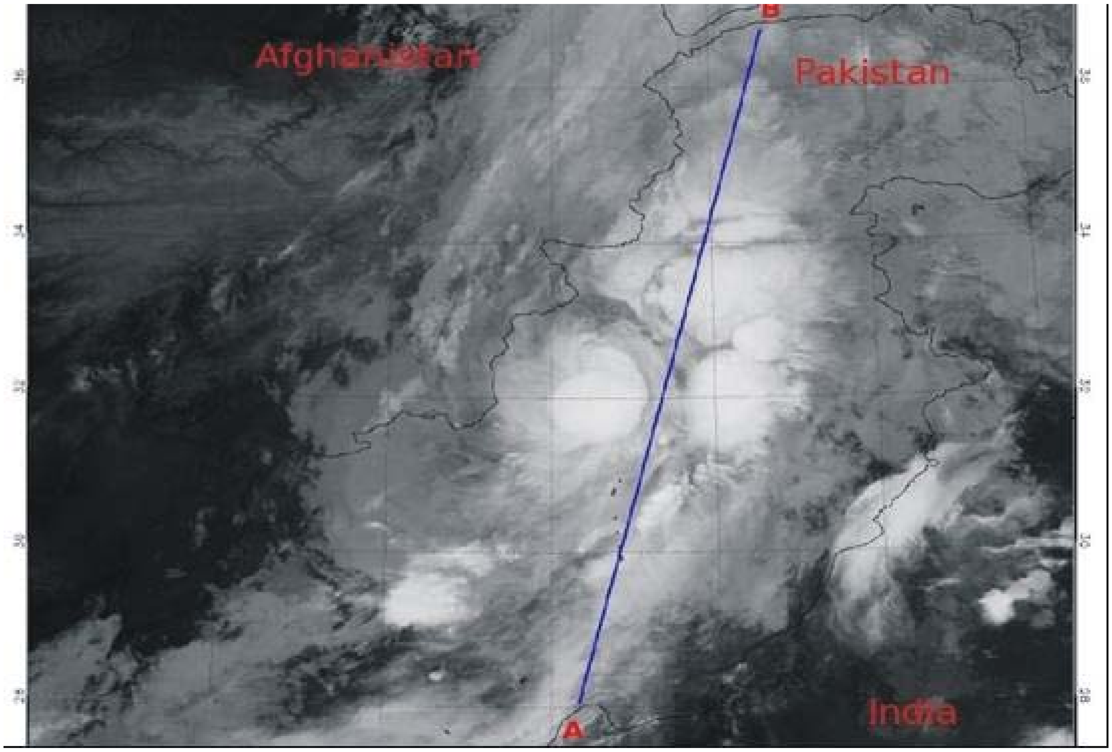


Figure 8: Satellite Image on 28-07-2010

NASA's Cloud Sat, satellite on July 28, 2010, at the beginning of the flooding event showing a large area of intense thunderstorms covered much of Pakistan as shown in the above figure. Between July 28 and 29, as much as 400 mm (16 inches) of rain fell from these cells, triggering flooding of the Indus and Kabul rivers. The top image reveals bright white cloud tops from the cluster of thunderstorms. The blue vertical line across the image represents the path of Cloud Sat at the time as seen in the top half of the image. Cumulative rainfall from 25th to 31st July at different locations in the upper catchment of Indus River are shown in **Figures 9** & **10**.

Under the influence of this heavy to very heavy downpour, historical flood peak of 8,32,000 cfs was generated in Indus River at Tarbela. The release of more than 6,00,000 cfs from Tarbela was joined by flow of more than 3,50,000 cfs from Kabul River at Nowshera. This massive flood wave struck Kalabagh barrage on 31st July and this flood wave continued downstream upto Arabian Sea.

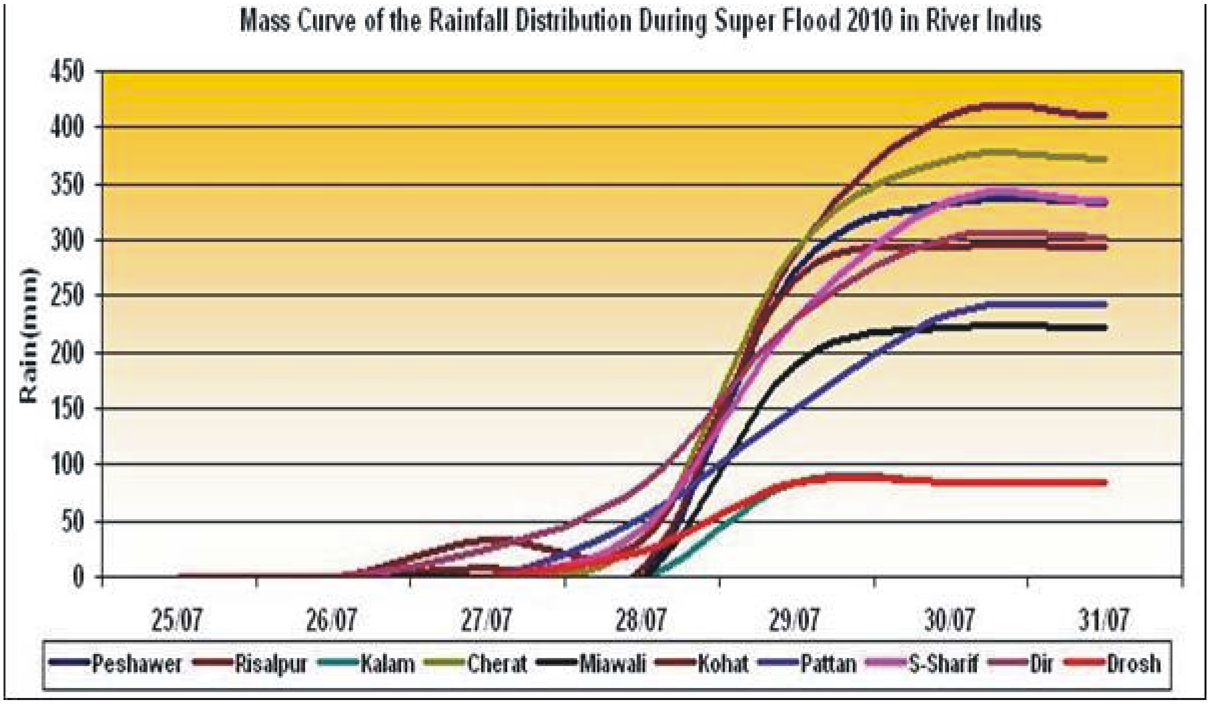


Figure 9: Mass curve from 25th to 31st July 2010

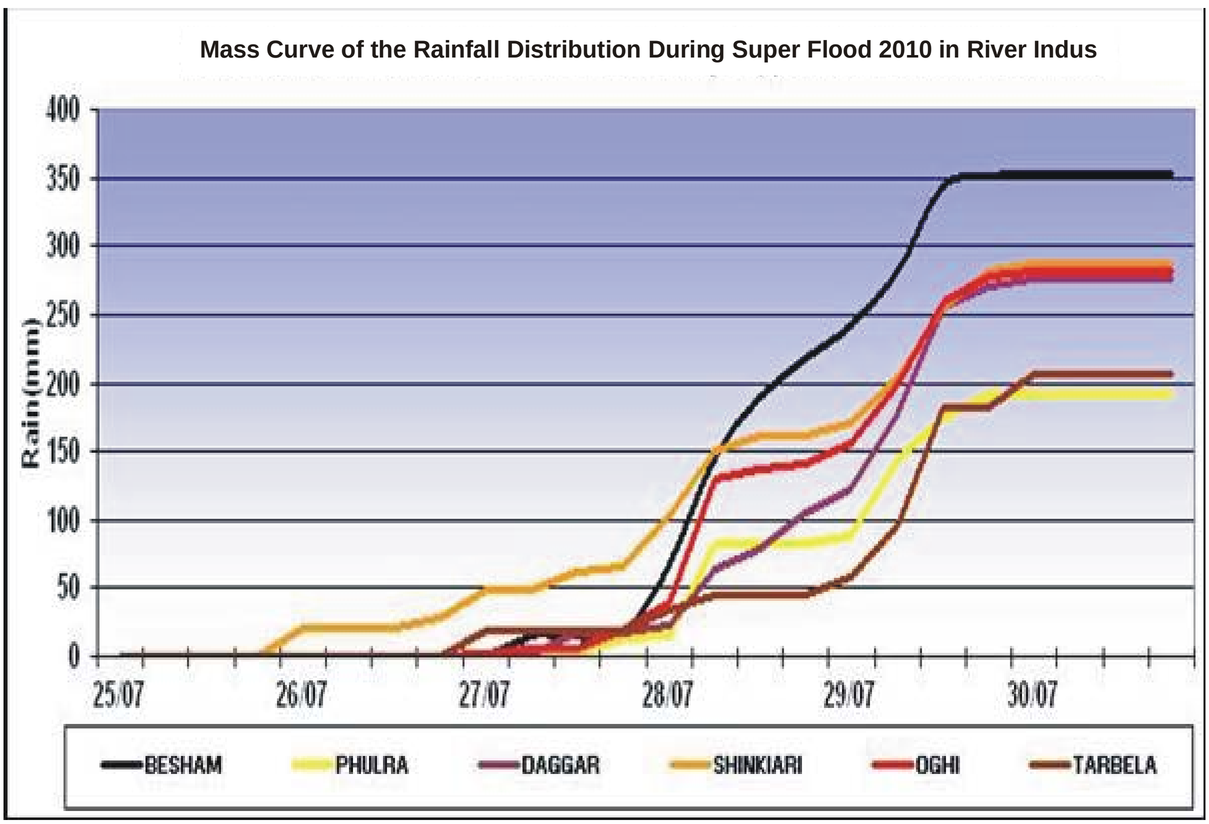


Figure 10: Mass curve from 25th to 30th July 2010

Comparison of peaks recorded at different sites (Barrages) of Indus River with the past maximum peaks observed is shown in the **Figure-11**.

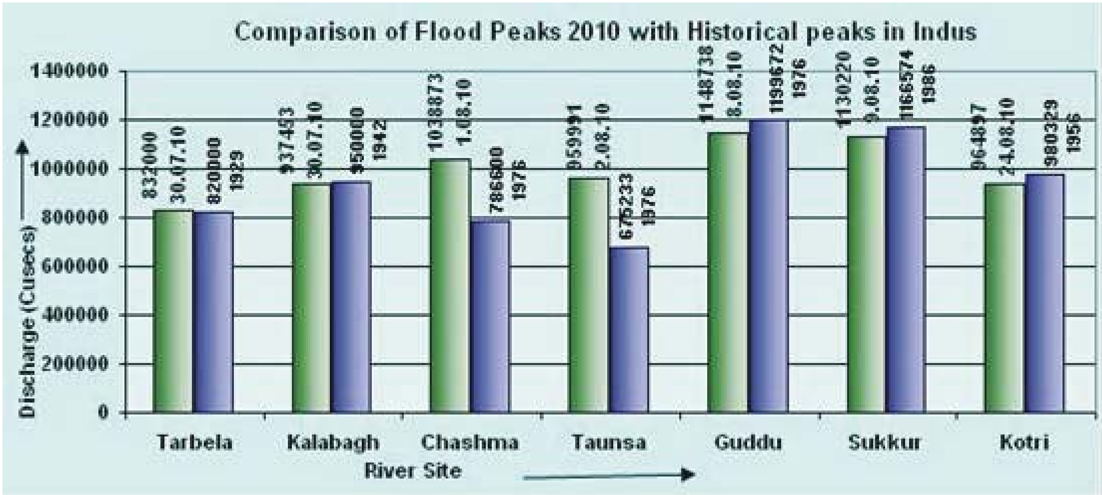


Figure 11: Comparison of 2010 Flood Peaks with Historical peaks in Indus river at different locations

A similar severe flood conditions in Jhelum river were experienced in 1992 when rainfall storm at midnight between 8th and 9th September occurred and it produced a peak flow of 9,87,000 cfs at Mangla Dam at 1700 hour on 9th of September. The rainfall storm at midnight between 9th and 10th of September produced 2nd peak of 10,90,000 cfs at Mangla at 0400 hour on the 10th of September. Consequently discharge of more than 10,00,000 cfs was released through the spillway of the dam which is perhaps the highest flow ever experienced for operation of the spillway on earth as seen in **Figure-12**.

Figure 12: Operation of Mangla Dam Spillway at discharge of 1 million cf

Assessment of Damage of 2010 Flood:

In addition to the misery of millions of people and loss of human life, tremendous damage to public and private property occur during major floods. Crops are lost not only during the year of flooding but also for the following seasons. It is impossible to estimate exactly the direct and indirect losses. During the flood of 2010, a number of disasters occurred in the areas situated along Indus River. The social infrastructure got damaged due to inundation and dislodging of infrastructure. Moreover, the important hydraulic structures like Jinnah and Taunsa Barrage suffered damages of various kinds. The Government took a serious notice of the unprecedented flood in Indus River by focusing attention on the damages of above barrages due to which irreparable losses occurred in the areas situated along left bank of the Indus on account of breach in Left Marginal Bund (LMB) of Taunsa Barrage as shown in **Figure-13**. Consequently Muzaffargarh Canal and Taunsa Punjnad Link Canal breached as shown in **Figures 14 and 15**. In the similar fashion, the Left Guide Bank (LGB) of Jinnah Barrage was completely washed away. Owing to the damage of LGB of the barrage, the structure lost its control.

Figure 13: Breach of LMB of Taunsa Barrage

The joint flow of Swat and Kabul Rivers created a disaster in Khyberpakhtun Khaw province. The major towns like Nowshehra and Charsadha were badly damaged on account of flowing water and inundation of areas around the rivers.

Figure 14: Breach of T.P. Link and Muzaffargarh Canals

Figure 15: Submergence of Superstructures of the Kotri Barrage

The structure of Munda Barrage existing across Sawat River was completely damaged. Keeping the above damages in view, it is also noticed that a number of Irrigation canals in the provinces were breached at different locations and ultimately the irrigation supplies were suspended. A similar phenomenon of damages of the flood was observed and a number of flood embankments were breached at different places in Sindh province. The barrages of the province were submerged and their component parts like divide walls were fully under water and superstructures at Kotri Barrage were dislodged as shown in **Figure-15**. If we look into the damages in the other provinces, it is noted that in KP, apart from social damage, the 2010 floods washed away the Munda Barrage and a source of Irrigation for about 0.15 million CCA of Mardan and Charsada Districts was lost. In the northern part of the KP, hundreds of the bridges existing across the streams contributing the Indus, Kabul and Sawat Rivers have been completely dislodged and connection between the towns was also lost in the area.

In Sindh Province, a number of (Natural/Intentional) breaches in flood bunds like Tori as shown in **Figure-16**, MS and PB embankments occurred in addition to a breach which occurred in Left Marginal Bund of Guddu Barrage. The flood waters released from the breach in Torri Bund were so large and severe that it did not only inundated the area lying along right side of Indus River below Guddu Barrage but it also caused breaches in other flood bunds, which ultimately inundated the large area of the province of Sindh as well as province of Balochistan. Similarly, Balochistan Province was also affected from the flow emanated from the breach of Tori embankment and ultimately eighteen districts were badly affected. The damages in the districts were augmented by the torrential flows of rain water. Details of the damages of the individual structures are out of scope of the current work. However, a financial loss of about US$ 277.6 million (ADB and World Bank, 2010) is estimated. The total sector-wise loss during the recent flood is elaborated in the **Table - 4**.

Figure 16: Initial Stage of Breach of Tori Flood Bund in Sindh Province

Table – 4: Financial and social damages during flood 2010

SECTOR	DIRECT DAMAGES PKR MILLIONS	INDIRECT LOSSES PKR MILLIONS	TOTAL DAMAGES	
			PKR MILLIONS	US$ MILLIONS
1. SOCIAL INFRASTRUCTURE				
Housing	91,843	43,171	1,35,014	1,588
Health	1,562	2,661	4,222	50
Education	22,047	4,418	26,464	311
Subtotal:	1,15,451	50,249	1,65,700	1,949
2. PHYSICAL INFRASTRUCTURE				
Irrigation & Flood Management	23,600		23,600	278
Transport and communications	62,491	50,420	1,12,911	1,328
Water Supply and Sanitation	3,194	6,112	9,306	109
Energy	13,184	13,116	26,300	309
Subtotal	1,02,469	69,648	1,72,117	2,025
3. ECONOMIC SECTORS				
Agriculture, Livestock & Fisheries	3,15,547	1,13,257	4,28,805	5,045
Private Sector & Industries	14,463	9,468	23,932	282
Financial Sector	110	57,141	57,251	674
Subtotal	3,30,120	1,79,866	5,09,987	6,000
4. CROSS CUTTING SECTORS				
Governance	3,141	2,835	5,976	70
Environments	992		992	12
Subtotal	4,133	2,835	6,968	82
Total:	**5,52,173**	**3,02,599**	**8,54,771**	**10,056**

The ADB and the World Bank (2010)

Future Flood Management Strategies:

It is difficult to devise such strategies which could completely avoid floods and flood damages. However, it is possible to minimize the flood damages by adopting appropriate measures. Some management measures include passage and disposal of floods as well as their prediction, relief measures and evacuation of affected people etc. The management in this regard will consist of two main aspects i) floods may be mitigated at source ii) effective efforts during floods for safety of the people and infrastructures. The Govt. has started planning for the construction of reservoirs and these are required for flood control in addition to other multiple-purposes. The proposal of Kalabagh Dam is well-convinced but the final decision is awaited since long. Chiniot Barrage on Chenab River is the only topographic possibility where some storage can be provided. Another aspect is flood protection bunds where emphasis and attention should be given not only for their construction where necessary, but also for their later maintenance. As Punjab, in the upper Indus Basin down to the confluence at Mithankot and beyond, has over 70% of its riverine area un-protected and the worst hit, special consideration/extra funds should be provided to protect the area along the major rivers. In addition to the above efforts, river training by bunds and transverse structures is necessary so that the rivers can meander within the acceptable limits. Moreover, forest and range management of the watershed on Jhelum and Indus Rivers and their tributaries, which lie in Pakistan are planned to be carried out continuously.

Govt. has started thinking that breaching sections in the marginal bunds of barrages and bridges over the rivers are to be kept in working order for operation in any emergency like flooding. Their design should be re-examined in the perspective view of the recent flood. Simultaneously with that, the waterways should be kept clear and properly marked downstream of the breaching sections even by imposing administrative action under the new canal legislation where necessary. Deliberate cutting of bunds at various places to provide access to private buildings and factories built inside the river plain during the recent flood should be checked at any cost. Moreover, the Govt. has also planned to rehabilitate discharge capacity of the barrages which has been reduced on account of their aging factors. In this regard, additional controlled waterways in the vicinity of these barrages are actively being considered in the shape of annexy weirs or separate spillweirs to be operated as and when required during flood conditions. As it has already been mentioned above that provision of breaching sections in such structures where this provision does not exist already is being planned considering it the cheapest technique for disposal of discharge during flooding. It is pertinent to mention here that the ADB and the World Bank have assessed the damages of hydraulic and social infrastructure and estimated financial involvement for their restoration as given in **Table-5**.

Table – 5: Estimate of Total Reconstruction Costs by Sector

Sector	Reconstructions Option 1		Reconstructions Option 2		Reconstructions Option 3	
	PKR millions	USD millions	PKR millions	USD millions	PKR millions	USD millions
1. Social Infrastructure						
Housing	126,075	1,483	143,676	1,690	187,491	2,206
Health	4,151	49	4,151	49	4,151	49
Education	42,907	505	42,907	505	42,907	505
Sub Total	173,133	2,037	190,734	2,244	234,549	2,759
2. Physical Infrastructure						
Irrigation & Flood Management	36,294	427	36,294	427	83,499	982
Transport & Communication	200,260	2,356	200,260	2,356	200,260	2,356
Water Supply & Sanitation	6,292	74	6,292	74	7,982	94
Energy	9,038	106	9,038	106	9,038	106
Sub Total:	**251,884**	**2,963**	**251,884**	**2,963**	**300,779**	**3,539**
3. Economic Sectors						
Agriculture, Livestock & Fisheries	21,879	257	56,925	670	89,134	1,049
Private Sector & Industries	8,636	102	8,636	102	10,923	129
Financial Sector	39,358	463	39,358	463	39,358	463
Social Protection & Livelihoods	58,076	683	58,076	683	58,076	683
Sub Total	**127,949**	**1,505**	**162,995**	**1,918**	**197,491**	**2,323**
4. Cross Cutting Sectors						
Governance	4,900	58	4,900	58	4,900	58
Disaster Risk Management	2,295	27	2,295	27	2,295	27
Environment	17,746	209	17,746	209	17,746	209
Sub Total	**24,941**	**293**	**24,941**	**293**	**24,941**	**293**
Total	**577,908**	**6,799**	**630,554**	**7,418**	**757,761**	**8,915**

The ADB and the World Bank (2010)

Recommendations:

1. Construction of dams across the rivers at potential sites for natural storage reservoirs for flood mitigation.
2. Regular maintenance of flood embankments with provision of wetting channels in marginal bunds.

3. The custodian engineers must be given full awareness about the safe operation of barrage by means of emergent exercise of barrage operation in their presence to show them the working of pertinent parts of the barrage.
4. Regular probing about the health of barrages and marginal bunds should be carried out.
5. Avoidance of partial implementation of flood works as well as restoration of stone apron must not be less than 50% of the designed quantity of the flood works. Moreover, availability of stone stacks at marginal bunds must be ensured.
6. Plane table survey of sufficient river reach upstream and downstream of the barrage after every flood season must be a regular feature for recording morphological conditions in the vicinity of the barrage.
7. Provision of breaching sections well away from the barrage on the basis of model study and availability of the breaching sections already existing at bridges/barrages must be ensured by removing obstructions upstream and downstream of them.
8. A pool of experts should always be available to discuss river engineering and barrage problems and hold emergent meetings during floods.

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References

1. Dr. Arora. K.R. (1996). Irrigation, Water Power & Water Resources Engineering.
2. Sharma. K.R. (1946). History of Irrigation Engineering (volume – II).
3. Federal Flood Commission Govt. of Pakistan (1978). National Flood Protection Plan (volume – I).
4. Irrigation & Power Department Govt. of Punjab (1998). Operation and Maintenance Manual for Punjnad Barrage.
5. Harza Engineering Company International (1975). Flood for Casting and Flood Warning System (volume – I).
6. History of Irrigation in the Indus Basin (volume – II).
7. West Pakistan Water & Power Development Authority (1969). Barrages and Link Canals of the Indus Basin Project.
8. Federal Flood Commission Govt. of Pakistan (1978). National Flood Protection Plan (volume – III).
9. Sharma. K.R. Irrigation Engineering (volume – III).
10. United Nations, Economic Commission for Asia and the Far East (1953). River Training and Bank Protection.
11. Seminar on National Productivity (1978). Symposium on Flood Management in Pakistan.

12. Ahmed Nazir and Ali Dewan (1961). Sediment Characteristic of the Indus with Reference to Erosion of its catchment.
13. Asian Development Bank & World Bank (2010). Preliminary Damage and Needs Assessment.
14. Federal Flood Commission Govt. of Pakistan (1978). National Flood Protection Plan (summary).
15. Pakistan Engineering Congress (1998). 67th Annual Session Proceedings.
16. Pakistan Engineering Congress (1996). 66th Annual Session Proceedings.
17. Pakistan Engineering Congress (1998 - 2000). 68th Annual Session Proceedings.
18. SETHI. H.K.L. (1960). River Training and Control for Bridges.
19. Central Board of Irrigation & Power (1971). Manual of Irrigation Behaviour Control and Training (Publication No. 60).