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ROLE OF TARBELA DAM IN WATER REGULATION OF INDUS RIVER AND ITS EFFECTS

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Abstract –
Tarbela Dam on Indus River is the only mega storage structure in the country which acts as its economic hub since more than 90% of the water is used for irrigation of agricultural land. Seasonal intense flow, and more than 70% availability of the annual water in 3 months time, demands a suitable solution for flood attenuation, and water storage for agricultural use in arid/semi arid conditions. Flow forecasting is one of the most important factors, for optimal utilization of water. A critical analysis shows the importance of this great structure; however certain improvements in water regulation, predicting inflow, power generation enhancement, flood control and educating the users (agriculturists) can further enhance the efficacy of this great hydraulic structure.

Keywords:
Tarbela Dam, Indus River, Water regulation, CBIS (Crop Based Irrigation System), Pakistan

1. Introduction and Background

Tarbela dam is a large dam constructed on River Indus in Pakistan and is located 50 km NW of Islamabad (Figure 1). The dam forms a reservoir of 250 square Km surface area. The construction of the dam was completed in 1974 and originally it was designed to store water for the purposes of irrigation and generation of hydel power. The dam consists of main dam walls built of earth and rock fill, stretches 2743 meters (8999ft) and is 148m (486 ft) high from the river bed. A pair of concrete auxiliary dams have two spill ways; the main spillway has the discharge capacity of 18406 Cumecs (650, 000 Cusec) and the auxiliary spillway has 24070 Cumecs (850,000 Cusec), respectively. Initial storage capacity of the dam was 11.6 MAF (gross storage) and 9.7 MAF (Live Storage) which has now been reduced to 9 MAF (gross storage) and 6.77 MAF (Live Storage). The planned power production of the dam was 2100 MW, which was revised and increased to 3478 MW with the passage of time. Pakistan is a water deficient agricultural country, therefore the water control is executed on the irrigation requirement and power generation is limited to irrigation requirement and flood control.

Figure 1: Location Map of Tarbela Dam

2. Aspects of Study

2.1 Irrigation

Pakistan is one of the most arid countries in the world and over 75% of its area receives less than 250 mm of rainfall annually, and 20% of it is less than 125 mm. The agriculture and economy are mainly dependent on the annual influx of the Indus River System of about 154 MAF which is mainly the snow and glacier melt, and the rain water in monsoon season. Pakistan's main economy is agricultural based, so water regulation and its optimal use is the only solution, keeping in view the arid and semi arid area of Pakistan. There are two main crop seasons in Pakistan, *Rabi* (Nov to Apr) and *Kharif* (May to October). Due to the storage capacity of dams, an additional 15.7% water, as shown in Table 1, has been made available for the crops annually (this addition includes the storage capacity of Mangla Dam as well).

Table 1: Additional Water Availability

Season	Initial Water Quantity (1962–1967)	After Mangla (1967–1976)	After Tarbela (1976-2003)	Additional Water	
				Quantity	%age
Kharif	62.38	65.02	67.77	5.39	8.6%
Rabi	28	30.78	36.80	8.80	31.4%
Total	90.38	95.80	104.57	14.19	15.7%

All quantities are in MAF
Source: Sardar Muhammad Tariq, Regional Chair, Global water Partnership (GWP) [4]

The problem becomes more aggravated as there will be no additional water to be inducted in Pakistan; rather there will be a reduction in water availability due to cross border water disputes and an increase in the non-agricultural use of water due to population growth and urbanization. Presently Pakistan is using 91% of its water for irrigation purposes.

Furthermore, due to climate conditions and the rainfall / snowmelt season, Pakistan gets 70% of available water in the 3 months of (July-September) *Kharif* season. With the available storage capacity of reservoirs, it has been able to shift 7% (Table 2) of water from *Kharif* to *Rabi* Crop season.

Table 2: Difference In Seasonal Availability Of Water

Season	Initial availability	Present Condition	Difference
Kharif	88%	81%	-7%
Rabi	12%	19%	+7%

Out of the available water, the agricultural outputs have been very low for Pakistan. As compared to 7.82 Kg/m^3 of Canada, 1.56 Kg /m^3 of USA, 0.82 Kg /m^3 of China and 0.39 Kg/m^3 of India, Pakistan is only getting 0.13 Kg of agricultural products per cubic meter of available water. [4] Apart from the above mentioned factors, this low value is due to different factors which include high seepage due to *Katcha drains*, high evaporation rates and mismanagement / pilferages in the irrigation water supply system. Out of the available water at source, up to 70% are the losses, before it reaches the user end. Ground absorption of water below the wilting point is another reason for wastage of water. It is due to all of the above mentioned reasons that the contribution of water to GDP, per cubic meter of water is very low in Pakistan, which is 0.34 US$ as compared to the world average of 8.60 US$.

The historic design of water allowance in Pakistan is about 0.25-0.28 liters per second per hectares of the cultivable command area (CCA) in major perennial canals. However, with the induction of remodeled and new irrigation system the capacity to meet the peak crop water demand has been regulated. As an experiment in 3 canals in Khyber Pakhtunkhwa the water allowance was increased to 0.60-0.77 liter per hectare per second by adopting the modern system. The system is known as Corps Based Irrigation System (CBIS). Details of the water distribution mechanism are given in Table 3.

Table 3: Traditional and New Rules for Irrigation System Operation

Traditional rules	**New Rules**
Run the system at full supply discharge continuously	Run the system at full supply discharge when a channel is open
Regulate flows in main canal according to water availability in the river.	Main canal maintains near constant water level to feed its distribution system. Water availability is not a constraint.
Rotation to be introduced when water availability / supplies falls below 70-80 percent of full supply discharge.	Introduce rotation when water requirements are lower than design full supply.
Keep off takes/outlets always open as their closure floods tail reaches of main or secondary canals.	Keep off takes / outlets open only when water is needed. Main canal has capacity for ponding extra water.

Source: Transition From Conventional To Modern Water Management In Pakistan (International Water Management Institute Lahore) [1]

2.2 Power Generation:

Out of the three main functions of Tarbela Dam, one important function is power generation. Hydropower is one of the most economical and sustainable power generation sources. The Indus River drops an elevation of 7000m and a length of 800 Km before entering the Tarbela Lake. Initial power generation capacity installed in the dam was 2100 MW which was enhanced to 3478MW (Table 4, Figure 2). For this purpose 4 tunnels have been made with diameters of 36 feet – 45 feet (10.97-13.72m). The peak production of the system has been 3702 MW which was 23% of the system and the record annual production of 16.463 billion KWH in 1998-99. The system has generated 341.139 Billion KWH since commissioning.

Due to an increase in the fossil fuel prices in the world, more emphasis was laid on the hydel power and power production capacity was enhanced. However there is still an additional power generation capacity in Tarbela Dam, as tunnel no 4&5 have yet not been installed with the power generation system. Presently Pakistan is mainly relying on the Thermal Power and IPPs and hydel to thermal ratio is 0.53 in present scenario.

Table 4: Power Generation Capacity

Power House	Planned	Actual
Tunnel 1	4x175= 700	4x175 = 700 (1977-78)
Tunnel 2	4x175= 700	6x175 = 1050 (1982-85)
Tunnel 3	4x175= 700	4x432 = 1728 (1992-93)
Tunnel 4	NIL	NIL
Tunnel 5	NIL	NIL
Total	**2100 MW**	**3478 MW**

Proportion of the hydropower of Tarbela Dam corresponding to the total capacity of the country's power generation was 39% (1971), 41% (1974), 45% (1980) and 30% (1998). Also the domestic use has increased from 72% to 83% and agricultural and industrial usage has been reduced from 4% to 1% and 5% to 2%, respectively. [5]

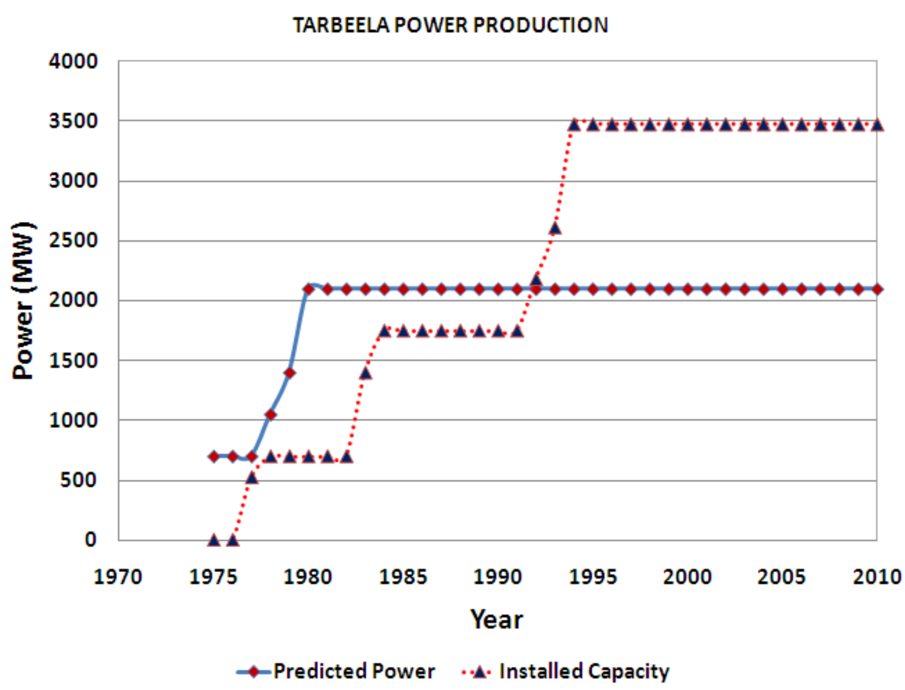

Figure 2: Actual and Predicted Power Generation of Tarbela

Although the period of post –Tarbela period has been relatively dry as compared to the pre-Tarbela period and there has been a delay in the installation of the power generation system but output of overall system until now is 78% of planned and from 1993 onwards the power generation is 13% more than planned (at average). It is also worth mentioning that water availability during this period has been 5% less than the predicted water flow.

2.3 Flood Control

Tarbela dam was not initially designed for flood management, however with a big reservoir capacity; it provides limited attenuation of flood peaks. The reservoir filling criteria developed by WAPDA, based on the forecasting system is of maximum allowance of 3m/ day gain up to a level of 460m and 0.3m/day above that. If the rainfall intensity upstream is low, then 0.6m/day is also practiced. Flood regulation is therefore an incidental aspect of Tarbela Dam. Normally floods occur in July and August, so the dam is generally filled to its maximum level around 20th August and from there on no additional water is stored. In 1992 a flood occurred in the month of September, so there was hardly any significant storage available to attenuate the peaks.

Indus River is one of the biggest sediment carrying rivers in the world. The life of Tarbela Dam was estimated to be 50- 55 years (up to year 2030), but due to the low actual sedimentation rate as compared to the predicted sedimentation rate (Table 5), the reassessed estimated life of the dam is up to year 2050. Chashma is another small reservoir downstream of Tarbela, which is mainly dependent on the inflows from Tarbela Dam. The storage capacity of the reservoirs is decreasing due to sedimentation thus, reducing the water regulation and storage capability for an already water deficient system.

Table 5: Storage Capacity Loss

	Original Capacity (MAF)	Capacity in 2004 (MAF)	Capacity in 2010 (MAF)	Storage Loss MAF (%age
Tarbela	9.7 (1976)	7.16	6.77	2.91 (30%)
Chashma	0.87 (1971)	0.44	0.22	0.65 (75%)
Total	10.57	7.6	6.99	3.58 (34%)

Loss of Capacity in Tarbela - 0.103 MAF / Year
Loss of Capacity in Chashma - 0.022 MAF / Year

If the information for catchment in Tarbela is ensured with a high level of reliability and accuracy, then using the flood routing procedures and simultaneously accessing the flood information of flow of downstream tributaries for the River Indus, flood peaks are attenuated at Tarbela (Table 6).

Table 6: Peak Inflows and Outflows at Tarbela

Period	Peak Inflow	Peak Outflow
23-7-88	13605	10765
31-7-89	14456	10739
10-9-92	14966	14682
27-8-97	11338	6431
30-7-10	23577	-

Source: Water Resource Management Directorate WAPDA

As general criteria 40% of the available water per year is to be kept in a storage capacity, whereas in Pakistan only 7% of the available water is being stored which is 30 days reserve. Even after the construction of Tarbela Dam 1125 MAF water has gone to sea unutilized which is equal to 10 years of canal withdrawal. In monetary terms the value of the unutilized water is 149 Billion US$, which is the total after deducting the 300 MAF required for environmental purposes. [4]

The present use of conventional rim stations and use of remote sensing devices for snow melt for the flow predictions has helped in predicting the flows. However the estimation has been as much as 43% over estimated, for the snow cover melt. [2]

3. Analysis:

For an arid/semi arid country like Pakistan with high rates of wastage and max flow of water taking place during 3 months of the year, water storage and regulation to the optimal level is the foremost requirement. Pakistan's economy mainly depends on the agricultural sector, but the contribution of agriculture in the GDP and the out put per cubic meter of water is very low as compared to other countries and the overall world average. Pakistan has one of the best canal networks in the world. The main reasons for the low out put are

a. Water losses due to seepage and evaporation
b. Misuse of water and pilferages
c. Use of ordinary and old methods of cultivation. Water received at the user end for the cultivation / agriculture already suffers 70% losses and the use of conventional ways (non technical methods for cultivation / agriculture) further worsens the situation.

With the induction of the CBIS, the viability and utility of water, both will increase. But there is a need to educate the people and make them conversant with this system. People affiliated with agriculture have a very low literacy rate and change from the conventional water allocation system to CBIS is not welcomed by them.

Due to the high rate of sedimentation, the life of Tarbela Dam was estimated to be 50- 55 years (up to year 2030), but due to the low sedimentation rate in the past as compared to the predicted sedimentation rate, the reassessed estimated life of the dam is up to year 2050. A decrease in the storage capacity of reservoirs is also affecting the availability and regulation capacity of the available water. Shift over of water from *Kharif* to *Rabi* crops can be more effectively utilized if there is additional storage capacity available. This can not only be used to attenuate the flood peaks but also in availability of more water for both crop seasons and also for additional power generation.

Enhancement of power generation from 2100 MW to 3478 MW is an indicator which shows the power potential of this dam. Presently only 3 tunnels are being used for power generation, against a total of 5 tunnels operating in the dam. Presently, out of the available resources of power generation in Pakistan, hydropower is the most economical. Owing to the power potential of Tarbela Dam, Tunnel 4&5 can also be installed with a power generation system to increase economical & sustainable power production.

Water flow forecasting in the catchment area is a point of concern which plays a very important role, not only in water regulation or flood control but also in hydel power generation and agricultural water availability and optimal utilization of the dam for water management. Use of rim stations has not proved to be a reliable source for the flow forecasting and flood peaks. Remoteness of the area and non availability/ reliance on the modern technology are the other factors which play a role in poor prediction of flows. Use of remotely sensed snow cover data for the flow forecasting has also shown high level of inaccuracy (as high as 43% in 1979). The efficacy of the dam can be much improved by the better flow forecasting system.

It is also pertinent to introduce the modern irrigation and cultivation techniques for the better outcome of used water, for a country like Pakistan where 91% of water is being used as agricultural requirement. Also the high rate of loss from the source (Dam) to the user end (agriculturist) is a point of great concern. The paving of the canals and *katcha drains* can result in a considerable reduction in the loss of water and beside this important aspect, the problem of water logging and salinity can also be addressed.

4. Recommendations

a. Special attention should be given to water forecasting and prediction in the catchment area to include the use of modern technology and advanced remote sensing devices.
b. Water regulation of Tarbela Dam should be planned on the revised forecasting system for better attenuation of flood peaks.
c. CBIS should be introduced on a permanent basis in the complete cultivable command area (CCA).
d. Additional reservoirs should be constructed to increase storage up to 40% of available water and to get more water for irrigation and to reduce the adverse effects of flood.
e. Tunnel 4&5 should be installed with hydel power generation units as per the dictates of site condition, for max out put.
f. Public education & incentives on the grass root level for optimal agricultural use of water should be promoted.

5. Conclusion

Role of Tarbela Dam has been analyzed in the preview of its three main functions of irrigation, power generation and flood attenuation. This analysis shows the utility and importance of this great structure. Measures to improve and enhance the efficacy have also been suggested. This will help in agricultural and socio economic growth of the country.

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