PERFORMANCE OF TARBELA DAM PROJECT

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ABSTRACT

Tarbela Dam Project (TDP) was constructed as part of Indus Basin Project, to mitigate the impact of ceding three eastern rivers (Ravi, Sultej and Beas) to India under 1960 Water Treaty. Though provided as part of the package for the replacement works, it was intended to: provide a live storage of 11.5 billion cubic meters (bcm) or 9.3 million acre feet (maf) including an element of development; generate cheap hydropower through staged development of 2100 MW capacity; increase agricultural production with emphasis on autarky in wheat; and provide a base for further development of agriculture through structural integration/regulation of Indus Basin Irrigation System (IBIS).

During the year 1999, World Commission on Dams (WCD) chose TDP as one of focused case studies for world wide knowledge base to draw upon for finalizing its report "Dam and Development – A New Framework for Decision Making". For this study, WCD engaged a Pakistani Group of Consultants (Asianics Agro- Development International) in which the author was also associated.

WCD case study on TDP was based around six key questions of: (i) projected versus actual benefits and costs; (ii) unexpected benefits and costs; (iii) distribution of costs and benefits; (iv) decision making; (v) compliance with prescribed criteria and guidelines; and (vi) lessons learnt. In conducting this study, a special effort was made to obtain micro-level information from stakeholders and affectees to supplement findings on socio-economic and environmental aspects of the Project.

This paper highlights the findings of WCD case study regarding predicted, actual and unexpected outcomes of TDP. The particular aspects covered are: water resources; sedimentation; surface water diversions; groundwater irrigation; agriculture, salinity and water-logging; hydropower; flood alternation; municipal water supplies; resettlement; and ecological impacts. Also touched upon are: distributional effects; decision making process and options assessment; and stakeholders.

1. BACKGROUND

In 1997, various international funding and development agencies established World Commission on Dams (WCD), which was mandated to assess "development effectiveness" of dams. The Commission decided to address this through thematic studies, cross-check surveys and a series of case studies of dam projects world-wide. Tarbela dam case study was an integral part of the overall study being carried out by the WCD as part of its mandate. During 1999, implementation of the case study was assigned to an Islamabad based Pakistani Consulting Group of Asianics Agro – Development International.

Case Study methodology was based around the following six key questions devised by WCD to provide the foundation for assessment of performance:-

i. What were the projected vs. actual benefits, costs and impacts?

ii. What were the unexpected benefits, costs and impacts?

iii. What was the distribution of costs and benefits – who gained and who lost?

iv. How were decisions made?

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v. Did the project comply with the criteria and guidelines of the day?

vi. What lessons can be learned for today's context?

Study was completed in July 2000 under the tile "WCD can studies Tarbala Dam and Related Aspects of the Indus River Basin Pakistan".

2. CONTEXT AND SCOPE

Indus Basin Irrigation System (IBIS)

In August 1947, British India was divided into two independent states – India and Pakistan. Shortly afterwards on 1 April 1948, India unilaterally closed the canals with headworks in its territory on the eastern rivers (Ravi and Sutlej) depriving Pakistan of irrigation supplies for about 0.7 million hectares (mha) of the most fertile land in Punjab. This issue bitterly strained relations between the two countries.

Indus Waters Treaty, 1960

World Bank (WB) took the initiative to facilitate negotiations between India and Pakistan that continued for 10 years and culminated in signing of the Indus Waters Treaty (IWT) in 1960. Indus Basin Project (IBP) was the mechanism to implement provisions of IWT and comprised: three storage reservoirs (Tarbela, Mangla and Chashma); six barrages including a siphon; eight new inter-river link canals; and remodelling of three existing link canals. The wording of the Treaty referred to 'a dam on the Indus'. After an evaluation of alternative sites, Tarbela was selected. An Indus Basin Development Fund (IBDF) of US $895 million was created to finance IBP with contributions from WB and other donors to which India made a fixed contribution of 62 million pounds ($ 173.8 m).

3. TARBELA DAM PROJECT (TDP)

3.1 The Project

Tarbela Dam Project (TDP) was constructed as part of IBP together with Mangla Dam and associated infrastructure. Besides the basic purpose of replacement flows, TDP was also planned to provide a substantial degree of integration/regulation of IBIS. Its salient features are listed in Appendix-1, while main predicted objectives were to:-

Provide an 11.5 billion cubic metres (bcm) or 9.3 million acre feet (maf) live storage capacity dam on river Indus (almost doubling Indus flows in the dry season of *rabi*) in order to: partly replace the water of eastern rivers ceded to India; and provide additional supplies during the low flow period to facilitate further development of irrigated agriculture.

Increase food production to achieve self sufficiency , especially in wheat.

Generate cheap hydropower through staged development of 2100 MW capacity.

Two documents were central to the planning of the project and its evaluation and provided the basis for comparison of predicted and actual outcomes in WCD the Study. Feasibility of the Project and proposals for wider development plans in the basin as contained in the Indus Special Study completed by the World Bank in 1967. The Study commonly referred to as the Lieftinck Report, was titled "Water and Power Resources of West Pakistan-A Study in Sectoral Planing"

3.2 Financing and Costs

Project was financed through World Bank Administered Tarbela Development Fund (TDF) created in 1968 out of the remaining balance from the Indus Basin Development Fund (IBDF) and additional loans and grants from friendly countries. All rupee component of the Project cost was borne by Government of Pakistan.

3.3 Implementation and Commissioning

Tarbela was the largest earth-fill dam of the day and presented a challenge in dam design and construction, particularly given complex geological conditions. During the initial test filling in 1974, one of the three intake gates of a diversion tunnel jammed while being lowered to achieve closure. This resulted in collapse of the intake structure of Tunnel No.2 (out of four) thus endangering safety of the dam. The reservoir was evacuated in emergency to avert this crisis; however after quick repairs, the problem was resolved and the dam was fully commissioned with out much delay.

Commencement of the Project in May 1968 was almost one year later than planned. The original period for construction and commissioning of the dam and reservoir was 7.25 years. As a result of special repairs and restoration, the Project implementation period was approximately one year longer at 8.3 years**.** The original schedule for full commissioning was September 1974. Against this, partial storage releases started in winter 1975 while first complete reservoir filling was accomplished in September 1976, two years behind schedule. The first four power units started generating in early 1977 on average twenty months later than scheduled. Overall electricity generation potential of 3478 MW (67% more than the planned 2100 MW) was developed in stages through 1993.

3.4 Operation and Maintenance

Operating rules of the reservoir were originally set for maximum irrigation releases but in late 1990s were amended in response to the need to manage sediment deposition due to formation of delta (this is further described under the following sub-section 4.2).

Because of lack of a formal agreement between the provinces on sharing Indus waters, the operation of the reservoir was conducted on an *ad-hoc* basis during1976 to 1993. A formal accord was reached between the provinces in 1991 that prescribed water allocation between provinces. Consequently, Indus River System Authority (IRSA) was created in 1993, under an Act of the Parliament, to oversee implementation of 1991 Water Accord. This body with representatives from all provinces and federal government is chaired by one of the representatives on annual rotational basis. Regulation of the Indus Rivers System including storage reservoirs at Tarbela and Mangla is now being handled by IRSA.

4. PREDICTED AND ACTUAL EFFECTS

4.1 Storage Releases

Primary goal of TDP was to ensure that the irrigated areas in the country continued to receive water supplies after India diverted the eastern rivers. Storage was also provided to bring additional areas under cultivation through increased cropping intensity in various existing canal commands. Approximately, two thirds of the reservoir storage was considered to be for replacement and one third for additional irrigation. Given the integral nature of Tarbela within IBIS and the influence of other investments and inputs on agricultural production, the comparison of actual storage releases with predicted provides a simple indicator of how the Project performed in terms of its original objectives.

'Predicted and Actual Annual Storage Releases from Tarbala Dam', are shown in Appendix-2. Prediction of storage releases from reservoir for irrigation in the dry (rabi) season assumed a declining trend from 10.17 bcm in 1975 to 6.95 bcm in 1998 based on effect of sedimentation in the reservoir. Overall, the actual releases were on average 20% more than predicted (19% higher during 1975-90 and 22% higher during 1990-98) although in 1990-92 releases were

8% lower than predicted.

4.2 Sedimentation

Predicted rate of sediment inflow to was 0.294 bcm per year meaning that the dam would silt up to Tarbela 90% capacity in 50 years and thereafter continue to provide only about 1.2 bcm of live storage. A number of sediment management measures were examined at the time of design but considered in-feasible.

In practice, the actual sediment inflow rate has been significantly lower than predicted, with an average rate of 0.106 bcm, 36% of predicted. However the proportion of sediment inflow trapped in the reservoir (trap efficiency) was slightly higher than predicted. The useful life of the dam is now considered to be 85 years, although, as with the prediction, the usable storage will gradually decline over this period. An unexpected aspect of the sediment deposition however, is quicker advancement of the sediment delta (in 1998 it was located 14km from the dam). There are concerns that under earthquake loading the sediment may liquefy and block all low level outlets including power intakes.

In terms of management measures during 1998, the minimum reservoir drawdown level was raised from 396m (1300 feet) to 417 m (1368 feet) Thereafter it would be raised gradually every year. This would have the effect of depositing sediment in the upper reaches and reduce advance of the sediment delta, but at the cost of reducing live storage and consequent reducing water availability in the dry season.

4.3 Surface Water Diversions

'Historical Canal Diversions to IBIS' are listed in Appendix-3. Lieftinck Report projected that annual average surface water diversions at the canal heads would be around 125.5 bcm by the year 1985. In actual practice, IBIS attained a 3% higher average figure of 129.4 bcm over the period 1978-82. This figure closely matched with planned abstractions for IBIS, based on the sanctioned allocations of individual projects in the provinces. Tarbela contributed on average about 9.3% (12.3 bcm) to the total annual irrigation supplies for IBIS; the contribution was 21% of *rabi* abstractions (9.8 bcm) and for 3% of wet season (*kharif)* abstractions (2.5 bcm). It was therefore concluded that Tarbela, along with Mangla dam, achieved the goal of replacing water lost to India and increasing diversions for irrigation.

Lieftinck Report projected average canal head diversions by 2000 to reach 149 bcm backed by completion of: three additional storage reservoirs almost aggregating to Tarbela capacity; a number of canal enlargement projects to withdraw additional surplus river flows; and ground-water developments with attendant drainage. However, none of the surface water projects was taken up in post-Tarbela period. Thus the canal head diversions attained immediately after Tarbela remained almost stagnant.

4.4 Groundwater Irrigation

Approximately, 64% recharge to the groundwater in the Indus Basin occurs in areas of usable water quality either directly or by mixing with canal water. Canal system conveyance losses directly associated with additional Tarbela storage were estimated to contribute about 10% of the overall recharge of groundwater (the issue of waterlogging and salinity is covered separately in the following sub-section 4.6). During 21 years (1972-97), the contribution of groundwater to irrigated agriculture nearly doubled from 31.6 bcm to 62.2 bcm. This expansion in groundwater irrigation was in part due to initial price incentives in the form of cheap electricity and later the availability of relatively low cost diesel technology. Groundwater irrigation provided a level of reliability that was deteriorating in the surface irrigation system. The number of irrigation tubewells increased by almost

500% from 1970 to 1996, with a total number of 484,000 installations.

4.5 Agriculture

Projections related to agricultural production in Lieftinck Report were based on implementation of TDP, and other infrastructure projects, some of which have been completed, while others have not. Lieftinck Report predicted cropping intensity for irrigated areas of Punjab and Sindh rather than the whole basin. Against the baseline of 95% for Punjab and 90% for Sindh during 1965, the cropping intensity in year 2000 was predicted to increase to 150% and 137%, respectively. Based on district level data collected for WCD study, the actual achievement for Punjab and Sindh through 1997-98 was 117% and 132%, respectively, that is 22% and 4% lower than the projected figures for the year 2000.

Tarbela was designed to compensate for loss of agricultural production as a result of ceding water of the three eastern rivers to India and to increase agricultural production to meet the growing needs of the expanding population. This objective has been partially achieved.

4.6 Salinity and Waterlogging

Waterlogging and salinity have been increasing in IBIS as a result of increasing diversion of water for surface irrigation. Where there is excessive irrigation and inadequate drainage, the groundwater levels rise, and where they are close enough to the surface, capillary action draws up salts from the soil into the root zone and land surface. Approximately 60% of the aquifer underlying IBIS is of marginal to brackish quality. Problem of waterlogging and salinity became apparent in the late 1950s. In areas with fresh groundwater, the water lost from the canal system can be re-used by pumping (at an additional cost to farmers). However, in brackish groundwater areas, this is generally not possible, although groundwater is sometimes mixed with fresh canal water. In 1975, IBIS area with groundwater less than 3 metres from the surface was 42% and the area less than 2 metres from the surface was 22%. In Sindh the area with depth less than 3 meters was 57%. Although groundwater use increased significantly in post-Tarbala period, about 22% of the command area of IBIS still has water table of less than 1.5 m.

4.7 Hydropower

Original design of Tarbela included staged development of twelve generators, each of 175 (MW) capacity, providing a total capacity of 2,100MW by 1980. Of these units, only civil works of the first four were included in the financing package of TDF. In early 1980s, a power optimisation study led to the decision to increase the installed capacity to 3,478 MW. By 1980, the installed capacity was 700 MW which increased to 1,750 MW by 1985 and the final capacity of 3,478 MW by 1993.

Predicted average annual generation at full power development of 2100 MW was 12600 GWh. After accounting for staged development, average predicted generation for the period 1975-98 was 11300 GWh (refer Appendix-4). Actual average annual generation (1978-98) once commissioning was complete, was 9255 GWh, 82% of predicted. After installation of full capacity in 1993, the average annual (1993-98) generation was 14300 GWh, 13% higher than the full development prediction of 12500 GWh. Total actual generation in the period since commissioning (1977-1998) was 194,500 GWh, 79% of the predicted figure of 245,300 GWh (adjusted for the two year delay).

Tarbela would also provide an unexpected power benefit by contributing 20% (1353 out of 6586 GWh) of generation from 1450 MW Ghazi-Barotha Hydropower Project currently under construction, immediately downstream of Tarbela.

4.8 Flood Attenuation

Flood management was not included as an important objective of the dam at the design stage and no predictions were made. However, the impact of TDP on attenuation of actual high flood peaks was significant during the filling period of June through August for impounding about 12 bcm or 19% out of the *kharif* inflow of 64 bcm. Attenuation of peak Indus flows was variable depending on timing of flood in relation to reservoir level that is drawndown prior to the wet season. The peak flows in July 1988 and July 1989 were reduced by 21% and 26% respectively, whereas a peak flow of similar magnitude in September1992 was attenuated by only 2% as reservoir level was already considerably higher in readiness for the forthcoming irrigation season.

4.9 Municipal Water Supplies

Augmentation of municipal water supplies and providing water for industries was also not a significant objective of Tarbela and no targets were fixed. However, the indirect contribution of IBIS and of Tarbela dam to supplement municipal water supply has been an important but unquantified benefit.

4.10 Resettlement

Project design estimated that 100 villages would be submerged resulting in resettlement of 80,000 people. Number of villages actually affected was 120, with affected people closer to 96000, an increase of 20% . Basic law governing resettlement was the Land Acquisition Act of 1894, and criteria for compensating land owners were set by Government in 1967. The main criteria for compensation with alternate land was whether land holdings were greater than 0.2ha of irrigated land or 0.8ha of rainfed land. Approximately one third of the affected population were eligible for replacement land in Punjab or Sindh provinces. Those with holdings less than these limits were eligible for cash compensation. People having houses in the affected area were to be paid cash compensation at 1968 market values and expected to purchase new housing and commercial lots in five new villages (town ships) to be built in vicinity of Tarbela.

There has been wide spread dissatisfaction with the resettlement process. Field surveys conducted as part of WCD case study showed that dam-affected people were not systematically associated with the planning and development process. Many felt the Project had problems with adequately compensating and resettling the affectees. Inspite of over 24 years operation of the dam this was still an active issue. An opinion strongly expressed was that the direct affectees, who made a major sacrifice for the Project, were not fairly compensated. They demanded that a part of the earnings from the dam should be earmarked for development of the communities where the displaced have settled and for those that were affected but kept outside the formal compensation mechanisms. In addition, the gender aspect had been totally neglected in the resettlement process and women specially suffered as a result of disruption of their social life due to migration from ancestral places.

4.11 Ecological Impacts

Ecological impacts of the dam were not considered at the inception stage as the international agencies involved in water resources development had not realised this need at that time. WCD case study revealed several important ecological impacts, mostly negative, on the physical and biological environment. It must however be stressed that these negative impacts on environment are the result of numerous dams and barrages on the Indus River System including developments in India, and cannot be ascribed to Tarbela alone. Area downstream of Kotri has been a contentious issue ever since the development of irrigation works on the Indus. Major negative impacts are obvious on the

Indus Delta like reduced mangrove areas, negative impacts on human livelihood, and large reduction of forests, flora and fauna. Though such impacts are primarily due to the construction of Kotri and Sukkur barrages that reduced downstream flow of sweet water into the Indus Delta; perception developed by communities downstream lends them to believe that any irrigation developments on the Indus would further aggravate the situation in the Delta.

Direct impacts of Tarbela are difficult to separate out from the impacts of other changes experienced in the Indus Basin as a whole, including the earlier dams, barrages, and flood bunds leading to abstraction of water and containment of the flood plain. Other factors include population growth and increased urban and industrial pollution Main influences of Tarbela on the ecosystem were due to the significant reduction on sediment flows causing transgression of the delta and the lower flood flows. Low season flows did not reduce significantly further as a result of Tarbela.

5. DECISION MAKING PROCESS AND OPTIONS ASSESSMENT

IBP included provision for a 'Dam on the Indus'. Investigations into alternative dam sites had already commenced after independence and reconnaissance studies for Tarbela started in 1954. Three alternative sites were initially considered, Tarbela and two sites 4km and 24km upstream of which Tarbela was favoured in terms of its capacity and cost.

As a follow up of IBP, in mid 1960s, World Bank initiated the Indus Special Study (ISS) headed by its Vice President Mr. Pieter Lieftinck. In the resultant Lieftinck Report, three alternative dam site for Indus were considered. Tarbela and Kalabagh were on the Indus main stem while Gariala was on the off-channel of Haro. The other alternatives to either raise the height of Mangla dam or pump underground water to replace the supplies lost to India were not considered feasible. As far as records show, no other options such as groundwater development were investigated.

The first phase of ISS confirmed the selection of Tarbela as the most appropriate site for development of 'Dam on the Indus'. In May 1968, a meeting of donors of the original Indus Basin Development Fund agreed to provide supplementary financing through the creation of Tarbela Development Fund (TDF) to cover the shortfall of funds from IBDF necessary to proceed with the Project. Problems with geology were identified and allowance made in the design. Technical problems encountered during impoundment required emergency repairs and remedial works. Two supplementary financing arrangements for TDF were made in 1975 and 1978 with the latter involving a major increase in contribution from the Government of Pakistan requiring funds to be diverted from other projects to ensure completion.

6. STAKEHOLDERS' VIEWS

Many of the stakeholders contacted during WCD case study considered Tarbela a useful project in terms of development effectiveness for the country since it helped stabilise and expand agricultural production. Contribution of Tarbela in power generation and averting severe power shortages prevailing in the country, till recently was also widely recognised. However it was also recognised that the displaced population was not associated in the planning process and the resettlement process resulted in considerable hardship to these communities. Furthermore, the interpretation of affected people was rather narrow, and many ineligible groups were adversely affected without receiving any compensation.

APPENDIX-1

SALIENT FEATURES OF TARBELA DAM PROJECT

Reservoir	
Length	97 km (60 miles)
Area	260 sq.km (100 sq. miles)
Gross Storage	14.3 BCM (11.6 MAF)
Usable Storage	11.48 BCM (9.3 MAF)
Main Dam	
Maximum Height	148m (485 Ft.)
Length of Impervious Blanket	2025m (6640 Ft.)
Original	1524m (4999 Ft.) modified
Auxiliary Dam 1: Max Height	105m (345 Ft.)
Auxiliary Dam 2: Maximum Height	67m (220 Ft.)
Service Spillway: Design Discharge	18,386 cms (650,000 cfs)
Auxiliary Spillway: Design Discharge	24,070 cms (850,000 cfs)
Tunnels	
Diameter	13.72m (45 Ft.)
Capacity at E1 457.3m (1500 ft)	
Tunnel 4	2605 cms (92,000 cfs)
Tunnel 5	2494 cms (81,000 cfs)

Power House	**Planned**	**Actual**
Power Units:		
Tunnel 1	4 x 175=700 MW(1975)	4 x 175= 700 MW(1977-78)
Tunnel 2	4 x 175=700 MW(1978-79)	6 x 175= 1050 MW(1982-85)
Tunnel 3	4 x 175=700 MW(1980)	4 x 432= 1728 MW(1992-93)
Total Installed capacity	**=2100 MW**	**= 3478 MW**

APPENDIX-2

PREDICTED AND ACTUAL ANNUAL STORAGE RELEASES FROM TARBELA DAM

Period	Annual Releases from Tarbela Dam (billion m^3)	
	Predicted	**Actual**
1975-80	10.17	10.13 (-0.4 %)
1980-85	9.50	12.22 (+28.6 %)
1985-90	8.76	11.43 (+30.5 %)
1990-92	8.00	7.48 (-6.5%)
1992-94	7.64	9.71 (+27.1%)
1994-96	7.29	8.37 (+14.8%)
1996-98	6.95	11.00 (+58.3%)
Average 1975-90	**9.48**	**11.26 (+19%)**
Average 1990-98	**7.47**	**9.14 (+22%)**

APPENDIX-3

HISTORICAL CANAL DIVERSIONS TO THE IBIS UNDER KEY–INFLUENCES

Key Influences	**Period**	**Canal Diversions (billion m^3)**		
		Kharif	***Rabi***	**Annual**
Pre-Partition	1940-47	58.5	24.9	83.4
Partition	1947-48	57.0	27.6	84.6
Water Dispute	1948-60	63.4	30.4	93.8
Pre-Mangla	**1960-67**	**74.2**	**34.0**	**108.2**
Post-Mangla	**1967-75**	**80.3**	**37.1**	**117.4**
Post-Tarbela	1975-80	83.7	47.0	130.7
Post-Tarbela	1980-85	84.1	45.9	130.0
Post-Tarbela	1985-90	81.6	46.4	128.0
Post-Tarbela	1990-95	81.5	47.3	128.8
Post-Tarbela	**1975-95**	**82.7**	**46.7**	**129.4**

APPENDIX-4

PREDICTED AND ACTUAL YEARLY GENERATION AT TARBELA

Year Ending June	Annual Generation (Gwh)		
	Predicted	**Actual**	**Difference (+/-)**
1975	5122	0	- 5122
1976	5122	0	- 5122
1977	5122	138	- 4984
1978	7039	3367	- 3672
1979	8954	3744	- 5210
1980	12585	4064	- 8521
1981	12585	4129	- 8456
1982	12585	4200	- 8305
1983	12585	5269	- 7316
1984	12585	7461	- 5124
1985	12585	7255	- 5330
1986	12585	7994	- 4591
1987	12585	8129	- 4456
1988	12585	9412	- 3173
1989	12585	10400	- 2185
1990	12585	9982	- 2603
1991	12585	11356	- 1229
1992	12585	11757	- 828
1993	12585	13955	+ 1370
1994	12585	12970	+ 385
1995	12585	14739	+ 2154
1996	12585	14840	+ 2255
1997	12585	14223	+ 1638
1998	12585	15108	+ 2523
Average : (1975-98)	**11,269**	**1978-98 : 9255** **1980-98 : 9854** **1993-98 : 14306**	