WCD Case Study

Tarbela Dam

and related aspects of the

Indus River Basin
Pakistan

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The WCD Knowledge Base

This report is one component of the World Commission on Dams knowledge base from which the WCD drew to finalize its report "Dams and Development-A New Framework for Decision Making". The knowledge base consists of seven case studies, two country studies, one briefing paper, seventeen thematic reviews of five sectors, a cross check survey of 125 dams, four regional consultations and nearly 1000 topic-related submissions. All the reports listed below, are available on CD-ROM or can be downloaded from www.dams.org

Case Studies (Focal Dams)
Grand Coulee Dam, Columbia River Basin, USA
Tarbela Dam, Indus River Basin, Pakistan
Aslantas Dam, Ceyhan River Basin, Turkey
Kariba Dam, Zambezi River, Zambia/Zimbabwe
Tucurui Dam, Tocantins River, Brazil
Pak Mun Dam, Mun-Mekong River Basin, Thailand
Glomma and Laagen Basin, Norway
Pilot Study of the Gariep and Van der Kloof dams-Orange River South Africa

Country Studies
India
China

Briefing Paper
Russia and NIS countries

Thematic Reviews

- TR I.1: Social Impact of Large Dams: Equity and Distributional Issues
- TR I.2: Dams, Indigenous People and Vulnerable Ethnic Minorities
- TR I.3: Displacement, Resettlement, Rehabilitation, Reparation and Development

- TR II.1: Dams, Ecosystem Functions and Environmental Restoration
- TRII.1: Dams, Ecosystem Functions and Environmental Restoration
- TR II.2: Dams and Global Change

- TR III.1: Economic, Financial and Distributional Analysis
- TR III.2: International Trends in Project Financing

- TR IV.1: Electricity Supply and Demand Management Options
- TR IV.2: Irrigation Options
- TR IV.3: Water Supply Options
- TR IV.4: Flood Control and Management Options
- TR IV.5: Operation, Monitoring and Decommissioning of Dams

- TR V.1: Planning Approaches
- TR V.2: Environmental and Social Assessment for Large Dams
- TR V.3: River Basins – Institutional Frameworks and Management Options
- TR V.4: Regulation, Compliance and Implementation
- TR V.5: Participation, Negotiation and Conflict Management: Large Dam Projects

Regional Consultations – Hanoi, Colombo, Sao Paulo and Cairo

Cross-check Survey of 125 dams

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AID - Assistance for India's Development

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Executive Summary

1. The World Commission on Dams Global Case Study Program

This case study is one of a number being carried out world-wide with a common methodology and approach to inform the World Commission on Dams about the development effectiveness of dams on a range of issues associated with the planning, design, construction, operation and decommissioning of large dams. This particular study deals with the Tarbela Dam Project (TDP) developed as a follow up to settlement of the river waters dispute between India and Pakistan. It formed part of a wider set of infrastructure projects to further develop the existing Indus Basin Irrigation System (IBIS) and facilitate transfer of stored water from the western rivers to replace water lost from the eastern rivers. The primary function of the dam was irrigation, with power as a secondary objective.

2. Context and Scope

2.1 Indus River Basin

The Indus River basin stretches from the Himalayan mountains in the north, to the dry alluvial plains of Sindh in the south. The alluvial plains of the Indus basin cover an area of 207 200 km^2, approximately 25% of the land area of Pakistan. The catchment area upstream of Tarbela dam is predominately a barren and glaciated landscape and the main source of inflow to the Indus is snowmelt and glacial flow. The climate in the Indus plain is arid to semi-arid with significant variability both throughout the year and from upstream to downstream. Mean minimum temperatures in the upper plain are 2°C in the winter with mean maximum temperatures in the summer reaching 49°C. Mean annual rainfall is low, ranging from 9cm in the lower plain to 51cm upstream in Lahore. Evaporation is high with mean annual values in the range 165 to 204cm. Agriculture is central to the culture and economy of Pakistan although urbanisation is rapidly increasing. At the time of planning the TDP in the mid-1960s, Pakistan's population was 51 million, which by 1999, has increased to 134.5 million. Although the percentage of rural population to total population has reduced from 82% to 67% during this period, the absolute number of rural population has increased from 41.9 to 90.1 million.

The IBIS is the world's largest contiguous irrigation system and has been developed over the past 140 years. Prior to the implementation of Indus Basin Project (IBP), the IBIS already comprised a major network of river barrages and irrigation canals as a sequel to the water treaty between India and Pakistan. 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 – part of the IBIS. Pre-independence flows of the eastern rivers in the dry (*rabi*) season amounted to an average of 3.84 billion cubic metres (bcm), approximately 12% of the total dry season flows of eastern and western rivers combined. India agreed to re-open these canals only after the Inter-Dominion Agreement of May 1948, asserting its right over the entire water of the eastern rivers that would affect an irrigation system commanding 2.9 mha (21% of the total canal command of about 14 mha in the Indus Basin). This issue bitterly strained relations between the two countries.

The 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. The 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 $895 million was created to finance the IBP with contributions from the WB and other donors to which India made a fixed contribution of £62 million ($173.8 million).

The most positive outcome of the Treaty from Pakistan's perspective was the attainment of water security through construction of the works that made its irrigation system and hydropower generation facilities fully independent of India. The Treaty was, however, opposed by those who maintained that IBP would only include (ever-depleting) large storage facilities, replacing water that Pakistan would be losing, by surrendering to India the perennial flow waters of the three eastern rivers. India, on the other hand, would get plenty of additional irrigation water for new development projects. They considered the development of IBP to be at the cost of development of other important sectors, especially education, health, and communication infrastructure. It was apprehended that IBP would consume most of the scarce financial resources and leave little for economic development. Finally, President Ayub Khan accepted IWT as a pragmatic solution to a very difficult problem[1].

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

- to provide an 11.5 billion cubic metres (bcm) storage dam on River Indus (almost doubling Indus flows in the dry season - *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;
- to increase food production to achieve self sufficiency, especially in wheat; and
- to generate cheap hydropower through staged development of 2100 MW capacity.

Two documents were central to the planning of the project and its evaluation and provide the basis for comparison of predicted and actual outcomes in the study. The feasibility study of the project and proposals for wider development plans in the basin were contained in the Indus Special Study completed in 1967– referred to as the Lieftinck Report. The specific elements to be financed under the TDP, including the dam, associated structures and civil works for the first four power units are described in the World Bank's Staff Appraisal Report (SAR) of 1968.

2.2 Financing and Costs

The project was financed through Tarbela Development Fund (TDF) created in 1968 out of the remaining balance from the IBDF and additional loans and grants from friendly countries. The calculation of cost overrun is dependant on the way in which annual payments are inflated (according to local or foreign inflation rates) and which document is taken as the base cost estimate. Two approaches are used to define the possible range of cost overrun. In the first approach, the total project cost including all 12 projected power units is taken from the Lieftinck Report and inflated to 1998 prices. The original estimated capital cost, including the proposed generating capacity of 2,100 MW, was 1136.4 million ($5 875 million 1998 prices) with a foreign exchange component in the order of 60%. The actual annual disbursements for all civil and power works (3 478 MW), including resettlement and debt servicing, were converted into dollars and inflated to 1998 dollar prices. This resulted in an estimate of actual costs in 1998 terms of $8 800 million, or an increase of about 50% over the estimated capital cost.

The second method makes a comparison of financial flows (in prevailing prices) related to the original cost in the SAR and supplementary loans. The final cost according to the Project Completion Report (PCR), excluding power units (WB 1986), was $1 497 million including a foreign exchange component of $800 million. It covered the cost reimbursed from TDF and related to: dam and associated civil works; power station civil works for four units only; design improvements; and special repairs/restoration. It did not, however, cover the cost of resettlement, additional Tunnel No. 5

[1] In his radio broadcast of September 4, 1960 about the IWT, President Ayub Khan said: "So, whereas there is no cause for rejoicing at this juncture, there is certainly a cause for satisfaction and thanksgiving, that a very ugly situation which might have arisen in the absence of such an agreement has been averted and that we have been able to get the best that was possible. (Speeches and Statements: Field Martial Ayub Khan President of Pakistan Vol. 111. July 1960 to June 1961. P.19)

and power installations (units 1–14) that were borne by the Government of Pakistan (GOP) and the Water and Power Development Authority (WAPDA), respectively. The original estimate for the same scope of work (excluding power etc) was $828 million. The cost overrun in purely nominal dollar terms was therefore 81%. Further work is required to determine more precisely the project cost over-run which is estimated to be in the range 50-81% from the two methods used.

The WB as administrator of TDF, arranged two supplements to fund the revised project cost. The increase in cost was mainly because of an initial under-estimation; design improvements; and major structural repairs/restoration of some project components damaged after impounding.

2.3 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 thus endangering the safety of the dam. The reservoir was evacuated to avert this crisis. After quick repairs, however, the problem was resolved and the dam was fully commissioned in 1976.

Commencement of the project in May 1968 was almost one year later than planned. The original estimate 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.

2.4 Operation and Maintenance

Detailed O&M procedures for the project were developed before its scheduled commissioning in 1975. These procedures required implementation under intense supervision backed by adequate logistic and funding support. This, unfortunately, did not occur, as, during initial filling, serious problems occurred, including damage to Tunnel No. 2, the appearance of sinkholes in the upstream blanket, damage to the stilling basin floor, and the erosion of spillway plunge pools. This resulted in most of the funds being diverted for special repair/remedial works. This funding constraint negatively affected O&M but was somewhat eased later when $3 540 million was provided by the WB. In the meantime, the essential O&M facilities, including equipment due from the main contractor, also became available.

Subsequently, the project is considered to have been well operated and maintained. Extensive monitoring of the engineering, technical and safety aspects of the project has also been carried out. Furthermore, standing arrangements have been made for constant monitoring of the project features. This has significantly contributed to the state of the art with respect to: design; construction, restoration/repair of seriously damaged infrastructure; and efficient operation and safety monitoring of large dam projects.

Operating rules of the reservoir were originally set for irrigation releases but in the 1990s were amended in response to the need to manage sediment deposition. This is described under Section 3.4 'Predicted and Actual Effects'.

Because of the lack of a formal agreement between the provinces on sharing Indus waters, the operation of the reservoir was conducted on an *ad hoc* basis during 1976 to 1993. A formal accord was reached between the provinces in 1991 that prescribed water allocation between provinces, and the Indus River System Authority (IRSA) was created in 1993 under an Act of the Parliament. 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 River system including storage reservoirs at Tarbela and Mangla is now being handled by IRSA.

3. Predicted and Actual Effects

3.1 Water Resources

The primary goal of the 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, a comparison of actual releases of water with those predicted provides a simple indicator of how the project performed in terms of its original objectives.

The prediction of storage releases from the 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 the predicted 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.

An analysis of flows along the Indus River over time and diversion to the canal systems, particularly in the dry season, provides an indication of the distribution of additional waters supplied from Tarbela. Three barrages were investigated: Taunsa barrage which lies upstream of the confluence of the Indus and other major tributary rivers; Guddu barrage, which is in Sindh close to the border with Punjab; and Kotri, the last barrage on the Indus before the river enters the delta area. Releases from Tarbela contributed to increases in mean dry season flows at Taunsa (30%) and Guddu (26%) measured over the period 1975-95. Reductions in mean wet season flows of up to 6% were attributed to the filling cycle of the reservoir.

The flow distribution at Kotri barrage provides valuable information about flow conditions in the downstream delta areas. A low flow analysis was carried out covering the period from 1940, before construction of Kotri barrage (1955) and commencement of major irrigation diversions (1960). *Rabi* flows downstream of the barrage averaged 13.5 bcm from 1940-61 and reduced markedly to an average of 3.6 bcm following diversions of water from Kotri barrage. They reduced further to 1.4 bcm in the period post-Mangla (1967-75). Average *rabi* season flows increased to 3.1 bcm in the post-Tarbela period (1975-98). Within these years there was significant variability. From 1980-85, for example, the seasonal mean was 1.2 bcm whereas from 1990-95 it was 5.9 bcm.

The extent of change in low flow conditions is also illustrated by a comparison of occurrences where there were zero flows downstream of Kotri during *rabi* season. In the pre-Kotri period, there were no years with zero flow. Following construction of Kotri barrage and the diversion of irrigation water, the number of years with zero flows was 80% during1962-67, 100% during post-Mangla (1967-75) and 96% during post Tarbela (1975-98) periods. The significant change in downstream flows was therefore initiated after commissioning of Kotri barrage, 16 years prior to construction of Tarbela. Additional *rabi* flows from Tarbela had only a marginal effect on increasing these low flows, but they were still well below the pre-Kotri levels.

In the Lieftinck Report, the estimation of the economic benefits of water released from the dam was based on ascribed value related to the value-added of irrigation water to agricultural production taking into consideration the losses in the Tarbela canal commands. Using the same value per unit of water applied to actual storage releases, a comparison of predicted and 'actual' economic benefits per unit of water was made. The predicted storage benefits over the period 1975-98 were estimated as $297 million at 1965 prices ($1 534 million in 1998 prices). The computed corresponding economic benefits in 1965 prices are $353 million ($1 825 million in 1998 prices) – an increase of 19%. This analysis identifies the potential value of the water released.

3.2 Sedimentation

The Indus is one of the largest sediment producing rivers in the world. The main source of sediment is from the glacial landscape and erosion from steep sided barren slopes. The predicted rate of sediment inflow was 0.294 bcm per year meaning that the dam would silt up to 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 but considered not to be feasible.

In practice, the actual sediment inflow rate has been significantly lower than predicted, with an average rate of 0.106 bcm, ie 36% of the predicted inflow rate. However the proportion of sediment inflow trapped in the reservoir (the 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 the advancement of the sediment delta, which is now 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.

Measures are being investigated to reduce the risk of liquefaction damage and also to prolong the life of the reservoir. These include physical measures, such as provision of an underwater protection to the low level outlets including power intakes and sluicing tunnels to remove sediment, and management measures to reduce the proportion of sediment deposited and its location. Reduction in sediment load entering the reservoir is not possible due to the altitude and nature of the catchment. In terms of management measures, the operating rule of the reservoir has been changed to raise the minimum drawdown level from 396m to 417m and thereafter raise it gradually every year. This would have the effect of depositing sediment in the upper reaches and would reduce the advance of the sediment delta, but at the cost of reducing live storage with the trade off of reducing water availability in the dry season.

3.3 Surface Water Irrigation

The following analysis of irrigated areas, cropping intensity, yields and agricultural production provides an insight into the actual experience, although Tarbela is only one factor among a range of factors that influenced the change (e.g. agricultural inputs, farmer response, impacts of waterlogging, and other investment projects).

The 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, the 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 bcm) to the total annual irrigation supplies for IBIS. The contribution has been 21% of *rabi* abstractions (9.8 bcm) and for 3% of wet season (*kharif)* abstractions (2.5 bcm). It is therefore concluded that Tarbela, along with Mangla dam, achieved the goal to replace water lost to India and increased diversions for irrigation.

The 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 the post-Tarbela period. Thus the canal head diversions attained immediately after Tarbela remained almost constant.

As a comparison of irrigation diversions downstream of Tarbela in the pre- and post-Tarbela periods, the dry season (*rabi*) diversions increased by: 98% at Taunsa (from 1.12 to 2.22 bcm); by 168% at Guddu (0.99 to 2.65 bcm;) and by 80% (2.15 to 3.87 bcm) at Kotri.

3.4 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. The canal conveyance losses directly associated with additional Tarbela storage are estimated to contribute about 10% of the overall recharge of groundwater (the issue of waterlogging and salinity is covered in a separate section below). In the last 21 years (1972-97), the contribution of groundwater to irrigated agriculture nearly doubled from 31.6 bcm to 62.2 bcm. In 1997-98 it declined to 49.6 bcm, equivalent to 38% of surface water diversions. The expansion in groundwater irrigation was due in part to initial price incentives in the form of cheap electricity and later on to 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.

3.5 Agriculture

The projections related to agricultural production in the Lieftinck report were based on the implementation of the TDP, and other infrastructure projects, some of which have been completed, while others have not. However other projects, identified subsequently by the Lieftinck Report (such as the On Farm Water Management projects and the Chashma Right Bank Canal), have been implemented and groundwater utilisation has expanded significantly. It is therefore not possible to disaggregate the contribution of Tarbela irrigation water separately. Comparison between actual production and predicted values for the IBIS as a whole is, however, considered useful to review the overall assumptions that formed part of the decision making process.

The cultivated and irrigated area increased after the construction of Tarbela dam, although not to the extent predicted. The cultivated area in the country increased by 12% from 19.6 mha in 1974-75 to 22.0 mha in 1997-98. The actual cultivated area in 1997-98 was, however, about 8% less than that predicted for the year 2000 (23.8 mha). The irrigated area served by canals met its predicted increase, although as mentioned above, some areas also received supplementary groundwater irrigation. The overall irrigated area increased from 13.3 mha in 1974-75 to 18.0 mha in 1997-98 - slightly higher than the predicted irrigated area in the year 2000 (17.9 mha). Canal irrigated areas increased 45% from 10.1 mha pre-Tarbela to 14.7 mha in 1997-98, and is mainly attributable to Tarbela and increased canal diversions.

There was a pronounced shift in the cropping pattern in the Indus basin as inferred from secondary data collected for this study in three selected districts of Tarbela command, viz: Rahim Yar Khan (Punjab); Nasirabad (Baluchistan); and Nawabshah (Sindh). Comparison of pre-Tarbela (1970-71) cropping with 1997-98 data shows that irrigated wheat, cotton, rice and sugarcane became predominant crops. Increases in the cropped area were found for wheat (36%), cotton (44%), rice (39%) and sugarcane (52%). The overall increase in cropping intensity was, however, less than predicted**.** The Lieftinck Report predicted cropping intensity for the irrigated areas of Punjab and Sindh rather than for the whole basin. Against the baseline of 95% for Punjab and 90% for Sindh during 1965-98, the cropping intensity in the year 2000 was predicted to increase to 150% and 137% respectively. Based on district level data, 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.

The achievement in crop yields for the major crops in Punjab and Sindh were far below the predicted levels. The predicted yield of wheat in Punjab and Sindh for the year 2000 was 3 339 and 3 379 kg/ha respectively. Against this, the estimated achievement in these provinces in

1997-98 was 2 327 and 2 374 kg/ha respectively, being 30% less than predicted in both cases. Corresponding cotton yields during the same period were 31% and 10% less than predicted. Similarly, for rice the actual yields were 51% and 9% less than those predicted for Punjab and Sindh.

The actual gross production value (GPV) of crops was 28% higher than predicted for 1975 while it was 3% lower than predicted for both 1985 and 1998**.** The actual GPV for 1998 was Rs.19.96 billion compared to the predicted Rs.20.57 billion for the year 2000 (prices in 1965 rupees). A series of causes influenced the GPV. Factors potentially reducing GPV were lower than predicted canal diversions as other planned reservoir storage was not developed, lower cropping intensity and lower yields. Factors that increased GPV included a shift to higher value crops from those predicted and higher prices. Actual compound agricultural growth for the period 1965 was 3.18% compared to the 3.9% predicted. The national population growth rate over the same period was approximately 3%.

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. Food security has been a prime policy goal of all policy makers in the country. Although the gross value of crop production has grown faster than the population rate, the domestic production of basic cereal has been inadequate and the country has had to import wheat for the last 25 years approximately.

3.6 Salinity and Waterlogging

Waterlogging and salinity have been increasing in the 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 the IBIS is of marginal to brackish quality. The 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 the proportion of the IBIS area with groundwater less than 3 metres from the surface was 42% and the area with groundwater less than 2 metres from the surface was 22%. In Sindh the area with a depth less than 3 meters was 57%. Although groundwater use has increased significantly, about 22% of the command area of IBIS has a water table of less than 1.5m.

Compared to the projected drainage coverage of 7.6 mha by 1980, the actual coverage by that date was 5.2 mha (32% less). Against the gross command of about 16.7 mha in IBIS, about 6.0 mha had been provided with drainage while projects in an additional 2.4 mha area were under implementation. It was further anticipated that over and above this, a remaining area of about 4.5 mha would require drainage. Out of the ongoing projects, The Left Bank Outfall Drain (LBOD), though substantially completed is still only partly operational. Similarly, the Right Bank Outfall Drain (RBOD) is still in the early stages of development. There are apprehensions based on the experience with the Salinity Control and Reclamation Projects (SCARPs) that the high O&M costs of these outfall drains may preclude their sustained utilisation to dispose of the saline effluent to the sea, despite the launch of the National Drainage Programme (NDP) in 1998.

3.7 Hydropower

The original design of Tarbela included staged development of twelve generators of 175 MW capacity providing a total capacity of 2 100 MW by 1980. Of these units, only civil works of the first four were included in the financing package of the TDF. In the 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.

The predicted average annual generation at full power development of 2100 MW was 12 600 GWh. To account for staged development, the average predicted generation for the period 1975-98 is 11 300 GWh**.** The actual average annual generation (1978-98) once commissioning was complete, was 9 255 GWh, or 82% of predicted. After installation of full capacity in 1993, the average annual generation was 14 300 GWh (1993-98), ie 13% higher than the full development prediction of 12 500 GWh. Total actual generation in the period since commissioning (1977-98), was 194 500 GWh, or 79% of the predicted figure of 245 300 GWh (adjusted for the two-year delay).

In June 1998 Pakistan had an overall installed capacity of 15 844 MW, comprising: hydro (4 825 MW); thermal (6 995 MW about equally divided between gas-fired and oil-fired); and independent power producers (4 024 MW all oil-fired). Out of this, Tarbela represented over 22% installed capacity providing 28% of annual generation requirements for the inter-connected national grid system of WAPDA.

The net economic benefit of hydropower from Tarbela was compared to the other alternatives at the time of planning in 1965. It was estimated that present net worth of economic power benefits of the TDP (at 8% discount rate), as compared to the next cheapest thermal alternative, would be $160m. Based on actual generation data from 1977-98, economic power benefits of the TDP have been determined on the basis of savings in generation cost per kWh as compared to the most efficient gas-fired plant in the WAPDA System. This exercise yields a present net worth of electric power from Tarbela (at 1965 prices and a 8% discount rate) of $225 million that is 41% higher than predicted. This is equivalent to a net benefit of $1 160 million in 1998 prices. It should be stressed that this is not the gross economic benefit, but the incremental benefit over the next cheapest option. Quantification of unpredicted dynamic benefits was $60 million and avoided thermal plant emissions was $162 million at 1965 prices ($310 million and $835 million respectively at 1998 prices).

The province of NWFP where Tarbela is located, has been receiving Rs.6 billion ($139 million in 1998 prices) annual royalty from hydropower generation at Tarbela after the promulgation of the 1973 Constitution. Tarbela will provide an unexpected power benefit by contributing 20% (1 353 out of 6 586 GWh) of generation from the Ghazi-Barotha Hydropower Project currently under construction immediately downstream of Tarbela.

3.8 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 is variable, depending on the timing of the flood in relation to reservoir level that is drawdown prior to the wet season. The peak flows in July 1988, July 1989 and August 1997 were reduced by 21%, 26%, and 43% respectively, whereas a peak flow of similar magnitude in September1992 was attenuated by only 2% as reservoir levels were already considerably higher in readiness for the forthcoming irrigation season.

3.9 Municipal Water Supplies

Augmenting municipal water supplies and providing water for industries was also not a significant objective of Tarbela and no targets were fixed. However, since groundwater in vast areas of Pakistan is saline and unfit for human consumption or use by industry, the progressive increase in population coupled with rapid urbanisation and expansion of industries necessitated the harnessing of canal water. For example, in the Sindh, 89% of groundwater is classified as brackish, which means that canal water is the sole source of municipal water supply, either directly, or as a result of the thin layer of freshwater that overlays the brackish water. Water supply to Karachi has benefited from diversions made through Kotri barrage. The indirect contribution of IBIS and of Tarbela dam to supplement municipal water supply has been an important benefit. It is estimated that about 40% of the population may presently be benefiting to some degree from the waters of the Indus that are supplemented by Tarbela storage during the dry season.

3.10 Resettlement

The project design estimated that 100 villages would be submerged, resulting in the resettlement of 80 000 people. The number of villages actually affected was 120, and the number of people affected closer to 96 000, an increase of 20%. The 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 criterion for compensation with alternate land was whether land holdings were greater than 0.2ha of irrigated land or 0.8ha of rainfed land. Approximately two-thirds of the affected population were eligible for replacement land in Punjab or Sindh provinces. Those with holdings of less than these limits were eligible for cash compensation. People with 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 villages to be built in the vicinity of Tarbela.

There has been widespread dissatisfaction with the resettlement process for the following reasons:

- lack of participation in the resettlement process;
- displacement occurred prior to receiving possession of alternate land and compensation;
- the Sindh government's refusal to release 65% of the land initially allocated;
- incompatible social and cultural backgrounds of affected and recipient communities;
- delays in the decision of eligibility;
- delays in making payments resulting in reduced real value of compensation due to devaluation of the rupee in excess of 100%;
- lack of employment opportunities in the new townships;
- corruption of officials seeking 'facilitation' payments;
- villagers who did not receive compensation in time had to moved from the reservoir area by the army during impoundment;
- disputed responsibility between institutions for maintaining infrastructure in the new townships; and
- landless and tenant farmers did not have the appropriate skills for non-agricultural employment.

A survey in 1996 showed that 1953 eligible families who applied for alternate land still await possession. A number of challenges were made to the resettlement and compensation process. The adopted criteria were challenged by local groups and a number of cases were taken to the courts of which 38 are still outstanding. The Government created the Nucleus Clearance Cell (NCC) to investigate claims pertaining to the TDP. More recently, in response to the financing conditionality of the downstream Ghazi-Barotha project, a Commission was formed under the NCC to address the outstanding claims. Of approximately 11 000 claims before the Commission, only 4.4% were considered eligible. Many were rejected due to problems with verification by the Revenue Department, although this is contested by local groups. The number of people affected by the project but not eligible for compensation has not been quantified, although assertions from concerned groups place this number in the same order of magnitude as the number of those that are eligible.

Field surveys conducted as part of this study show that people affected by the dam were not systematically involved in the planning and development process. Many felt the project had problems with adequately compensating and resettling those affected. In spite of over 24 years of operation of the dam, this is still an active issue. An opinion strongly expressed is that those directly affected and who made a major sacrifice for the project, have not been fairly compensated. They demand that a part of the earnings from the dam should be earmarked for the 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 has been totally neglected in the resettlement process, and women, specifically, have suffered as a result of the disruption of their social life due to migration from ancestral places.

3.11 Social Impacts Downstream

A series of local surveys were carried out as part of the study to obtain an insight into the changes that occurred over the period of project operation. Two sites were selected in the Punjab: an agricultural area in Mailsi; and locations along the river in Muzzaffargarh, DG Khan. In general, respondents stated that agricultural production had increased significantly, confirming the changes in cropping patterns to sugarcane, cotton, wheat and rice and orchards, and that land rental values had increased more than 20 fold, almost double the local inflation rate. Negative changes included the loss of forest land to agriculture and loss of livelihood opportunities to the landless who made products from forest and wetlands along the river, representing marginalisation of poorer sections of the population who depended on the river.

In the Sindh, two areas were selected for survey: Thatta and Badin, an area dominated by river and marine fisheries; and Keti Bandar and Ibrahim Hyderi in the coastal mangroves. From Thatta and Badin, there are two main fishing points, a series of lakes including Kinjhar lake where approximately 400 000 people fish, and the open sea. Overall, approximately 3 million people are involved in fishing. Fish catches were considered to have decreased significantly as a result of reduced dry season flows in the Indus (starting with the construction of the Kotri barrage), loss of mangroves, and the sharp increase in numbers of fishers. (Further information on fish migration is included under section 3.12.1Ecological Effects). In the areas served by the surface irrigation system, however, sugarcane has increased substantially, requiring high amounts of irrigation and increasing disparities in distribution of irrigation water.

During field hearings at Ibrahim Hyderi and Keti Bandar, it was stated by the local residents that the upstream developments of barrages and dams on the Indus River (especially the Kotri barrage and Tarbela dam), have further reduced the flow of river water below Kotri into the Indus delta, especially during the *rabi* season. This has resulted in a reduced supply of fresh water for drinking purposes and for agriculture. The intrusion of sea water has been gradually increasing and agriculture in the delta has received a severe setback. Mangrove forests and fish breeding grounds have also been adversely affected. There has been a large-scale out-migration of population from the lower Indus delta to Karachi and other places in search of livelihood.

3.12 Ecological Impacts

The 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. This study has revealed several important ecological impacts, mostly negative, on the physical and biological environment. It must, however, be stressed that these negative impacts on the environment are the result of numerous dams and barrages on the Indus River system including the developments in India, and cannot be ascribed to Tarbela alone. The 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 massive destruction of forests, flora and fauna. While such impacts are primarily due to the construction of Kotri and Sukkur barrages that reduced downstream flow of sweet water into the Indus delta, the perception developed by communities downstream lends them to believe that any irrigation developments on the Indus further aggravate the situation in the Delta.

Tarbela has contributed significantly to the increased storage and abstraction of water from the Indus resulting in an increased frequency of low floods that now cover less than 25% of the flood plain. The sediment carried down the Indus has also reduced due to abstractions during high flow period. This has shifted the balance between erosion due to high-energy waves and sediment deposition particularly in the Indus delta.

Lower flows and the construction of flood *bunds* all along the Indus in Sindh has led to the reduction in riverine flood coverage and caused a change in the habitat of the flood plain. Higher forested areas, islands and agricultural lands have dried out and experienced species changes, from *Acacia* to the less economic *Prosopis*. Increased use of pumped irrigation has been required to maintain riverine forests, especially in Sindh. The forested areas in Sindh have reduced to only 50% of the original 240 000 ha and the remaining areas are of variable quality.

Building of the dam has prevented the migration of *Mahseer* (*Tor putitora*) into the cooler waters upstream during summer, and the occasional operational peak releases can wash out the substrate and fish immediately below the dam, causing a loss to local fishermen. The reduction in flooding also causes losses in fish populations, and in the downstream area the proportion of wild fish caught has declined in comparison to aquaculture. The catches of migratory fish such as *Palla* and *Baramundi* have also decreased but these are principally due to the building of Kotri Barrage, rather than as a result of Tarbela. The catch of *Palla* has reduced from about 10 000 tonnes during the 1980s, to about 200 tonnes per year in the 1990s.

Tarbela reservoir is a staging point for migratory birds, but is not suitable for over-wintering birds. In contrast, Taunsa and Chashma barrages have become significant wetlands important for migratory birds and fisheries although they are under considerable pressure. Populations of smooth coated otter and hog deer are struggling to survive due to a lack of controls. Changes to the floodplain due in part to flood bunds has reduced the indigenous *Acacia nilotica* and beds of *Typha,* and allowed the invasion of exotic species with negative impacts on wildlife. The contribution of Tarbela to the decline in wildlife has been relatively minor in comparison with other interventions in the river system.

A sanctuary for the Indus River dolphin between Sukkur and Guddu barrages has stabilised numbers to about 500. Further downstream, however, the salinity increase in Manchar lake resulting from saline drainage has changed the species distribution and loss of the main commercial species Rohu. Due in part to the flood bunds, and also to reduced flood flows from Tarbela, there has been a reduction in the dilution of salinity in the lake.

Because of extended zero flow periods caused by diversion of water following construction of the Kotri barrage, the river bed below Kotri has become severely braided and the channel can become blocked by sand bars. Seawater intrusion has increased during the *rabi* season, reaching approximately 25km upstream from the delta. The active Indus delta has been reduced to about one tenth of its original size, largely as a result of the construction of river flood bunds confining the river. The freshwater and sediment discharge during the flood period is restricted to the active delta, but the increase in salinity during the low flow periods has reduced the suitability of the delta for the cultivation of red rice, the production of exotic fruit, and raising of livestock.

The mangrove ecosystem is being degraded and the mangroves are now virtually mono-specific and comparatively stunted with losses of about 2% per year. Degradation of the mangroves is both because of reduced water flows and direct human destruction and over use. The major changes in river flow below Kotri have affected the ecology in lower Sindh and the coastal areas significantly, besides adversely affecting agricultural production. Marine fisheries have been affected due to the decrease in freshwater, sediment and nutrient flows. Although overall fish catches increased from 1950-84 to a total of 221 500 tonnes, the fishing fleet also expanded considerably and the catch per unit of effort reduced threefold. The protective nature of the riverine and mangrove forests has also reduced thereby increasing the risk of storm damage.

The 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 particularly from the eastern rivers, such as the Ravi (from Lahore). The 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 the Tarbela.

4. Distributional Effects of the Tarbela Dam Project

The Lieftinck Report gave a broad indication of the distribution of benefits from the TDP indicating that the benefits would be split, with approximately 75% deriving from irrigated agriculture and 25% from hydropower. The irrigation benefits relate to the protection of water supplies to approximately 1.8 mha, and to providing additional irrigation supplies to 6.9 mha. The electricity generated would be fed into the national grid system and therefore beneficiaries would be widespread urban, industrial and rural consumers. Specific mention was made of electrification of groundwater tubewells. More detailed analysis of benefit distribution was not implicit in the planning documents. As mentioned earlier, the negative social and environmental impacts of the project were not identified at the planning stage and therefore affected groups were not identified. The agricultural benefits and negative impacts are due not only to Tarbela, but also to other developments and investments.

Surface irrigation water made available by Tarbela and hydropower generated by the dam have directly or indirectly benefited a large proportion of the population of Pakistan. The rural farming population directly affected by irrigation benefits is estimated to be in the order of 7 to 10 million. Farms receiving additional water supplies were located in southern Punjab and Sindh. The additional water resulted in increased cropping intensities, a shift from 6 monthly supplies to a perennial supply, and increased availability of water per unit of land. Although detailed studies were not carried out, there is a general perception that the larger landholders benefited more than medium and smaller landholders. Land prices for irrigated areas have increased significantly from Rs.37 000 per ha in 1970 to Rs.620 000 per ha in 1998. In real terms this represents a 300% increase (also see discussion on property values in section 4.2.2.6) Increased water supplies from surface and groundwater irrigation have contributed to price stabilisation of wheat, cotton and sugarcane, benefiting consumers across the country.

Major beneficiaries have been the enterprising industrialists who received cheap electricity thus reducing their cost of production, and large landholders with access to cheap power to pump groundwater. The small farmers and landless tenants have also benefited by being able to buy tubewell water from neighbours. With increased agricultural mechanisation there was some displacement of farm labour who had to find alternative livelihoods in the urban areas. Employment in agro-industries, such as cotton- and sugarcane-related industries have increased significantly, together with forward and backward linkages including the transport sector.
Currently, at about 28%, Tarbela dam has maintained a significant proportion of the overall share of electricity generated in the country and can therefore claim to have helped stimulate urban and industrial growth. WAPDA's urban electricity consumers increased to about 5.6 million by 1998 compared to 1.5 million in 1976. In rural areas, the electricity consumers increased from 0.4 million to 4.6 million The budget of NWFP benefited significantly from the TDP with annual transfers of Rs.6 billion ($139 million equivalent in 1998) in royalty payments. Other unexpected benefits were the availability of water for domestic purposes and livestock production in areas where groundwater supplies are too saline.

The social costs suffered by those displaced by the reservoir were immense and are described above in section 3. Directly affected people numbered 96 000. No compensation or development opportunities were provided for those indirectly affected. Negative aspects were the result of inadequate compensation and the loss of livelihood leading to lowered social status in many cases. In downstream riverine areas, those dependant on flood based recession agriculture and the natural resources of wetlands and forests were negatively affected by reduced flood flows, due in part to reduced flows, and to the impact of flood embankments. Fishermen were also negatively affected due to the reduction of fish in the river. However, this was predominately caused by the construction of barrages in the river and the reduction of dry season flows that commenced with the construction of Kotri barrage in the late 1950s.

In the coastal areas, the reduced dry season flows and the reduction in sediment flows, led to saline intrusion, and a reduction in mangrove and forest areas and consequent loss of livelihoods. The contribution of Tarbela dam to this loss cannot be desegregated from other causes as the major changes in flow regime started 16 years before the dam was commissioned. Although dry season river flows in the Indus directly downstream of Tarbela have increased as a result of the dam, this has not led to increased flows downstream of Kotri barrage, but rather to additional abstraction of irrigation flows from the river. Increased population pressure also plays an important but unquantified role in deterioration of natural resources in the area.

General development indicators have improved since construction of Tarbela although this cannot be attributed to the project but rather to other development activities. Life expectancy has increased from 45.8 in 1970 to 55.8 in 1998 and there has been an increase in literacy rate form 18.4% to 34.9% in 1990 although female literacy remains almost half that of male literacy.

During the peak construction period, a labour force of about 15 000 was employed at Tarbela. This offered jobs at high rates, helped to train highly skilled manpower for further national development and for lucrative international employment. Even during the current phase of O&M, Tarbela employs a workforce of about 4 000 thus benefiting about 20 000 members of their families.

5. Decision Making Process and Options Assessment

Discussions relevant to diversion of eastern rivers by India were carried out for a decade (1951–60) within the GOP and tough negotiations with India were mediated by the World Bank. The final decision of Pakistan to accept the Indus Waters Treaty (IWT) was made by the President of the martial law Government, Field Marshall Ayub Khan. During this period, interim arrangements for water distribution were agreed. The final decision to accept the IWT, although quite controversial at that time, was a follow-up of the Inter-Dominion Agreement of May 1948 between India and Pakistan, and the World Bank’s plan for division of the Indus waters in 1956. The IWT 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 sites were initially considered: Tarbela and two sites 4km and 24km upstream, of which Tarbela was favoured because of higher capacity and cost effectiveness.

Following the signing of the IWT, the World Bank initiated the Indus Special Study (ISS) headed by a vice president of the Bank, Pieter Lieftinck. In the resultant Lieftinck Report, three alternative sites were considered: Tarbela and Kalabagh on the Indus downstream, and Gariala on the Haro river. 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. In May 1968, a meeting of donors of the original Indus Basin Development Fund agreed to provide supplementary finance through the creation of Tarbela Development Fund (TDF) to cover the shortfall of funds 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 the 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. Criteria and Guidelines

Soon after the commissioning of the dam in 1976, it was realised that the overall efficiency of irrigated agriculture was unsatisfactory and needed to be improved substantially to derive maximum benefit from major irrigation projects like Tarbela and Mangla. A Revised Action Programme (RAP) to improve O&M and reform institutional structures was prepared by WAPDA in 1979 with UNDP assistance and administered by the WB. This plan was comprehensive in scope.

The Water Sector Investment Planning Study (WSIPS) of 1990 reviewed the achievements of RAP and concluded that little headway had been made to bring about institutional reforms to effectively co-ordinate the activities of irrigation and agriculture departments. WSIPS also emphasised the need to rehabilitate the deteriorating irrigation system of the Indus basin and improve the agricultural production system through improvements in research and extension.

The issue of transforming the irrigation bureaucracies in the provinces in order to make them more autonomous and sensitive to the economic and biological aspects of irrigated agriculture, as compared to the prevalent emphasis on engineering aspects, was taken up by the WB during the processing of the National Drainage Programme (NDP) in 1997. As a result of extended negotiations with GOP and provincial governments, the semi-autonomous Provincial Irrigation and Drainage Authorities (PIDAs) were established through acts of the provincial assemblies. Although the enactment to establish PIDAs has fulfilled the WB requirement for disbursement of the loan for NDP, it still requires considerable improvement to achieve its aims of institutional reform and improved accountability and performance.

Another major issue impacting on irrigated agriculture has been cost recovery and taxation of agricultural income. Major aid donors to Pakistan have insisted on realistic water taxes to generate income to meet the huge operation and maintenance (O&M) costs of the irrigation infrastructure. This item has been included as a covenant in most foreign-aided development projects in the irrigation sector. However, this has been a highly controversial issue with bitter opposition by the farmers' lobby. Although some increases in water rates have been made, the rates are still far below what would be required to recover O&M for the irrigation supplies. The issue of agriculture taxation, though agreed in principle, has not been faithfully implemented. This is mainly because of collusion between large landholders and the lower level revenue administration that helps conceal the actual landholdings to evade agricultural tax.

On the power side, the government is moving towards the creation of a competitive market through restructuring and privatising the existing thermal generation and transmission and distribution functions. In 1997 the autonomous National Electric Power Regulatory Authority (NEPRA), was established for licensing generation, transmission and distribution. Unfavourable experience with the high cost of generation from Independent Power Producers in the early 1990s, led to a policy in 1998 that gives preference to utilising hydropower, but with the active participation of the private sector.

Environmental impact assessments were introduced as a requirement of all major projects from 1975 and included as a separate chapter in feasibility studies. Comprehensive assessments, however, were not included until later when multilateral banks adopted policies on environmental impact assessment. From 1990, environmental considerations were incorporated in regional and sectoral planning studies. The National Environment Protection Act of 1997, established an Environmental Affairs Division at federal level with cells at provincial level. A more participatory approach to environmental issues is demonstrated by the National Conservation Strategy published in 1998.

7. Lessons Learned

The following main lessons were presented for discussion at the meeting of stakeholders held in Karachi in January 2000. Some participants declined to take part for various reasons including concerns that their response could in some way compromise discussions over any future project in the basin. The responses are therefore not fully representative. Of those that did respond there was general agreement on all except lessons 5, 8, and 10 where comments are noted.

1. The sensitivity of fluctuations in future production due to climatic factors and response to pricing signals and changing circumstances needs to be given more attention in the planning stage.
2. The benefits of irrigation for agricultural production need to be targeted. Unequal distribution of benefits generates inequality amongst groups in specialised crop production systems.
3. Technical improvements through research and extension have a major pay-off through increased productivity and net incomes. This component needs to be incorporated in the plans at planning stage of major irrigation projects.
4. Planning of power production should take greater account of variability of production and its effect on the power system. Power benefits vary during dry and wet cycles, whereas for appraisal the average generation is used. Though in case of Tarbela the predicted output was considered to be broadly stable from year to year, it has been variable in actual practice due to a variety of reasons.
5. Hydropower has a distinct comparative advantage in reducing CO_2 and other greenhouse gases emissions. This has substantial benefits in the regional/global context. (This lesson was challenged by a number of participants who considered that there could be significant emissions from reservoirs and that any benefits on the emissions side should not be used to balance other negative environmental impacts of dams).
6. Pre-project base-line knowledge of the river ecosystem and environmental parameters is essential to draw any meaningful inference for project planning and to design in-stream flow requirements.
7. It is desirable to undertake an independent review of large projects to confirm feasibility and a full options assessment before the start of implementation.
8. For large projects like Tarbela, phasing is sometimes necessary due to funding and other constraints. However, preferably, it should be avoided lest a changing context may lead to dropping of subsequent phases especially during implementation. (There were contrasting views on this point but most agreed that planning stages need careful phasing to ensure that social and environmental concerns are adequately addressed).
9. Developments within a basin context must recognise the broader implications of upstream project development. The quest to harness water resources must be sensitive to impacts on lower riparians. This can have far reaching socio-economic and political ramifications. Water requirements of the Indus delta must be viewed in a wider policy framework to mitigate massive ecological imbalance
10. Some downstream water quantity and quality concerns especially below Kotri, can be addressed by maximising storage releases from the dams under favourable inflow conditions. Besides improved hydropower generation, it would help reduce cumulative impacts of the dams on the riverine ecosystem. (Some disagreed as it might compromise irrigation releases).
11. Compensation and resettlement policies must be discussed with the targeted affectees through some process of participatory consultation. Care should also be taken to identify and adequately benefit the genuine affectees, especially the landless tenants, traders and artisans, etc.
12. Major disputes (international/national) on distribution of river water should be resolved before embarking on large water harnessing projects.
13. Project O&M activities must be established at the onset of project along with adequate funding. These operations must be integrated with overall national/provincial planning systems to accommodate differences between predicted and actual conditions and changing circumstances and priorities.
14. Monitorable targets are required for project objectives including rural and national development and an appropriate monitoring system established. Normally, macro project objectives such as “improving the rural economy” and “promoting national development” are impossible to evaluate post-hoc unless targets are set, and a deliberate monitoring system is designed and implemented.
15. Even when no formal post-project evaluation is intended, periodic in-house performance reviews are helpful for ongoing planning and decision-making.
16. Post-project impact monitoring can help identify, assess, and rectify unforeseen adverse impacts of the project that may occur over the longer term, or to identify opportunities to

enhance positive impacts of the project. Such monitoring also provides a credible basis for new operational criteria, standards and regulation.

Subsequent to the meeting additional fieldwork gave rise to an additional lesson namely, "Developments within a basin context must recognise the broader implications of upstream project development. The quest to harness water resources must be sensitive to impacts on lower riparians. This can have far-reaching socio-economic and political ramifications. Water requirements of the Indus delta must be viewed in a wider policy framework to mitigate massive ecological imbalance".

Further lessons were suggested by the participants including the need for a new national resettlement policy, greater participation in planning and design, more attention to social and environmental impacts, internalising of external costs, evaluation of distributional aspects, greater attention to risk, and attention to monitoring and resolving impacts during operation.

8. Stakeholders' Views

Many of the stakeholders contacted during the study consider Tarbela a useful project in terms of development effectiveness for the country since it has helped stabilise and expand agricultural production. The contribution of Tarbela to power generation and averting the severe power shortages prevailing in the country until recently, is also widely recognised. However, it is also recognised that the displaced population was not involved 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.

Reduction in river flow below Kotri, initiated 16 years prior to Tarbela, also adversely affected some communities, especially the fishermen, who were not included in any compensation package. Stakeholders also emphasised the adverse environmental effects of the dam and other interventions especially in the downstream areas. Some of these communities faced accelerated migration to other areas. These communities have strongly expressed the view that upstream developments on the River Indus impacted on them negatively. Such stakeholders feel that while royalties are provided to those regional governments where projects are constructed and direct and indirect costs are generated, project designs must be sensitive to incorporate “damage compensation” for those affectees (especially downstream) who are normally not considered as “legitimate affectees”.

There was no overall consensus on whether positive impacts outweighed negative impacts, which points to the difficulty in determining trade-offs among widely different communities, some of whom benefit and some who lose. There was, however, general agreement that there was inadequate participation in the decision-making processes.

Regarding water use efficiency for agricultural production, most stakeholders felt that there was considerable room for improvement. More efficient management of the complex agricultural production system can also significantly increase crop yields with emphasis on water use efficiency.

9. Summary of Predicted, Actual and Unexpected Outcomes of the TDP

	Predicted	Actual	Unexpected
Design	Tarbela dam, and power station (2 100 MW) as part of a wider Indus Basin Project including Mangla dam, downstream barrages and link canals within the existing Indus Basin Irrigation System.	148m high earth and rockfill dam and associated infrastructure were constructed as predicted. Power generation capacity was increased to 3 478 MW. A fifth tunnel was added on the left bank for additional irrigation releases and provision for an additional tunnel made on the right bank for subsequent development.	

Schedule	Commencement: June 1967 Commissioning of: Reservoir: Sept 1974 Power (units 1-4) Mar 1976 Power units complete: 1980	May 1968 Sept 1976 July 1977 1982, 1985, 1992, 1993	Major problems experienced with seepage through upstream blanket, damage to tunnels, low level outlets and spillways
Project costs	Estimate excluding power units $828 million (nominal) Including debt servicing and all power units calculated in 1998 prices $5875m	$1 497 million (nominal) (+81% overrun) $9258 million (+58% overrun)	Overrun due to cost of remedial works
Water resources	Storage releases: 10.17 bcm in 1975 reducing to 6.95 bcm in 1998	On average releases were 20% higher than predicted. Flows at downstream barrages increased in dry season except Kotri where major reduction due to irrigation diversions started 16 years prior to Tarbela	Reduction in predicted storage releases due to effect of sedimentation has not yet been significant
Irrigation and irrigated agriculture	Surface water diversions for whole IBIS: in 1985 125.5 bcm in 2000 149 bcm Cultivated area in 2000: 23.8 mha Irrigated area in 2000: 17.9 mha Cropping intensity – Punjab 150% Sindh 137% Yield of wheat 3.39 t/ha Gross Production Value predicted for year 2000 Rs.20.6 bln. (1965 prices)	Surface water diversion for whole IBIS: in 1985 129.4 bcm in 1998 132.6 bcm in 1998 22 mha in 1998 18 mha canal irrigation increased from 10.1 mha to 14.7 mha from1975-98 Punjab 117% Sindh 132% Yield of wheat 2.3 t/ha GPV in 1998 Rs.20.0 bln. (1965 prices) It is not possible to identify the contribution of Tarbela on irrigated production due to interaction of other factors	Additional diversions lower than expected as other dams not constructed Major expansion of groundwater irrigation from 31.6 bcm in 1972 to 62.2 bcm in 1997. Number of tubewells increased by 400% Shift in cropping patterns to sugarcane, cotton, rice and wheat Lower productivity of land and water
Waterlogging and salinity	Predicted drainage area coverage 7.6 mha	Actual drainage area coverage 5.2 mha 22% of IBIS subject to severe waterlogging and salinity	Low irrigation efficiencies
Hydropower generation	Capacity 2 100 MW by 1980 Annual average generation: 1975-98: 11 300 GWh 1993-98: 12 500 GWh Total generation to ‘98: 245,300 GWh	Capacity of 3 478 MW (+65%) by 1993 Annual average generation: 1978-98: 9 255 GWh (-18%) 1993-98: 14 300 (+13%) (due to higher capacity) Generation to '98 194,500 (-21%)	Power optimisation study undertaken leading to increased installed capacity.

	Net economic benefit $160 million (1965 prices)	Net economic benefit $225 million (1965 prices)	
Flood control	Not predicted	Attenuation of approximately 20% of floods in June/July with virtually no attenuation of late floods in September.	Reduction of flood flows to wetland areas downstream
Municipal water supply	Not predicted	Unquantified; canal water is a major source of domestic water in areas with saline groundwater	
Recreation	Not predicted	None	
Sedimentation	Predicted rate 0.294 bcm/yr. Predicted life with about 10% residual storage: 50 years	Actual rate 0.106 bcm/yr. Expected life with about 10% residual storage: 85 years	Advance of sediment delta to within 14km of the dam requiring modification of operating rules
Resettlement	80 000 people in 100 villages	96 000 people from 120 villages directly affected. Indirectly affected people not quantified	Continuing claims for settlement after completion resulted in establishment of a new commission; considerable number of indirectly affected people not eligible. -Still 1953 affectees who hold valid allotment letters have not been given land due to non-availability. -Sindh Govt decided in 1974 to withhold 7 826 ha of land originally promised for allotment to Tarbela affectees.
Other social impacts	None predicted	Not quantified, but significant reduction in fish catch and livelihood from floodplains, wetland areas and coastal areas is attributed to a sequence of physical interventions in the river including Tarbela dam	Lack of sediment replenishment to the delta area and flooding of areas along the Indus
Ecological impacts	None predicted	Degraded mangrove areas, reduced fish migration, change in riverine habitat; contribution of Tarbela difficult to assign as no pre-project survey and many other interventions; those due to changes in sediment flow can be attributed directly to the dam; and reduced flood flows partially relate to dam and also to construction of flood embankments	

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List of Acronyms and Abbreviations

ADB	Asian Development Bank
ACSAP	Additional Chief Secretary for Agricultural Production
bcm	billion cubic meters
bln	billion
BOQ	bill of quantities
CAM	Command Area Management
CAP	Central Cell for Agricultural Policy and Planning
CCA	Culturable Command Area
CDWP	Central Development Working Party
CRBC	Chashma Right Bank Canal
ECNEC	Executive Committee of the National Economic Council
EIA	Environmental Impact Assessment
FEC	foreign exchange component
FGW	fresh ground water
ft	feet
GBTI	Ghazi Barotha Taraqiati Idara
GCA	Gross Command Area
GDP	gross domestic product
GEF	Global Environmental Facility
GOP	Government of Pakistan
GPV	gross production value
GWh	Giga watt-hours
IBDF	Indus Basin Development Fund
IBIS	Indus Basin Irrigation System
IBP	Indus Basin Project
ICID	International Commission on Irrigation and Drainage
IPPs	Independent Power Producers
IRSA	Indus River System Authority
ISS	Indus Special Study
IUCN	International Union for Conservation of Nature and Natural Resources
IWT	Indus Waters Treaty
KESC	Karachi Electric Supply Corporation
KFW	Kreditanstalt fur Wiederaufbau
km	Kilometre(s)
kWh	kilo watt-hours
LAC	Land Acquisition Collectorate
LBOD	Left Bank Outfall Drain
LG&RDD	Local Government and Rural Development Department
mps	meters per second
MAF	million acre feet
mcm	million cubic meter
mha	million hectare
mln	million
MREP	Mona Reclamation Experimental Project
tmt	thousand metric tonnes
mt	million tonnes
MW	mega watts
MWC	Minor Works Corporation
NCC	Nucleus Clearance Cell
NDP	National Drainage Programme
NEPRA	National Electric Power Regulatory Authority
NWFP	North-West Frontier Province
O&M	operation and maintenance
PARC	Pakistan Agricultural Research Council

PCR	Project Completion Report
PDWPs	Provincial Development Working Parties
PIDA	Provincial Irrigation and Drainage Authority
PIDE	Pakistan Institute for Development Economics
PM	partite material
ppt	parts per thousand
RAP	Revised Action Programme
RBOD	Right Bank Outfall Drain
SAR	Staff Appraisal Report
SCARP	Salinity Control and Reclamation Project
SGW	Saline Groundwater
STPMT	Sindh Taraqee Passand Mallah Tanzeem
TAMS	Tippetts-Abbett-McCarthy-Stratton
TDF	Tarbela Development Fund
TDP	Tarbela Dam Project
TDRO	Tarbela Dam Resettlement Organisation
TJV	Tarbela Joint Venture
USAID	United States Agency for International Development
WAA	Water Apportionment Accord
WAPDA	Water and Power Development Authority
WB	World Bank
WSIPS	Water Sector Investment Planning Study
WUAs	Water Users Associations

Local Words	**English Meaning**
Doab	Area between two rivers (*do*=two and ab=water)
Kanal	unit of area (one kanal equals 0.125 acre or 506 sq.m
Kharif	summer season crops(April to September)
Mahseer	fish variety, *Tor putitora*
Marlas	unit of area (One acre = 160 marlas)
Rabi	winter season crops (October to March)

1. Introduction

1.1 Purpose of the Report

The World Commission on Dams (WCD) faces a considerable challenge in meeting the mandate given to it by the reference group at its inception in 1997. This includes *inter alia* an assessment of the "development effectiveness" of dams, an issue that the Commission has decided to address through thematic studies, the cross-check surveys and a series of case studies of dam projects world-wide, with a view to learning lessons from these experiences.

The Tarbela dam case study is an integral part of the overall study being carried out by the WCD as part of its mandate. This study deals with the Tarbela Dam Project (TDP) developed as a follow-up to the settlement of the river waters dispute between India and Pakistan. The main objective of Tarbela dam was to create an initial live storage of 11.5 billion cubic meters (bcm) in order to protect irrigated agriculture of over 1.8 million hectares (mha) that was hitherto dependent on the eastern rivers. It also aimed to provide supplemental irrigation supplies to another 7 mha, and develop a hydro-power potential of 2 100 mega watt (MW). The historical context of TDP and the decision making process is described in more detail under section 5.

The report places particular emphasis on comparing the predicted and actual achievements of the project. Throughout the study a key distinction is therefore drawn between what was predicted and what was not. This "predicted and actual" approach is important as it is not the purpose of this study to answer the question, "should this dam project have been implemented”, but instead to determine what the project achieved compared to what was planned and predicted. In addition, the study documents how effective the planning and implementation process was in delivering the anticipated benefits, and how the decision-making process has addressed changing circumstances and unexpected consequences since the project was completed. Focus on the planning and decision-making process is essential, as lessons learned from this study will provide input to the Commission’s findings and its proposals for future a decision-making framework as well as criteria and guidelines.

The concept of “development effectiveness” is interpreted in the broadest sense. It includes the relevance and appropriateness of large dams as a response to the needs that motivated their construction (eg irrigation, electricity generation, flood management, water supply, navigation and other multi-purpose benefits), and examines the projected *vs* actual services and benefits delivered. It further assesses the costs and impacts associated with the achieved results, the distribution of gains and losses among groups, and the general conditions under which the dams were built and have been operated.

1.2 Case Study Procedure

As with the other WCD case studies, the Tarbela study has mainly used existing data sources and published reports. In addition, a special effort was made to obtain micro-level information from stakeholders and affectees to supplement findings on the socio-economic and environmental aspects of the project**.** The study has used various sources of information outside the Water and Power Development Authority (WAPDA) and has sought historical documentation from international agencies like the World Bank (WB). In order to achieve a wider participation in the conduct of the study, and especially, to involve the main stakeholders as an integral part of the methodology, two consultation meetings were organised. The first at the scoping stage was held on June 22, 1999 at the dam site itself and mapped out the issues to be addressed and identified available data sources; and the second took place on January 17-18, 2000 at Karachi to consider the draft final report. (see Appendix A) Besides these large meetings one-day field workshops were held at Haripur, Muzaffargarh, Hyderabad, Ibrahim Hyderi, and Keti Bandar. These meetings allowed full participation of stakeholders at the community level. These meetings were intended to ensure that the different interest groups were provided an opportunity for comment and input, so the study team could take cognisance of their views during the finalisation of its report.

The Commission's approach recognises that there is always some divergence in the interpretation of the available data, or in the perceptions of different interest groups; and that these convergent and divergent views are a key aspect of different perceptions of development effectiveness. Assessing development effectiveness thus entails taking account of the views and perspectives of different stakeholders and project-affected groups. This report does not take up a unique position, nor does it evaluate the "goodness" or "badness" of values but it attempts to faithfully state the facts obtained from different sources and views of various interest groups. It also does not pass judgement, with the benefit of hindsight, on whether or not the project should have been undertaken, or how things could, or should, have been done differently. Nor will it comment on the future evolution and management of the project. Its main purpose is to learn lessons from the past, focussing on those that are especially relevant to the planning, implementation and operation of large dams world-wide. The case study is intended to provide an analysis of performance, an assessment of how the decision-makers planned and implemented the different phases of the project, and the way in which decision-making has responded to an evolving social, economic, and political context since completion of the project. The category "unexpected" includes all features and consequences not included in the original project design. At times this will refer to issues genuinely unknown to the planners, at others to issues known at the time but unaccounted for or overlooked in the planning process.

The case study methodology is based around the six key questions devised by WCD that provide the foundation for the assessment of performance and decision-making:

- What were the projected vs. actual benefits, costs, and impacts?
- What were the unexpected benefits, costs, and impacts?
- What was the distribution of costs and benefits – who gained and who lost?
- How were decisions made?
- Did the project comply with the criteria and guidelines of the day?
- What lessons can be learned for today's context?

1.3 Structure of the Report

The report is broadly structured according to the six key questions listed above. Section 2 introduces the project purpose, design features and predicted benefits. Section 3 deals with sector-wise performance of the project and enumerates the study's findings concerning predicted and unexpected costs, benefits and impacts. Predicted and unexpected benefits are presented together for each sector to improve the clarity of the analysis. A summary of findings is also given at the end of each section to facilitate reading.

Thereafter the sections follow the order of the key questions above. Section 4 provides a sketch of the distributional intentions and outcomes of the project. The decision-making process that shaped the project's planned and actual outcomes is examined in section 5 while section 6 gives an analysis of evolution of the project and compliance with criteria and guidelines. A summary of the main study findings arranged according to the six questions posed by the WCD, is given in section 7. The lessons learned from the study, especially those relating to the project planning and operation cycle, are described in section 7. The feedback about the impact of Tarbela dam and developments in the Indus basin from the stakeholders is summarised in section 8. Written comments received on earlier drafts of the report are given in Appendix G.

2. The Context and Scope of the Case Study

This section provides brief background information on the context in which the Government of Pakistan (GOP) initiated the Tarbela Dam Project (TDP) in the mid-1950s. After giving a brief description of the Indus river basin, the main objectives and components of the Indus Basin Project (IBP), of which the Mangla and Tarbela dams are the two main components, have been described. The present study, however, deals exclusively with the effectiveness of Tarbela dam. The decision-making process leading to the development of IBP and TDP is discussed in more detail under section 5.

2.1 The Indus River Basin

2.1.1 Land, Climate and Water

The Indus river basin stretches from the Himalayan Mountains in the north to the dry alluvial plains of Sindh in the south. The area of Indus basin is 944,574 sq.km. The vast alluvial plains of the Indus basin (the Indus plains) cover an area of 207,200 sq.km. The relatively flat plain is largely made up of deep alluvium deposited by Indus river and its tributaries.

The climate in the Indus plain is arid to semi-arid. In lower Indus plain December to February is the cold season and mean monthly temperatures vary from 14-20°C. Mean monthly temperatures during March to June vary from 42-44°C. In the upper Indus plain mean temperature ranges from 23-49°C during summer and from 2-23°C during winter.

Average annual rainfall in the Indus plain is about 23cm. In lower Indus, Larkana and Jacobabad areas receive on the average about 9cm of rainfall annually. In the upper Indus plain, Multan receives 15cm and Lahore about 51cm of rain. Because of hot climate, evaporation rate is very high and mean annual evaporation in lower Indus plain (Nawabshah) is 204cm while in upper Indus plain (Sargodha) it is 165cm.

Primary source of surface water is precipitation in the form of rainfall and snow and the glacier melt. Glaciers in the upper Indus basin are the largest outside the polar region and serve as natural storage reservoirs that provide perennial supplies to river Indus and some its tributaries.

Soils in the whole of the Indus plain consist of deep deposits of unconsolidated and highly permeable alluvium brought in by Indus river and its tributaries (mostly over 300 meters). The alluvium mass is mostly homogeneous and forms highly transmissive aquifer. Recharge to the aquifer in the Indus plain is through rainfall and deep infiltration from the irrigated fields and seepage from earthen irrigation channels. Presently, estimated groundwater extraction from the aquifer is almost equal to the recharge in fresh groundwater areas although the balance between recharge and abstraction is not uniform across the basin.

Prime mover of Pakistan's economy is the irrigated agriculture in the Indus plains. At the time of partition in 1947, population of area now forming Pakistan was about 33 mln. In 1965, it increased to 51.2 mln. (18% urban, 82% rural) The present (1999) population of Pakistan is 134.5 mln. (33% urban, 67% rural).

2.1.2 River System

Indus river system can be divided into western rivers (Indus, Jhelum and Chenab) and the eastern rivers (Ravi, Beas and Sutlej). This division came into effect at the time of settlement of water dispute between India and Pakistan in 1960. Flows of western rivers are assigned to Pakistan while India has the right to flows of eastern rivers. All the rivers of the Indus system are perennial. The first record of gauge heights was made on the Indus at Attock in 1848. The next was on Chenab at Alexandria Bridge in 1879. The most important river gauging stations, called the rim-stations, have continuous discharge data from early 1920s when the Indus Discharge Committee was established for this purpose.

2.1.3 Indus Basin Irrigation System

Indus Basin Irrigation System (IBIS) is the largest contiguous irrigation system in the world developed over the last 140 years (Figure 2.1). The lengths of main canals, branches, distributaries and minors are 4230, 6835, 25874 and 19189km respectively, servicing IBIS through 110,000 watercourses. The irrigation system is supported by 3 storage reservoirs, 19 diversion structures (headworks/barrages) and 12 link canals transferring water from western rivers to canals previously taking their supplies from eastern rivers now assigned to India. IBIS commands a culturable commanded area (CCA) of about 14 mha out of which about 5 mha is under command of Mangla and the remaining 9 mha under Tarbela command.

The relevant information about canals, which are the main device for taking supplies from the rivers, is given in Table 2.1. Starting from early 1960s, IBIS was augmented/remodelled under the IBP as a consequence of the Indus Waters Treaty (IWT) 1960. The relevant information of IBP is given in Table 2.2.

2.2 Indus Basin Project

On April 01, 1948 India unilaterally cut off supplies to Pakistan canals originating from the head-works locate on the eastern rivers of Ravi and Sutlej thereby asserting its right on the waters of three eastern rivers (Ravi, Beas and Sutlej) Besides causing a serious setback to national economy, this would have seriously disrupted Pakistan’s water resources development plans. Therefore right from its creation, the country had to accord highest priority to the resolution of water dispute created by India. After protracted negotiations, it was finally resolved through good offices of the WB and culminated into signing of Indus Water Treaty (IWT) on 19 September 1960.

The Indus Basin Project (IBP) was developed in pursuance of the agreement reached with India under the IWT. The two main components of IBP (Table 2.2) were the major storage reservoirs on Jhelum (Mangla) and Indus (Tarbela) to mitigate the effect of diverting the three eastern rivers by India and to increase agricultural production in the IBIS. As a part of implementation schedule of IBP, Mangla Dam Project was taken up first and completed by 1968. In the meantime, decision was also taken to go ahead with Tarbela dam after its re-evaluation by the WB and lining up of the additional funding. Consequently construction started in 1968 and substantially completed by 1974.

Several major policy measures have been taken during the past 50 years to deal with the impending crisis from India's intention to divert eastern rivers through: implementation of IBP; and expanded irrigation facilities to meet the needs of the rapidly growing population. This has led to evolution of the basic policy of emphasising sustainable and progressive irrigated agriculture.

The scope of this case study is restricted to the Tarbela dam, while other relevant components of IBIS are briefly described but not given detailed treatment in the text.

2.3 Tarbela Command Canals

The IBIS, though substantially integrated under IBP, is fed from the two major storages of Mangla and Tarbela. Tarbela command canals fall under two categories: (i) canals off-taking from the Indus Main; and (ii) canals fed from trans-Indus link canals. A list of Tarbela command canals is given in Table 2.3.

Figure 2.1: Schematic Diagram of Indus Basin Irrigation System

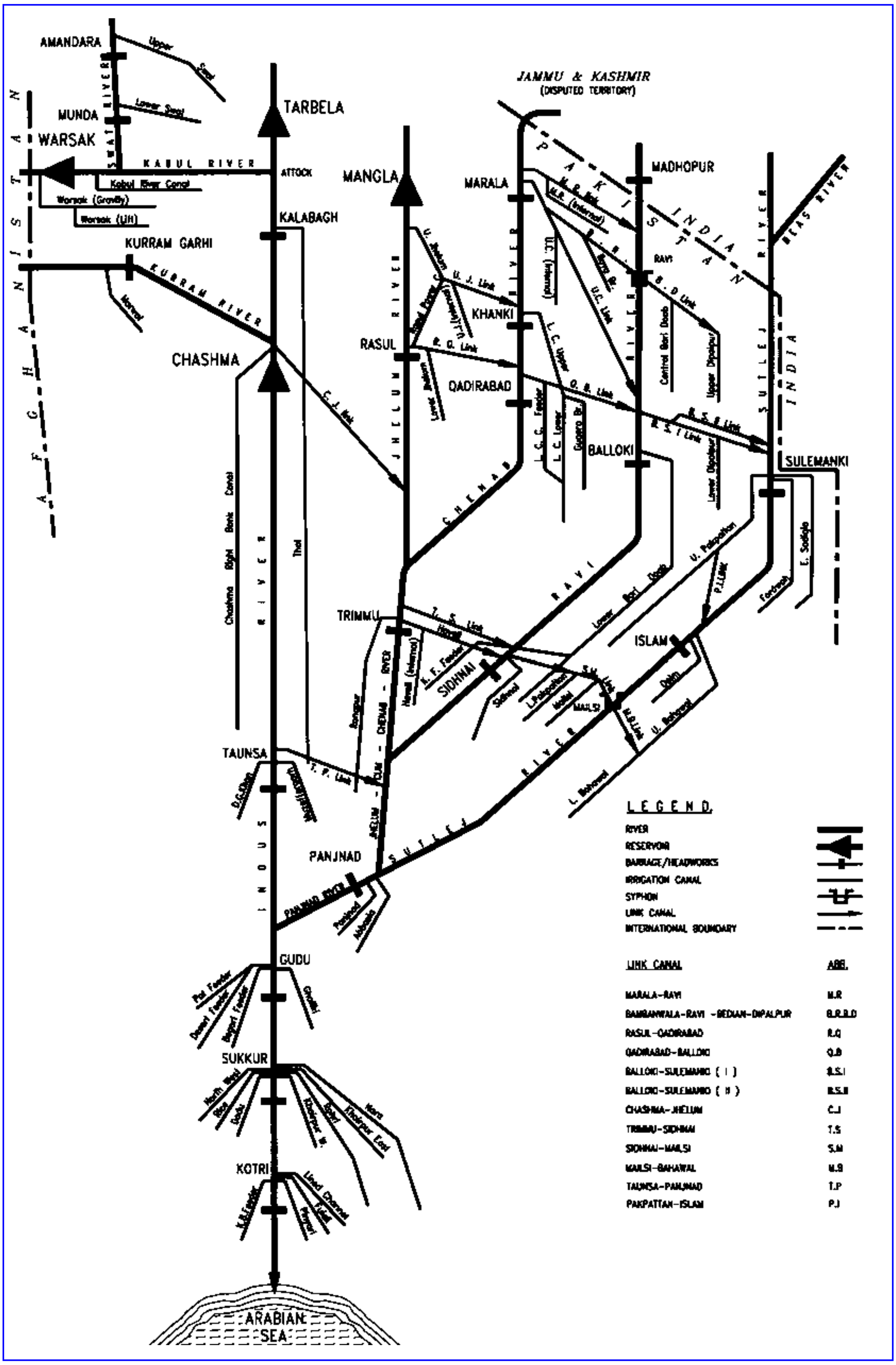


Table 2.1 Indus Basin Irrigation System - Canal Commands

Canal	Year of Commissioning	Barrage/Source of Supply	River
Peshawar Vale			
Lower Swat	1890	Munda	Swat
Kabul River	1890	Below Warsak	Kabul
Left Bank	1962	Warsak	Kabul
Right Bank	1962	Warsak	Kabul
Upper Swat	1915	Amandra	Swat
Paharpur/Chashma Right Bank	1909/1987	Paharpur/Chashma	Indus
Upper Indus Plain			
Central Bari Doab	1859	Marala/UCC/BRBD	Chenab
Sidhnai	1887	Sidhnai	Ravi
Lower Chenab	1892	Khanki	Chenab
Lower Jhelum	1901	Rasul	Jhelum
Upper Chenab	1912	Marala/UCC	Chenab
Raya	1912	Marala/UCC/BRBD	Chenab
Lower Bari Doab	1913	Balloki	Ravi
Upper Jhelum	1915	Mangla	Jhelum
Eastern Sadiqia	1926	Suleimanki/B S Link I&II	Sutlej/Ravi/Chenab
Pak Pattan	1927	Suleimanki/SM Link	Sutlej/Ravi/Chenab
Fordwah	1927	Suleimanki/B S Link I&II	Sutlej/Ravi/Chenab
Qaimpur	1927	Islam	Sutlej/Ravi/Chenab
Bahawal	1927	Islam/M.B. Link	Sutlej/Ravi/Chenab
Upper Dipalpur	1928	Marala/UCC/BRBD	Jhelum/Chenab/Ravi
Lower Dipalpur	1928	Belloki/BSI Link	Indus/Chenab/Ravi
Mailsi	1928	Islam/SM Link	Indus/Chenab/Sutlej
Panjnad	1929	Panjnad	Indus/Chenab/Sutlej
Abbasia	1929	Panjnad	Indus/Chenab
Rangpur	1939	Trimmu	Indus/Chenab
Haveli	1939	Trimmu	Indus/Chenab
Thal	1947	Kalabagh	Indus
M.R. Link	1956	Marala	Chenab
D.G. Khan	1958	Taunsa	Indus
Muzaffargarh	1958	Taunsa	Indus
Lower Indus Plain			
North West	1932	Sukkur	Indus
Rice	1932	Sukkur	Indus
Dadu	1932	Sukkur	Indus
Khairpur West	1932	Sukkur	Indus
Rohri	1932	Sukkur	Indus
Khairpur East	1932	Sukkur	Indus
Eastern Nara	1932	Sukkur	Indus
Pinyari	1955	Kotri	Indus
Fuleli	1955	Kotri	Indus
Lined Channel	1955	Kotri	Indus
Kalri Baghar	1955	Kotri	Indus
Pat	1962	Guddu	Indus
Desert	1962	Guddu	Indus
Begari	1962	Guddu	Indus
Ghotki	1962	Guddu	Indus

Table 2.2. Works Completed Under Indus Basin Project

S#	Description of Work		
1.	**Link Canals**	**Between Rivers**	**Command**
	Trimmu – Sidhnai Sidhnai – Mailsi Mailsi – Bahawal Rasul – Qadirabad Qadirabad – Balloki Balloki Suleimanki II	Chenab – Ravi Ravi – Sutlej Jhelum – Chenab Chenab – Ravi Ravi – Sutlej	Mangla
	Chashma – Jhelum Taunsa – Panjnad	Indus – Jhelum Indus – Chenab	Tarbela
2.	**Barrages (Year of Completion)**	**River**	
	Sidhnai (1965)	Ravi	Mangla
	Marala (1968) Qadirabad (1967) Rasul (1967)	Chenab Chenab Jhelum	Mangla
	Chashma (1971) Mailsi (Siphon) (1965)	Indus Under Sutlej	Tarbela
3.	**Dams (Year of completion)**	**River**	
	Mangla (1967)	Jhelum	Mangla
	Tarbela[1] (1976) Chashma (Barrage) (1971)	Indus Indus	Tarbela
4.	**Remodelling of Existing Works**	**Between Rivers**	
	Balloki - Suleimanki Link I Marala - Ravi Link BRBD Link Balloki Headworks	Ravi-Sutlej Chenab-Ravi Chenab-Ravi Ravi	Mangla

[1]. *Scope of the study restricted to this project.*

Table 2.3. Tarbela Command Canals

Barrage	Canal	Culturable Command Area	
		Mha	Mln. acres
A. Canals Off – taking from Indus Main			
Jinnah	Thal	0.664	1.641
Chashma	Paharpur/Chashma Right Bank Canal (CRBC)	0.042/0.190	0.104/0.470
Taunsa	D.G. Khan Muzaffargarh	0.696	1.718
Guddu	Pat Feeder Desert Begari Ghotki	1.188	2.935
Sukkur	North west Rice Dadu Khairpur West Rohri Khairpur East Nara	3.176	7.845
Kotri	Kalri Fuleli Pinyari Lined Channel	1.123	2.775
	Sub-total (A):	**6.889/7.037**	**17.017/17.383**
B. Tributary Canals Fed From Trans-Indus Links			
Link	Canal System		
Chashma-Jhelum & Trimmu – Sidhnai-Mailsi-Bahawal Links Taunsa-Panjnad	Haveli (Internal) Rangpur Sidhnai Lower Pakpattan/Mailsi Lower Bahawal Panjnad Abbasia	0.072 0.139 0.352 0.403 0.245 0.546 0.062	0.179 0.344 0.869 0.996 0.605 1.348 0.154
	Sub-total (B):	**1.819**	**4.495**
	Grand Total (A+B):	**8.708/8.856**	**21.512/21.878**

2.4 The Objectives and Components of the Tarbela Dam Project

The primary objective of Tarbela Dam Project (TDP) was to store water to mitigate the effect of diverting the three eastern rivers by India and to increase agricultural production in the existing canal command areas along the Indus main river. Relevant details including predicted benefits, as they appeared in official documents of the time, are further elaborated in the various sub-sections of Section 3. Tarbela was designed to: provide storage to replace the water of existing canals (command of about 1.8 mha) dependent on the three eastern rivers; and improvement of supplies to the canals off-taking from the Indus main (command of about 6.9 mha). A subsidiary goal was to generate low-cost hydropower to meet the country's requirements. The ultimate goal of TDP was to provide a firm base for progressive development of the irrigation system to bolster the national efforts of increased agricultural productivity to meet the requirements for the burgeoning population.

Because of its storage capacity of 11.5 bcm and re-regulatory-cum-integrating impact of large reservoir, it was expected that TDP would substantially increase the canal head diversions. It was projected that after full utilisation of Tarbela storage (1985) the existing (1960-67) average IBIS withdrawals of about 108 bcm would have increased to about 128 bcm. Consequently it was expected that cropping intensities in the provinces of Punjab and Sindh (comprising about 97% of IBIS) would also increase substantially. According to feasibility estimates contained in the Indus Special Study [hereafter referred to as the Lieftinck Report (1968)], the cropping intensities in Punjab would increase from 95% (1965) to 114% (1975), 131% (1985) and 150% (2000). Similarly, cropping intensities in Sindh would increase from 90% (1965) to 100% (1975), 115% (1985) and 137% (2000).

Regarding power, on full development of 2100 MW, TDP was predicted to provide an annual average generation of 12600GWh.

TDP as evaluated in the Lieftinck Report was the largest water storage and hydroelectric project in Pakistan. In fact, it probably represented the largest single construction work ever to have been contracted in the world. The project, as envisaged, comprised essentially a major earth and rock-fill dam with an impervious upstream blanket, two auxiliary embankment dams, two chute spillways, and four outlet tunnels each of 13.7m maximum diameter.

The powerhouse would be located on the right bank of the river at the foot of the dam. The sub-structure was designed to be constructed in stages of four generating units each served by pen-stock from one tunnel. It was decided to initially build the powerhouse for four generating units. Eight more units would be installed at a later date to equip three right bank tunnels with power.

3. Predicted and Actual Impacts of the Tarbela Dam Project

Though constructed as part of IBP, Tarbela Dam Project was re-evaluated in the Lieftinck Report (1968). Its predicted impacts in the context of specific and overall objectives were also assessed as part of this exercise. These were:

- To provide a live storage capacity of 11.5 bcm, out of which two-thirds would cater to the needs for replacement of the water of the eastern rivers ceded to India, and the remaining one-third would improve the low-flow period supplies in the existing canals being fed from the Indus main river.

- To produce a large proportion of the country's power requirements, through a staged ultimate development of 2100 MW of hydropower capacity at relatively low cost.

Overall, it would provide, through its re-regulating capability, a base for progressive development of irrigated agriculture by increasing crop intensities and yields. This was envisaged in conjunction with a comprehensive "Program for Irrigation Development in the Indus Basin" as presented in the Lieftinck Report (Annex 1). Extending from 1965–2000, through various Five Year Development Plans, the Program proposed very large water sector investments in groundwater development, canal enlargements and sub-surface drainage covering the entire IBIS. In addition, it provided for the construction of additional surface storages almost equal to the capacity of Tarbela.

Since Tarbela dam is closely integrated with IBIS, the project outputs as predicted in the Lieftinck Report relate either directly to Tarbela dam itself (water storage releases, hydropower etc.) or to the developments in IBIS (irrigated area, cropping intensity, crop yields). The benchmarks for predicted objectives/targets have been taken from the Lieftinck Report, while the actual achievements are drawn from the TAMS and World Bank Project Completion Reports (PCR), or from the statistics issued by the Planning and Development Division of the Ministry of Food, Agriculture and Livestock of the Government of Pakistan (GOP).

3.1 Design Characteristics

Design characteristics of Tarbela Dam Project were evolved on the basis of site investigations over the period of 1955–62. Initial focus was on selection of the dam site out of three locations in close vicinity. This led to the final choice (at Bara) on account of the factors further elaborated under section 5.4. Then followed the project planning stage when various design characteristics were evolved.

As Tarbela was the largest earthfill dam in the world at that time, it was well known at the stage of original design that a number of the concepts adopted involved extending knowledge beyond the existing frontiers. This is true of the following features in particular:

- very large tunnels with gates and stilling basins for low level outputs;
- an upstream clay blanket to reduce reservoir seepage with no close competitor, with regard either to its extent, or to the height of the dam; and
- flip bucket type spillways with huge plunge pools in a somewhat unfavourable geology.

The original design of the project essentially comprised:

- a major earth and rock fill dam requiring a fill of 121 million cubic meters (mcm), rising 148m above ground level, with a crest length of about 2 744m and an impervious blanket extending 1 524m upstream;
- two auxiliary earth and rock fill dams;
- two chute spillways;

- four outlet tunnels each of 13.7m maximum diameter; and
- a power station.

The power station would initially have four generating units rated at 175 MW each on Tunnel No. 1 aggregating to 700 MW. Each unit, rated at 175 MW, would have a capability range of 183 MW (or 210 MW with 15% overload under full head and low tail-water conditions) to about 40 MW at the maximum draw-down level of 396.3m. By 1980, it was planned to convert in stages two more tunnels to power, installing eight more units giving a total installation of 2 100 MW. One tunnel (Tunnel No. 4) was to remain as an irrigation outlet. The reservoir would initially contain a live storage of 11.5 bcm between the minimum draw-down level of about 396m and maximum conservation level of 472.6m above mean sea level (amsl).

Tarbela was the only major storage project that had been investigated thoroughly, the technical feasibility of which had been firmly established, and which could be completed by the mid 1970s, to cope with water replacement requirements. Also, its location was favourable for future diversion by gravity flow to additional side-valley reservoirs, in which sedimentation would take place slowly. Thus, as Tarbela ages, its value to power would increase by progressively raising the minimum draw-down level higher than the original 396m above mean sea level (amsl). Reduced storage for irrigation supplies could be replaced by side-valley reservoirs and/or by another dam on the Indus main stem. As the River Indus carries large quantities of sediment, any main stem project would have a limited life. The problem of loss of reservoir storage volume due to sedimentation was, therefore, studied at the design stage and has continued subsequently during operation. Early studies indicated that Tarbela reservoir would be depleted to a residual storage capacity of about 1.2 bcm in about 50 years. To enhance this limited life, the possibility of sediment sluicing was examined. It was, however, concluded that effective sluicing was precluded by nature of the site.

Soon after the start of construction, GOP reviewed the total water release capacity of three power and one irrigation tunnel, and concluded that it was inadequate to meet the irrigation demands of early *kharif*. A fifth irrigation tunnel was therefore added to the project and sited on the left bank. Initially, to minimise current expenditures and also to avoid interference with the construction of the main project, the work on the left bank irrigation tunnel was limited to construction of a 213m length of stub-tunnel with intake works that could be closed by means of removable bulkhead sections. The tunnel could then be completed later without having to lower the reservoir below the tunnel intake level. Subsequently, however, construction of the remainder of the tunnel was authorised and the work completed in 1975. The stub-tunnel was designed by the project consultants (Tippetts-Abbett-McCarthy-Stratton - TAMS) and constructed by the main contractor of Tarbela Joint Venture (TJV) under a variation order. The remainder of the tunnel, including the gate shaft, downstream tunnel, gate structure and flip bucket arrangement, was designed by the National Engineering Services of Pakistan (NESPAK) and constructed by the Pakistan Tarbela Consortium, a joint venture of TJV and the National Construction Corporation of Pakistan. Throughout, the design of the left bank irrigation tunnel followed closely the design of the right bank Tunnel No. 4.

On the right bank also, a small irrigation tunnel – Gandaf Tunnel – was added, extending inland from the reservoir to the Baisak-Gandaf area, to help satisfy the local irrigation needs of the North West Frontier Province (NWFP). In this case, however, the initial construction was limited to entrance works comprising: a small intake and length of tunnel; a gate shaft for the gates; and an underground stilling basin. The downstream length of tunnel, to deliver water to the irrigation system was to be constructed later. (This construction is now under implementation as part of Pehur High Level Canal Project).

Thus, with the addition of a large tunnel on the left bank, and a small stub-tunnel on the right bank, the design characteristics of the project were finalised in 1972 and comprised:

- An earth and rockfill embankment across the entire width of the main Indus River valley and the attributal reservoir.

On the left bank:
- Two auxiliary earth and rockfill embankments to close saddles at the upstream end of a side valley;
- Two spillways discharging into the side valley; and
- A tunnel through the left abutment to provide controlled irrigation releases downstream.

On the right bank:
- A group of four tunnels through the right abutment to provide for river diversion during the last phase of main embankment construction, regulated power releases (Tunnels 1, 2 and 3)and regulated irrigation releases (Tunnel 4);
- A small diameter stub-tunnel to provide irrigation flows through the right abutment ridge to the Gandaf plateau some two miles distant; and
- A powerhouse and switchyard with overall installed capacity of 2 100 MW (later on through optimisation, an actual installation of 3 478 MW has been achieved as explained under section 3.6).

The reservoir created behind Tarbela dam would cover an area of 260 km^2 and extend approximately 100km over a reach of transitional topography. The uppermost 64km was in a narrow steep-sided valley between high mountains where the Indus flowed in a single, well-defined channel. In the course of the lower 32km length, the valley broadened and the river meandered flowing as a braided stream in many reaches, with the mountains on either side diminishing into hills, eventually becoming a broad alluvial plain extending down to Attock. The dam, 2 744m long, would close the valley at practically the same point before the hills dwindled away.

The regulated releases from Tarbela Dam along with downstream additions from the Kabul/Panjnad rivers would be diverted into various commands of IBIS with the existing and new irrigation infrastructure to be constructed as part of IBP. Evolution of the project is described in Table 5.1 (section 5.2 Chronology of Events in Project Cycle of Tarbela Dam) while salient features of the TDP are listed in Table 3.1.

Table 3.1. Salient Features of Tarbela Dam Project

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

Findings on Design Characteristics

- Design characteristics including a number of state-of-art concepts were evolved on the basis of detailed site investigations and analytical studies spread over a period of seven years starting in 1955, after final selection of the Bara site out of three alternative sites in the vicinity of Tarbela.
- To enhance the limited storage life (50 years), investigations were carried out into the possibilty of passing down heavily sediment-charged waters during the high runoff season. It was, however, concluded that effective sluicing at Tarbela was precluded by the nature of the site.
- The project, with a live storage of about 11.5 bcm, was essentially constructed in accordance with the original design characteristics, with the addition of another irrigation tunnel (No. 5) on the left bank, and a small stub-tunnel on the right for future irrigation development in NWFP.
- The risks of construction in an area with a complex geology were identified, but these were considered manageable.

3.2 Time Schedules for Implementation

An original schedule for project implementation was outlined in the Lieftinck Report (1968). This envisaged that, starting from June 1967, the storage part of Tarbela would be commissioned in July 1974 followed by the first four 175 MW units during 1975. 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 3 478 MW (67% more than the planned 2 100 MW) was developed in stages through 1993.

A comparison between scheduled and actual completion of various construction stages is given in Table 3.2.

3.3 Capital and Operational Costs, Financing and Benefits

3.3.1 Predicted Capital Costs

An estimate of financial requirements (capital costs) of the Tarbela Dam Project was indicated in the Lieftinck Report. Accordingly (Table 5-12, page 138 Vol. I), the estimated financial requirements for the project in 1965 prices were $1 047.3 million including land/resettlement and the first eight power units of 175 MW each. This also included $150.5 million for import duties but excluded interest during construction (IDC). Correspondingly estimated financial requirements (Table 5-13, page 139 Vol. I) excluding all mechanical and electrical power, but including civil engineering work for the first four units, were $947.7 million. Thus, the net financial requirement for installation of the first eight power units of 175 MW each was $99.6 million. As it was planned to ultimately install 12 power units, this financial requirement for additional civil works and for power units 5 to 12 has been estimated at $188.7 million as per computation in Annex 2.

The above estimates of $947.7 million for reservoir works and $188.7 million for power facilities have been broken down into yearly expenditure schedules in Table 3.3.

Table 3.2. Scheduled and Actual Construction of Various Stages of TDP

Construction Stage	Project Component/ Activity	Construction			
		Scheduled[1]		Actual[2]	
		From	To	From	To
Mobilisation	Including award of main contract	Jun. 1967	Dec. 1969	May 1968	Dec. 1970
Stage I- River flow in natural channel	River diversion, main embankment, spillways and tunnels	Jan. 1968	Sep. 1970	May 1968	Sep. 1970
Stage II- River flow in diversion channel	Main and auxiliary dams, spillways and tunnels	Oct. 1970	Sep. 1973	Oct. 1970	Sep. 1973
Stage III- a) Flow through tunnels b) Full commissioning of reservoir	Auxiliary dams and power station After initial testing	Oct. 1973 Jul. 1974	Sep. 1974 Sep. 1974	Sep. 1973 Jul. 1974[3]	Sep. 1974 Sep. 1976[4]
Stage IV- Commissioning of power	Units 1 and 2 Units 3 and 4	Jan. 1975 Oct. 1975	Mar. 1975 Mar. 1976	Apr. 1977 Jun. 1977	May 1977 Jul. 1977

1 *Annex 1, Figure 1, Lieftinck Report, Vol. I, 1968.*
2 *PCR on Design and Construction, TAMS, 1984.*
3 *Initial filling started on schedule but the reservoir had to be evacuated in emergency due to a problem with one of the gates in Tunnel No.2 which got stuck when being closed.*
4 *After completion of repair/restoration work and testing; partial storage made available effective Sep. 1975.*

Table 3.3. Tarbela Dam Projected-Predicted Costs and Schedules

Financial Year Ending June	Reservoir Works		Power Facilities		Total	
	1965 Prices [1]	Current Prices[2] (US$)	1965 Prices [3]	Current Prices[2] (US$)	1965 Prices (Rs)	Current Prices[2] (US$)
1965	14	15			14	15
1966	99	105			99	105
1967	117	119			117	119
1968	895	877			895	877
1969	663	617			663	617
1970	650	572	33	29	683	601
1971	730	621	33	28	763	649
1972	659	461	33	23	692	484
1973	559	196	34	12	593	208
1974	338	112	83	27	421	139
1975	86	27	83	26	169	52
1976			133	39	133	39
1977			133	36	133	36
1978			133	33	133	33
1979			133	31	133	31
1980			67	13	67	13
Total	**4810**	**3721**	**898**	**297**	**5708**	**4018**

1 *Estimated financial requirement of $947.7 million converted to Rs.4 810 million by multiplying with 4.76; yearly schedule derived according to ratios for the corresponding economic costs in Appendix Table A 6-7, page 358, Vol. II, Lieftinck Report.*
2. *Converted in 1998 $ prices as per WCD methodology.*

3. *Estimated financial requirement of $188.7 million converted to Rs.898 million by multiplying with 4.76; yearly schedule arbitrarily evolved in keeping with installation programme of power units predicted in The Lieftinck Report.*

3.3.2 Predicted Operational Costs

In the Lieftinck Report, it had been estimated that the annual operation and maintenance cost of the project would be Rs.10.4 million (1965 prices, that is, equivalent to Rs.184.4 million in 1998 prices based on conversion given in Annex 3) starting from the year 1972.

3.3.3 Actual Capital and Operational Costs

The original estimated capital cost, including the proposed generating capacity of 2 100 MW, was $1 136.4 million ($5 875million 1998 prices) with a foreign exchange component in the order of 60%. Actual annual disbursements for all civil and power works (3 478 MW), including resettlement and debt servicing, were converted into dollars and inflated to 1998 dollar prices. This resulted in an estimate of actual costs (in 1998 terms) of $8 800 million or an increase of about 50% over the estimated capital cost. Actual operation and maintenance costs of WAPDA in current prices for both reservoir works (Water Wing) and power infrastructure (Power Wing) were Rs.21 526 million.

Details of yearly expenditure on various items are given in Table 3.4.

The O&M costs given in the Lieftinck Report were assumed to be Rs.10.4 million in 1965 prices and would start occurring in 1972. This estimate of Rs.10.4 million multiplied by 27 years gives a gross figure of Rs.280.8 million. This stream of constant O&M costs valued at current prices is equivalent to $44.62 million. However, the actual O&M costs for power and irrigation (Table 3.4) are in the region of $1 234 million in 1998 prices. This indicates that there was a gross under-estimation of the O&M costs at planning stage.

3.3.4 Financing of Costs and Over-runs

The project was financed through the Tarbela Development Fund (TDF) which was created in 1968 out of the remaining balance from the IBDF and additional loans and grants from friendly countries. The calculation of cost overrun is dependant on the way in which annual payments are inflated (according to local or foreign inflation rates) and which document is taken as the base cost estimate. Two approaches are used to define the possible range of cost overrun. In the first approach, the total project cost including all 12 projected power units is taken from the Lieftinck Report and inflated to 1998 prices.

The second method makes a comparison of financial flows (in prevailing prices) related to the original cost in the SAR and supplementary loans. The final cost as per Project Completion Report (PCR)-WB 1986 excluding power units was $1 497 million including a foreign exchange component of $800 million. It covered the cost reimbursed from TDF and related to: dam and associated civil works; power station civil works for four units only; design improvements; and special repairs/restoration. It did not, however, cover the cost of resettlement, additional Tunnel No. 5 and power installations (units 1-14) that were borne by the Government of Pakistan (GOP). The original estimate for the same scope of work (excluding power etc.) was $828 million. The cost overrun in purely nominal dollar terms was therefore 81%. Further work is required to determine more precisely the project cost overrun which is estimated to be in the range 50–81% from the two methods used.

The WB as administrator of TDF, arranged two supplements to fund the revised project cost. The increase in cost was mainly because of: an initial under-estimation; design improvements; and major structural repairs/restoration of some project components damaged after impounding.

Table 3.4. Tarbela Dam Project-Capital and O&M Expenditure Through 1997-98

Financial Year ending June	Capital Costs(Rs. X 10)					Operation & Maintenance Costs (Rs.x10[6])				Debt[6] servicing (Rs.x10[6])	Total Expendi-ture (Rs.x10[6])	1998 Basis Cost		
	Civil Works[1]	Resettlement[2]	Tunnel No.5[2]	Power Installment[3]	Sub-total	Water Wing[4]	Power wing[5]	Sub-Total	US$ 1998 Prices			Con- version Factor[9]	Amount in Millions: Total Cost US$	Amount in Millions: Capital Cost US$
Upto Jun. 65	47[8]				47						47	1.09	51	51
1965-66	3[8]				3						3	1.06	3	3
1996-67	54[8]				54						54	1.02	55	55
1967-68	122	21			143						143	0.98	140	140
1968-69	619	45			664						664	0.93	618	618
1969-70	1081	36			1117						1117	0.88	983	983
1970-71	1348	38		15	1401						1401	0.85	1191	1191
1971-72	1495	59	14	87	1655						1655	0.7	1159	1159
1972-73	792	83	43	208	1126						1126	0.35	394	394
1973-74	1117	141	154	443	1855						1855	0.33	612	612
1974-75	697	151	313	443	1604						1604	0.31	497	497
1975-76	560	76	170	344	1150	151		151	43.79		1301	0.29	377	334
1976-77	481	80	33	400	994	126		126	34.02		1120	0.27	302	268
1977-78	485	64	8	400	957	74	3	77	19.25		1034	0.25	259	239
1978-79	451	61	4	410	926	125	4	129	29.67		1055	0.23	243	213
1979-80	740	4	4	380	1128	112	8	120	24		1248	0.2	250	226
1980-81	810	32	8	267	1117	86	39	125	22.5		1242	0.18	224	201
1981-82	897	74		75	1046	149	182	331	52.96		1377	0.16	220	167
1982-83	1010	47		187	1244	166	207	373	48.49		1617	0.13	210	162
1983-84	488	41		359	888	184	418	602	72.24		1490	0.12	179	107
1984-85	149	57		719	925	119	479	598	59.8		1523	0.1	152	93
1985-86	132	44		1266	1442	145	304	449	40.41		1891	0.09	170	130
1986-87				2061	2061	132	705	837	66.96		2898	0.08	232	165
1987-88				3539	3539	148	730	878	70.24	2124[7]	6541	0.08	523	283
1988-89				3096	3096	183	736	919	64.33	161	4176	0.07	292	217
1989-90				884	884	178	894	1072	64.32	184	2140	0.06	128	53
1990-91				10	10	213	902	1115	55.75	206	1331	0.05	67	1
1991-92						241	1152	1393	69.65	227	1620	0.05	81	
1992-93						249	2900	3149	125.96	138	3287	0.04	131	
1993-94						297	1680	1977	79.08	162	2139	0.04	86	
1994-95						336	797	1163	34.89	181	1344	0.03	40	
1995-96						353	1176	1529	45.87	60	1589	0.03	48	
1996-97						337	1793	2130	63.9	121	2251	0.03	68	
1997-98						358	1925	2283	45.66	134	2417	0.02	48	
Total:	**13578**	**1154**	**751**	**15593**	**31076**	**4462**	**17034**	**21526**	**1234**	**3698**	**56300**		**10033**	**8560**

1. *Financed through Tarbela Development Fund (except otherwise noted) including structures of power units 1-4 and cost of repair/remedial works; 1982-83 level figures from Annex 6/Table-4 of PCR, World Bank, 1986 converted to current prices as per Pakistan Inflation conversion factors in Annex 3.*
2. *1982-83 level figures for these non-reimbursable costs taken also from Annex 6/Table 4 of PCR, World Bank, 1986 and converted to current prices as per Pakistan Inflation Factors in Annex 3.*
3. *Including; only electrical and mechanical (E&M) equipment costs of units 1-4; cost of units 5-14 including civil works as obtained from WAPDA; and funding of these costs arranged by WAPDA outside TDF.*
4. *Figures obtained from WAPDA; also include cost of common services, overheads and minor works.*
5. *Figures obtained from WAPDA; also include cost of common services, overheads, interest and depreciation to cover the principal*
6. *Only covers the liability of TDF being serviced by the Federal Government.*
7. *Total up to and including 1987-88.*
8. *Expenditure reimbursed from Indus Basin Development Fund.*
9. *Based on WCD methodology*

To meet the capital costs, excluding land acquisition and resettlement, the remaining balance of $354 million available from Indus Basin Development Fund (IBDF) was transferred to create Tarbela Development Fund (TDF) in 1968. It may, however, be noted that IBDF was originally intended to cover Tarbela, but the cost overrun of Mangla required additional finances. In addition, bilateral loan agreements were signed with friendly countries and the World Bank. Originally, TDF had a capital base of $989 million with a commitment from the Government of Pakistan to provide local currency of $461 million equivalent including a contribution in lieu of duties and taxes. In 1975, the resources were augmented by $46 million including local currency of $9 million Later on in 1978, additional commitments of $336 million were obtained including a local currency equivalent of $223 million by Pakistan. This augmentation was basically to provide for the additional remedial/repair works. Other contributions of $126 million were also received from EEC, Saudi Arabia, Kuwait and Abu Dhabi.

Details of funding resources, along with expenditures reimbursed through TDF are given in Annex 4. Table 3.5 summarises the resource position of TDF including two supplements of 1975 and 1978.

Table 3.5. Resources of Tarbela Development Fund (TDF)

S. No.	Resource	Amount ($ million Equivalent) [1]				
		Original TDF (1968)	Ist Supplement (1975)	IInd Supplement (1978)	Other Contribu-tions	Total
1.	Transfer from IBDF	354				354
2.	Western Friendly Countries:					
i.	*Australia*	-	*1*	-		*1*
Ii.	*Canada*	*5*	-	*9*		*14*
Iii.	*France*	*30*	-	-		*30*
iv.	*Germany*	-	*6*	*10*		*16*
v.	*Italy*	*40*	*7*	*9*		*56*
Vi.	*UK*	*24*	*5*	*22*		*51*
Vii	*USA (EXIM Bank)*	*50*	*10*	-		*60*
	Sub-total (2)	149	29	50		228
3.	World Bank/IDA	25	8	38		71
4.	EEC			14[4]	6	20
5.	Saudi Arabia				59	59
6.	Kuwait				18	18
7.	Abu Dubai				25	25
8.	Pakistan	461	9	223	4	697[2]
9.	Others			11[5]	14[3]	25
10.	**Total**	**989**	**46**	**336**	**126**	**1497**

1. *Figures approximate and compiled from the information in the Project Completion Report, World Bank, 1986.*
2. *Contributions in local currency.*
3. *Including accumulated income and adjustment for currency fluctuations, etc.*
4. *Including special action credit of $7 million*
5. *Including insurance*
6. *the exact source used to disburse funds for example USAID or EXIMBAK for each financial contribution is unknown*

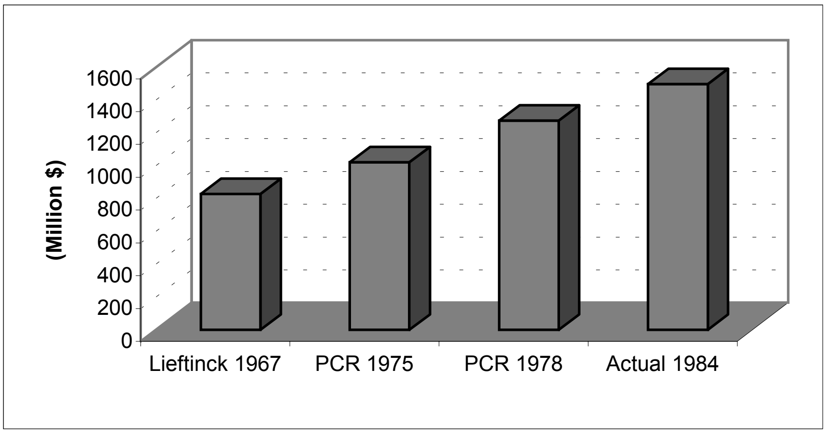
As of June 1983, the total cost disbursed from TDF was $1 496.6 million ($2 454 million in 1998 prices) including a rupee component equivalent of $696.6 million ($1 142 million in 1998 prices) provided by Pakistan. This cost covered civil works including those for the first four hydropower units without electrical and mechanical (E&M) equipment and remedial works. However, it excluded the the costs of: land acquisition/resettlement; additional Tunnel No. 5; and all power installations.

The foregoing estimated capital cost of $947.7 million (1965 prices) derived on the basis of information in the Lieftinck Report, also included $59 million for land and resettlement. By adding a financial contingency (10%) and then allowance for inflation (10%), this comes to a sum of $71.4 million that was not reimbursable from TDF. For the purpose of financing through TDF, therefore, the capital cost could be assumed to be $876.3 million (947.7-71.4) with a foreign exchange component of $489.5 million, if the import duties of $48 million are also included. As Pakistan had to make contributions to TDF for import duties, the net financing requirement would be about $828 million (876-48).

It may be noted that the originally estimated net capital cost of about $828 million in 1965 prices to be financed through TDF increased to $1 496.6 million by June 1983. Thus it increased by about 81% in nominal terms. The main reason for the initial increase was cost for the remedial works necessitated by the damages caused during first filling. Later increases financed by supplements were also used for repairs/restoration and so on of subsequent structural damages. This created several problems and also resulted in minor delays. While it was not possible to fix the responsibility for the damages, Pakistan ended up absorbing the brunt of these expenses through added loans and rupee component enhancement. The World Bank played a facilitator's role and helped Pakistan to progressively raise the needed funds (refer Table 3.5).

Evolution of cost estimates in current and 1998 Dollars as per 1986 PCR of the World Bank is depicted in Figure 3.1.

Figure 3.1. Evolution of Cost Estimates in Nominal Dollars



3.3.5 Cost Recovery

Being a replacement project under IBP, the cost of the water (storage) component was not to be recovered from the beneficiaries. Instead, GOP was liable to service the loan portion of TDF. Regarding the power component, the cost recovery including debt servicing for foreign loans was WAPDA's responsibility by offsetting against electricity sale revenues.

There has been no attempt to recover the capital cost of major irrigation works like Tarbela dam directly from the users. However, the O&M costs were planned to be recovered through the *abiana* or the water tax levied on the farmers. Abiana is collected by the provincial governments along with the land revenues and becomes a part of the provincial revenues. It is not directly related to the O&M costs (World Bank 1994). The O&M of water reservoirs including the Tarbela dam and link canals is the responsibility of WAPDA while the provincial irrigation departments are responsible for O&M of the canal system down to the mocha.

Revenues from *abiana* nearly covered the O&M costs of the irrigation system until 1970. However, after that the abiana revenues were consumed by the SCARP tubewells. The gap between O&M expenditure and recoveries has been increasing since 1970 and reached 44.4% in 1992. Punjab and Sindh *abiana* collections amount to about 70% of the O&M expenditure (30% gap).

Regarding power, the tariffs are set by WAPDA so that the O&M cost for power generation is fully recovered from the tariff with some savings for future expansion. Power revenues from 1975 to 1998 are given in Table 3.6 in which the last column indicates the revenues collected from Tarbela generation.

The actual costs of O&M (both for water and power including debt servicing) for Tarbela from 1976-98 aggregated to over Rs.21.5 billion in nominal terms (Table 3.4 refers). Against this the corresponding net revenue from electricity attributable to Tarbela has been computed on the basis of the average sale price of power excluding surcharges etc. This exercise yields on aggregate net revenue from Tarbela to the tune of Rs.101 and 152 billion assuming an attribution of 40% and 60%, respectively. Thus the project, besides meeting the direct O&M costs and debt servicing is also providing revenue to WAPDA for further development of the power system.

In the spirit of the 1973 Constitution stipulations, NWFP is entitled to a royalty payment from hydropower generation at Tarbela. According to an agreed upon formula devised by GOP, NWFP is currently receiving Rs.6 billion per annum ($139 million in 1998 prices) on this account (also refer to section 3.6.8). NWFP has received a total of Rs144 billion in royalties for the period 1975–98 (equivalent to $17.46 billion in 1998 prices).

3.3.5.1 Overall Irrigation (Storage) and Power Benefits

Based on the assumptions described elsewhere in this report (sections 3.5.7 and 3.6.3.3), Table 3.6 summarises the overall predicted and actual economic/financial benefits of Tarbela over the period 1975–98, for both the components of irrigation (storage) and power.

Table 3.6. Tarbela Dam Project-Summary of Irrigation (Storage) and Power Benefits over the Period 1975–98

Benefits	Predicted Benefits ($ million)		Actual Benefits ($ million)	
	1965 Prices	1998 Prices	1965 Prices	1998 Prices
I. Economic				
1. Irrigation (Storage)[1]	296.6(65)	1533.6(65)	352.9(61)	1824.5(61)
2. Power	160.0[2](35)	827.2[2](35)	225.0[3](39)	1163.3[3](39)
3. Total	456.6(100)	2360.6(100)	577.9(100)	2987.8(100)
II. Financial				
1. Irrigation (Storage)[4]	408.7(60)	2113.0(60)	375.4(51)	1940.8(51)
2. Power[5]	276.2(40)	1428.3(40)	356.1(49)	1841.0(49)
3. Total	684.9(100)	3541.3(100)	731.5(100)	3781.8(100)

Note: Figures in brackets denote percentage share.
1 = From Table 3.6; 2 = From Table 3.4; 3 = From Annex-6; 4 = From Table 3.7; 5 = From Table 3.8

Table 3.6 shows that the predicted economic benefits for irrigation and power had a ratio of 65: 35. Actually, the corresponding economic benefits had a ratio of 61: 39. For the predicted financial benefits, the ratio for irrigation and power was 60: 40. Actually, the corresponding financial benefits had a ratio of 51: 49. The financial aspects include the inflationary trends especially on rising fuel costs.

Findings on Capital and Operational Costs, Financing and Benefits

Costs

- To fund the cost of Tarbela, TDF was created in 1968 with leftover funds from IBDF, additional contributions from friendly western countries and a commitment of Pakistan to provide all the local currency.
- Subsequent supplementing of TDF was done twice to cater for enhanced costs primarily due to heavy repair/restoration work necessitated by damages, which started after first filling in 1974.
- Compared to the original estimated capital cost (including the proposed generating capacity of 2 100 MW) of Rs.1 136.4 million ($5 875 million 1998 prices), the actual annual disbursements for all civil and power works (3 478 MW), including resettlement and debt servicing (converted into 1998 dollars), amounted to $8 800 million, or an increase of about 50% over the estimated

capital cost. Making the comparisons in nominal terms for the projected and actual expenditure showed an increase of about 81% in the project cost reimbursed out of TDF.
- Further work is required to determine more precisely the project cost overrun which is estimated to be in the range 50-81% according to the two methods used.

Cost recovery and benefits

- Cost recovery for the water (storage) component was not made, due to the replacement nature of the project, while debt servicing for the foreign loans was picked-up by GOP. Moreover, the O&M cost of the water component of TDP was assumed to be offset against the power revenues.
- There is a significant shortfall in collection of *abiana* (irrigation charges) that is adversely affecting the maintenance of the overall irrigation system in the country.
- Regarding the power component, the capital cost recovery including debt servicing for the foreign loan was WAPDA's responsibility, to be offsett against revenues from the sale of electricity.
- Aggregate O&M cost (for both water and power) of TDP for 1976–98 was over Rs.21.5 billion in nominal terms. Against this, the corresponding net revenue from Tarbela on the basis of average sale price of power (excluding surcharges) aggregated to Rs.101 and 152 billion assuming attribution of 40% and 60% respectively.
- In lieu of hydropower generation at Tarbela, NWFP was being paid royalty of Rs.6 billion per annum under provision in the 1973 Constitution of Pakistan. NWFP has received a total of Rs144 billion in royalties for the period 1975-98 (equivalent to $17.46 billion in 1998 prices).
- In economic terms, over the period 1975-98, the accumulative estimated irrigation (storage) and power benefits from Tarbela were about $2 988 million (1998 prices) with share of 61 and 39%, respectively. Correspondingly predicted figures were $2 361 million (1998 prices) with share of 65% for irrigation and 35% for power.
- In financial terms, over the period 1975-98, the accumulative estimated irrigation (storage) and power benefits from Tarbela were about $3 782 million (1998 prices) with share of 51 and 49%, respectively. The corresponding predicted figures were $3 541 million (1998 prices) with share of 60% for irrigation and 40% for power. It may be worth noting that there was significant increase in the share of power from 34 to 49%.
- In 1998 prices, the overall estimated water (storage) and power financial benefits were over Rs.163 billion ($3 782 million), as per Table 3.6. As compared to this, the total capital expenditure was about Rs.190 billion ($4 388 million), as per Table 3.4. This performance over 23 years (about half of the originally estimated useful life of 50 years) was quite impressive.

3.4 Water Resources and Operational Management

This section starts with a brief introduction to the water resources of the basin prior to the commissioning of the Mangla (1967) and Tarbela (1976) dams and then examines the predicted and actual patterns of releases and flow distribution in the Indus rivers system. It looks at both seasonal distributions at various points down the Indus and a more detailed analysis of low flow conditions downstream of the last barrage in the system at Kotri (commissioned in 1955 and fully operational in 1962 for canal diversions) along with Guddu barrage

3.4.1 Water resources – Pre-Indus Treaty

3.4.1.1 Precipitation

Incident precipitation and river flows are two major sources of surface water used to meet the requirements of agriculture and other sectors. Mean annual rainfall in the country varies from less than 10cm in Baluchistan and parts of Sindh provinces to over 150cm in the foothills and northern mountains. About 60% is received during monsoon (July to September). Most summer rains are not available for crop production because of rapid runoff due to torrential showers. The contribution of rainwater to crops in the IBIS is estimated at about 16.5 bcm (Ahmad, 1993a).

3.4.1.2 Surface Water Resources

Glacier melt, snowmelt and rainfall-runoff constitute the river flows. An inflow discharge measurement facility has been established on the Indus River and the tributaries, and at points where these enter into the plains, they are referred to as rim-stations. The rim-stations of the western rivers are located at Kalabagh (below Tarbela), Mangla and Marala for the Indus, Jhelum and Chenab rivers, respectively. The rim-stations for the eastern rivers are located at Balloki and Sulaimanki for the Ravi and Sutlej rivers, respectively.

River flows during the *rabi* season are low because of retarded glacier- and snow-melt and low rainfall during the winter season. The bulk of the river flow is during the *kharif* season, which is more than five times the flow in the *rabi* season. The western rivers provided 173 bcm of water in an average year (50% probability) during the pre-storage period of 1937-67 with a variability of 135 and 232 bcm. Variability in flows of the eastern rivers was even higher than that of the western rivers. Before the construction of Mangla and Tarbela storage, the eastern rivers contributed about 26 bcm of water to the Indus river system in an average year (50% probability) of which about 84% was in the *Kharif* season (Table 3.7). Annual contribution of the eastern rivers to the annual total inflows of the Indus river system was around 13%, whereas it was 11% during the *rabi* season, which was a significant contribution. Under the provisions of the 1960 Indus Waters Treaty, India has the right to divert the whole of the flow (26 bcm) of the eastern rivers.

3.4.1.3 Groundwater Resources

The Indus basin represents an extensive groundwater aquifer covering a gross command area of 16.2 mha. The water table was well below the surface (>30 m) and the aquifer was in a state of hydrological equilibrium before the development of the canal irrigation system. The recharge to aquifer from rivers and rainfall was balanced by outflow and crop evapo-transpiration. When the canal irrigation system was introduced, percolation to the aquifer was increased in irrigated areas of the Indus basin resulting in the twin menace of waterlogging and salinity.

Although, there are disadvantages in having a high water table, it was used for irrigation through the use of dugwells/tubewells in the fresh groundwater zone. The groundwater contribution to irrigation was around 12 bcm during the pre-storage period, which was 11% of the total water available for agriculture.

Table 3.7. Variability of Rim-station Inflows to the Indus River System for the Pre-Storage Period

Probability(%)	Rim-station Inflows (bln. m^3) for Pre-Storage Period 1937-67						
	Western Rivers			Eastern Rivers			Total
	Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual	
Minimum	**111.0**	**19.1**	**134.5**	**9.6**	**1.7**	**11.3**	**145.8**
10	123.9	22.8	143.9	15.6	1.9	17.5	161.4
25	136.2	24.2	163.1	17.9	2.9	22.3	185.4
50	144.5	26.3	173.0	22.1	3.3	26.2	199.2
75	155.3	30.5	184.9	27.4	4.9	35.2	220.1
90	166.8	32.6	198.2	32.2	8.6	38.1	236.3
Maximum	**192.7**	**40.7**	**231.7**	**39.3**	**18.1**	**44.5**	**276.2**

Source: Water Resource Management Directorate, WAPDA.

3.4.2 Predicted versus Actual Water Resources Distribution

3.4.2.1 Surface Water Distribution

Substantial changes in the irrigation system resulted from the implementation of the Indus Waters Treaty of 1960. Out of the total measured discharge entering the Indus plain (in Pakistan and India together), averaging about 216 bcm per year in early 60s, about 206 bcm were available to Pakistan. Under the treaty, India would have the right to divert virtually all the flows in the eastern rivers of Ravi, Beas and Sutlej, which have an average annual discharge of 31 bcm. Thus, the average annual flows remaining available to Pakistan would be 175 bcm in the Indus including Kabul, Jhelum and Chenab. Some uncontrolled supplies from the catchment areas within Pakistan and above the rim-stations of Ravi and Sutlej rivers would make contributions of a few bcm in the *kharif* season and hardly any significant flows in the *rabi* season.

Commissioning of Mangla dam in 1968 with initial storage of about 6.5 bcm (20% of the average annual discharge of Jhelum River) would alter the pattern of river flows. Transferring this water from *kharif* to *rabi* more than doubled mean-year discharge as well as increased critical year discharge by some 130% in the *rabi* season. Tarbela dam with a live storage of 11.5 bcm (1976) also altered the Indus river flows by storing around 15.4% of the average annual flows, around 80% of which would be available in the *rabi* season.

3.4.2.2 Comparison of Inflows to the Basin

Variability of inflows to the basin

Variability in river flows is a major limitation in the development of run-of-river type irrigated agriculture in the Indus basin, especially to meet crop irrigation requirements during the low flow period of the *rabi* season and early and late *kharif* season.

The period of 1968-96 was considered to represent the post-storage period. This also helped to have at least 28 years of data for the probability analysis. The western rivers provided 162 bcm of surface water in an average year (50% probability) during the post-storage period (Mangla and Tarbela), that was 6.4% less than the pre-storage period. The bulk of the river flow was during the *kharif* season*,* which was around five times the flows in the *rabi* season. The variability in flows of the eastern rivers was even higher than the western rivers. After the construction of Mangla and Tarbela dams and major diversions by India, the eastern rivers contributed about 10.7 bcm of water to the Indus River system in an average year, of which about 77% were in the *kharif* season. The annual contribution of the eastern rivers to the Indus River system was about 6%, whereas it was 5.6% during the *rabi* season (Table 3.8).

Table 3.8. Variability of Rim-station Inflows to the Indus River System for Post-Storage (Mangla and Tarbela) Period

Probability(%)	Rim-station Inflows (bln. m^3) for Post-Storage Period 1968-96						
	Western Rivers			Eastern Rivers			Total
	Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual	
Minimum	**94.0**	**19.9**	**114.9**	**2.3**	**0.0**	**3.6**	**118.5**
10	111.6	20.4	135.5	3.7	0.9	5.3	140.8
25	124.2	24.0	153.2	5.1	1.1	7.1	160.3
50	136.0	27.1	162.1	8.2	1.6	10.7	172.8
75	148.5	29.5	180.9	12.7	2.4	15.4	196.3
90	159.7	32.8	189.6	18.5	3.4	20.1	209.7
Maximum	**182.0**	**37.8**	**206.0**	**20.4**	**7.7**	**23.8**	**229.8**

Source: Water Resource Management Directorate, WAPDA.

3.4.2.3 Variation of Rim Station Flows

Average annual flows of the eastern rivers during 1948-60 were around 32 bcm, which got reduced to 11 bcm during the post-Tarbela period (Table 3.9) at the conclusion of the Transition Period of the Indus Waters Treaty in 1970.

Table 3.9. Variation of Rim Station Flows for Western and Eastern Rivers

Key-Influences	Period	River Flows at Rim-stations (bln. m^3)					
		Western Rivers			Eastern Rivers		
		Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual
Pre-Independence	1937-47	145.80	26.96	172.76	21.69	3.84	25.53
Independence	1947-48	123.89	28.46	152.35	28.44	3.27	31.71
Water Dispute	1948-60	152.71	30.00	182.71	26.18	6.14	32.32
Pre-Mangla	1960-67	140.11	25.00	165.11	20.11	1.35	21.46
Post-Mangla	1967-75	135.11	24.27	159.38	12.35	2.59	14.94
Pre-Tarbela	**1937-75**	**144.11**	**27.03**	**171.14**	**21.03**	**3.83**	**24.86**
Post-Tarbela	1975-80	136.60	27.03	163.63	13.20	2.79	15.99
Post-Tarbela	1980-85	131.24	25.22	156.46	5.61	1.97	7.58
Post-Tarbela	1985-90	130.79	30.00	160.79	6.50	2.91	9.41
Post-Tarbela	1990-95	152.79	31.59	184.38	10.53	0.88	11.41
Post-Tarbela	**1975-95**	**137.86**	**28.46**	**166.32**	**8.96**	**2.14**	**11.10**

Source: Water Resource Management Directorate, WAPDA.

The initial live storage capacity of Tarbela dam of 11.5 bcm is about 15.4% of the average annual inflows to the Indus River that is further reduced to 12% in the wettest year and increases to about 23% in the driest year. Thus, the capacity carry over the storage from wet to dry years is limited.

Seasonal and annual river flows in the Indus River system are highly variable (Warsi, 1991; Kijine *et al.,* 1992; Ahmad, 1993a; Mohtadullah, 1997). The analysis of the daily and monthly flows also indicated a similar trend (Bhatti, 1999). This variability in river flows complicates the assessment of the real contribution of Tarbela in regulating the flows of the Indus River system (Table 12). The average *rabi* season flows in the western rivers were 27 bcm during the pre-Tarbela period (1937-75), whereas these flows were around 28.5 bcm during the post-Tarbela period. The average *kharif* season flows in the western rivers were 144 bcm during the pre-Tarbela period (1937-75), whereas these flows were around 137.9 bcm during the post-Tarbela period (1975-95).

The average *rabi* season flows in the eastern rivers were 3.8 bcm during the pre-Tarbela period (1937-75), whereas these flows were reduced to 2.1 bcm during the post-Tarbela period. The average *kharif* season flows in the eastern rivers were 21 bcm during the pre-Tarbela period (1937-75), whereas these flows were reduced to around 9 bcm during the post-Tarbela period (1975-95). The annual flows of the eastern rivers were 24.9 bcm in the pre-Tarbela period, that were reduced to 11.1 bcm during the post-Tarbela period. Thus there was a 55% reduction in the annual flows of the eastern rivers during the post-Tarbela period as a result of influences upstream in India.

3.4.2.4 Flows Distribution in the Indus River - Upstream of Tarbela

There was a slight variability in the inflows of the Indus River upstream of Tarbela (Table 3.10). The *kharif* season flows in the Indus River upstream of Tarbela were 69.1 bcm during the pre-Tarbela period (1937-75), which were reduced to 63.9 bcm during the post-Tarbela period (1975-95). The *rabi* season flows in the Indus river upstream of Tarbela were 10.5 bcm during the pre-Tarbela period (1937-75), which were slightly increased to 10.7 bcm during the post-Tarbela period (1975-95) The average river flows in the *kharif* season (post-Tarbela period) were around 86% of the annual flows. The post-Tarbela period was relatively dry as average annual flows of 74.6 bcm were received compared to 79.6 bcm during the pre-Tarbela period (Table 3.10).

Table 3.10. Effect of Key-Influences on the Flow Distribution in the Indus River upstream of Tarbela

Key Influences	Period	Indus River In-Flows at Tarbela (bln. m^3)		
		Kharif	*Rabi*	Annual
Pre-Partition	1937-47	70.00	10.91	80.91
Partition	1947-48	58.61	8.81	67.42
Water Dispute	1948-60	70.18	11.18	81.36
Pre-Mangla	1960-67	68.00	9.94	77.94
Post-Mangla	1967-75	68.54	9.88	78.42
Pre-Tarbela	**1937-75**	**69.09**	**10.54**	**79.63**
Post-Tarbela	1975-80	62.10	10.06	72.16
Post-Tarbela	1980-85	60.55	9.81	70.36
Post-Tarbela	1985-90	62.45	11.11	73.56
Post-Tarbela	1990-95	70.36	11.74	82.10
Post-Tarbela	**1975-95**	**63.87**	**10.68**	**74.55**

3.4.2.5 Actual Releases from Tarbela

The release of water from the dam is the amount of water released from irrigation spillways and power tunnels. The predicted releases from Tarbela dam show a decreasing trend over time based on the gradual sedimentation of the reservoir (Table 14). Further details of predicted and actual sedimentation rates in the reservoir are provided in section 3.4.5.2.

The actual storage releases were in line with the predicted releases during the first five years (1975-80) of Tarbela reservoir operation (WAPDA-TDP 1997; WAPDA-TDP 1998). Afterwards, the actual releases were more than those predicted, except during the period of 1990-92 where a slight decline was observed. Actual releases exceeded predicted releases by 19% and 22% during the periods of 1975-90 and 1990-98, respectively (Table 3.11). This increase in actual releases is an indicator of better operational performance than predicted resulting partly from a lower actual sedimentation rate than predicted and operational practices (refer to section 3.4.5. on sedimentation).

Table 3.11. Predicted and Actual Annual Storage Releases from Tarbela Dam

Period	Annual Releases from Tarbela Dam (bln. 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%)**

Source: a) TAMS (1984); b) Survey and Hydrology, OM&M, TDP, WAPDA, 1999.

All major floods are routed at the maximum conservation (gross capacity) level of 473m through the spillways and outlets. Further details of flood control are provided in section 3.7.1.

3.4.2.6 Reservoir Operation Criteria

Tarbela is a multi-purpose dam, where irrigation requirements dictate power generation. The priority of irrigation over power generation for reservoir operation criteria is an indication of integration of the dam within the IBIS.

Based on the irrigation demands, forecasted river inflows and available storage capacities, system operation studies were carried out to develop the reservoir operation criteria in the form of rule curves. This process was initiated with commissioning of Mangla reservoir in 1968. For Tarbela, the rules were contained in the special report by project consultants (TAMS 1974) entitled "Procedures for First Filling of the Reservoir in Summer 1974".

The first filling of Tarbela reservoir started on schedule in July 1974. With flow passing through the tunnels, one of the three intake gates on Tunnel No. 2 became stuck during lowering. This resulted in the collapse of the intake structure of Tunnel No. 2 along with part of the hillside. The repair took six months. Emergency emptying of the reservoir following this tunnel collapse, forced the asymmetrical operation of the outlet gates on both Tunnel Nos. 3 and 4, which damaged the stilling basin. This damage was discovered in 1975 when these outlet gates were used during repairs to Tunnel No. 1. Later on, minor difficulties were observed until satisfactory operation was achieved in the spring 1977. The reservoir operation rules under strategies of usable capacity above lowest elevation of 396m and between 427 and 457m were tested during 1976-77. Later on Tarbela was integrated into IBIS and its operation criteria along with those of Mangla were prepared by the operating agency of WAPDA for filling and draw-down seasons. This furnished a guide for actual subsequent operations.

Based on the experience acquired during the years 1974-84 and the reservoir operation criteria, annual reservoir operation procedures were presented by TAMS in the PCR of 1984. In addition, reservoir draw-down computations were made to address any emergency. Since then, Tarbela reservoir is being operated as part of the system on the basis of prescribed operation criteria. The storage capacity has been estimated almost annually since the start of the reservoir operation.

Maximum conservation (gross capacity) level of 473 m for Tarbela is generally achieved around 20 August every year. Operation criteria are also based on safety principles and the reservoir is filled at an average rate of about 3m/day up to the elevation of 460m. After attaining this level, the allowable rise is about 0.3m/day. However, during the low flow periods, after attaining the level of 466m, the allowable rise is around 0.6m/day.

After allowing for the daily permissible rise of 0.60m beyond the capacity level of 466m, the additional inflows are released from the spillways and outlets to ensure dam safety. For seasonal operation criteria, the operation of the reservoir is evaluated over 10-day periods, taking into consideration: estimated flows of the Indus at Tarbela and Kabul at Nowshera; provincial water allocations at the canal head; systems' gains and losses; and other operational requirements. During operations, provinces prepare and submit their indents of water requirement to the regulating agency (previously WAPDA and now the Indus River System Authority-IRSA). These form the basis for actual reservoir outflows.

Releases from Tarbela dam were dictated by water allocations of the provinces initially as per seasonal *ad hoc* arrangements and later on as per Water Apportionment Accord. The Water Apportionment Accord values represent agreed indicators of provincial allocations based on average river flow. In years with river flows that are above or below the average, the allocations are adjusted as per agreed indicator. Power generation is incidental to releases for the irrigation requirement which is a priority. Details on power generation are discussed in Section 3.6.

3.4.2.7 Flows Distribution in the Indus River – Taunsa and Guddu barrages

The Indus River flows at the downstream of Taunsa and Guddu barrages were analysed under key influences to evaluate the effect of Tarbela (Table 3.12). The river flows at Taunsa were higher than the inflows of Tarbela primarily due to the contribution of other rivers like the Kabul, Kurrum, Gomal and Sanghar to the Indus between Tarbela and Taunsa. The increase in flow at Guddu was primarily due to the contribution of the Jhelum, Ravi, Chenab and Sutlej rivers after Taunsa although some other right bank hill torrents also contribute to the flow after Panjnad.

Table 3.12. Indus Flows Downstream of Taunsa and Guddu Barrages

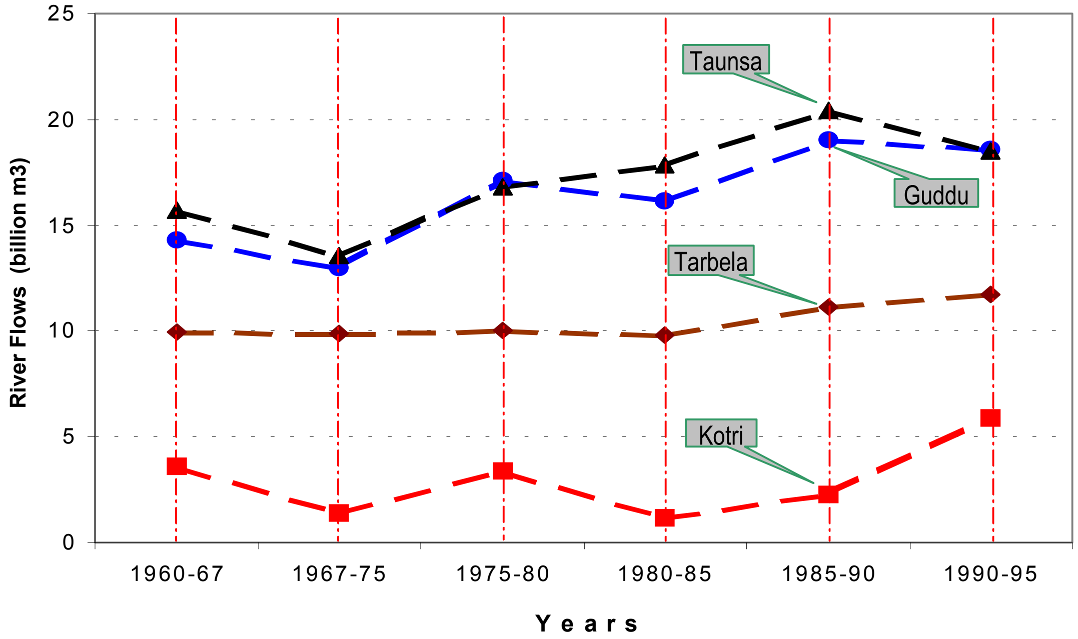
Key Influences	Period	River Flows (bln. m^3)					
		Indus Downstream Taunsa			Indus Downstream Guddu		
		Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual
Pre-Mangla	1960-67	77.90	14.33	92.23	97.46	15.71	113.17
Post-Mangla	1967-75	77.23	12.95	90.18	87.88	13.60	101.48
Pre-Tarbela	**1960-75**	**77.54**	**13.59**	**91.13**	**92.35**	**14.58**	**106.93**
Post-Tarbela	1975-80	72.26	17.12	89.38	101.79	16.85	118.64
Post-Tarbela	1980-85	68.89	16.15	85.04	80.14	17.83	97.97
Post-Tarbela	1985-90	66.97	19.00	85.97	76.47	20.43	96.90
Post-Tarbela	1990-95	84.10	18.57	102.67	104.19	18.48	122.67
Post-Tarbela	**1975-95**	**73.06**	**17.71**	**90.77**	**90.65**	**18.40**	**109.05**

Source: Water Resource Management Directorate, WAPDA.

Tarbela dam substantially increased the Indus River flows during the *rabi* season downstream of Taunsa (30%) and Guddu (26%). Some reduction in river flows was observed during the *kharif* season downstream of Taunsa (5.8%) due to the filling of Tarbela reservoir. This effect was more pronounced in the dry years. There was a major increase in the flows downstream of of Guddu in the *rabi* season (26%) and a minor decrease (1.8%) in the river flows during the *kharif* season (see Table 3.12).

The flows downstream of Tarbela, Taunsa, Guddu and Kotri are presented in Figure 3.2. The variation in flows is mainly due to the stochastic nature of river flows effect of reservoirs in altering river flows and canal diversions in the *rabi* season.

Figure 3.2. Indus Flows Downstream Tarbela, Taunsa, Guddu and Kotri during *rabi*



3.4.2.8 Flows Distribution in the Indus River - Downstream Kotri Barrage

i) Historical Distribution of Flows

Historical river flows downstream of Kotri barrage were influenced both by seasons and extreme variability of the river flows (Ahmad 1993a). The average annual flows were around 99 and 64 bcm during pre-Kotri and post-Kotri periods respectively. This reduction in average annual flows was due to the construction of the Kotri barrage and the temporal variability.

The average annual flows during the post-Mangla period of 1967-75 were reduced to around 52 bcm. This reduction of 12 bcm was mainly due to the increased canal diversions (at Kotri and the upstream barrages including Guddu and Taunsa) and temporal variability (refer to Tables 4.14 and 4.15). The flows were marginally reduced to 51 bcm during the post-Tarbela period (Table 3.13).

Table 3.13. Historical Surface Flows Downstream of Kotri Barrage under Key influences

Key-Influences	Period	Flow Downstream of Kotri Barrage (bln. m^3)			Peak Discharge (m^3/Sec)
		Kharif	***Rabi***	**Annual**	
Pre-Kotri	**1955-61**	**84.4**	**14.85**	**99.25**	**27,787**
Post-Kotri	**1962-67**	**60.2**	**3.6**	**63.8**	**16,639**
Post-Mangla	**1967-75**	**50.6**	**1.4**	**52.0**	**22,269**
Post-Tarbela	1975-80	58.1	3.4	61.5	21,690
Post-Tarbela	1980-85	33.1	1.2	34.3	13,441
Post-Tarbela	1985-90	28.7	2.3	31.0	18,406
Post-Tarbela	1990-95	67.7	5.9	73.6	23,174
Post-Tarbela	1995-98	50.5	2.6	53.1	10,895
Post-Tarbela	**1975-98**	**47.6**	**3.1**	**50.7**	**23,174**

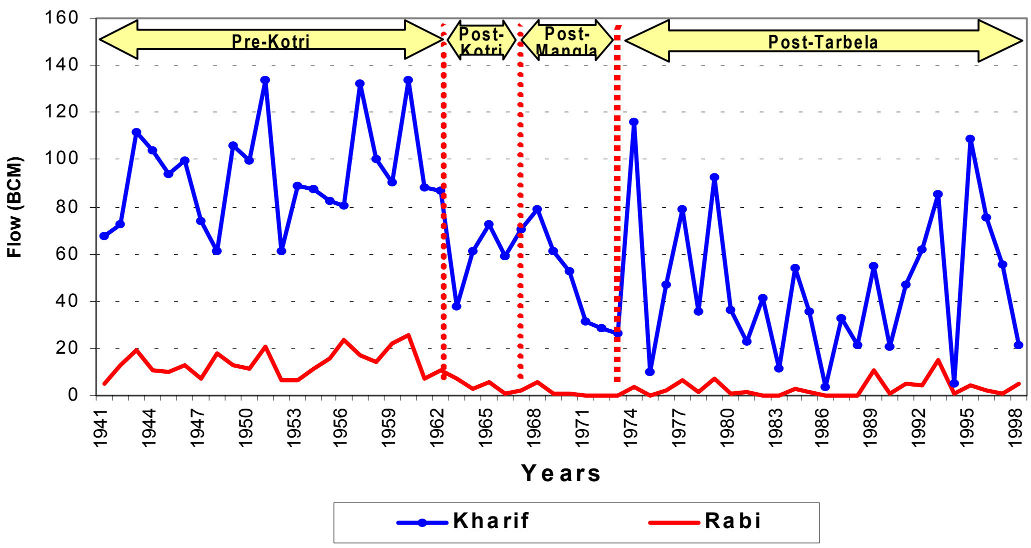
Data Source: Water Resource Management Directorate, WAPDA.

The *rabi* season flows were reduced from 14.9 bcm during the pre-Kotri period (1955-61) to 3.6 bcm during the post-Kotri period (1962-67). This was further reduced to 3.1 bcm during the post-Tarbela period (1975-98).

Flows below Kotri were very low during the period of 1980-85 and 1985-90, because these years were relatively dry compared to the average annual and *kharif* season flows of the western and eastern rivers during the post-Tarbela period (see Tables 4.9 and 4.12). The annual flow below Kotri was 31 bcm during the period of 1985-90. The minimum annual flows below Kotri were 10.0 and 11.95 bcm during 1974-75 and 1982-83, respectively.

The periodic average does not provide a clear analysis of the extreme situation. Therefore seasonal surface flows downstream of Kotri barrage are presented in Figure 3.3. In the pre-Kotri period (1940-61), the *rabi* flows averaged 13.5 bcm and always exceeded 1.0 bcm. In the post-Kotri (1962-75) and post-Tarbela periods (1975-98), the *rabi* flows downstream of Kotri were less than 1.0 bcm.for 7 out of 10 (54%) and for 10 out of 23 (43%) years respectively.

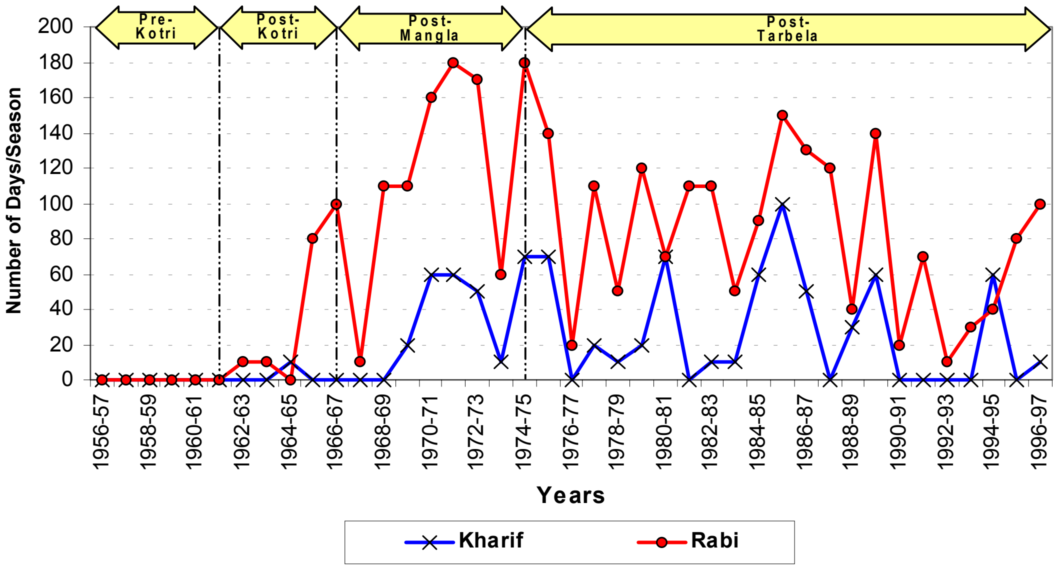
Figure 3.3. Seasonal Flows Downstream Kotri Barrage for Pre-Kotri, Post-Kotri, Post Mangla and Post-Tarbela Periods



ii) Distribution of Days with Zero Flows per Season

A clearer picture emerges when looking at the extreme events when there was no flow below Kotri. Analysis was made of the number of days per season when flows downstream of Kotri barrage were zero (Figure 3.4). In the pre-Kotri period (1956-61), there was not a single day with a zero flow during both the *rabi* and *kharif* seasons. Zero flow days were observed during the post-Kotri period (1962-67). One year (20%) in the *kharif* season and four years (80%) in the *rabi* season were identified as having zero flows. Occurrence of zero flow days increased to six years (75%) in the *kharif* season and eight years (100%) in the *rabi* season in the post-Kotri and post-Mangla period (1967-75). Zero flow days were marginally reduced to 14 years (61%) in the *kharif* season and 22 years (96%) in the *rabi* season in the post-Tarbela period (1975-98). In the *rabi* season it was effectively the same at 96% compared to 100%.

Figure 3.4. Number of Days per Season with Zero Flows Downstream Kotri Barrage



Thus occurrence of zero flow days progressively increased following the commissioning of the Kotri and Guddu barrages and the Mangla dam in the *rabi* season (Figure5). In fact, the frequency of zero flow days in the *rabi* season has a direct impact on the downstream system. In the post-Kotri period (1961-67), the maximum number of days with zero flows in the *rabi* season was 10. This increased to 180 days in the post-Kotri and post-Mangla period (1967-75). The highest number of zero flow days recorded post Tarbela was a slight reduction to 150 days, although even this represents 82% of the *rabi* season. In the pre-Kotri period there were no days with zero flows. In the post Kotri/Mangla periods there were on average 33 days with zero flows in the *rabi* season; and in the post-Tarbela period there were 81 days. The implications of the significant change in hydrological regime are further discussed in the sections on environmental and social issues.

iii) Variability in Flow Distribution

The annual variability of flows distribution downstream of Kotri barrage has been very high and is presented in Table 3.14. In the average year (50% probability), the annual flow was reduced from 104.1 to 59.7 bcm (43%) during pre- and post-Kotri periods. The corresponding reduction in annual flows in extremely dry years (10% probability) was higher than the average years, where flows were reduced from 72.8 to 26.2 bcm (64%) during pre- and post-Kotri periods. As shown in Table 17, the corresponding percent reduction in annual flows in wet years was relatively less than that in the average and dry years (32% reduction at 75% probability and 35% reduction at 90% probability).

The annual variability of flows distribution downstream of Kotri barrage for the post-Kotri and post-Tarbela periods is presented in Table 3.15. In the average years (50% probability), the annual flow was reduced from 59.7 to 48.4 bcm (19%) during the post-Tarbela period, compared to the post-Kotri and pre-Tarbela period. The corresponding reduction in annual flows in extremely dry years (10% probability) was higher than that in the average years, when flows were reduced from 26.2 to 13.5 bcm (48%) during the post-Tarbela period compared to the post-Kotri and pre-Tarbela periods. As shown in Table 3.15, the corresponding percent reduction in annual flows in wet years was relatively less than in the average and dry years (18% reduction at 75% probability). A minor increase of 3% was observed in very wet years (90% probability).

Table 3.14. Annual Variability of Flows Distribution Downstream Kotri Barrage under Pre- and Post-Kotri Scenarios

Probability	Flow Downstream Kotri Barrage (bln. m^3)						Percent Change (+/-)
	Pre-Kotri Period (1940-61)			Post-Kotri Period (1961-75)			
	Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual	
Minimum	**61.25**	**5.0**	**67.66**	**10.04**	**0.0**	**10.04**	-85
10%	61.35	6.18	72.76	25.96	0.0	26.19	-64
25%	74.25	7.15	84.87	31.34	.31	31.65	-63
50%	90.21	12.97	104.06	59.24	0.98	59.71	-43
75%	103.70	17.89	114.64	72.33	5.97	78.31	-32
90%	132.02	22.31	149.37	86.36	6.85	96.79	-35
Maximum	**133.84**	**25.52**	**158.97**	**115.81**	**10.43**	**119.33**	**-25**

Table 3.15. Annual Variability of Flows Distribution Downstream Kotri Barrage under Pre- and Post-Tarbela Scenarios

Probability	Flow Downstream Kotri Barrage (bln. m^3)						Percent Change (+/-)
	Post-Kotri Period (1961-75)			Post-Tarbela Period (1975-98)			
	Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual	
Minimum	**10.04**	**0.0**	**10.04**	**11.6**	**0.05**	**11.9**	+19
10%	25.96	0.0	26.19	13.5	0.1	13.5	-48
25%	31.34	.31	31.65	23.1	0.5	33.2	+5
50%	59.24	0.98	59.71	41.4	1.7	48.4	-19
75%	72.33	5.97	78.31	55.2	4.5	65.3	-18
90%	86.36	6.85	96.79	85.4	6.9	99.5	+3
Maximum	**115.81**	**10.43**	**119.33**	**108.9**	**15.2**	**113.4**	**-5**

In the pre- and post-Kotri periods, the *rabi* season flows in the average years (50% probability) were reduced from 13 to 1.0 bcm (92%), respectively (see Table 3.14). The effect was more pronounced in the dry years (< 25% probability), where seasonal flows were even less than 0.5 bcm in one out of two years. A reduction in seasonal flows of 25 to 43% was also observed during the wet years (>50% probability) primarily due to increased upstream withdrawals including Kotri barrage.

In the pre-Tarbela (post-Kotri) and post-Tarbela periods, the *rabi* season flows in the average years (50% probability) were increased from 1.0 to 1.7 bcm (70%), respectively. This increase has reduced the probability of flows less than 0.5 bcm from one out of two to one out of three years. Reduction in seasonal flows of 5 to 18% was also observed during the wet years (>50% probability) primarily due to increased upstream withdrawals including Kotri barrage. The canal diversions at Kotri barrage were increased from about 10 to 13 bcm during the post-Tarbela period (refer Table 3.20).

The variability of flow distribution downstream of Kotri for the *kharif* and *rabi* seasons (for pre-Kotri, post-Kotri and post-Tarbela periods) are presented in Figures 4.5 and 4.6, respectively. The figures demonstrate the scale of reduction in *rabi* flows in the post-Kotri period.

Figure 3.5. Variability of Flows Distribution Downstream Kotri Barrage during *Kharif* Season

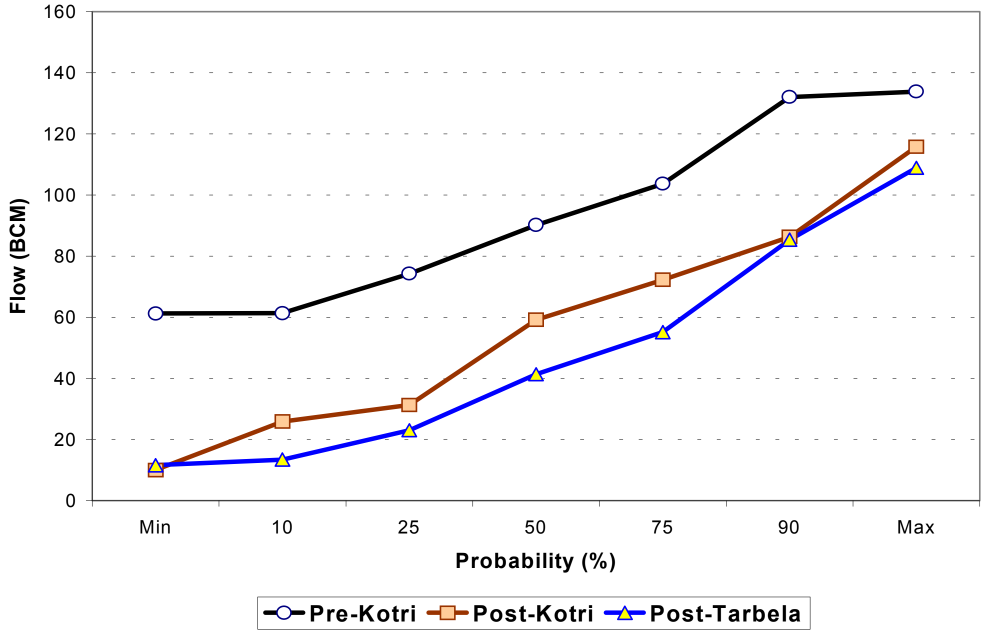
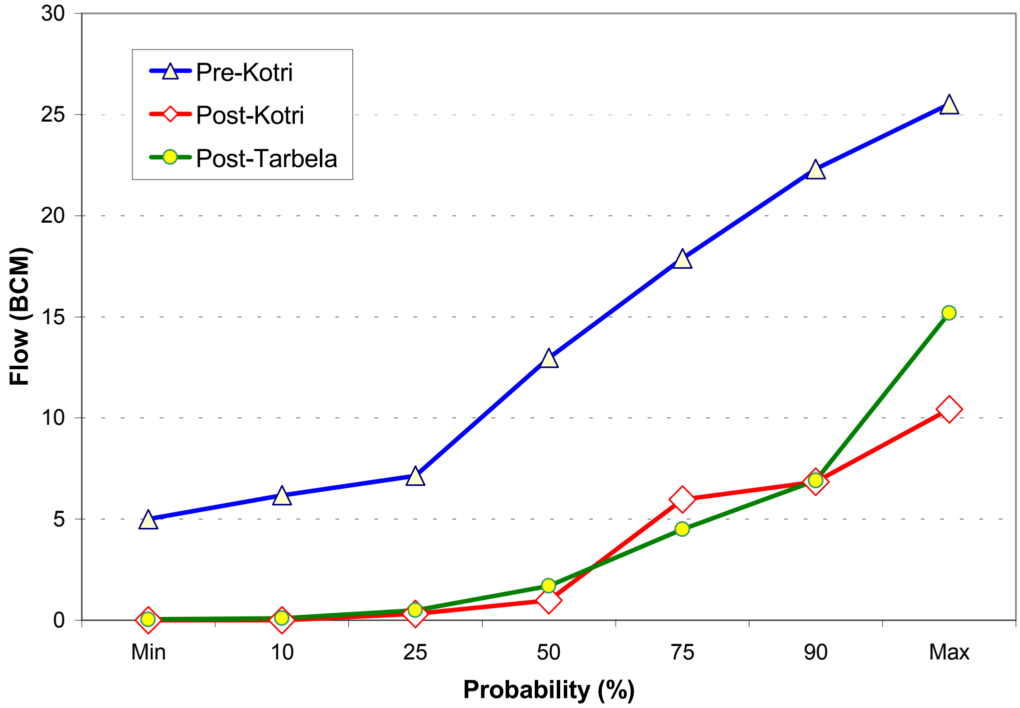


Figure 3.6. Variability of Flow Distribution Downstream of Kotri barrage during *Rabi* Season



3.4.2.9 Peak Flows Distribution in the Indus River - Downstream Kotri Barrage

The development of infrastructure in the basin also affected the peak flows downstream of Kotri barrage. The highest peak flow of 27 787 m^3/sec was observed during the pre-Kotri period of 1955-61, whereas subsequently the highest peak flow recorded was 22 269 m^3/sec during the post-Kotri period of 1975-98 (lower by 20%). The peak flow corresponding to the mean annual event reduced by 42%, which will have a direct impact on the inundation of the riverine areas. The annual variability was extremely high. The minimum and maximum peak flows of 12 513 and 27 787 m^3/sec were observed during the pre-Kotri period, respectively, having a ratio of minimum to maximum peak flows of 1:2.2. The ratio of minimum to maximum peak flows was increased to 1:5.9 during the post-Kotri period, which was more than double of the pre-Kotri period (Table 3.16).

Table 3.16. Variability of Annual Peak Discharge in Indus River Downstream Kotri barrage under pre- and post-Kotri, and post-Tarbela Scenarios

Probability	Flow Downstream of Kotri Barrage (m^3/Sec)			Percent Change*
	Pre-Kotri Period (1955-61)	Post-Kotri Period (1961-75)	Post-Tarbela Period (1975-98)	
Minimum	**12,513**	**3,782**	**3,475**	**-8**
10%	12,513	5,278	6,225	+18
25%	13,692	7,552	7,677	+2
50%	18,654	10,806	10,995	+2
75%	21,077	14,995	18,409	+23
90%	22,422	16,639	21,859	+31
Maximum	**27,787**	**22,269**	**23,174**	**+4**

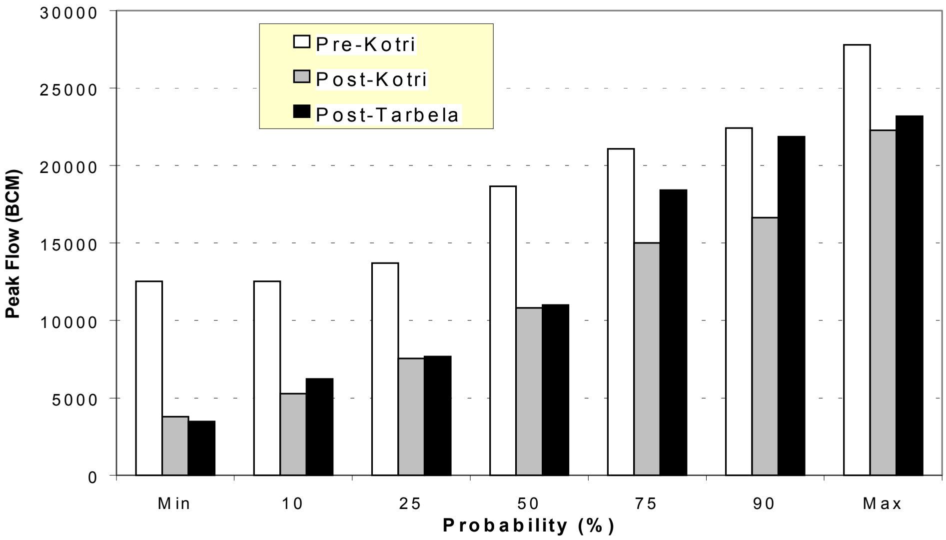
* *Percent change represents change in post-Tarbela period compared to the post-Kotri period.*

The highest peak flow of 23 174 m^3/sec was observed during the post-Tarbela period of 1975-98, which is slightly higher than the pre-Tarbela/post-Kotri period (higher by 4%). The peak flow corresponding to the mean annual event was increased by 2%. The annual variability was extremely high. The minimum and maximum peak flows of 3 475 and 23 174 m^3/sec were observed during the post-Tarbela period, respectively. The ratio of minimum to maximum peak flows was increased to 1:6.7 during the post-Tarbela period, which was almost 12% higher than the pre-Tarbela/post-Kotri period (Table 3.16). The variability of annual peak discharge in the Indus River downstream of Kotri is presented in Figure 3.7.

The peak flow analysis did not illustrate the effect of the dam on flood peaks. There was a slight reduction (8%) in the low peak flows, whereas there was a minor increase in the maximum peak flow (4%). The variation in peak flows might be due to variability related to the stochastic nature of river flows instead of the influence of the dams. This is because only the minimum flow was reduced slightly, otherwise there was a minor increase in peak flows in the post-Tarbela period.

Total soluble salts of the Indus River system at northern sites ranges from 200 to 250 ppm. Likewise, total soluble salts increased as the water approaches the delta, with a degree of seasonal variation. The pre-Kotri total soluble salts at the upstream of Kotri barrage were 230 to 260 ppm (Ahmad 1993a). The post-Kotri and post-Tarbela data are not available. However, there are chances of an increase in the salinity levels upstream of Kotri as the disposal of effluent into the river has increased tremendously during the last 40 years.

Figure 3.7. Variability of Annual Peak Discharge Downstream Kotri Barrage



3.4.3 Indus Basin Canal Diversions

3.4.3.1 Indus Basin Canal Diversions under Key Influences

As noted earlier, the main objective of Tarbela was to provide storage for replacing the water for the existing canal commands of about 1.8 mha dependent on the three eastern rivers and the improvement of supplies to the canals off-taking from the Indus main commanding 6.9 mha.

The canal diversions in the IBIS represent a total amount of water diverted at all the barrages constructed on rivers of the IBIS. The increase in water diverted to individual canals at their off-take from the barrages is one of the direct indicators of the contribution and effect of the storage reservoirs (Mangla and Tarbela) and other projects in the IBP. A considerable increase in canal diversions of about 9 bcm was observed during the post-Mangla period. A further substantial increase of around 12 bcm was observed during the post-Tarbela period. Out of this, the major increase was in the *rabi* season (9.6 bcm per annum) as shown in Table 3.17. The increase in the *kharif* season represents increased diversions in the early period when river flows are relatively lower (April and May). Furthermore, the increase in canal diversions during the post-Tarbela period was in line with the releases from Tarbela (refer Table 3.11).

Table 3.17. Historical Canal Diversions to the IBIS under Key Influences

Key Influences	Period	Canal Diversions (bln. m^3)		
		Kharif	***Rabi***	**Annual**
Pre-Partition	1940-47	58.5	24.9	83.4
Partition	1947-48	57.0	27.6	84.6
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**

Source: Water Resource Management Directorate, WAPDA.

The figures in Table 3.17 may be compared to the prediction of annual diversions of 125.5 bcm in the Lieftinck Report for 1985. The actual diversions during 1980-85 were 130 bcm, which were 3.6%

higher than predicted. The predicted contribution of Tarbela was achieved. In the Lieftinck Report predictions for the year 2000 were based on the premise that other dams on the Indus would be constructed and would provide a total diversion of 149.5 bcm. These additional storages have not been implemented. The actual diversions in 1998-99 were 132.57 bcm which is 6% more than the prediction with Tarbela alone, but only 89% of the prediction for the year 2000 that assumed additional storage (refer to Table 3.19).

The contribution of Tarbela to total canal diversions during the *rabi* season was almost 26% (9.6 bcm) which is significant, as most of the staple food grown in the country is produced during this season. However, in addition to this diversion, the securing of existing diversions that would otherwise have been lost due to the diversion of the eastern rivers by India, indicate that this 26% is a conservative estimate of Tarbela's contribution.

Tthere was, however, variability in the canal diversions in both the seasons. The percent variability between the highest and lowest post-Tarbela canal diversions was 25 and 17% during the *kharif* and the *rabi* seasons, respectively. Tarbela dam is designed to provide more secured *rabi* diversions by transferring the *kharif* season water to the *rabi* season in a given year. Therefore, the variability for the *rabi* season was lower than for the *kharif* season. However, given the relatively small size of the reservoir compared to the annual discharge of the river, it is not possible to carry over the water of a wet year to a dry year. This shows that the stochastic nature of the river flows also has an effect on the canal diversions, in addition to the reduced storage capacity of Tarbela (Table 3.18).

Table 3.18. Variability of Post-Tarbela Canal Diversions in the IBIS

Probability (%)	Canal Diversions (bln. m^3)		
	Kharif	***Rabi***	**Annual**
Minimum	**70.7**	**43.0**	**116.5**
10	72.2	43.7	118.9
25	76.0	44.4	122.1
50	81.0	46.9	126.4
75	84.2	47.6	130.6
90	87.7	48.6	134.6
Maximum	**88.0**	**50.3**	**135.4**

Source: Water Resource Management Directorate, WAPDA.

3.4.3.2 Predicted and Actual Canal Diversions

Province-wise analysis of predicted and actual canal diversions for the post-Tarbela period was made considering the predicted and planned uses and actual post-Tarbela averages. The actual canal diversions during the period of 1978-82 were 2.23 bcm higher than predicted in the Lieftinck Report for the year 1985. Afterwards, the canal diversions were almost stagnant because of limited further developments in the water sector, especially the new storage (Table 3.19).

The predicted canal diversions for the year 2000 as per Lieftinck report were subject to additional storages and other developments in the water sector. The development of new storage could not take place as planned and therefore comparison with the year 2000 prediction is not valid. (For actual post-Tarbela canal diversions for the period 1982-95 and their variability, refer to Tables 3.17 and Table 3.18, respectively).

Table 3.19. Province-wise Predicted and Actual Canal Diversions in IBIS

Province	Predicted Canal Diversions (bln. m^3)		Actual Post-Tarbela Canal Diversions (bln. m^3)	
	1985	2000	1978-82	1998-99
NWFP	2.59*	2.59*	3.83*	4.05
Punjab	66.54	79.37	67.28	66.59
Sindh	56.41**	67.50**	53.70	58.02
Baluchistan			2.96	3.91
Total	**125.54**	**149.46**	**127.77**	**132.57**

Sources: Lieftinck Report, 1968; Water Resource Management Directorate, WAPDA.
* *Exclude the civil canals.*
** Both for Sindh and Baluchistan.

3.4.3.3 Canal Diversions at Selected Locations

i) Canal Diversions at Taunsa Barrage

The pre- and post-Tarbela canal diversions were compared at the Taunsa barrage on the Indus main for the period 1960-98. The increase in average canal diversions during the *rabi* season was 1.10 bcm (representing 98%) from that of the pre-Tarbela and post-Mangla period (1967-75). The increase in *kharif* season canal diversions during the post-Tarbela period (0.45 bcm or 9.6%) from that of the pre-Tarbela period and post-Mangla period (1967-75) was observed. (Table 3.20).

Table 3.20. Canal Diversions to Indus Main Commands at Taunsa, Guddu and Kotri Barrages

Key Influences	Period	Canal head withdrawals (bcm)								
		Taunsa			Guddu			Kotri		
		Kharif	*Rabi*	Annual	*Kharif*	*Rabi*	Annual	*Kharif*	*Rabi*	Annual
Pre-Mangla	1960-67	5.20	0.98	6.18	6.96	0.54	7.50	7.18	1.45	8.63
Post-Mangla	**1967-75**	**4.68**	**1.12**	**5.78**	**8.70**	**0.99**	**9.70**	**7.82**	**2.15**	**9.97**
Post-Tarbela	1975-80	4.58	2.25	6.83	8.29	2.46	10.74	7.97	3.24	11.21
Post-Tarbela	1980-85	5.07	1.98	7.05	8.91	2.54	11.45	9.30	3.54	12.85
Post-Tarbela	1985.90	5.17	2.20	7.37	9.11	2.56	11.68	9.33	3.63	12.96
Post-Tarbela	1990-95	5.41	2.42	7.83	9.18	2.90	12.09	8.90	4.76	13.65
Post-Tarbela	1995-98	5.59	2.24	7.83	9.43	2.85	12.28	10.50	4.37	14.87
Post-Tarbela	**1975-98**	**5.13**	**2.22**	**7.35**	**8.94**	**2.65**	**11.59**	**9.09**	**3.87**	**12.96**

Source: Water Resource Management Directorate, WAPDA

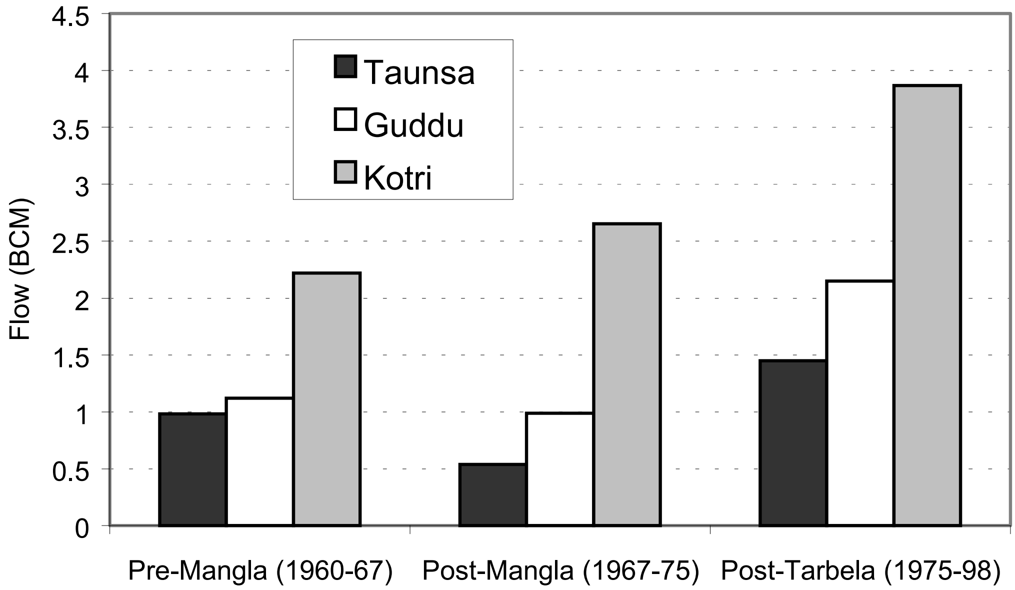
ii) Canal Diversions at Guddu Barrage

The pre- and post-Tarbela canal diversions were compared at Guddu barrage on the Indus main. The increase in average canal diversions during the *rabi* season was 1.66 bcm (representing 168%) from that of the pre-Tarbela period and post-Mangla (1967-75). The minor increase in canal diversions during *kharif* (0.24 bcm or 2.7%) from that of the pre-Tarbela and post-Mangla period was primarily due to the variability in river flows (Table 3.20).

iii) Canal Diversions at Kotri Barrage

The pre- and post-Tarbela canal diversions were compared at the Kotri barrage on the Indus main. The increase in average canal diversions during the *rabi* season was 1.72 bcm (representing 80%) from that of the pre-Tarbela and post-Mangla period (1967-75). The increase in canal diversions during the *kharif* season was 1.27 bcm (representing 16%) from that of the pre-Tarbela period, which was primarily due to the enhanced canal deliveries. Among the three selected barrages, the largest average annual increase of 2.99 bcm in canal diversions was observed at the Kotri barrage compared to the pre-Tarbela and post-Mangla period (Table 3.20). The canal diversions for the selected three barrages in the *rabi* season are presented in Figure 3.8. The canal diversions upstream of Kotri at Taunsa, Guddu and Sukkur were also increased during the post-Tarbela period.

Figure 3.8. Rabi Season Canal Diversions to Indus Main Commands at Taunsa, Guddu and Kotri Barrages



3.4.3.4 Irrigation System's Losses

i) River System Gains and Losses

The Indus River flows through alluvial plains and therefore the phenomenon of losses and gains assumes significance (Ahmad 1993b). In the Indus River system, losses generally occur in the rising stage during April to July. During the falling flows, covering the periods from end of July to September and from October to March, the river usually gains water from base flow. Analysis of annual historic gains and losses was conducted using the data between the period 1940-41 to 1997-98 for the *kharif* and *rabi* seasons (Table 3.21).

Table 3.21. River Gains and Losses in the Indus River System

Period	River Gains and Losses (bln. m^3)		
	Kharif	*Rabi*	Total
Pre-Mangla 1940-67	-20. 23	5.71	-14.52
Pre-Tarbela 1967-76	-10.80	3.64	-7.16
Post-Tarbela 1976-98	-14.36	1.02	-13.34
Average 1940-98	-16.54	3.61	-12.93

Source: Water Resource Management Directorate, WAPDA

ii) Canal Command Losses

Earlier studies revealed that conveyance losses in canals varied between 15-30% (Ahmad 1993b; Harza 1963; IACA 1966; LIP 1966). The Water Sector Investment Planning Study (WSIPS) of 1990 provided a synthesis of the work done by WAPDA (1979) on annual canal conveyance losses for 24, 5 and 14 canal commands in the Punjab, NWFP and Sindh provinces, respectively. The average annual canal losses computed were 23, 12 and 20% for the canal commands of the Punjab, NWFP and Sindh provinces, respectively. These losses were around 21% for the whole basin. The losses to the canal system become gains to groundwater as described in section 3.4.4.1.

Systematic work on watercourse loss measurement was initiated jointly by the Colorado State University and WAPDA. Based on the two systematic studies of 40 and 61 watercourses, the actual watercourse losses were 47 and 45%, respectively. The field application losses were around 25% (Ashraf *et al.,* 1977; WAPDA 1979; Trout and Kemper 1980; PARC-FAO 1982). Thus the overall irrigation efficiency is projected to be around 36% (Ahmad 1990).

Average losses of 21, 40 and 25% were used to compute losses from canals, watercourses, and fields, respectively, in this study. The conveyance losses corresponding to Tarbela storage releases were around 5.5 billion m^3 per year during the 90s, which represented around 64% of the water contributed by the project (Table 3.23). In fresh groundwater areas, this induced recharge resulted in accelerated installation of tubewells to exploit the resource for which further details are provided in section 3.4.6. In saline areas, this water could not be recovered.

Table 3.22. Canal Command System Losses Corresponding to Additional Supplies Contributed by Tarbela Storage

Description of Losses	Annual System Conveyance Losses (bln. m^3)			
	1975-80	1980-85	1985-90	1990-96
Canal Conveyance losses	2.1	2.6	2.4	1.8
Watercourse Conveyance Losses	3.2	3.8	3.6	2.7
Field Application Losses	1.2	1.4	1.3	1.0
Total	**6.5**	**7.8**	**7.3**	**5.5**

In the local area of the Tarbela reservoir, the seepage losses from the reservoir also contributed towards recharge with a consequent increase of bank storage and development of recession agriculture during the draw-down season. In the adjacent area of reservoir periphery and downstream, farmers started using wells to irrigate citrus orchards (WAPDA and TNO 1985; Sajjad, *et al.,* 1996). Initially, there were significant seepage losses under and around the dam due to its peculiar geology. However, this seepage has drastically reduced after sedimentation in the lake.

Annual evaporation loss from the lake surface, fluctuating within a level of about 70m, is estimated at around 0.20 billion m^3. This is only about 0.30% of the average volume of reservoir inflow.

3.4.4 Groundwater

3.4.4.1 Recharge and Water Table

About 64% recharge to the groundwater in the Indus Basin occurs in areas of usable groundwater (Zuberi and Sufi 1992). The additional conveyance losses in the IBIS due to Tarbela contributed 10% to the overall recharge of groundwater (Ahmad 1993b). The 1979 basin-wide survey of WAPDA indicated that the water table in 42% of the Indus basin was less than 3m and classified as waterlogged, whereas the water table in 22% of the area was less than 2m. In the Sindh province, around 57% of the area was affected by waterlogging, where the water table was less than 3m (Table 3.23). The anti-waterlogging activity in the IBIS was started in late 1950s and early 1960s, after which large scale Salinity Control and Reclamation Projects (SCARPs) were initiated to combat the menace.

Table 3.23. Province-wise Water Table Depths and Areas Affected in the Indus Plain 1979

Province	Total Area (mha)	Percent Area in mha under Water Table Depth of (m)					Total <3 m
		<1	1-2	2-3	>3	Misc.	
Punjab	10.17	7	11	17	63	2	35
Sindh	5.57	6	24	27	40	3	57
Baluchistan	0.35	1	6	9	84	0	16
NWFP	0.62	6	12	6	66	10	24
Total	**16.71**	**7**	**15**	**20**	**55**	**3**	**42**

These surveys were actually conducted during 1976-78 and therefore represent to some extent pre-Tarbela conditions. Although, groundwater use has increased significantly in the last two decades, waterlogging still affects large tracts of land. About 22% of the command area of the Indus basin presently has a water-table within 1.5 m. This rise in the water table demonstrates the worsening situation, but is in part due to additional diversions resulting from Tarbela. This continued increase in waterlogging, has been exacerbated by a lack of appropriate drainage facilities and inadequate improvements in irrigation management. The failure of the SCARPs has also contributed to the rise in the water table.

Additional water supplies from Tarbela diverted to the newly constructed canal commands also contributed to recharge of groundwater. One example is the Chashma Right Bank Canal (CRBC) command area, where the observed rise in the water table was far faster than expected, creating a freshwater aquifer (Alurrade *et al.,* 1998). To remedy the problem of waterlogging, surface and surface drainage facilities were provided to control the water table depth. This required additional financial resources from an external loan.

The positive groundwater contribution is in the areas adjacent to Tarbela reservoir located in Gadoon-Amazai and Haripur district. Here, the recharge has facilitated the utilisation of the groundwater for industrial development as well as high value agriculture. However, this is only a small area compared to the area suffering from waterlogging and salinity problems in the basin.

3.4.4.2 Water Quality

Although investments in drainage have been significant in Pakistan during the last two decades, waterlogging still affects large tracts of land (WB 1994). Salinity and sodicity also constrain farmers and affect agricultural production. These problems are further exacerbated by the use of poor quality groundwater (Kijne and Kuper 1995). In fresh groundwater areas, excessive pumping by private tubewells leads to mining of the aquifer (NESPAK 1991) and redistribution of the groundwater quality (Zuberi and Sufi 1992; WRRI, MREP and IIMI 1999).

The recharge to the freshwater zone by the additional supplies from Tarbela, contributed significantly in maintaining groundwater quality by strengthening the top layer of fresh water over the deep groundwater of relatively marginal quality. However, recharge to the brackish groundwater zone created serious concerns for the disposal of the saline effluents despite creating a top thin layer of potable water for the concerned population (Ahmad 1993a).

About 60% area of the aquifer in the Indus basin provides water of marginal to brackish quality. Use of this water has resulted in secondary salinisation in around 4 mha.

3.4.4.3 Groundwater Contribution to Irrigation

In the last 21 years (1976-97), the groundwater contribution to irrigated agriculture has doubled from 31.6 to 62.2 bcm (GOP 1998a). It is not possible to quantify the exact contribution of Tarbela towards groundwater exploitation. However, the canal command losses due to the additional supplies from Tarbela give an indication of the contribution of Tarbela at about 5 to 7 bcm. The increase in the groundwater contribution in the post-Tarbela period was 14.5% higher than the predicted contribution of groundwater for the year 2000, as per the Lieftinck Report. The country has made considerable progress in the development of an innovative and indigenous tubewells technology. However, with the rise of the electricity tariff and diesel fuel prices and the problem of soil salinity in marginal quality zones, there was a recent decline in the groundwater pumpage. It is now around 50 bcm, which is a significant decrease (Table 3.24). However, the groundwater still contributes 38% of surface water available at the canal head.

Table 3.24. Pre- and Post-Tarbela Groundwater Contribution to Irrigation Water Supplies

Key Influences	Period	Groundwater Contribution (bln. m^3)	Increase in Groundwater Contribution * (%)	Contribution as Percent of the Canal Diversions
Pre-Mangla	1965-66	11.3	-	10.0
Post Mangla	1967-68	14.5	28.3	12.4
Post Mangla	1970-71	21.6	91.2	19.7
Post-Tarbela	1975-76	31.6	179.6	25.2
Post-Tarbela	1980-81	40.2	255.8	29.6
Post-Tarbela	1985-86	48.3	327.4	39.6
Post Tarbela	1990-91	54.3	380.5	39.2
Post Tarbela	1995-96	61.0	439.8	46.9**
Post Tarbela	1996-97	62.2	450.4	47.8**
Post Tarbela	1997-98	49.6	338.9	38.2**

Source: Agricultural Statistics of Pakistan, Ministry of Food, Agriculture and Livestock, 1998.
* *Base year of 1965-66 is used for computations.*
** *Average value of canal diversion of 130 bln.* m^3 *is used for computations.*

3.4.4.4 Tubewells Development

Enhanced power generation including that from Tarbela, and the government policy of price incentives for electric power, motivated farmers to install electric tubewells. Consequently, there was a more than three-fold increase in the number of tubewells in 1990-91 as compared to the pre-Tarbela situation. The innovative and low cost development of tubewell technology further motivated the farmers to install diesel operated tubewells. Tubewells also provide water on a demand basis compared to the rigidity of the continuous-flow and fixed-rotation system of canal irrigation. Furthermore, deterioration in the canal irrigation supplies (inequity and unreliability) forced farmers to install tubewells.

The progressive increase in electricity tariffs starting in early 1990s resulted in stagnation of the growth of the electric tubewells. However, a two-fold increase in diesel tubewells was observed during 1990-95. This is a clear indication of the effect of Tarbela and of the government's power policy during late 1970s and 1980s on the growth of tubewells and the development of innovative tubewell technology in the country (Table 3.25).

Table 3.25. Tubewells (Electric and Diesel) Development in Pakistan

Key Influences	Period	Number of Tubewells			Percent Increase		
		Electric	Diesel	Total	Electric	Diesel	Total
Post-Mangla	1970-71	36921	60301	97222	-	-	-
Post-Tarbela	1975-76	60386	100569	160955	63.6	66.8	65.6
Post-Tarbela	1980-81	83855	115818	199673	127.1	92.1	105.4
Post-Tarbela	1985-86	99224	158058	257309	168.7	162.1	164.7
Post-Tarbela	1990-91	113635	226205	339840	207.8	275.1	249.6
Post Tarbela	1995-96	113823	369962	483785	208.3	513.5	397.6

Source: Agricultural Statistics of Pakistan, Ministry of Food, Agriculture and Livestock, 1998.

3.4.5 Sedimentation

3.4.5.1 Sources of Sedimentation and Design Options

The Indus River has its source near Lake Mansrowar in the Himalayan catchment area and emerges from the land of glaciers on the northern slopes of the Kailash ranges, some 5 182m above sea level. It largely brings in snowmelt supplies in addition to some monsoon rains. Four main upstream tributaries join the Indus: Shyok River at an elevation of 2 438m near Skardu, the Gilgit and Hunza rivers near Bunji; and Siran River just north of Tarbela. All these tributaries, except Siran, are located in a semi-arid to hyper-arid environment, and hardly any vegetation exists in the watershed area. Geologic erosion is a common phenomenon.

At Tarbela, the Indus River drains a catchment area of 167 700 km^2 mostly comprising a highly denuded barren and glaciated landscape. The Indus is, in fact, one of the largest sediment-producing rivers of the world. Just upstream of Tarbela, the Indus is fed by the left bank tributary of Siran, draining a monsoon-influenced area of about 10 200 km^2, which is only 6% of the total catchment area. Thus 94% of the catchment area is located in a semi-arid to hyper-arid environment.

The main source of inflow of sediment is glacial and snowmelt. The glacial flow and snowmelt is also an indicator that plantations beyond the snowline are not possible. Tt is not possible, therefore, to control the geologic erosion. Furthermore, glacial and snowmelt is drained to the river through steep slopes in formations which are geologically young. These areas are completely barren, with some natural vegetation only seen along these waterways below the snowline. Thus, plantations cannot help to reduce the sediment inflow to the river (see section 3.4.5.4 on "Possible remedial or mitigative measures").

Because the sediment inflow to Tarbela reservoir was known to be very high, TAMS, during the design phase, investigated the feasibility of providing sluiceways to pass the heavily charged waters during the high run-off season (principally in June and July when over 50 % of the annual sediment load occurred). It was clear that sluicing would serve to increase the useful life of the reservoir, otherwise estimated at 50 years. Three schemes were studied in detail, one based on the project design and two on modifications. It was, however, concluded that effective sluicing at Tarbela was precluded by the nature of the site. Owing to the broad valley and the great depth of alluvium underlying the dam, enough outlets could not be provided. The five tunnels appeared to be the maximum practicable for installation. Sluicing through these tunnels was not considered possible, particularly during the critical months of June and July when the head increased, because of the hazards created by the high tunnel velocities in the range of 9 to 13 meters per second (m/s). The generally accepted design practice for large steel-lined conduits carrying substantial quantities of sediment was to limit velocities to less than 6 m/s to avoid excessive damage by abrasion. It followed that any plan involving tunnel velocities of more than twice the safe figure would be unacceptable. While this would seem to constitute a sufficient reason in itself for discarding any hope of profitable sediment sluicing at Tarbela, the detrimental effects of reducing water availability for power production confirmed the conclusion. Power generation capabilities would have had to be eliminated for upwards of 60 days each year. For both reasons, therefore, TAMS concluded that sluicing would be impracticable. (This was later concurred with by the Lieftinck Report of 1968.)

3.4.5.2 Predicted and Actual Sedimentation Rates

The sediment load varies with discharge, seasonal differences and conditions of the watershed and river morphology. In the design stage, the average annual sediment transport of the Indus at Darband, the gauging site above Tarbela, was estimated at 440 million tonnes (mt) or 0.294 bcm per annum

Sediment deposited in the Tarbela reservoir was expected to consolidate to a final density of about 1.1 kg/m^3**.** This high value was estimated because of the predominance of fine sand in the suspended sediment. Based on these predicted estimates, Tarbela reservoir was expected to silt up at the rate of approximately 2% per year. Thus the predicted life was 50 years when the reservoir would be depleted to a final volume of 1.2 bcm (Lieftinck Report 1968). The predicted life of 50 years in the Lieftinck Report was also an indication of the additional storage required as replacement for the lost storage of Tarbela. It may be pointed out that a basic consideration in selecting the Tarbela site was its suitability for diverting the water to off-channel storages in the side valleys with a much longer life. This would provide for additional storage and distribution of sediment in the side valleys.

A systematic sediment survey of the reservoir was started in 1979. The results indicated total sedimentation of 0.891 bcm during 1974-79. Thus the average annual loss of around 0.149 bcm was almost half of that predicted. It reduced further and the average annual sedimentation was 0.127 and 0.092 bcm for the periods of 1974-83 and 1984-99, respectively. The overall average annual sedimentation was 0.106 bcm during the period of 1974-99, which was almost 36% of the predicted annual sedimentation of the reservoir (Table 3.26). The lower rate of actual sedimentation during 1979-82 was due to reduced river flows, as these years were drier compared to the average years.

Table 3.26. Actual Sedimentation of Tarbela Reservoir

Observation Period	Elapsed Years	Total Sedimentation of Reservoir		Average Annual Sedimentation of Reservoir	
		Mt	Bln. m^3	Mt	Bln. m^3
1974-79	6	1320	0.891	220	0.149
1974-81	8	1635	1.102	204	0.138
1974-82	9	1726	1.165	192	0.129
1974-83	10	1879	1.268	188	0.127
1979-81	2	315	0.212	158	0.106
1979-82	3	331	0.223	110	0.074
1981-82	1	91	0.062	91	0.062
1982-83	1	153	0.103	153	0.103
1984-99	15	2057	1.385	137	0.092
Average 74-83					**0.127**
Average 84-99					**0.092**
Average 74-99					**0.106**

Source: Tarbela Dam Project Completion Report on Design and Construction. Vol. I, TAMS. 1984, WAPDA, and Tarbela Dam Project, WAPDA.

Measurements of suspended sediment in outflow from the low-level outlets indicate that the actual trap efficiency in the 1980-84 period was about 97% rather than the predicted 89%. The trap efficiency was reduced to around 70% during the period 1984-99, which is in line with design predictions. This reduction was mainly due to the increased sediment now flushing out of the reservoir due to the reduced capacity of the dead storage. As the sediment delta reaches the dam in the next 7 to 10 years, the trap efficiency may drop significantly.

The storage life refers to the period from the completion date of the dam to the date when the live storage will be reduced to 1.2 bcm. This holds true for both the predicted and expected life. Table 3.26 shows that sedimentation of the reservoir is taking place more slowly than originally foreseen. Therefore, the life of the reservoir is expected to be more than 50 years. It is estimated that with careful operation in the future, the expected storage life could be enhanced to around 85 years. Assuming the average annual sedimentation rate of 0.106 bcm, and the satisfactory resolution of delta movement (see the following sub-section), the expected life of the reservoir could increase to around 100 years.

The total sediment volume deposited in the Tarbela lake since the commissioning of the dam was 2.76 bcm (1974-99). This reduced the gross storage capacity of Tarbela dam by about 23.7% and the live storage capacity by about 17.8%.

3.4.5.3 Problems Associated with Sedimentation

Currently the most serious problem associated with the reservoir sedimentation is the under-water sediment delta (Figure 3.9). With the yearly cycle of reservoir operation, the delta formation is continuously reworked and moved downstream closer to the dam. The pivot point of the delta has been advancing at about one kilometre per year on average. It is presently located at about 14km upstream of the dam at an elevation of around 416 m. The yearly hydrographic surveys have revealed that approximately 62m of sediment deposits have accumulated between 16-48km upstream of the dam. The position is further illustrated in Figure 3.9 giving progressive longitudinal profiles of accumulated sediments.

The accumulation of sediments within Tarbela reservoir is causing two major problems. Firstly, there is loss of live storage, which is causing gradual reduction in the regulated yield of the reservoir. This in turn will result in a reduction in water availability for agriculture especially for *rabi* and early *kharif* seasons, and will lead also to a reduction in the firm energy available from the project. Secondly, there is a risk of the lower power intakes and low level tunnel outlets becoming clogged by liquefaction of the delta sediment in the event of a seismic activity with ground acceleration of 0.13 g. The erosive action of sediment-laden water on outlet concrete structures and power turbines would also result in exorbitant maintenance costs.

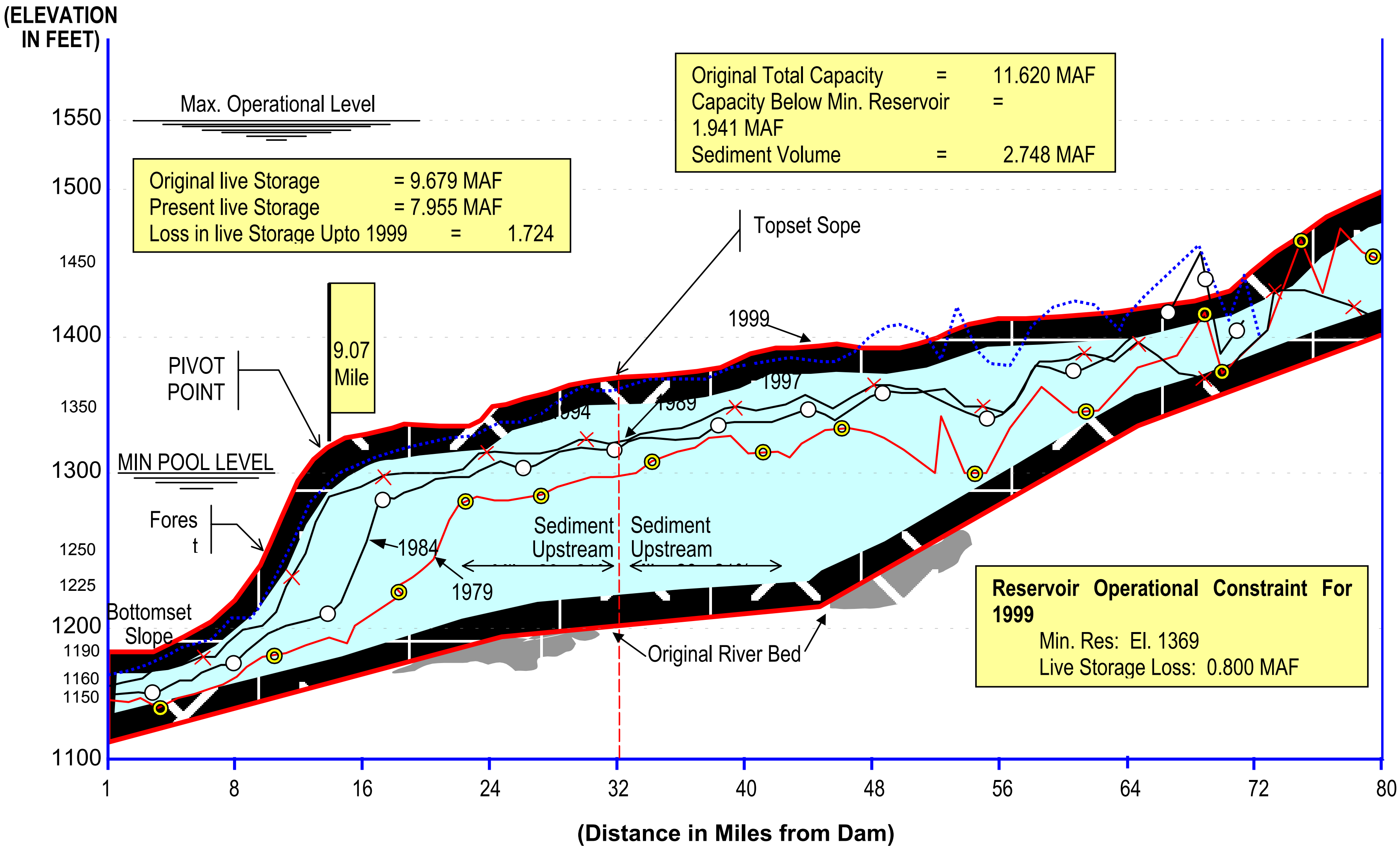
A combination of favourable conditions, particularly lower inflows, has resulted in actual loss of live storage in the Tarbela reservoir of around 18% during the period from 1974 to 1999. The remaining live storage above the design minimum reservoir level is 9.8 bcm. However, due to the serious operational problems created by advancement of the sediment delta towards the dam, the actual available live storage for the year 1998-99 was around 9 bcm. This further reduction (about 7% of original live storage) is due to the revised operational strategy, as the reservoir had a dead storage level of 417m in 1998-99 compared with the design dead storage level of 396 m. This had some impact on reduction in power generation. Power generation is dictated by the releases from the Tarbela reservoir. Details of the effect of reservoir operations on power generation are provided in section 3.6.3.

3.4.5.4 Possible remedial or mitigative measures

Current Sediment Management

Sediment management is targeted for maintaining the reservoir level between 396–417m by the end of the draw-down season in May. The level of 396m represents the design dead storage, whereas the level of 417m is presently being used as part of the reservoir operation strategy to arrest the advance of sediment delta towards the dam. Therefore, since start of the Tarbela operation, the dead storage level has been raised by 21m in 25 years. This is almost similar to the original operation plan of Tarbela for the progressive raising of the dead storage level in managing actual sedimentation.

Figure 3.9. Tarbela Reservoir - Longitudinal Profiles of Accumulated Sediments



At present, WAPDA has adopted a policy of progressively raising minimum reservoir levels on a yearly basis subject to close monitoring of sediment erosion over the delta at the end of drawdown season. This has several advantages and one major disadvantage: that active live storage would be reduced at a faster rate.

In the meanwhile, the existing mathematical and physical model studies for Tarbela sediment management are to be firmed up by WAPDA in order to evolve the most viable and practical solution to the Tarbela sedimentation problem.

Other Remedial Options

To reduce the rate of sedimentation and maximise Tarbela benefits, four potential options are theoretically available:

- manage the distribution of sediments within the reservoir;
- minimise flow of sediments into the reservoir;
- maximise evacuation of sediments from the reservoir; and
- increase the live storage volume of the reservoir.

These options have been analysed by WAPDA in the light of their practicality, safety and sustainability and current position is as per following.

Managing Distribution of Sediments within the Reservoir

The sedimentation pattern within the reservoir can be managed by means of a reservoir operational policy and by protecting low level tunnel intakes from sediment clogging. Raising the minimum reservoir level every year over 1m would result in the deposition of sediments in the upper reaches of reservoir only and thus would delay the advancement of the sediment delta. This would help to reduce the inflow of sediments to the lower reaches of the reservoir and thus protect clogging of the low-level inlets. Though this option entails no capital cost, it would progressively result in increased loss of live storage. This option is presently being implemented by WAPDA and a minimum reservoir level of ±417m is considered safe. By following this strategy, with the prevailing rate of sedimentation, the expected storage life (minimum 1.2 bcm live storage) could be around 85 years.

The protection of tunnel intakes against sediment clogging, by construction of an under-water dyke in front of the intakes to protect against liquefaction, as proposed by TAMS, has been studied (WAPDA 1999). This option not only involves tremendous stability and construction problems, but in the absence of sediment flushing from the reservoir, its benefits seem minimal.

Minimising Sediment Inflow to the Reservoir

Effective sediment erosion control in the Tarbela catchment is not possible, as the source of sediment is predominantly from geologic erosion in the catchment areas that are unsuited to afforestation. Afforestation is not possible as the climate is arid to hyper-arid and soils are very unstable due to young geological formations. Over 90% of the catchment area of the Indus River at Tarbela falls under this category. At the most, there is some possibility of alleviation in the monsoon-affected catchment of the Siran River. Consequently, a pilot project of watershed management was initiated in 1964-65 for a part of the Siran catchment. It was expanded in 1971-72 with the support of the World Food Programme into the Duar watershed of the Siran River. The Forest Department of the NWFP in collaboration with WAPDA implemented this project. Further expansions were made in 1977 to cover four divisions east of the Indus, and again in 1984-85 to include the Kohistan and Buner districts to the west of the Indus. The latter project was concluded in June 1993. The current project is now a second phase of the World Food Programme and is also supported by the German Development Bank, Kreditanstalt fur Wiederaufbau (KFW). This Tarbela watershed management programme has a limited impact on sediment control as the project activities cover only 6% of the area draining water into Tarbela. In fact, actual coverage in the project was even less than the potential area.

Reduction of sediment influx either by watershed management or by construction of check dams in the upper catchment is impractical as about 90% of total runoff is dominated by snow/glacier melt. The proposed upstream Bhasha dam may have only a partial positive impact, as in about 20 years it would be too late for it to play its role. Moreover, in order to be sustainable itself, it would need to be operated to flush sediment to the downstream river channel.

Maximising Evacuation of Sediment from the Reservoir

The evacuation of 200 mt of sediment every year by either flushing or sluicing through low or intermediate level high capacity outlets from the right or left banks has recently been proposed by the consultants (TAMS). This proposal raises a number of complex issues that need careful consideration before taking it to a feasibility stage. WAPDA considers this an unprecedented option and one that does not exist elsewhere in the world. In WAPDA's opinion, this option would soon adversely affect the downstream hydropower projects of Ghazi-Barotha and Chashma. Although, it is not possible to predict the exact expected life with sluicing, it may be doubled (from 85 to 170 years), if sluicing is feasible.

Increasing Live Storage Volume of the Reservoir

No known measures in terms of the dredging of sediments from a reservoir of this size are possible. The dredging of sediments is generally carried out at seashores where mobilisation from open seas is possible. The dredging option in the case of the Tarbela reservoir would be not only prohibitive in cost, but is also without precedence and is completely impractical. Any dredging proposal to be effective must provide for the removal and disposal of 0.55 mt of sediment every day. Realistically, the target is unattainable even if hundreds of dredgers and ancillary equipment is deployed over the reservoir stretch of 260 km^2 to work round the clock. A preliminary estimate of the cost of dredging yearly deposits of about 136 million m^3 of sediment, indicates that about Rs.27 billion would be required annually. This estimate is based on a nominal dredging rate of Rs.200/m^3 of sediments.

The project design at planning stage duly considered and adopted the alternative for development of an optimal storage capacity. Notwithstanding this, if the measure to further increase the live storage capacity of the reservoir were re-considered, it would entail raising of crests of all embankment dams. Considering the existing conditions of the foundation at site and other geo-technical problems of the embankment dams, this option poses serious stability threats to the project. This option, therefore, is also discounted as being non-feasible, impractical and highly hazardous.

Findings on Water Resources and Operational Management

- The bulk of river flows is in summer (*kharif*) and is more than five times the flows in winter (*rabi*). There is great variability in river flows (the highest seasonal flows are almost double the minimum flows). Currently, the flows in the eastern rivers are considerably smaller than those in the western rivers (contributing 7% and 6% of the total mean flows in *rabi* and *kharif* seasons, respectively). The flow of the eastern rivers is considerably more variable than the western rivers.
- There has been little change in the flows of the Indus River over time compared to the stochastic variability, which is a characteristic of river systems in Pakistan. The changes in the average flows of the eastern rivers were significant as these were reduced to 11 bcm compared to 26 bcm in the pre-storage period.
- Actual storage releases from Tarbela were equal to the projected releases (Lieftinck Report) during the first 5 years (1975-80) of operation. Over the following 20 years actual releases were

more than predicted (a 19% increase during 1975-90 and a 22% increase during 1990-98) except for a slight decline during 1990-92.

The construction of Tarbela resulted in an increase in the Indus River flows during the *rabi* season at Taunsa, Guddu and Kotri barrages.

- An assessment of changes in the dry (*rabi*) season flow regime downstream of the southern-most barrage, Kotri, was carried out for three phases: immediately after construction of Kotri in 1962; after construction of Mangla (1967); and post-Tarbela. Prior to construction of Kotri, the main diversion of water from the Indus River was at Sukkur barrage. After sizeable irrigation diversions at Kotri commenced in 1962, the *rabi* season flows in the Indus downstream dropped dramatically from an average of 14.85 bcm (1955-61) to 3.6 bcm (1962-67). Post-Mangla (1967-75) this dropped further to 1.4 bcm. Post-Tarbela (1975-98) there was an increase to 3.1 bcm. In 1991, The Water Apportionment Accord mentioned an indicative figure for downstream flows of 12 bcm per annum (with no break-up for the *kharif* and *rabi* seasons) subject to further studies to establish the minimum escapages/needs downstream Kotri.
- After sizeable canal diversions commenced in 1962, the *kharif* flows in the Indus downstream of Kotri barrage dropped from an average of 84.4 bcm (1955-61) to 60.2 bcm (1962-67). Post-Mangla (1967-75) this dropped further to 50.6 bcm. Post-Tarbela (1975-98) these were further reduced to 47.6 bcm.
- In the pre-Kotri period (1956-61), during both the *rabi* and *kharif* seasons, there was not a single day when the flow downstream of Kotri was zero. Zero-flow days were observed during the post-Kotri period (62-67), where one year (20%) in the *kharif* season and four years (80%) in the *rabi* season were observed as having zero flows. Zero flow days were observed in six years (75%) in the *kharif* season and eight years (100%) in the *rabi* season in the post-Kotri and post-Mangla period (1967-75). Zero flow days marginally reduced to 14 years (61%) in the *kharif* season and to 22 years (96%) in the *rabi* season in the post-Tarbela period (1975-98). In the *rabi* season, it was effectively the same at 96% compared to 100%.
- The occurrence of zero flow days in the *rabi* season increased due to the commissioning of the Kotri barrage and Tarbela dam. In the post-Kotri period (1961-67), the maximum number of days with zero flows in the *rabi* season was 10. This increased to a maximum of 160 days in the post-Kotri and post-Mangla period (1967-75), further increasing to a maximum of 180 days in the post-Tarbela period (1975-98). This effect was mainly due to the enhanced canal diversions at Kotri and upstream barrages including Guddu and Sukkur and due to variability in river flows.
- The diversion of eastern rivers by India and increased canal diversions at and upstream of the Kotri barrage reduced river flows below Kotri both in terms of reduced peak flows and quantity. Major reductions in river flows occurred during the dry years of both the *kharif* and *rabi* seasons. The effect of increased canal diversions was more pronounced during less than average years (probability <50%), especially in the *rabi* season. A statistical analysis of peak flows downstream of Kotri barrage for pre-Tarbela (post-Kotri) and post Tarbela periods yielded a range of –8 to +31% for peak flows at various return periods.
- Total canal diversions to IBIS during the period 1975-95 were 129 bcm, slightly higher than the prediction of 125 bcm. The prediction for the year 2000 of 149 bcm was not attained as other proposed dams were not constructed. Tarbela contributed 26% to increased canal diversions during the *rabi* season. There was an increase of 12 bcm in canal diversions during the post-Tarbela period, which helped to provide water for the replacement of eastern rivers command of 1.8 mha and improvement of supplies to 6.9 mha for the canals off-taking from the Indus main.
- Annual (year to year) variability in canal diversions during the post-Tarbela period was 25 and 17% during the *kharif* and *rabi* seasons, respectively, primarily due to the variation in river flows.
- Additional canal diversions in the post Tarbela period resulted in an increased recharge of groundwater in the Indus basin, especially the creation of a thin layer of freshwater, which is being used for domestic and agricultural use in the marginal and brackish groundwater zone.

Increased recharge in the fresh groundwater zone helped reduce the negative effects of groundwater mining and the redistribution of salts in the profile.

- The increased recharge and ineffective drainage resulted in increased waterlogging in the IBIS with a further increase in salinity in the brackish groundwater zone (including the secondary salinisation due to the use of brackish groundwater). The water table in 22% area of the IBIS was less than 2m in the pre-Tarbela period, which has changed to less than 1.5m in the post-Tarbela period. Therefore, the problem of waterlogging is now severe in 22% area of the IBIS.
- Groundwater contribution to agriculture doubled during the post-Tarbela period from 32 to 62 bcm through installation of 484 000 tubewells due to the power policy in the post-Tarbela period, enhanced recharge and participation of private sector in drilling of tubewells.
- Predicted annual sediment transport of the Indus (0.294 bcm) was almost double the actual inflow during 1974-99. However, trap efficiency during the initial 10 years was 97% and more than the predicted value of 89%. Total loss of gross storage in the Tarbela reservoir until 2000 was around 2.76 bcm (19%) since the completion of the dam in 1974. Based on reduced average annual sediment inflow to the reservoir of 0.106 billion m^3 during the post-Tarbela period, and effective sediment management within the reservoir, the expected storage life of Tarbela is now predicted to be around 85 years. This is 35 years longer than the predicted 50 years (at which point sedimentation would have occupied 90% of the live storage capacity).
- Alternative approaches to further lengthen the life of the reservoir including sediment sluicing and modified operational rules are being examined.
- Watershed management in the Siran River catchment was taken up. However, as it constitute only 6% of the total catchment area of the Tarbela reservoir, watershed management impact on sediment inflow was negligible.

3.5 Irrigation and Agriculture

The predictions about various aspects of agricultural development made in the Lieftinck Report were based on several related developments in irrigation and in the agricultural sector1, for example, new irrigation projects, a sizeable drainage program to control salinity and waterlogging. There were also extensive plans for: improvement of agricultural institutions (research, extension, education); policy measures regarding agricultural prices; and increased use of farm machinery and agricultural inputs. It was also assumed that water development in the IBIS would be continued until the year 2000. Therefore predictions for the irrigated and cultivated area, cropping intensity and yields were based for the IBIS as a whole. However, after the completion of Tarbela dam and the IBP works, no major storage or canal networks were added. Therefore, while comparing the predicted with actual achievements, it should be borne in mind that these predictions were based on certain assumptions for future development most of which were not carried out. Similarly, the achievements are not only due to Tarbela but to the related developments in IBIS especially Mangla.

The storage projects designed under the IBP were constructed well on time, except the Tarbela Dam which was delayed by two years due to reasons mentioned earlier along with the network of link canals, barrages and remodelling of the existing works. Salinity Control and Reclamation Projects (SCARPs) were also completed as planned, except LBOD and RBOD that were started much later than envisaged in the Lieftinck Report and still are not completed. Thus there was less coverage of the drainage works in the IBIS compared to plan targets (further details in section 3.12.6.4).

3.5.1 Irrigated and Cultivated Area in the IBIS

Tarbela dam was designed to provide storage to replace the water of the eastern rivers canal commands of about 1.8 mha and to improve supplies to the canals of Tarbela commands of 6.9 mha being fed directly from the Indus. Thus the benefits of Tarbela were spread to about 8.7 mha in the IBIS. Therefore, without the IBP, additional water to 6.9 mha and replacement supplies to about 1.8 mha could not be made available.

In pre-Tarbela period, there was a considerable water shortage and application of water to crops was only about three-quarters of irrigation requirements (Lieftinck Report, 1968). The transfer of Indus water to priority areas was aimed to increase canal flow up to limits of canal capacities. The irrigated area predicted for the years 1975, 1985 and 2000 was 14.1, 16.4 and 17.9 mha, respectively. The total cultivated area predicted for the years 1975, 1985 and 2000 was 19.4, 22.0 and 23.8 mha, respectively (refer Table 3.30).

The analysis of predicted and actual area in the IBIS indicated that the actual irrigated area during 1997-98 was around 18.0 mha, slightly higher than predicted for the year 2000 in the Lieftinck Report. The actual cultivated area during 1997-98 was 22.0 mha, which was 7% less than the predicted area for the year 2000. This shows that although the target of the irrigated area has been achieved as per predictions, the target of the total cultivated area, however, could not be achieved as per predictions for the post-Tarbela period (Table 3.27).

Table 3.27. Predicted and Actual Irrigated and Cultivated Area in IBIS covering both Surface and Groundwater Resources

Period	Irrigated Area (mha)		Cultivated Area (mha)	
	Predicted	Actual	Predicted	Actual
1975	14.1	13.3	19.4	19.6
1985	16.4	15.3	22.0	20.6
2000	17.9	18.0	23.8	22.0

Sources: Lieftinck Report, Vol. I, 1968; Agricultural Statistics of Pakistan, Govt. of Pakistan.

As a result, there was a considerable increase in the canal-irrigated area in the Indus basin from 10.1 mha in 1974-75 to 14.7 mha in 1997-98. The increase in the canal-irrigated area of 4.6 mha during the post-Tarbela period can be attributed to the additional supplies from the Tarbela dam and enhanced diversion during high flow periods. The area irrigated by tubewells increased from 2.8 mha in 1974-75 to 3.2 mha in 1997-98 (only tubewell commands). In addition to this, within the canal command area of 6.9 mha in 1997-98, tubewells provided additional water to supplement the canal supplies, whereas in 1974-75 this facility was not available. The installation of tubewells within the canal command area in Punjab was mainly concentrated in the Mangla command (for details of canal diversions and the groundwater contribution refer to sections 3.4.3 and 3.4.4.3).

3.5.2 Cropped Area in the IBIS

At the macro level, there was a significant shift in cropping patterns with the increased availability of water from Tarbela dam. There was a net increase in the cropped area of food grains and cash crops like wheat, rice, cotton and sugarcane. Consequently, there was a decrease in the cropped area of coarse grains and conventional oilseeds. In the Indus basin, irrigated agriculture saw an increase in area of 36%, 44%, 39% and 52% for wheat, cotton, rice and sugarcane, respectively. The overall increase in the cropped area was around 39% (Table 3.28).

Table 3.28. Cropped Area of Selected Crops in the Indus Basin Irrigated Agriculture

Crops	Cropped Area (mha)					Percent Increase
	1971-75	1976-80	1980-85	1986-90	1990-95	1971-75 to1990-95
Wheat (R)	5.93	6.49	7.24	7.60	8.06	36
Cotton (K)	1.92	1.91	2.22	2.53	2.76	44
Rice (K)	1.51	1.88	1.98	2.01	2.10	39
Sugarcane (A)	0.61	0.76	0.90	0.82	0.93	52
Oilseeds (K&R)	0.59	0.53	0.41	0.41	0.61	4
All Fruits (A)	0.20	0.26	0.36	0.44	0.50	150
Total Area	10.76	11.83	13.11	13.91	14.96	39

Source: Agricultural Statistics of Pakistan, Govt. of Pakistan.(R = rabi; K = kharif; A = annual.)

Although the cropped area was not given in the Lieftinck Report, it can be estimated from the cropping intensity. Section 3.5.4 provides details of cropping intensity, which was less than predicted. Therefore, the lower actual cropping intensity than predicted during the post-Tarbela period is an indirect indicator of lower actual cropped area.

Land in the Indus basin is not a limitation for the expansion of agriculture. Irrigation is essential for crop production because of the arid environment, where rainfall contributes 10-20% of crop evapo-transpiration. Therefore, the cropped area increased with the increased availability of water from Tarbela. Other factors also helped to increase the cropped area: increased numbers of tractors, availability of planting machinery and credit support. A rapid increase in population also encouraged the cultivation of additional areas to meet the growing needs of the population.

The major *rabi* crops in the Tarbela command are wheat, fodder and horticultural crops. Sugarcane also needs irrigation during the *rabi* season and thus competes for water with *rabi* crops. The trend in areas under *rabi* crops in the Tarbela command shows considerable increases in the area under wheat, fodder, sugarcane, and horticultural crops. Wheat is the leading food grain for human consumption, while its straw is used as a source of cheap roughage for livestock feed. Farmers generally consider water to be a key input. With the availability of sufficient water, therefore, they normally increase the cropped area.

The increase in the area under sugarcane, in particular, is due to the availability of additional irrigation water from the Tarbela reservoir as it is a crop that demands high levels of irrigation. Other factors that contributed towards this increase were the development of the sugarcane industry and the road infrastructure, both of which provided the necessary backward and forward linkages for growth.

3.5.3 Cropping Patterns in the Tarbela Command

For a more detailed evaluation of the changes in cropping patterns, three districts were selected in the Tarbela command. In these districts, there was a significant shift in cropping patterns with the increased availability of water from the Tarbela dam. There was increase in the area under food grains and cash crops like wheat, rice, cotton, sugarcane and horticultural crops. Consequently, there was a decrease in the area under coarse grain crops such as millets, sorghum and barley. For instance, in the Rahim Yar Khan district of the Punjab province, the shift in the cropping pattern was from a cotton-wheat mixed cropping pattern to a a predominantly cotton-wheat system, as 83% of the cropped area is now occupied by this system. Increases of 121 and 84% were observed in cropped areas under cotton and wheat, respectively. The overall increase in the cropped area in this district was around 60%.

In the Nasirabad district of Baluchistan province, the shift in the cropping pattern was from a sorghum-wheat mixed cropping pattern to a predominantly rice-wheat system, as 81% of the cropped area is now occupied by this system. Increases of 279 and 212% were observed in the areas under rice and wheat, respectively. Overall, the increase in the cropped area was around 128%.

In the Nawabshah district of Sindh province, the shift in the cropping pattern was from a cotton-wheat mixed pattern to one that is predominantly cotton-wheat with sugarcane as a major crop, as 87% cropped area is now occupied by this system. Increases of 250, 116 and 212% were achieved in the areas under cotton, wheat, and sugarcane, respectively. The overall increase in the cropped area was around 107%.

The changes in the cropping pattern in these three districts were considered in line with the developments in similar areas in IBIS as these districts are typical of the basin under the Tarbela command.

3.5.4 Cropping Intensity

In the Lieftinck Report, projected cropping intensities were given for the Punjab and Sindh provinces, instead of the Indus basin. In the irrigated area of the Punjab province, actual cropping intensity was around 122 and 117% during 1985 and 1998, compared to the predicted values of 131 and 150% for the same period. In the Sindh province, the actual cropping intensity was 124 and 132% for 1985 and 1998, compared to the predicted value of 115 and 137% during the same period (Table 3.29). The increase in cropping intensity during the post-Tarbela period was less than predicted. This low cropping intensity could be attributed to problems of waterlogging and salinity, use of marginal quality groundwater, increases in the area of crops demanding high quantities of water, and insufficient technological improvements in irrigated agriculture. Some of the planned projects could not be implemented and this also contributed to a low cropping intensity. This is because cropping intensity is directly related to the availability of water.

Table 3.29. Predicted and Actual Cropping Intensity in the IBIS

Period	Cropping Intensity (%)			
	Punjab Province		Sindh Province	
	Projected	Actual	Projected	Actual
1965	95	-	90	-
1975	114	105	100	116
1985	131	122	115	124
2000/1998	150	117	137	132

Source: Lieftinck Report, Vol. I, 1968; Agricultural Statistics of Pakistan, Govt. of Pakistan.

As a result of increases in canal diversions from about 94 bcm in the 1960s, to 129 bcm in the 1990s, and of changes in the macro-economic environment, farmers in the Indus basin have increased their annual cropping intensities from the original levels of 50-70% (over 100 years ago), to an average of 120% in 1993-94 (Mellor and Asianics, 1994). The present study confirms these observations, since a cropping intensity of 117% was achieved by Punjab province in 1998 and this represents 70% of the country's cropped area.

The increased cropping intensity has increased pressure on surface water resources (cheap fresh water) and this translates into a significant interference by water users in the upper and middle reaches into the operation of the irrigation distribution system (Rinaudo *et al.,* 1997). Therefore, farmers, particularly at the tail end, have installed a large number of private tubewells to tap fresh groundwater to have flexibility in water availability to meet their demand. However, since the groundwater in most parts of central and southern Punjab is brackish to saline, this trend has resulted in the acceleration of secondary salinity in many irrigated areas (IIMI).

3.5.5 Crop Yields

The Lieftinck Report projected the yield levels for various crops in three regions of the country: Punjab (irrigated); Sindh (irrigated); and areas outside the basin. The dominating influence of additional water supplies on yield level was implied in the projections of the Lieftinck Report. The projected yields for these crops were based on three periods: 1965-75; 1975-85 and 1985-2000. For the period of 1965-75, annual growth rates of 3.1, 2.3 and 2.2% were projected for wheat, cotton, and rice, respectively. For 1975-85, higher annual growth rates of 4.6, 5.0 and 4.1% were projected for the same crops. Lower annual growth rates were projected for these crops for 1985-2000 period.

The actual yields of wheat, cotton and rice were compared with the predicted yields for the years 1985 and 2000. The actual yields of all three crops were lower than the predicted yields during the post-Tarbela period in Punjab and Sindh (Table 3.30). However, Sindh province performed better than Punjab in almost every crop when compared to the predicted yields.

Table 3.30. Predicted and Actual Yields of Crops in the Indus Basin Irrigated Agriculture

Province	Crops	Predicted Yield (kg/ha)		Actual Yield (kg/ha)		Percent Difference	
		1985	2000	1984-85	1997-98	1984-85	1997-98
Punjab	Wheat	2658	3339	1610	2327	-39.4	-30.3
	Cotton Lint*	553	718	483	494	-12.7	-31.2
	Rice**	2133	2824	1370	1382	-35.8	-51.1
Sindh	Wheat	2430	3379	2019	2374	-16.9	-29.7
	Cotton Lint*	528	734	374	662	-29.2	-9.8
	Rice**	1904	2928	1950	2671	+2.4	-8.8

Sources: Lieftinck Report, Vol. I, 1968; Agricultural Statistics of Pakistan, Govt. of Pakistan.
* *Predicted yield of seed cotton is converted to lint by multiplying with a factor of 0.33*
** *Predicted yield of paddy is converted to grain by multiplying with a factor of 0.66.*

Pakistan is a hot and arid country with fertile alluvial soils and plenty of sunshine, where irrigation is an essential element of crop production. In the post-Tarbela period, high yielding seeds of paddy (IRI6), wheat (Mexi-Pak) and maize (hybrids) were popularised, which largely replaced the low yielding, lodging type traditional crop varieties. This technological shift helped to increase crop yields but still fell short of potential.

3.5.6 Irrigation (storage) Benefits

In the Lieftinck Report (1968), economic benefits were estimated on the basis of per acre-foot release of storage water. Later on, a similar exercise was conducted for the Project Planning Report of Kalabagh Dam Project (1984). Yearly values per acre-foot of storage under both the alternatives are listed in Annex 5, which indicate close agreement for the overlapping period. The values given in the Lieftinck Report have been adopted for comparing the economic benefits of irrigation from Tarbela storage water[2].

The economic and financial benefits (predicted and actual) in this regard for 1965 prices are listed in Tables 3.31 and 3.32. It will be noted that the present worth in 1965 at an 8% discount rate for the predicted and actual economic benefits from 1975 to 1998 is, respectively, Rs.1412 million ($296.6 million) and Rs.1680 million ($352.9 million). In 1998 prices the corresponding value of predicted and actual storage benefits was $1 533.6 and 1 824.5 million, respectively, signifying a 19% higher value than predicted.

3.5.7 Production of Crops and Farmgate Prices

Production of crops in the country for the periods of 1975, 1985 and 1998 is presented in Table 36. The production figures are in million tonnes and represent total production of a particular crop reported by Agricultural Statistics. There is a continuous increase in production of most of the crops since 1975 except coarse grains and oilseeds production of which was reduced due to a decrease in area under these crops as this was diverted to crops of high-value with high water requirements. The farmgate prices of various crops for 1965 constant level are presented in Table 3.33.

[2]. The methodology used in Lieftinck Report, and followed in this study, accounts for the the system losses.

Table 3.31. Predicted and Actual Economic Irrigation Benefits of Tarbela Storage (1965 Prices)

Year Ending June	Predicted Benefits					Actual Benefits			
	Storage[1] Availability (MAF)	Average[2] Value/Acre Foot (Rs.)	Total Benefits (Rs. million)	Present Worth In 1965 Prices		Storage Release (MAF)	Average Value [2]/ Acre Foot (Rs.)	Benefits (Rs. million)	Present Worth in 1965 Price @ 8% Discount (Rs.million)
				Factor @ 8% Discount	Amount (Rs.million)				
1975	5.0	21.5	107.5	0.44	47	0	21.5	0	
1976	8.6	22.0	189.1	0.40	76	3.33	22.0	73	29
1977	8.4	23.5	197.8	0.37	73	9.07	23.5	213	79
1978	8.2	27.5	225.5	0.34	77	10.00	27.5	275	94
1979	8.0	31.2	249.2	0.32	80	8.71	31.2	272	87
1980	7.9	34.2	269.9	0.29	78	9.91	34.2	339	98
1981	7.7	37.2	286.5	0.27	77	10.63	37.2	395	107
1982	7.6	40.6	308.2	0.25	77	11.33	40.6	460	115
1983	7.4	43.3	320.3	0.23	74	9.12	43.3	395	91
1984	7.3	46.8	341.4	0.21	72	9.18	46.8	430	90
1985	7.1	49.3	350.1	0.20	70	9.24	49.3	456	91
1986	7.0	51.8	362.5	0.18	65	9.76	51.8	506	91
1987	6.8	54.5	370.7	0.17	63	9.98	54.5	544	92
1988	6.7	57.1	382.9	0.16	61	7.52	57.1	429	69
1989	6.6	59.8	394.9	0.15	59	11.12	59.8	665	100
1990	6.4	62.9	402.6	0.14	56	7.32	62.9	460	64
1991	6.3	64.8	408.4	0.12	49	6.19	64.8	401	48
1992	6.2	66.3	410.9	0.11	45	5.93	66.3	393	43
1993	6.0	68.5	410.7	0.10	41	6.31	68.5	432	43
1994	5.9	69.2	415.2	0.10	42	9.41	69.2	651	65
1995	5.7	72.0	410.4	0.09	37	5.39	72.0	388	35
1996	5.6	73.4	411.1	0.08	33	8.17	73.4	600	48
1997	5.4	75.0	405.2	0.08	32	9.15	75.0	686	55
1998	5.3	76.6	406.2	0.07	28	8.66	76.6	663	46
Total:			**i) Rs. million:**	**=**	**1412**		**i) Rs. million**	**=**	**1680**
			ii) $ million 1965 Prices:	**=**	**296.6**		**ii) $ million 1965 Prices:**	**=**	**352.9**
			iii) $ million 1998 Prices:	**=**	**1533.6**		**iii) $ million 1998 Prices:**	**=**	**18245**

1. *From Table A6-3, pages 352-53, Vol.-II, Lieftinck Report.*

In 1965 prices and derived from Table A6-3, pages 352-53, Vol.-II, Lieftinck Report based on average value of incremental water (including net ground water recharge) in the total project area.

Table 3.32. Predicted And Actual Financial Irrigation Benefits From Tarbela Storage (1965 Prices).

Year Ending June	Financial Benefits										
	Predicted Benefits						Actual Benefits				
	Storage[1] Availability (MAF)	Possible [2] Additional Wheat Cropping (million Acres)	Yield Per [3] Acre (Metric Tonne)	GPV In 1965 Prices[5] (Rs. million)	Present Worth In 1965 Prices		Storage[6] Release (MAF)	Possible Additional Wheat Cropping (million Acres)	Yield Per Acre[7] (Metric Tonne)	GPV in 1965 Prices[5] (Rs.million)	Present Worth in 1965 Price @ 8% Discount (Rs.million)
					Factor @ 8% Discount	Amount (Rs. million)					
1975	5.0	1.67	0.614	295	0.44	130	0	0			
1976	5.6	2.87	0.656	541	0.40	216	3.33	1.11	0.633	202	81
1977	8.4	2.80	0.697	561	0.37	208	9.07	3.20	0.623	541	200
1978	8.2	2.73	0.739	580	0.34	197	10.00	3.33	0.587	562	191
1979	8.0	2.67	0.780	599	0.32	192	8.71	2.90	0.696	539	191
1980	7.9	2.63	0.822	622	0.29	180	9.91	3.30	0.688	653	172
1981	7.7	2.57	0.864	638	0.27	172	10.63	3.54	0.722	753	189
1982	7.6	2.53	0.905	658	0.25	165	11.33	3.78	0.719	781	198
1983	7.4	2.47	0.947	672	0.23	155	9.12	3.04	0.757	662	195
1984	7.3	2.43	0.988	690	0.21	145	9.18	3.06	0.684	602	152
1985	7.1	2.37	1.030	702	0.20	140	9.24	3.08	0.735	651	126
1986	7.0	2.33	1.055	707	0.18	127	9.76	3.25	0.822	768	130
1987	6.8	2.27	1.081	705	0.17	120	9.98	3.33	0.735	704	138
1988	6.7	2.23	1.106	709	0.16	118	7.52	2.51	0.779	562	120
1989	6.6	2.20	1.132	716	0.15	100	11.12	3.71	0.838	894	90
1990	6.4	2.13	1.157	709	0.14	99	7.32	2.43	0.789	551	134
1991	6.3	2.10	1.182	714	0.12	86	6.19	2.06	0.810	480	58
1992	6.2	2.07	1.208	719	0.11	79	5.93	1.98	0.863	491	54
1993	6.0	2.00	1.233	709	0.10	71	6.31	2.10	0.842	508	51
1994	5.9	1.97	1.258	712	0.10	71	9.41	3.14	0.781	705	71
1995	5.7	1.90	1.284	701	0.09	63	5.39	1.80	0.877	454	41
1996	5.6	1.87	1.309	704	0.08	56	8.17	2.72	0.835	653	52
1997	5.4	1.80	1.335	691	0.08	55	9.15	3.05	0.850	745	60
1998	5.3	1.77	1.360[4]	692	0.07	48	8.66	2.89	0.952	791	55
Total:				Gross (Rs. Mln) = 2993 Net Rs. @ 65% = 1945 $ (million) = 408.7					Gross (Rs. Mln) = 2749 Net Rs. @ 65% = 1787 $ (million) = 375.4		

1. *From Table A6-3, page 352-53, Vol.-II, Lieftinck Report.*
2. *By using the factor of 3 acre feet per acre of wheat at source with average conveyance loss of 45% and total crop delta of 1.67 foot (5 watering of 4 inches each)*
3. *Average for Punjab and Sindh derived from information in Table 2-15, page 49, Vol. II, Lieftinck; for the base year 1975, 1985 & 2000 and then interpolated.*
4. *Predicted value for the year 2000.*
5. *At 1965 wheat price of Rs.287.5 per metric tonne.*
6. *As obtained from Tarbela Dam Project, WAPDA.*
7. *Actual figures based on average of Punjab and Sindh from Agricultural Statistics, Government of Pakistan.*

Table 3.33. Production of Crops and Constant Farmgate Prices in Pakistan

Crops	Production (million Tonnes)			Farmgate Prices for 1965* (Rs./tonne)
	1975	1985	1998	
Wheat	7.67	11.70	18.69	287.5
Rice	2.31	3.32	4.33	662.5
Maize	0.75	1.03	1.25	287.5
Bajra	0.27	0.28	0.21	250.0
Jawar	0.27	0.23	0.23	250.0
Barley	0.14	0.13	0.17	287.5
Sugarcane	21.24	32.14	53.10	75.0
Lint Cotton**	3.73	5.93	9.18	2500.0
Sugarbeet	0.24	0.10	0.08	75.0
Guar	0.18	0.25	0.15	662.5
Gram	0.55	0.52	0.77	312.5
Pulses	0.72	0.73	1.01	512.5
Groundnut	0.06	0.07	0.11	575.0
Oilseeds	1.58	0.25	0.42	575.0
Potato	0.29	0.54	1.43	75.0
Vegetables***	1.70	1.91	2.95	150.0
All Fruits	2.06	3.41	6.30	250.0

* *Farm prices as used by Lieftinck Report which were based on after harvest market prices by making allowances for transport costs and marketing costs.*

** *Lint cotton yield is given in million bales, where a bale is 170.45 kg, the price given in the Lieftinck Report was converted to lint.*

*** *Exclude potato and sugarbeet.*

3.5.8 Gross Value of Agricultural Production

The comparison of the gross value of agricultural production presented in this section is not a direct comparison of production attributable to the TDP. This comparison is rather based on the assumptions made in the Lieftinck Report for the agriculture (crop sector) as a whole.

The Lieftinck Report predicted the gross production value (GPV) of agriculture for three regions and three ‘time slices’ representing periods from 1965 to 2000. The gross production value is computed using production and constant farmgate prices of various crops (Table 3.33). The three regions selected in the study are: commanded areas, areas outside the basin and total area. The three time periods selected for estimation of compound annual growth rates for the cropped area, yield, and total GPV were: 1965-75; 1975-85; and 1985-2000. Different compound growth rates were used in the Lieftinck Report for the three periods. For total GPV, the compound annual growth rates of 3.5, 5.9, and 2.9 were used for 1965-75, 1975-85 and 1985-2000, respectively. Higher compound growth rates were used for the period 1975-85, on the assumption that increased water supplies with improved production practices would result in a higher growth rate. The compound annual growth rate for the total GPV was 3.9% for the overall period of 1965-2000 (IACA Comprehensive Report, Vol. 1, page 203). The predicted GPVs for the total area were Rs.7.59, 13.44 and 20.57 billion (1965 prices) for 1975, 1985, and 2000, respectively (Table 3.34).

Since the irrigation districts do not match with the agricultural districts in Pakistan, revenue officials tend to under-report in connivance with farmers to hide land and water taxes. The irrigation districts are based on canal commands, whereas the agricultural districts are geographically administered. Therefore for estimation of GPVs, total cultivated area instead of irrigated area has been considered. This is in line with the assumptions made in the Lieftinck Report. Furthermore, reliable information about prices of all the crops, especially farm gate prices, was not easily available. Seventeen crops were selected for estimation of GPVs as detailed in Table 3.33. The cropped area used in this study can be considered as the lower limit.

Table 3.34. Predicted and Actual Gross Crop Production Value[1] in Pakistan
(Constant 1965 prices $=Rs.4.76 in 1965)

Period	GPV (Rs. in bln.)		GPV Annual Growth Rate Since 1975
	Predicted	Actual	
1975	7.59	9.72	-
1985	13.44	13.04	2.98
2000/1998	20.57	19.96	3.18

Sources: Lieftinck Report (1968), Vol. II, Table 8-3, page 220; Agricultural Statistics of Pakistan, Govt. of Pakistan.

The Lieftinck Report has followed official national accounts procedures in preparing projections of gross value added by the agriculture sector. A constant price factor was used for the estimation of a compound annual growth rate for crop yields. For the sake of consistency and to enable comparison, the same procedure and assumptions were followed in this study to estimate the actual GPVs. Therefore, constant farm prices of crops for the base year of 1965 were used for estimation of GPVs for 1985 and 1998. The prices of commodities and inputs have changed over the time period. However, the relationship between the input and output prices does not change much in real terms.

The actual GPVs estimated were 9.72, 13.04 and 19.96 billion rupees for 1975, 1985 and 1998 respectively, using the constant farm prices of 1965 (refer Table 3.34). The actual GPVs of crops were less than the predicted values for the post-Tarbela period (1975-98) for reasons explained earlier, especially those related to the inefficiencies of the crop sector, hindering it from moving to a higher production level. Therefore, although the actual achievement of GPV was only slightly short of the predicted targets, cropping intensities and yields were much lower than predicted. Increases in crop prices and shifts to higher value crops also contributed to higher GPV in spite of lower crop yields and cropping intensity. The assumptions in the Lieftinck Report about irrigated area and crop yield were somewhat liberal, because these were based on assumptions of increased inputs especially with regard to water availability at the farm gate.

There is a need to interpret the GVP estimates with care. 1965 prices were used in the analysis both by Lieftinck and the present study. In this study, actual crop production and farm gate prices (1965) of different crops are used to derive the actual crop GPV.

The major change in agriculture was in cropping pattern, where low value crops were replaced with cash crops like cotton, sugarcane, fruits, and vegetables. There was also a significant increase in the area under rice. The shift in cropping pattern and irrigated area was higher than predicted.

The compound annual growth of actual GPV for 1965-98 was 3.18% compared to the predicted GPV compound growth rate of 3.9% during 1965-2000[1]. It may be pointed out that the annual population growth rate during this period was slightly over 3%. The actual GPV growth rate was just higher than the population growth and considerably lower than the predicted GPV growth rate for this period.

The lower values of actual GPVs compared to the predicted were also due to the fact that higher projections for canal water availability were made in the Lieftinck Report for the year 2000. The predicted canal diversions for year 2000 were 149.46 bcm, whereas the actual canal diversions in 1998 were about 129 bcm. In fact, additional water storage and other water development schemes envisaged at the planning stage of Tarbela could not be developed due to various constraints resulting in less than predicted canal water availability (refer section 3.4.3.2 and Table 3.19).

[1] *The team was provided a methodology to estimate SGVP based on IWMI's research. However to attain consistency in comparing it with the predicted GPVs, estimate of GPVs was based on 1965 farm gate prices.*

3.5.9 Livestock Population and Products

The actual number of livestock in Pakistan was more than predicted during the post-Tarbela period, whereas the milk and meat production was less than predicted during the same period (Table 3.35). This shows that productivity of livestock sector was less than predicted. This was due to several factors including inadequate feeding, animal diseases and other management factors. Actual GPV of livestock products is significantly lower than predicted for 1875, 1985 and 2000.

Table 3.35. Predicted and Actual Livestock Population and Products

Parameter	1975		1985		2000/1994-95		Percent Change* (+/-)
	Predicted	Actua	Predicted	Actual	Predicted	Actual	
Livestock (million)	63.0	65.9	77.3	88.5	90.0	118.3	+79.5
Milk (million Tons)	8.94	8.17	14.04	10.86	22.91	18.99	+132.4
Meat (million Tons)	0.84	0.62	1.39	0.98	2.79	1.81	+191.9

Sources: Govt. of Pakistan (1996); Pakistan Economic Survey, 1995-96. Finance Division, Islamabad.

* *Percent change represents change in actual of 1994-95 from that of actual of 1975.*

Findings on Irrigation and Agriculture

The comparison of agricultural production presented in this section is not a direct comparison of production attributable to the TDP. This comparison is based rather on the assumptions made in the Lieftinck Report for the agriculture (crop) sector as a whole.

- The actual irrigated area in the Indus basin during 1997-98 (18.0 mha) was slightly higher thanpredicted for the year 2000 (17.9 mha). The cultivated area was 22.04 mha in 1997-98 which was 7% less than the predicted area for the year 2000 (23.8 mha).
- There was a marked change in the cropping pattern in all the three sample districts (Rahim Yar Khan, Nasirabad, and Nawabshah) with increases of up to 279% in areas of high value irrigated crops like wheat, cotton, sugarcane, and rice, and a simultaneous reduction in the area under coarse grains like sorghum and millets. The increase in the area under crops demanding high levels of water (sugarcane, rice, fruits, and vegetables) was primarily due to availability of additional irrigation water from the Tarbela reservoir. The other factors that contributed towards this increase were the development of the processing industry and the road infrastructure.
- In the Lieftinck Report, predicted cropping intensities were given for the Punjab and Sindh provinces, instead of the Indus basin. The actual cropping intensities for Punjab (in the irrigated area) was 122% (1985) and 117% (1998), compared to the predicted values of 131% (1985) and 150% (2000). In Sindh, actual cropping intensities were 124% (1985) and 132% (1998), compared to the predicted values of 115% (1985) and 137% (2000). The increase in cropping intensity during the post-Tarbela period was thus less than predicted.
- The actual yields of wheat, cotton, and rice were much less than predicted during the post-Tarbela period both in Punjab and Sindh provinces (refer Table 3.30). However, Sindh province performed better than Punjab in almost every crop, compared to the predicted yields.
- The actual GPV of crops was 28% higher than predicted for 1975 while it was 3% lower than predicted for both 1985 and 1998. The actual GPV for the year 1998 was Rs.19.96 billion compared to the predicted Rs.20.57 billion for the year 2000 (1965 prices). Part of the reason for lower GPV was less availability of irrigation supplies compared to predicted.
- The actual number of livestock was more than predicted during the post-Tarbela period, whereas milk and meat production was less than predicted during the same period.

3.6 Hydropower

3.6.1 Projected and Actual Power System Expansion With Tarbela

At the time of planning for TDP, the power system of Pakistan consisted of two isolated grids in north and south. According to the Lieftinck Report, the northern grid had an installed capacity of 467 MW including 165 MW hydropower. The southern grid had an all- thermal installed capacity of 280 MW. It was projected that before commissioning of Tarbela power in 1975, the northern and southern grids would be inter-connected through 380 Kv lines leading to complete integration by the time of full developments at Tarbela through installation of 12 x 175 MW units in 1980. It was also envisaged that the cumulative inter-connected system capability would increase from 1 681 MW in 1971 to 2 056 MW in 1974 and 3 615 MW in 1980. In actual practice, installed capacity was: 1 704 MW in 1971; 2 123 MW in 1974; and 3 495 MW in 1980. Corresponding hydro installations as a proportion of total capacity was: 39% (1971); 41% (1974); and 45% (1980); and 30% (1998). North-south grid inter-connection would also start in 1981 when the first single-circuit 500 Kv transmission line between Multan and Guddu was completed. This process continued till 1995 when two more single-circuit 500 Kv transmission lines between north and south were completed. In June 1998 Pakistan had an overall installed capacity of 15 844 MW comprising: 9 948 MW (WAPDA); 4 024 MW (IPPs – Independent Power Producers); 1 735 MW (KESC – Karachi Electric Supply Corporation); and 137 MW nuclear.

Predicted and actual installation at Tarbela is shown in Table 3.36.

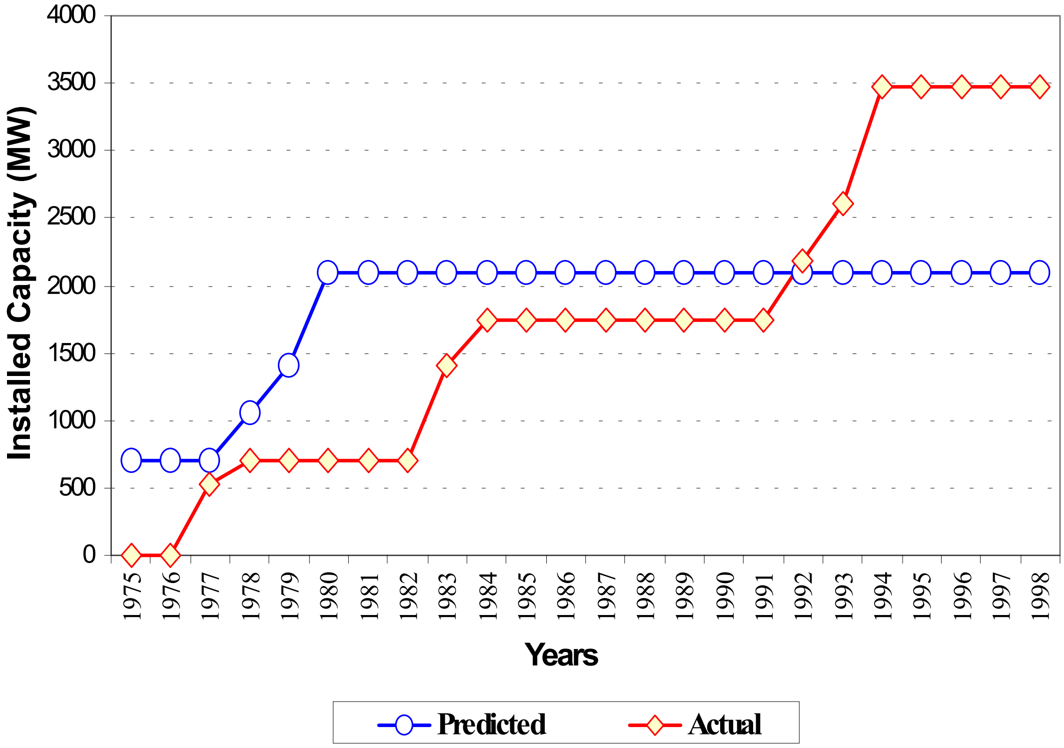
Table 3.36. Predicted and Actual Power Installation at Tarbela

Power Units		Year of Installation		Remarks
No.	Capacity (MW)	Predicted	Actual	
1-4	700	1975	1977	Initially planned installed capacity of 2 100 MW enhanced to 3 478 MW; basic decision for optimised development of three right bank power tunnels taken by WAPDA in early 1980s
5-6	350	1978	1982	
7-8	350	1979	1982	
9-10	350	1980	1985	
11-12	350	1980	-	
11-12	864	-	1992	
13-14	864	-	1993	

For better appreciation, the year to year predicted and actual installed capacities are depicted in Figure 3.10.

Pakistan has a low per capita annual consumption. Current (1998) per capita annual consumption in Pakistan is 343 kWh as compared to: 7 500 kWh in OECD counties; 482 kWh in Asia excluding China; 490 kWh in Africa; and 1402kWh in Latin America. In 1975 (pre-Tarbela), there were less than two million consumers in the WAPDA system, which grew to over 10 million in 1998. This represents present access of electricity to about 60% of the population. There have also been significant shifts in electricity consumption by various economic groups between 1975 and 1998. The trend for various groups was: domestic, from 72 to 83%; commercial, from 19 to 14%; industrial, from 5 to 2%; and others including agriculture from 4 to about 1%. The position on load-shedding at peak demand (4 hours in the evening) has also undergone some transformation. In 1980 it was 22%; went up to 42% in 1986; dropped to 21% in 1993; and was around 2% in 1998 due to the induction of large capacity thermal IPPs.

Figure 3.10. Predicted and Actual Installed Capacity at Tarbela



Regarding fuel utilisation in thermal generation within the WAPDA system, the trend from 1980 through 1998 was:

- local natural gas, from 1 313 to 4 037 million cubic meters;
- imported furnace oil, from 5 to 1 282 thousand metric tonnes (tmt);
- high speed diesel, from 13 718 to 20 176 litres; and
- local coal, from 21 to 347 tmt.

By way of share in thermal generation from different fossil fuels the trend from 1980 to 1998 was: natural gas from 97.9 to 70%; imported furnace oil from 0.5 to 29%; high speed diesel from 0.9 to 0.5%; and local coal from 0.7 to 0.5%.

At the time of designing TDP it was envisaged that 3 out of 4 right bank diversion tunnels would be equipped with 12 x 175 units. However, as part of the Tarbela Dam Project, only the civil works for the first 4 units on Tunnel No. 1 were to be financed from TDF. Electrical and mechanical (E&M) equipment for these units was to be financed by WAPDA. Soon after, work was started by WAPDA from its own resources to equip tunnel No. 2 with 6 x 175 MW units instead of 4 x 175 MW units for Tunnel No. 1. When taking up conversion of Tunnel No. 3, another optimisation study by WAPDA led to its equipping with 4 x 432 MW units, instead of the 4 x 175 MW on Tunnel No. 1 and 6 x 175 MW on Tunnel No. 2. The delay in overall power installation, when compared to the original schedule, resulted from financial constraints and optimisation studies by WAPDA. While taking decisions for large capacity units 11–14, it was realised that most of the additional energy would be generated during the high flow season of summer. However, their utility for large-scale peaking capability during the low flow season was considered the main advantage. Furthermore, due to a uniform WAPDA tariff round the year, the additional generation of about 2 000 GWh per annum would bring significant extra revenue.

The overall cost of power expansion at Tarbela, funded by WAPDA from its own resources, was Rs.15.6 billion in current prices. This comprised: Rs.0.5 billion for E&M equipment for units 1–4; Rs.2.9 billion for units 5–8; Rs.1.2 billion for units 9–10; and Rs.11 billion for units 11–14. In 1998 prices it aggregated to about Rs.61 billion, comprising: units 1–4 (Rs.5.1 billion); units 5–8 (Rs.18 billion); units 9–10 (Rs.8.7 billion); and units 11–14 (Rs.29.2 billion).

3.6.2 Predicted and Actual Hydropower Generation

3.6.2.1 Reservoir Inflow Operations

Predicted reservoir operations were based on the average monthly inflows from 1922-63. Actual reservoir inflows based on the monthly average data for the period 1977-98 compared with the prediction**:** *Kharif* 64.3 bcm against 68.5 bcm predicted; *rabi* 10.8 bcm, the same as predicted; and an annual 75.1 bcm against 79.3 bcm predicted, or about 95%.

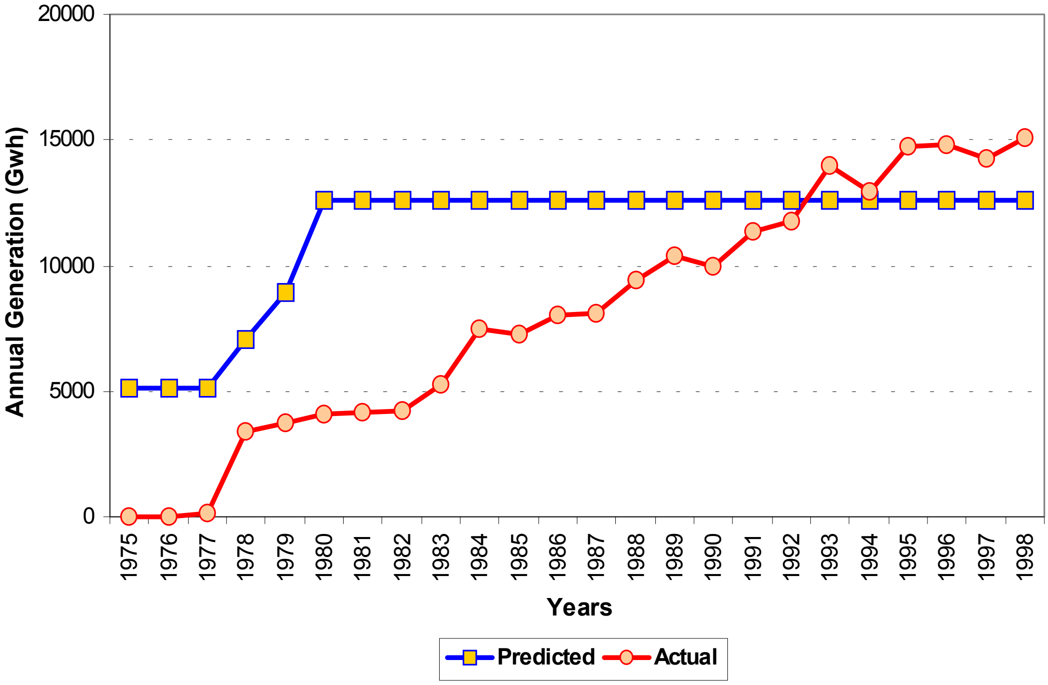
3.6.2.2 Power Generation

It was predicted that the average annual generation with 12 x 175 units installed would be about 12 600 Gwh. For the purpose of realistic comparison with actual Tarbela generation to date, this prediction has been broken down into yearly figures in keeping with the installation schedule. This is then compared with the actual yearly generation at Tarbela from 1977 to 1998 in Table 3.37 and Figure 3.11. Taking into account the five-year gradual development period, the average annual predicted generation for 1975-98 equates to 11 300 GWh. The actual annual generation over this period was 8 840 GWh (78%).

Table 3.37. 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**	**1977-98 : 8840** **1980-98 : 9854** **1993-98 : 14306**	

Figure 3.11. Predicted and Actual Yearly Generation at Tarbela



Actual generation compared with the corresponding average predicted generation of about 11 300 GWh for the total period, and 12 600 GWh excluding the initial development phase, is given below:

- average 1978-98: 9 255 GWh (82% of predicted);
- average 1980-98 (excluding the initial testing years): 9 900 GWh compared to 12 600 (79% of predicted); and
- average 1993-98 (after full development of 3 478 MW): 14 300 GWh compared to 12 600 (113% of predicted).

3.6.3 Economic Value of Power Benefits

3.6.3.1 Main Power Features

Existing power installations at Tarbela are located in two stations on the right bank. Power Station No. 1 houses 10 x 175 MW units equipped with vertical axis hydraulic turbines with umbrella type generators each connected to 13.2/220 or 500 Kv step-up transformers. Each unit, rated at 175 MW, would have a capability range of 183 MW (or 210 MW with 15% overload under full head and low tailwater conditions) to about 40 MW at the maximum draw-down level of 396.3m. Power Station No. 2 houses 4 x 432 MW units also equipped with vertical axis hydraulic turbines with semi-umbrella type generators each connected to 18/500 Kv step-up transformer. Each of these units has capability range of 432 MW (elevation 457.3m and above) and 125 MW (maximum draw-down level of 396.3m).

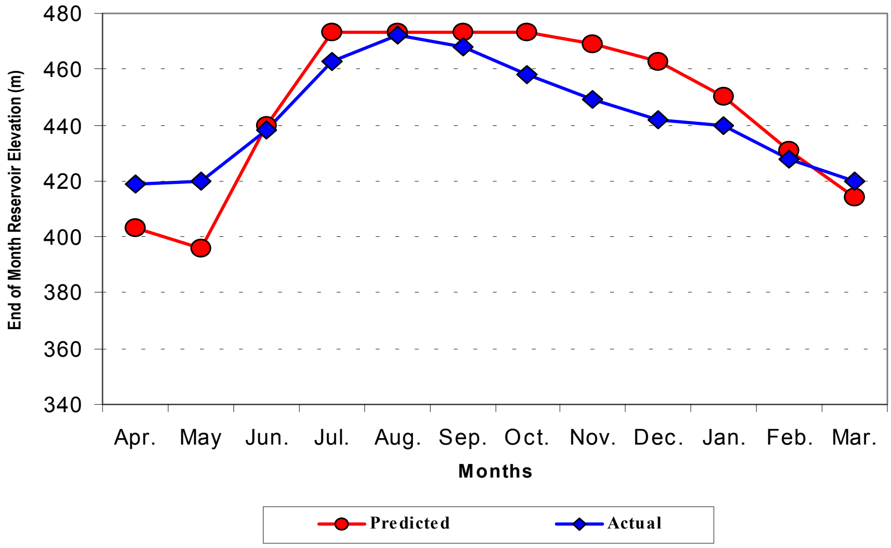
Energy from the power stations is fed into adequate capacity 220 and 500 Kv open type switchyards. In turn, these are connected to WAPDA's National Power Grid through: three 220 Kv double circuit transmission lines; and four 500 Kv single circuit transmission lines. The integration of Tarbela power within the overall WAPDA System is handled by the National Power Control Centre (NPCC) located at Islamabad.

3.6.3.2 Seasonal Fluctuations and Reservoir Elevations

It was realised that the extreme seasonal fluctuations in flows on the Indus and variations in storage releases required for irrigation purposes in different months of the year would provide a poor distribution of water for power production. Though Tarbela would reach minimum capability in early June, the critical period in the System as a whole was likely to be in May and June when Tarbela was fully depleted. Predicted and actual mean monthly elevations of the Tarbela reservoir (1977-98 data) are compared in Figure 3.12.

It may be noted from Figure 3.12 that during the critical period from March to June, actual reservoir elevations were significantly higher than predicted. This feature helped in substantially enhancing actual generation during the maximum load-shedding months of May and June as compared to predicted.

Figure 3.12. Predicted and Actual Monthly Elevations of Tarbela Reservoir (1977-98)



Another important feature of somewhat higher reservoir elevations during June, was the significant Tarbela contribution to the annual peak demand of the WAPDA System occurring predominantly in this period. It will be noted from Table 3.38 that during the maximum demand period of June, Tarbela has contributed 25 to 48%, thus playing an important role in the alleviation of load-shedding.

In the Lieftinck Report, economic benefits were predicted on the basis of differences in present worth costs of programs excluding and including Tarbela. It was estimated that present worth of resultant economic benefits in 1965 prices at discount rate of 8% and fuel price of 45 cents per million British Thermal Units (BTU) was $160 million (refer Table 3.40). On the basis of current savings in generation cost per kWh, as compared to most efficient gas-fired generation in WAPDA system, the present worth in 1965 prices at 8% discount rate of actual economic power benefits of Tarbela from 1977 to 1998 are estimated at $225 million (Annex 6). In 1998 prices, these were worth $1 163 million.

As regards financial benefits the yardstick of fuel cost saving per kWh has been used. On this basis, the predicted and actual financial benefits from Tarbela for the period 1975-98 are compared in Table 3.39. It will be noted that the present worth in 1965 prices at 8% discount rate of predicted financial power benefits was Rs.1 315 million ($276.2 million). Corresponding actual financial power benefits were Rs.1 695 million ($356.1 million). In 1998 prices, the predicted financial power benefits were $1 841m, 29% higher than the predicted value of $1 428.3.

Table 3.38. WAPDA Power System Year-wise Peak Demand and Contribution by Tarbela

Year Ending June	Peak Demand Including Load-Shedding		Contribution By Tarbela	
	MW	Month	MW	Percent
1980	2145	Jan.	820	38
1981	2473	Jun.	790	32
1982	2866	""	800	28
1983	3163	""	1115	35
1984	3300	""	1575	48
1985	3791	""	1575	42
1986	3933	Jan.	2000	51
1987	4325	Jun.	1952	45
1988	5031	""	2000	40
1989	5440	""	1980	36
1990	5680	""	2000	35
1991	6090	""	1980	33
1992	6532	""	2000	31
1993	7522	""	2000	27
1994	8067	Aug.	2110	26
1995	8252	Jun.	2040	25
1996	8288	Jul.	2088	25
1997	8772	Jun.	3687	42
1998	9209	""	3679	40

Source: *Power System Statistics, Twenty Third Issue, WAPDA, March 1999.*

3.6.3.3 Establishing the Cheapest Alternative to Tarbela

As part of the re-evaluation under the Lieftinck Report, the first task was to establish the best alternative to Tarbela from the power point of view. The first alternative program prepared included a 380 Kv inter-connection between Mari and Karachi (to take advantage of the gas reserves at Mari) and the Kunhar Hydropower Project. The project on the Kunhar River, between 48–112km upstream of its confluence with the Jhelum river, would be primarily for power, but would add an estimated 0.466 bcm storage capacity in the Jhelum River basin. The project would develop power of about 500 MW in three stages from a drop of 1 220m over a 56km reach of river. In evaluating this alternative, it was found that, except at high prices for thermal fuel, Kunhar was a relatively unattractive project. Therefore, two other programs were prepared, one including Kunhar commencing in 1981, and the other excluding Kunhar altogether. The last constituted a purely thermal alternative in effect (except for the existing small hydels and Warsak, and the planned Mangla Units 1–8 and Warsak Units 5 and 6). Since it was doubtful whether there existed at Mari such a large reserve of cheap gas as was believed to be the case two years ago, the 380 Kv transmission line between Mari and Karachi was also eliminated from the program. Thus: Program A included Kunhar commencing in 1974; Program B included Kunhar commencing in 1981; and Program C related to an essentially all-thermal option.

Table 3.39. Predicted And Actual Financial Power Benefits From Tarbela Generation (1965 Prices)

Year Ending June	Predicted					Actual				
	Generation (Gwh)	Fuel Saving Per kWh (Paisas)[1]	Amount (Rs. million)	Present Worth in 1965 Prices @ 8% Discount		Generation (Gwh)	Fuel Saving Per kWh (Paisas)[2]	Amount (Rs. million)	Present Worth in 1965 Prices @ 8% Discount	
				Factor	Amount (Rs. million)				Factor	Amount (Rs. million)
1974-75	5649	2.6	147	0.44	65					
1975-76	5649	2.6	147	0.40	59					
1976-77	5649	2.6	147	0.37	54	138	3.0	4	0.37	1
1977-78	8134	2.6	211	0.34	72	3367	3.0	101	0.34	14
1978-79	9977	2.6	259	0.32	83	3744	3.0	112	0.32	16
1979-80	12458	2.6	324	0.29	104	4064	3.0	122	0.29	35
1980-81	12458	2.6	324	0.27	87	4129	3.0	124	0.27	33
1981-82	12458	2.6	324	0.25	81	4200	3.0	126	0.25	32
1982-83	12458	2.6	324	0.23	75	5269	3.6	190	0.23	44
1983-84	12458	2.6	324	0.21	68	7461	4.3	321	0.21	67
1984-85	12458	2.6	324	0.20	65	7255	4.9	355	0.20	71
1985-86	12458	2.6	324	0.18	58	7994	6.2	496	0.18	89
1986-87	12458	2.6	324	0.17	55	8129	7.5	610	0.17	104
1987-88	12458	2.6	324	0.16	52	9421	8.7	820	0.16	131
1988-89	12458	2.6	324	0.15	49	10396	8.5	884	0.15	133
1989-90	12458	2.6	324	0.14	45	9982	8.3	826	0.14	116
1990-91	12458	2.6	324	0.12	39	11356	8.1	920	0.12	110
1991-92	12458	2.6	324	0.11	36	11769	7.9	930	0.11	102
1992-93	12458	2.6	324	0.10	32	13955	7.7	1075	0.10	108
1993-94	12458	2.6	324	0.10	32	12970	7.6	986	0.10	99
1994-95	12458	2.6	324	0.09	29	14739	7.5	1105	0.09	99
1995-96	12458	2.6	324	0.08	26	14840	7.5	1113	0.08	89
1996-97	12458	2.6	324	0.08	26	14223	7.4	1053	0.08	84
1997-98	12458	2.6	324	0.07	23	15108	7.4	1118	0.07	78
Total		**Rs. (million)**	**7067**	**i. Rs. (million) ii. $ (million) : - 1965 Prices - 1998 Prices**	**1315 276.2 1428.3**		**Rs.(million)**	**13391**	**i. Rs. (million) ii. $ (million) - 1965 Prices - 1998 Prices**	**1695 356.1 1841**

1. *Assuming generation of 83 kWh per million BTU costing Rs.2.142 (45 cents) in 1965 prices.*
2. *Assuming generation of 83 kWh per million BTU and actual costs in 1965 prices.*

Virtually all the thermal generation in these programs was assumed to be gas-fired. The only significant exception was a small amount of nuclear capability included in the south in each of the programs for the early 1980s. Natural gas was also assumed, for these analyses, to have a uniform price throughout West Pakistan.

3.6.3.4 Programs Including Tarbela vs Cheapest Alternative

Power programs that included Tarbela, as discussed in the Lieftinck Report, were cheaper than the cheapest alternative, in terms of the discounted price at all fuel prices above 20 cents per million British Thermal Units (BTU). Even at 20 cents per million BTU, the fuel savings achieved in a 'with Tarbela' program, were about $40 million. However, the estimates suggested that a reasonable middle range for comparing programs with and without Tarbela (in terms of contribution to overall energy supply), might be at least 40–50 (average 45) cents per million BTU. Thus, the program including Tarbela versus the cheapest (thermal) alternative would have a benefit of around $160 million at 1965 prices (refer Table 3.39).

3.6.3.5 Power Benefits of Tarbela and Shadow Prices

The valuation of the costs and benefits of Tarbela in the Lieftinck Report in terms of current prices resulted in underestimation, and Tarbela looked less attractive when foreign exchange was valued at its scarcity price than when it was valued at the current official price. This was in line with what might be expected: all foreseeable power generation and transmission programs would make intensive use of capital equipment purchased with foreign exchange, but programs including Tarbela would involve somewhat greater use of foreign exchange and somewhat less use of locally available fuels.

An analysis were also carried out using a combination of shadow foreign exchange rates and shadow fuel prices to determine when Tarbela became preferable to a thermal (or Kunhar) alternative. It was based on a shadow foreign exchange rate of 1.6 times the current rate of Rs.4.76 to the dollar (ie Rs.7.6 per dollar). It indicated that at the current foreign exchange rate, a program including Tarbela was preferable to the cheapest alternative at thermal fuel prices above 9 cents per million BTU. At two times the current exchange rate, a program with Tarbela was preferable to the cheapest alternative at any fuel price above 15 cents per million BTU. Considering all the above factors it was estimated, therefore, that benefits taking into account the foreign exchange variance, appeared to be something in the order of the $160 million (refer Table 3.40).

3.6.3.6 Predicted vs Actual Economic Power Benefits

As per the Lieftinck Report, the predicted economic power benefits of Tarbela versus the cheapest alternative (thermal) at various fuel prices and exchange rates are summarised in Table 3.40. Annex 6 also indicates actual Tarbela economic benefits to power, determined on the basis of savings in generation cost per kWh at Tarbela, and most efficient gas-fired plant in the WAPDA System.

It is evident (refer Table 3.40) that actual discounted economic power benefits (8% to 1965 prices as in the Lieftinck Report) from Tarbela of $225 million over the period 1977-98 exceeded by about 41% the maximum planned benefit of $160 million at the official exchange rate of Rs.4.76 to $1.00. The corresponding benefits at the shadow exchange rate of Rs.9.52 to $1.00, amounting to $113 million, were also close to the maximum predicted benefit of $130 million. In 1998 prices, the actual power benefits of $225 million equalled $1 163 million (refer Annex 6).

The main contributing factor was manifold increases in the gas price in Pakistan. Starting from Rs.12 per million BTU in 1982, it increased to: Rs.24 (1985); Rs.48 (1988); Rs.56 (1991); Rs.68 (1994); and Rs.102 (1998). Corresponding to 1965 prices these varied between 53 to 129 cents with an average of

115 cents. Even considering the maximum planned fuel price of 45 cents this was about 2.5 times higher.

Table 3.40. Planned/Actual Economic Power Benefits of Tarbela

Basis	Present Worth of Costs in 1965 Prices ($million)[1]					
	Programme excluding Tarbela		Program including Tarbela		Tarbela Benefits due to Avoided Costs	
	Current Exchange Rate[2]	Shadow Exchange Rate[3]	Current Exchange Rate[2]	Shadow Exchange Rate[3]	Current Exchange Rate[2]	Shadow Exchange Rate[3]
i. Planned Fuel Price Per million BTU						
15 US Cents	520	820	520	820	0	0
20 US Cents	570	850	530	840	40	10
30 US Cents	650	920	555	860	95	60
40 US Cents	720	1000	580	890	140	110
45 US Cents	750	1030	590	900	160	130
ii. Actual (1977-98) [4]					**225** [5]	**113** [5]

1. *At 8% discount rate and extracted from Supplemental Paper VII Power Aspects of the Tarbela Project, Vol. III, Lieftinck Report.*
2. *1$ = Rs.4.76*
3. *1$ = Rs.9.52*
4. *On the basis of savings in generation cost per kWh at Tarbela and most efficient gas-fired plant in the WAPDA System.*
5. *Discounted @ 8% to 1965 prices for comparison with Lieftinck Report as per supporting computations in Annex 6.*

3.6.4 Dynamic Benefits

By virtue of their characteristics, large hydropower plants like Tarbela have a substantial ability to govern and stabilise power systems. They contribute to a number of functions which thermal plants or other facilities would otherwise have to perform. Besides a quick response to peak demand, these include frequency/voltage control and synchronous condenser operations. The importance of Tarbela in this respect can be appreciated from the fact that its installed capacity constitutes a substantial part of WAPDA’s integrated power system: 27% at the time of commissioning in 1977; 43% in 1982; 40% in 1985; and 43% in 1993 after the installation of 14 units. Even at present (1998), it constitutes about 38% of the WAPDA system and about 22% of the overall system including private installation.

In a power system where large hydropower stations like Tarbela are used for system control and peaking, the resultant dynamic benefits are quite significant. According to recommendations in the May 1984, Boston, "Symposium on the Dynamic Benefits of Energy Storage Plant Operation", the estimates vary from $20–$50 per installed kW per year. However, the average value of $35 has been assumed for Tarbela. The present worth of computed benefits discounted at 8% to 1965 prices, comes to about $60 million (Annex 7). In 1998 prices, it was equivalent to $310 million

3.6.5 Avoided Thermal Plant Emissions

One of the key arguments advanced in favour of hydropower over thermal power generation is the avoidance of emissions that may influence global warming through combustion of fossil fuel. This is a contentious area where there are as yet few hard and fast rules concerning how calculations should be made. Including this aspect in the methodology, however, is recognising this potentially important issue in the planning and implementation of dams.

When TDP was planned, no explicit values were attributed to savings in thermal (predominantly gas-fired) plant emissions as a result of its power operations. An attempt has been made to estimate the avoided thermal plant emissions corresponding to the energy actually generated at Tarbela over the years 1976-77 to 1997-98. Using the prevalent standards for efficient combined cycle gas-fired plants, the thermal emissions avoided through hydropower generation at Tarbela have been computed. Depending on the power system characteristics, one avoided ton of: SO_2 emission can be valued at \$100–500; NOx at \$50–200; and partite material (PM) at \$100–500. Avoided CO_2 emission is a global benefit, with widely varying values, ranging from \$2 per ton (cheapest cost of sequestering CO_2), to hundreds of dollars per ton (an estimate of actual damage due to climatic change). A figure of \$7 per ton is used in our calculations, that is, the current value applied by the Global Environmental Facility (GEF).

Computed thermal plant emissions over the period 1977-98 and the resultant equivalent avoided costs are indicated in Table 3.41.

Table 3.41 brings out significant benefits through avoided economic costs of thermal plant emissions. More than 95% of the avoided thermal plant emission value is due to CO_2 which constitutes a global rather than regional or local benefit. However, the precise values to be attributed to this effect, and the role they play in assessing the costs and benefits of alternatives, is debatable.

Table 3.41. Estimated Emission Levels from Thermal Plants with Equivalent Hydropower Generation at TDP

Parameter	Estimated Emissions (Tonnes)[1]	Cost At 1998 Price Level		Main Impact
		Per Tonne (\$)	Total (\$ million)	
CO_2	116 000 000	7	805	Global warming
SO_2	389	300	-	Acid rain, respiratory problems
Nox	294 000	100	29	Acid rain
PM	11 700	100	1	Respiratory Problems
		Total :	835[2]	

1. *As per supporting computations in Annex 8.*
2. *Equivalent 1965 Prices = \$162 million*

3.6.6 Quantification of Overall Economic Benefits from Power

The overall economic power benefits of Tarbela could be primarily attributed to the avoided cost of thermal generation. The incidental benefits due to dynamic impact of Tarbela and avoided emissions were also significant as per position summarised in Table 3.42.

Table 3.42. Overall Contribution of Tarbela to the Economic Value of Hydropower*

S. No.	Cost Item	Estimated Benefit (\$ million)	
		1965 prices	1998 prices
1.	Avoided Thermal Generation (primary)	225	1163
2.	Dynamic Benefits (incidental)	60	310
3.	Avoided Emissions (global)	162	835

* *Based on WCD methodology*

It may be noted that the primary benefits of the avoided cost of thermal generation estimated at \$225 million in 1965 prices (\$1 163 million 1998 prices) were about 41% higher that the predicted amount of \$160 million over the total useful life of reservoir. Notwithstanding somewhat lower generation than prediction, these higher benefits have been realised due to: about 66% higher power installation costs (effective 1993) against prediction; more than expected (about 7%) storage release essentially during the *rabi* season; and almost a tripling of the gas-price by the late 1980s.

3.6.7 Impact of Tarbela on Power System Operations

Although the generation of power is essentially a by-product of Tarbela, in actual operations Tarbela has made a sizeable contribution to the inter-connected national power system of Pakistan. The variability of generation at Tarbela from year to year has been due to a combination of factors such as: staged power installation over a period of 17 years (1978-94); overall system demand; and hydrology. Variations in annual generation during various development stages of Tarbela power and its overall share in the total system and hydel component follow:

- Stage I – 700 MW (1978-82): Average annual generation was about 3 900 Gwh with variations between 3 400 to 4 200 Gwh. The corresponding contribution of energy to the WAPDA System averaged 32% with variations between 28 and 35%. Tarbela's share in overall hydel generation was around 45% with minor variations between 44 and 47%.
- Stage II – 1 400 MW (1983 & 1984): This was a short two-year period during which the impact on WAPDA Power System was transitory.
- Stage III – 1 750 MW (1985-91): Average annual generation was about 9 200 Gwh with variations between 7 300 and 11 400 Gwh. The corresponding contribution of energy to the WAPDA System averaged 35% with variations between 33 and 39%. Tarbela's share in overall hydel generation was around 58% with variations between 53 and 62%.
- Stage IV – 2 614 MW (1992-93): This was again a short two-year period during which the impact on the WAPDA System was transitory.
- Stage V – 3 478 MW (1994-98): This was the stage of full development during which average annual generation was about 14 400 Gwh with variations between 13 000 and 15 100 Gwh. The corresponding contribution of energy to the WAPDA System averaged 30% with variations between 28 and 32%. Tarbela's share in overall hydel generation was about 66% with variations between 64 and 68%.

The above analysis shows that, notwithstanding year to year variability of generation, Tarbela contribution to the WAPDA System remained well over 30%. As regards its share in the hydel generation, it progressively increased: to 45% (1978-82); 58% (1985-91); and 66% (1994-98). Thus, despite a very major switch in thermal contribution to the WAPDA System (from 26% in 1978 to 59% in 1998), the Tarbela contribution was always on the increase, without any visible impact of year to year energy variations.

Whereas the overall economic benefits are covered in section 3.6.6, the following impacts on power system operations also need to be highlighted:

- Due to large capacity development (3 478 MW against the predicted 2 100 MW) the project has become not only helpful in peaking and frequency regulation in the WAPDA power system but a major contributor of energy.
- Though the average energy production so far (refer Table 3.38) has been somewhat lower than predicted, primarily due to delays in initial power installation, the operation has generally benefited power generation during the critical periods. This has come about due to a combination of favourable deviations from predictions by way of additional storage release during *rabi*; and significantly higher reservoir levels during the critical period from March to June.
- While releasing water above the minimum irrigation requirements during the annual canal closure period of December/January, a reasonable trade-off was made between water and power needs. Furthermore, sufficient storage was retained to carry over to the end of draw-down season in May for meeting the irrigation needs of early *kharif* crop sowing.
- A preliminary assessment has been made of the possible additional power generation through release of retained Tarbela storage and benefits foregone due to unserved energy during load-shedding. This indicates that invariably the value of retained storage was substantially more than the scarcity value of unserved energy (supporting computations in Annex 9).

3.6.8 Unexpected Benefit

Under the 1973 Constitution of Pakistan, any hydropower facility located in a province will be entitled to a royalty payment. According to an *ad hoc* formula devised by the Federal Government, NWFP is presently receiving about Rs.6 billion per annum from WAPDA on this account. The amount thus received is treated as revenue by the provincial government and pooled with other resources for the annual budgets.

TDP has also made feasible the 1 450 MW under implementation of the Ghazi-Barotha Hydropower Project (GBHP) that would utilise the regulated outflows from the reservoir. This was not envisaged at the time of planning Tarbela. The estimated contribution to the average annual generation of this project from Tarbela would be about 20% (or 1 353 out of 6 586 GWh).

Findings on Hydropower

- The direct economic benefits of hydropower generation from Tarbela are estimated at $225 million (present worth at 8% discount rate for 1965 prices), with a 1998 price equivalent of $1 163 million. Against this, the Lieftinck Report predicted $160 million ($828 million in 1998 prices). These benefits have been achieved over the first 22 years (1977-98) of actual operation, against the assumed 50 years useful life of the project.
- The indirect economic benefits due to the dynamic impact and avoided greenhouse gas emissions have also been estimated as sizeable. These are, respectively, $60 million in 1965 prices ($310 million in 1998 prices) and $162 million in 1965 prices ($835 million in 1998 prices).
- Despite somewhat delayed installation in power units, actual average generation has been about 78% of the predicted. Further, due to development of 3 478 MW capacity as compared to the predicted 2 100 MW, the prevailing (1993-98) average annual generation of about 14 300 GWh is 13% higher than the original prediction. This feature has also made Tarbela helpful for peaking and frequency regulation in the WAPDA system.
- Due to about 7% excess storage releases during the dry *rabi* season, as compared to the projected, the year to year fluctuations in power output have somewhat stabilised. There has been a reasonable trade-off between water and power needs particularly during the annual canal closure period of December and January. A preliminary assessment supports the fact that the value of retained storage for subsequent use was invariably more than the scarcity value of unserved energy as a result of load-shedding.
- Over the period 1976-78, the net revenue attributable to Tarbela hydropower aggregated to Rs.101 and 152 billion respectively on the basis of 40% and 60% attribution. Against this, the corresponding aggregated O&M costs (for both water and power) were Rs.21.5 billion.
- Due to a provision in the 1973 Constitution of Pakistan, NWFP is presently receiving from Tarbela, a Rs.6 billion ($0.14 billion in 1998 prices) annual royalty.
  Tarbela has made feasible the 1 450 MW Ghazi-Barotha Hydropower Project (GBHP) not envisaged at the time of project planning. Regulated Tarbela reservoir outflows would contribute around 20% of the annual generation on GBHP.
- Although collection of electricity charges by WAPDA has improved overtime, there is still major pilferage in the system and thus revenue collection falls short of established targets

3.7 Flood Control

3.7.1 Effect of TDP in Attenuating Flood Peaks

Tarbela dam was not basically designed for flood management. However, within the design limitations and management procedures followed, the Tarbela reservoir provides limited attenuation of flood peaks. The prevailing low to very high flood limits below Tarbela vary between 7 085 to 22 671 m^3/sec. The valley immediately downstream of Tarbela can take high discharges safely without causing extensive damage. It is, however, desirable to temporarily hold Indus flood peaks in the reservoir and then affect their controlled subsequent release to prevent synchronisation with peaks of other tributaries at downstream locations. On the other hand, the safety of dam is warranted at all costs. For this purpose, the design criteria for flood routing through Tarbela reservoir are based on three elements. Firstly, all major floods are routed at the maximum conservation level of 473m through the spillways which have a capacity of 42 225 m^3/sec. Secondly, a designed flood of 50 244 m^3/sec is routed through the existing outlet facilities with a nominal surcharge of 0.6m above the maximum conservation level of 473m. Thirdly, a probable maximum flood of 60 276 m^3/sec is handled by various outlets with a surcharge of about 2.1m above the conservation level, still having a free board of about 2.4m to the top embankment elevation of 477m.

Reservoir filling criteria, though developed by WAPDA from safety considerations, can also provide limited flood regulation. Maximum allowed changes in reservoir levels are limited to 3m per day up to an elevation of 460m. Above an elevation of 460m the filling criterion is 0.3 m/day. If the monsoon is weak, then it becomes 0.6 m/day above this elevation.

Normally the floods on the Indus occur during the months of July and August. However, during 1992, the flood occurred in September. The filling of the reservoir in the early period can help to attenuate flood peaks, whereas in late floods there is hardly any significant storage available to attenuate the peaks.

Flood regulation is, therefore, an incidental aspect of Tarbela. Filling of the reservoir is accomplished based on 'Rule Curve' criteria evolved from estimated inflows and irrigation requirements. During actual filling of the reservoir, ‘Rule Curve’ is followed as far as possible with incidental flood regulation within this envelope.

By ensuring the availability of catchment information at Tarbela, and using flood routing procedures, while simultaneously accessing information about inflows from downstream tributaries (the Kabul, Soan and Kurram rivers and the Panjnad discharge before its confluence with the Indus), flood peaks can be somewhat attenuated at Tarbela and later at Chashma to avoid the incidence of high peaks in downstream locations. Relevant data of peak reservoir inflows/outflows is given in Table 3.43, which shows that peak flows in July 1988, July 1989, and August 1997 were reduced by 21%, 26% and 43% respectively. On the other hand, a peak flow of almost similar magnitude in September 1992 was attenuated by only 2% as the reservoir was very close to the maximum level.

There was a reduction in overall, flood frequency/heights due to the cumulative impact of progressive upstream diversion and storage water including Tarbela. The impacts in this regard are dealt with under section 3.12 on "Environmental Effects".

Table 3.43. Peak Inflows and Outflows at Tarbela Dam

Period	Peak Inflow (m^3/sec)	Peak Outflow (m^3/sec)
23-7-88	13605	10765
31-7-89	14456	10739
10-9-92	14966	14682
27-8-97	11338	6431

Source: Flood Management Manual and peak flood data obtained from TDP Monitoring Organisation, 1999.

3.7.2 Downstream Benefits of Controlling Floods

Floods in the Indus basin occurred in the years 1929, 1950, 1955 to 1959, 1973 (PANCID, 1997) and 1975, 1976, 1978, 1981, 1988 and 1992 (Shams-ul-Mulk, 1993). Total monetary loss since 1947 has been estimated at Rs.78 billion with a loss of 7 530 lives. Basic loss is to irrigation, drainage and communication infrastructure, industrial installations, and agriculture. There is tremendous loss to small-scale private property, which is seldom accounted for or compensated. Assistance is provided to affectees on a donation basis. Above all, the loss of human life and suffering cannot be translated into monetary terms. Therefore, even incidental or manipulated shaving of very high flood peaks through Tarbela, as in 1997 (Table 3.43), could significantly contribute to avoidance of synchronisation at the critical locations downstream.

Planning for flood control in the Indus basin was started since 1861 (Govt. Sindh, 1954 – Bund Manual). In 1973 the Federal Government entrusted the responsibility of flood management to the Flood Control Committee instead of the Provincial Irrigation Departments. This was, in fact, an arrangement to co-ordinate the provincial efforts. In 1977, the Federal Flood Commission was constituted to formulate flood management and protection plans at national level. For the purpose of flood forecasting, the National Flood Forecasting Bureau was established at Lahore and all federal and provincial organisations work with it for real-time flood management.

Other impacts of flooding and flood control are described in section 3.12.2: Description of the Indus Basin Ecosystems.

Findings on Floods

- The contribution to flood control of dams in Pakistan and particularly Tarbela is incidental, because no specific provision in this respect was made in the original design.
- Normally the floods at Tarbela occur during July and August. Filling of the reservoir in the early period (June to August) can help to attenuate flood peaks, whereas in late floods (September) there is hardly any storage capacity available to attenuate the flood peaks.
- The impact of TDP on attenuation of high flood peaks during the filling period was, in some cases, quite significant (Table 3.43).

3.8 Municipal and Industrial Water Supply

No predictions were made for municipal and industrial water supply in the Lieftinck Report and at the planning stage. More recently, water needs by other sectors of the economy in Pakistan, such as municipalities and industries, have assumed considerable importance and priority, although the overall quantity used by these sectors remains marginal as compared to water use by the irrigation sector. Less than 5% of total water resources are used, for example, for municipal consumption (WB, 1994). Competition over water resources between sectors has been limited to specific areas close to large cities and industrial complexes. However, the demand for human and industrial water consumption is increasing with economic development and population growth (GOP, 1992). The main issues requiring attention include competition for groundwater use (quantity), and problems of effluents and pollution of irrigation water (quality).

Groundwater in almost 60% of the Indus basin (essentially Tarbela command) is marginal to brackish in quality and not fit for human consumption or use in industry (Zuberi and Sufi 1992). Several major cities including Karachi and Faisalabad are already suffering from acute shortage of fresh water for municipal and industrial use. TDP has indirectly augmented the supply of water for municipal and industrial use through direct use of canal water and pumping of seepage water through shallow tubewells, but this has not been quantified.

Only 53% of the population in Pakistan have access to piped water – including 79% of those in urban areas and 40% in rural areas (GOP and IUCN, 1991). Even within urban areas, only 40% of households or individuals have access to piped water or connections to their homes. Therefore, the majority of the population either depends on shallow groundwater, or on surface water from rivers and canals. It is estimated that presently, about 75% of Pakistan's population (105 of 140 million) reside in the command of IBIS. At least half of this population, say, 53 million, in the area of brackish/marginal, quality groundwater is dependent on canals for drinking water. Similarly, about 20% of Karachi's population (around 2 million) can be assumed to have benefited from the increased water supply via Kotri barrage. Thus, it is estimated that presently around 55 million people (about 40%) may be benefiting to some unquantified degree from the waters of the Indus that are supplemented by Tarbela storage during the dry season.

3.8.1 Fresh Groundwater Zone

In the fresh groundwater zone, the additional recharge due to seepage from canals helped to raise the water table especially in the Punjab province (WAPDA, 1979). The groundwater in 90% of the four *doabs* and Bahawalpur area in the Punjab province is freshwater and fit for irrigation and domestic use (Table 3.44). The pumpage cost from shallow depths is less and therefore motorised pumps are being used to pump water.

Table 3.44. Quality of Shallow Groundwater in Various Zones of Punjab Province

Zones	Total Area (mha)	Percent Area with Total Dissolved Solids in ppm		
		<1000	1000-2000	>2000
Thal Doab	2.58	96.6	1.7	1.7
Chaj Doab	1.14	90.0	6.2	3.8
Rechna Doab	3.04	88.3	9.1	2.6
Bari Doab	3.16	91.1	4.8	4.1
Bahawalpur	1.53	82.3	4.9	12.8

Source: Revised Action Program, Master Planning and Review Division, WAPDA, 1979.

Additional water from Tarbela dam has enhanced the availability of fresh groundwater (FGW) in Taunsa command of lower Thal Doab, through recharge from canals (see section 3.4.4.1 on groundwater recharge). Simultaneously, the demand for municipal and industrial water has grown in this area due to population growth and increased economic development including the establishment of small-scale industries. In the absence of TDP, freshwater groundwater in this area would have been mined, with much more serious consequences, around urban and sub-urban areas.

3.8.2 Brackish Groundwater Zone

WAPDA has classified groundwater in the Sindh province at most places (89%) as brackish and unfit for irrigation or domestic use. The rural and urban communities in the brackish groundwater zone are directly dependent on canal water for their domestic requirements. The recharge from the canals partly due to additional water supplies from the Tarbela reservoir has resulted in the creation of a very thin layer of freshwater underlain by the brackish groundwater. The rural and peri-urban communities in these areas have installed shallow hand pumps to skim the fresh water (GOP and IUCN 1991; GOP 1992) (Table 48).

In Sindh province, and predominantly in Karachi, 92% of the urban area depends on surface water supplies. TDP has helped to provide enhanced surface water supplies to cater for the major needs of the growing population of the Karachi metropolitan area.

Table 3.45. Canal Commands and Quality of Shallow Groundwater in the Sindh Province

Canal	Barrage	Command Area (mha)	Percent Area	
			Freshwater	Brackish (>3000 ppm)
Begari Feeder	Guddu	0.340	50.0	50.0
Ghotki Feeder	"	0.368	50.0	50.0
North West Canal	Sukkur	0.309	15.0	85.0
Rice Canal	"	0.210	22.0	78.0
Dadu Canal	"	0.244	16.0	84.0
Khairpur West Canal	"	0.195	100.0	0.0
Khairpur East Canal	"	0.182	0.0	100.0
Rohri Canal	"	1.045	55.0	45.0
Nara Canal	"	0.883	0.0	100.0
Kalri Baghar Feeder	Kotri	0.257	0.0	100.0
Lined Channel	"	0.22	0.0	100.0
Fuleli Canal	"	0.361	0.0	100.0

Source: Revised Action Program, Master Planning and Review Division, WAPDA, 1979.

Findings on Municipal Industrial Water Supply

- In most of IBIS under command of Tarbela, supplies from canals and shallow groundwater are used for drinking and cooking purposes. The amount has not been quantified.
- It is estimated that at present a population of over 50 million in Tarbela canal commands is benefiting to some degree from supplements to the drinking water supply by the project in the *rabi* season.
- Karachi is the largest metropolis in Pakistan (present population of 10 million) and mostly fed by Indus water for its municipal and industrial needs.

3.9 Recreation and Tourism

The Lieftinck Report did not mention recreation or tourism as a secondary benefit of the dam. Nor was there any exploration of the reservoir and how it might contribute to the rather restricted tourism industry in the country. The economic analysis at the time of appraisal did not account for any recreation benefits.

The pre-dam situation at the site was rather non-conducive for tourism. The area of the upper catchment known as *Dakas,* fell under a tribal life-style, and crimes such as robbery, burglary, the illegal arms trade, and poppy production were common. All these social evils restricted the movement of those seeking recreation (USAID, 1993/94).

Whereas several types of facilities are most attractive to tourism in the area, especially water sports, government policy has discouraged and prohibited such activities around the reservoir. Some minor navigation also takes place along the upper reservoir and it has helped reduce long travel distances by foot for the local population. WAPDA's own guesthouse facilities at the dam provide excellent accommodation to the incoming visitors. The dam has several boatmen providing services around the reservoir and there are some shops and small hotels in the nearby townships. Most visitors are locals (foreigners require special permission) who visit the dam as school groups, study tours, government sponsored visits of various dignitaries and so forth. They come mainly to see the scenic views around the reservoir, and to enjoy water sports upstream, away from the main structure. Fishing is only permitted with a license. A review of WAPDA data and that from its security section, clearly suggests that people passing through the Tarbela area are termed as visitors, even if they are going to Topi or into NWFP via Swabi. There is a small airfield about 20km from the dam that was constructed for use by WAPDA and its contractors. At present, the airfield is not operational and is surrounded by Afghan refugee villages.

The Tarbela field survey revealed that there is potential to promote the dam as a tourist resort. Amongst nine key informants interviewed in October 1999 about the prospects for tourism, only two stated that tourist activity significantly contributed to their income. Most tourist traffic comes between June to August and again in February to March. Most of the tourists are Pakistanis. The main attraction on the dam is the lake and spillway. All key informants said there were no facilities for visitors who visit the dam for a day only. The anticipated likely affects of tourism would be better awareness amongst the local population, job opportunities and improvement in income. There was some apprehension that water pollution and general upkeep of the surrounding lake would be affected as facilities to manage the dam as a potential recreation site are lacking. However, present government policy strictly prohibits such developments. In October 1999, the government employed special security measures around Tarbela in the wake of heightened concerns over terrorism.

3.10 Social Effects

The human dimension of Tarbela dam is the least well understood. In addition to a lack of scientific documentation on the sociological aspects of the Indus River and the impacts of water development schemes, there is limited understanding of the issues or even debate on how people are affected by such changes.

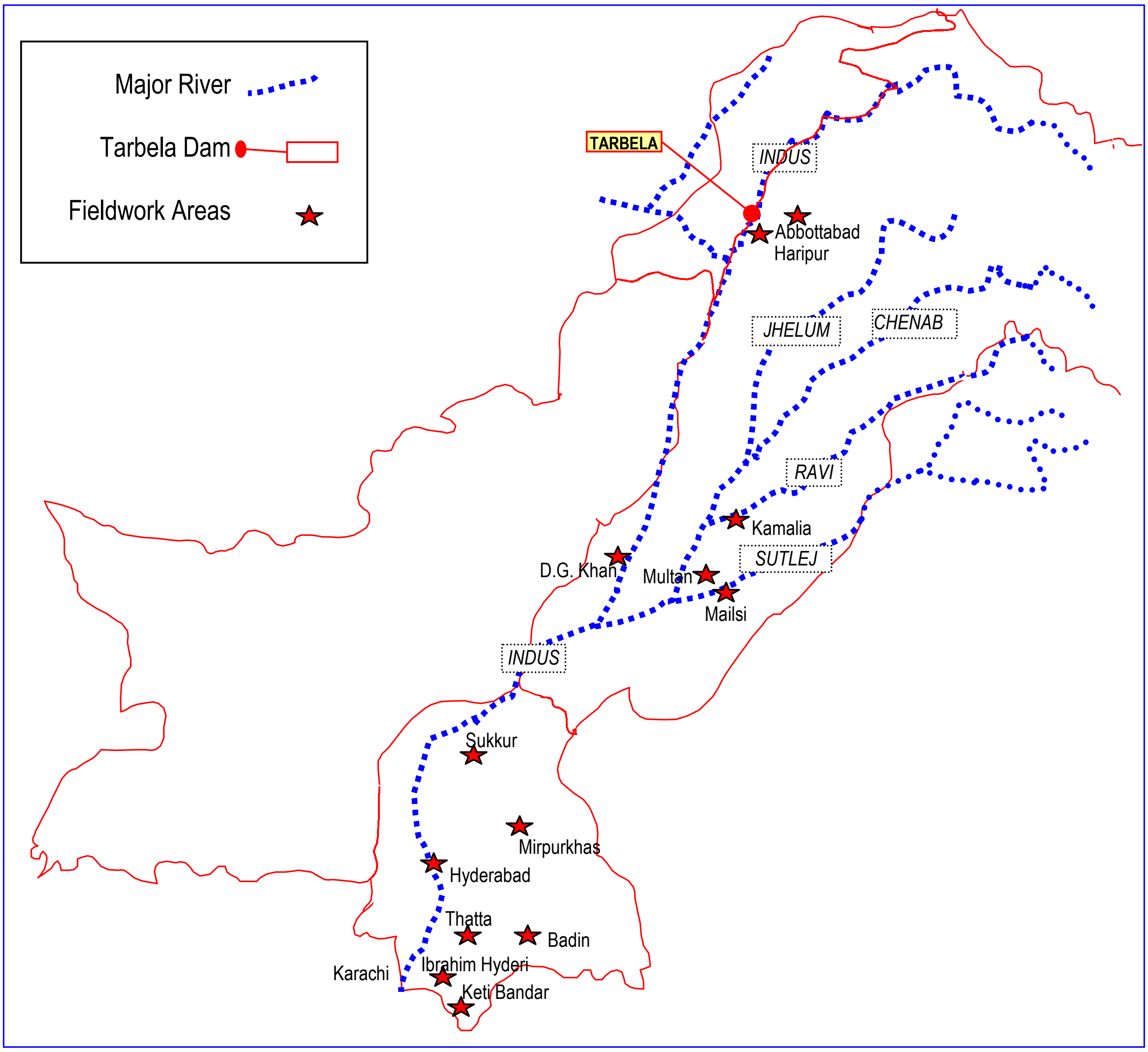
Resettlement policies and procedures established for TDP were implemented under the provisions of the Land Acquisition Act of 1894 according to the decisions taken at the high level meeting of May, 1967 under the chairpersonship of the then President of Pakistan, General Muhammad Ayub Khan. The act, drafted over 100 years ago, while suitable at the time of its conception perhaps had shortcomings for settlement, rehabilitation and development activities in the1960s and 1970s. The objective of resettlement and rehabilitation of affectees, as currently followed by the GOP is that it should, at the very least, restore the quality of life prior to project development.

In this sub-section issues relevant to resettlement, environment, and livelihood are discussed. The discussion is organised around focal issues and resettlement is dealt with in some detail. Livelihood issues follow this. For the purpose of this study, the Indus basin was divided into two areas: upstream (the area around the reservoir and nearby areas of Haripur district); and downstream (below Attock).

The downstream aspects of the Punjab are represented by the fieldwork conducted in Multan, Mailsi, Muzaffargarh, Dera Ghazi Khan and Kamalia while downstream Sindh is covered by the areas of Mirpur, Thatta, Badin and Keti Bandar (Figure 3.13). Thatta, Badin and Keti Bandar represent the areas below Kotri with significant environmental impacts on livelihoods, delta regions and mangroves. Details regarding the methodology of the fieldwork are provided in Annex 10.

This sub-section also addresses questions such as: acquisition of land for the project; families affected; resources allocated both in terms of money and alternate land, projected and actual; and families already settled and yet to be settled. A comparison was possible only if government departments, NGOs and communities (the affectees) were approached for data. Government departments including WAPDA, Revenue, Irrigation, Agriculture, and Fisheries were contacted to get the pertinent information. Socio-economic aspects of the settled and yet to be settled families, beginning with their occupation, their income, education, change in cultural values and the other impacts on their lives are possibly even more important. Information was obtained from government departments, through stakeholders' workshops, public hearings, key informants from communities, NGOs, local councillors and community leaders/members and the affectees. Primary as well as secondary sources of information were used to collect the required information. The data collected from these sources was presented at the stakeholders' workshops held on November 2, 1999 at Haripur and on November 13, 1999 at Muzaffargarh, and was endorsed by the participants. (Brief reports on the deliberations of the Haripur and Muzaffargarh workshops are presented in Annex 10 - Appendix A & B.) During the formal survey the sample size varied by area and occupation. The sample size from the five hamlets in the upstream area around Haripur was 249. Out of the affectees settled in Mailsi, Toba Tek Singh and the Kamalia area, 169 respondents were randomly picked representing different livelihoods such as agriculturists, orchard owners, and livestock ranchers.

Figure 3.13. Downstream Field Work Areas



3.10.1 Resettlement

Issues pertaining to resettlement are complex and inter-linked; this partially explains why many remain unresolved to this day. At the time of design it was predicted that 80 000 people would be resettled and about 100 villages would be submerged**.** In May 1967 it was decided that those who had a minimum of 0.2 ha of irrigated and/or 0.8 ha of non-irrigated land would be eligible for alternate land. In Punjab, each eligible affectee would receive a minimum of 5 ha and a maximum of 20 ha. In Sindh the minimum was set at 6.5 ha, but affectees were given an option to purchase more land. The total eligible affectees including those from the tribal areas were 5 317. These families were to be resettled in nearly townships and provided with alternative land in the Punjab and Sindh. The procedures adopted for the allocation of such lands, problems encountered by the affectees and the outstanding issues they face to date are discussed below.

The predicted numbers of displaced persons is compared with the actual numbers. This is an issue of some controversy, and is discussed in this section. The confusion has arisen partly from the definitions of an affectee and displaced person. For this study the comparison is restricted to the resettlement of the population surrounding the reservoir and no downstream resettlement statistics are used, as none of those displaced downstream were resettled. Eligibility criteria, anomalies experienced during the award process, and the outstanding issues are covered in the remainder of this section**.**

Area and Population Affected

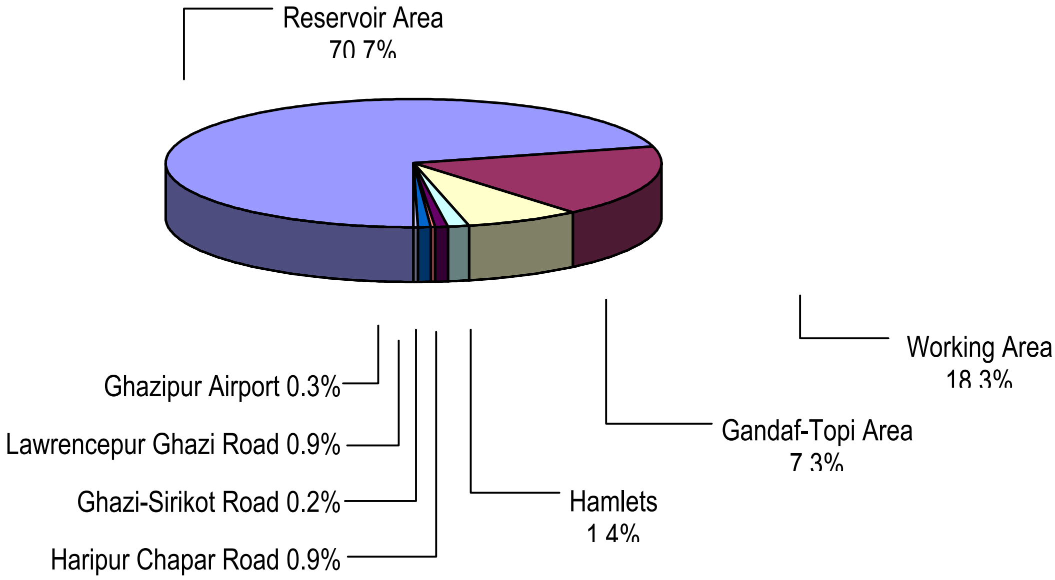
Two types of information have been utilised to review the resettlement issue. The first set is based on government and donor reports. To supplement this information and to obtain first hand data, a sample survey covering all five major hamlets that were established to resettle the affectees, was undertaken. During surveys, information was collected through public hearings, focussed group discussions, formal surveys, and meetings with NGOs/CBOs. A review of this information revealed that the dam affected about 33 200 hectares in 135 villages. A total of 96 000 persons, ie about 10 000 families (or households: the married sons invariably live with the father as a joint family system and the family land is not divided until the father dies), were displaced, and 120 villages were submerged. This can be compared to the predicted 80 000 people and 100 villages. The maximum population of any village affected was 2 000 persons while the minimum was 150. About 45% of the affected population were below 20 years of age and 35% within the age group 20–60 years. The main occupation of those displaced was agriculture, while 5% worked as artisans or semi-skilled workers and another 2% earned their livelihood as boatmen transporting people and material between the river banks (Tariq, 1993). Since the area is hilly, it was estimated that only 46% of the land is cultivable and capable of supporting human populations. To resettle the displaced persons both the Punjab and Sindh governments allocated 12 000 ha in their respective provinces. Those owning less than 0.2 ha of irrigated land or 0.8 ha of rainfed land were given cash compensation, while those above these limits were to be allotted a minimum of 5 ha of canal-irrigated land.

Most of the inundated area was situated in:

- Former State of Amb, Hazara Division
- Tribal area of district Mansehra
- District Swabi
- Alpuri Tehsil of district Swat

Ethnically, the inhabitants from the above areas were of Tanoli origin from the Hazara Division and administratively fell under the Nara Amazai and Beetgali union councils. They were Pushto and Hindko speaking Muslims. The economy consisted of landlords and tenants involved in subsistence agriculture. Most land coming under water was *barani* (rainfed) having 75–100cm rainfall per annum. Maize and a local wheat variety were cultivated in the area. Most displaced persons were of rural background and relied on agriculture and had minimum access to social services. Some were large landowners of Amb State settled on the left and right banks of the river, with their tenants (who were treated like slaves). These tenants had a bare minimum to eat and did not own any land or house. These landless affectees were compensated with residential plots in the five hamlets developed by WAPDA. The area acquired for the project is shown in Figure 3.14. Similarly, the utilisation of the acquired area is shown in Table 3.46.

Figure 3.14. Area Acquired for Tarbela



Source: WAPDA and NGO Report

Table 3.46. Utilisation of the Acquired Area

Utilisation	Area (hectare)
Total Land Acquired	33221
Reservoir Area	22579
Working Area	6069
Gandaf-Topi Area	2419
Hamlets	492
Haripur-Chaptar Road	288
Ghazi-Sirikot Road	55
Lawrencepur-Ghazi Road	310
Ghazipur Airport	117

Five new townships and several hamlets were developed by WAPDA for the resettlement of the displaced people (Table 3.47).

Experience gained from the resettlement of large numbers of refugees from India that took place at the time of partition, was used by the government to develop resettlement procedures for the Tarbela affectees. Precedents on compensation rates were available from the Mangla dam experience.

Table 3.47. Number of Affected Villages Settled in the Five Hamlets

S. No.	Name of Hamlet	No. of Villages	Population
1	Ghazi	4	3000
2	Khalabut	84	33300
3	Kangra Colony	4	2580
4	Pehur	4	2400
5	New Darband	4	1800
6	Hamlets spread over Chapar road, Haripur, Darband Road, Swabi and Raqibabad	30	30000
7.	Migrated to other towns like Fatehjang, Rawalpindi, Lahore, T.T. Singh etc.	-	23080
Total:		**130**	**96000**

People with houses in the affected area were paid cash compensation based on 1968 market value estimates. The government announced a total of 235 awards[3] (an award refers to the finalisation of a claim based on a first come, first served principle). Simultaneously they were also offered residential plots for Rs.1300/ per kanal ($508m^2$), and shops measuring $38m^2$ for Rs.75. Government provided transportation to the affectees to shift their belongings and building material. Options existed to get land in any of the five hamlets on a "first come, first served" basis. A total of 1 906 residential plots of $127m^2$, $254m^2$ and $508m^2$ were awarded. Additionally, 1 573 commercial plots were made available. For the 1 282 affectees of Kala Dhaka, only 311 residential plots were provided in the New Darband Township. These were refused by the affectees with the plea that all of them should be given compensation instead of plots.

A sample survey of 249 respondents was conducted in September-October 1999. The number of affectees allotted residential plots, and agricultural land, and their size, is reproduced in Table 3.48.

Table 3.48. Number of Allottees and Size of Residential Plots (Survey of 249 respondents)

No. of Respondents	Size of Residential plot	Agricultural Land	Not compensated	Percent
112	1 Kanal (0.05 ha)			45%
2	15 Marla (0.04 ha)			1%
25	10 Marla (0.025 ha)			10%
21	5 Marla (0.012 ha)			8%
30		✔		12%
59			✔	24%
Total 249				100%

Source: WCD sponsored survey conducted in Sep-Oct, 1999.

Criteria for eligibility for alternate land and its impacts: In May 1967 it was decided that those who had a minimum of 0.2 ha of irrigated and/or 0.8 ha of non-irrigated land would be eligible for alternate land. In Punjab, each eligible affectee would receive a minimum of 5 ha and a maximum of 20 ha. In Sindh the minimum was set at 6.5 ha, but affectees were given the option of purchasing more land.

Approximately two-thirds of the affected population was categorised as 'eligible' for alternate lands. The ineligible population consisted of those who either owned no land or owned less than the required minimum holdings (0.2 ha irrigated or 0.8 ha), and included landless tenants, fisherman and artisans. In the early 1970s the affectees challenged the eligibility criteria but no change was made. The

[3] Recently several NGOs have pursued the issue of outstanding awards and a formal commission has been formed.

portfolio on resettlement policies and procedures provided by WAPDA indicates that the decision regarding eligibility criteria was not re-considered because it was considered inappropriate to reopen and revise decisions arrived under the authority of the President of Pakistan. However, mitigation measures were adopted to allow as many people as possible to qualify for land. Specifically, new provisions made it possible for those who fell under the ceiling to increase their ratio of non-irrigated *(barani*) land to irrigated land (through dug wells). It was assumed that by putting part of their barani land under the category of irrigated land farmers with more than 4 *kanals* (0.2 ha) of barani land could become eligible for alternate land.

An outcome of the eligibility criteria was the lack of displacement rights for the majority of those who were deemed ineligible for alternate land or residential plots. Like most resettlement projects at that time, the focus of resettlement policy was on land valuation, cash compensation, and the provision of alternate lands to eligible displaced persons. There appears to have been a lack of focus on ensuring the integration of 'ineligible affectees' into new market and livelihood contexts. Many of the complaints in the five resettlement townships where most ineligible affectees now live, can be attributed to the lack of a clear policy regarding the ineligible population, especially regarding employment opportunities.

Provision of alternate lands: Both the Punjab and Sindh governments were to commit 30 000 acres (12 000 ha) each for the resettlement of Tarbela Dam affectees. While Punjab handed over all of this land, the Sindh government has continued to withhold 7 823 hectares of the alternate land it was supposed to provide. As a result, a sizeable number of affectees have been unable to claim alternate lands in Sindh, which has severely disturbed the resettlement process for 2 197 affectees.

Cost of Resettlement

The original cost of the PC-1 of Tarbela Dam Resettlement Organisation (TDRO) was estimated at Rs.415.6 million for the total project. The Executive Committee of the National Economic Council (ECNEC) of GOP approved the second revised PC-1 in September 1985 for Rs.997.6 million (equivalent to $99.8 million in 1998 prices).

Process followed to Settle Issues

The Tarbela Dam Resettlement Organisation was disbanded in June 1985 and the Nucleus Clearance Cell (NCC) was established for the clearance of outstanding liabilities of the resettlement claims. The latter's PC-1 for Rs.60.447 million was approved by GOP (ECNEC).

The major reasons reported for the non-accomplishment of the assigned task of providing mitigation awards to affectees, have been:

- abnormal delays in the announcement of decrees in judicial cases;
- the refusal by the Sindh government to provide the balance of 7 800 ha out of 12 000 ha which it had committed to provide to affectees; and
- provision of only 311 plots in the Kala Dhaka housing scheme at New Darband township instead of the 1 282 plots originally planned.

At the time of the Ghazi-Barotha Hydropower Project (GBHP) loan negotiations with the donors, the affectees of TDP protested to the WB against unjust treatment by the WAPDA authorities regarding settlement of their claims. As a result, the donors, especially the WB made it a pre-condition that the GOP should settle the outstanding claims. In compliance with this requirement, WAPDA appointed a review team to carry out an independent review of the outstanding claims. This team submitted its report in May 1996. The stakeholders disagreed with several aspects of the report and there was no action on the recommendations until August 1998 when GOP formed a Commission to examine the report of the review committee. This Commission submitted its report to the Ministry of Water and Power GOP in July 1999. The salient findings of this Commission are:

- The Commission received a total of 12 000 applications including 112 applications already pending with WAPDA. In addition, there were 385 applications of the affectees of tribal areas. Remaining applications were in response to the advertisement in the newspapers inviting any outstanding claims by affectees.
- Of the pre-Commission applications, 74% met the criteria while 26% failed to meet the established criteria. In the case of new applications submitted to the Commission, only 4.4% of the total 19 803 applications met the criteria, while the rest were rejected for failing to provide the necessary documentary evidence in support of their claims.

The report of this Commission has been submitted to ECNEC for a final decision.

The review committee had determined that a total of 2 197 alternate land and 1 282 residential plots had not been compensated to legitimate affectees. The Commission identified 4 089 additional claims for alternate land and 7 649 for residential plots.

The issue of compensation awarded to affectees has been a major bone of contention of the displaced communities. Although successive governments established a series of commissions to resolve the problem, it still remains an outstanding issue. Furthermore, the townships developed in the areas surrounding the reservoir are reported to be in a poor condition. Field visits to these townships showed lack of maintenance activities especially on roads, sanitation and schools. WAPDA claims that maintenance and repair work is the responsibility of Local Government and the Rural Development Department (LG&RDD) while the LG&RDD claims that they are WAPDA townships and hence its responsibility.

To provide alternate land to landowners the entitled affectees were defined as owners of 4 *kanals* (0.2 ha) of *Chahi* (well-irrigated) land or 16 *kanals* (0.8 ha) of barani (rainfed) land. Affectees holding less than 0.2 ha of irrigated land or 0.8 ha of rainfed land were not allotted agricultural land. The worst affected were landless tenants. 2 400 families were allotted 5 ha of land in the Punjab. A further 667 families were allotted 6.5 ha of land in Sindh.

According to the present study by WCD, out of 249 respondents surveyed in October 1999, 30 respondents were compensated with agricultural land in different areas of Punjab and Sindh. Details are shown in Table 3.49. This table is indicative of the situation and does not necessarily reflect the overall distribution of land.

Some of the allottees were not satisfied with the criteria for compensation and filed court cases against the government. Based on WAPDA figures that were verified through the commission formed to sort out the claims, there are 38 cases still pending: 13 in the Supreme Court; 6 with an Additional Judge, 2 with Senior Civil Judge Mansehra, and 11 in Swabi courts (WAPDA Report, TDP Resettlement Organisation).

Table 3.49. Number of Allottees and Size of Agricultural Plots as per Sample Survey

No. of affectees	Size of Agricultural land	District/Tehsil	Province
1	100 Kanal (5.1 ha)	T.T. Singh	Punjab
11	1000 Kanal(51 ha)	Khanewal	Punjab
5	600 Kanal(30.4 ha)	Jhang	Punjab
4	500 Kanal(25.3 ha)	Gojra	Punjab
3	350 Kanal(17.9 ha)	Kamalia	Punjab
4	100 Kanal(5.1 ha)	Faisalabad	Punjab
2	300 Kanal(15.2 ha)	Guddu Barrage	Sindh
Total 30			

* *The 30 respondents are part of a sample of 249.*

3.10.1.1 Resettlement Issues - Agricultural Land

As noted earlier in this section, the current view of resettlement implies that the previous quality of life of the displaced persons is restored as far as possible. Possession of alternate land means undisputed ownership, the right to cultivate, and the right to draw income from the land. Resettlement issues are specific to the area where affectees were settled and can be grouped as follows:

- Persons who moved to hamlets earmarked/developed by WAPDA.
- Persons who moved on their own close to the dam but not in the formal settlement (hamlets developed by WAPDA).
- Persons who were settled in Punjab.
- Persons who were settled in Sindh.

The following procedure was followed:

An allotment chit was issued to the displaced persons containing the necessary information and verification to possess alternate land. To receive an allotment chit, the affectees would have to be declared eligible for alternate land by the allotment committee. The allotment chit would then be presented to the Assistant Colonisation Officer in the resettlement area either in Punjab or Sindh. Affectees displaced first were provided alternate land in the Punjab while those displaced later were given an option to obtain land in Sindh. The payment schedule for alternate land was based on twenty years with 4% interest. The rate per acre for alternate land was Rs.700 (Rs.1 729 per ha) in Sindh. The announcement of awards was completed in 1967 while payment was made in 1974. Over this period Pakistan currency was twice devalued. As a result the affectees were unable to purchase alternate land with the cash compensation received from the government.

Outstanding issues

Following are the main outstanding issues relating to resettlement:

i) Provision of alternate land: Land valuation was conducted under the provisions of the Land Acquisition Act of 1894. Accordingly, the assessment of values, and announcement of awards fell under the purview of Land Acquisition Collector (LAC) of the project area. An Advisory Committee was also established with the facilitation of WAPDA to ensure that fair and reasonable values were assigned by the LAC. Their responsibilities included monitoring compensation payments to displaced persons, and ensuring that the acquisition of land was conducted in a timely and effective manner. The composition of the Advisory Committee varied over time, but usually consisted of Member, Board of Revenue as Chairperson and Divisional Commissioner, Peshawar.

It is difficult to ascertain the efficiency of the Allotment Committee since most displaced persons were unaware of the institutional designation of the officials involved in each phase of the resettlement process.

- The affectees were displaced before receiving possession of alternate lands. WAPDA's current estimate shows that 1 953 eligible affectees hold allotment orders but still do not have possession of land. The majority of such violations occurred with affectees entitled to land in Sindh, due to the Sindh government's 1974 decision to withhold 19 330 acres (7 826 ha) of land. It is presumed that the Sindh government refused to provide additional land was because of the non-acceptance of non-Sindhi population in interior Sindh, owing to fears for the law and order situation. Besides, once the "One Unit" was dissolved in 1971, Sindh government no longer felt obligated to meet its earlier commitment.
- Despite the announcement of compensation awards by the LAC, the Allotment Committee had not completed its assessment of affectees' eligibility.
- Such delays created uncertainties amongst the affectees who were unsure if they met the eligibility criteria. One can presume, however, that those who received late eligibility/allotment

notification were at a disadvantage in terms of acquiring a residential plot (if they were deemed to be eligible).

- The excessive delays in the period of notification left such affectees with limited access and finances for housing, since housing was acquired by the affectees on a 'first come, first served' basis. Thus, the long waiting period for eligibility decisions, forced affectees to rely on their housing compensation for purposes other than residential construction.
- In addition, delays in eligibility announcements reduced the time-frame within which the decision of the Allotment Committee could be contested.
- The allotment chits, entitling affectees to alternate land often did not include an official seal. Consequently, fraudulent claims were filed.

ii. Eligibility and its impacts for alternate land criteria: In May 1967 it was decided that those who had a minimum of 0.2 ha of irrigated and/or 0.8 ha of non-irrigated land would be eligible for alternate land. In Punjab, each eligible affectee would receive a minimum of 5 ha and a maximum of 20 ha. In Sindh the minimum was set at 6.5 ha, but affectees were given the option of purchasing more land.

iii. Issues related to return of surplus land: The return of surplus land in the area of Topi, district Swabi remained unresolved. About 2 935 ha of land was acquired by the TDP management in 1968 for development of the project. At the end of the project 167 ha of this land was declared surplus by WAPDA. Under the rules stipulated in the NWFP Revenue Circular 54, surplus land should first be offered to the original owners at the price at which it was acquired from them. If the original owners were unwilling to repurchase their property, then the land could be auctioned. In the case of the land in Topi the original owners claim that they were never given the option to repurchase their original holdings. Instead the land was transferred to the University of Engineering without cost, and was subsequently transferred, again without cost, to the Ghulam Ishaq Khan Institute of Technology, which has been constructed on this land. The affectees of the area are seeking compensation for their original land since it was declared surplus and under law they were entitled to the option of repurchasing this land.

iv. Problems encountered: With regard to the provision of alternate land, two inter-related categories of problems emerged:

- Problems relating to possession due to the non-availability of alternate land in Sindh.
- Problems occurring on the local level in Sindh relating either to the affectees' demand for or smooth possession of alternate land. WAPDA's 1996 records indicate that there are 1 953 eligible families who have applied for alternate land but await possession. A breakdown of WAPDA's figures supplemented by NGOs' reports and verified through public hearings and a stakeholders' workshop is given in Table 3.50.

Table 3.50. Allotment Status of Displaced Families Applying for Land

A. Statement provided by NCC (1996)*	
1. Total eligible families (including Tribal Areas)	5 317
2. Eligible families who did not apply for alternate land	244
3. Eligible families not allotted land in Sindh due to non-availability	1 567
4. Eligible families from Tribal areas who have not received land	386
5. Total eligible families who have applied for land but await possession.	1 953
B. Findings from Field Hearing /Workshop in Haripur 1999**	
Total Number of families who received allotment in Punjab	2 400
Total Number of families who received allotment in Sindh	667
Total number of eligible families who have been given residential plots	7 000

* *Compiled from a statement provided by NCC (revised April 10,1996)*

** *Formal Survey Public Hearing and Stakeholders' Workshop conducted by Asianics, Nov. 1999.These figures were provided by NGO representatives and confirmed by various stakeholders that were present in the workshop. The numbers however were not collected as part of the survey.*

The recent GBTI study report (June 1999) reveals that out of total applications only 4.4% were found correct while 69% were incorrect and therefore rejected. 26% of applications were listed but not found in the record provided by WAPDA. It is interesting to note that those applications that were rejected were due to incorrect verification by the Revenue Department. Representatives of the affectees still not compensated feel that the screening process often penalised genuine affectees, even for minor clerical mistakes, and thus the rules were unfairly biased against them.

At the time of preparing the Resettlement Plan by WAPDA (in the late 1960s), West Pakistan was under one unit and the consent of provincial government was presumed for allotment of alternate lands in various canal commands. On dissolution of one unit after 30 June 1970, the provincial government of Sindh refused to honour this commitment to provide its share of 7 823 hectares. This decision left many affectees with little possibility of obtaining alternate land.

A critical review of WAPDA's 1996 affectee figures, indicates that the remaining land in Sindh is far too little to meet the minimum existing demand. Therefore, even if the 19 330 acres (7 823 ha) were to be made available for the affectees, it would be insufficient.

To provide the minimum 6.5 ha to each of these 2 197 affectees, as was the intention of WAPDA, the amount of available alternate land would have to be increased from 7 823 ha to 14 226 ha. The figures for outstanding claims continue to increase, so that more land will be needed to compensate all legitimate claimants.

The affectees who were allotted agricultural land in Sindh faced serious hostility from local land-owners and farmers who actively jeopardised their agricultural potential in these localities. In a number of cases, local groups were making use of the affectees' land before the displaced persons arrived in Sindh. This took place without tenurial agreements with the local government (ie they were squatting on this land). Despite being given legal title to the land at the time of their arrival in Sindh, affectees were often confronted with the threat of having their irrigation supply disrupted by local power groups (water user groups), who were deriving benefit from the vacant land. Also, officially-confirmed reports established that new residents attempting to cultivate land in Sindh, were physically threatened by the local population, for reasons that were largely economic in nature. It is also important to note that land ownership in Sukkur Division is based on a feudal system and a small farmer from Hazara would obviously be disrupting this if he/she were to enter the local socio-economic arena. Moreover, there are vast cultural differences between the local ethnic Sindhis and ethnic Hazarawals and Pashtuns – the latter two groups broadly comprising the affectee population. This partly explains the problems of possession and resettlement in the new agricultural zones in Sindh.

3.10.1.2 Provision of Housing for Displaced Persons

Throughout the affected areas, displaced people have consistently cited two obstacles to their ability to provide housing for their families. In the first place, while their previous homes were valued at a certain amount of the reward, the compensation received was insufficient to begin construction of a new home. In part this occurred because of the devaluation of the rupee during the home construction period. Those affectees whose properties were evaluated before 1973 were particularly affected, as a 123% devaluation of the rupee occurred at this time. Secondly, WAPDA did not regulate the provision of housing to ensure that affectees ineligible for land received preference in the disbursement of residential allotments. As a result, eligible affectees, who had received agricultural and residential plots in either Punjab or Sindh, purchased many of the housing plots. Moreover, eligible affectees had the capital to purchase contiguous plots, which they (informally) purchased from ineligible affectees. This, thereby, decreased the ratio of plots to families in the resettlement townships/hamlets. Despite a one-affectee, one-allotment housing policy, there was no regulation of informal trade in residential plots. What occurred, then, was a situation where affectees who sold their allotment chits to others would still purchase a housing plot in their name with the money of the other buyer. They would then hand over the property to the buyer through an informal agreement. As a result, many affectees who were entitled to build on plots, but could not do so, immediately relinquished their right to build a house on a residential plot. They have subsequently had to rent plots from others, or share plots with family members. Here, one should note that a number of affectees still hold on to unsold or unprocessed residential allotment chits. Such affectees were usually members of a jointly owned home, and despite each co-owner receiving separate allotments and compensation, they contributed their compensation towards the construction of a new joint family home on single-family plots.

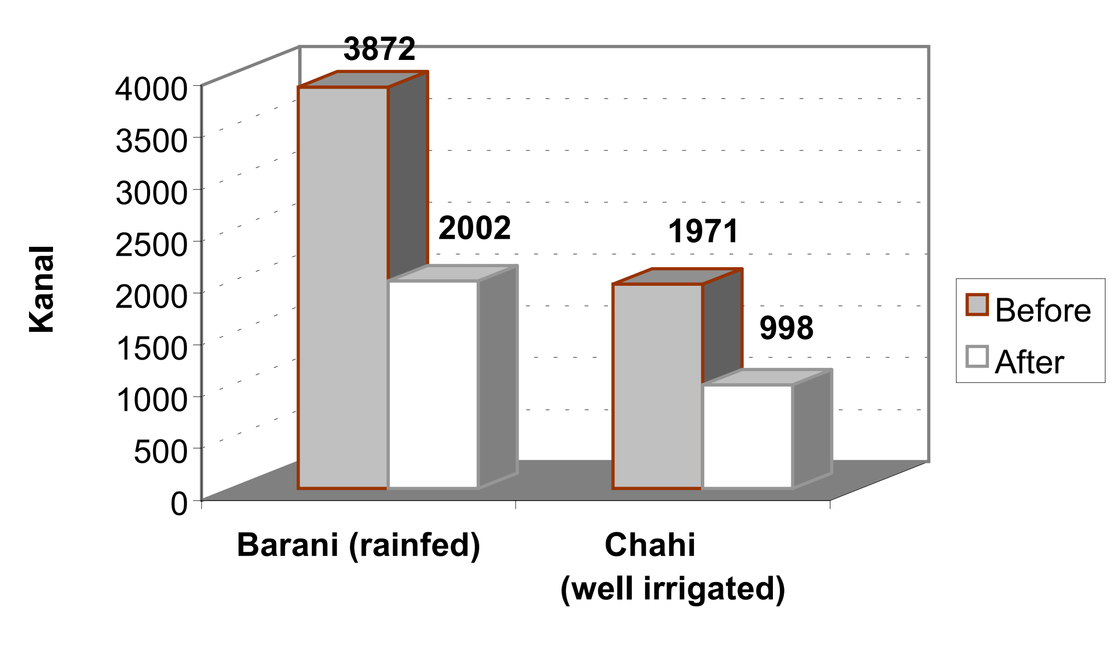
3.10.1.3 Employment, Rehabilitation and Livelihood

The loss of livelihood from agriculture is the most significant impact of the project displacement. The majority of the displaced population received income and subsistence from ownership, either of agricultural land, or as tenants, and was not qualified for other vocations. Figure 3.15 shows the land holdings before and after dam construction.

It is concluded that the livelihood of landless and ineligible affectees was adversely affected by the resettlement process. Additional factors that contributed to this deterioration were:

- The above segment of the community (tenants and ineligible persons) had no productive skills compatible with the new semi-urban economy of the resettlement areas. This resulted in male affectees opting for casual and/or unskilled labour and out-migration.
- There was inconsistency in providing employment opportunities for township settlers. After deciding against the establishment of an industrial estate in the region, the High Level Meeting in 1967 came to the conclusion that smaller industrial units should be established throughout the affected area. Most units were located in the densely populated Khalabut township, but, as reported by the affectees, none is in operation today mainly because after the tax holiday (5 years) they have totally abandoned production. In the few industrial units that were established, employers did not give proper employment preference to affectees and often discriminated against them on the basis of their lack of skills.

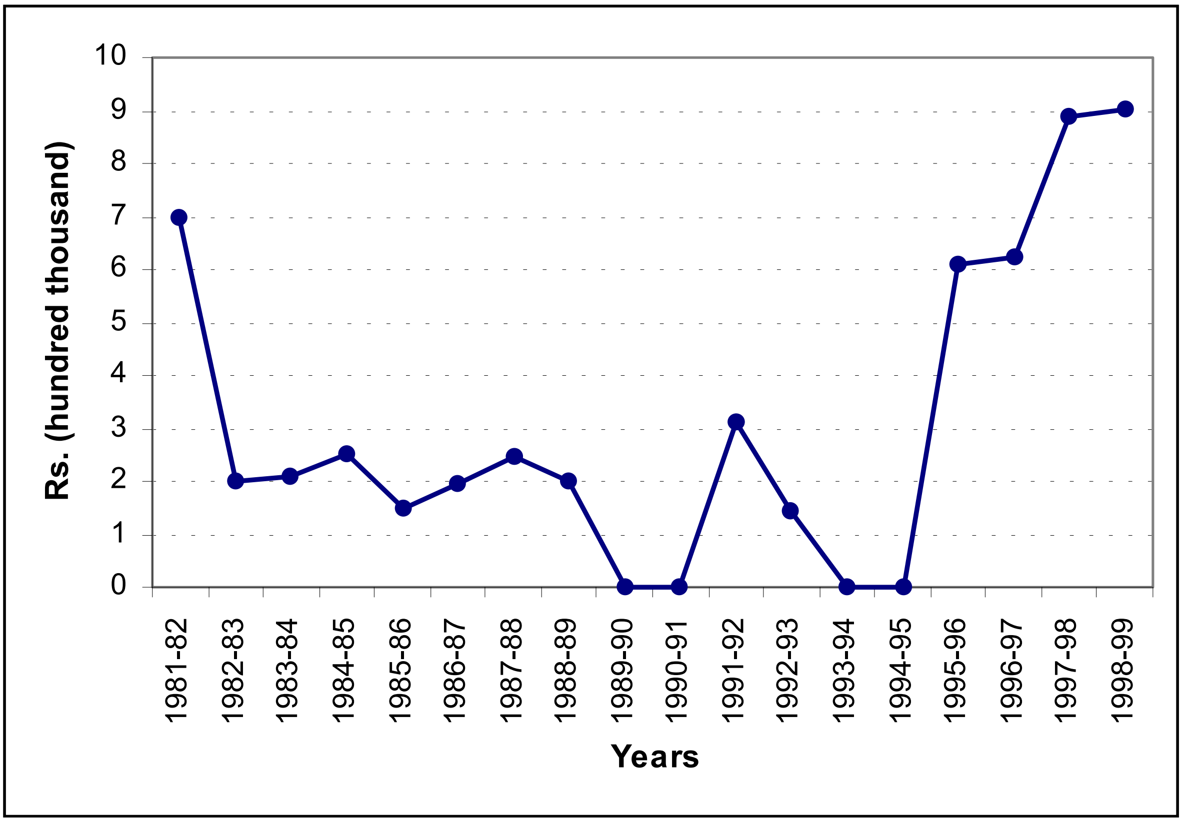
Figure 3.15. A Comparison of Cultivable Landholding Before and After Dam Construction in Surrounding Areas



Source: WCD field survey of 249 respondents, 1999.

- The remote location of a number of re-settlement areas, such as Durband, Kail, Khabal, Sohaia and the Kala Dhaka region, have lesser development opportunities due to their inaccessibility. Absence of industrial development in the region has led to out-migration. Inhabitants of these regions mostly get their livelihood primarily through remittances from families employed outside the region.
- The fishing economy of the affectees was disrupted due to the impact of Tarbela Dam. Currently no initiatives exist to develop fisheries and or a fishing economy in the reservoir area for those displaced. Fishery projects do exist in the reservoir, but are currently under the control of large contractors who bring fishermen from other parts of the country, especially Sindh. Affectees are indirect beneficiaries, catching the comparatively smaller numbers of fish that swim freely in the reservoir. But their participation is not included in any formal fisheries program. The fishermen stated that WAPDA was earning a substantial amount through leasing out fishing rights, which was later confirmed by figures provided by the Assistant Director Fisheries as shown in Figure 3.16.
- The local fishermen, especially in Khalabut, stated that if WAPDA leased fishing rights to a group of affected fishermen they would have not been deprived of their ancestor's profession and could earn their livelihood.
- In addition to these, the persons who were neither owners of the agricultural land nor tenants were the worst affected people at the time of displacement. This group included artisans, cobblers, boatmen, gold wrenchers, *Mirasis* etc. Most of them out-migrated and switched over to other vocations. The focus group discussions revealed that this group is much better placed now when compared to their previous life. The contributing factors include their acceptance of a changing environment and their ability to switch over to market driven vocations.

Figure 3.16. Year-wise Income through Leasing out Fisheries



3.10.1.4 Problems Specific to Tribal People

The specific social and cultural values of the tribal community aggravated their resettlement issues. One specific example is that the clan or the extended family of one tribe lives together. During the resettlement process this important factor was not taken into account, with the result that when 140 residential plots and 30 commercial plots were allotted to the tribal communities, they refused to take possession. They demanded to be settled collectively in one hamlet.

3.10.1.5 Tarbela Dam Affectees Settled in Punjab

Twenty four hundred affectees were settled in different parts of Punjab including Toba Tek Singh, Kamalia, Mailsi, Faisalabad, Jhang and Khanewal. Formal surveys, using-structured questionnaires, were conducted in Mailsi, Toba Tek Singh and Kamalia. The sample included respondents from different occupations and sources of livelihood. More than 51% of respondents were agriculturists, followed by 16% dam affectees settled in the study area and engaged in agriculture (Table 3.51).

Toba Tek Singh and Kamalia

These two areas near Faisalabad and Jhang have a large number of settlers from Tarbela. Affectees in Toba Tek Singh and Kamalia said they had encountered numerous problems in getting settled in this area. The problems identified by them are listed below:

- Barren land was allotted to the affectees.
- The cost was equivalent to that for developed land.

Table 3.51. Sample Size Distribution by Area and Occupation

Area/Villages	Dam Affectees	Agriculture	Fisheries	Boating	Environ-ment	Orchards	Livestock/ Pastures	Total
Mailsi		100			16	7	13	**136**
Alampur, Shaman, Naimat Ali,								
Shahpur, Sargana, Pir Bakhsh								
Pattan, Omar, Fatiana,								
Mailsi Siphon, Daroad Nagana Bella Kotla								
Sargana Aminpur, Shergarh								
Toba Tek Singh	13							**13**
Chak 303 GB, 305 GB, 346 GB								
Kamalia	20							**20**
Chak 289GB, 290 GB								
Muzaffargarh/ D.G. Khan		7	13	8	4		7	**39**
Bhaid Mando, Bhaid Chainwala,								
Bhaid Maitla, Ghazi Ghat								
Total	**33**	**107**	**13**	**8**	**20**	**7**	**20**	**208**

Source: WCD field survey, 1999.

- WAPDA's interest rate for compulsory land acquisition was 4% but a 13% rate of interest was levied.
- Possession rights to allotted land were not given to the allottees. Every allottee was entitled to 3 residential plots comprising 12 *marla* (0.03 ha) each, but in fact they were allotted only 18 *marlas* as a residential plot.
- The settlers filed a suite against WAPDA in the High Court and won the case, but no remedy has been given by WAPDA so far.
- In the original plan basic facilities like electricity, schools, dispensary, water supply, drainage, sewerage, bricklaying of streets etc. were to be provided. Nothing has been done except supply of water and electricity. Electricity has been supplied after 25 years while the water supply is inadequate and the quality is not potable.
- Settlers are discriminated against in the government departments such as irrigation, agriculture, and revenue.
- After 25 years the settlers are still considered aliens.
- Their language, dress, and style of living are still different.
- Family clans are divided, which has hindered the settlment of the affectees here.
- The hot climate, compared to Tarbela, is also considered a constraint in settling.
- It was observed that where the land was allotted to group of families, it was easy for them to settle, but individual families could not cope with the local communities.

Notwithstanding the above problems the resettled communities felt that their economic position had improved significantly after resettlement. Now they have productive land that is high in value. Their access to education, health and other amenities is far better than in the pre-Tarbela period when they resided in isolated locations.

Findings on Resettlements Issues

- Original estimates that 80 000 people would be displaced and 100 villages would be submerged were exceeded as actual displacement affected 96 000 persons and 120 villages.
- Only two-thirds of the affected families were eligible for alternative land. Of the total eligible 5 317 families, 1 953 have still not got possession of land mainly because the Sindh government decided in 1974 to withhold 7 826 ha. of the land it had originally committed.
- The resettlement Commission established to review outstanding cases for land allotment, determined that only 4.4% of the applicants who responded to public advertisement (out of a total of 19 803 applications) met the criteria while the rest were rejected for lack of evidence in support of their claims.
- Lack of a clear policy framework for resettlement created numerous problems, both for the government and for the affectees. In the absence of a regulatory framework, certain groups benefited while others lost.
- Lack of resources – for both land and finances – created problems in resettlement.
- Given the large number of outstanding claims and dissatisfaction with the resettlement process, a commission had to be appointed to address grievances.
- Due to delayed payment (estimates were prepared in 1967 and payment only made in 1974), the majority of the affected population was not ready to shift because the alternate arrangements could not be made in time by WAPDA. Consequently, upon the first filling, the reservoir water level rose in the area, submerging the houses with the belongings of the affectees who were evacuated by Pakistan army personnel with the help of boats.
- Resettlement for residential plots is still incomplete due to the shortage of plots.
- The original cost estimates of $59 million ($295 in 1998 prices) for land acquisition and re-settlement were much lower than the actual costs incurred. Since compensation was paid over a delayed period, when true inflationary trends are taken into account, the actual payments received had much reduced value.
- Affectees re-settled in the Punjab faced numerous problems related to possession of land and cultural adjustment. While many have adjusted to local conditions and customs, some chose to sell their allotted lands and re-migrate back to areas close to their origins.
- Families settled in block villages (*chaks*) tend to stick together to preserve their cultural identity. The economic prosperity of these groups has improved because of the availability of quality land.

3.10.2 Social Aspects (Upstream)

3.10.2.1 Social Issues

The problems of security, both economic and physical, had significant repercussions on affectees' resettlement decisions. One reason is that affectees who successfully took possession of alternate land in Sindh left the province soon afterwards and resettled elsewhere. They continued to derive income from the alternate land through tenancy arrangements with local farmers. Many of them bought homes in one of Tarbela's five resettlement townships in order to be near family and kin members. Currently only one affectee actually resides in Shikarpur District, which contains the largest number of affectees' plots in Sindh.

The second repercussion of the Sindh scenario was that the difficulties of taking possession of land there became common knowledge to eligible affectees who had not yet resettled. As a result, many of them have either not attempted to present their allotment chits for possession, or have not pursued their outstanding claims in court very actively. This is primarily because they would prefer not to be awarded land in Sindh. If rehabilitation activities had been properly conducted in Sindh, including the sensitisation of the local population, then affectees would have felt secure about taking possession.

Once the Sindh government refused to distibute the balance of the allotted land of 19 330 acres (7823 ha), the idea of possessing land became even more remote in the mind of affectees.

Resettlement in the adjoining areas of five hamlets was within known environments and the displaced persons absorbed themselves into the society more comfortably, and could keep in touch with places retaining most of their culture and social norms. They have their own tribal Jirga system, the same system of "purda" (seclusion of women) and marriage practice, and, in the case of any emergency, they could easily contact their relatives.

The resettled people from Tarbela came from a satisfied and egalitarian society and the compensation package offered to them reflected this fact. Landlords who were given land in the Punjab benefited from the package. The small owner-agriculturist, however, was not compensated for the land, and was forced to participate in the urbanised economy characterised by inadequate provision of employment. The older generation continued their trades, but in a monetary economy rather than following the barter system, and were thus better off.

These economic changes had profound social and political implications and some complained that caste distinctions were breaking down and more intra-caste marriages were taking place.

A structured questionnaire was given to a sample of 249 respondents to assess their perception regarding the construction of Tarbela Dam. Generally, the respondents perceived the TDP as positive with few exceptions. For instance 18 respondents (7%) were not given a residential plot. The reason was that residential plot was given to the head of the displaced family. The grown up and married children have to share the residence with rest of their family members. When asked (Question 10) whether their (individual) life condition (livelihood) had improved, only 23% responses were affirmative. Whereas, in response to question 51 regarding overall benefits of the dam, 67% of the respondents considered the dam to have been beneficial to them. Further, after the construction of dam, the basic amenities like electricity, school, dispensaries, water supply, and sanitation had improved the quality of life of the inhabitants of these hamlets.

Water logging and salinity had adversely affected their agricultural land, according to 25% of the respondents. However, increases in the water table is perceived as a positive effect by 63% of respondents, because they now have easy access to under-ground sweet water for drinking as well as for irrigation purposes, especially for those respondents who have land holdings on hilly terrain or at high altitude.

The majority of respondents (86%) were of the opinion that government did not take prompt action to provide them with alternate means of livelihood.

Perceptions of respondents regarding construction of Tarbela and its impacts are summarised in Table 3.52.

In the pre-dam era there was an unequal distribution of land-holding in the community, that promoted economic disparity and also gave rise to stratification on a caste basis.

After construction of the dam and settling in urban communities, the attitude of previous landlords changed, and they addressed their ex-tenants politely if they desired reciprocity.

Another change reported was in the increased use of narcotics amongst youngsters. It was reported that, although the area grew poppies prior to the construction of dam, the local inhabitants never used it.

Another change concerned the mobility of women: previously they resided with close relatives in the village and could move easily in the neighbourhood. Now, in the hamlets, the neighbours are not necessarily their relatives, and the women been confined to their houses. People who availed themselves of the opportunity to settle elsewhere, acquired formal education and moved up the socio-economic ladder, while many who sold the allotment chits given to them, suffered a social downfall.

The families settled in Sindh and in southern Punjab encountered communication problems. The native language was a major communication barrier for their school going children who were ridiculed. Their schoolmates considered the children of settlers as aliens.

Table 3.52. Overall Perception of Community in 5 hamlets surrounding the reservoir regarding the Construction of Tarbela Dam
(Total no. of respondents = 249)

Q#	Question	Yes/(%)	No/(%)
1	Are you affectees of Tarbela?	248(100	1(0)
2	Are you settled?	231(93)	18(7)
9	Are you satisfied with the rehabilitation?	68(27)	188(73)
10	Did your life conditions improve after Tarbela dam?	58(23)	191(77)
13	Is Tarbela dam fulfilling the water needs?	75(30)	174(70).
19	Did the under groundwater level increase after Tarbela?	157(63)	92(37)
20	Did water logging and salinity affect your land?	64(26)	184(74)
22	Did the natural vegetation increase with Tarbela dam?	127(51)	122(49)
23	Do you pay water tax?	152(61)	97(39)
24	Did cropping increase after the dam was built?	140(56)	109(44)
32	Did the Govt. fulfil its promises?	42(17)	207(83)
41	After Tarbela dam was built did number of the schools and colleges increases?	199(89)	50(20)
42	Were electricity facilities available before the dam?	81(33)	168(67)
43	Do you face load shedding?	222(89)	27(11)
45	Is your life condition better then before?	88(35)	161(65)
48	Were the means of transport improved after the Tarbela?	208(83.5)	41(16.5)
51	Do you think that benefits of the dam were more then the drawbacks?	167(67.1)	82(32.9)
52	Did the Govt. take quick action to give alternate occupation to people?	34(13.7)	215(86.3)

Source: Survey in reservoir surroundings for WCD Study, October 1999.

Families who opted to settle in the developed WAPDA hamlets had better opportunities to educate their children because there was no language barrier or cultural differences in their dress.

The geographical terrain of Tarbela did not require drainage while in the central Punjab it was mandatory to construct drains that were usually cleaned by females and finally emptied into a pond on the periphery of the village, which was socially unacceptable to the settlers. Moreover the pond served as breeding ground for mosquitoes and flies that was a health hazard and the settlers encountered malaria and cholera etc.

For drinking water most settlers had to depend on canal or saline water that was unsafe for health.

3.10.2.2 Positive and Negative Impacts of Tarbela Dam

In addition to data collected through the public hearings, focus group discussions and informal discussions with NGOs, a formal survey with a questionnaire was conducted. During the sample survey of 249 affectees, they identified positive and negative impacts of Tarbela Dam. The views of the affectees residing in the five hamlets and in the proximity of Tarbela Dam are summarised below:

Positive

- There is a positive impact on the overall economy of the country.
- Mechanised farming has been introduced.
- Skilled labour was given an opportunity to work in the Ghazi Barotha Hydropower Project.
- Living standards have been raised due to urbanisation.
- Means of communication have improved.
- The literacy rate of women has improved.
- The construction of the dam has improved awareness so people know how to stand up for their rights.
- The literacy rate, as well as the social status of disadvantaged groups in the society has improved.
- Feudal lords have lost their position.
- There is an increase in the value of land.
- The production of fisheries has been increased.
- There have been changes in the professions.
- Opportunities for higher education and other social activities have improved for the young generation
- Women have received education and employment.

Negative

- Agricultural land, livestock, forest and pastures have been totally abolished.
- Locally produced wheat, grains, fruits, and vegetables, which were previously free of cost, now have to be purchased from the market.
- Drinking water is polluted.
- The settlement is incomplete.
- There are certain basic facilities like schools and hospital that are without staff and equipment.
- Families have been divided and have lost their identity.
- It is very difficult to obtain the national identity cards and domicile certificates required for admission to the professional colleges and for finding employment.
- There are social and moral costs, especially amongst youngsters in Khalabut who are mostly addicted.
- The affectees who were earning their livelihood directly or indirectly from the agriculture are now unemployed.
- Pollution and an unhealthy environment because of crowded conditions, non-functional/inadequate sewerage systems and unsafe drinking water.
- WAPDA promised to construct roads for public use around the reservoir but did not construct in full. The result is that the remaining communities have to cover long distances to meet each other.

Findings on Upstream Social Aspects

- Families of the affectees have been divided and are spread over various places. The families cannot get together due to geographical distances even for important events like marriage, death or other events.
- The shift from a rural economy to an urban economy has adversely affected the income of affectees as they have to pay for food grains, milk products, and vegetables etc.
- There is a shift in occupation because of the changed environment.
- There are increases in the unemployable category because the affectees did not possess skills compatible to the changed socio-cultural and economic environment.
- They feel confined in small houses as compared to their native houses in the villages.
- Previously they resided with their close relatives in the villages where the women could move in the neighbourhood easily. In the hamlets, as the neighbours are not necessarily their relatives, the women have been confined to their houses.

- Women's daily chores like fetching water, collecting fuel wood, working on agricultural farm, and knitting and embroidery during their leisure time was a source of social life and enjoyment in their native villages. After settling down in the hamlets these have vanished.
- People who availed the opportunity to settle, acquired formal education and moved up the socio-economic ladder while others lost in relative social status.
- Their emotional attachment with their forefathers was severely damaged when their graveyards were submerged under water.

Findings on Changing Cultures in Upstream Areas

- There was a lack of acceptance of the downstream affectees by the local communities and they were considered to be a minority.
- In order to be accepted as part of the communities they had to change their dress (*shalwar* was replaced with *dhoti* and the cap was replaced with *pagri*)
- Inhabitants had to accept games like rabbit hunting with dogs, kabaddi and wrestling instead of dog fighting, stone lifting, hunting, and shooting etc.
- Some of the shrines that were the site of annual festivals and the source of social gathering for the communities were inundated. Construction of Tarbela Dam has deprived communities of such social gatherings and means of entertainment.

3.10.3 Downstream Effects

There is considerably diversity in the ethnic background of the people downstream (Punjabis, Pathans, Seraiki, Sindhis etc.) Besides the diversity in language, food, culture and ethnology, the Indus River presents a unique amalgamation of small sub-cultures around the river belt that lends to some form of specialisation in occupation and trade. The river is well endowed with flora and fauna that facilitated settlement directly on the riverbank and along the numerous canals and tributaries that flow from the Indus. As it was not considered possible to capture all of this diversity, the study team decided early on to choose one command area that would provide insights into the impacts on agriculture. For this purpose Mailsi in Multan, and areas surrounding Ghazi Ghat near Muzaffargarh on the bank of the river, were selected. These areas are traditionally known as cotton-wheat belts. The river embankments are inhabited by livestock herders, fishermen, boatmen and those who are dependent on riverine forestry.

In the case of Sindh it was decided to gain insight in areas where water shortages have the greater impacts. For this purpose, the districts of Thatta and Badin where selected to represent the below-Kotri situation. The impacts on agriculture in downstream Sindh were studied through sample surveys conducted in Mirpur, and earlier survey data was collected by the Sindh Development Studies Center. In addition to these areas, field hearings were held in the coastal areas and near Keti Bandar to investigate problems in the mangrove areas

The sites selected both in Punjab and Sindh are generally representative of the situation along the Indus River with special reference to agriculture, fisheries, livestock and livelihood aspects. The dominant farming systems they represent are cotton-wheat-fodder in the Punjab areas, and cotton-rice-fodder and sugarcane-fodder in Sindh.

3.10.3.1 Communities residing along the River Indus south of Attock have been treated as downstream affectees in this study. This includes central Punjab, southern Punjab and the province of Sindh.

3.10.3.2 Punjab Region

a) Mailsi

Survey efforts in Mailsi on Bahawalpur Abassia focused on gaining insight into the dam's contribution towards agriculture. General responses regarding effects of canals on agriculture are presented in Table 3.53. A sample of 115 respondents was selected randomly. The survey showed an increase in vegetable production for domestic use (52% respondents). The area brought under agriculture increased significantly after dam water releases into the canal. Seasonal employment opportunities increased, especially with the intensification of cotton production. Before the canal was operational, land rents were a meagre Rs.200–300 per acre. In 1999 land rents stand at Rs.8 000–10 000 per acre, whereas present land values range from Rs.150 000 to Rs.300 000 per acre in nominal terms.

Table 3.53. Affects of Canals on Agriculture (n=115)

Item	Indicator	% responded
Vegetable	Production on commercial sale increase	22%
	Production for domestic use increased	52%
	No change	17%
	No response	8%
Agricultural Land	Area increased	100%
Employment	Seasonal opportunities increased	61%
	No increase	26%
	No response	13%
Land Rental	Rs.200–300 per acre (before canals)	100%
	Rs.8 000–10 000 per acre (after canals)	100%
Cost of land	Rs.4 000 to 7 000 per acre	
	Rs.150 000 to Rs.300 000 per acre	100%
Forest	Area decreased	78%
	No change	13%
	No response	8%
Irrigation water resources	Canals	70%
	Tubewells/canal	30%

Source: WCD field survey, 1999.

After the construction of Tarbela, 78% of respondents thought that the forest area had been reduced. Regarding sources of irrigation, 70% of respondents relied on canals, while 30% said that their land was irrigated by both canals and tubewells.

In general, respondents stated that the main benefits of the dam related to soil fertility, as the dam water running in the canals was perceived to be rich in nutrients and silt. This resulted in increased food availability, increases in rent and the price of land, and changes in the cropping patterns (with increases in sugarcane, cotton, wheat, and rice). The seasonal demand for labour also increased due to crop intensification and the modernisation of agriculture technology. Mango orchards in the area also increased after increased canal water availability.

The main drawbacks were increases in diseases like coughs, allergies and malaria. The respondents' perception was that these diseases increased due to the canal water. Perhaps the more intensive agriculture also increased the use of pesticides and the establishment of ginning factories in the area lead to increases in some of these diseases. Forests have been negatively impacted, as areas under forest or tree cover have been cleared for agriculture.

b) Muzaffargarh/D.G. Khan

The local administration in district Muzaffargarh and D.G. Khan were approached to identify the communities/villages located on the bank of the River Indus. Out of 10 villages thus identified, a sample of 4 villages/communities was picked up at random. The communities visited included Bhaid Mando (45km away from Muzaffargarh on the Karimdad-Alipur Road), Bhaid Maitla (40km from Muzzafargarh on the Shah Jamal road), Bhaid Lunda (23km on D.G. Khan Road) and Bhaid Cheenwala.

The main groups in the survey included agriculturists (land-owners as well as tenants), and landless people whose livelihood was directly dependent on the river, like fishermen, boatmen, and basket weavers and cattle ranchers.

Basic facts about the area:

Parameter	***Area (ha)***
Total area on River Indus in Tehsil Muzaffargarh	1 744
Total land	3 696
Forested area	8
Flood area	225
Non-flood area	105
Area irrigated through canals	187
Non-canal irrigated area	1 232
Old barren land	1 233
Uncultivable	710

Impact on agriculturists: Prior to the construction of the dam, landowners possessing land near the bank, often suffered inundations due to the frequent changes in the river course. After the construction of dam, this land was recovered and the landowners benefited. It increased their landholding, and the recovered land was highly fertile, and crop yields increased. Cotton, wheat, rice, and sugarcane are the major crops grown on recovered lands and this has improved their economic condition. Similarly, the canal network also had a positive impact on agricultural production. Tenants working for these landlords also benefited from the extra water. It may be noted that, while most respondents attribute the agriculture improvements to the extra water, flood bunds also played an important role by making agriculture more secure.

Impact on landless people*:* This group included people who pursued professions other than farming (fishermen, boatmen, basket makers, and weavers). This segment of the community was adversely affected, mainly because there used to be significant spill-over of the river before the dam, resulting in marshy areas and wild growth. These forests, natural vegetation and ponds provided a means of earning a living for people residing on the river bank. After the dam water flow was controlled, the ponds, forests and wild vegetation diminished. The wild growth was used to weave baskets, mats, roof ceilings and handicrafts. These days this indigenous product is produced in much smaller quantities.

Cattle ranchers**:** This group, which possessed small pieces of land and earned their livelihood from raising cattle along the river bed, lost this land due to change in the river course. These communities migrated to other areas mainly because they lost grazing areas for their livestock. Prior to the construction of Tarbela, the spillover of the Indus generated marshy areas on the banks that provided grazing fields. After the construction of the dam, the marshy land dried up and the inhabitants had either to reduce their heads of cattle or migrate to other places. There was, however, a positive effect of this migration: milk products now fetched higher prices due to easily accessible urban markets, so these ranchers were able to purchase more livestock and start buying green fodder. At present, the numbers of livestock range from 20–100 heads per family. In the new settlements their livestock losses have been reduced due to availability of veterinary cover, and better fodder etc. and, according to them, only 2% of their community members have switched over to other professions.

The number of livestock kept by the respondents varied from 5 to 100 head of cattle. About 50% of the respondents had from 25 to 50 head of cattle. When probed, these respondents replied that although they had more cattle prior to the dam, the return on the sale of cattle and milk products was much lower.

3.10.4 Downstream Impacts in Sindh Province

The micro level of field work in Sindh focused on aspects related to the livelihood of the groups residing on the Indus, the broader impacts on agriculture and different types of externalities that have resulted from the historical changes in the Indus. It is almost impossible to separate the impacts of Tarbela on the below-Kotri areas from other interventions. Major changes in the hydrology of the area occurred following the commissioning of the Kotri barrage (see section 3.4.2.7). The findings of this section must therefore be interpreted with care. The fieldwork was aimed to solicit stakeholder viewpoints on the current economic status of affected groups. This is influenced by numerous social, biological, and physical factors. Dependence on the basin is not absolute, and positive or negative viewpoints cannot be exclusively attributed to the basin or the dam. While the effects of the basin are somewhat apparent, it becomes difficult to assign all of them to a specific dam on the Indus.

For this section of the study 80 respondents in 18 villages in the districts Thatta and Badin were interviewed. Out of eighty, fifty respondents were from 13 villages of Talukas Thatta and Jatti, whereas 30 respondents belonged to 5 villages of Taluka Badin. These 18 villages were selected, through joint consultation with local NGOs, NRSP and the Commissioner's Office. The villages represent the general socio-economic profile of lower Sindh with the majority of the community facing water shortages and declining agricultural productivity.

The population in the selected villages was mainly fishermen who fished in the Kinjhar Lake and the open sea. Information on the economy of fishing, the problems/constraints and the expectations from fishing , was drawn through a formal questionnaire to fishermen. Key informants such as President Sindh Taraqee Pasand Mallah Tanzeem (STPMT) and officials in the Fisheries Department were interviewed through a checklist. Some of the secondary information about the fishing population, and the contract system etc. was drawn from research reports, periodicals and news clippings. Findings of this section are based upon qualitative data collected from various stakeholders, and the argument is substantiated with quantitative data wherever necessary.

3.10.4.1 Socio-economic Profile of Fishermen and Impacts

Almost all families in a village were involved in fishing activities exclusively, with hardly one or two belonging to any other occupation. The villages are, therefore, widely known as *Mallahan Ja Goth* (fishermen's villages). However, it should not be assumed that all fishermen belong only to the Mallah caste. Most villages surveyed were multi-caste villages, but they are all linked together through fishing. Previously, mallahs were only fishermen, and their caste was named after the occupation. But presently mallahs not only fish, but also work in almost all professions. Some mallahs are highly educated and work at the university and other government jobs, while castes such as Soomro, Bhatti, Bhund, Khokhar, and Malkani are in the fishing occupation. Therefore, fishing is no longer a single caste profession.

The Fishermen Population

Fishermen are categorised as full time, part time and occasional fishermen and spend from about 90% of their time to less than 30% of the time in fishing-related activities. Full time fishermen earn 90% of their income from fishing, with 10% of the income coming from other sources, usually from labouring for daily wages during the lean fishing season. According to a conservative estimate the fisher population in Sindh is about 5 million including men, women and children. According to data provided by the Livestock and Fisheries Department, Government of Sindh, the fishing population increased from 2.18

million to 3.10 million during 1984-93. The full time population of fishermen, including the coastal and mangroves areas, increased at the rate of 2%, whereas the part time fisher population rose at the rate of 3.8% per annum during the last decade.

By surveying different livelihood groups it was observed that fishing families are extended families with a maximum of 25 and minimum of 9 members in a family. The average fishing family size is 13 persons. This may not be the case throughout Sindh, but our survey of eighty families shows an average of 13 members per family. Men usually start fishing at the age of 18 years, and women help in weaving nets and fish drying.

b) Fishing Points

There were two main points either on lakes or sea mentioned by the fishermen interviewed. Most fishermen belonging to Taluka Thatta fished on Kinjhar Lake, whereas fishermen of Jati Taluka either fished in the open sea or on other lakes like Rabbar, Pochari, Wakie. One of the respondents said that there were approximately 400 000 people fishing on Kinjhar Lake. Fishermen of Badin Taluka mostly fished in lakes such as Kadhan Patteji, Choranni, Dann, Bakkar, Kubbo, Wiaro and at Zero point of Left Bank Outfall Drain (LBOD) famous Tidal Link. Some of them also ventured out to open sea as well; those fishing in the sea spend about 8–10 hours daily. Previously, fishermen of coastal districts mostly fished in the sea, but now they are involved in inland fishing as well.

c) Fish Catch

Table 3.54 shows the common species of fish caught in the coastal districts of Sindh and their corresponding value in rupees per maund (40 kg). All considered *sanho* (shrimp) as the prized specie and it is caught in the open sea and in lakes adjacent to the sea. The retail price for one kilogram of shrimp is Rs.150–200, whereas fishermen sell to contractors for only Rs.1 200 per 40 kg. In terms of monetary value, *singhari* and *kurriro* follow shrimp, at Rs.900 and Rs.800 per 40 kg respectively. Other types of fish are considered to have low monetary and nutritional value.

Table 3.54. Fish Species and Value (Rs./40kg)

Specie	Value	Specie	Value	Specie	Value
Popri	200	Singhari	900	Dahhi	700
Gindan	300	Thalhi	600	Bam	400
Danghri	500	Jarko	600	Kurirro	800
Tarro	500	Sanho	1200	Chilori	800
Morakhi	800				

A family of four members catches approximately 20–40 kg of fish daily depending upon climate and fish population. Some respondents even recorded fish catches as low as 3 kg per person. They were of the opinion that catches had decreased drastically due to increases in the fishing population. Some of the fishing points were considered over-crowded. Previously, 1 000 persons were fishing, now more than 5 000 people fish. Fish catch per capita has therefore decreased. Deforestation of the mangroves is considered another important reason for the decline in marine fish. Some groups link this to the reduced water flows below Kotri. The quantity of shrimp has declined significantly, and, especially after the occurrence of cyclones in Thatta and Badin, the fish catch has been severely affected.

January to March is a poor period for fishermen as the fish catch is negligible. During these months (the *Baddhe* season as it is known in Sindhi), fishing is prohibited as the fish are hatching eggs. Although fishing is prohibited during these months, some fishermen do nevertheless fish for a non-hatchery supply to various fish farms in Sindh. However, from October to December the catch increases, and some fishermen mentioned that they are able to catch plenty of fish during these months.

Referring to the dam's impact on the fish catch, key informants in the Fisheries Department were of the view that the catch was lower, due to reduced water flows below Kotri, and fewer fish coming down the Indus. While the latter may perhaps be true due to the building of barrages and heavy fishing upstream, the data presented earlier does not support the idea that water flows have been reduced post-Tarbela in any significant manner. Besides an increased sea intrusion, sweet water fish escape in large quantities through Karachi canal from Kinjhar Lake, causing huge economic losses to fishermen and to total revenue generation for the province.

d) Fishing License and Contract System

There are two systems prevalent in the area: for sea fishing the contract system exists at zero point, whereas at Kinjhar, the license system is prevalent. Comparatively, fishermen at Kinjhar seemed satisfied with the license system, and said they had benefited under the system. The license system was abolished some time ago, even at Kinjhar, and the contract system was established; however, under the contract system, fishermen suffered.

Some of the fishermen stated that perhaps the contract system is appropriate for sea fishing since there is a huge area to fish, whereas the lake is limited, and it can only support a limited number of fishermen. In the absence of the license system people from anywhere can fish. Therefore, under the contract system, the local fishermen are deprived of their due share. Under the contract system, the contractor extracts too many fish from the lake, depriving the local fishermen of their livelihood, and also causing quick depletion of the fish stock. Some fishermen, even under the license system, are fishing illegally. This matter has been brought up with the Fishermen's Welfare Committee.

e) Fish Marketing

In the case of either license or contract, transportation is the responsibility of middlemen or contractors. One popular mode of transporting the fish from zero point or Kinjhar Lake is pick-up vans. Those fishermen with some sort of transportation sell fish in nearby towns like Tatti and Thatta, in the case of Kinjhar, or send it direct to the fish harbour in Karachi for better profits.

Fishermen at Kinjhar pointed out cold storage problems and said if cold storage had been available, they would have sent fish directly to Karachi and obtained better returns. In summer, fish perishes quickly, and they are therefore unable to store it for transportation to Karachi. In such cases they are compelled to sell it to the middleman for less than a reasonable price.

Middlemen are thought to exploit the economy of fishermen. This is especially so in the lean season when fishermen desperately need loans to provide the necessities of life for their children. Besides, fishermen also take loans to purchase fishing nets, boats and high-powered motors. A wooden boat, locally called *Horho*, costs Rs.80 000 to 100 000, while a simple boat of reasonable size without any motor costs Rs.40 000, and a small boat is Rs.30 000.

A brand new outboard motor costs Rs.32 000 whereas second-hand motors could be in the range of Rs.18 000 to 22 000. Middlemen knowingly take undue advantage of the situation and grant loans to fisherman, against the guarantee of their catch. Almost everybody is trapped in some kind of debt. The tyranny is that the middleman pays ten times less than the retail price of the fish, especially for shrimp; which is a species with a high value.

It is difficult to compute fishermen's *daily incomes*, because there is no authentic source of data available. However, from a survey of eighty families, it seems their income largely depends upon the fishing point, the climate and the fish and the fishing population. The family income of fishermen fishing on Kinjhar Lake ranges between Rs.4 000 to 6 000 per month. Those fishing in other lakes in Badin district, were earning Rs.3 000 to 4 000 per month. Fishermens' income could possibly increase if they were freed from the middlemen. Under the middleman system they do not have any negotiating power to earn better income from the fish crop. All forward pricing is done at the middleman's whims.

Almost all fishermen are mono-skilled and only know fishing and face a difficult situation in the months of January to March when there is no fishing. Most complained about the lack of jobs in the off-season, when they are forced to sit idle. Even those who find some work cannot make ends meet.

Findings on Socio-economic Impacts on Fishermen depending on Indus Basin

- NGOs and certain government departments believe that the reduction in downstream Kotri flows are attributable to Tarbela dam, whereas data from Singh's Irrigation Department indicates that the major changes in hydrology happened after the commissioning of Kotri barrage, which occurred before Tarbela.
- Fishermen families depending on the Indus River report that the fish catch has been reduced over time. Most ascribe this to reduced flows, while others believe that as the human population has increased, the catch per fisherman has reduced, as more people fish in a given fishing regime.
- Due to over-population in fishermen families, it is difficult for them to feed their children and provide reasonable schooling and health. Over-population has also reduced per the per capita fish catch and corresponding income from fish.
- The fishing community is heavily indebted, and it seems that they will remain trapped in poverty unless they seek negotiating opportunities to get better value for their fish.
- Under the contract system they are bound to sell fish to a contractor at throw-away prices, whereas middlemen and contractors make money. Fishermen are receiving less than 10% of the revenue generated by their catch.
- Due to heavy silting in Kinjhar Lake, sailing boats find it difficult to fish in certain pockets of the lake. The catch is also decreasing due to silt, and fishermens' incomes are being affected.
- Sweet water fish in Kinjhar move towards salt water during the hatching season. Hence the loss of a good proportion of "Gandan" fish. It has been suggested that iron grills should be installed at the Karachi canal to stop fish from escaping to the sea.
- Fishermen of the coastal area complained of maltreatment by the law enforcing agencies. They are forced to provide fish free of cost in bulk, and sometimes even their boats are taken away for official duty without any compensation.

3.10.4.2 Irrigated Agriculture in Thatta and Badin

Being largely an arid area, irrigation in Sindh province relies on the weir-controlled irrigation system. The province has three barrages, viz., Guddu, Sukkur and Kotri. These barrages command about 14 million acres (3.5 mha) of land. Kotri barrage is the last one in the irrigation system's infrastructure. The Indus travels about 100km below Kotri barrage before falling into the Arabian Sea. It commands the districts of lower Sindh at its tail. These parts face water shortages particularly in the *rabi* season.

Prior to construction of Tarbela dam, water shortages in *rabi* were common, but people would grow a variety of crops after the recession of floods in the *kharif* season. Areas enclosed between the banks of the river would get enough recharge to support such cropping. Silt brought through the high floods would settle in the vast catchment and provide a fertile blanket for *rabi* cropping. These areas receive very little recharge in post-Tarbela regime. The same area also developed pastureland to support a livestock population. This is also a vital source of livelihood for the local population. Forest production was also attributed to high floods. These valuable resources have dwindled considerably and gradually vanished with longer dry spells

The construction of Tarbela dam helped increase water availability for *rabi* crops in Sindh. However, the construction of bunds along the river to protect against floods, together with some reduction in the extent of the floods, as a result of the shaving of flood peaks by Tarbela, has resulted in a lower recharge of water in the *katcha* areas. This has adversely affected the growing of crops and the productivity of pastures on residual moisture and the productivity of pasteurlands that are dependent on residual moisture

The boom in the sugar industry in the lower Sindh, is attributed to Tarbela by large producers. The profitability of the sugarcane crop also led to violations of crop zoning in certain districts, increasing the area under this crop often at expense of other crops. Six sugar mills are presently operating in Thatta and Badin districts. These industries are the main source of employment and infrastructure development in the area.

During field surveys, local communities said that water supplies were unreliable in the *rabi* season. They claimed that the shortages at tails are partially attributable to inter-provincial mismanagement of water and a corrupt irrigation department. Crop production, particularly of sugarcane, has increased due to perennial irrigation after the dam. The annual canal diversions were increased from 5.4 bcm to 10.8 bcm during the post-Tarbela period (refer to Table 3.23 for diversions at Kotri). Increases in areas allocated to sugarcane were motivated by the fact that huge loans were procured (often accompanied by political bribes) to establish new sugarcane mills. These factories offered high prices to lure farmers to allocate a greater area to sugarcane. While sugarcane demands large quantities of water, its production was considered lucrative relative to other crop options. Improvement in the sugarcane crop has benefited local communities in terms of on-farm employment and jobs in the sugar industry. Presently, sugarcane farmers are facing considerable problems related to lower prices and non-payment by factories that are having difficulty selling sugar abroad.

According to local communities, inundation of `Katcha' [4] land has been considerably reduced after the construction of the dam (also see environmental impacts). This has resulted in previously fertile pockets becoming permanently dry, depriving the local population of their traditional source of livelihood. Many communities left their ancestral villages and had to migrate to barrage-commanded areas in search of livelihood.

The other important impact of the upstream diversion is the intrusion of seawater in areas downstream of Kotri. The issue is environmental but also impacts on the livelihood of the communities. Local residents attributed this intrusion to reduced flows in the Indus. In a natural balance, fresh water from the river continuously abates the tidal impact of the sea. Since downstream of Kotri flows did not change significantly after construction of Tarbela, it is not possible to ascribe this phenomenon to Tarbela dam.

The local communities stated that in the coastal areas seawater is gradually increasing, and thereby causing irreversible salt deposition in the lands that are thereby rendered unsuitable for agricultural activity. The areas of Kharochaan, Garho, Shahbunder, Keti Bandar, Golarchi, Seerani and Bhugra Memon, in particular, are worst hit. According to the communities, over 0.2 million acres of previously fertile lands were devastated. They attribute this loss to diminishing river flows below Kotri since the construction of Kotri barrage and Mangla dam. After losing lands to the sea, people are trying to find ways to reduce seawater intrusion (see the report of field hearing in Keti Bandar in Annex 10 - Appendix C regarding the impacts on mangroves).

The overall social status of the communities in the area shows a high poverty amongst the lower echelons of the society. All these areas are deprived of infrastructure development and health and education facilities are less than adequate. It is also reported that, due to changing climatic patterns in coastal areas and continuous soil erosion by tides, the remaining land resources are also at risk. Another impact on groundwater resources is the pollution of the aquifers situated close to the Arabian Sea. The rising salt content of the groundwater has also made it unsuitable for irrigation. Also, salt depositions in the land have affected their yields and overall production. This ultimately leads to

[4] Local word for area between confining bunds on Indus river

socio-economic degradation of the people. A workshop on various downstream affects on livelihood and agriculture in Sindh was held in Hyderabad on 27 December, 1999. A brief report is attached as Annex 10 - Appendix D.

Impacts in the coastal and mangrove areas

Two meetings were held in the coastal areas of the Indus delta to gain first hand information from local residents. The problems of Ibrahim Hyderi near Karachi relate to the impacts of out-migration from the interior delta due to the shortage of water resulting from the construction of Kotri and later the construction of Tarbela dam, as conceived by the respondents. The impacts voiced by residents of Ibrahim Hyderi are reported in the field hearing in Annex 10 - Appendix E.

Residents of Keti Bandar and nearby coastal areas elaborated the highly negative consequences of upstream water developments on the land, flora and fauna of the coastal areas. They made it clear that the mangroves are just one aspect of the coastal ecology; a holistic approach is needed to identify and quantify the negative impacts in the coastal areas. Problems in the Kati Bandar area started immediately after construction of Kotri barrage. Most of the deleterious consequences of reduced water flows are also linked to that event. However, some of the stakeholders were concerned that what little agriculture remained after Kotri barrage, was further affected after construction of Tarbela dam. Not only were fishermen and boatmen affected, but the agriculture of the area has been virtually wiped out. The prized wild brown rice once famous in the area has vanished. The area was a major milk producer and exporter of surplus milk and *ghee* (clarified butter) to cities as far away as Bombay. Navigation by boats and steamers also flourished before the dams and barrages, and the Indus was used for navigation upto Dera Ismail Khan. The coastal areas supported a wide range of aquatic, marine and wildlife and the local communities were prosperous.

Lack of drinking water and livelihood opportunities has forced people to migrate to Karachi. Disintegration of the family structure due to out-migration has resulted in immense social costs.

Women currently have little work outside the household due to reduced fishing opportunities. While provision of water to arid lands upstream has helped agricultural development and improved the income of the communities living in those areas, these developments have impacted negatively on the coastal areas. Stakeholders seriously questioned the anomalies associated with perceptions regarding flows below the Kotri: if, as is claimed, enough water is passing through Kotri and no shortages exist, why then have the coastal areas been so badly affected. There were also serious doubts expressed regarding "the minimum" flow concept. Stakeholders held a perception that, due to reduced flows, they were facing seawater intrusions. They showed the consultants negative impacts on agriculture, and major reductions in the value of lands that were once considered fertile and cultivable. The detailed comments on each of the main questions posed to the stakeholders at the Keti Bandar meeting are presented in Annex 10 - Appendix C.

Findings on Impacts on Agriculture in Lower Sindh

- Deficient irrigation flows in the area despite construction of Tarbela, caused major difficulty in sowing the *rabi* crop.
- Sugarcane is the major crop and numerous processing mills have come into existence after Tarbela. This has significantly increased employment opportunities for local people. However, as sugarcane is a water-demanding crop this could have induced diversions allocated at Kotri.
- Local inhabitants apprehend that reduced flows have increased sea water intrusion spreading over an area of almost 200 000 ha. As the sea retreats, it leaves salt behind that makes agriculture difficult (in the delta or coastal area).
- Migration to areas near Karachi is attributed to the reduced water flows upon construction of Kotri in 1955, and this migration further increased after Tarbela.

- Local inhabitants and NGOs point to the lack of infrastructure development in the area that has accentuated poverty that is further aggravated by reduced water flows in the Indus and the canals.
- Inhabitants in the Keti Bandar stated that problems of reduced flow had occurred essentially upon construction of Kotri barrage. They perceive that Tarbela dam further aggravated the problem, even though there is recognition that population pressure and general degradation in the conditions of the delta has negatively impacted on their livelihood.
- There is considerable uncertainty and apprehensions regarding future development works upstream on the Indus as inhabitants apprehend that their present livelihood would further deteriorate.

3.11 Regional and National Aspects

It is difficult to separate all the regional impacts of a large dam like Tarbela, especially when many other projects were also implemented concurrently. Many regional issues cut across provincial boundaries and, while closely linked with Tarbela, cannot be considered mutually inclusive for all "cause and affect" relationships.

Employment: When Tarbela was constructed, local employment opportunities were limited. The unskilled population worked in agriculture and the surplus often moved to other areas for employment. Tarbela generated employment for a large pool of unskilled workers in many construction activities. The local population also got jobs as truck, tractor and crane operators and was employed in civil contracts. WAPDA expanded its skilled manpower and a large talent pool was created. On-the-job training and experience received by WAPDA engineers became a large national asset. After the dam was completed this talented manpower was absorbed within the country and many went abroad. In 1998 WAPDA still continued to employ around 4 000 people to manage the dam. Agriculture also increased the demand for labour in the command areas. Mechanisation, however, had a displacement affect on the labour pool as anticipated. Particular reduction occurred in the planting and harvesting operations. The backward and forward linkages created ripples in the industrial and processing industries linked to agriculture and new areas developed through expanded electricity. Table 3.55 is presented as background data, and shows employment of major industries as an indication of the magnitude of changes across the country.

Table 3.55. Employment of Major Industries in Pakistan (000)

Sector	1969/70	1980/1	1990
Food	34	48	84
Textile	198	220	238
Ginning, processing and bailing	13	10	4
Electricity	16	17	19

Source: Pakistan Economic Survey, 1995.

In the pre-Tarbela period agriculture employed about 377 000 people while in 1984/85 it employed 457 000 persons. The aggregate affect of agricultural development has had a positive impact on employment.

The following general socio-economic indicators provide an indication of changes in the project area over the study period.

Health: Following the development of Tarbela, in areas surrounding the reservoir, public and private health facilities have improved significantly. Hospitals, small clinics and part-time private consultations have increased. The total number of drug stores in Haripur has increased manifold. Field interviews confirmed a general decline in infant mortality with greater access to maternity homes. Life expectancy on a national basis increased from 45.8 in 1970 to 55.8 in 1990.

In the downstream areas of Multan, Kamalia and Vehari, where some of the displaced persons were resettled, and the area generally benefited from increased canal water releases in the post-Tarbela period, medical services were greatly enhanced. While the government undertook many 'basic health development projects', retaining qualified staff in these isolated units is a chronic problem. Notwithstanding this, there is far greater access to health facilities as compared to the 1960s or pre-Tarbela era (Table 3.56).

Table 3.56. Basic National Medical and Health Establishments

Year	Hospitals	Dispensaries	Basic Health Unit (BHU)	Maternity
1961	345	1251	3	422
1971	495	2136	249	668
1981	600	3478	774	823
1994	814	4280	4843	820

Source: GOP, Economic Survey 1994-95.

Access to Food: In all the areas surveyed access to quantity and quality of food has increased significantly. It was reported that there was a significant increase in consumption of basic food items. While the inflationary trends have increased the price of basic staple foods like wheat and rice, there were no problems reported on their availability. Rural milk consumption has declined as milk (especially downstream) is marketed to the urban areas. Increased per capita availability of fruits and vegetables has brought these commodities within reach of the common man.

Access to Education: The post-Tarbela era shows improvements in the availability of primary and higher levels of schooling. While the overall literacy rates in the surveyed areas have not changed significantly, access to schooling has improved. National literacy statistics show a total literacy of 18.4% in 1961 improving to 34.9% in 1990. However, it is disturbing to note that female literacy is half that of male literacy (Zaidi, 1999). In particular, greater attention is being given to female education. Privatisation of schools has further encouraged private operators to invest in schools. The five townships surveyed have government and private schools within easily approachable distances. Similarly, the access to these services improved dramatically for settlers in the areas of Mailsi, Vehari and Kamalia. Access to higher education is based on competition and certain quotas are reserved for disadvantaged groups.

It is beyond the scope of the Tarbela study to calculate the net economic impact of Tarbela on the economy. The PIDE (1983) input-output model[5] has the capability to generate aggregates for the economy. However, with the separation of individual project impacts and multiplier effects, this was beyond the scope of this analysis (Table 3.57). Instead, available documents have been used to sketch the regional development scenario.

Table 3.57. Output Multipliers for Selected Sectors of the Pakistan Economy (1984-85) (1965 as 1.0)

Sector	Multiplier
Agriculture	
Farm input manufacturing	1.97
Agriculture (farming)	2.39
Manufacturing	3.00
Transport, storage and communication	1.82
Wholesale and retail (trade)	1.32

[5] This model includes endogenous variables in agriculture related to value added and demands for agriculture inputs.

Rest of the Economy	
Manufacturing	2.63
Transport, storage and communication, wholesale and retail trade	2.00
Mining and quarrying service	2.85
Public administration and banking	2.18
Households	3.01

Source: M. Akhtar and Forest Walters, Pakistan Agriculture, A description of Pakistan Agricultural Economy EAN 1990.

The Lieftinck Report predicted certain specific national benefits (later also documented in the Bank Appraisal missions) which were:

- A rapid increase in wheat production that would reduce dependence on imports.
- Multifarious increases in livestock production and modernisation of milk and meat industries due to expansion in the fodder area, especially in the canal command areas.
- A massive transfer of modern agricultural production technology that would lead to production increases in all types of crops and also makes agriculture an attractive investment.
- Agricultural production that exceeded predicted population growth rates. This objective was achieved despite the fact that the population growth rate did not decline significantly.

It was postulated that gains from agricultural development would directly influence the manufacturing sector through backward and forward linkages.

3.11.1 Regional Development Programs

Anticipated regional programs included massive installation of electric tubewells. Such electrification was expected to directly boost cotton, sugarcane, wheat and fodder production.

In the context of the Third Plan and further development strategy it was envisaged that Tarbela would contribute significantly to achieving self-sufficiency in wheat production. An explicit assumption of the Tarbela planners was that government pricing and marketing policies would favour economic shifts in cropping patterns that would facilitate achieving higher wheat production.

Within a regional planning framework it was proposed that agricultural employment was likely to increase by two-thirds between 1965-85, or by about 2.5% annually. Furthermore, the proportion of labour employed in agriculture would remain unchanged.

The anticipated impacts, therefore, were assumed to revolve around the crop and livestock sectors.

Amongst predicted national benefits, the explicit assumption was that, besides direct water benefits, Tarbela would have widespread economic impacts on all four provinces, especially through the stimulation of the industrial and manufacturing sectors as a result of significant power generation. Since Tarbela-generated electricity was to be placed at the disposal of WAPDA through the National Grid, its impacts would cut across regional boundaries.

The contribution to agriculture has been widespread, both directly to crop and livestock production, as well as to agricultural marketing and processing. Agribusiness development also witnessed substantial growth in the post-Tarbela period. Growth in the cotton and sugarcane sectors generated backward and forward linkages conducive to growth of agribusiness opportunities.

While all these multifarious impacts cannot be attributed to Tarbela alone, rapid rural transformation through increased water, rural electrification, and shifting cropping patterns has nevertheless been widespread in Sindh and Punjab. Electrification in NWFP and Baluchistan has also positively impacted on agriculture and brought changes in social and economic welfare.

Another explicit assumption in the perspective plan that was relied upon by the Lieftinck Report (1968), was that the farm to market roads network would be increased. The overall increase in the communication infrastructure before and after Tarbela also contributed to enhancing agricultural productivity. In particular, farm to market roads, provision of widespread telephonic facilities to rural areas, and increases in print and mass communication media led to reduced communication costs and rapid information transfer. These factors positively impacted on agriculture through rapid technology transfer.

As crop volumes rose, individual farms that were essentially subsistence in nature, were progressively converted into commercial units and integrated with the factory product market. More than 80% of small-holders were brought into the crop and livestock markets, and moved away from subsistence and barter agriculture. With the rapid rise in the use of agricultural inputs, productivity increases brought most small producers into the mainstream economy. Again, water and electricity triggered major surpluses in the wheat, cotton and sugarcane producing belts as noted in the section on agriculture (see section 5).

Though growth rates in various sectors showed erratic trends during the past two decades, agriculture has generally been slightly more stable as shown in Table 3.58.

Table 3.58. Growth Rates in Different Periods (per cent)

Sectors	1960s	1970s	1980s	1988-97
GDP	6.77	4.84	6.45	4.70
Agriculture	5.07	2.37	5.44	4.09
Manufacturing	9.93	5.50	8.21	4.95
Commodity-producing sector	6.83	3.88	6.49	4.67
Service sector	6.74	6.26	6.65	4.75

Source: GOP Pakistan Economic Survey, 1996-97, Islamabad.

It is interesting to note that major increases in cotton production led to accelerated impacts on the manufacturing industry from the 1970s to the 1980s. There was greater diversification in the choice of textile-based products in lieu of international market demand trends. Pakistan also opted for a higher value-added strategy as opposed to raw ginning of cotton for export.

Besides the military rule during 1977-88, there was judicious attempt to increase growth by capitalising on earlier investments, especially in heavy industries, reliance on remittances and on the Afghan crisis by virtue of which massive aid and humanitarian assistance entered the system (Zaidi, 1999).

It is difficult to disaggregate the attributable value of Tarbela water including impacts on tubewell irrigation. However, data reported in three selective canal command areas showed major increases in agricultural field crop production. Findings from WCD sponsored fieldwork in Mailsi (Multan) suggest that rapid increases in cotton, and wheat and fodder production became possible after the Mailsi-Sidhnai link canal was built under the Indus Basin Project. Farmers stated that Mailsi was transformed into the most productive Tehsil in the Punjab with high yields and cropping intensities.

Electric tubewells combined with canal water have resulted in a major shift in the production function. New lands have been brought under cultivation, and input use together with intensive mechanisation has taken place. It was reported that increases in cotton and wheat productivity have directly benefited the livestock sector, as products like oilseed cake and wheat straw are direct inputs into commercial milk and meat production.

It must be borne in mind that Tarbela alone has not brought about changes in rural life. The water and electricity benefits were harnessed by associated investments in agricultural research, technology, industry and policy initiatives. Widespread economic gains were registered from cotton in the southern Punjab and upper Sindh benefited most from Tarbela waters. Another interesting phenomenon that has been noted, is that in certain areas, farmers cashed in on their high value lands (especially those with smallholdings) as a result of post Tarbela productivity increases, and decided to purchase low value land in arid areas like the Thal desert, Jhang and Bahawalpur. This inter-regional resource transfer, while increasing the overall asset position of certain groups, also helped increase agricultural productivity in the marginal areas due to investment.

It has also been apprehended, however, that Tarbela water, due to overuse in the non-perennial canals of southern Punjab and Sindh, might have contributed to water logging and salinity. Similarly, cheaper electricity at subsidised rates can lead to water over-use. Both these factors have resulted in non-optimal water allocations in certain areas.

Assured water supplies have had a stabilising affect on prices and food stocks in the country. Gains in the Punjab and Sindh were also transferred to urban and rural wheat consumers in NWFP and Baluchistan. Price stabilisation in wheat, cotton and sugarcane for year-to-year variations was achieved as a result of increased production. For example, the market prices for wheat in Lahore from 1975 to 1992 showed an average annual change of 10.4% with 0.7% minimum and 23.1% maximum. The average inflation rate during this period was around 10% varying between 7–25% as measured by the GDP inflation index. Cotton prices have been influenced by international price trends. Rather high sugarcane prices resulted in expanded output. A large number of sugarcane factories were developed with indigenous technology. Such expansion led to factories offering lucrative incentives to farmers to expand sugarcane areas often leading to over-investment of resources.

Findings on Regional and National Impacts

The findings presented here need to be read with a degree of caution. Not all the impacts can solely be attributed to the dam, even though the direct and indirect linkages are clearly noted and the link to Tarbela established. The magnitude of the contribution cannot be established and is beyond the scope of this study.

- Wheat production increased from 8.7 mt in 1975 (pre-Tarbela) to 18.7 mt in 1998 (215%) and benefited the whole economy. The growth in wheat production was, however, lower than predicted in the Lieftinck Report. Employment increased significantly in the agribusiness sector especially related to the processing of sugarcane, cotton, and milk and fruit juices. Much of this growth can be attributed to Tarbela, but not exclusively.
- Tarbela-generated power helped the development of rural electrification, which directly impacted on rural life and brought about social transformation.
- Extra availability of electricity and increased agricultural production set the stage for massive farm to market road development. This enhanced road system brought the rural sector in direct contact with the urban markets, thus increasing rural incomes and also facilitating technology transfer.
- Increased land values provided an incentive for certain groups to sell land at higher prices and substitute this with lower value land in arid regions like Jhang and Bahawalpur etc. This pattern fostered a transfer of resources from high value irrigated land to land of lesser value in arid areas.

3.12 Environmental Effects

3.12.1 Ecological Effects

No environmental impact assessment (EIA) was required to be carried out before the design and construction of Tarbela, so there is no description of the baseline ecological conditions with which to compare the present conditions. This assessment of the environmental effects has had to be developed from an interpretation of the present conditions, and a rather sparse and patchy literature. It is also extremely difficult to separate out the direct effects of the construction of Tarbela by itself, against the background of changes occurring due to the irrigation and hydropower network as a whole, and other pressures upon the environment. The approach taken has been to describe the changes that have occurred and highlight those to which Tarbela has contributed. Reference to the changing hydrology that was directly affected by Tarbela, is made where appropriate.

3.12.2 Description of the Indus Basin Ecosystems

The ecosystems of the Indus basin can broadly be grouped into four:

a) The mountain river ecosystems: These extend from the headwaters of the Indus and its tributaries as they flow through the Himalayas to the point where it emerges from the foothills at Tarbela. The dam at Tarbela, at an altitude of 471m, has created a reservoir of about 25 600 ha. with a depth of 64m., backing up the river by 97km. The Indus is the main river, making up about two-third of the total annual flow. It is almost entirely fed by melt water from the snows and glaciers. Other tributaries, (Jhelum and Chenab), are also fed by monsoon rains. The climate around the Tarbela dam site is sub-tropical with an average rainfall of 950cm, and winter temperature ranges from 2-19°C, and from 20-39°C in summer.

Immediately after Tarbela, there is a transition zone, in which the river Indus emerges onto a wider plain where it is joined by the Kabul River at Attock, passing through a narrow gorge through the Salt range, before emerging onto the Punjab plains at Kalabagh. The mountain river ecosystems are typified by fast flowing, cold waters cutting through steep narrow gorges of alpine scrub and moist temperate and sub-tropical pine forest, and carrying very high silt loads. The riverbed tends to be made of rocks and gravel, with some deposition of sand and silt only at bends or junctions with other streams. The river is rather unproductive, with little emergent vegetation, or a substantial fish population.

The reservoir is an important staging post for migratory waterfowl but is less important as a wintering site because of its depth and lower productivity. The characteristic species of fish are the snow trout, *Schizothorax spp.* and loaches, *Cobitidae.* In the foothills the fish species are a mixture of high Montana and South Asian species, with a variety of Cyprinids including *Puntius spp*, and catfish. The most famous fish species in this area is the *Mahseer*, *Tor putitora.* A cold water fish, it migrates seasonally into the upper, cooler waters during the hot season. Within the reservoir itself, *Cyprinus carpio* has been introduced.

b) The upper Indus ecosystems of the Punjab plains: After Kalabagh, (250m amsl. and 1 500km to the sea) the Indus River becomes a typical, large, lowland river, with a wide alluvial flood plain, meanders and oxbow lakes. It is joined by several smaller rivers draining the drier lands from the west. There are three major barrages on this stretch of the Indus: Kalabagh Chashma, Taunsa being the main offtakes for irrigation and re-distribution of water through link canals to the other Punjab rivers. The inundations behind the latter two barrages are important permanent wetland areas (Ramsar sites) with a number of shallow lakes and seasonally flooded lands. The surrounding land may be affected by seepage from the reservoir and irrigation channels.

Before the Indus reaches the province of Sindh, the five rivers of the Punjab (Jhelum and Chenab and the three eastern rivers, the Ravi, Sutlej and Beas) merge below the Panjnad headworks. Dry season flows in the eastern rivers (under the control of India) are minimal, exacerbating the heavy pollution in the Ravi from domestic and industrial wastes from Lahore. Mangla Dam was constructed on the Jhelum to transfer water between the rivers to compensate for water abstracted by India. A total of ten other barrages/headworks have been constructed on these five rivers in the Punjab for irrigation purposes.

The climate in the upper Indus plains is dry sub-tropical with hot summers and cool winters. The annual rainfall varies from 300–500mm and the annual average maximum temperature is 41°C in June and the average minimum is 4.5°C in January. The principal vegetative zones through which the river passes are the tropical thorn forests and sand dune desert. However, within the flood plain itself, the main vegetation associations are the riverine areas typified by *Acacia nilotica* forest, with *Tamarix* and *Populus* species in less stable areas, along with grasses such as *Saccharum* species. There are also areas of swamp and seasonal inundations, typified by *Tamarix, Phragmites* and *Typha* species. Around Chashma, most of the natural thorn forest on the lands to the east of the river has been cleared for agricultural lands and irrigated plantations of *Dalbergia sissoo* and *Populus euphratica.* Much of the area alongside the Indus around Taunsa is cultivated.

The barrage ponds and seasonal wetlands in the Indus plain are very important staging and wintering areas for a wide variety of waterfowl. Chashma supports over 50 000 *Anatidae* and coots in mid-winter, and the common and demoiselle cranes (*Grus grus, Anthropoides virgo)*. Taunsa is a breeding ground for the lesser whistling teal (*Dendrocygna javanica)* and a wintering ground for the bar-headed goose (*Anser indicus)*. The typical mammals in this area include the Indus dolphin (*Platanista indi),* the smooth coated otter (*Lutra perspicillata),* and the hog deer *(Axis porcinus),* although all of these are under serious threat. The gharial (*Gavialis gangeticus),* last seen in 1980 at Taunsa barrage, is now considered extinct. Fish species are predominantly South Asian, dominated by cyprinids and catfish.

c) Ecosystems of lower Indus: At Guddu barrage (80m amsl and 800km from the sea) the Indus passes into the plains of Sindh. From this point to outfall into the sea, the whole river length has a system of bunds (confining dyks) on both sides. It meanders through a very wide flood plain (several kilometres wide), flooding is common and results in accumulated silt being deposited. Due to confinement, the river bed is being gradually raised so that some riverine forests now lie high above the regular flooding levels. Most of the plains of Sindh have been built up by alluvium from the Indus. There are four relict channels of the Indus.

The climate of the lower Indus plain is arid sub-tropical with very hot summers and cool winters. The annual rainfall is about 150–200cm, the minimum temperature in winter about 2°C, and the maximum in summer is 49°C.

Manchar Lake, an important wetland on the west bank of the Indus river receives flood waters from the river. In recent years it has been receiving the saline discharge from some right bank drainage projects, with the result that the water quality in the lake has seriously deteriorated, affecting fisheries and wildlife in the area. Major barrages have been constructed at Guddu, Sukkur and Kotri enabling water to be abstracted for irrigation throughout Sindh and for water supply to Karachi.

The Indus Dolphin Sanctuary (another Ramsar site) extends for 135km between the Sukkur barrage upstream to the Guddu barrage. The river floods during the summer monsoon (average width 2.6km and depth between 8–10m). At low water levels in winter, numerous islands, sand banks and mudflats are exposed and many of the river channels are reduced to a series of pools (main channel 0.5–1km wide, average depth 6m). There are some marshy areas on the adjacent floodplain, typified by grasses such as *Saccharum spontaneum, Phragmites karka, Typha spp.* Riverine scrub is dominated by *Tamarix dioica.* This is the key area for the endemic Indus Dolphin, *Platanista indi,* with its population highly fragmented by the system of barrages.

Within the flood *bunds,* the riverine forest ecosystem is now dominated by plantations of *Acacia nilotica.* This ecosystem is dependent upon annual out of bank flooding (for seed dissemination and establishing young seedlings) which occurs when the flow at Guddu is more than 8 490 cumecs. There are a total of 161 852 ha of riverine forest between Guddu and the Indus delta, representing about 19% of the total land area between the flood *bunds*. About 30% of the land is cultivated and the rest is uncultivated scrub or water, sand and mudflats.

The commercially important Anadromous Shad, *Palla* or *Tanualosa ilisha,* comes into the Indus for breeding. Before Kotri barrage was built in 1955, *Palla* reached Sukkur, 800km from the sea, and as far as Multan before the Sukkur barrage was built in 1932. The spawning grounds of Palla have been restricted by over two-thirds to the stretches of river downstream of Kotri barrage. Another commercially important fish of the lower Indus is the *baramundi*, *Lates calcarifer,* which migrates from freshwater to the sea. Fish landings of *Palla* and *Baramundi* have shown significant declines in recent years.

d) The Indus Delta: The Indus Delta is one of the largest areas of arid climate mangroves in the world and is the seventh largest delta. Its formation was characterised by high river discharge, moderate tides and high wave energy conditions. The Indus delta is unique amongst the large world deltas in that it experiences the highest wave energy of any river in the world. At times the delta has moved southwards and westwards by rates of between 4–30m/year due to a silt discharge of over 400 million tonnes per year. With the increased abstraction of water upstream, the quantity of silt reaching the delta is now less than a quarter of this.

The climate of the Indus delta is arid sub-tropical, with an average rainfall of about 220cm, a relative humidity of 76%, a mean annual temperature of 29°C, and a mean surface water temperature of 21.8°C. Strong monsoon winds blow from the south-west during the summer and from the north-east during the winter. During the summer, seawater inundates both the active and inactive parts of the delta leaving behind evaporated salt deposits.

It occupies an area of about 600 000 ha consisting of creeks, mudflats and mangrove forest between Karachi in the north and the Rann of Kutch in the south. There are 16 major creeks making up the original delta. Because of the confinement of the flood *bunds* below Kotri, however, and the reduced flows down the river, only the area between Hajamro and Kharak creeks now receives water from the Indus with one main outlet to the sea, Khobar Creek. These *bunds* were built between 1900 and 1910, and again at the time of Kotri construction in 1955. The active delta is only 10% of its original area.

The mangroves in the Indus delta are predominantly *Avicennia marina.* Four out of the original eight recorded species remain, although *Rhizophora mucronata* has been re-introduced. There has been a significant reduction in mangrove cover (from around 263 000 ha in 1978 to around 158 500 ha in 1990). The distribution of mangroves is patchy, with smaller areas of mangroves around the active delta, and more substantial areas in the abandoned delta to the north and south. Recent estimates show that there might be as little as 160 000 ha of mangrove cover left.

The active delta was used for the cultivation of red rice during the floods and there is little control over the cutting of mangroves for timber, and grazing by up to 16 000 camels herded in the delta. Buffalo, and even sheep and goats used to be kept on the banks of the creeks. The Indus delta is an important fish breeding and nursery ground, especially for shrimp and other crustaceans, such as crabs.

Mangrove ecosystems are considered to be important for many of the commercially caught species along the Pakistan coast. The total fish production of the Sindh coast is estimated to be about 350 000 tonnes. Within the creeks of the Indus delta, the main catch is the small pelagics, *(Sardinella spp,* anchovies, thryssas and other clupeids*).* In 1988 the landings from the creeks was estimated to be about 96 410 tonnes, but many other species rely upon the creeks as nursery grounds.

The Indus delta is also an important destination for migratory birds, including waterfowl and shorebirds, pelicans and flamingos. It is a breeding area for herons and egrets, four species of gull and several species of tern. It is visited by the osprey, *Pandion halietus* and the brahminy kite, *Haliastur indus*. Three species of cetaceans, the plumbeous dolphin (*Sousa plumbea),* bottle-nosed dolphin (*Tursiops aduncus),* and the finless porpoise (*Noemeris phocaenoides)* are also reported in the creeks regularly.

e) Ecological changes of riverine belt The Indus River banks and upper strata of its bed are fragile as these are composed of sandy and clay soils. The river meanders across the plains of Sindh and has intricate patterns downstream.

The *katcha* lands (*kacho)* have been formed in a continuous belt along the flat plains of the meandering course of River Indus, extending on the either side in varying widths ranging from 5 to 10km of a flood-prone area. *Katcha* lands are rich and fertile due to nutritional silt depositions during river spill-over periods, and excellent ground drainage.

The *katcha* belt extends over 750 000 ha and the best part of it over 250 000 ha, depending on the frequency of yearly flooding, is cultivated for growing cash crops: lentils, mustard and oil seed crops. Riverine forests are distributed in beats and blocks of varying sizes and cover an area of 240 000 ha of *katcha* lands within the flood plains. Grazing lands sprawl in most of the *katcha* belt (approximately 500 000 ha including grazing grounds under the forest cover). These expanses of grass lands and pasture, support and feed large numbers of livestock including an estimated 450 000 cattle, 450 000 buffalo and 675 000 small ruminant goats and sheep (Revenue Department Sindh, 1996). Riverine forests and grasslands, prior to the barrages and dams, provided abundant pasture to the multitude of domestic and wild animals residing in the riverine tract.

The productivity and distribution of riverine forests and grass lands in the *Katcha* belt have undergone considerable changes in the past 30 years due to varied stresses upon them. The reduction of fresh water seasonal flows and the alteration of the natural flow regime of the river are the principal stresses that have caused retrogression and depletion in the riverine forests and pasturelands.

Riverine forests, hitherto comprised two distinct classes of lands, low-lying areas and high-lying areas. These areas, which provided timber and fuelwood yields and supported large numbers of livestock and a variety of wild animals and avifauna, have changed their formation course and natural distribution limits. Very high lying areas emerged due to a discontinuation of flood inundation, after alteration of the natural flow regime and a reduction of seasonal flows of fresh water.

The formation of very high-lying lands in the peripheral parts of the flood plains were determined through the aerial survey of riverine forest lands and inventory of forest stock conducted in the years 1973-74 by the Sindh Forestry Department. Further periodic investigations and sample field surveys have revealed vast changes in the extent of the three forest land classes. Very high-lying lands (VHL) are increasing with the passage of time, and the estimated area ranges between 30 000 to 35 000 ha (Sindh Forest Department, 1997).

VHL are covered with heaps and mounds of drifting sand or fixed sand dunes, and these are devoid of tree cover and ground vegetation. High-lying areas contain bushy and stunted growths of *prosopis cineraria* mixed with xerophytic ground species, and have mostly been invaded by the noxious weeds, *prosopis glandulosa* and *P. juliflora* (mesquite or *Devi*).

Agro-forestry practices were common from 1930 to 1975 in the high-lying forests, as these offered ideal conditions for growing crops and tree seed strips, and water flows could easily be hauled/transported through numerous extant natural channels and ditches (*dhands* and *dhoras*).

Such practices have now been greatly decreased due to the high costs involved in various development operations, including land levelling and the installation of tubewells or other mechanical devices to lift water from distant channels containing water.

Low-lying areas are still sustainable to an extent, but these have also undergone deterioration due to disruptions of the ecological habitats, low seasonal water flows, and shorter inundation durations during peak floods.

A majority of farmers are small land-owners and livestock plays an important role in the economic sustenance of these smallholders. Even landless classes maintain livestock, which is an important and stable source of their family income. This vital source of subsistence for one million people residing in the *Katcha* areas (riverine tract) and adjoining villages have declined in quality and number as a result of degraded forests and pastures, and emaciated flocks of livestock are now found in the *Katcha* belt.

Livestock/cattle have largely been depleted and reduced from very high-lying (VHL) and high-lying lands and other peripheral areas, and bio-diversity has been damaged in the *Katcha* belt and riverine forests.

3.12.3 Man-made Changes to the Indus River

There have been three main types of man-made change to the Indus River over the past 150 years:

- The construction of *bunds* to protect agricultural lands from inundation by the flood waters of the Indus, starting in 1869 near Sukkur. By the time the Sukkur Barrage was constructed in 1932, the right bank had a complete line of *bunds* from the Sindh/Punjab border to Sehwan, and from Sonda to the Indus delta. When Kotri barrage was built (in 1955), flood *bunds* were completed, effectively constricting the active Indus delta.
- The construction of the barrages and the link and irrigation canals has, over the years, led to a systematic abstraction of water from the Indus. Overall, a total of 23 barrages, with a total diversion capacity of 69 500 cumecs (245 100 cusecs) to feed 45 canal commands, had been constructed by the time the Tarbela dam was planned. The commissioning of Kotri barrage in 1960 has been noted as a key point in this process.
- A number of dams have been built in the Indus basin: at least two in India on the eastern rivers; the Warsak dam on the Kabul River; and Mangla dam on the Jhelum in 1967. Tarbela dam, the largest, with a storage capacity of about 12 bcm (9.4 MAF) was the last in a long series. The total storage capacity of the dams is about 19 bcm, with Tarbela being about two-third of this.

Originally, the average annual inflow to the Indus River system was about 217 bcm (176 MAF), but the apportionment of the eastern rivers to India potentially deprived the Indus basin ecosystem of about 42 bcm (34 MAF), giving a potential average annual flow of 175 bcm (142 MAF). Before Mangla dam was built, the total average abstraction was 108.2 bcm (87.7 MAF). Mangla dam resulted in an increased average abstraction of 117.4 bcm (95.2 MAF), and Tarbela dam has raised this average to 129.4 bcm (104.9 MAF).

The overall impacts of man-made changes in the Indus River system are:

- The main effect of Tarbela has been to store water flowing down the upper Indus during the highflow periods, and to release them more gradually during the lower flows in the river. More water flows in most stretches of the river during the *rabi,* and less during the *kharif*.
- Downstream of Kotri barrage, where the full impact of upstream abstractions is observed, the present average *rabi* flow is only slightly less than the pre-Mangla *rabi* flows. In the pre-Kotri period, the average *rabi* season flows (at 50% probability) were around 13 bcm for the period 1940-61. These were reduced to 1.0 bcm during the post-Kotri and post-Mangla period (1961-

75) mainly due to increased upstream abstractions. In the post-Tarbela period there was a slight increase in the average *rabi* season flows to 1.7 bcm (refer to tables 3.17 and 3.18).

- The average *rabi* flows do not accurately represent the downstream impacts: the number of days with zero flows is more important. Prior to the Kotri barrage there were no days with zero flows in the *rabi* season. Zero-flow days were observed during the post-Kotri period (1962-67), and one year (20%) in the *kharif* season and four years (80%) in the *rabi* season were recorded as having zero flows. During the post-Mangla period, zero flow days were observed in six years (75%) in the *kharif* season and eight years (100%) in the *rabi* season. Zero flow days marginally reduced to 14 years (61%) in the *kharif* season and 22 years (96%) in the *rabi* season in the post-Tarbela period (1975-98). In the *rabi* season, it was effectively the same at 96%, compared to 100%.
- Average flows do not give a good picture of the real conditions in the river. Ecologically, the peak and minimum flows are more important, since the peak flow determines the extent and duration of flooding, the quantity of silt transported downstream, and the minimum flows determine drought stresses upon the riverine and delta ecosystems. The frequency of low and very low flooding at Kotri (very low flood is less than 5 669 cumecs, and low flood is between 5 669–9 921 cumecs), has increased from about 10% of the years before Kotri was built, to 32% after Kotri, and about 53% after Tarbela. The frequency of very low flooding, covering only 25% of the riverine forest area, has increased from 1 in 4 years before Kotri, to 1 in 3 years after Kotri and to 1 in 2 years after Tarbela. The more years in which there is only a low flood, the greater the drought stress upon the flood plain.
- The effect of water storage in the dams, and water abstraction in the barrages has progressively reduced the area of the flood plain. The original area is not available, but now the Punjab Indus has a flood plain of nearly 400 000 ha and, in Sindh, of 855 400 ha. Of these, 302000 ha and 600 000 ha. respectively, are cultivable with *sailaba* crops and riverine forest. The general reduction in peak flows in the post-Tarbela years, has reduced the total area of the flood plain. In the Indus below Kalabagh, the average 4-monthly peak flows have been reduced from 6 800 cumecs between 1967-76 (ie before Tarbela) to 5 731 cumecs between 1977-86 (ie after Tarbela). The same pattern is seen after Taunsa and after Sukkur barrages for the *kharif* averages and for the average 10-day maximum peak.
- Within the flood plain below Kotri barrage, the flood *bunds* extending from the barrage have significantly reduced the area flooded at peak flows and the distribution of flood waters through the different channels and creeks into the delta. The active delta is now only 119 169 ha compared to the 618 000 ha before these works were completed.
- The sediment load carried by the River Indus is a significant ecological factor. Tarbela dam has had a major effect in reducing this sediment load, as have the other major dams and barrages. The original sediment load of the Indus basin as a whole has been estimated at between 200 and 400 MT per year as measured at Kotri barrage. When water flows are high, the sediment load discharged will also be high. There are three distinct periods of discharge ranges as shown below. There are anomalies with high discharges of water and sediment in 1955/56 and again in 1972/73, probably associated with the building of Kotri barrage and Tarbela respectively (Table 3.59).

Table 3.59. Three Periods of Sediment Discharge to the Indus Delta

Period	Discharge range	Sediment load range (MT)
1931-47	70-150 bcm	190-330
1948-61	50-150 bcm	10-100
1962-86	10-100 bcm	10-130

Other factors may have affected the Indus ecosystems. These include the following, which are largely related to the relentless growth in population at 3.1% per annum:

- Water pollution: With the growth in population throughout Pakistan, there is increased discharge of domestic sewage into the Indus and its tributaries. With industrial development, waste water discharge from factories has increased, especially in the Ravi and Kabul River, and in the northern Indus delta adjacent to Karachi. The few systematic studies carried out show gross organic and other pollution in a number of reaches of the river system. However, such conditions are usually comparatively localised with very high BOD and COD values. Over longer stretches the overall self-cleaning mechanisms in the river maintain reasonable conditions. The dilution offered by the river at times of high flow is more than adequate to maintain oxygenated conditions, but there can be problems during the low flow season in some stretches and tributaries.
- More persistent pollutants such as heavy metals and agricultural chemicals have increased in the river waters. The World Wildlife Fund (WWF) reports that pesticide use in Pakistan has increased by almost seven-fold, growing from 900 tonnes in 1981 to 6 000 tonnes in 1991. These chemicals may accumulate in the food chain, especially when they are washed into the river and associated wetlands, but no detailed studies have been done to confirm this.
- The demand for agricultural land has increased, and this has been met by irrigation. However, the availability of agricultural land has also decreased, owing to increasing salinisation of irrigated land and the creation of large areas of degraded waste land. Nevertheless, the pressure to cultivate land has resulted in the loss of natural vegetation and habitat in riverine areas, especially where flood risks have been reduced.
- Habitat loss has also been caused by the removal of forest cover in the upstream areas above Tarbela. This has increased erosion and sediment transport in the hilly areas. There is some evidence to show that the presence of the Tarbela reservoir has facilitated the removal of such forests because the logs may be floated down for easy collection in the reservoir.
- Clearance of riverine forests for security reasons, especially in Sindh, has also caused habitat loss. Pressures from grazing and lopping for fodder and fuelwood have added to the degradation of riverine forest – another result of the pressure on natural resources caused by population increases.

3.12.4 Resulting Changes to the Indus Ecosystems

Mountain river ecosystems have largely remained unchanged up to the Tarbela reservoir. The fast flowing mountain river has been converted into a deep, narrow lake with cold oligotrophic waters. The flora and fauna of the mountain river will have been lost or pushed upstream, and over a period of time, a lacustrine flora and fauna has established. The lake remains relatively unproductive. The reservoir is subjected to such extensive draw-down that the banks are virtually devoid of aquatic vegetation, except in the shallower water near Haripur, where fish productivity is higher.

The Tarbela reservoir has provided a large body of water as a staging point for migratory birds. However, neither their variety nor number is as high as might be expected of a wetland of this size because the reservoir lacks the shallow water and aquatic vegetation necessary for a good waterfowl habitat. The dam has prevented the migration of *Mahseer* fish, *Tor putitora,* from the warm waters of the Indus plain reaches into the cooler upper reaches in summer. The shallow gravel banks suitable for *Mahseer* spawning have been inundated, as have the well-known fishing spots in the Tarbela area.

The operation of the dam affects the reaches of the river immediately downstream, ie, down to Attock. Flows in the reach are determined by the requirements of the irrigation systems downstream, but occasional very high releases, of up to 14 000 cumecs (more than double the high flow average of about 6 100 cumecs in mid-August), have been recorded as well as times of virtually no flow. Local fishermen immediately downstream have complained of both substrate and fish being washed downstream by sudden releases of water.

The upper Indus ecosystems of the Punjab plains have been changed by the construction of the barrages, creating reservoirs that have increased the permanence of previously seasonal wetlands.

Chashma and Taunsa barrage reservoirs have become significant wetlands for migratory birds and fisheries. The barrages and unlined irrigation canals have increased the level of the groundwater due to seepage. Seepage lagoons are very common and have provided a similar type of wetland habitat to the seasonal wetlands, but the quality of the water may be impaired by salinisation. Saline seepage lagoons, and freshwater *dhands* have different characteristics and attract different flora and fauna.

Increased abstraction has reduced the extent of flooding from up to 8km on each side to only 2km at present. This has had a number of associated effects. It has permitted the raising of some small areas of riverine forest in previously low lying areas where the trees would have washed away, but it has also allowed the invasion of exotics such as *Prosopis juliflora* in areas no longer flooded. These have replaced the indigenous *Acacia nilotica.* The gradual shrinking of beds of *Typha* which used to line the banks of the main river and the increase in *Saccharum* grasses, indicates a drying out of the flood plain. The riverine forest is drying out and being reduced to a few patches. The many forested islands (*belas)* used to be refuges for wildlife. Access to these *belas* is now easier and many forests have been cleared and the land used for agriculture.

Natural fish populations have suffered since many species rely upon seasonal flooding for spawning and the *dhands* were used as nursery areas. The fall in the fish populations in the river may be partly due to over-fishing, but a major cause is the reduced flooding of spawning areas.

Wetlands such as Taunsa and Chashma are under considerable pressure. Taunsa, in particular, has experienced significant declines in the number of breeding birds and the populations of smooth coated otter and hog deer are struggling to survive. The decline in the wildlife at Taunsa is attributed to:

- the invasion by Typha, Lotus, and Tamarix species resulting from flood reduction;
- eutrophication of shallow waters due to seasonal burning of vegetation;
- poaching and disturbance by nomadic fishermen;
- over-exploitation of natural resources and encroachment on the wildlife sanctuary by farmers; and
- lack of overall management infrastructure.

There have been extinctions of certain wildlife species, e.g. *gharial* and swamp deer, and a decline in the hog deer populatiom in these upper Indus plains, probably as a result of loss of habitat and hunting pressure. However, the Indus dolphin population has stabilised over the past decade to about 175 individuals in Punjab between the Chashma and Guddu barrages. The Indus dolphin has now been confined to less than one fifth of its original range. There may be a direct correlation between dolphin density and the complexity of the river in terms of sites with eddies and counter-current systems. Any human development that reduces the complexity of a river's natural flow pattern, such as the reduction in sediment load as a result of Tarbela, lessens the potential for bars and sand island formation.

The lower Indus ecosystems of the Sindh plains have also been changed by the construction of barrages from the meandering lowland river to a series of shallow reservoirs backing up the flood plain. The impoundments have maintained a permanence of wetlands in this arid region, counteracting the effects of upstream abstraction.

The construction of the flood *bunds* throughout the whole of Sindh have constrained the flood plain, causing changes in habitat, making the thorn forest susceptible to degradation or clearance for irrigated agriculture. Riverine forest succession has changed, especially in the higher lying areas. The indigenous species of the thorn forest, *Acacia nilotica,* is now being replaced by the faster growing *Prosopis* species.

Within the bunded flood plain there have been serious changes in the riverine forest due to the increase in low flood frequency and the reduction in area of flooding; the grazing of cattle; the lopping for fuelwood and fodder by local people; and cutting down of forests for security reasons. The increased use of pumped irrigation to establish or maintain riverine forest plantations is an indicator of the failure of flooding to provide sufficient water. The forested areas have reduced from 240 000 ha to about 112 000 ha of variable quality forest. In 1987, the Sindh Forest Department stated that almost 50% of the riverine forests had so degenerated that productivity was no longer of economic value, and deterioration would continue without effective improvements in the water regime. Without this, timber and fuelwood resources would be lost, as would protection against adverse climatic conditions, and wildlife habitat.

Largely as a result of protection of the Indus Dolphin Sanctuary between Sukkur and Guddu barrages, dolphin numbers in Sindh have stabilised at about to 500. This is may be the optimum number with the available habitat and food resources. There is a linkage between the fish productivity of the river and the number of dolphin it can support. The reduction of the natural fisheries in the river is a factor in the survival of the Indus dolphin. The natural fish populations are dependent upon the out-of-bank flooding for access to spawning and nursery areas in *dhands*.

The situation in Manchar Lake has become very serious with a change in the total dissolved solids from about 800 ppm in the 1970s to 2 000–3 000 ppm now. The fish species composition has changed with the loss of rohu (*Labeo rohita),* the main commercial species. The few remaining fishermen rarely catch more than snake fish. The cause of ecosystem degradation cannot be simply explained by the building of Tarbela. However, since the dam was built, the lower frequency of flooding to refresh Manchar Lake has contributed to its decline. Water quality (as measured by TDS content) in the main river has also declined due to increased use of irrigation water and the return of more saline waters back to the river.

Below Kotri barrage the most serious effects of water abstraction can be observed. The river below Kotri currently receives on average 40 bcm (30 MAF) during the *kharif* with a minimum of around 12.3 bcm (10 MAF). There have been 14 years (61%) in the kharif season and 22 years (96%) in the rabi season in the post-Tarbela period (1975-98) in which zero flows below Kotri were observed. The frequency of very low *rabi* flows has increased with the building of Kotri barrage and Mangla and Tarbela, although the average rabi flow has only reduced from 3.6 bcm (2.9 MAF) in the post-Kotri period (1962-67) to 3.1 bcm (2.5 MAF) in the post-Tarbela period (1975-98).

As a consequence, the river below Kotri shows increased braiding and sand bar development. Sediment passing down the system tends to be deposited in the section below Kotri, rather than maintaining the growth of the delta. This has increased the risks of high flooding, and clear channels to the delta must be maintained through releases of flushes of water. The extent of saline intrusion during the low *rabi* season has also increased, reaching approximately 25km upstream towards Kotri from the sea, where the river is almost dry, with water depths of about 0.1 – 0.2m spread over a large area.

Indus delta ecosystems. At the time of building Tarbela, any releases of water to the Indus delta were considered as wasted. The Indus delta itself was seen as a wasteland of mudflats, creeks and mangroves. The construction of Kotri barrage and the associated flood *bunds* restricted the distribution of freshwater in the delta and caused significant ecosystem changes that have been compounded by increased freshwater abstraction. The active delta is now much smaller than it used to be, and the dilution effects of the freshwater upon the highly saline, arid environment of the delta has been largely restricted to this area. A salt wedge forms as far as 12km from the mouth (the only remaining mouth of the Indus) up Khobar Creek, during the SW monsoon, with low salinity at the surface increasing with depth. A combination of low precipitation, high temperatures and high evaporation gives rise to hyper-saline conditions in other shallow creeks (over 41 parts per thousand ppt in the backwaters). It is only during the rainy season that salinity levels in the creeks may fall to 27 – 29 ppt, but normally they remain around 35 ppt.

The sediment brought down to the delta is now estimated at about 60 mt per year, about one fifth of original quantities. The balance of sedimentation and erosion may now have been tilted in favour of erosion. The combined effects are:

- high energy waves eroding the delta;
- increased subsidence of between 2 – 4mm/yr caused by reduced sediment flux; and
- a global sea-level rise of up to 6mm/yr, which may give a relative sea level rise in the Indus delta of up to 8 – 10mm/yr. At this rate the inundation of the delta could be as rapid as several metres per year with the establishment of a transgressive beach dominated by aeolian dunes and a progressively greater saline intrusion inland.

Nutrients carried in freshwater and sediment flows reaching the delta, have also been reduced with implications for the overall productivity of the delta. Increasingly, the nutrients are of marine origin, although there is an increasing contribution from the waste waters from Karachi, swept down the coast by the south east currents. In the northern creeks and mudflats there has been increasing evidence of phytoplankton blooms and growth of algal mats as a result of eutrophication.

The most often quoted changes relate to the loss of mangrove cover in the Indus delta, but there is still no definitive answer to this. Assessments of mangrove cover range from around 263 000 ha in 1978, to around 158 500 ha in 1990, and annual losses may be of the order of 2.5 – 1.8% per year. Whatever the exact figures, the mangroves of the Indus delta are declining in area, with excessive stunting and relatively low productivity. The diversity of mangrove species in the delta has decreased from the eight previously recorded species. It is now virtually mono-specific, apart from efforts to re-introduce species such as *Rhizophora.* Changing conditions, especially increasing salinity, in the creeks, has favoured the predominance of *Avicennia marina,* the most salt tolerant of mangroves. Despite this, the mangroves provide the most productive ecosystem that can survive under these harsh conditions.

One anomaly of the Indus delta is that the densest areas of mangrove cover are not found in the active delta, which has only about 4.7% cover, compared to 26% in the wider delta. This may be explained by the historic land-use in the active delta where mangroves were cleared for red rice cultivation, provision of timber for colonial steam ships going up the Indus, grazing by camels, and lack of management of mangrove resources. In addition, the regular deposition of sediments in the active delta may make the substrates less stable and suitable for mangrove seeding compared to other creeks.

3.12.5 Changes in Ecosystem Uses, Functions and Values

It is difficult to distinguish the impacts upon the ecosystem that have been directly caused by Tarbela, from those to which Tarbela has contributed within the overall framework of the development of the irrigation network. The changes in the ecosystem that have been affected by Tarbela include:

- Groundwater recharge, especially around the dam site itself where the water table has risen. Tarbela has had a direct and significant local effect.
- Reduced flooding both in average height, coverage and frequency of flooding. Whilst this has reduced groundwater in areas around the river, the use of abstracted water for irrigation and seepage from unlined canals has increased the overall water table and given rise to permanent wetlands.
- Reduced sediment transport has reduced the alluvium deposited in the flood plain, causing a reduction in the nutrient status of soils. However, reduced flows of water, especially below Kotri barrage, have increased the deposition of sediment in the main channels, causing sandbar formation. Tarbela has contributed significantly to the reductions in sediment and nutrient transport down the river.
- Reduced sediment reaching the sea has stopped the growth of the delta and it may even now be transgressing. With the lower flows a greater proportion of such sediment as is transported is deposited in the channels before it reaches the sea. Tarbela has contributed significantly to this.

- The protective character of the riverine and mangrove forests in alleviating the harsh climactic conditions has been reduced, increasing the risks of damage from storms, such as the cyclone in early 1999. Tarbela has contributed to this indirectly.

The uses of the natural resources of the river have also been affected. These include:

Fisheries resources

- Natural spawning grounds have been lost, especially for *mahseer*, and for commercially important species in the upper and lower Indus plains. The recorded statistics of inland fisheries, both in Sindh and in Punjab, show an increase in fish production over the years, but this is due to increases in aquaculture rather than increased catches of the indigenous fish from the river. Inland capture fisheries have been declining, and some of the marginalised fishing communities, without access to land for aquaculture, have lost their livelihoods. Tarbela has had some effect upon these fisheries as part of the overall changes in the river.
- Migratory fish, such as *palla* and *baramundi* have shown significant decreases. Catches of *palla* have reduced from high levels of about 10 000 tonnes during the 1970s to about 400 – 600 tonnes per year in the late 1990s. Similarly the catches of *baramundi* have decreased from highs of between 1 – 3 000 tonnes per year during the 1980s, to about 200 tonnes per year during the 1990s. This has been attributed to the construction of barrages and dams and the resultant reduction in flows of freshwater to the sea. It is likely that the construction of the barrages at Kotri and Sukkur have had a greater effect than Tarbela on these fish.
- Marine fisheries have also suffered due to the decrease in freshwater, sediment and nutrient flows down the Indus. In analysing the effects of reduced Indus discharges upon the fish catch, Quraishee (1993) noted that the fish catch off the Sindh coast had increased by 8.5 times between 1950 and 1984, to a level of 221 505 tonnes. However, at the same time, the numbers of boats increased by 27 times with the result that the catch per unit effort actually fell by a factor of 3. Similarly, the catch per unit effort of shrimp has decreased during the same period. Significant decreases in the catch per unit effort coincide with the construction of the major dams and barrages of Kotri and Tarbela. Tarbela comes at the end of a long line of changes, and has had a significant contributory effect upon the marine fisheries.

Agricultural production

- The cultivation of agricultural crops in the flood plain has decreased as a result of the reduction of flooded areas and availability of fresh alluvium. This has been compensated by the increase in irrigated agriculture. Tarbela has contributed significantly to both the primary effect and the compensatory irrigated agriculture.
- Red rice cultivation was the principal crop grown within the active delta. This was dependent upon flooding with freshwater, and crop yields met both subsistence and commercial needs. Orchards of banana, papaya and guava also generated income on lands in the delta. All of these have now virtually disappeared. It is probable that the principal reason for this has been the building of the flood *bunds* and Kotri barrage, but the building of Tarbela will have accelerated the decline.
- Grazing of buffalo, sheep and goats is now rare in the Indus delta, and camels are only maintained through the provision of boat-loads of fresh water through much of the year. This has meant that the only remaining livelihood for people living in the delta is fishing. As noted above, this is a result of the building of Kotri barrage, combined with the general abstraction of water and the building of Tarbela.

Timber production

- The riverine forests of Sindh are important sources of timber for construction and for the coal mines. The yields of timber and fuelwood have been erratic in recent times, since the productivity of the growing stock has generally deteriorated. Between 1993 and 1998, GOP imposed a complete ban on regular commercial harvesting of timber and fuelwood species from all forest lands. Tarbela has contributed significantly to the decline in riverine forest production, by increasing the frequency of low floods.

- The increased use of pumped irrigation of high-lying riverine forests has been inadequate to compensate fully for the loss of natural flooding, and adds substantial costs.
- The riverine forests are as important for grazing and browsing animals, and for the provision of fuelwood for local communities, as they are for timber. With the general deterioration and change in predominant species from the more useful *Acacia nilotica* to *Prosopis*, so these values have been lost. As above, Tarbela has contributed significantly to the decline in this resource.
- *Populus euphratica* is another timber species that has degraded. This was used for lacquer work furniture and has now almost ceased to grow due to lower deposition of alluvium during floods in the *katcha* lands.

Wildlife values

- The wetlands in the Indus plains, have remained more or less the same, with the losses due to lower flooding being balanced by increases due to the barrage reservoirs and seepage from the canals. The provision of wetland areas for migrating birds has been maintained, although there has been some variation and reduction in bird species and populations due to a variety of factors. The contribution from Tarbela to these declines has been relatively minor.
- Loss of habitat is probably the main factor in losses of fauna, such as the extinction of the swamp deer, and the gharial, and the reductions in the populations of hog deer and smooth coated otter. Tarbela's contribution to such loss of habitat is one of many pressures upon the riverine environment.
- The Indus dolphin populations appear to have stabilised, but are split up by the barrages. Expansion of the dolphin populations is limited by the availability of fish in the river. The building of Tarbela has had less of an effect upon the Indus dolphin populations than the building of the barrages.

Main Findings of Ecological Aspects

The direct ecological impacts of Tarbela Dam are difficult to separate out from the impacts of the other changes experienced in the Indus basin as a whole, including the earlier dams, barrages and flood *bunds* leading to increased abstractions of water and containment of the flood plain. Other factors, such as population growth giving rise to increased pollution from domestic and industrial wastes, demand for agricultural land, and clearance of riverine forest areas have all contributed to a decline in the quality of the Indus basin ecosystems. The absence of an EIA carried out before Tarbela was built, or a systematic baseline study, makes a review of this nature even more difficult. Some of the impacts that can be partially attributed to the building of Tarbela follow:

Mountain Rivers

- The building of Tarbela dam has changed the ecosystem of the mountain upstream, converting it into a deep, narrow oligotrophic lake. The productivity of this lake is low, and there is no emergent vegetation due to operational draw down. The lake is a staging point for migratory birds, but is not suitable for over-wintering birds.
- The building of the dam has prevented the migration of *mahseer* (*Tor putitora*) into the cooler waters upstream during summer, and the occasional operational peak releases can wash out the substrate and fish immediately below the dam, causing a loss to local fishermen.

Upper Indus

- Tarbela has contributed significantly to the increased storage and abstraction of water from the Indus, so that whilst the abstraction of water has increased by about 10%, the patterns of water flowing down the Indus has changed more dramatically. This is especially apparent in the increased frequency of low floods, which cover less than 25% of the flood plain.
- The many forested islands in the river – the belas – used to be refuges for wildlife, but with reduced flooding in the river, access to these belas has been made easier with the result that many forests have been cleared and increasingly the land on the belas is being used for agriculture.*
- The reduction in flooding also causes losses in the fish populations, and whilst inland fisheries have shown increases in production over the years, the proportion of indigenous fish caught has declined in comparison to aquaculture.*
- Reduction in the sediment discharge has meant that the balance between erosion due to high energy waves and sediment deposition has changed towards erosion. The delta is expected to become transgressive and with the rise in sea-level, inundation of the delta may be as high as several metres per year.*

Lower Indus

- The sediment carried down the Indus has reduced, so that it is now less than one fifth of the original sediment discharge below Kotri. A significant proportion of sediment trapped in the system is attributable to Tarbela.

- The reduction in the flood coverage by the river as it flows through Punjab and Sindh, has caused a change in the habitat of the flood plain, with the higher forested areas and islands becoming more dried out, and changes in species from acacia to the less economic prosopis occurring. Increased use of pumped irrigation has been required to maintain riverine forests in Sindh. The forested areas in Sindh have reduced by over 50% and the remaining ones are of variable quality.*

- Changes in habitat have resulted in losses of important wildlife species, for example, swamp d eer, and gharial that have become extinct, while hog deer and smooth coated otter have become increasingly threatened. However, wetland habitats suitable for migratory birds have been maintained, largely as a result of the barrages and seepage from the canals. The populations of Indus dolphin appear to have stabilised, especially in the barrage reservoirs.*
  Livestock in the Katcha areas has been negatively impacted through reduced downstream water flows. This has lead people to migrate to other areas or reduce their herd sizes in line with available feed resources.*

- There have been marked decreases in the catches of migratory fish such as *palla* and *baramundi*, but these are principally due to the building of Kotri barrage, rather than to a shortage of water as a result of Tarbela.*

- In the delta, the active delta has been reduced to about one tenth of its original size, largely as a result of the construction of the flood bunds at the time of constructing Kotri barrage. The freshwater and sediment discharge during the flood period is restricted to the active delta, but the increase in salinity during periods of low flow has reduced the suitability of the delta for the cultivation of red rice, and for livestock. The herds of cattle, sheep and goats which used to be kept in the delta are no more, and only herds of camel are still found there.*

- The mangrove ecosystem is being degraded, although there are anomalies about the distribution of mangrove cover, which is most sparse around the active delta. The mangroves are now virtually mono-specific and comparatively stunted with losses of about 2% per year. Mangroves nevertheless represent the most productive ecosystem for these conditions.*

- Marine fisheries, which depend upon the mangrove ecosystems of the wider Indus delta as nursery areas, have experienced increases in catches over the years as a result of improved technology and increased numbers of boats. However, the more significant criterion of catch per unit effort, shows a threefold decrease, with significant changes both after the building of Kotri barrage and Tarbela dam.

- The most evident ecosystem changes resulting from changed flow patterns have occurred below Kotri barrage, where the river can sometimes cease to flow for up to three months at a time. It has become severely braided and the channel can become blocked by sand bars. Saline intrusion upstream has increased during the *rabi* season, reaching approximately 25km upstream from the delta.*

- With the growth in population throughout Pakistan, the discharge of domestic sewage has increased dramatically from towns and cities along the Indus River and its tributaries. This increase in pollution of rivers has adversely affected the ecological situation especially in downstream areas.*

- TDS content in Manchar Lake has increased from 800 to 3 000 ppm since the saline waters of the Indus right bank SCARP programme started to be discharged through the RBOD in 1970s.*

3.12.6 Waterlogging and Salinity

3.12.6.1 Area Affected by Waterlogging and Salinity

There was some inherent salinity in the soils of the Indus basin and when these soils came into contact with high levels of groundwater, the capillary rise in the arid environment resulted in the accumulation of salts in the surface of the soils. If large irrigation schemes do not include initial provision for drainage of the affluence, then the twin menaces of waterlogging and salinity continue to spread until they render vast areas unfit for cultivation.

The salinity data computed from the survey reports (1956-65) for the Punjab showed that of the 11.23 mha surveyed area, 8.13 mha (72.4%) were non-saline, 1.6 mha (14.37%) were slightly saline, 0.44 mha (3.99%) moderately saline and 0.63 mha (5.66%) were strongly saline. In the Sindh province, out of the 5.3 mha, 3.38 and 1.96 mha were moderately and severely salt-affected, respectively.

At present, in Pakistan 37.6% of the gross command area (GCA) is waterlogged (water table shallower than 3m below the surface) of which 15% is severely waterlogged (water table shallower than 1.5m) (WB, 1997 - SAR).

In most fresh groundwater areas, the water table is declining rapidly due to pumping for agriculture. For example, the water table declined from 3.6 in 1988 to 7.1m in 1995 and is declining by up to 1.5m per annum in some areas, and at 0.64m per annum in Punjab. However, it is stabilised or is still increasing in some SGW areas such as Kotri barrage (WB, 1992 - Tech. Paper No.166).

Soil salinity is also increasing. In saline ground water (SGW) areas salinity remains at a very high level of 3 900 – 4 000 ppm while in fresh ground water (FGW) areas, salinity is estimated to have increased from 900 ppm in 1988 to 940 ppm in 1995. The twin problems of waterlogging and salinity are most severe in Sindh province (lower Indus plain) where more than half of the waterlogged and

* Note that this impact cannot be directly attributed to Tarbela dam. Interactions and externalities do exist.

salinity affected area is located (WB, 1997 – SAR). The total dissolved solids of less than 1 000 ppm are considered safe for good quality groundwater for agriculture.

According to WB Report No. 15530-Pak, 1997, in lower Indus plain, the water table is less than 2.4m deep in 37% of the area, 56% of the area is moderately saline and 32.5% is severely saline. In the Indus basin the area requiring drainage in the near future, inclusive of completed and ongoing project areas, is estimated at 6.47 mha, of which 2.36 mha are covered under ongoing projects, 0.90 mha are in areas with completed projects requiring further rehabilitation and 4.49 mha have no drainage.

3.12.6.2 Impact of Waterlogging and Salinity

The rise of groundwater tables to near the surface in SGW areas, and the consequent soil salinisation became, and continue to be, a serious environmental problem associated with irrigation in the Indus basin. The impact of salinity on agricultural productivity is severe, and a 25% reduction in Pakistan's major crops is attributed, by many experts, to soil salinity alone (WB, 1994 – Report No. 11884). In Sindh province where the problem is much more severe, the estimated impact may be closer to 40 – 60% in SGW areas. The critical threshold at which salinity begins to affect the productivity of agricultural land varies by crop. Similarly, the impacts of waterlogging on yields are startling. High groundwater tables inhibit root growth and therefore reduce crop yields. As the depth to the water table decreases to within 1.5m, yields of all major crops begin to decline rapidly. At 0 to 0.24m depth to the water table, yields decreased to 2% for cotton, 9% for sugarcane, and 21% for wheat. In addition, there are serious environmental and poverty impacts associated with waterlogging and salinity.

Additional supplies from Tarbela coupled with inefficiency in irrigation resulted in waterlogging and in SGW zone, which further aggravated the salinity problem. The waterlogged area was highest during the late 1970s (1978-80), but reduced later on, and is now reducing due to pumping and other drainage measures. However, it became severe during the mid-1990s in certain areas, especially in areas of shallow water table, with the transition of Salinity Control and Reclamation Projects (SCARPs).

3.12.6.3 Remedial Measures

The SCARPs provided for achieving efficient drainage, while it was perceived that farmers would reclaim their salt-affected soils through leaching with increased irrigation supplies. To reclaim the salt-affected soils through leaching, extra irrigation water was supplied by the Irrigation Department through the Directorate of Land Reclamation in Punjab, which did help in some cases. Reclamation of salt-affected soils, especially of the sodic soils was not focussed upon as a specific objective. Use of gypsum was encouraged on a limited scale by providing a subsidy for this intermittently. This subsidy has been withdrawn now.

The efforts to control the water table through SCARPs have largely been successful in the fresh groundwater zone, where pumped water was used for supplemental irrigation. However, in certain areas, where large SCARP investments were made, further sustaining the tubewells was not considered feasible due to high maintenance costs. In some cases, the salt content was so high that mixing with fresh water did not improve the water quality to levels suitable for agricultural production.

According to a study, reported by the International Commission on Irrigation, 7 500 mt of salts are present in the upper 100 metres of the groundwater reservoir of the Indus plain while about 50 mt of salts are added to the system every year through the canal irrigation water. Compared to this amount, only 10 – 15 mt of salts are presently exported out of the system every year, mainly in the summer flows to the sea below Kotri barrage. If sub-surface drainage is provided to all the irrigated areas of the Indus plain, the drainage effluent shall pick up 100 mt of salts every year. Out of this 20 mt/year would immediately be returned to the land by the recycling of the FGW discharges, and 80 mt/year would remain requiring disposal.

Presently, in the upper Indus plain the drainage effluent is either being used locally by mixing with canal supplies, or it is disposed off into the river or put into the evaporation ponds.

The recently completed Left Bank Outfall Drain (LBOD) Stage I Project is expected to export 25 – 30 mt of salts from the system to sea every year. By extending LBOD to cover the whole of the Sukkur Left Bank command, this outfall will eventually dispose off higher amounts of salts to the sea, although it will still leave a considerable amount of salts in the basin that would need disposal.

The rest is disposed into the Arabian Sea via the lower Indus River itself. This means that salinity levels increase rapidly as extraction of irrigation supplies increases in the lower Indus. In addition to distributing river supplied salt, additional salts are mobilised directly onto the surface (and retained) in FGW areas due to tubewell irrigation.

Research studies are underway to develop methods for the cultivation of salt-affected lands with brackish groundwater, where traditional agriculture is not possible. This approach is called as 'saline agriculture'.

3.12.6.4 Projected and Actual Accomplishments in Drainage

The Lieftinck Report (1968) provided the following projections for drainage measures to be funded outside the Tarbela project:

- Completion of SCARP coverage of 4.8 mha by 1975 in the useable groundwater zone.
- SCARP coverage of an additional 2.8 mha by 1980 in useable groundwater zone during the period of 1975-80.
- After completion of the coverage in the useable groundwater zone, a shift to SGW areas by providing SCARP wells, surface and tile drainage, and an expansion of canals for additional water diversions.
- Canal remodelling for the command area of 2 mha.
- Provision of another link canal in eastern Punjab.
- In the lower Indus basin completion of projects like Sheen Barrage and Sheen Rohri Feeder in 1982; Rohri-Nara Feeder in 1985; LBOD in 1985; and RBOD to be built during the period 1980-90.

The existing drainage facilities cover an area of 5.16 mha representing a shortfall of about 32%. Surface drains of 15 456km have been provided in the IBIS, whereas the sub-surface drainage includes 15 443 SCARP tubewells, tile drainage for 0.22 mha and 561km of intercepting drains (Table 3.60).

Table 3.60. Existing Drainage Facilities in the Indus Basin Irrigation System (IBIS)

Province	Drainage Area (Mha)	Surface Drains (km)	Subsurface Drainage				
			Tubewells (Number)			Tile Drains (km)	Interceptor Drains (km)
			FGW	SGW	SkW*		
Punjab	3.15	7326	8065	1985	-	0.05	-
Sindh	1.74	5980	4161	365	376	0.02	561
NWFP	0.21	1990	491	-	-	0.15	-
Baluchistan	0.06	160	-	-	-	-	-
Total	5.16	15456	12717	2350	376	0.22	561

* *Skimming Wells*

Findings on Waterlogging and Salinity

- Lack of an effective drainage system for the IBIS is by far the major threat to the sustainability of agriculture.
- Waterlogging and salinity has been a growing concern in Pakistan; Tarbela alone has not created or contributed to this menace.
- The actual coverage through existing drainage facilities in the country is on 5.2 mha compared to the projected coverage of 7.6 mha, a coverage that is 32% less than predicted in the Lieftinck Report. The low crop yields in the IBIS indicate widespread salinity and waterlogging that is estimated to cause an average 25% reduction in crop yield. At the beginning of Tarbela dam (1976-78), the water table in 22% of the IBIS, was below a 2.0m depth. It is now at 1.5m.

3.13 Summary of Predicted, Actual and Unexpected Outcomes

The predicted and actual outcomes of Tarbela dam have been compared, based on the available data from project planning documents (mainly the Lieftinck Report presented to GOP in August 1967 and published in 1968) and the PCRs and other publications of different government agencies. Because of the paucity of relevant data, it is not always possible to compare the identical parameters for the predicted and actual outcomes. The unexpected outcomes of the dam, both positive and negative, have also been identified (Table 3.61).

Table 3.61. Predicted, Actual and Unexpected Outcomes of the TDP

	Predicted	Actual	Unexpected
Design	Tarbela Dam, and power station (2 100 MW) as part of a wider Indus Basin Project including Mangla Dam, downstream barrages and link canals within the existing Indus Basin Irrigation System.	148m high earth and rockfill dam and associated infrastructure were constructed as predicted. Power generation capacity was increased to 3 478 MW. A fifth tunnel was added on the left bank for additional irrigation releases and provision for an additional tunnel made on the right bank for subsequent development.	
Schedule	Commencement: June 1967 Commissioning of reservoir: Sept 1974 Power (units 1-4) Mar 1976 Power units complete: 1980	May 1968 Sept 1976 July 1977 1982, 1985, 1992, 1993	Major problems experienced with seepage through upstream blanket, damage to tunnels, low level outlets and spillways
Project Costs	Estimate excluding power units $828m (nominal) Including debt servicing and all power units calculated in 1998 prices $5 875m	$1 497m (nominal) (+81% overrun) $9258m (+58% overrun)	Overrun due to cost of remedial works
Water Resources	Storage releases : 10.17 bcm in 1975 Reducing to 6.95 bcm in 1998	On average releases were 20% higher than predicted. Flows at downstream barrages increased in dry season except Kotri where major reduction due to irrigation diversions started 16 years prior to Tarbela	Reduction in predicted storage releases due to effect of sedimentation has not yet been significant
Irrigation and irrigated agriculture	Surface water diversions for whole IBIS: in 1985 125.5 bcm in 2000 149 bcm	Surface water diversion for whole IBIS: in 1985 129.4 bcm in 1998 132.6 bcm	Additional diversions lower than expected as other dams not constructed Major expansion of

	Cultivated area in 2000 23.8 mha Irrigated area in 2000 17.9 mha Cropping intensity – Punjab 150% Sindh 137% Yield of wheat 3.39 t/ha Gross Production Value predicted for year 2000 Rs.20.6 bln. (1965 prices)	in 1998 22 mha in 1998 18 mha canal irrigation increased from 10.1 mha to 14.7 mha from1975-98 Punjab 117% Sindh 132% Yield of wheat 2.3 t/ha GPV in 1998 Rs.20.0 bln. (1965 prices) It is not possible to identify the contribution of Tarbela on irrigated production due to interaction of other factors	groundwater irrigation from 31.6 bcm in 1972 to 62.2 bcm in 1997. Number of tubewells increased by 400% Shift in cropping patterns to sugarcane, cotton, rice and wheat Lower productivity of land and water
Waterlogging and Salinity	Predicted drainage area coverage 7.6 mha	Actual drainage area coverage 5.2 mha 22% of IBIS subject to severe waterlogging and salinity	Low irrigation efficiencies
Hydropower Generation	Capacity 2100 MW by 1980 Annual average generation: 1975-98: 11300 GWh 1993-98: 12500 GWh Total generation to '98 : 245,300 GWh Net economic benefit $160 million (1965 prices)	Capacity of 3478 MW (+65%) by 1993 Annual average generation: 1978-98: 9255 GWh (-18%) 1993-98: 14300 (+13%) (due to higher capacity) Generation to '98 194,500 (-21%) Net economic benefit $225 million (1965 prices)	Power optimisation study undertaken leading to increased installed capacity.
Flood Control	Not predicted	Attenuation of over 20% of high flood peaks in June/July with virtually no attenuation of late floods in September.	Reduction in frequency/heights of flood flows to wetland areas downstream
Municipal Water Supply	Not predicted	Unquantified canal water is a major source of domestic water in areas with saline groundwater	
Recreation	Not predicted	None	
Sedimentation	Predicted rate 0.294 bcm/yr Predicted life with about 10% residual storage: 50 years	Actual rate 0.106 bcm/yr Expected life with about 10% residual storage: 85 years	Advance of sediment delta to within 14km of the dam requiring modification of operating rules
Resettlement	80 000 people in 100 villages	96 000 people from 120 villages directly affected. Indirectly affected people not quantified	Continuing claims for settlement after completion resulted in establishment of a new commission; considerable number of indirectly affected people not eligible - 1953 affectees who hold valid allotment letters still have not been given land due to non-availability. -Sindh Govt decided in 1974 to withhold 7 826 ha of land originally promised for allotment to Tarbela affectees.

Other social impacts	None predicted	Not quantified, but significant reduction in fish catch and livelihood from floodplains, wetland areas and coastal areas is attributed to a sequence of physical interventions in the river including Tarbela dam	Lack of sediment replenishment to the delta area and flooding of areas along the Indus
Ecological impacts	None predicted	Degraded mangrove areas, reduced fish migration, change in riverine habitat; contribution of Tarbela difficult to assign as no pre-project survey and many other interventions; those due to changes in sediment flow can be attributed directly to the dam; and reduced flood flows partially relate to dam and also to construction of flood embankments	

4. Distributional Effects of the Tarbela Dam Project

4.1 Anticipated Distributional Effects of the TDP

4.1.1 Direct Irrigation and Hydropower Effects

As noted earlier, the Lieftinck Report expected Tarbela to provide protective canal irrigation to a command of about 1.8 mha previously dependent on the eastern rivers, and accelerate development in an area of about 7 mha under command of the canals off-taking from the Indus main. Further, its installed capacity of 2 100 MW would provide a large quantity of hydropower.

It was also estimated that three-quarters of the benefits would be generated from irrigation and one-quarter from hydropower. The distributional impact of the water was targeted towards the Indus Basin Irrigation System (IBIS) in Punjab and Sindh. It could be further broken down into: (i) those farmers and inhabitants who would otherwise have suffered due to diversion of three eastern rivers by India, and (ii) those who would gain from the supply of additional water from Tarbela. Regarding Tarbela power it was proposed to be utilised by feeding into the National Power Grid of WAPDA to provide for growing demands by various sectors of the economy beset with chronic shortages and frequent load-shedding. However, as part of overall development it was clearly understood that electrification of agricultural tubewells would be accelerated.

The predicted impact postulated for various groups was not explicit. Greater attention was given to the raw outputs of electricity and water, without specific attention to the likely impacts on the various segments of the society. Whereas, distributional gains were identified in terms of urban vs. rural electricity consumers in areas coming under canal command, no specific segments of particular communities, ethnic groups or regional social boundaries were studied.

The Lieftinck Report also failed to point out likely negative externalities of the project, and specifically how different groups downstream might be impacted. Nor is there clear categorisation of the various broad groups that were to be affected by the dam. For instance: (i) those farmers and inhabitants who would otherwise have lost waters from the three eastern rivers diverted by India; (ii) those who would gain by supplies of additional water from Tarbela; and (iii) urban rural consumers and industries that would benefit from electricity generation.

Not only were the broader socio-economic groups not clearly identified, but sub-groups like the large, small, medium, or the tenant share cropper and landless group, were not recognised in the design phase.

The lack of rigor in the delineation of postulated future impacts, lead to difficulties in matching predicted impacts on groups at the time of inception, with the actual impacts on various groups and their livelihood.

4.1.2 Direct Effects on Consumers and Production

The linear programming exercise conducted by the Indus Special Study (ISS) Group – Lieftinck of the WB, as contained in the Lieftinck Report, analysed various efficiency scenarios with consequent impacts on different groups. The increase in agricultural production was to directly affect consumers through sustained availability and price stabilisation, alleviating supply shortages in the market, and assuring a broader mix of agricultural enterprises.

Livestock was especially targeted to benefit urban consumers with higher per capita disposable incomes.

Landed classes and those involved in the agricultural production process were to be positively affected by the water for irrigation and electricity. It was anticipated that even at a medium input level, significant production gains would be realised by producers. Increases in the cost of production were postulated based on expected input increases. It was anticipated that an additional area to that expected would be brought under agriculture. These distributional effects were known at the time of designing the dam.

4.1.3 Employment Effects on the Local and National Economy

The direct employment impacts were estimated, based on 5-year planning documents. The Planning Commission had estimated that agricultural employment in 1965 was equivalent to 7.6 million man-years. This was based on 395 man-hours per cropped acre. The Lieftinck Report adjusted the figure to 300 hours and its estimates of employment in agriculture from 1965-85 are presented in Table 4.1.

It may be noticed that the Lieftinck Report assumed that employment would increase by two-thirds from 1965-85, with an annual growth of 2.5%. However, it was explicitly assumed that the proportion of employment in agriculture would remain mostly unchanged in relation to the total labour force.

Further analysis at the time of appraisal suggested that agriculture would gradually be mechanised and by 1975, about 10% of the farm area would be fully mechanised. Furthermore, labour utilisation on mechanised farms would be about 65% as opposed to those farms that are not mechanised (Lieftinck Report, 1968 - Vol. III).

Table 4.1. Estimate of Employment in Agriculture (1965-85)

	1965	1975	1985
Crops			
Cropped Acres (million)	40.72	47.84	54.30
GPV of Crops per Acre (Rs.)	133	184	260
Employment (million man-years)	4.7	5.8	6.9
Livestock			
GPV (Rs. million)	3.3	5.6	9.8
Employment (million man-years)	1.9	2.7	3.9
Total Agricultural Employment (million man-years)	**6.6**	**8.5**	**10.8**
Total Labour Force Employment (million man-years)	**16.2**	**21.2**	**28.1**
Agriculture as % of total labour force	40.7%	40.1%	38.4%

Source: Lieftinck Report (Vol. I) - Water and Power Resources of West Pakistan - A Study in Sector Planning.

4.1.4 Positive and Negative Distribution Effects

Reflecting general practice at the time, the various background papers, including the Lieftinck Report, did not evaluate the overall distribution effects. In fact, "human aspects" as a whole were not taken into consideration at that stage. While broader implications were considered within the Planning Commission's long-term framework, specific targeting of the effects on particular groups was given less emphasis. Perhaps the social analysis framework at the time of appraising the dam simply did not exist. The panels of experts used for the Lieftinck study did not have professional expertise in sociology or anthropology. The economic analysis was also restricted to an evaluation of broad impacts on agriculture and power and on the national economy as opposed to specific groups.

With regard to the distribution of the additional irrigation water that would become available after Tarbela, it was presumed that it would be distributed to end-users in various canal commands on an equitable basis as embedded in the original design of the '*Warabandi*' system. In actual practice, however, IBIS gradually became beset with many serious problems including distribution inequity in the secondary (distributaries/minors) and tertiary (water-course) systems. Though it was the outcome of overall institutional, economic and social factors unrelated to Tarbela, this inequity in water distribution could have contributed to the failure to reach the targeted benefits of irrigated agriculture (refer to sections 3.5 and 4.2).

The evaluation did not make any significant observations on the pareto-optimiality of Tarbela. Only the positive impacts of the investment were considered, with little realisation that there would be social costs.

4.1.5 Complementary and Competing Investments

The financing and cost recovery aspects have been discussed in sections 3.3.4 and 3.3.5. It was conceived that adequate allocations would be made in the 5-year plans to accommodate the rupee component for the financing of Tarbela. Development Fund and supplementary loans fell under administration of the World Bank.

Table 4.2 shows the pattern of investment in agriculture, irrigation and power over the period 1960-75.It may be noticed that compared to the Second Five Year Plan, the proportion of investment in agriculture, irrigation and power would increase to 41% in the period from 1965-70. In absolute terms, public sector development expenditures on agriculture, irrigation and power were expected to double between the second and third plans.

Table 4.2. Investment in Agriculture, Irrigation and Power (1960-75)
(Rs. million[1] and Percentage)

Item	2nd Plan (1960-65) (est. actual)	3rd Plan[2] (1965-70) (projected)	4th Plan[2] (1970-75) (projected)
Private-Agriculture and Irrigation	1500 (7.1)	2330 (8.5)	4120 (11.0)
Public-Agriculture	625 (3.0)	1640 (6.0)	3200 (8.6)
Irrigation	1658 (7.9)	2461 (9.0)	2836 (7.6)
Surface Storage	-	1916 (7.0)	2195 (5.9)
Power	1194 (5.7)	2849 (10.5)	3468 (9.3)
Total	**4977 (23.7)**	**11196 (41.0)**	**15819 (42.4)**
Indus Basin Works	2910 (13.9)	3500 (16.7)	-
Total Investment (Plan Documents)	20973	27250	373000
Total Investment (Projected on basis of 6% growth of GDP)		31175	43050

Source: Lieftinck Report, 1968

[1] *Current prices for the 2nd Plan period and 1964/65 prices for 3rd and 4th Plan. Percentages in parentheses relate to total investment (Plan Documents).*

[2] *Investment in agriculture, irrigation and power as projected by the Study Group (Lieftinck Report).*

While very much enhanced investments were envisaged, the importance of dramatically increasing revenue generation from the agriculture sector was also realised. Whereas the financial outlays were amongst the highest, its relative contribution to government revenue was low. Particular stress was laid on water pricing and its rationalisation since agriculture was to benefit the most. Financial payback was anticipated from foreign exchange saving by import substitution; increased agricultural production; increased tax revenues; and revenues directly from the sale of electricity. Originally, hydro-power contributions to project pay-back were considered less important.

Since Tarbela was considered a national commitment with the highest priority, it was ensured that local finances were directed to the timely completion of Tarbela, even at the expense of other development projects. Cut-backs in other development programs proposed in the 5-year plans were anticipated to finance Tarbela. Any savings were to be diverted to finance Tarbela by re-allocating within the Indus Basin Works including any savings in the rupee component.

4.2 Actual Distribution Effects of the TDP

4.2.1 Direct Affectees

A range of distribution effects amongst gainers and losers is presented in Table 4.3. While the distribution effects of Tarbela were postulated at the national level, the prime beneficiaries were those dependent on agriculture and the consumers of electricity. Given the increased demand for electricity, the hydropower component of the project was expanded to avert the chronic problem of load-shedding. Both rural and urban consumers in all provinces of the country benefited from this expanded capacity.

4.2.1.1 Agriculture Groups

The farms that received additional irrigation supplies were located in southern Punjab and Sindh, in front of Sukkur barrage. In terms of additional canal diversions, both these areas benefited in proportionately more than expected. This additional water contributed to: increased cropping intensities in some areas; changed water flow periods in some canals from six monthly to an all year around basis; and also increased availability of water per hectare. Moreover, lands developed through the link canal system fed by Tarbela, were ensured a secure supply of water, when they may have suffered declining agriculture due to increased water abstractions on the eastern rivers by India. The overall effect of Tarbela from predicted and actual canal diversions in the different provinces can be assessed. It must be noted that larger and more influential farmers, often the feudal land-owners, have benefited more from additional canal diversions. Political influence and, indeed, threat of force has been used to capture the extra waters. This conclusion is supported by a study carried out by Mirza and Haq (1990) wherein they identified the major types of disputes at the village level in Punjab (Table 4.4).

It is interesting to note that both the intensity and the frequency of water-related conflicts are medium to high. The actual distributional effect of Tarbela power is evidenced by the stability of Tarbela's contribution, within a range of 28-39% (on average, 33%), despite a five-fold increase in annual generation in the WAPDA system from 1978-98. Furthermore, whereas the overall hydropower contribution in the corresponding period dropped from 74 to 41%, the Tarbela's share jumped from 45 to 68%. One significant spin-off from this was an accelerated electrification of tubewells, with reduced water-pumping costs, especially for large farmers. In some areas, like the rice belt, small farmers also benefited from these tubewell connections. Since the tubewells operated on a flat rate basis, there was a tendency to overuse water with negative long-term impacts on yield and land quality. The smaller farmers, however, still rely on diesel tubewell irrigation, and there has recently been a switch over to 'Petter engine' technology from China.

4.2.1.2 Electricity Consumers

Starting from about 1.5 million in 1976 (pre-Tarbela), the number of WAPDA's urban electricity consumers had increased to about 5.6 million by 1979-98. On the other hand, rural consumers increased phenomenally from about 0.4 to 4.6 million in the corresponding period.

4.2.1.3 Inhabitants around the Reservoir

Tarbela affected over 96 000 people around the reservoir. Besides generating a high social cost up-stream, the dam also affected downstream inhabitants though reduced fish catches, and negative externalities due to reduced flows especially downstream of Kotri. However, one must be cautious in attributing all the downstream ills to Tarbela. The progressive development of irrigated agriculture throughout the Indus basin has impacted negatively on fishermen groups in certain areas; has marginalised livestock producers; and, arguably, has created negative externalities for groups downstream. Given the fact that Indus River flows are sensitive to snow and rainfall patterns in the northern areas, variations are a natural phenomenon and not necessarily attributable to Tarbela. Such impacts have not been quantified and make it difficult to attribute all such ills to dams in general and Tarbela in particular.

Table 4.3. Distribution Effects amongst Gainers and Losers

Types of Gains/Losses expressed in $1998 million/yr			Benefits or Who Gains											Costs or Who Loses/Pays										
			Benefits derived from the Project - in terms of the use of water, land, vegetation and atmosphere							Social Benefits and Indirec Economic Benefits				Project Costs				Ecosystem Function and Biodiversity				Social Costs and Indirect Economic Costs		
			Direct Use Values					Ecosystem and Biodiversity Impacts																
Group/Spatial Dimension	Extent-Then	Extent-Now	Electricity	Irrigation	Food Mitigation	Urban/Industrial Water Supply	Recreation	Local Air Pollution	Carbon Cycle	Indirect Economic Impacts	Access to Social Services	Job Creation	Compensation	Construction	Resettlement	Operating	User Fees	Change in Nutrient Flows	Habitat alteration	Biodiversity	Cultural heritage	Displacement and Relocation	Local Resource Ac	Forced Social Change
A. Indus River Basin	1.5 mln. persons	2.5 mln. persons	$1841 mln.	$16245 mln.[1]								6600 emp.		$31978 mln.		$234 mln.								
1.Project Impact Area					++	++	++																	
a. Reservoir Lands													$6000		+++				++++	++++				++++
b. Downstream	43000		+++++	++++	++++	++++		++++		+++++	++++	++++							+++	+++		++		
Producers										++++	+++													
Livestock Producers	less	more	+++++	+++++	+++	+++			++++	++++	+++	+++						++++	+++			+++		+++
Farmers in TDP Irrigation Scheme	less	more	+++++	+++++	+++	+++		+++		++++	+++	+++					+++							++++
Households																								
Farmworkers	more	less	++++	++++	++++	+++				++	+++	+++												+++
Property Owners	less	more	++++	++++	+++					++++	+++++		+++++											
Fishers	more	less			+++		+++			++++	+++	+++						+++	+++	+++	+++	++++	++++	+++
Landless groups	more	less	++++		++++	++				++	+++	++++												++++
Artisan groups	more	less	++							++	+++++	+++++									++++	++++		++++
Firms																								
Diary Products Processing	+++	+++++++	++++			++++		++++	++++	++++		+++++												
Agricultural processing/service firms	++	+++++++	++++	++++		++++		+++	+++	+++		+++												
Electrical goods industry	+++	++++++++	++++							+++		++++												
Chemical Industry			++++	++++		++++		++++		+++		++++							++++	++++				
Pastorals	+++++++++	++++			++					++	+++								++++	++	++	+++		+++++
Provincial Government	less	more	++++	++++	+++	++++		+++++		++++			6 bln.[2]				++++							
B. Indus Basin (Outside project area)																								
Producers in TDP Irrigation Scheme	++++	+++++++++	++	++++	++		++	++++	++	++++	++++						+++			++	++++			++++
Households - Farmworkers	+++++++++	++++		+++						++	++++	++++												
Households -unskilledworkers	+++++++	+++++++++								++	++++													
Firms																								
Diary Products Industry	+++	++++++++				+++				+++		++++												
Pastorals	++++++++	+++++																						
Chemical Industry	+++++	+++++++++																						
Agricultural processing/services										++++		++++												
C. Rest of the Nation																								
Households	less	more				+++				++++														
Visitors to IR sites	less 1000	10000	+++				+++			++++														
Conservationists										++++								++++	++++	++++				
Central Government	<1000	5000	1500							++++														
D. Rest of the World - Global Interests																								
Tourist to Indus River	++	++					+++			++++														
Conservationists	+++	+++++++								+++										+++				
Mid. Middle Eastern Countries	++	++++++++								+									++					
International Consulting Firms	few	more								+++		+++	+++											
International Equipment Manufacturers										+++		+++	++++											
Carbon Consumers									++++	+++														
Losses in Delta Region																		+++	+++	++++		++	++	++

Key = ++ (Low) +++ (Medium) ++++ (High) ; 1 = In Prices, 1998 ; 2 = To NWFP government annually

2-Table 87 Loss & Gain. (Main) - 29 May 2000.xls

Table 4.4. Respondents Perception of Dispute Issues, their Frequency and Intensity

Dispute Issue	Frequency			Intensity		
	High	Medium	Low	High	Medium	Low
Water	80(35.55)	100(44.44)	45(20.00)	36(16.00)	176(78.00)	13(5.78)
Family/Marriage	90(40.00)	45(20.00)	90(40.00)	32(14.22)	159(70.67)	34(15.11)
Land Distribution						-
Sale and Purchase	25	19	181	167	58	-
Leadership	51(22.67)	70(31.11)	104(46.22)	105(46.67)	120(53.33)	-
Election Campaign	60(26.67)	80(35.55)	85(37.78)	200(88.89)	15(6.67)	10(4.44)
Inter-kin Rivalries	90(40.00)	89(39.55)	46(20.45)	46(20.45)	57(25.33)	122(54.22)

Source: Mirza and Haq, 1990.

The primary beneficiaries have been downstream farmers in the Punjab and Sindh and upstream farmers in Ghazi and Haripur who have benefited through enhanced irrigation supplies. Prior to the construction of Tarbela, the local inhabitants had a simple life style in isolated situations that promoted low mobility, longevity and healthy living patterns. The movement to urban settlements has made these people more sedentary. While health facilities have improved over time, disease, especially related to the kidney, heart attacks, and allergies have increased. (This observation is based on survey results and reports of group hearings in October, 1999).

4.2.2 Indirect Affectees

4.2.2.1 Agro-industry and Employment

Direct productivity gains from Tarbela water have largely impacted on employment in the agricultural sector as mentioned under section 4.1.3. Electricity, besides meeting rural and urban needs, has stimulated the development of agro-industries and employment in these industries. In particular, sugarcane and cotton related industries have shown marked improvements in productivity. This also increased the vertical and horizontal integration of marketing operations, improving their efficiency. These backward linkages also influenced the transport sector, which is responsible for long distance as well as farm to market haulage.

Power generation from Tarbela also influenced other industrial growth (large-scale and cottage) in urban and rural areas. These expansions established vital growth linkages that are transforming rural areas and opening them up to the market economy. Consumerism is on the rise and a greater proportion of family incomes is spent on processed goods (Zaidi, 1999).

4.2.2.2 Livestock Producers and Industries

Tarbela has affected the livestock sector in different ways. Additional water for agriculture meant intensified cropping patterns. Increased cotton and sugarcane by-products became available in the form of oilcakes or *'khal'*, while cottonseeds and sugarcane molasses provided valuable concentrates that helped to increase milk production. Farmers of all categories, especially those coming in direct contact with expanded urban milk markets, benefited. The small farm and non-agricultural rural population has benefited from the buffalo and goat rearing opportunities resulting from intensification. However, certain groups around the periphery of the river, and in areas with reduced water flows, lost free grazing lands.

Industrial development in the livestock sector expanded at an accelerated pace. Livestock and poultry witnessed significant gains in the processing and marketing sectors.

4.2.2.3 Agro-chemicals and Seed Industries

Intensified agriculture after Tarbela accelerated the use of chemicals like pesticides, herbicides and fertilisers. This ‘green revolution’, with its emphasis on high-tech inputs, increased local manufacturing and imports. Various multinationals, involved in the marketing of such goods, benefited from the enhanced business opportunities in the post-Tarbela area.

4.2.2.4 Pastoral Groups

These groups, often dependent on free grazing lands, were impacted on variably. Some moved to more fertile grazing grounds, while others settled and started dairy farming. In lower Sindh, especially in the *Katcha* area, the negative effects of reduced water flows has impacted on the pastoral, livestock population, especially those who reside beyond functional markets.

4.2.2.5 Royalties and Revenues

The provincial governments of Punjab, Sindh and NWFP have benefited directly and indirectly from increased tax revenue flows. Royalty payments to the tune of Rs.6 billion per annum were also being made to the NWFP government. The dam supplemented the incomes of WAPDA employees who also benefited from the increased job opportunities for its surplus pool.

4.2.2.6 Property Values

In general terms, there have been improvements in the overall value of assets after the dam, with positive effects on the prices and rentals of land. Land in Mailsi, for instance, which was Rs.37 000 per ha in 1970 (equal to Rs.145 040 in 1998 prices), is now valued at over Rs.620 000 per ha. This translates into a 16-fold increase in nominal terms and about a 300% increase in real terms. Similarly, land rents of about Rs.700 in 1970, were over Rs.17 000 per ha. in 1999. This amounts to roughly a 24-fold increase in nominal terms or 16-fold in real terms.

4.2.2.7 Change in Social Status

Those affectees who received lands in Punjab/Sindh lost prestige and social status when they were forced to move to other areas. The social costs imposed on these groups were immense. The compensation process was also cumbersome and based on outdated procedures as discussed in section 3.10.1.1. Originally, the provinces of Punjab and Sindh committed to providing state land to compensate the affectees and facilitate their resettlement. However, Sindh decided in 1974 not to distribute this land for this purpose. This further upset the resettlement process with the result that there are still 1 953 families who have legitimate claims but are still waiting for possession of the land. This is causing a lot of hardship to the affected families.

The details of the compensation packages paid are given in section 3.10.1. The distributional effects of this package have been uneven. Those who did not get the land due to them obviously suffered. Those re-located in the vicinity of the project, or who received irrigated lands found wealth in the form of financial liquidity. Land and assets, which were previously of meagre value, started commanding very high market prices. The effects on people of this sudden wealth and changes in the investment climate are not fully understood.

Survey findings based on interviews with almost 650 upstream/downstream farmers suggest that the impacts on their livelihoods were generally positive.

Displaced individuals, and especially the artisan classes, were affected in different ways. For example, as noted by participants in the upstream workshop held at Haripur on 2 November 1999, artisans like barbers, cobblers, and donkey owners were positively affected (a brief report on the delibrations of the Haripur field work is presented in Annex 10 - Appendix A). Although they lost their permanent abodes, they moved to urban townships and were released from the economic bondage of land-owners. Some of these groups were paid on a six-monthly basis, and were treated as low class citizens. By the same token, classes like "*mirasi*", including the village singer, the fortune-tellers and lineage record keepers and the gold-seekers who would receive the Indus waters for gold, were negatively affected with the disintegration of the village structure.

Ownership of assets also changed hands and the class structure was affected. Those who once ruled in the rural communities now became commoners in the new social structures.

4.2.2.8 Distributional Impacts on Ecology

The distributional impacts on the ecology are rather poorly documented in the literature. The survey by the study team suggests that there has been a reduction in fish catches and species through the progressive construction of barrages and dams upstream. This decline could also be attributed to a changing hydrology as a result of river embankment works, population pressure and increased netting. Certain groups of boatmen and fishermen were brought under regulated fishing, and were obliged to fish for influential contractors who able to obtain such contracts at the expense of the fishing communities.

Wildlife has also been reduced as more intensive agriculture is practised and new lands are brought under the plough.

Reduced water flows, due to upstream dams/barrages, have shifted the traditional travel routes and resting places of waterfowl. Hunting for sport is now concentrated around barrages while earlier it was practised all along the Indus River. These groups have therefore been affected.

4.2.2.9 Migration in Downstream Areas

Downstream coastal areas have been affected, and in certain areas, people have been forced to migrate to Karachi or other parts of Sindh. Saline water intrusion from the sea, due to reduced water flows downstream of Kotri, has also been observed.

Mangroves and their degradation in the active delta of Indus is an area of major concern to bio-diversity experts internationally.

The impacts of upstream water abstractions, including Tarbela, on the downstream Kotri inhabitants have been largely ignored.

4.2.2.10 Flood Control

Tarbela dam, built primarily for irrigation purposes, had no specific provision for flood-control. As it is a large-capacity reservoir, however, it did help in reducing peaks, particularly during July and August, and helped to avoid synchronisation of early flood peaks at the downstream river locations. The occurrence of large floods in the Indus River system is linked to the severity of the monsoons. Huge losses occur in the Punjab plains, with occasional breaches of the *bunds* that confine the Indus River, taking place in Sindh. These losses are further exacerbated when late monsoon rains force India to release large quantities of water into the eastern rivers without adequate warning.

4.2.2.11 Drinking Water

In several areas, both upstream and downstream, storage water is used for drinking purposes.

There is no primary data to confirm or refute claims that the water from the canals is used for drinking purposes, especially in those areas where the groundwater is saltine. It is well known that in several areas of the Punjab, such as the districts of Bahawalpur, Bahawalnagar, Rahim Yar Khan and the Cholistan desert, canal water is used for drinking purposes. Similarly, the bulk of the Karachi water supply is fed directly from the Indus River.

Findings on Distributional Effects

No formal distributional analysis of the impacts was conducted at the time of project planning and appraisal. The noteworthy aspects were restricted to the surroundings of the reservoir. The designers did not consider the distribution of benefits, nor were any procedures adopted to ensure equitable distribution of gains from the project. The actual distribution of benefits and impacts was not equitable.

- Data limitations and lack of verifiable sources of information restrict the assigning of "damage values" for specific group impacts. Furthermore, as it has not been possible to carry out any distributional analysis, actual distribution of benefits and impacts may be distorted.
- Both urban and rural consumers of agricultural products through out the country benefited from Tarbela.
- Tarbela employed 12 000 – 15 000 people during its construction phase and continues to provide direct employment to 4 000 persons with an estimated 20 000 dependent family members.
- Mechanisation of agriculture resulted in job displacement for certain groups who have moved to urban areas in search of better opportunities.
- Increased agricultural output improved government revenues but was not commensurate with the gains achieved from agriculture.
- Large owners benefited most from electrification of tubewells. Smaller farms have used diesel driven tubewells and more recently switched over to the 12 HP 'Petter Engine' from China.
- Due to the provision of cheap hydropower from Tarbela, the number of rural electricity consumers of WAPDA increased phenomenally from about 0.4 to 4.6 million over the period 1976 to 1998.
- The prioritisation of Tarbela as a national commitment put other development activities on "the back burner" as scarce financial resources were utilised during its construction phase.
  Wealth changes occurred amongst some of those who were re-settled and these groups enjoyed an increase in financial liquidity.
- Downstream groups of fishermen, boatmen, livestock owners, and pastoralists were not included in the compensation package.
- Those who did not own land and artisan groups were affected variably.
- Groups dependent on fragile ecologies like riverine forests and mangroves were negatively affected due to increased diversions in the Indus basin.
- Several groups downstream, especially in the *Katcha* and below Kotri areas, developed a perception that the dam had reduced water availability to them, negatively affecting their livelihood. Migration due to a multitude of reasons is perceived as having been stimulated by Tarbela.
- Though not specifically designed for flood control, Tarbela did contribute to significant absorption of very high flood peaks during the filling season, helping to avoid their synchronisation at downstream locations, therefore, and reducing the risk of flood damages.
- Though not substantiated by factual data, it is recognised that the drinking water supply was significantly improved in commands of IBIS underlain by brackish water, and in large urban centres like Karachi.

5. Options Assessment and the Decision-Making Process

5.1 Background

This section deals with the various assessment options and decision-making processes followed during the course of planning and construction of Tarbela dam. It also tries to investigate the rationale as to why certain decisions were taken. It highlights the conflict with neighbouring India with regard to water distribution in the Indus basin, and the different alternatives evolved to resolve the conflict. This conflict, which threatened to precipitate a disastrous war between the two newly independent countries,[6] was eventually resolved after protracted negotiations, with the signing of the IWT 1960 by India, Pakistan and the WB. This culminated in the implementation of the Indus Basin Project including the TDP. This section is organised under the traditional project cycle of planning and appraisal, design and construction, and operation and monitoring.

5.2 Chronology of the Tarbela-Related Events

The Indus Basin Irrigation System was traditionally a run-of-river system until partition of the Indian sub-continent in 1947, and continued as such until inclusion of storages in the IBP. Serious thought about storages started with stoppage of the eastern river supplies by India to Pakistan canals, in April 1948. This compelled Pakistan to sign the Inter-Dominion Agreement with India in May 1948 after which supplies to the canals were restored but with the assertion of India’s rights over the waters of the eastern rivers. This action resulted in a substantial loss to the *kharif* crop sowing of that season in Punjab canals commanding about 0.7 mha (about 5% of IBIS). In 1953, GOP created the Dams Investigation Circle that identified a number of storage sites on the western rivers besides Tarbela.

Chronology of events related to Tarbela itself is spread over a period of about 45 years as summarised in Table 5.1.

Table 5.1. Chronology of Events in the Project Cycle of Tarbela Dam

S.No	Significant Event	Date/Year	Remarks
1.	Partition of India	Aug. 1947	Creation of two independent states of India and Pakistan
2.	Unilateral cut-off of supplies to eastern river canals of Pakistan by India after Partition	Apr. 1948	Creation of Indo-Pakistan water dispute
3.	Interim restoration of canal supplies by India	May 1948	Inter-Dominion Agreement
4.	Start of tripartite water dispute negotiations	1952	Under aegis of the WB
5.	Identification of Tarbela Dam on Indus River	1953	By Dams Irrigation Circle, Government of Pakistan (GOP)
6.	Start of site investigations	1955	By Dams Investigation Circle, GOP
7.	Creation of WAPDA	1958	Through enactment of WAPDA

[6] *A divergent view brought to the attention of the study team by a reviewer from India suggests that there was no threat of war between the two countries. The differences that arose on this serious issue were settled through negotiations between the two prime ministers (Nehru and Liaquat Ali Khan)., Pakistan, however, as the lower riparian, felt strongly that India's unilateral cutting off of the water supplies threatened the very existence of Pakistan. The conflict was therefore serious and could have created a very ugly situation. Views on the seriousness of the issue differ between Indian and Pakistani scholars. Source: Selected Works of Jawahar Lal Nehru, second Series (Vol. 6). Chapter 3-Relations with Pakistan (1. The Canal Waters Dispute) as quoted in Mr. L.C. Jain's memorandum to Mr. A. Steiner, Secretary-general WCD.*

			Act passed by the Government of West Pakistan
8.	Transfer of project/appointment of project consultants	1958	WAPDA/TAMS
9.	Signing of Indus Waters Treaty (IWT)	Sep. 1960	Between India and Pakistan in the presence of WB
10.	Indus Basin Development Fund (IBDF) Agreement	Sep. 1960	Between Pakistan, WB and friendly western countries regarding financing of IBP including Tarbela
11.	Project Planning Report of TDP	1962	By TAMS
12.	Desk Study on Economics of Tarbela Dam Development	Feb. 1963	By WB
13.	Start of construction on Mangla	1963	By WAPDA under IBP
14.	MOU for undertaking Indus Special Study (ISS)	Nov. 1963	Between Presidents of Pakistan and the WB
15.	Start of ISS	1964	By a WB Group headed by Dr. Pieter Lieftinck and with the assistance of consultants
16.	Report on a Dam at Indus at Tarbela	Feb. 1965	Part I of ISS giving 'clean bill of health' for proceeding with TDP
17.	Water and Power Resources of West Pakistan: A Study in Sector Planning (Lieftinck Report)	Aug. 1967	Comprehensive programme for the optimum exploitation, for agricultural and power purposes, of the water resources to become available after implementation of IBP including Tarbela
18.	Signing of Tarbela Development Fund (TDF) Agreement	May 1968	To fund the project from the balance of the IBDF and additional commitments from friendly countries
19.	Award of first major civil work construction contract of TDP	May 1968	Largest ever single peacetime contract in the world to Tarbela Joint Venture (TJV) a consortium of 13 European firms led by Impregilo of Italy
20.	Start on first test filling of reservoir after substantial completion	27 Jul. 1974	Resulted in emergency draw-down due to a mishap to one of three gates of the right bank Tunnel No. 2 leading to substantial damage to the works on right abutment
21.	Start of emergency draw-down of reservoir after initial test filling	22 Aug. 1994	After collapse of Tunnel No. 2 intake portion
22.	Observation of sinkholes/cracks in upstream blanket after emergency draw-down of reservoir	Sep. 1974	
23.	Repairs to outlets of Tunnels 3 & 4 completed	16 Dec. 1974	
24.	TDF Agreement (Supplement 1)	Early 1975	
25.	Repairs of Tunnels 1 & 2 completed	23 Jul. 1975	
26.	Initial operation of spillway resulting	07Aug. 1975	

	in serious erosion of left bank of Dal Darra Channel		
27.	Major damage to floor of Stilling Basin 3 observed	17 Aug. 1975	
28.	Service spillway closed and auxiliary spillway initially opened	19 Aug. 1975	
29.	Initial operation of left bank tunnel 5	07 Apr. 1976	
30.	Loss of slab blocks of floor of stilling basin 3	27 Apr. 1976	
31	Large rock falls near plunge pools of auxiliary and service spillways	12 Jul. 1976	
32.	All sinkholes repaired through large dumping	19 Aug. 1976	
33.	Commissioning of full reservoir	Sep. 1976	After completion of repair/restoration work and testing: partial storage provided also in 1975
34.	Tunnel 3 made operational after repairs to stilling basin 3	01 May 1977	
35.	Sinkhole like depressions noted in main dam	31 Aug. 1976	
36.	Service spillway plunge pool retrogression towards protective wall	07-11 Aug. 1977	
37.	Two sinkhole like depressions found in auxiliary dam 1	24 Sep. 1976	
38.	Service spillway closed for inspection	15 Aug. 1977	
39.	Auxiliary spillway closed	12 Oct. 1977	
40.	Issuance by engineer of the certificate of completion of the main contract (651) to TJV	30 Sep. 1977	
41.	Commissioning of power units 1-4	Apr-Jul. 1977	175 MW each
42.	TDF Agreement (Supplement 2)	Early 1978	
43.	Remedial measures for plunge pools of auxiliary and service spillways completed	07 Jun. 1978	
44.	Additional remedial works for spillways completed	29 Nov. 1978	
45.	Commissioning of power units 5-8	Aug-Dec. 1982	175 MW each
46.	Final settlement of claims between WAPDA and TJV	03 Jun. 1984	
47.	Issuance of fnal payment certificate by the engineer	17 Jun. 1984	Including settlement of claims of TJV
49.	Commissioning of power units 9-10	Feb-Apr. 1985	175 MW each
50.	Commissioning of power units 11-12	May-Jul. 1992	432 MW each
51.	Commissioning of power units 13-14	Sep-Oct. 1993	432 MW each

5.3 Historical Context

5.3.1 History of the Region

Pakistan emerged as an independent state in August 1947 when British India was given freedom and partitioned into two sovereign states of India and Pakistan. At the time of partition, Pakistan comprised of two wings – East and West – separated by more than 1 500km of Indian territory.

During initial tripartite water dispute negotiations with India through 1955, Pakistan was a federation with four provinces in the west wing and one province in the east wing. For the sake of parity between the two wings, all provinces in the west were merged in 1955 into one unit called West Pakistan, while the eastern wing was renamed as East Pakistan. These arrangements were formally embedded in the 1956 Constitution of Pakistan. The eastern wing, constituting the province of East Pakistan, ceded from Pakistan in 1971 and emerged as a new country –Bangladesh. Present Pakistan has borders with India, China, Afghanistan and Iran. The country has four provinces: Punjab, Sindh, NWFP and Baluchistan. The total area is 796 000km^2. The population of the part now forming Pakistan, was about 46 million at the time of signing IWT in 1960. Currently (1998) it is about 134 million, of which about 75% reside within IBIS. The Indus plain has been the home of a prosperous civilisation for some 5 000 years. Excavations at Moenjo-Daro in Sindh and Harappa in Punjab have yielded skeletal remains and the remnants of well-planned cities, especially at Mohenjodaro. The Indo-Aryans who predominate in contemporary Pakistan arrived between about 1500 and 2120 BC. The Persian Empire was extended to the Indian sub-continent in 6th century BC and Alexander the Great and his armies passed through the region in 4th century BC. The region became a melting pot of diverse races and cultures as a result of foreign invasions as well as internal migration from other parts of India (Encyclopaedia Britannica 1973-71, Vol. 17; Qureshi[7], 1977).

Agriculture was always a dominant activity and wheat has been produced in the region[8] since time immemorial. Livestock domestication and production featured prominently on the banks of the Indus. Fish and wildlife were plentiful and a large number of species, including the famed blind dolphin, has its origins in the Indus River. The civilisations that developed around the Indus, including Mohenjodaro, Harrapa and Taxila, contributed significantly to human knowledge of pottery, grain storage, and irrigated agriculture and food preservation. Present knowledge of traditional agriculture has its origins in the system of riverine crop production tested over centuries.

The semi-arid Indus plain has always depended on the waters of the Indus River and its tributaries for agricultural production. In the early days before the rivers were controlled, the floodwater used to spread over vast tracts leaving fresh fertile silt and moisture to enable crop production. Dug wells and use of Persian wheels also helped draw up water for irrigation, especially in the winter months.

Perhaps the most significant contribution of the Indus basin has been its service as an abode for different cultures. This amalgamation of different races has resulted in a diverse germplasm consisting of numerous tribes, groups and families of both humans and animals. The resultant inhabitants have been hardened by the diversity of extreme climatic conditions, which are manifested in a unique group of people, and are able to undertake agriculture in diverse areas. Foreign invasions by the Greeks, Mongols, Persians and Turks ensured steady progress in the technologies used for agriculture.

5.3.2 History of Irrigation Development

One of the earliest canals in the region was constructed in 1351 in the reign of Emperor Feroze Shah Tughlaq of Delhi to take water from Jamuna River to his hunting grounds in Hissar (now in Haryana, India). This canal was used during the next four centuries by the successive Mughal emperors until it was abandoned around 1770.

The earliest irrigation project relevant to Pakistan was the construction of Shah Nehr on the River Ravi that originated from Madhopur, and irrigated a part of the Bari Doab[9] and brought water to the famous Shalimar Gardens in Lahore. A number of inundation canals were also developed in the Punjab and Sindh primarily on the Sutlej, Chenab and Indus rivers. Inundation canals did not have any diversion structures

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7 See I. H. Qureshi, 1997. A Short History of Pakistan, for sequential details on historical development.
8 KeNoyer. M. J, 1998: Indus Valley civilisation, Oxford Press, Pakistan.
9 Persian word for land surrounded by two rivers.

on the rivers and withdrew water through head regulators only during the flood season due to higher levels in the parent river channels.

The British Army engineers started construction of canals in India in 1817 but, as they lacked experience with the flow of large alluvial rivers and their seasonal variations, their initial efforts were not successful. After the defeat of the Sikhs and the annexation of Punjab in 1846, a British engineer, Major Napier, started improvement of the existing canals to rehabilitate the soldiers of the disbanded Sikh armies. Plans for remodelling the existing Hasli canal, (now renamed Bari Doab Canal), were prepared by Lt. Dyas of the Royal Engineers and the canal opened in 1859. The first canal provided with permanent masonry headworks was at Sirhind, originating from Ruper (now in East Punjab, India). It was planned in 1832 and started operating in 1872. In the late 19^{th} and early 20^{th} century, the basic philosophy of irrigation development was to support extensive agriculture to provide subsistence to the rural population as well as to produce food for the prevention of famine. This ultimately led to the development of the largest contiguous irrigation system of the world in the Indus basin, which became the breadbasket of undivided India.

The basic design philosophy of the irrigation system was to spread water thinly over large areas (extensive agriculture) with deferred drainage; and to provide equitable distribution of available river supplies with the least human interference. These philosophies, though somewhat tempered over time due to increased demand for water and other developments such as IWT, essentially remained dominant. Consequently, the distribution of canal waters has historically been regulated by specific enactments from the days of the British government. One of the earliest instruments was the Northern India Canal and Drainage Act No.VIII of 1873. By 1920, most of the perennial flows of rivers had been appropriated through the construction of various canals. At this juncture, occasional shortages in water distribution started occurring. Furthermore, serious concerns were expressed by the riparians regarding water allocations for the proposed new passes. In order to deal with the issue, the Government of India established the Indus Discharge Committee in the early 1920s, followed by the Anderson Committee (1935), and the Rau Commission (1941) to prescribe water allocations for various projects. By the time of partition in 1947, the Sindh-Punjab Draft Agreement had been evolved for water distribution, based on the recommendations of the Rau Commission.

The Indus irrigation system was initiated as a relief mechanism, and to meet the growing need for agricultural products, especially foodgrains. The objective was equitable distribution of water to all the farmers in the command area, rather than to meet full crop requirements. This has changed somewhat over time as the demand for water has grown while supplies are limited.

During the pre-Treaty period between 1947 and 1960, protracted negotiations between India and Pakistan with vigorous participation by the WB, resulted in interim arrangements for water distribution with the following provisions:

- Pre-independence water allocations: entitlements of the canals as per Anderson Committee recommendations (1935) and Sindh-Punjab Draft Agreement (1945) modified by the Indian action in the post-independence period;

- Seasonal ad-hoc agreements between India and Pakistan regarding eastern rivers deliveries and use of Marala-Ravi and Balloki-Suleimanki links to divert surplus Chenab water;

- Construction of Kotri (1955) and Taunsa (1958) barrages to provide assured water supplies to the inundation canals of lower Sindh and those in D.G. Khan and Muzaffargarh districts. Guddu Barrage was also under construction in 1960 to serve the upper Sindh inundation canals.

The Indus Waters Treaty was effective retrospectively from 01 April 1960 and had the following main provisions:

- The supplies of three eastern rivers, *viz* Sutlej, Ravi and Beas would be available for unrestricted use by India.

- The three western rivers, *viz* Chenab, Jhelum and Indus would be available for unrestricted use by Pakistan except for certain specified uses in the territories held by India along the three western rivers.

- A transition period of 10 years, ending 31 March 1970, would be allowed during which Pakistan would receive, for unrestricted use, a specified quantity of waters of the eastern rivers, which would be released by India. After the end of transition period, Pakistan should have no claim or right to releases by India, of any of the waters of the eastern rivers. The transition period could be extended up to a maximum of three years, on payment of a penalty by Pakistan. Pakistan should construct replacement works from the western rivers and other sources of water supply for the canals in Pakistan that had been taking their supplies from the eastern rivers until 15 August 1947.

- India would make a fixed contribution towards its share for construction of replacement works in Pakistan.

- A regular exchange of data between India and Pakistan would take place with respect to flow and utilisation of the waters of the Indus basin rivers.
  India and Pakistan should each create a permanent post of Commissioner for Indus Waters and appoint to this post a person who should ordinarily be a high ranking engineer competent in the field of hydrology and water use. Each commissioner would represent his government on matters arising out of the treaty and relating to its implementation. The two commissioners would form the "Permanent Indus Commission".

- Settlement of any differences and disputes should be by the Commission/by agreement/by a neutral expert/or any other way agreed by the irrigation commissioners.

The issue of distribution of river waters has been quite contentious throughout the history of Pakistan. After signing of the IWT, a Water Allocation and Rates Committee (the Akhtar Hussain Committee) was established in May 1968, and submitted its report in June 1970. Since that was the last day of the One Unit (West Pakistan) and the original four provinces were revived on 1 July 1970, the report was not considered by the Provincial Council who recommended that it be submitted to the new committee with all the provincial governors as members.

Another committee was constituted by GOP *vide* a resolution on 16 October 1970 under the chairmanship of Justice Fazl-e-Akbar, a retired Chief Justice of Pakistan, to recommend the apportionment of waters of the Indus and its tributaries. The report of this one-man committee was submitted to GOP in 1971. However, while the recommendations of this report were under consideration, an *ad hoc* distribution of the water from Chashma barrage and Tarbela dam was started to the provinces. The issue thus remained unresolved.

A commission consisting of the chief justices of all the four provinces was appointed in 1977 under the chairmanship of the Chief Justice of Supreme Court of Pakistan to examine the issue of apportionment of water among the provinces. The report of this commission is still lying with the GOP.

The matter was again discussed in a high-level meeting on 4 March 1991 chaired by the Prime Minister and including all the Chief Ministers of the provinces and relevant federal ministers. Another meeting was held on 16 March 1991, where the participants unanimously agreed on a formula to resolve this thorny issue. As a result, an accord on "Apportionment of the Waters of the Indus River System between the Provinces" was signed on 21 March 1991 (Annex 11). The Indus River System Authority (IRSA) was set up in 1993 under provisions of this accord, after passage of the necessary act by parliament. Further details regarding the composition and working of IRSA are covered under section 5.6.2.2.

As per the Water Apportionment Accord (WAA), all the four provinces were allocated additional water supplies of about 15 bcm over the post-Tarbela (1977-82) average canal withdrawals of about 129 bcm in the Indus basin (refer Annex 11). The bulk of these additional supplies were for the ongoing projects or for those on the priority implementation list of the smaller provinces (NWFP and Baluchistan). The Lieftinck Report had predicted diversions of around 150 bcm by the year 2000 (refer Table 22).

Almost all of the additional allocations under WAA were in the high flow *kharif* season. Therefore, for meeting the *rabi* requirements of projects in the smaller provinces, the existing post-Tarbela average withdrawals of Punjab and Sindh were adjusted downwards by about 1 and 0.5 bcm respectively. The salient features of WAA are:

- The balance of river supplies over the agreed allocations of 144 bcm (including flood supplies and future storages) shall be distributed among the provinces: Punjab (37%); Sindh (37%); Baluchistan (12%); and NWFP (14%).
- The need for storages, wherever feasible on the Indus and other rivers, was admitted and recognised for planned future agricultural development.
- The need for certain optimum escapes to sea below Kotri, and to check the sea intrusion was recognised and it was decided that further studies would be undertaken to establish these needs. No firm figure was agreed upon.
- There would be no restriction on the provinces to undertake new projects within their agreed share.
- For implementation of the accord, an Indus River System Authority (IRSA) would be established.
- The system-wise allocations would be worked out separately by each province on a 10-day basis, and would form part and parcel of the accord.
- The record of actual post-Tarbela (1977-82) average system uses would be used to form the guideline for developing a future regulation pattern for all Pakistan, including sharing of shortages and surpluses.
- The existing reservoirs (Mangla and Tarbela) would be operated with priority given to the irrigation uses of the provinces.
- The provinces would have the freedom within their allocations to modify system-wise and period-wise uses.

Findings on Historical Perspective

- The fertile Indus plain has been subjected to many invasions from foreign powers over several centuries. The civilisation that developed as a result of this racial mixing evolved into a prosperous agrarian society, remnants of which still exist.

- Agricultural development was progressive with successive injections of technology from diverse groups of invaders. These invasions provided a genotype base, which has been exploited to produce highly diversified flora and fauna.

- An extensive contiguous irrigation system was developed in stages in the Indus basin from 1859 to 1962 to enhance agriculture on barren lands in a semi-arid region, commanding an area of about 14 mha.

- Water sharing from common rivers of the Indus basin emerged as a major regional conflict between India and Pakistan almost immediately after partition of the sub-continent in 1947, by which time the very large network of barrages and irrigation canals was already in place.

- The water dispute was resolved with the signing of the Indus Waters Treaty between India and Pakistan in 1960 through good offices of the World Bank.

- An increasing demand for agricultural products resulted in inter-provincial rivalries for a higher share of irrigation supplies, and water allocation became a source of conflict between competing provinces, both in the pre- and post-partition scenarios.

- The latest effort to resolve inter-provincial disputes was the signing of WAA of 1991 between the four provinces and the consequent establishment of IRSA in 1993 to regulate the river supplies.

5.4 Planning and Appraisal[10]

Following the signing of the Indus Waters Treaty (IWT) with India through the good offices of the WB, the Government of Field Marshal Ayub Khan decided to undertake a comprehensive study of integrated water resources development, with storages at potential sites on the Indus River. Construction of a dam on the Indus and Mangla Dam on Jhelum river were included in the list of works to be financed through the IBDF Agreement that was signed in September, 1960.
The search for a dam site on the Indus River started soon after independence. Reconnaissance studies for Tarbela were started by the Dams Investigation Circle of GOP in 1954 with the engagement of Tipton and Hill of USA as consultants. After the creation of WAPDA in 1958, the responsibility for this project was transferred to this organisation, which started site investigations. At the same time, WAPDA engaged TAMS as project consultants. It took three years of thorough investigations to select the site and two more years to establish its feasibility including preparation of detailed design.

Though reconnaissance studies for Tarbela dam started in 1954, it was not until 1959 that site selection studies commenced after the selection of project consultants. Three alternative sites were chosen for detailed investigations: at Bara (the final site), with a potential storage capacity of 13.7 bcm; at Kiara, 4km upstream of Bara, with a potential storage capacity of 12.3 bcm and at Kirpalian, 24km upstream of Kiara, with a storage potential of only 5.3 bcm. These studies considered a minimum capacity of 6.3 bcm, and also examined the potential for second-stage raising of the dams to provide increased capacity.

Comparing the sites at Bara and Kiara, the studies indicated that, because of more favourable geology and topography, the arrangement of structures at Bara would result in a less expensive project than at Kiara. Equally important, the outstanding problems of design and construction at Bara appeared to be more susceptible to solution than those at Kiara. Lastly, the potential storage capacity at Bara was greater. A dam at Kirpalian would have had limited capacity and could not have been raised. In fact, to attain the desired minimum capacity of 6.3 bcm, it would have been necessary to supplement the Kirpalian reservoir with one on the Siran River to be filled through an expensive canal and tunnel system leading

[10] This section draws heavily on the Project Design and Construction Report by TAMS (1980), Tarbela Experience by Sir Alexander Gibb & Partners (1980), and World Bank, PCR (1986).

from Kirpalian to the Siran. The estimated cost of the Kirpalian reservoir was far greater than the estimated cost of other alternatives. The Bara site, with more usable storage than either of the alternative sites, was consequently selected for further study and development.

At the selected site thorough investigations were carried out on abutments and foundations for the main dam, which included 11km of exploratory tunnels, and 52 000m of borings and test-pits. These revealed poor rock conditions throughout but the full ramifications of this were only revealed as construction proceeded. The rocks of the abutment areas were mixed and all strongly folded, sheared and jointed to the extent that Class I rock, 'solid stable rock', could not be found anywhere. Alluvial deposits were found in the 3km-wide river bed that included beds of sand, boulders and open-work gravels. (Subsequent subsurface explorations continued during the early construction stage and revealed alluvial deposits of up to 180m deep and a buried escarpment on the right side of the river valley.) The site was also in a known seismic area and this was duly reflected in the design provision of 0.10g to cope with horizontal earthquake acceleration. After commissioning, the adequacy has been checked at 0.50g for embankment and 0.35g for other structures.

The only suitable type of dam under such conditions was an embankment-type with an upstream impervious blanket.

In 1963, WB agreed to undertake the Indus Special Study (ISS) by a team of consultants headed by Dr. Pieter Lieftinck. The first task of ISS was to focus on the re-evaluation of the proposed Tarbela Dam Project including other viable alternatives. This team identified a number of potential sites on the Indus and tributaries for water storage. The IBDF Agreement mentioned only “the construction of a dam on the Indus” thus leaving the choice of specific site open. Three major sites of Tarbela and Kalabagh on the River Indus, and Gariala on the Haro River were considered particularly suitable. The more serious contenders were Kalabagh and Tarbela. The Indus Special Study (ISS) Team of the WB initially focussed on Kalabagh because of its lower indicated cost, while GOP insisted on Tarbela, given its larger storage capacity and power potential. This followed detailed comparative evaluations by the ISS Team, which revealed that in the context of engineering studies, Tarbela was much ahead of Kalabagh. The latter could not be available for service before 1979 as compared to Tarbela that could be ready by 1975. Consequently, it was decided to proceed with Tarbela after a recommendation by the WB and its acceptance by GOP.

It must be noted that the Tarbela site, as part of project planning, underwent extensive investigations, both technical and economic, before recommendations were forwarded to GOP for its inclusion in IBP. The government had ample time to examine the documents prepared by various consultants related to design, economics and finance. Chief Engineer Mr. S.S. Kirmani was entrusted with the responsibility of evaluating the technical aspects of the design, and with overall responsibility of IBP on behalf of WAPDA . Tarbela was originally envisaged as a storage project with a prime focus on irrigation in the lower tributary command areas of the Punjab and Indus main stem projects, both in Punjab and Sindh, with hydropower generation as a by-product.

As regards development of hydropower, the projected demands in the near future did not warrant full development at the initial stage. Therefore, it was decided to develop this in stages with an initial installation of 700 MW out of the estimated potential of 2 100 MW. Whereas the basic infrastructure for further expansion was provided, further development was envisaged over a period of five years after commissioning the project.

As the first part of ISS, the World Bank re-evaluated TDP, and its technical and economic viability was established. This led to a decision to take up implementation of the project. Discussions subsequently took place to consider how the balance of funds for Tarbela might be provided to supplement the sum likely to be available for transfer from the IBDF. During November 1966, the WB presented to the Pakistan Consortium (contributors to IBDF) the estimated financial requirements for Tarbela. After considering the expected balance from IBDF, a shortfall of about $200 million ($976 million in 1998 prices) was expected in foreign exchange. Negotiations culminated in the consortium meeting in Paris on

05 March 1968, where the friendly countries and WB committed additional grants and loans to meet the shortfall. Consequently, the Tarbela Development Fund (TDF) was signed on 02 May 1968. Financing of TDP is covered under section 3.3.4, while details of funding through TDF, is given in Annex 4. Information on the cost of construction is also contained in section 3.5.4.

Sensitivity analysis under varied scenarios had indicated Tarbela to be economically feasible at a medium level of crop yields with a basic two-prong focus on irrigation and hydropower. At the appraisal stage, no particular consideration was given to the other multiple benefits that would be generated by Tarbela. Nor was there any mention of Tarbela's significant role in flood mitigation. The economic analysis did not consider indirect benefits such as river navigation, fisheries, and the likely backward and forward linkages between agriculture and industry and long term-impacts on employment. No social or environmental analyses were attempted by the WB during the appraisal of the project. Re-settlement issues were given little consideration except for relying on the model prepared by WAPDA on the basis of the Land Acquisition Act 1879, and the proposal under implementation for Mangla Dam. In retrospect, this lapse at the planning stage had serious consequences for the inhabitants surrounding the dam and in certain areas downstream.

WAPDA, as the implementing agency for IBP, was assigned the sole responsibility for ensuring that the dam was constructed on schedule and in a satisfactory manner. The WB played a leading role as administrator of TDF. Under its charter, WAPDA also had the lead role for the integrated planning/development of water and power resources. In the process, the provincial departments of irrigation and agriculture, and other concerned line agencies were also involved in one way or the other.

Since Tarbela was to be built under an international competitive bidding process, the tender documents and specifications were exhaustively scrutinised for compliance with international standards of construction. When the tenders for the main Tarbela contract were received, there was a difference of $100 million between the lowest bid (by a German consortium) and the next lowest (by an Italian consortium led by Impregilo). After an evaluation of the tenders by the consultants/WAPDA, the lowest bid was considered unresponsive as it contained a number of qualifications. The next lowest bid by Impregilo for $623 million was considered fully responsive and recommended for award. Soon after the commitment of the necessary financing through TDF, the largest single peace-time contract ever was awarded on 14 May 1968 to TJV, a consortium led by Impregilo of Italy.

The keen interest of the WB in seeing the project through is evident throughout the project cycle. The review team considered that a high level of professionalism prevailed amongst the concerned parties based on the standards of the day, namely: GOP (through WAPDA and its consultants); WB and its consultants; and the international contractors selected to build the project. While most of the technical designs conceived during appraisal were followed, it was evident that due to the size and complexity of the project and the poor geological conditions, its features were almost touching the frontiers of knowledge. This resulted in some further design improvements during construction and appropriate provisions for prototype observational monitoring of the critical project components. Technical challenges of a significant magnitude were thrown up during the subsequent structural problems that occurred after initial operation. These were resolved through innovative approaches, which made significant contributions to the state-of-art, although at significant cost.

Overall procedures for decision-making, control and forward management during implementation of IBP were established in 1960 by WB as an administrator of IBDF and consented to by WAPDA. The organisational structure of WAPDA consisted of the following components: Head Office, set up under the Chief Engineer IBP; and Project Director at site. The project consultants assisted the Project Director. The World Bank was represented by their consultants at Head Office and by site observers for individual projects.

For Tarbela, these procedures were generally followed, with adjustments for site review of the designs and drawings prepared by the project consultants, by WAPDA's General Consultants (HARZA) and by WB Consultants (site observers) before commitments were made. The following areas in particular were covered:

- engineering and financial procedures;
- procedures for financing and purchase of construction plants;
- procedures for financial control and administration; and
- procedures for variation orders and review of construction drawings.

Financial management and control was closely linked to technical control. The annual capital cost estimates were prepared bi-annually by the WB consultant (Gibb), on the basis of information provided by WAPDA and project consultants. In addition, WAPDA had its own internal government audit systems.

The overall strategy of management was to ensure rational and effective decision-making with minimum time loss. On-site decisions were taken for minor variations, but in cases requiring major variations, formal requests for approval by the Head Office of WAPDA had to be obtained before orders were issued to the contractor.

Findings on Planning and Appraisal

- The project was a direct result of the IWT 1960, to resolve the water dispute between India and Pakistan.
- The IBDF Agreement mentioned only 'the construction of a Dam on the Indus" thus leaving the choice of specific site open. During the 1967 appraisal by the WB, through ISS, the basic options of Tarbela and Kalabagh were considered. Initially, ISS focussed on Kalabagh because of the lower indicated cost. However, after a detailed comparative evaluation by ISS, the alance finally tilted in favour of Tarbela. This was because its engineering was much advanced as compared to Kalabagh; it had a larger storage capacity and power potential; and it could be brought on line by 1975 as against 1979 for Kalabagh.
- Tarbela was conceived, investigated, planned and designed over a decade with due consideration of a range of alternative dam sites. Out of these, the Bara site was selected for location of the Tarbela dam due to more favourable geology and topography, arrangements of structure, and a usable storage capacity that could provide for significant development over and above the basic replacement needs.
- Out of the estimated hydropower potential of 2 100 MW, only 700 MW would initially be developed. Basic infrastructure was, however, provided for future staged expansion in keeping with power demands.
- Tarbela had the benefit of the Mangla experience in the form of detailed procedures for contracting, procurement and supervision.
- Appraisal conformed to prevailing standards of the WB.
- Storage releases for irrigation and hydropower were conceived as direct benefits from Tarbela. Other benefits like flood mitigation, fisheries, navigation and environmental impacts were not considered.

- No assessment regarding re-settlement or downstream impacts was undertaken. Nor was there any social analysis to understand the livelihood impacts and the long-term consequences of a changing river morphology. Tarbela was therefore viewed as an integral part of IBP in the context of its likely impact on irrigated agriculture.

- The assignment of implementation to WAPDA, created in 1958 for the integrated development of water and power resources, was instrumental in assuring that Tarbela as part of IBP would be successfully completed and commissioned.

- The WB as custodian of TDF exercised strict financial control even at the planning stage.

- Tarbela, by the sheer size of its various components, had to be designed with concepts that stretched the frontiers of knowledge. This, together with the serious structural problems experienced during initial operations, contributed to advances in knowledge on design and construction but at a substantial cost.

- As a result of the prevailing “top-down” management style of the public sector, the affected groups were not consulted including the critical issue of resettling the displaced persons.

5.5 Detailed Design and Construction

5.5.1 Detailed Design

5.5.1.1 Extending frontiers of knowledge

TDP was constructed in accordance with the design characteristics originally incorporated. However, it was well known that a number of design concepts involved advancing beyond the frontiers of knowledge. Further, serious damage occurred during initial test operations of some of the project components: the right bank tunnels and stilling basins; the upstream impervious blanket; and plunge-pools of the spillways. These necessitated emergency design modifications and innovative approaches. In the process, Tarbela made significant contributions to engineering knowledge on the design and construction of dams. These state-of-art contributions were in the following areas:

i. **Rollcrete:** Large quantities of rollcrete were used as a fill material (on a much larger scale than heretofore). It was used to repair damages to Tunnel No.2; in the work of lining the plunge pools of the service and auxiliary spillways; and in the conversion of Tunnel No.4 outlet from a stilling basin to twin flip buckets. Rollcrete is a form of concrete containing less than one-half the amount of cement in comparison to regular concrete and with aggregate sizes of up to 25cm, and can be produced in very large quantities (at Tarbela at a maximum rate of 18 000m^3/day) and transported, placed and compacted with regular earth-handling equipment (large dump trucks, bulldozers and vibratory rollers). The experience at Tarbela demonstrated the usefulness of rollcrete as a structural material where large volumes must be placed quickly and where there are low requirements for uniform strength, impermeability, resistance to high velocity flows and weather. Rollcrete is now used frequently and economically as a fill material in dam construction and this trend is the direct result of the Tarbela experience.

ii. **Large capacity gates and stilling basins for low level outlets:** The outlet gates on Tunnels 3 and 4 had to be capable of releasing varying quantities of water as irrigation requirements change and as reservoir levels fluctuate. To do this with large discharges, and when the pressure head on the gates could be as high as 132m, required outlet control structures, ie, steel transitions from tunnels to twin, radial, outlet gates and stainless steel lined gate chambers, with dimensions beyond anything ever constructed. The massive structures were heavily reinforced, pre-stressed and anchored. The design, fabrication, installation and final fitting all involved concepts and techniques never before accomplished on such a large scale.

iii. **Steel-fibre concrete:** Final repairs to the stilling basin of Tunnels 3 and 4 carried out in 1976-77 included placement of a 50cm final surface of steel-fibre concrete to provide greater resistance to cavitation and abrasion. This large-scale use of steel-fibre concrete appears to have given full protection against the very large forces. Inspections have revealed negligible erosion of the protected floor of the chute and basin despite extensive use of these structures during more than two decades.

iv. **Extensive upstream blanket:** Of the large embankment dams employing an upstream blanket to reduce reservoir seepage, Tarbela has no close competitor, either in extent of the blanket or in height of the dam utilising the blanket. Functional performance of the blanket, after repair of sink holes detected following the emergency drawdown, has been as expected. (Later investigations have confirmed the phenomenon of sink holes in some dams even with trouble free initial operations.) Under-seepage has consistently reduced as each season passes, and performance of the blanket has further been enhanced by consolidation of the blanket, and by the deposition each year of a deepening layer of sediment.

v. **Analysis and treatment of blanket sinkholes:** The presence of sinkholes in the upstream blanket was observed in 1974 after an emergency emptying of the reservoir. While the blanket was exposed, sinkholes were filled with blanket material and the thickness of the blanket was increased. In the following years there was a continuing programme of underwater surveys to monitor previous sinkhole locations and to locate and fill new ones by dumping filter material from barges. The consensus was that sinkholes are initially cracks developing from differential settlement, and begin at the bottom when the fines from the blanket material wash into open layers in the foundation. The treatment was effective and the performance of the blanket continued to improve. Formation of the sinkholes on draining the reservoir in August-September 1974 and their successful treatment have added a valuable page to engineering knowledge and experience. No published experience of sinkholes in blankets existed in 1974, but subsequent enquiries revealed that sinkholes had occurred in the upstream blanket of Arrow Dam in Canada. Primarily based on the Tarbela experience, it is now recognised that sinkholes must be anticipated where blankets rest on gravel and sand alluvial foundations and differential settlement can occur.

vi. **Side-scan sonar and sonic profiling:** On the basis of experience in North Sea oil exploration, side-scan sonar equipment and sonic profiling equipment were used for the location and study of sinkholes. This unique application was successful from the beginning. This equipment, (together with the radio navigation equipment used to locate sinkholes, and the barges for dumping the blanket material), although initially under the control of the main contractor, was later operated by WAPDA personnel.

vii. **Other areas of technical advances:** In addition to the areas mentioned above, Tarbela added to engineering knowledge and experience in other ways: for example, a great variety and number of monitoring instruments were installed in Tarbela facilities. These included:

- the new double fluid settlement devices which gave data on instrument performance and instrument comparison;
- new knowledge gained in instrument and cable installation;
- important experience gained in the manufacture of the core material which replaced the conventional homogeneous material with a mechanical blend of dissimilar materials; and
- considerable knowledge gained on the effects of small surface irregularities in causing cavitation damage under high velocity flows.

5.5.2 Construction

On 04 November 1968, the President of Pakistan performed the groundbreaking ceremony for Tarbela. Guests included the Speaker of the National Assembly, the Governor of West Pakistan, the Governor of East Pakistan, Ministers of Central and Provincial Governments, members of diplomatic corps, and representatives of the WB, and WAPDA. By that time, the contractor (TJV) had already mobilised and the construction proceeded as per the following stages:

- **Stage I:** From May 1968 through September 1970, Stage I construction proceeded generally as scheduled. The diversion channel was excavated, and the diversion channel closure buttress dam was built. The first stage of the main embankment was constructed; the cellular coffer-dam and the tunnel inlet and outlet area excavations were completed; excavation of the tunnels was started; and excavation and concrete work on the power house had begun.

- **Stage II:** Stage II construction started on 09 October 1970 when the river was diverted into the diversion channel, and continued through September 1973. Construction of the main embankment, except for the closure section was essentially completed. The upstream blanket and the fill for the auxiliary embankments were placed and the intake structures, outlet structures and tunnels were completed. The two spillways were essentially completed, except for the installation of the crest gates; construction of the power house continued; and the installation of the power house equipment was commenced.

- **Stage III:** On 27 September 1973 the buttress dam gates were closed and the river was diverted through Tunnels 1 and 2 without incident, thus initiating Stage III. During Stage III the closure section of the main embankment was completed and work continued on the right and left banks to complete those features as yet uncompleted. Except for the power installation, all work was expected to be essentially finished by October 1974, when the reservoir would be filled to spillway crest and begin discharging through the irrigation outlets and possibly over one of the spillways.

5.5.3 The Civil Works Contract

The main civil works contract (651) was awarded to TJV on 18 May 1968. It was of the unit-price type, under which the total tender price was based on the Engineer's estimate of quantities, set forth in a detailed bill of quantities (BOQ), at the tenderer's stated unit prices for each item. Many factors subsequently affected the final cost of the contract, including: changes in the work covered by variation orders; changes in the final quantities of BOQ items; escalation of costs (as allowed by the contract); claims; provision for a bonus; changes in reimbursable items; special items, such as customs duties and taxes; and the need for remedial works.
The construction proceeded as per schedule, and by July 1974, the project was substantially completed.
Initial test filling of the reservoir was started because of the complex nature of the foundation geology. This led to subsequent major structural damages that occurred in a chain of unfortunate events as enumerated under section 5.2.

5.5.4 Construction Civil Works

The overall construction costs in the form of capital investments are dealt with under section 3.3.3, while their financing is covered under section 3.3.4.

Problems with construction arose in mid-1975 and incidents occurred in 1976 and 1977. These were related to damage to the Tunnel No. 3 stilling basin, sinkholes in the main embankment, erosion of the service spillway plunge pool and a threat to the foundation of service spillway flip bucket (refer Table 5.1 under section 5.2).

From an operational point of view, the project was substantially completed in 1978. Irrigation water had been available for some time and power generation had begun in May 1977. Yet the final completion date kept slipping. The auxiliary spillway plunge pool had also experienced erosion, which required work until June 1982.

The cost increase of $669 million ($1050 million in 1998 prices) arose largely from the need for repair/remedial measures following the damages that began in 1974. The main damage was caused by the loss of bearing rails from one of the three upstream control gates of Tunnel 2 (because the fixing bolts had not been tack welded, resulting in sticking and the consequent collapse of the intake structure); and early erosion of the plunge pools of the spillways. Further damage resulted from the material failure of the floor slab of the stilling basin for Tunnel No. 3. These incidents were investigated by consultants/WAPDA/WB. In summary, the problems were, for the most part, exceptional and unforeseeable at the then existing level of knowledge and experience. In retrospect, it was clear that the potentially damaging effect of the large quantities and high velocities of water on structures based on such complex and adverse geology had not been fully appreciated. As reflected in Table 5.1, all these events created situations that had to be dealt with accordingly.

The cost increase put severe economic strain on the Pakistan economy and funds were diverted from other priority projects to ensure completion. While these cost escalations held back development in other areas, the government's desire to succeed was explicit from its financial management. Tarbela was conceived as the bloodline of the economy, and no further progress in energy and agriculture was perceived without this project.

At no stage of the project were there any thoughts that the project would not succeed. The political support exhibited in supporting the government when major disasters were experienced, demonstrated the will of the nation to succeed against all odds.

Findings on Design and Construction

- The dam, at the storage capacity that was finally approved, could be built as part of the Indus Basin Project or could stand alone. In either case, it was both technically and economically feasible.

- Construction of the principal elements of TDP began in 1968 and proceeded on schedule. After substantial completion, however, an unfortunate chain of events resulted in serious structural damages. The repair and restoration programme continued until the early 1980s at a substantial cost. Despite all this, partial commissioning took place in 1975 and full reservoir storage was made available with a delay of about two years in 1976. Similarly, power generation from the first four units started in early 1977 with a delay of less than two years.

- Added costs put severe economic stress on Pakistan economy. However, Tarbela was given priority over all other projects. Some downstream project components related to efficiency were postponed or scrapped to finance remedial work on Tarbela.

- The completion target date (refer Table 5) was August 1974 and the first filling took place around that time. The project was therefore completed essentially on time. However, as problems arose during the first filling the final completion was extended to undertake repairs and remedial works. The delays that occurred were caused mainly by circumstances beyond the control of the contractor and consultants. Risk remained a hidden variable during the history of the dam construction.

5.6 Operation and Monitoring

5.6.1 Project Operation

Planning and implementation of the O&M programme was the responsibility of WAPDA. TAMS developed the necessary organisation, monitoring structure, and schedules and prepared the relevant manuals. World Bank consultants (Gibb) also reviewed their procedures.

By the initial filling of the Tarbela reservoir in 1974, the necessary O&M arrangements were essentially in place. However, due to the accident to one of the three gates controlling the right bank Tunnel No. 2, the reservoir had to be evacuated in emergency. The resultant repair and remedial programme, that began in 1974 and continued till 1984, diverted attention and resources from normal O&M. Further, Pakistan had no prior experience in development, management and operation of such large infrastructure on complex geology. The earlier experience with Mangla was with a smaller dam of conventional design located on favourable geology and thus not entirely relevant to the Tarbela situation.

Due to adoption of the state-of-the-art design in a number of project features, appropriate monitoring arrangements were incorporated by way of extensive instrumentation and special “observational methods” for behavioural evaluation during actual operations. These covered: seepage under the upstream impervious blanket through and around the embankments; safety of various structures against hydraulic pressure; and efficacy and durability of various repair/restoration measures. The arrangements also proved extremely helpful in coping with serious problems at Tarbela through initial diagnosing and subsequent confirmation of the remedial measures. In addition, almost yearly hydrographic surveys were conducted to monitor reservoir sedimentation. Most of these monitoring activities are now an integral part of the project operations. These are also backed by special independent project inspections every 2 to 3 years by specially constituted panels of experts.

As TDF did not include any provision to fund an O&M programme, it became necessary to arrange additional resources. WAPDA suffered considerably in timing and putting in place an efficient O&M system because of delays caused by remedial works. Office buildings, residential colonies, vehicles, equipment and facilities due from the contractor were not released on time. In later years, however, better facilities became available and these allowed the adequate functioning of WAPDA management. Separate O&M organisations were created to look after the water and power-related facilities. Some of the chronic O&M problems were:

- Significant differences in remuneration and the isolated environment of Tarbela, making it difficult for WAPDA to recruit and retain high quality staff.

- Inadequate foreign exchange resoources which restricted provision of O&M plant, equipment, spares, supplies, workshops, training and technical assistance.

- Safety and security of such a large key project being a significant concern of management and the government.

During the initial years of operation, the WB arranged loans and bilateral assistance for this purpose. Different sources provided about $35.4 million to support O&M (TAMS, 1984 - PCR).

During the overlapping phases of repair/remedial works and O&M until early 1980s, the management style followed at site required active participation of the concerned project consultants, in order to short cut the time needed to take decisions as well as their implementation. Chains of command were clearly established and all concerned knew what, when, by whom, how, and under what authority decisions were being made. During meetings only action points were listed and agreement sought on those action points. Time frames and feed-back on implementation were decided there and then in the meeting. Whenever problems arose at the dam, there was greater involvement of the World Bank and its consultants to find technical solutions.

This management style facilitated rapid decisions, which were credited for the prompt implementation of technical solutions that helped completion of certain critical repair items, especially remedial measures to restore the damaged infrastructure, before filling the reservoir during the following high flow season(s). This was considered a major achievement of such team work.

At times, when damage was anticipated, material procurement was undertaken in bulk and without much planning. The assumptions used for such emergency procurement, given the shortage of time, could not be validated.

Continuous training is a pre-requisite in the O&M of large-scale dams such as Tarbela. Pakistani counterparts received high quality on-the-job training during construction of the project from the consultants/contractors. Mutual experience was gained in building the world's largest dam, which often taxed the capabilities of the engineers within the teams of WAPDA, the consultants and the contractors.

5.6.2 System Monitoring

5.6.2.1 Ad-hoc Arrangements

With regard to monitoring of system water resources, including Tarbela storage and hydropower, GOP initially put into place the following *ad-hoc* mechanism:

i. ***Operational Planning.*** For effective utilisation of Tarbela storage water, GOP approved in advance the seasonal ad-hoc *rabi* and *kharif* sharing arrangements between the provinces. These were based on the suggested 10-daily reservoir operation evolved by the Water Resource Management Directorate of WAPDA with due consideration of: forecasted river inflows; any special constructional/repair constraints; and water requirements established by the Provincial Irrigation Departments. Though incidental, the generation requirements projected by the Power Wing of WAPDA were also accommodated to the extent possible.

ii. ***Operational Monitoring and Surveillance.*** During actual system operations, monitoring in accordance with approved *ad-hoc* storing arrangements was done by a high powered Water Distribution Committee at the federal level headed by the Chief Engineering Advisor and represented by Secretaries of Provincial Irrigation Departments and senior management of WAPDA.

At actual operational level the monitoring was done by the Water Distribution Sub-Committee headed by the Chief Engineer: Hydrology and Water Management, WAPDA with membership of Directors (Regulation) of the Provincial Irrigation Departments and Director (Power Control) WAPDA and the representative of the Chief Engineering Advisor.

The instructions for actual system operation were based primarily on the irrigation indents placed by the respective provinces with due consideration of: prevailing inflows; prevailing reservoir levels in comparison with the suggested criteria; and allocations as per *approved ad-hoc* sharing. During periods of acute power shortages, accommodation, to the extent possible, was also attempted. For instance, there was serious conflict between irrigation and power demands during the annual canal closure period of December and January. Notwithstanding this, the Power Wing of WAPDA was generally allowed a 15-20% increased reservoir outflow by the Provincial Irrigation Departments in order to ease serious load shedding.

During actual seasonal operations, the Water Distribution Committee carried out the overall surveillance by convening as and when necessary. On the other hand, the Water Distribution Sub-

Committee would convene monthly or more frequently, if necessary, to review actual operations of the previous month and refine operational plans for the forthcoming month.

5.6.2.2 Regular Arrangements

Ad-hoc arrangements continued until early 1993. In April 1993, the Indus River Systems Authority) IRSA was established under an act of the parliament to oversee as well regulate distribution of water among the provinces according to the Water Apportionment Accord (WAA) of 1991. According to the Act (No. XXII of 1992), IRSA would comprise five members, one each to be nominated by the provinces and the Federal Government. The chairmanship would be rotated yearly among the members alphabetically starting first with the member from Baluchistan.

The functions of IRSA would be to:

- Lay down the basis for the regulation and distribution of surface waters amongst provinces according to the allocations and policies spelt out in the Water Accord;
- review and specify river and reservoir operation patterns and periodically review the system of such operation;
- co-ordinate and regulate the activities of WAPDA in an exchange of data between the provinces in connection with the gauging and recording of surface water-flows;
- determine priorities with reference to sub-clause (c) of Clause 14 of the Water Accord.
- compile and review canal withdrawal indents as received from the provinces on a 5-day or, as the case may be, on a 10-day basis, and issue consolidated operational directives to WAPDA (refer Annex 11) for river and reservoir operations for irrigation and hydro-power requirements consistent with the Water Accord;
- settle any question that may arise between two or more provinces in respect of distribution of river and reservoir waters; and
- consider and make recommendations on the availability of water against the allocated shares of the provinces within three months of receipt of fully substantiated water accounts for all new water projects for the assistance of the Executive Committee of National Economic Council (ECNEC).

In addition, IRSA will have an advisory committee headed by its Chairman with membership of: WAPDA's Member (Water) and Member (Power); Chief Engineering Advisor; Secretaries Agriculture of provinces; and Secretaries Irrigation of provinces.

IRSA started functioning in April 1993, with members nominated by the federal and provincial governments, which, inter alia, covered operation and monitoring of the on-line reservoirs including Tarbela. After completing the first term of four years, all the incumbent members of IRSA were re-nominated in 1997. During July 1998, GOP issued an ordinance, whereby the composition of the Authority was amended to appoint the Chief Engineering Advisor as chairman, and the Provincial Irrigation Secretaries as members. This amendment aimed at the smooth and uninterrupted working of IRSA through a regular *ex-officio* chairman and provincial members, instead of demanding fresh nominations at the end of each term. Later on, in October 1998, GOP withdrew this ordinance and invited fresh nominations for members from the provinces, which are still going through the process of evaluation and approval in accordance with the prescribed rules. Meanwhile, according to the provisions of the act, the Chief Engineering Advisor and Provincial Irrigation Secretaries have been acting as respective representatives including rotational chairmanship. Therefore, IRSA has remained functional and is effectively regulating the distribution of river waters among the provinces.

5.6.3 Findings on Operation and Monitoring

a. Project operation

- Initially, there was a serious dearth of resources for project operation as most of the funds were diverted to pay for special repair and remedial works. This funding constraint was somewhat eased with the arrangement of $35.4 million by the WB.

- Pre-occupation of the prime contractor with repair/remedial works delayed release of O&M facilities and equipment to be made available to WAPDA.

- Initial lack of experience on part of Pakistani counterparts created problems of taking over full O&M control. However, in the process, a large pool of highly trained manpower was created.

- For emergency situations created by concurrent special repairs, O&M decision-making was decentralised and timely commitments made in the presence of all concerned. Similarly, appropriate emergency procurement procedures were developed and implemented.

- Elaborate monitoring of the engineering, technical and safety aspects of the project was carried out under well-designed and implemented methods. This, besides fulfilling the basic purpose, significantly contributed to the state-of-the-art on: design; construction, restoration/repair of seriously damaged infrastructure; and efficient operation and safety monitoring for projects of this type and size.

- Inter-provincial surface water distribution is being overseen by the regulatory body of IRSA since 1993, established under WAA of 1991.

b. System Monitoring

- GOP timeously approved the policy and procedures for effective utilisation of Tarbela storage in the dependent irrigation system.

- For implementation, monitoring and surveillance of the approved procedures, appropriate organisational structures were created at the Federal and WAPDA level, with active participation of Provincial Irrigation Departments.

- *Ad-hoc* sharing arrangements were followed from late 1976 (reservoir commissioning) to early 1993 due to the non-resolution of inter-provincial water disputes.

- Regular arrangements for system monitoring and water distribution were introduced from early 1993 under IRSA, created under an Act of the Parliament to implement the Water Apportionment Accord (WAA) of 1991.

6. Criteria and Guidelines: Policy Evolution and Compliance

Irrigated agriculture has provided the foundation to Pakistan's economy ever since the creation of the country. Agriculture contributed more than 60% to the national economy in 1950 and continues as the single largest sector of the economy with a 24% contribution in 1998-99. Since 75-80% of national agricultural production comes from irrigated areas, irrigation development and management has naturally dominated national economic planning since the creation of Pakistan.

The basic thrust for increasing agricultural productivity in Pakistan has been through irrigation development by harnessing the river waters. Despite an initial serious set-back cause by the Indo-Pakistan water dispute in 1948, this process was pursued, firstly, through completion of the Kotri (1955), Taunsa (1958) and Guddu (1962) irrigation projects. Secondly, progressive developments in irrigated agriculture continued in conjunction with the national five-year plans (1955 onward); the Lieftinck Report (1968); the Revised Action Programme for Irrigated Agriculture (1979); and the Water Sector investment planning study (1990). On the environmental side, the initial instrument dealing essentially with land, was the land acquisition act of 1874, which did not provide any specific provisions for resettlement. At the time of implementing Tarbela, however, a resettlement plan was developed based on the model for the recently completed Mangla Dam Project under IBP. At that time even the international funding agencies like the World Bank, did not have any specific environmental assessment criteria, or criteria covering social aspects, such as consultation with or participation of affectees. Accordingly, the economic/financial assessment of Tarbela covered only the directly quantifiable costs and benefits. Over time, and with increasing emphasis on proper environmental assessment from all quarters, the above elements are now required to be incorporated in the “Resettlement Action Plan” of each project and should conform to the requirements of the international funding agencies. These factors have brought about marked improvement as reflected in the resettlement plan under implementation in the Ghazi-Barotha Hydropower Project. This plan has been developed in consultation with the affectees and is now being implemented with their active participation through a number of NGOs.

6.1 Systematic National Economic Development Process

To streamline the national economic development process, the vehicle of five-year development plans was used. These plans are prepared by the Planning Commission after thorough scrutiny at various federal/provincial levels, including: the Provincial Development Working Parties (PDWPs); the Central Development Working Party (CDWP); and the National Economic Council (NEC). This systematic economic planning and development process was started in Pakistan with the launch of the First Five Year Plan (1955) followed by similar 5-year plans until the Eighth Plan (1993-98). The Ninth 5-Year Plan, though currently under implementation, is in the process of being reviewed in the light of the prevailing difficult economic situation.

Major reports/documents relating to the planning and development of the water sector and the related areas of agriculture and environment are listed below:

- Indus Basin Settlement Plan (1960)
- Revelle Mission Report (1962)
- WAPDA's Regional Water Development Plan - North Indus Plain (1963)
- WAPDA's Regional Water Development Plan - Lower Indus Plain (1964).
- WAPDA's Master Plan for Water Development (1965)

- Lieftinck Report, titled, "Water and Power Resources of West Pakistan - A Study in Sector Planning" (1968).
- Accelerated Anti-Waterlogging and Salinity Programme (1973)
- WAPDA's Revised Action Program (RAP) for Irrigated Agriculture (1979)
- GOP's On-Farm Water Management Projects (1976 onwards)
- National Commission on Agriculture Report (1987)
- WAPDA's Water Sector Investment Planning Study (WSIPS) 1990.
- Water Apportionment Accord (WAA), 1991
- National Conservation Strategy (1992)
- National Environmental and Drainage Programme (1993)
- Institutional Reforms to Accelerate Irrigated Agriculture (1994)
- National Environmental Protection Act (1997)
- Provincial Irrigation and Drainage Authorities Acts (1998)
- National Drainage Program (1998)

6.2 Surface Water – Indus Basin Project

The first major policy decision concerning water resources development was the formulation of the Indus Basin Project (IBP) and GOP's decision to go ahead with its implementation as a sequel to the Indus Waters Treaty (IWT), 1960. The most positive outcome of the Treaty from Pakistan's point of view was the attainment of water security through construction of the works that made its irrigation system and hydropower generation facilities fully independent of India. The main argument of its opponents was that it would consume the bulk of the country's financial resources and trained manpower, in order to develop a project that, in the end, would only replace what the country already had (the waters of the eastern rivers). This would impose a constant liability for O&M of large infrastructure and the progressive addition of make up storages for sustained water availability. In addition, colossal investment on the storage dams and link canals would be at the opportunity cost of development in other sectors, especially education, health and communication, which were so badly needed by the country.

The following major reports, development projects and government actions have largely determined national policies in the development of irrigated agriculture in Pakistan. These are related directly or indirectly to the development, operation and optimal utilisation of Tarbela and other similar projects in the irrigation sector. Most of these projects relate to improvement of the efficiency of irrigated agriculture that continues to be the backbone of the national economy. These developments have a strong bearing on the present case study on Tarbela dam/Indus basin and are briefly described in the following sub-sections.

6.3 Groundwater and Soil Salinity - Revelle Report

In addition to the works under IBP, the twin menace of salinity and waterlogging was perceived as a major threat to the country's agriculture sector. This problem was attached such importance by GOP that President Ayub Khan specially requested President Kennedy to help Pakistan solve this problem during his visit to the White House in the early 1960s. In response to this request, Kennedy sent a high level mission under the leadership of Dr. Roger Revelle to examine the situation and prepare a report recommending measures to combat the problem and arrest the decline in agricultural yields in Pakistan. The Mission's recommendations advocated the introduction of Salinity Control and Reclamation Projects (SCARPs) in the severely affected fresh groundwater areas. The SCARPs were comprehensive projects that aimed at increasing agricultural productivity through amelioration of salinity and waterlogging, and improved management of agricultural production. A major component of SCARPs was the installation of large-capacity tube wells to pump fresh ground water (FGW) as a measure of vertical drainage, and to increase water supplies for leaching of surface salinity and to increase agricultural production. This concept was accepted and implementation of public sector SCARPs taken up in the early1960s with international technical/financial assistance, including the USA. Initially, SCARPs were highly successful in reclaiming waterlogged areas, but they were gradually beset with the following problems: increased soil profile salinity due to the circulation of groundwater; deterioration of water quality due to salty groundwater intrusion from the adjacent areas; lack of resources to maintain and operate the costly tubewells; and serious management and institutional problems. It was therefore decided to privatise these facilities as a part of the SCARP Transition Project that is currently under implementation. This initiative is also facing difficulties.

6.4 Revised Action Programme for Irrigated Agriculture (1979)

The Revised Action Programme (RAP) was a major policy effort by GOP, initiated through WAPDA in 1975, to review the recommendations of the Lieftinck Report (1968) as well as to provide a sound basis for long-term planning of irrigated agriculture. The objective was to develop a comprehensive strategy for planning investment in irrigated agriculture, including irrigation development, and drainage and salinity control until 1990. RAP initiated the policy that all government-related investments and policies should be directed towards the improvement of agricultural production and not, as had been the practice, to the development of the inputs (water, fertiliser, seed). Furthermore, the cost of development should generally be borne by the beneficiaries, the state's role being to facilitate the investments. The following measures were recommended for acceptance by the government in pursuance of the RAP:

- Subsidies for private tubewell installation and fertiliser purchase should be phased out;
- wherever possible, the capital and O&M costs of intrinsically profitable technologies (tubewell, fertiliser) should be transferred to the private sector;
- public sector SCARPs in usable groundwater water areas should be phased out;
- all future developments of usable groundwater should be entrusted to the private sector, with the assistance of public sector in the form of supervised credit, technology transfer and information;
- a major criterion for choosing projects and programmes should be to channel national savings (at a significantly expanded rate) in the form of capital "controlled" by (tubewells, water-course lining) or of direct benefit (rural infrastructure) to the rural population;
- the O&M costs of facilities provided by the public sector (irrigation and drainage infrastructure) should be fully recovered from the direct beneficiaries of these services;

- full costs of investments made by the public sector (watercourse lining) for the farmers should be recovered from them in financially feasible instalments; and
- cost recovery policies ought to be supplemented by taxation of farmers' rising incomes through progressive income taxation (or through progressive land taxation).

For implementation of these recommendations the government should:

- Significantly accelerate the "supervised type" of credit for farmers and for technology suppliers (small diesel engines, threshers, fractional pumps, service centres) directly catering to farmers;
- significantly strengthen the agricultural extension service, and supplement it by a parallel water use and reclamation extension service; and
- drastically modify the focus of agricultural research by making it farm-based rather than university- or research station-based.

The total investment recommended by RAP for the 11-year period (1979-90) was Rs.68.427 billion in 1978 prices. This included funds for completion of the on-going projects and those for which international commitments had been made: SCARP-VI; CRBC; Mardan SCARP; Khairpur East Tile Drainage; Rohri North; Sukkur Right Bank; Kotri Surface Drainage; Khanpur Reservoir; and Tarbela of IBP. RAP also recommended several new projects both relating to irrigation development and management and agricultural development.

RAP recommended the following support programmes:

- Supervised Credit for Tubewells
- SCARP Transition Programme
- Watercourse Lining Programme
- Water Use Extension Programme
- Irrigation and Drainage System Rehabilitation Programme
- Basin and Canal Water Management Program
- Agricultural Extension and Input Supply Programme
- Agricultural Research Programme
- Seed Certification Programme

RAP particularly recommended the following institutional improvements:

- Central Cell for Agricultural Policy and Planning (CAP). This was to be the co-ordinating body at the federal level and the principal unit serving as a spearhead for managing agriculture in Pakistan
- Additional Chief Secretary for Agricultural Production (ACSAP) at the provincial level to co-ordinate the activities of Provincial Irrigation and Agriculture Departments.

- Command Area Management (CAM-I) for all major agricultural (water) development projects to ensure multi-disciplinary co-ordination at the project level.

- Command Area Management (CAM-II) for "farmer demand articulation" in the areas where major development projects were not envisaged.

- Autonomous Provincial Minor Works Corporations (MWC) executing works relating to watercourse lining and on-farm level investment and services.

RAP was, in fact, a major policy initiative to systematically pursue the development of irrigated agriculture. Major recommendations by RAP were implemented with varying degrees of success. The most difficult to implement were the institutional recommendations, which generally remained outstanding.

6.5 Agricultural Prices Commission

Realising that prices of agricultural commodities and inputs play an important role in the overall efficiency of the national agricultural enterprise, impacting on both the producers and consumers of agricultural products, often with serious political consequences, GOP established an Agricultural Prices Commission under the Ministry of Food, Agriculture and Livestock, in 1981. The major function of the Commission is to advise the government on price policies for various agricultural commodities and inputs. The government adopts a floor price policy for the major crops whereby it undertakes to buy the crop from the farmers at the established floor prices. This mechanism was established primarily to save farmers from financial collapse because of a major drop in the free market prices of some major agricultural commodities. Two marketing agencies, Pakistan Agricultural Storage and Services Corporation (PASSCO) and Agricultural Marketing and Storage (AMSL) have also been created in the public sector to help implement the government price policies, especially through procurement at the government established floor prices.

6.6 Water Sector Investment Planning Study (1990)

The last major planning exercise in the water sector initiated through WAPDA was the Water Sector Investment Planning Study (WSIPS) financed by UNDP under the administration of the WB. It was completed in 1990 with the following objectives:

- Develop a medium-term plan for the period 1990-2000;

- develop procedures and criteria for evaluating water sector projects and programmes to prepare rolling plans; and

- recommend specific proposals for upgrading the federal and provincial water sector planning institutions.

WSIPS comprehensively reviewed the achievements and experience on implementation of RAP. It identified the following main constraints in the development of the water sector:

- *Physical Constraints*: Water availability, waterlogging and salinity, drainage, flood control, and environmental protection.

- *Financial Constraints:* Timely availability of adequate funds for implementation of various projects.

- *Institutional Constraints:* Water apportionment, system operation, project preparation, project implementation, training of farmers, institutional interaction, role of agriculture/irrigation departments, and research.

WSIPS recommended: a basic investment plan of Rs.75 billion; an alternate plan including the Left Bank Outfall Drain (LBOD) and Pat Feeder as national projects of approximately Rs.118 billion; and a "maximum plan" of approximately Rs.155 billion if unlimited funds were available.

The Study recommended the following agenda for priority action:

- Management issues
- Water apportionment
- Improved irrigation management
- Environmental protection of the Indus basin
- Sector financing
- Cost recovery
- Institutional issues

The emphasis on institutional reforms and the need to bring closer the two important sectors of irrigation and agriculture, at least for perspective planning purposes, was given a practical shape when the Federal Planning Commission created a Joint Working Group for Irrigation and Agriculture in order to develop proposals for the 8th Five Year Plan (1993-98). This was a radical departure from the previous practice of preparing plans for the two sectors separately with little interaction.

6.7 National Environmental and Drainage Programme (1993)

In recognition of the crucial drainage issues, WAPDA commissioned a study with the objectives to:

- Provide a macro assessment of environmental effects of envisaged and on-going sub-surface and surface drainage programmes.
- Develop environmental and other criteria, processes and arrangements to facilitate preparation of a preliminary proposal of a design concept for an appropriate National Drainage Programme (NDP).
- Promote economic and sustainable development with appropriate environmental safeguards.

This study, "Pakistan-Drainage Sector Environmental Assessment – National Drainage Programme (NDP)", was carried out by a consulting consortium of M/S National Engineering Services of Pakistan (NESPAK) and Mott MacDonald International. WB acted as the Executing Agency, and Government of Japan provided the financing. The study was completed in June 1993, including a conceptual framework for a National Drainage Programme (NDP). The scope of work was later extended to cover the Feasibility Study of NDP, which was completed in May 1995.
The study recommended adoption of a sectoral approach to drainage. Previous experience had indicated that large, internationally funded projects needed a very long gestation period and required large local finances that affected the investment capacity of the Government to start other new projects. However, due to different reasons, new projects were also started and this resulted in a shortage of funds on all the on-going projects. Large projects therefore took a much longer time to

complete and tended to concentrate investment in a few favoured areas while projects in other areas, in greater need of drainage, were deferred due to funding constraints. Large drainage projects in Pakistan had generally suffered delays in completion, cost over-runs and inefficient O&M after completion. The delayed completion not only resulted in cost escalation and delayed benefits, but also often rendered these projects economically unfeasible.

According to the feasibility study of the National Drainage Programme (NDP) (May 1995), NDP would provide funds for: (i) expediting completion of the on-going projects that had suffered delays due to funding constraints; (ii) provide funds for schemes in areas requiring drainage on priority basis; (iii) improve performance of existing facilities through their rehabilitation and remodelling; and (iv) finance the O&M of selected large completed drainage projects through performance contracts.

NDP also envisages strengthening of the key institutions involved in the drainage sector and would encourage beneficiary participation in construction and O&M of drainage systems at the tertiary level. In addition to tackling the problem of drainage, its collection, and environmentally acceptable disposal, NDP would finance works in the irrigation sector aimed at reducing the seepage losses and therefore the drainage requirements, at a cost of $785 million (foreign exchange $525 million). These works include the modernisation and rehabilitation of selected canal systems and improvement of watercourses.

NDP was formally launched in 1998 with financial assistance from the WB, Asian Development Bank (ADB) and Japanese Government (OECF). The Programme objectives would be achieved through implementation of:

- Irrigation and drainage institutional reform.
- Drainage investment.
- Drainage monitoring, research and studies.

Pilot institutional reforms are underway, but it is too early to evaluate their effectiveness.

6.8 Institutional Reforms in Irrigated Agriculture (1994)

As recommended by WSIPS, a comprehensive study was carried out (Mellor and Asianics, 1994) on the institutional aspects of irrigated agriculture. This study identified the major constraints to efficient use of water in agriculture and analysed different components of the irrigation and agriculture sectors in order to identify the existing problems and recommend policy measures to improve the institutional aspects. In particular, the study presented a proposal to establish Provincial Irrigation Authorities that later formed the basis for a major re-organisation. Other aspects covered in this study were irrigation, cost recovery, water users associations (WUAs), agricultural education, and research and extension. Several sub-studies on specific topics related to irrigated agriculture were included. This study also involved a close association with important stakeholders, especially the irrigation and agriculture departments, economists, planners and farmers.

6.9 Cost Recovery

Many of the problems of the water sector have been identified in almost all the major reviews carried out so far, but remain, by and large, unresolved. One of the main issues is cost recovery. All past reviews concluded that the *abiana,* or water rates being charged from the farmers, are very low, particularly in comparison to the irrigation system costs of lower quality tubewell water; and in the light of the income received by farmers from increased crop production resulting from the irrigation supplies. The 1994 study on "Institutional Reforms to Accelerate Irrigated Agriculture" compared the costs of tubewell water which farmers purchase from neighbours, and canal water. It was concluded that, while farmers would willingly pay Rs.30 – 40 per $100m^3$ (acre-inch) for (inferior) tubewell water with a higher salt content and no silt, they would only grudgingly pay Rs. 0.74 per $100m^3$ (acre-inch) for canal water for rice and Rs.1.12 per $100m^3$ (acre-inch) for wheat. Thus, even a 5-fold increase in *abiana* rates would still mean much less expensive canal water as compared to the lower quality tubewell water. When farmers' representatives were confronted with these figures and the apparent irrationality in their insistence on not accepting the increased water rates, they emphasised that the availability of canal water was erratic and the flows so variable that they could not rely on its availability at critical crop production stages. The position has been further aggravated by the increasing inequity in surface water distribution in the distributary and water course commands. This results in excessive water diversion by the head-end farmers, either by bribing the field staff of the Irrigation Department or by coercive (political/physical/social) measures, to the serious detriment of tail-enders. It may be mentioned that the incidence of bribing the field staff has increased over the years, resulting in a major distortion of equitable distribution process. Thus, the effectiveness of surface water in crop production was drastically reduced, whereas tubewell water was available when needed and thus very effective in crop production. *This then is the crux of the matter*. If irrigation management is so improved that the supplies can be relied upon in terms of previously notified canal scheduling and quantities of water, then the farmers would find it a reliable input that gives them higher economic returns.

Most studies so far have recommended an increase in water charges to meet the rising costs of O&M of the ageing irrigation system. The major donor agencies for water sector projects, especially the ADB and the WB, have included a covenant to commit GOP to increase the water rates to at least recover O&M charges from water users. There has been a gradual increase in water charges in response to these pressures but successive governments have failed to implement the recommendations for full cost recovery because of strong political pressure from the farmers' lobby. The issue is indeed complex and has to be considered in the overall perspective of the production cost of various commodities incurred by the farmers and the prices of the output, compared to the international market prices. The farmers' lobby maintains that the agriculture sector is already subjected to so much indirect taxation (supporting the rest of the economy, in fact), that any substantial increase in direct taxation, through increases in water rates, or the imposition of agricultural income tax, would make farming totally uneconomical.

6.10 Participatory Approach and Creation of PIDAs

One of the major institutional issues has been the reorganisation of the Provincial Irrigation Departments and their linkage with the agriculture sector, especially the effective involvement of the Water Users Association (WUAs) in water distribution and related issues. The principal prevailing legislation for irrigation in the Punjab province (Canal and Drainage Act 1873) and Sindh Irrigation Act of 1879, on which the management of irrigation operations are based, do not provide for formal association of the water users. To facilitate this, the Punjab (1981) and Sindh (1982) WUAs Ordinances were issued, providing for formal organisation of WUAs and their *modus operandi*, at the water course level (but not at the distributary and canal levels which were later incorporated in the PIDA acts).

A major decision was taken in 1997 to promote improved integration between irrigation management and agricultural production through the involvement of water users, based mainly on the recommendations of the Institutional Reforms Study (JMA and Asianics, 1994). There were several important omissions from the original recommendations, however. These concerned mainly the measurement of irrigation supplies delivered from various outlets and the publication of the data in order to promote transparency; the provision of an ombudsman function that would receive complaints from the end-users and pass judgement on such complaints; and the strengthening of the in-house capabilities within the PIDAs with regard to the agronomic, socio-economic and environmental aspects of irrigated agriculture. The provincial governments of Punjab and Sindh promulgated the Punjab Irrigation and Drainage Authority Act 1997 (Annex 12) and the Sindh

Irrigation and Drainage Authority Act 1997 thus establishing PIDAs; NWFP and Baluchistan followed suit in 1998.

The main objective of PIDAs was to improve the working of Provincial Irrigation Departments (PIDs) through technical/financial autonomy with an integrated multi-disciplinary approach to irrigated agriculture. This new mechanism, though being tried on a pilot scale, is likely to further dilute the writ of already weak PIDs in an environment of a deteriorating governance situation in the country and large-scale misuse of authority, especially by the autonomous bodies.

6.11 Inter-provincial Water Distribution

Another issue that had often caused bitter disputes between the provinces was the inter-provincial distribution of irrigation water. This is a long-standing issue that emerged almost from the time when weir-controlled irrigation started in undivided India. The latest measure to resolve this thorny issue was Water Apportionment Accord (WAA) of 1991 between the provinces. To implement the Accord an inter-provincial authority at the federal level (IRSA) was created in 1993 under an Act of the Parliament (also see section 5.6.2.2).

6.12 Environmental Aspects and Legislation

Before the 1960s, the international funding agencies (IFAs) paid little attention to environmental parameters for regional economic development, planning or project feasibility studies. By 1975, however, environmental impact assessments (EIAs) of the projects were required. Because the EIAs utilised data from the feasibility studies, they were produced at a later date. From 1975 onward, however, the EIA was required to be included in each feasibility study as a separate chapter. From 1990 onward, comprehensive EIA was integrated into overall development planning at regional/project level. Consequently, all IFAs prescribed detailed environmental guidelines for development projects. For instance, in 1991, ADB issued "Environmental Guidelines for Selected Agricultural and Natural Resources Development Projects". Accordingly, the parameters to be covered during planning, construction and the operation of each project should include: effects on environmental resources and values; damage to the environment; and feasible recommended measures in mitigation. A specific assessment was also required regarding irrigation, fisheries and aquaculture, forestry land acquisition including resettlement, and coastal zone development.

To address the growing national/international concern with environmental issues, GOP promulgated the "Environmental Protection Ordinance" in 1983. This was later on passed by Parliament as an act during 1997. To oversee its compliance, a separate "Environment and Urban Affairs Division" has been created at the federal level, with Environmental Cells headed by directors-general in all the provinces.

On the ground, GOP is also paying growing attention to addressing the adverse environmental impacts of development. The recent example is the Ghazi-Barotha Hydropower Project. In this case, a comprehensive EIA is being followed by suitable mitigatory measures through implementation of an extensive environmental management plan under the oversight of NGOs. This includes a resettlement action plan and an environmental management plan.

6.13 Power Sector Policies

Since 1995, it has been the intention of GOP to move towards the creation of a competitive power market in the country. It proposes to do so through the following measures: restructuring and privatising existing thermal power generation, transmission and distribution functions, as well as the assets of public sector utilities (WAPDA/KESC); an autonomous regulatory body known as National Electric Power Regulatory Authority (NEPRA); and its future policy on Independent Power Producers (IPPs).

The NEPRA Act (XL of 1997) was approved by parliament and signed into law in December 1997. Consequently, an autonomous and independent regulatory authority was created with sole responsibility to oversee the power sector and exercise control through its mandate to license power generation, transmission and distribution. It would also regulate tariffs for all these activities and perform its functions through transparent processes.

Hydro-power is recognised as the least expensive mode of power generation, helping to keep power tariffs within affordable and economic levels for the domestic, industrial and agricultural consumers in Pakistan. The position in Pakistan has been further exacerbated by large capacity installation through very costly thermal IPPs. Therefore, the new Power Policy of the Government, announced in July 1998, prescribed that preference should be given to utilising hydro-energy for future expansion, with active participation of the private sector through IPPs.

Transformation of the power sector into a privatised, competitive electricity industry under oversight of NEPRA will be an evolutionary process likely to take a number of years. In the transition period, efforts are in hand to create an environment that facilitates the efforts of IPPs towards this end, particularly through hydro-power development.

6.14 Policy Evolution of Resettlement

WAPDA essentially used the resettlement experience based on resettlement undertaken after partition from India. The land acquisition act mentioned in section 3.10 was used as the essential policy instrument. Refinements have taken place since, and the Ghazi Barotha Project loan required the government to re-examine the whole issue of resettlement. The general principle now accepted is that the displaced persons must be resettled to a level that brings their livelihood as close as possible to the pre-displacement period. One outstanding issue to date is the definition of a legitimate affectee, especially in the case of downstream impacts. The debate on this issue is highly vocal, with major participation from NGOs with strong national and international networks, eg PNRDP.

Findings on Criteria and Guidelines

- The primary thrust of water sector criteria and guidelines was food security for a growing population and to ensure healthy growth of the agriculture sector as the main engine of economic development. Expansion of irrigation facilities was considered fundamental to achieving this objective.

- The initial policy of subsidisation of agricultural inputs, especially fertilisers and pesticides, which developed in the wake of the Green Revolution of the mid-1970s, was changed in the 1980s through the gradual removal of subsidies. This was a major policy change that resulted in increased cost of production to the grower and ultimately led to increased prices of agricultural commodities including wheat and other cereals. An Agricultural Prices Commission was established by GOP in 1981 to recommend floor prices of important crops in the light of production costs. A mechanism was also developed to ensure the enforcement of procurement of crops from farmers at government-approved floor prices.

- The Revised Action Program (RAP) of 1979 emphasised irrigation development as an important tool to improve agricultural production. It strongly recommended a comprehensive improvement of the institutional linkages between irrigation and agriculture, and the improvement of agricultural institutions (research and extension) to facilitate the more efficient use of the costly irrigation water. RAP stimulated the review of the institutional aspects to better co-ordinate irrigation and agriculture activities and look at the whole enterprise as irrigated agriculture.

- As a follow up of the Lieftinck Report (1968), RAP also recommended an 11-year development plan for 1979-90. Besides the investment plan, it strongly recommended a comprehensive improvement of the institutional linkages between irrigation and agriculture; and the reorientation of agricultural institutions (research and extension) to facilitate the more efficient use of costly irrigation water.

- The Water Sector Investment Planning Study (WSIPS) of 1990 further reviewed RAP including the status of its implementation. It developed a medium-term investment plan (1990-2000) along with specific recommendations for upgrading federal and provincial water sector planning institutions.

- The National Environmental and Drainage Programme (1993) recommended a sectoral approach to this sub-sector instead of the prevailing project approach. This led to a launching in 1998 of the National Drainage Programme (NDP).

- Cost recovery of irrigation services has been a highly controversial issue in Pakistan. There has been some increase in water rates in response to pressure from the major donors of irrigation works, but these increases have been inadequate to meet the O&M costs with the result that the vast irrigation system has gradually deteriorated and become progressively inefficient.

- Institutional change to integrate irrigation more closely with agricultural production and the water-users has been emphasised a great deal in governmental policies. The only tangible outcome has been the formation of WUAs at the water course level with defined functions, to help physically improve the water-courses and water use efficiency through appropriate management measures.

- As part of NDP, the Provincial Irrigation and Drainage Authorities (PIDAs) were established in 1998 with the objective to improve the working of Provincial Irrigation Departments (PIDs) through technical/financial autonomy. This new mechanism is being tried on a few pilot canal commands under PIDAs to see as to how it works. With the deterioration of governance mechanisms in the country and large-scale misuse of authority, especially by the autonomous bodies, there is apprehension that this experiment may lead to further deterioration of the already weak PIDs, and consequently of irrigation management.

- Under the National Environmental Protection Act (1997) an Environmental Affairs Division is functional at federal level with cells in all the provinces.

- GOP is moving towards the creation of a competitive power market in the country. It is proposed that this will be achieved through corporatisation/privatisation of the existing public sector utilities (WAPDA/KESC) and active participation of private sector. This would be under the oversight of the autonomous NEPRA established in 1997.

7. Lessons Learned

Issues raised herein are based on the extensive experience gained in the planning cycle of Tarbela, and about 23 years of its operation. There have been major political changes in the country since Tarbela was planned (11 major government changes) resulting in changes in priorities in the economic development process. Several of the water resources development, irrigation, and drainage projects included in the Lieftinck Report could not be taken up, resulting in distortions in the planned development of irrigated agriculture. In contrast, the Ghazi-Barotha Hydropower Project – a major new project – was conceived solely due to the presence of Tarbela and represents major changes in the approach to the design, including social, environmental and technical aspects.

7.1 Main Lessons Learned

Lessons learned from the Tarbela project for different aspects of the project cycle ie planning, design and construction, and operation and monitoring are described below. The lessons included in the boxes were reviewed and discussed at the second stakeholders meeting held in Karachi on 17-18 January 2000.

7.1.1 Planning

TDP 1	*Issue:* Predicting benefits from agricultural commodities
	Component of project cycle: Planning
	Lesson: The sensitivity of fluctuations in future production due to climatic factors and response to pricing signals and changing circumstances needs to be given more attention in the planning stage.
	Evidence: Increase in gross margins for wheat, rice and cotton over 1975-99. Higher input use (fertiliser, seed and pesticide).
	Views (convergent/divergent): The technocrats claim that, due to increased irrigation supplies, improvements in inputs and resultant yields and farmgate prices, the agricultural community has benefited significantly. The agricultural community, on the other hand, holds that exorbitant production costs and inefficient management of input supplies, especially irrigation, has reduced their net incomes.

TDP 2	*Issue*: Increased agricultural productivity due to irrigation development affects the land-owning and landless classes differently.
	Component of project cycle: Planning
	Lesson: Benefits of irrigation for agricultural production need to be targeted. Unequal distribution of benefits generates inequality amongst groups in specialised crop production systems.
	Evidence: While land owning classes in Mailsi (lower tributary command of Tarbela) have registered unprecedented growth in land values and rents, landless and working classes have become relatively poorer. The price of land in 1970-73 in Mailsi was Rs.42 000 per hectare, whereas the 1999 price was more than Rs.600 000 per hectare. Land rents also went up from Rs.1 700 in 1970-73 to Rs.17 000 per hectare in 1999.
	Views (convergent/divergent): Government planners are mainly interested in agricultural surpluses and the distribution of benefits is not given sufficient attention in project planning and design. At times, artificially high land values are not suitable indicators of the economy.

TDP 3	*Issue*: Increase in agricultural productivity
	Component of project cycle: Planning and Operations
	Lesson: Technical improvements through research and extension have a major pay-off through increased productivity and net incomes. This component needs to be incorporated in the plans at planning stage of major irrigation projects.
	Evidence: Cotton productivity recorded unprecedented growth during 1980-90 due to development of HYVs like the NIAB-.78 variety of cotton and improved agronomic practices. Use of modern inputs also doubled over this period.
	Views (convergent/divergent): Technology for increased agricultural productivity is often restricted to a few selected crops. An increase in cotton production was at the expense of extensive use of pesticides with adverse environmental impacts downstream. More sustainable and environmental friendly technology should be developed through increased governmental investment in agricultural education, research and extension, which is among the lowest in the world in Pakistan. Lack of balanced investment in science and manpower development slows the pace of economic transformation despite progress in individual sub-sectors.

TDP 4	*Issue*: Prediction of power benefits
	Component of project cycle: Planning
	Lesson: Planning of power production should take greater account of variability of production and its effect on the power system. Power benefits vary during dry and wet cycles, whereas for appraisal the average generation is used. Though in case of Tarbela, the predicted output was considered to be broadly stable from year to year, it has been variable in actual practice due to a variety of reasons.
	Evidence: Against the predicted average annual Tarbela generation of about 11 300 GWh, it actually varied between 3 400 (1978) and 15 100 (1998) GWh.
	Views (convergent/divergent): Variation between 3 400 to 15 100 GWh was quite large as compared to the prediction of 11 300 GWh. On the other hand, average annual generation so far, excluding the initial testing year, was 9 300 GWh or about 82% of predicted.

TDP 5	*Issue:* Costing and internalising of externalities
	Component of project cycle: Planning
	Lesson: Hydropower has a distinct comparative advantage in reducing CO_2 and other greenhouse gases emissions. This has substantial benefits in the regional/global context.
	Evidence: According to WCD methodology, estimated benefits of avoided emissions due to hydropower generation at Tarbela are about 72% of the direct economic benefits.
	Views (convergent/divergent): The actual benefits from reduced GHG emissions are probably much higher than the conservative figures used in this study based on the National Power Plan (1994) of WAPDA that uses the criteria for a highly efficient gas-fired thermal power station in the WAPDA System. Broad agreement on the values to be used is currently lacking. Having more realistic figures for comparison with average oil and gas-fired thermal stations would be useful for future planning. During a stakeholders discussion, this lesson was challenged by a number of participants who considered that there could be significant emissions from reservoirs and that any benefits on the emissions side should not be used to balance other negative environmental impacts of dams.

TDP 6	*Issue*: Definition of in-stream flow requirements
	Component of project cycle: Planning
	Lesson: Pre-project base-line knowledge of the river ecosystem and environmental parameters is essential to draw any meaningful inference for project planning and to design in-stream flow requirements.
	Evidence: Due to complete lack of any specific requirement guidelines, there was no EIA or appraisal at the time of conception or subsequent re-evaluation. There are no data available on the past or even the present environmental status, although there is evidence of adverse environmental impacts in downstream areas, especially on the mangroves in the Indus delta. Sea water intrusion, due to reduced flows in the river resulting from upstream diversions for progressive irrigation development, also took place.
	Views (convergent/divergent): The downstream adverse environmental impact is the cumulative effect of progressive upstream water abstractions, specially since the construction of Sukkur Barrage in 1932 and was further accelerated by Kotri barrage since 1955. Therefore, it is unfair to attribute this to a single project like Tarbela. The other view is that this has largely resulted from Tarbela.

TDP 7	*Issue:* Project phasing and predicted benefits
	Component of project cycle: Planning
	Lesson: It is desirable to undertake independent reviews of large projects to confirm feasibility and full options assessment before the start of implementation.
	Evidence: Though in initial planning, phased development of Tarbela storage capacity was considered, the final decision was for its full development in a single phase. However, the development of power was to be phased in keeping with increasing energy needs. This decision proved instrumental in completion of the storage part of the project despite serious technical/financial problems. an initial tentative evaluation of Tarbela indicated an EIRR of only 6%. However, subsequent reviews and careful re-evaluation by the World Bank for single stage development enhanced the EIRR by between 9–13%. This was based only on the direct water (storage) and power benefits without considering the social and environmental costs and the cost of additional requirements for drainage.
	Views (convergent/divergent): Engineering studies tend to over-estimate the benefits and depress the cost. Tarbela estimates had also to be revised several times creating considerable anxiety amongst decision-makers, including lining up of additional funding. On the other hand, it is contended that over-runs in Tarbela costs was basically due to unanticipated structural problems and the resultant repair/remedial measures required. Furthermore, actual direct benefits so far have been greater, establishing thereby that original estimates were conservative. There were contrasting views on this point during the stakeholders discussion but most agreed that planning stages need careful phasing to ensure that social and environmental concerns are adequately addressed.

TDP 8	*Issue:* Project phasing
	Component of project cycle: Planning
	Lesson: For large projects like Tarbela, phasing is sometimes necessary due to funding and other constraints. However, preferably, it should be avoided lest the changing context may lead to the dropping of subsequent phases, particularly during implementation. (There were contrasting views on this point but most agreed that planning stages need careful phasing to ensure that social and environmental concerns are adequately addressed.)
	Evidence: The original design of Tarbela was based on resources to become available from TDF. Later, various components were changed or delayed, such as power capacity, and delays in establishing monitoring units due to funding limitations and phasing.
	Views (convergent/divergent): Difficult to correctly estimate funding requirements of such large projects. Phasing not by design but due to lack of resources. Often planning took adequate consideration of the long-term development path of the economy.

7.1.2 Design and Construction

TDP 9	Issue: Impacts on lower riparians
	Component(s) of project cycle: Design
	Lesson: Developments within a basin context must recognise the broader implications of upstream project development. The quest to harness water resources must be sensitive to impacts on lower riparians. This can have far-reaching socio-economic and political ramifications. Water requirements of the Indus delta must be viewed in a wider policy framework to mitigate massive ecological imbalances.
	Evidence: Field hearings in Sindh (Ibrahim Hyderi) and Keti Bandar reveal the plight of the Indus delta. NGOs and e-mail traffic through the media highlight the problems that have been created because of reduced flows below Kotri.
	Views (convergent/divergent): Tarbela dam made little contribution to reduced flows below Kotri which were due mainly to other works like Mangla dam and Kotri barrage. There is a strong NGO lobby that supports the need to recognise and compensate inhabitants in the delta region that have been impacted by upstream developments.

TDP 10	*Issue*: Water quality at downstream locations
	Component of project cycle: Design
	Lesson: Some downstream water quantity and quality concerns especially below Kotri, can be addressed by maximising storage releases from the dams under favourable inflow conditions. Besides improved hydropower generation, it would help to reduce cumulative impacts of the dams on the riverine ecosystem.
	Evidence: The cumulative consequences of upstream diversion in the Indus basin for irrigation/storage have adversely affected the dry season water quality, particularly below Kotri.
	Views (convergent/divergent): This is not a critical concern in the case of Tarbela as the below-Kotri releases have not been significantly reduced after construction of Tarbela. It is, however, essential that new reservoirs should maintain minimum essential downstream flows in order to minimise negative impacts on the ecosystem. Some participants among the stakeholders disagreed with this lesson as this practice might compromise irrigation releases.

TDP 11	*Issue*: Compensation and resettlement
	Component of project cycle: Design and Construction
	Lesson: Compensation and resettlement policies must be discussed with the targeted affectees through a process of participatory consultation. Care should also be taken to identify and adequately benefit the genuine affectees, especially the landless tenants, traders and artisans, etc.
	Evidence: Reportedly, over 11 000 unresolved claims have been lodged to date, although the majority have been deemed to be inadmissible. Lack of well-documented procedures, presented in a way that could be understood by an illiterate population, was primarily responsible for certain groups losing and others gaining from this opportunity. Rapid changes of property ownership create disharmony and require sufficient advanced planning through consultation. However, since the planning/construction of Tarbela, reforms have been implemented and guidelines are being reviewed and updated. The latest evidence is the model being followed on the under-implementation of the Ghazi-Barotha Hydropower Project.
	Views (convergent/divergent): The implementation agency feels that the best possible efforts were made to deal with a very complex issue, despite the refusal of Sindh province to allot irrigated lands to about half of the land affectees. The measures included: liberal cash compensation; establishment of hamlets on the reservoir periphery to settle the displaced persons; and provision of access roads to facilitate communication and other developments. On the other hand, the affectees feel that they received unfair treatment at the hands of WAPDA, which is the basic cause of lingering unresolved issues.

7.1.3 Operations and Monitoring

TDP 12	*Issue*: Accommodation of changing legal framework
	Component(s) of project cycle: Operations and Monitoring
	Lesson: Major disputes (international/national) on distribution of river water should be resolved before embarking on large water-harnessing projects.
	Evidence: Timely resolution of Indo-Pakistan water dispute through IWT averted potential serious conflict. On the other hand, an ad-hoc distribution of Tarbela storage had to be carried out over 17 years (1976-93) due to the non-resolution of inter-provincial water disputes.
	Views (convergent/divergent): As water is the life blood of the rural economy, it is an eternal cause of disputes, which take time to resolve. On the other hand, these need to be given timely attention to avoid disastrous situations (IWT is a case in point).

TDP 13	*Issue:* Reassessment of project operation
	Component(s) of project cycle: Operations and Monitoring
	Lesson: Project O&M activities must be established at the onset of the project along with adequate funding. These operations must be integrated within overall national/provincial planning systems to accommodate differences between predicted and actual conditions and changing circumstances and priorities.
	Evidence: O&M of Tarbela, though well planned, required implementation under intense and close supervision backed by adequate logistical and funding support. This, unfortunately, was not the case during the initial serious problems at site, when most of the funds had to be diverted for special repair/remedial works. This funding constraint negatively affected O&M but the position somewhat eased later with the arrangement of $35.4 million by the WB. In the meanwhile, the essential O&M facilities, including equipment due from the main contractor, also became available, including adequate budgeting by WAPDA.
	Views (convergent/divergent): Except for the initial problems, the project was well operated and effectively contributed towards achieving its objectives of making available additional canal water during low flows and providing large amounts of hydropower. On the other hand, it is contended that the adverse environmental and sociological impacts of the project have been quite severe.

TDP 14	*Issue:* Monitoring achievement
	Component of project cycle: Operations and Monitoring
	Lesson: Monitorable targets are required for project objectives including rural and national development and an appropriate monitoring system should be established. Normally, macro project objectives such as "improving rural economy" and "promoting national development" are impossible to evaluate post-hoc unless targets are set, and a deliberate monitoring system is designed and implemented.
	Evidence: Authentic data on the social and environmental impacts of Tarbela have not been collected through systematic monitoring. However, the sample surveys conducted in this study have brought out some supportive evidence. As regards engineering, and technical and safety aspects of the project, extensive monitoring arrangements were designed and implemented. This activity has, in fact, significantly contributed to the state-of-art of design, construction, restoration and repair of seriously damaged infrastructure; and efficient operation and safety monitoring for projects of this type and size.
	Views (convergent/divergent): Lack of data on certain issues leads to a sterile, politicised debate as proponents and opponents are unable to defend their qualitative appreciation of the project situation. This study has attempted to address the issue through sample surveys. As regards technical monitoring/evaluation, the model of TDP could be adopted for similar large and complex projects.

TDP 15	*Issue*: Post-project evaluation	
	Component of project cycle: Operation and Monitoring	
	Lesson: Even when no formal post-project evaluation is intended, periodic in-house performance reviews are helpful for ongoing planning and decision making.	
	Evidence: The historical data available to this study was limited and sometimes conflicting, particularly in the social and environment sectors. The study included rapid sample surveys, which provided useful information. The performance of TDP did figure in WAPDA's post-project planning exercises of RAP (1979) and Water Sector Investment Planning Study (1990). It was of considerable value in informing decision-makers and wider interests on the range of issues and options for future reference.	
	Views (convergent/divergent): Some aspects of the experience with large projects are captured in ongoing policy and planning work undertaken by ministries and development agencies. However, opportunities for seriously assessing experience with large projects are lost in the absence of an independent and rigorous post-project evaluation. Rigorous post-project evaluation and appraisal arrangements should have been incorporated at the planning stage of Tarbela. In cases where such arrangements are not in place, some useful information can still be captured through rapid sample surveys as in case of this study.	

TDP 16	*Issue*: Post-project planning
	Component of project cycle: Monitoring and Post-planning
	Lesson: Post-project impact monitoring can help identify, assess and rectify unforeseen adverse impacts of the project that may occur over the longer term or to identify opportunities to enhance positive impacts of the project. Such monitoring and post-planning also provides a basis for new operational criteria, standards and regulation.
	Evidence: Tarbela is almost 25 years into operation and debate about its useful life continues. Downstream ecological impacts are often partially attributed to Tarbela. Options for enhancing the usefulness of Tarbela and ensuring sustainability of the Indus Basin System are continuosly debated and the subject of study. Issues related to large variances in the predicted O&M costs of the original design compared to the actual costs, point to the need for more rigorous evaluation of strategies in the post-Tarbela period.
	Views (convergent/divergent): The technocrats and development specialists feel that Tarbela has served its purpose well and there is not much to learn in the post Tarbela period. Few lessons have been taken to heart to alter the course of events related to the dam. The divergent view is that in the context of such a large investment the usefulness of the dam must be enhanced – in particular on the cost recovery and water management side. To date, there is no clear strategy on how to incorporate the experience of Tarbela into a cohesive future plan. Such a debate is marred by political implications, and lacks the facilitation role or leadership required to resolve one of the most crucial issues facing the nation.

7.2 Stakeholders' Evaluation of Lessons Learned

Feedback from the participants in the stakeholders' meeting at Karachi (January 17-18, 2000) was obtained through a questionnaire. There was considerable discussion on individual lessons with areas of agreement and disagreement. There was broad agreement on many of the lessons, although three (5, 8 and 10), generated a number of differing views. This was partly due to the original formulation, which has now been clarified. However, a number of participants were concerned over how these lessons might be used in the future planning of dam projects in Pakistan and consequently preferred to reserve their judgement.

Proposals for Additional Lessons Learned

Additional proposals were made by the participants of the stakeholders' meeting in Karachi when asked to rate the lessons learnt, and to propose additional lessons that could be learnt from the study. They were not discussed at the meeting due to time limitations. Only the titles of the proposals received are listed, without elaboration:

Policy

- National resettlement policy is required prior to major projects being implemented and steps should be taken to ensure implementation capacity.
- Implementation of resettlement policies needs to be ensured through greater participation and involvement of affectees.

Planning and Design

- Environmental costs should be internalised.
- Costs of ancillary facilities such as canals should be incorporated, and costs of agricultural inputs should be included when comparing benefits.
- Outline design of main elements should be open to review.
- Affectees should include directly and indirectly affected people, and compensation provided to indirect affectees.
- Distribution of costs and impacts needs greater attention.
- Losses should be internalised.
- The effect of a project, (including reduced flows, water quality and reduced sedimentation), on livelihoods in the downstream river and delta, should be taken into account.
- The importance of drainage needs be fully accounted for as a cost of irrigation projects.
- Negotiated settlement of water disputes is preferable.
- Planning of water allocation should not be based on mean flows, as variability needs to be planned for.
- Favour more conservative design and construction to reduce the risk of cost overruns and delay.

- The risk of financial overruns needs improved analysis (financial hazard).
- Aspects that are at frontiers of knowledge should be fully researched and independent reviews carried out.
- Targeted attention should be given to the impacts and benefits for women.
- Mechanisms are needed to identify and resolve secondary social impacts of the project.
- Better information needs to be provided to all stakeholders on the project and its overall benefits.
- Water losses should be reduced through canal lining.

Operation Phase

- Major projects can fail if the distribution of water is not settled – even where there is a permanent responsible body (IRSA).
- Post-resettlement follow up is necessary.
- Operate the reservoir to gradually reduce trapped sediment.
- Real-time data collection for river quantity and quality should be made widely accessible to stakeholders.
- The operator, (WAPDA), should be privatised.
- Affectees should be directly involved in maintenance of the project and increased ownership developed.
- Independent reviews should continue through operation phase to incorporate prudent changes over time.

Mitigation

- Studies/commissions needed for resolution of downstream water quantity and quality concerns, and impacts on people, including the payment of reparations for negative impacts.

8. Stakeholder Views on Development Effectiveness

8.1 Stakeholder Views

8.1.1 Views obtained during the fieldwork of the study

As part of the data gathering exercise, various categories of stakeholders were consulted to determine the effectiveness of Tarbela dam on regional and national development. Details of the various groups consulted are given in Annex 10 on 'Methodology'. Over 900 individuals were consulted in one or another context related to the dam through formal questionnaires, mail-in questionnaires, group discussions, open hearings, individual interviews and workshops. The cumulative findings of these stakeholder consultations are briefly summarised in this section in relation to the specific questions posed in the questionnaire.

1. Whether Tarbela has led to extensive development?

The widespread consultation revealed a broad consensus on the development contribution of Tarbela. The majority of the stakeholders, including land-owners, tenants, farm workers, artisan classes, government officials, private sector, and NGOs said that Tarbela had made a highly positive contribution to the national economy with special reference to the electricity and irrigation benefits. In particular, agriculture gains in the southern Punjab and upper Sindh were attributed to Tarbela Dam. All groups consulted also said that while individual gains and losses varied, the country as a whole continues to benefit from Tarbela, in the form of water stored to support irrigated agriculture and power generation.

2. How far are the negative consequences of Tarbela acceptable, considering the benefits of the project to the region and the economy as a whole?

There was no overall consensus on this issue partly because detailed information on all the negative externalities is not available. Often the debate centred around individual viewpoints, suppositions, and, at times, outright provincial sensitivities – the latter often extending beyond the Tarbela debate. There is ageneral feeling that the electricity produced by Tarbela benefited the whole economy including the rural and urban areas. Some regions, especially inhabitants below Kotri, feel that the dam affected them adversely due to a reduction in the river flows. Similarly, the displaced persons have individual grievances. Even some of those that consider Tarbela to have impacted them negatively, concede that the dam has helped contribute to the economic development of the country.

3. Did the construction of Tarbela foreclose other options that could have been more effective than Tarbela?

Most stakeholders debated the preference for Tarbela over other options. An initial option proposed by the World Bank, was to raise the level of Mangla, but it was rejected outright as it did not provide even the bare minimum replacement requirement for the water loss to India. Another option was to build a dam at Kalabagh. In this case also, the option was dropped, as its engineering preparedness was much behind that of Tarbela. Some stakeholders felt that "no dam should have been built at all", often not realising the gravity of the conflict with India. A majority changed their viewpoint once they became aware of the grave implications of the lack of a treaty with India. Some stakeholders also informed the study team that Tarbela was the most realistic option. However, many attributed construction of Tarbela to the sole discretion of Field Marshal Ayub Khan who took the final decision to build the dam. It is said that since the President belonged to the area, there might have been a motivation to benefit his constituency.

4. Do you feel that long-term impacts cannot be fully assessed unless the externalities of the project, like displacement of population and impacts on the ecosystem, are internalised in the project costs and benefits?

Responses to this question were varied, depending on the background of the stakeholders. Most agree to the notion that there are negative impacts on the eco-systems and directly attributable social costs. Since the beneficial aspects have been pre-eminant in the minds of most respondents, they have less knowledge about the cost side. There is, however, a feeling that for long-term planning more realistic estimates on the externalities and their true costs are needed. Some respondents, while appreciating this concern, stated that several hundred dams were built in the United States alone that involved major social costs. Since the Western countries have already acquired major development and economic benefits in spite of considerable social costs, why should they question the poorer countries when they undertake similar projects? The overall viewpoint on this question points to the need for better analysis and quantitative information to ascertain the impacts of externalities. However, some stakeholders cautioned that this concern for social and environmental costs by some of the developed countries is a ploy to deny financial assistance for such projects from bilateral and international sources. There was uneasiness on "waiting period" cost and who should pay for it when it came to incorporating social and environmental concerns.

5. Were major project decisions made in an equitable manner?

Many consulted on this question said that this aspect was neglected when the major decision of whether or not to build a dam of the size of Tarbela was made. Most of the displaced stakeholders stated that they were never consulted about the development of this project, or other better alternatives to achieve the same objective. However, when government officials were approached, they based their comments on official records and stated that compensation issues were intensely debated between the various concerned organisations and the compensation criteria were established on prevailing rates for acquisition of private property for public purposes. Most upstream affectees stated that they were not associated with decision-making about the construction of the dam, or procedures for resettling the affectees and payment of compensation, which, they felt, was inequitably treated. Though initial distribution of Tarbela storage was achieved on an ad-hoc basis, it was approved by GOP season-to-season after due consultation/consensus of the province. Later on this was resolved through the Water Apportionment Accord (WAA) of 1991.

6. Was there compliance with applicable policies and laws of the day?

All rules and regulations and government procedures were faithfully followed during the implementation of the project. Project-related policy issues were examined by the Federal Ministry of Water and Power, and the approval of the competent authority was obtained, wherever necessary. Furthermore as the WB was administering the TDF, it ensured strict compliance with its prescribed procedures. Some stakeholders felt that although various compensation awards to the affectees were made on the basis of the prevalent rules and regulations, delays have meant that the introduction of new laws and regulations have negatively impacted on still unsettled displaced groups. Strong disagreement and vocal resentment has been expressed about the resettlement issue by the affectees, even after such a long lapse of time. There has been a considerable "learning phase" for the builders of the dam and consequent shifts in viewpoints regarding adherence to laws established with a long-term historical flavour.

7. Did the project deliver significant development benefits to: the local area around the dam; the regional economy; and the national economy?

All groups consulted felt that the project had generated significant irrigation and hydropower benefits with varying impacts on different groups. The benefits for the regional and national economy were conceived as highly positive, with the exception of certain segments of the population in the lower Sindh which blamed Tarbela for reduced water flows to downstream areas affecting fishermen's livelihoods, mangroves, and increased salt water intrusions. Stakeholders around the dam felt that while new townships were developed, those who had been provided lands in areas like Faisalabad did not gain in any significant manner. Most stakeholders stated that the regional and national economy had benefited from the direct outputs of the project and through multiplier effects on the economy.

8. Was the project poorly planned with the benefits accruing mainly to the inhabitants of a small region, rather than to all the inhabitants of the basin or the country, while the cost over-runs related to the project were borne by all the taxpayers?

The project was considered well planned within certain known risks because of the geophysical aspects of the site. Most cost over-runs occurred because of the extensive repairs and restoration of damaged infrastructure after the initial test filling in 1974. Some stakeholders also mentioned the opportunity cost of this project, including delayed start-up of other competing projects. There was, however, general belief that the national and regional benefits far surpassed the expectations. The hydropower benefits reached far-flung areas of urban and rural centres. The irrigation benefits, while immediately evident to the users of the increased surface water, also generated benefits to those areas like NWFP and Baluchistan that import surplus food from Sindh and the Punjab. Most respondents stated that that the dam helped to reduce poverty in the country. Most thought that the dam should have been built, but the inhabitants surrounding the reservoir said that they should be given a fair share of the benefits in return for the sacrifices they and their families had made. If projects adequately compensate for social and environmental costs, their execution can be justified in the national interest.

9. What do you perceive as the major adverse consequences of Tarbela?

Several stakeholders expressed concern in regard to: the policies and procedures adopted for resettlement of the displaced persons; the adverse environmental and economic consequences for the population downstream of Kotri, especially the fishermen communities; and the adverse environmental consequences for the ecology of the riverine areas.

8.1.2 Discussions during the stakeholders meeting in Karachi

The issue of the development effectiveness of Tarbela dam was discussed during the break-out groups and in plenary sessions during the stakeholders meeting in Karachi on 17-18 January 2000. There was a general agreement that the dam had provided relatively inexpensive electricity badly needed by the country. There were, however, divergent views about the irrigation component of the dam. It was agreed that the dam had provided assured irrigation supplies that compensated for the allocation of water from the three eastern rivers to India, besides providing additional supplies for an expansion of irrigated agriculture that helped increase food production in the country and provided a measure of food security. However, several participants pointed to the increased incidence of salinity and waterlogging, and to the inequitable distribution of the benefits of the additional irrigation supplied to different categories of farmers, which they ascribed to the development of large dams like Tarbela.
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Several participants also alluded to the negative impacts of Tarbela, especially on the communities displaced by the dam, who were not effectively resettled for a long time. The inhabitants of the Indus delta areas also suffered because of increased salinisation of drinking water, negative impacts on agriculture and pasture lands in the area, and the intrusion of sea water due to reduced river flows. There was a general agreement that the population in the areas below Kotri, who had been negatively affected due to reductions in river flows as a result of Tarbela dam, Kotri barrage, and other upstream developments, deserved to be treated as affectees and adequately compensated.

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