

**PERFORMANCE EVALUATION OF TAUNSA BARRAGE  
EMERGENCY REHABILITATION AND  
MODERNIZATION PROJECT**

**S.M.A. Zaidi, Mehr Muhammad Amin, Muhammad Ajmal Ahmadani**



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Engr. Syed Mansoob Ali Zaidi<sup>1</sup>- P.E., Engr. Mehr Muhammad Amin<sup>2</sup>- P.E. &  
Engr. Muhammad Ajmal Ahmadani<sup>3</sup>- P.E.

## SYNOPSIS

Taunsa Barrage located on Indus River at about 39 km south of Taunsa Sharif town and 16 km north west of Kot Adu was constructed from 1954-1958 to provide weir controlled irrigation supplies to originally flood fed areas on both banks of the river alongwith some new lands in Thal desert area. This Barrage serves 2.351 million acres (951,400 hectares) besides diverting flows from Indus River to the Chenab River through Taunsa Panjnad (TP) Link Canal. The barrage also serves as an arterial road bridge, a railway bridge, and crossing for gas and oil pipelines, telephone line and EHV transmission lines.

The barrage soon after its completion in 1958 ran into multiple problems like oblique right sided river approach to the barrage causing heavy siltation in DG Khan canal with reduction in its capacity, excessive retrogression of water levels on the downstream, damage to stilling basin floor, breakdown of subsurface flow monitoring system and defects developing in mechanical installations. Extensive repairs were carried out during 1959-62 and periodically thereafter and in 2003 the latest, but problems persisted. Punjab Government constituted committees of experts in 1966 and 1973 but no specific measures, were taken to address the problems that continued to aggravate.

Evaluation by Consultants engaged to review health of the barrage indicated the need for major rehabilitation works. An Expert Group recommended some major rehabilitation works in 1999 to obviate sudden collapse of this key structure of paramount importance. Finally a feasibility study was completed in June-July 2004 which proposed remedial measures.

The World Bank indicated their willingness in April 2004 to finance the Project. Consequently the Taunsa Barrage Emergency Rehabilitation and

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<sup>1</sup> Project Coordinator, Punjab Barrages Consultants Technical Advisor & Associate, National Development Consultants

<sup>2</sup> Ex-Chief Engineer, DG Khan Zone Punjab I&P Deptt

<sup>3</sup> Senior Engineer Quantity and Contracts, NDC Lahore

Modernization Project was put on fast track and implemented from May 2005 to December 2008. Project accounts were finally closed on April 30, 2010.

This paper presents the introduction to the history of Taunsa Barrage, the problems, their impacts, proposed remedial measures, design and construction of works and finally evaluation of performance of the project, after 4 years of completion which is a total success story of the project implementation.

## **INTRODUCTION**

Barrages play a pivotal role in providing sustained irrigation supplies to millions of acres of fertile land in the country and specially Punjab Province. Several Barrages were suffering from aging, hydraulic, structural and sedimentation/retrogression problems. Some Barrages and Headworks including Taunsa were endangered by multitude of problems and their overall safety was threatened.

### **Background and History of the Taunsa Barrage Project**

Taunsa Barrage Project was initially conceived in 1936 and after passing through many vicissitudes was sanctioned in 1953. Construction also commenced the same year. The project was commissioned in 1958 and formally inaugurated in March 1959. The evolutionary history of the project is very interesting and provides extremely useful information to the staff managing and operating barrages and specially this complex structure.

### **The Taunsa Barrage**

The Taunsa Barrage, built across Indus River is located at about 16 Km from Kot Addu, with location coordinates of 30° 31' N 70° 51' E. The Barrage has 65 bays with a total width of 4,346 ft between the abutments. Width of each bay is 60 ft except for bay No. 8 which is 22 ft wide and serves as navigation lock. Bays No. 9 to 61 constitute main weir and there are two sets of undersluices (bays No. 1 to 7 and 62 to 65) separated from the weir by two divide walls at left and right flanks. The Barrage has 2 fish ladders each 11 ft wide alongside these divide walls.

The barrage initially fed Muzaffargarh and DG Khan canals system. The former was completed in 1960 and is in operation since then, while the latter although opened in 1958 continued to remain under construction in some later years. TP Link canal was added in 1970, as a component work of the Indus Basin project

Taunsa Barrage is the most important barrage amongst those built across the mighty Indus and it commands large areas in Punjab and Balochistan provinces. Three canals namely Muzaffargarh, DG Khan and TP Link canals off-take from this Barrage, Muzaffargarh and TP Link canals from the left flank of the Barrage while DG Khan is on the right flank. Recent construction of head regulator of Kachhi canal on right flank will enable a withdrawal of 6000 cusecs for irrigation of Kachhi plain in Balochistan. TP Link conveys Indus River water to Chenab River to supplement irrigation in Panjnad command during shortage period.



*Figure 1:* Upstream View of the Barrage

### Functions of the Barrage

The functions of a conventional Barrage are:

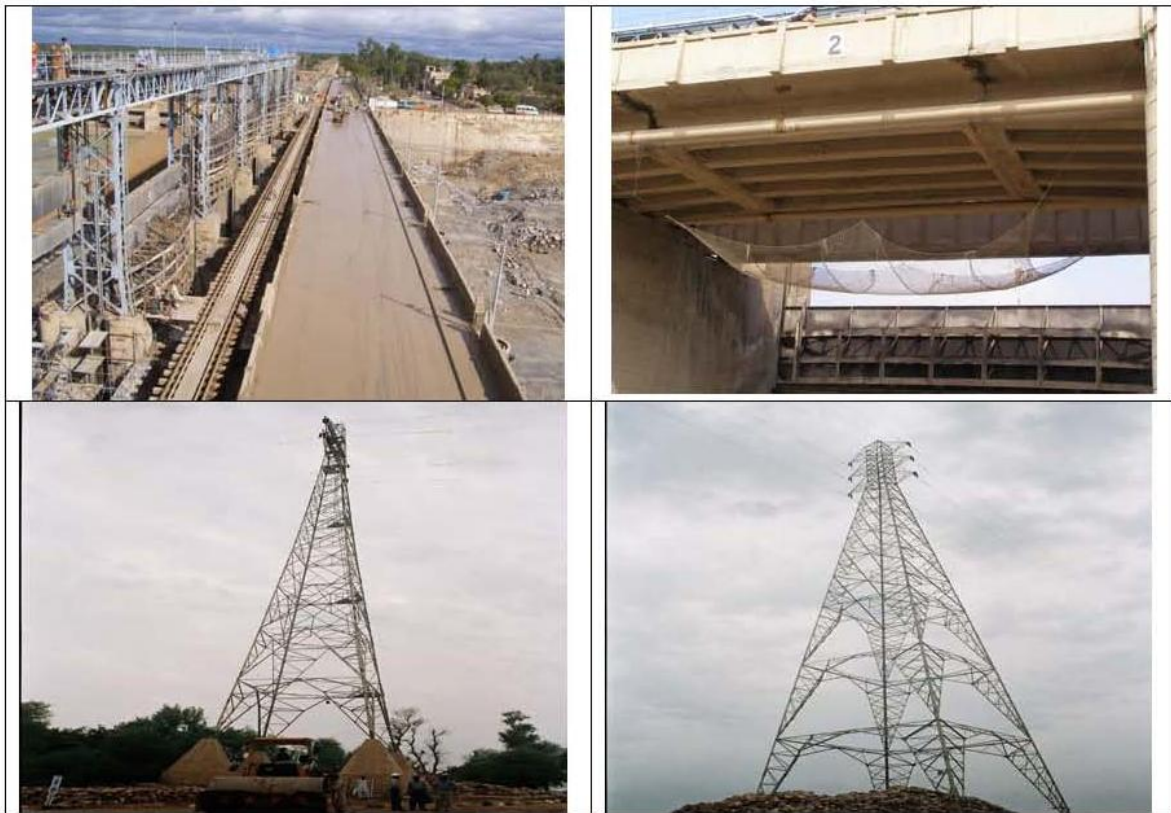
1. Raising water level in the river to an extent required for feeding the off-taking canals;
2. Pinning down the river at one location and to facilitate transportation needs;
3. Regulation and control of the river flows.

But Taunsa Barrage is more than a conventional Barrage because It provides the following:

- i) Irrigation facilities to areas in Muzaffargarh, DG Khan and Rajanpur Districts (2.35 million acres);
- ii) Accommodates a trans Indus rail road link between Kot Adu on the left bank and DG Khan, Rajanpur and Kashmore on the right bank of Indus River;

- a) A Class 70/AA loading Arterial Road Bridge;
  - b) A 16 inch dia high pressure pipeline owned by PARCO for conveying petroleum products from Karachi to the up country storage at Mahmood Kot terminal carried on top of downstream end of the piers.
  - c) A 16 inch dia high pressure natural gas pipeline conveying natural gas from Dhodak gas field to KAPCO and serviceable areas on piers under the roadway deck.
- iii) Facilitates two single span EHV transmission line crossings (Figure-2).

Taunsa Barrage is thus a truly multipurpose complex.



**Figure 2:** Transport and Energy Infrastructure Accommodated by the Barrage

**Table-1:** Original Design Data of Taunsa Barrage

|   |                            |
|---|----------------------------|
| Maximum flood discharge                             | 1,000,000 Cusecs           |
| Normal Pond level upstream                          | 446.0                      |
| Highest flood level upstream & emergency pond level | 447.0                      |
| Highest flood level downstream                      | 444.0                      |
| Left Undersluice (Bay No. 1 to 7)                   | 7 No. of 60 ft. span each  |
| Right Undersluice (Bays No. 62 to 65)               | 4 No. of 60 ft. span each  |
| Weir (Bays No. 9 to 61)                             | 53 No. of 60 ft. span each |
| Navigation Lock Channel (Bays No. 8)                | 1 No. of 22 ft. width      |
| Fish ladders  | 2 No. of 11 ft. width each |
| Width of pier and divide walls                      | 7 ft. each                 |
| Total width between flanks                          | 4346 ft.                   |
| Crest RL in the undersluice Bays and navigation Bay | 425.0                      |
| Crest RL in the weir Bays                           | 428.0                      |
| upstream floor RL in the undersluices               | 419.0                      |
| upstream floor RL in the weir                       | 421.0                      |
| downstream floor RL in the undersluice section      | 415.0                      |
| downstream floor RL in the weir section             | 416.0                      |
| Total length of impervious floor                    |                            |
| i) Undersluice Bays                                 | 238 ft.                    |
| ii) Weir Bays                                       | 233 ft.                    |

### Identification of Problems and Proposed Remedial Works

A feasibility study conducted by Punjab Barrages Consultants (PBC), a joint venture of NDC and NESPAK in association with M/s Atkins (Global) of UK, confirmed the need for an immediate rehabilitation of the Barrage to restore its designed functions in July 2004. The feasibility study was also reviewed and supported / endorsed by an International Independent Panel of Experts (POE) comprising international and national experts.

## Project Need and Objectives

Based on the facts and recommendations contained in the feasibility report, the need for rehabilitation and modernization of the handicapped Taunsa Barrage was established with the following objectives:

- a) Restoration of the discharge capacity of the barrage which had been reduced to about half the design value due to serious retrogression of levels and consequent reduction in conjugate depth (depth in stilling basin “y<sub>2</sub>”) resulting in the exposure and washing down of hydraulic jump.
- b) Minimize the sediment entry into DG Khan canal to restore the discharge capacity and obviate the need of repeated flushing closures.
- c) Restore and improve the uplift pressure monitoring system of peizometers.
- d) Improve the defective drainage behind the flared out walls to enhance the stability by stopping repeated subsidence of the backfill.
- e) Restore the structural health of the stilling basin floor.
- f) Rehabilitate and improve the regulation gates and gearing system without creating environmental, ecological and social issues.

The following table depicts the problems and remedial measures proposed for meeting the project objectives.

**Table 2:** Problems and Proposed Remedial Works

| Sr. # | Problems   | Proposed Remedial Works/Solutions   |
|-------|--|---|
| 1.    | Retrogression of levels on the D/S of Barrage and consequential issues including reduction in Barrage capacity           | Construction of a subsidiary weir 925 ft D/S of the Barrage to raise tail water levels to safe elevation.   |
| 2.    | Repeated damages to stilling basin appurtenances including rupture of skin concrete and leaking joints of mass concrete. | Grouting of leaking concrete and cavities in or underneath the D/S floor, removal of existing shattered skin and new concrete overlay with nominal reinforcement. |
| 3.    | Sedimentation problems in DG Khan canal  | Construction of silt excluder in the U/S right pocket, raising crest of head regulator.   |
| 4.    | Repeated subsidence of the backfill of left and right flared out walls on the downstream.                                | Provision of a proper filter drainage and effective seepage control.  |



| Sr. # | Problems  | Proposed Remedial Works/Solutions  |
|-------|---|--|
| 5.    | Choking of about 80% of pressure pipes and mal-functioning of the remaining 20% | Provision of vibrating wire piezometers in 10 bays of the Barrage and 7 rows in the new subsidiary weir.   |
| 6.    | Problems associated with gates structure, their operation, and hoists           | <ul style="list-style-type: none"> <li>• Replacement of undersluice gates.</li> <li>• Rehabilitation of main weir gates.</li> <li>• Replacement and rehabilitation of Canal Head Regulators Gates.</li> <li>• Electrification of existing hoists</li> <li>• Automation of gates with Central Control System for better regulation of flows.</li> </ul> |

## Project Formulation and Financing

PC-1 Form of the Project was initially approved by ECNEC on December 07, 2004. In May 2005, the World Bank (IBRD) helped launch the construction phase of Taunsa Barrage Rehabilitation Project with a loan of Japanese Yen 13.10 billion (US \$ 123 million equivalent). Similarly, in April 2005, JICA (Japan International Cooperation Agency) agreed to provide a grant of Japanese Yen 4.98 billion for the Project. The GOPunjab contributed Rs 857.86 million for the Project. Total approved cost of the Project was Rs 11,232.38 million as contained in the revised PC-1 approved by ECNEC on August 26, 2006.

## Packaging of Construction Works

It was agreed between the Government and the World Bank (WB) to procure construction works of the Project through International Competitive Bidding procedure. Civil works were packaged into a single Contract named ICB-01 Contract, while M & E works were divided into two components i.e. the WB financed and JICA funded works. The former was designated as ICB-02 Contract and the latter was divided into 4 Contract Packages (CP), namely CP 1 to 4.

## World Bank Financed Contracts

### a) ICB-01 Contract

Tender schedule for ICB-01 Contract was based on three years duration with rehabilitation of Barrage to be executed in three stages and construction of silt

excluder in two stages. But based on this re-assessment of site conditions, the Contractor decided to execute the under water works in two stages with of more resources and working round the clock. The works to go under water were completed according to work schedules by July, 2007.

### **b) ICB-02 Contract**

The baseline schedule prepared by the contractor was approved by the Engineer and followed by the Contractor. The works were completed within the stipulated period by 24 December 2008.

### **Consultancy Services for Construction Supervision**

M/s PBC who had provided services for feasibility study and detailed design of Taunsa Barrage, were selected by Irrigation & Power Department and the World Bank to provide construction supervision services for ICB-01 & 02 Contracts, financed by the WB. Project Manger-PBC was designated as “the Engineer” for administration of these two Contracts.

A consortium of M/S Sanyu Consultants Inc. and Yachiyo Engineering Co. Ltd, Tokyo, Japan provided consultancy services for part of the Project financed by JICA.

### **PROJECT PERFORMANCE**

The performance assessment of an infrastructure project like Taunsa Barrage can generally be spread over the following aspects:

- a) Technical;
- b) Operational;
- c) Financial Aspects;
- d) Environmental and ecological Issues; and
- e) Social Issues

Brief description for each aspect appears in the following:

### **TECHNICAL**

#### **General**

Going over the project phases it is evidently established that the project has achieved all that it was envisaged to achieve and has been completed quite successfully.

The objectives of the project as laid down earlier are expressed briefly in the following:

- a) Restoration of the discharge capacity of the barrage which had been reduced to about half the design value due to serious retrogression of levels and consequent reduction in conjugate depth (depth in stilling basin “y<sub>2</sub>”) resulting in the exposure and washing down of hydraulic jump.

- b) Eliminate or at-least minimize the sediment entry into DG Khan canal to restore the discharge capacity and obviate the need of repeated sediment flushing closures.
- c) Restore and improve the uplift pressure monitoring system of peizometers.
- d) Mitigate the defective drainage behind the flared out walls to improve the safety and stability by stopping repeated subsidence of the backfill.
- e) Restore the structural health of the stilling basin floor.
- f) Rehabilitate and improve the regulation gates and gearing system without creating environmental, ecological and social issues.

### Performance of Sub-Weir

On account of heavy retrogression of tail water levels (TWLs), the safe discharging capacity of the barrage had been reduced to almost half the design capacity and had also indirectly affected the safe limit of head across the barrage.

As a remedy, a subsidiary weir with a crest RL 424.0 was constructed 925 ft downstream of the barrage gate line. The sub-weir was expected to raise the TWLs of the barrage to the elevation required (as a minimum) for formation of hydraulic jump. The comparison of the TWL actually achieved as against design levels are shown in table 3 (a) & (b).

The barrage successfully negotiated a discharge of 960,000 cs (very close to design discharge of 1,000,000 cs) during the last monsoon season of 2010.

The stilling basin of the barrage was kept under vigilant observation by the barrage staff who reported a perfect behaviour.

In addition the jump formation was physically observed by a research scholar (working for his Masters) during the monsoon period 2010. The observed data is contained in table 4 and Figure-4. A graphically presentation in figure-3 compares the TWLs for limits of jump formation, design, actual attained on model and the actual prototype observations.

The data contained in the tables and figures mentioned supra established that the sub-weir has performed exceptionally well as explained in the following:

1. It has raised the TWLs to the extent of providing tail water depth ( $D_2$ ) adequate enough to form the hydraulic jump at the toe of glacis or above.
2. It has restored the discharge capacity of barrage (the barrage has negotiated the design discharge successfully with an HFL of 446.6 against the design level of 447.0).
3. It has created a pool of 7 ft additional depth to restore the head across limit for the barrage.
4. The constraint in maintaining pond level has been removed.

The sub-weir has therefore achieved all its objectives fully and has been a total success.

### **Performance of Silt Excluder**

The DG Khan canal used to suffer with excessively high coarse sediment entry at the head regulator and consequent siltation in the head reach reducing the canal capacity. This high sediment intake into the canal was considered to be due to:

- Excessive sediment concentration in the right pocket and DG Khan canal intake being located on the inner side of the river approach curve.
- Quite a few potent hill torrents discharging into the river from the right side a short distance on the upstream of the barrage bring very heavy coarse sediment charge in the right half of the river channel.
- Due to use of semi still pond regulation, the right pocket used to get silted up frequently and DG Khan canal received the supply direct from the river channel with heavy concentration of sediment.

The canal had to be closed a few times during Kharif almost every year (Monsoon season i.e. June to September) specially in July and August, to flush out the accumulated sediment from the right pocket. This disturbed the canal regime and flow with adverse effect on tail supplies. Each such closure of about 2 days effected the supplies at the tails of the system for over a week, sometimes at crucial stages of the Kharif crop.

To eliminate the above malady, a tunnel type silt excluder was constructed in bays # 65, 64 & 63 adjacent to the head regulator of DG Khan canal. A proper Standard Operating Procedure (SOP) was prepared and enforced.

Tables 5 (a to e) and figures 5 (a to c) exhibit the sediment charge data for the monsoon periods of 2003 (pre excluder) and 2009 (with excluder) at the head regulator of DG Khan canal. The sediment carrying capacity of the canal for sediment of 65 to 250 microns is about 250 ppm. The tabulated data and the figures clearly establish that the excluder operation has reduced the sediment entering the canal by about 31% (average), improving the canal capacity to the designed / authorized level and has eliminated the need for canal closures for flushing the accumulated sediment from the right pocket.

According to site information, the canal is being run to capacity without any closure since the excluder come into operation, five Kharif seasons ago (2006). The feeding capacities for Muzaffargarh and TP Link canal have also improved.

The efficiency of this excluder has been quite high and better than the older excluders in service at other headworks, like Khanki, Trimmu and Kalabagh. Typically, the efficiency increases with increase in sediment charge in the river flow.

The excluder has achieved the planned objectives and the canal is continuously drawing its indented supplies.

### **Strengthening of the Stilling Basin Floor**

The stilling basin floor had developed several serious problems like damages to impact blocks washing away of cubical blocks, ripping up of the reinforced concrete skin and leaking concrete. The stilling basin was remodeled by replacing top 2 ft of nominally reinforced concrete with a three ft thick overlay anchored to the lower layers through 1"  $\Phi$  expanding rawl bolts installed in the lower layers as epoxy anchors. The overlay concrete was proportioned to yield a compressive strength of 4000 psi to improve abrasion resistance to minimize the chances of recurrence of surface erosion of stilling basin and glacis concrete. This strengthening has worked well and no damage or infirmity has been reported or observed since construction in two working seasons ending in April of 2006 and 2007.

### **Instrumentation**

The pressure pipes installed under the barrage structure at the time of original construction had become choked or otherwise defective and ceased to provide acceptable pressure values under the structure especially under the stilling basin floor.

For improving the uplift pressure variation monitoring, new peizometers were installed in ten rows in bays # 3, 14, 19, 23, 27, 40, 46, 51, 59 and 64. The location of these new peizometers is depicted in figure-6. The observations for residual pressure in the new peizometers are being taken regularly. According to available data the piezometers are working quite satisfactorily. As a sample, data for 3 bays for 15/10/2008 has been recorded in table 6. This data has also been graphically presented in figure-7 (a, b & c)

The above presentation established that the peizometers are working quite satisfactorily and projecting a correct picture of the variation of residual pressure under the barrage structure.

### **Flared out walls of the Main Barrage**

These warped walls had originally been constructed with cuboid blocks of concrete, placed to the required line and grade on normal fill with no filter/transition layer. This resulted in suction of fine particles from the back fill and consequent, subsidence of the pavement.

Initially it was proposed to dismantle and relay the walls block structure with filter, but POE # 2 opined that the proposal was very expensive and fraught with many pit falls and risks. The POE recommended that the fill be properly dressed and covered with a thin concrete slab sloping out wards and drained through a drain placed along the grassy lawn wall.

This was endorsed by all and implemented successfully. This solutions is behaving satisfactorily.

## **Fish Ladders**

The stepped zig zag micro fall fish ladders of the main barrage had gone out of action due to high invert of intake and a slope steeper than that negotiable by the local varieties of fish. The fish ladders were extended and slope and chambers modified by reducing the chamber falls from 12 inches to 9 inches to reduce the velocity in the fish ladders from 7-8 ft per second to 6-7 ft per second. The fish ladders are now functional and normal fish migration has been reported.

The remodeling has thus been quite successful.

## **Performance of Rehabilitated Gates and Gearings**

The gates and hoisting systems of the barrage and the off-taking canals rehabilitated under the project by end of 2008, are working without any problem and maintenance expenditure except the oiling and greasing is almost zero. The rehabilitation and improvement has sustainably brought about smooth and reliable working.

## **Financial**

The project works were completed at a cost of Rs. 10,832 million which is well within the approved cost of Rs. 11,232 million. The Economic Internal Rate of Return (EIRR) also improved.

## **Environmental Issues**

The project had apparently no significant environmental implication and was thus placed in category 'B' under the World Bank safeguard and other guidelines. Since all the component works were constructed very close to the barrage and due monitoring and mitigation efforts were exercised, significant environmental or ecological issue came-up. Additional plantation grown around the project also improved the ecology. More details are available in the PCR (Project Completion Report).

## **Social Issue**

160 families of workers and fisherman who were living on government land were shifted to a alternate location close by and provided all necessary infrastructure like roads, paved streets, power, water supply, public washrooms, schools and a mosque through a well prepared and efficiently implemented RAP. A district level hospital was set-up near the rest house to cater for all the population including these squatters. The project provided jobs and improved sociological living conditions. More details are available in the PCR (Project Completion Report).

## Overall Completion Assessment

|   |                                  |  |
|---|----------------------------------|--|
| A | Commencement                     | May 2005 (Planned date – April 2005)   |
| B | Physical Completion              | <ol style="list-style-type: none"> <li>1) Civil works – July 2007 (planned June 2008)</li> <li>2) Mechanical and related works <ol style="list-style-type: none"> <li>a) Left half – Ahead of planned date</li> <li>b) Right half – As per planned date</li> </ol> </li> </ol> <p>All works completed on time.</p> |
| C | Project Cost                     | <ol style="list-style-type: none"> <li>(1) Approved Rs. 11,232 million</li> <li>(2) Actual Rs. 10,832 million (Within approved cost)</li> </ol>  |
| D | Internal Economic Rate of Return | Improved over Approved PCI figure  |
| E | Environmental Issues             | <p>No substantial issues.</p> <p>Project improved environmental conditions with additional plantation.</p>   |
| F | Social improvements              | The project affected persons (PAPs) were resettled and their living/earning conditions improved  |

Overview: The project was completed/implemented with no time or cost, over run and work quality appreciated by all.

- The project met all the objectives to the full.
- A most reviewed (3 PoE reviews) most visited and most appreciated mega project in the province / country.
- A real success story.

**TABLE 3(a)**  
**COMPARISON OF PRE AND POST SUB-WEIR TWLs AT THE BARRAGE**

| Discharge<br>(Cfs) | Tail Water Levels D/S of Barrage (FT) |                                 |                           |        |         | Remarks |
|--------------------|---------------------------------------|---------------------------------|---------------------------|--------|---------|---------|
|                    | Design                                | Actual                          |                           |        |         |         |
|                    |                                       | Year 2003<br>(Pre Sub-<br>weir) | Year 2010 (With Sub-weir) |        |         |         |
|                    |                                       |                                 | Left                      | Right  | Average |         |
| 1                  | 2                                     | 3                               | 4                         | 5      | 6       | 7       |
| 50,000             | 426.59                                | 423.5                           | 426.4                     | 426.5  | 426.45  |         |
| 100,000            | 428.06                                | 425.5                           | 427.8                     | 427.9  | 427.85  |         |
| 200,000            | 430.34                                | 428                             | 430.3                     | 430.8  | 430.55  |         |
| 300,000            | 432.18                                | 429.5                           | 432.4                     | 433.2  | 432.8   |         |
| 400,000            | 433.80                                | 430.3                           | 434.2                     | 435.1  | 434.65  |         |
| 500,000            | 435.26                                | 431.1                           | 435.5                     | 436.9  | 436.2   |         |
| 600,000            | 436.61                                | 431.7                           | 436.4                     | 438.4  | 437.4   |         |
| 700,000            | 437.86                                | 432.2                           | 437.1                     | 439.3  | 438.2   |         |
| 800,000            | 439.05                                | 432.7*                          | 437.8                     | 439.8  | 438.8   |         |
| 900,000            | 440.17                                | 433.1*                          | 438.4                     | 440    | 439.2   |         |
| 960,000            | 440.82                                | 433.3*                          | 438.6                     | 440.2  | 439.4   |         |
| 1,000,000          | 441.25                                | 433.4*                          | 438.9*                    | 440.4* | 439.65  |         |

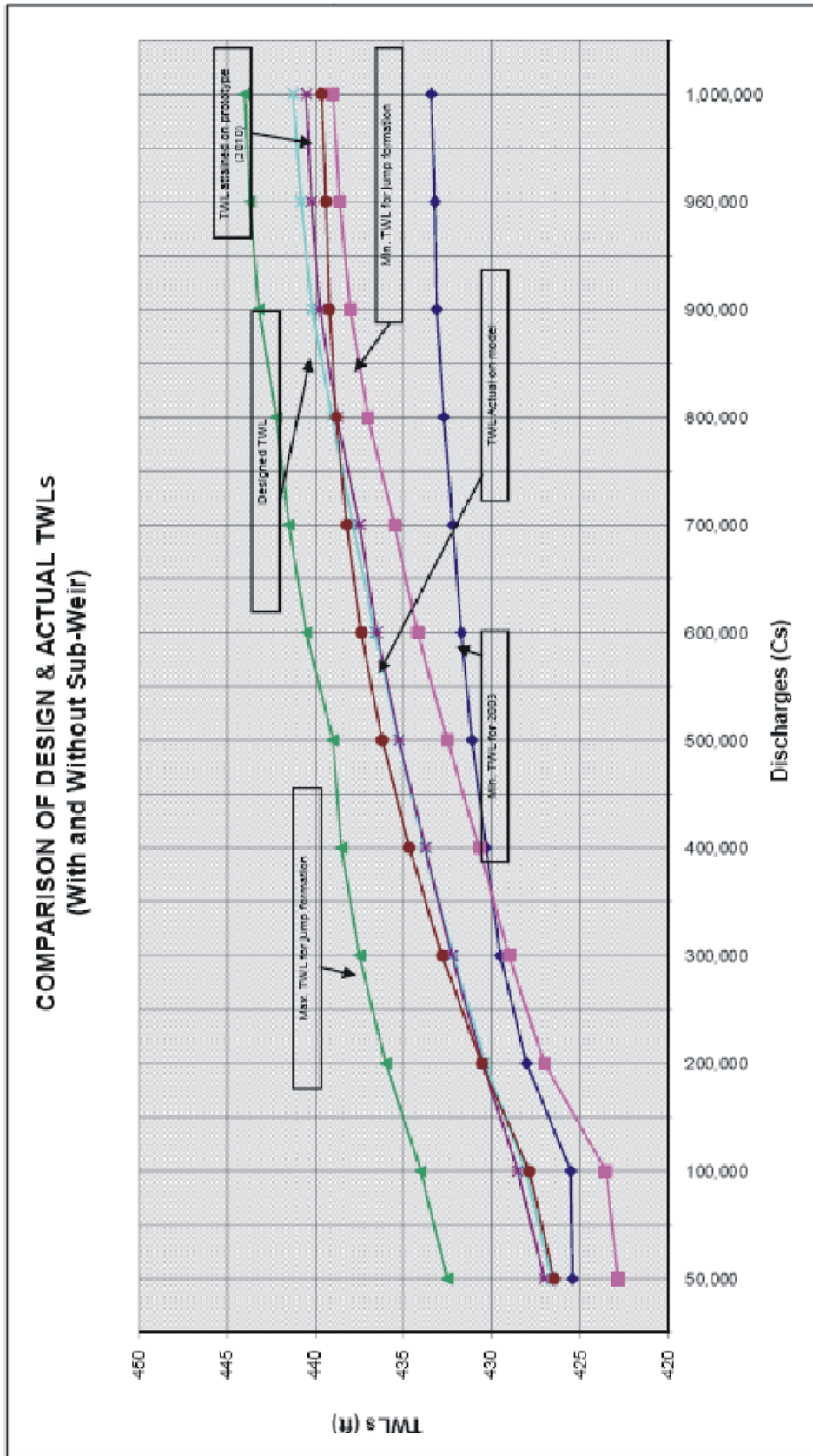
\* Extrapolated values



**TABLE 3(b)**  
**COMPARATIVE STATEMENT FOR TAIL WATER LEVELS AT THE BARRAGE**

| Sr. No. | Discharge (Cusecs) | Tail Water Levels for the Barrage (ft) |                            |                            |          |                      |                           | Remarks |
|---------|--------------------|--|----------------------------|----------------------------|----------|----------------------|---------------------------|---------|
|         |                    | Minimum TWL for 2003                   | Minimum for Jump formation | Maximum for Jump formation | Designed | Actual with Sub-Weir |                           |         |
|         |                    |  |                            |                            |          | Model                | Prototype* 2010 (Average) |         |
| 1       | 2                  | 3                                      | 4                          | 5                          | 6        | 7                    | 8                         | 9       |
| 1       | 50,000             | 425.40                                 | 422.80                     | 432.50                     | 426.59   | 427.00               | 426.45                    |         |
| 2       | 100,000            | 425.50                                 | 423.50                     | 434.00                     | 428.06   | 428.50               | 427.85                    |         |
| 3       | 200,000            | 428.00                                 | 427.00                     | 436.00                     | 430.34   | 430.50               | 430.55                    |         |
| 4       | 300,000            | 429.50                                 | 429.00                     | 437.50                     | 432.18   | 432.25               | 432.80                    |         |
| 5       | 400,000            | 430.30                                 | 430.70                     | 438.50                     | 433.80   | 433.75               | 434.65                    |         |
| 6       | 500,000            | 431.10                                 | 432.50                     | 439.00                     | 435.26   | 435.25               | 436.20                    |         |
| 7       | 600,000            | 431.70                                 | 434.20                     | 440.50                     | 436.61   | 436.50               | 437.40                    |         |
| 8       | 700,000            | 432.20                                 | 435.50                     | 441.50                     | 437.86   | 437.50               | 438.20                    |         |
| 9       | 800,000            | 432.70                                 | 437.00                     | 442.20                     | 439.05   | 438.75               | 438.80                    |         |
| 10      | 900,000            | 433.10                                 | 438.00                     | 443.20                     | 440.17   | 439.75               | 439.20                    |         |
| 11      | 960,000            | 433.20                                 | 438.60                     | 443.70                     | 440.82   | 440.20               | 439.40                    |         |
| 12      | 1,000,000          | 433.40                                 | 439.00                     | 444.00                     | 441.25   | 440.50               | 439.65                    |         |

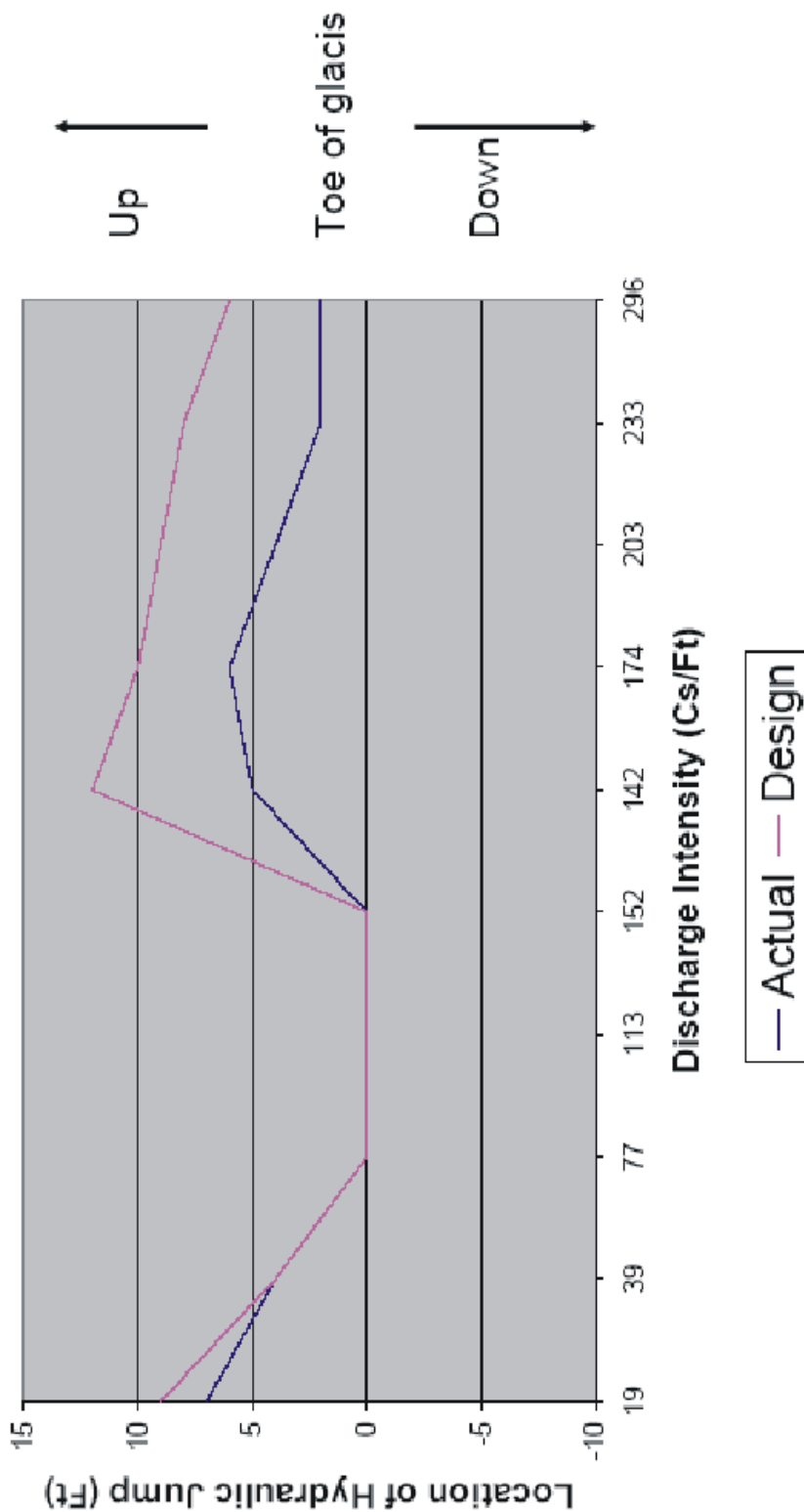
\* Picked from Col. 6 of Table 3(a)



**TABLE 4**  
**COMPARISON OF DISCHARGE INTENSITIES AND LOCATION OF**  
**HYDRAULIC JUMP WITH DESIGNED VALUES**

| Sr. No. | Pond Level (Ft) | U/S Discharge (Cs) | Actual                          |   | Design              |  |
|---------|-----------------|--------------------|---------------------------------|---|---------------------|--|
|         |                 |                    | Discharge Intensity (cusecs/ft) | Location of jump (feet above toe of glaxis) | Discharge Intensity | Location of jump (distance from Toe of glaxis) |
| 1       | 445             | 50,233.00          | 20                              | 7   | 19                  | 9  |
| 2       | 445.9           | 102,287.00         | 40                              | 4   | 39                  | 4  |
| 3       | 447.8           | 225,372.00         | 82                              | 0   | 77                  | 0  |
| 4       | 447.6           | 307,808.00         | 102                             | 0   | 113                 | 0  |
| 5       | 445.3           | 396,796.00         | 149                             | 0   | 152                 | 0  |
| 6       | 445.5           | 461,823.00         | 136                             | 5   | 142                 | 12   |
| 7       | 446             | 617,602.00         | 163                             | 6   | 174                 | 10   |
| 8       | 443.5           | 692,981.00         | 194                             | 4   | 203                 | 9  |
| 9       | 446.2           | 798,601.00         | 232                             | 2   | 233                 | 8  |
| 10      | 446.6           | 959,177.00         | 272                             | 2   | 296                 | 6  |

## COMPARISON OF DISCHARGE INTENSITY AND LOCATION OF HYDRAULIC JUMP



**TABLE 5(a)**  
**SEDIMENT DISTRIBUTION IN RIGHT POCKET AND DG KHAN CANAL AT TAUNSA BARRAGE**  
**JULY 2003 (PRE-EXCLUDER)**

| Date      | Discharge (Cs)   |       |                  | Sediment Charge (g/Liter) |       |                  | Remarks |
|-----------|------------------|-------|------------------|---------------------------|-------|------------------|---------|
|           | U/S Right Pocket | Canal | D/S Right Pocket | U/S Right Pocket          | Canal | D/S Right Pocket |         |
| 1         | 2                | 3     | 4                | 5                         | 6     | 7                | 8       |
| 1-Jul-03  | 12,414           | 9,200 | 2,814            | 3.47                      | 0.62  | 0.99             |         |
| 2-Jul-03  | 12,414           | 9,200 | 2,814            | 2.70                      | 0.71  | 1.18             |         |
| 3-Jul-03  | 13,111           | -     | 3,511            | 1.77                      | -     | 1.67             |         |
| 4-Jul-03  | 12,111           | 9,200 | 3,511            | 1.82                      | 0.53  | 2.02             |         |
| 5-Jul-03  | 12,111           | 9,200 | 3,511            | 0.79                      | 0.41  | 1.54             |         |
| 6-Jul-03  | 12,111           | 9,200 | 3,511            | 0.79                      | 0.41  | 1.54             |         |
| 7-Jul-03  | 11,183           | 8,000 | 2,783            | 0.35                      | 0.27  | 0.43             |         |
| 8-Jul-03  | 12,205           | 9,000 | 2,805            | 0.44                      | 0.33  | 0.49             |         |
| 9-Jul-03  | 12,211           | 9,000 | 2,811            | 0.53                      | 0.35  | 0.39             |         |
| 10-Jul-03 | 12,925           | 9,000 | 3,525            | 0.39                      | 0.36  | 0.37             |         |
| 11-Jul-03 | 13,624           | 9,000 | 4,224            | 0.44                      | 0.33  | 0.49             |         |
| 12-Jul-03 | 13,624           | 9,000 | 4,224            | 0.84                      | 0.48  | 0.63             |         |
| 13-Jul-03 | 13,624           | 9,000 | 4,224            | 0.84                      | 0.48  | 0.63             |         |
| 14-Jul-03 | 13,624           | 9,000 | 4,224            | 2.46                      | 1.12  | 2.12             |         |
| 15-Jul-03 | 13,624           | 9,000 | 4,224            | 2.46                      | 1.12  | 2.12             |         |
| 16-Jul-03 | 13,624           | 9,000 | 4,224            | 2.46                      | 1.12  | 2.12             |         |
| 17-Jul-03 | 17,771           | 9,000 | 8,371            | 0.30                      | 0.23  | 0.20             |         |
| 18-Jul-03 | 17,718           | 9,000 | 8,318            | 0.32                      | 0.26  | 0.29             |         |
| 19-Jul-03 | 17,954           | 9,000 | 8,354            | 0.37                      | 0.30  | 0.43             |         |
| 20-Jul-03 | 17,954           | 9,000 | 8,354            | 0.37                      | 0.30  | 0.43             |         |
| 21-Jul-03 | 17,954           | 9,000 | 8,354            | 0.73                      | 0.41  | 0.66             |         |
| 22-Jul-03 | 17,954           | 9,000 | 8,354            | 0.52                      | 0.33  | 0.43             |         |
| 23-Jul-03 | 17,272           | 9,000 | 7,672            | 0.41                      | 0.24  | 0.48             |         |
| 24-Jul-03 | 17,322           | 9,000 | 7,722            | 0.52                      | 0.31  | 0.54             |         |
| 25-Jul-03 | 16,583           | 9,000 | 6,983            | 0.96                      | 0.40  | 0.79             |         |
| 26-Jul-03 | 15,961           | 9,000 | 6,361            | 0.67                      | 0.33  | 0.56             |         |
| 27-Jul-03 | 15,070           | 8,000 | 6,870            | 0.65                      | 0.93  | 0.52             |         |
| 28-Jul-03 | 13,114           | 7,200 | 5,514            | 0.92                      | 1.33  | 0.62             |         |
| 29-Jul-03 | 13,339           | 7,200 | 5,539            | 0.56                      | 0.99  | 0.46             |         |
| 30-Jul-03 | 14,247           | 7,200 | 6,247            | 1.29                      | 0.84  | 0.75             |         |
| 31-Jul-03 | 14,347           | 7,700 | 6,247            | 1.11                      | 0.59  | 0.72             |         |

**TABLE 5(b)**  
**SEDIMENT DISTRIBUTION IN RIGHT POCKET AND DG KHAN CANAL AT TAUNSA BARRAGE**  
**AUGUST 2003 (PRE-EXCLUDER)**

| Date      | Discharge (Cs)   |       |                  | Sediment Charge (g/Liter) |       |                  | Remarks |
|-----------|------------------|-------|------------------|---------------------------|-------|------------------|---------|
|           | U/S Right Pocket | Canal | D/S Right Pocket | U/S Right Pocket          | Canal | D/S Right Pocket |         |
| 1         | 2                | 3     | 4                | 5                         | 6     | 7                | 8       |
| 1-Aug-03  | 20,254           | 8,500 | 10,907           | 0.70                      | 0.24  | 0.50             |         |
| 2-Aug-03  | 20,289           | 8,500 | 10,907           | 0.79                      | 0.24  | 0.51             |         |
| 3-Aug-03  | 20,345           | 8,500 | 10,907           | 0.70                      | 0.24  | 0.51             |         |
| 4-Aug-03  | 20,307           | 8,500 | 10,907           | 0.72                      | 0.26  | 0.52             |         |
| 5-Aug-03  | 20,429           | 8,500 | 11,029           | 0.70                      | 0.31  | 0.56             |         |
| 6-Aug-03  | 20,597           | -     | 11,197           | 2.62                      | -     | 3.08             |         |
| 7-Aug-03  | 20,597           | 7,500 | 11,197           | 2.62                      | 0.40  | 3.08             |         |
| 8-Aug-03  | 19,356           | 7,500 | 10,956           | 1.06                      | 0.44  | 0.87             |         |
| 9-Aug-03  | 17,326           | 8,500 | 8,226            | 0.92                      | 0.40  | 0.59             |         |
| 10-Aug-03 | 17,326           | 8,500 | 8,226            | 0.92                      | 0.40  | 0.59             |         |
| 11-Aug-03 | 17,744           | 8,700 | 8,244            | 0.67                      | 0.39  | 0.48             |         |
| 12-Aug-03 | 17,744           | 8,700 | 8,244            | 0.56                      | 0.36  | 0.40             |         |
| 13-Aug-03 | 18,063           | 8,700 | 8,263            | 0.51                      | 0.39  | 0.43             |         |
| 14-Aug-03 | 18,063           | 8,700 | 8,263            | 0.51                      | -     | 0.43             |         |
| 15-Aug-03 | 19,209           | 8,700 | 9,609            | 0.84                      | 0.40  | 0.40             |         |
| 16-Aug-03 | 19,167           | 8,700 | 9,567            | 0.47                      | 0.42  | 0.37             |         |
| 17-Aug-03 | 19,167           | 8,700 | 9,567            | 0.47                      | 0.42  | 0.37             |         |
| 18-Aug-03 | 17,182           | 8,700 | 7,582            | 0.53                      | 0.38  | 0.39             |         |
| 19-Aug-03 | 17,182           | 8,700 | 7,582            | 0.44                      | 0.31  | 0.47             |         |
| 20-Aug-03 | 17,282           | 8,700 | 7,582            | 0.42                      | 0.33  | 0.53             |         |
| 21-Aug-03 | 17,432           | 8,700 | 7,632            | 0.46                      | 0.27  | 0.53             |         |
| 22-Aug-03 | 17,232           | 9,000 | 7,632            | 0.48                      | 0.23  | 0.52             |         |
| 23-Aug-03 | 17,232           | 9,000 | 7,632            | 0.39                      | 0.25  | 0.29             |         |
| 24-Aug-03 | 17,232           | 9,000 | 7,632            | 0.39                      | 0.25  | 0.29             |         |
| 25-Aug-03 | 17,514           | 9,000 | 7,714            | 0.45                      | 0.34  | 0.32             |         |
| 26-Aug-03 | 17,432           | 9,000 | 7,632            | 0.43                      | 0.29  | 0.25             |         |
| 27-Aug-03 | 17,399           | 9,000 | 7,599            | 0.33                      | 0.26  | 0.26             |         |
| 28-Aug-03 | 15,473           | 7,000 | 7,673            | 0.29                      | 0.23  | 0.33             |         |
| 29-Aug-03 | 16,042           | 7,000 | 8,042            | 0.32                      | 0.21  | 0.27             |         |
| 30-Aug-03 | 15,781           | 7,000 | 7,481            | 0.26                      | 0.24  | 0.22             |         |
| 31-Aug-03 | 14,347           | 7,700 | 6,247            | 1.11                      | 0.59  | 0.72             |         |

**TABLE 5(c)**  
**PERFORMANCE OF SILT EXCLUDER IN RIGHT POCKET OF TAUNSA BARRAGE**  
**JULY 2009 (EXCLUDER)**

| <b>Date</b> | <b>Discharge (Cs)</b> | <b>Sediment Charge (g/Liter)</b> | <b>Excluder Efficiency in %age</b> | <b>Remarks</b> |
|-------------|-----------------------|----------------------------------|------------------------------------|----------------|
| <b>1</b>    | <b>2</b>              | <b>3</b>                         | <b>4</b>                           | <b>5</b>       |
| 1-Jul-09    | 7500                  | 0.30                             | 25%                                |                |
| 2-Jul-09    | 7500                  | 0.26                             | 37%                                |                |
| 3-Jul-09    | 7500                  | 0.23                             | 36%                                |                |
| 4-Jul-09    | 8500                  | 0.25                             | 26%                                |                |
| 5-Jul-09    | 8500                  |                                  |                                    |                |
| 6-Jul-09    | 8500                  | 0.29                             | 22%                                |                |
| 7-Jul-09    | 8500                  | 0.27                             | 33%                                |                |
| 8-Jul-09    | 8500                  | 0.24                             | 31%                                |                |
| 9-Jul-09    | 8500                  | 0.26                             | 16%                                |                |
| 10-Jul-09   | 8500                  | 0.25                             | 14%                                |                |
| 11-Jul-09   | 8500                  | 0.21                             | 45%                                |                |
| 12-Jul-09   | 8500                  | 0.25                             | 34%                                |                |
| 13-Jul-09   | 8500                  | 0.27                             | 27%                                |                |
| 14-Jul-09   | 8500                  | 0.29                             | 29%                                |                |
| 15-Jul-09   | 8500                  | 0.28                             | 20%                                |                |
| 16-Jul-09   | 8500                  | 0.23                             | 30%                                |                |
| 17-Jul-09   | 9000                  | 0.27                             | 33%                                |                |
| 18-Jul-09   | 9000                  | 0.21                             | 42%                                |                |
| 19-Jul-09   | 9000                  | 0.20                             | 43%                                |                |
| 20-Jul-09   | 9000                  | 0.20                             | 39%                                |                |
| 21-Jul-09   | 9000                  | 0.17                             | 45%                                |                |
| 22-Jul-09   | 9000                  | 0.21                             | 45%                                |                |
| 23-Jul-09   | 9000                  | 0.19                             | 53%                                |                |
| 24-Jul-09   | 9000                  | 0.21                             | 52%                                |                |
| 25-Jul-09   | 9000                  | 0.18                             | 54%                                |                |
| 26-Jul-09   | 9000                  | 0.15                             | 65%                                |                |
| 27-Jul-09   | 9000                  | 0.12                             | 73%                                |                |
| 28-Jul-09   | 9000                  | 0.14                             | 70%                                |                |
| 29-Jul-09   | 9000                  | 0.16                             | 64%                                |                |
| 30-Jul-09   | 9000                  | 0.18                             | 58%                                |                |
| 31-Jul-09   | 9000                  | 0.17                             | 59%                                |                |

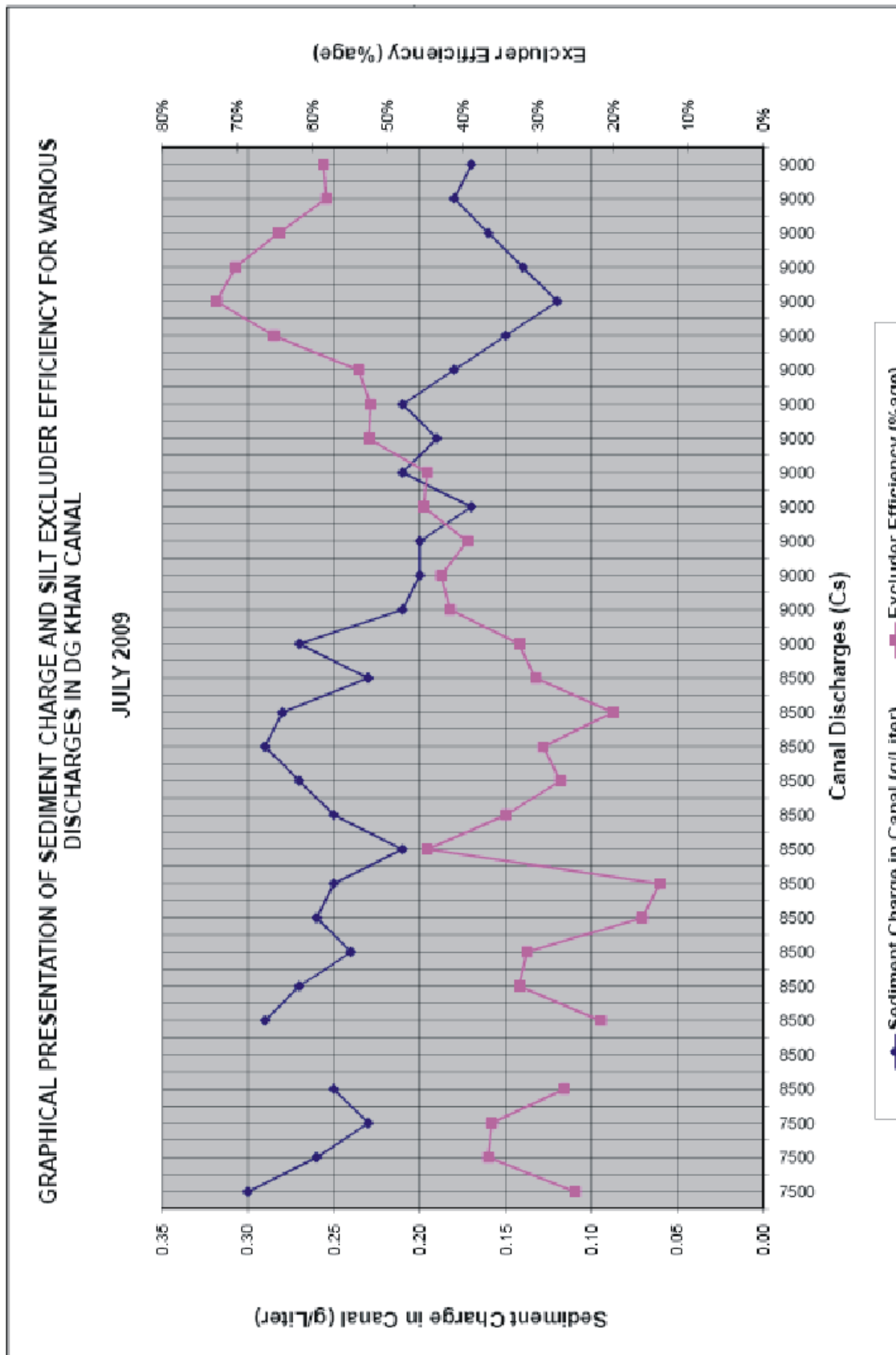
**TABLE 5(d)**  
**PERFORMANCE OF SILT EXCLUDER IN RIGHT POCKET OF TAUNSA BARRAGE**  
**AUGUST 2009 (EXCLUDER)**

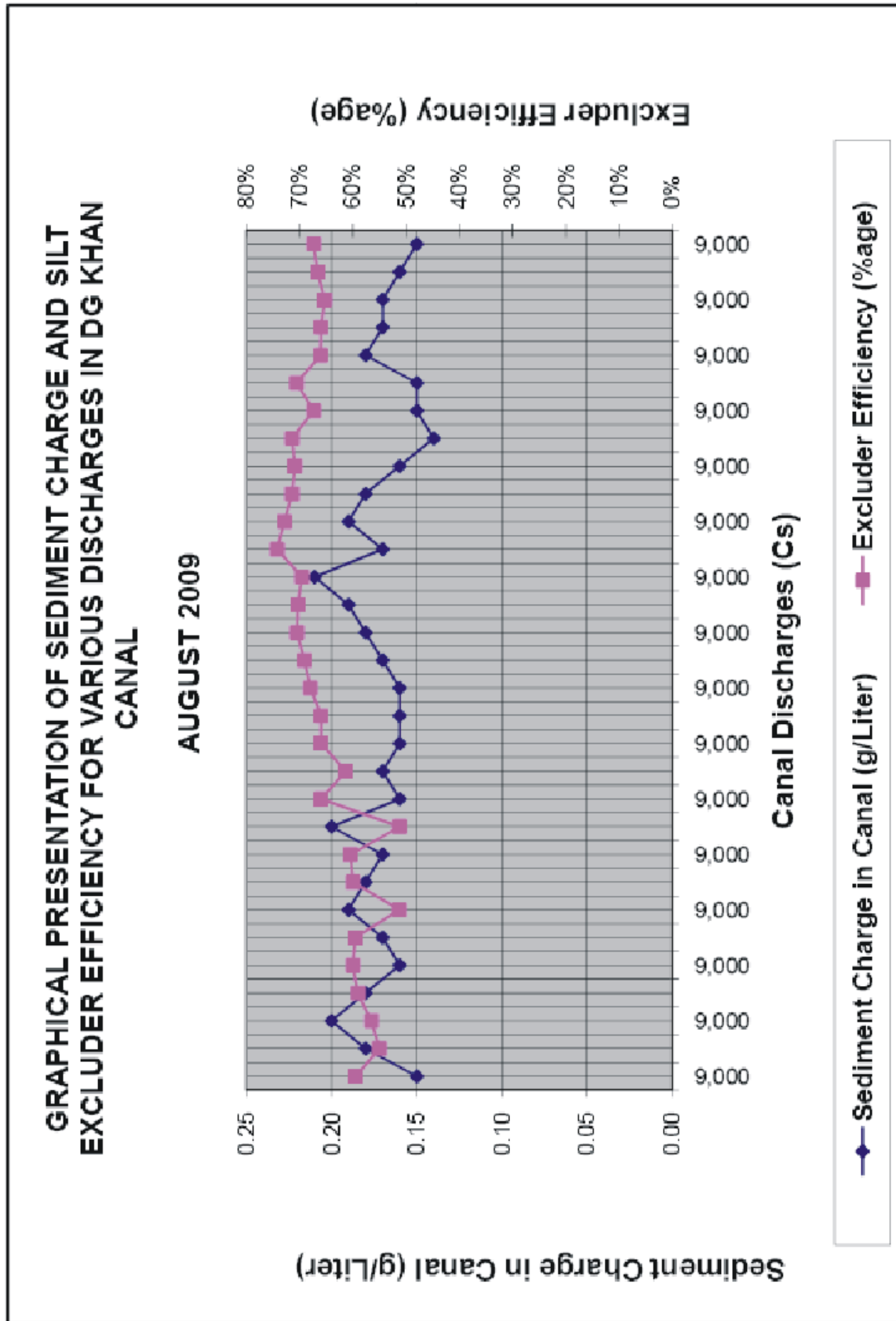
| <b>Date</b> | <b>Discharge (Cs)</b> | <b>Sediment Charge (g/Liter)</b> | <b>Excluder Efficiency in %age</b> | <b>Remarks</b> |
|-------------|-----------------------|----------------------------------|------------------------------------|----------------|
| <b>1</b>    | <b>2</b>              | <b>3</b>                         | <b>4</b>                           | <b>5</b>       |
| 1-Aug-09    | 9,000                 | 0.15                             | 59%                                |                |
| 2-Aug-09    | 9,000                 | 0.18                             | 55%                                |                |
| 3-Aug-09    | 9,000                 | 0.20                             | 57%                                |                |
| 4-Aug-09    | 9,000                 | 0.18                             | 59%                                |                |
| 5-Aug-09    | 9,000                 | 0.16                             | 60%                                |                |
| 6-Aug-09    | 9,000                 | 0.17                             | 60%                                |                |
| 7-Aug-09    | 9,000                 | 0.19                             | 51%                                |                |
| 8-Aug-09    | 9,000                 | 0.18                             | 60%                                |                |
| 9-Aug-09    | 9,000                 | 0.17                             | 60%                                |                |
| 10-Aug-09   | 9,000                 | 0.20                             | 51%                                |                |
| 11-Aug-09   | 9,000                 | 0.16                             | 66%                                |                |
| 12-Aug-09   | 9,000                 | 0.17                             | 61%                                |                |
| 13-Aug-09   | 9,000                 | 0.16                             | 66%                                |                |
| 14-Aug-09   | 9,000                 | 0.16                             | 66%                                |                |
| 15-Aug-09   | 9,000                 | 0.16                             | 68%                                |                |
| 16-Aug-09   | 9,000                 | 0.17                             | 69%                                |                |
| 17-Aug-09   | 9,000                 | 0.18                             | 70%                                |                |
| 18-Aug-09   | 9,000                 | 0.19                             | 70%                                |                |
| 19-Aug-09   | 9,000                 | 0.21                             | 70%                                |                |
| 20-Aug-09   | 9,000                 | 0.17                             | 74%                                |                |
| 21-Aug-09   | 9,000                 | 0.19                             | 73%                                |                |
| 22-Aug-09   | 9,000                 | 0.18                             | 71%                                |                |
| 23-Aug-09   | 9,000                 | 0.16                             | 71%                                |                |
| 24-Aug-09   | 9,000                 | 0.14                             | 71%                                |                |
| 25-Aug-09   | 9,000                 | 0.15                             | 67%                                |                |
| 26-Aug-09   | 9,000                 | 0.15                             | 71%                                |                |
| 27-Aug-09   | 9,000                 | 0.18                             | 66%                                |                |
| 28-Aug-09   | 9,000                 | 0.17                             | 66%                                |                |
| 29-Aug-09   | 9,000                 | 0.17                             | 65%                                |                |
| 30-Aug-09   | 9,000                 | 0.16                             | 67%                                |                |
| 31-Aug-09   | 9,000                 | 0.15                             | 67%                                |                |



**TABLE 5(e)**  
**PERFORMANCE OF SILT EXCLUDER IN RIGHT POCKET OF TAUNSA BARRAGE**  
**SEPTEMBER 2009 (EXCLUDER)**

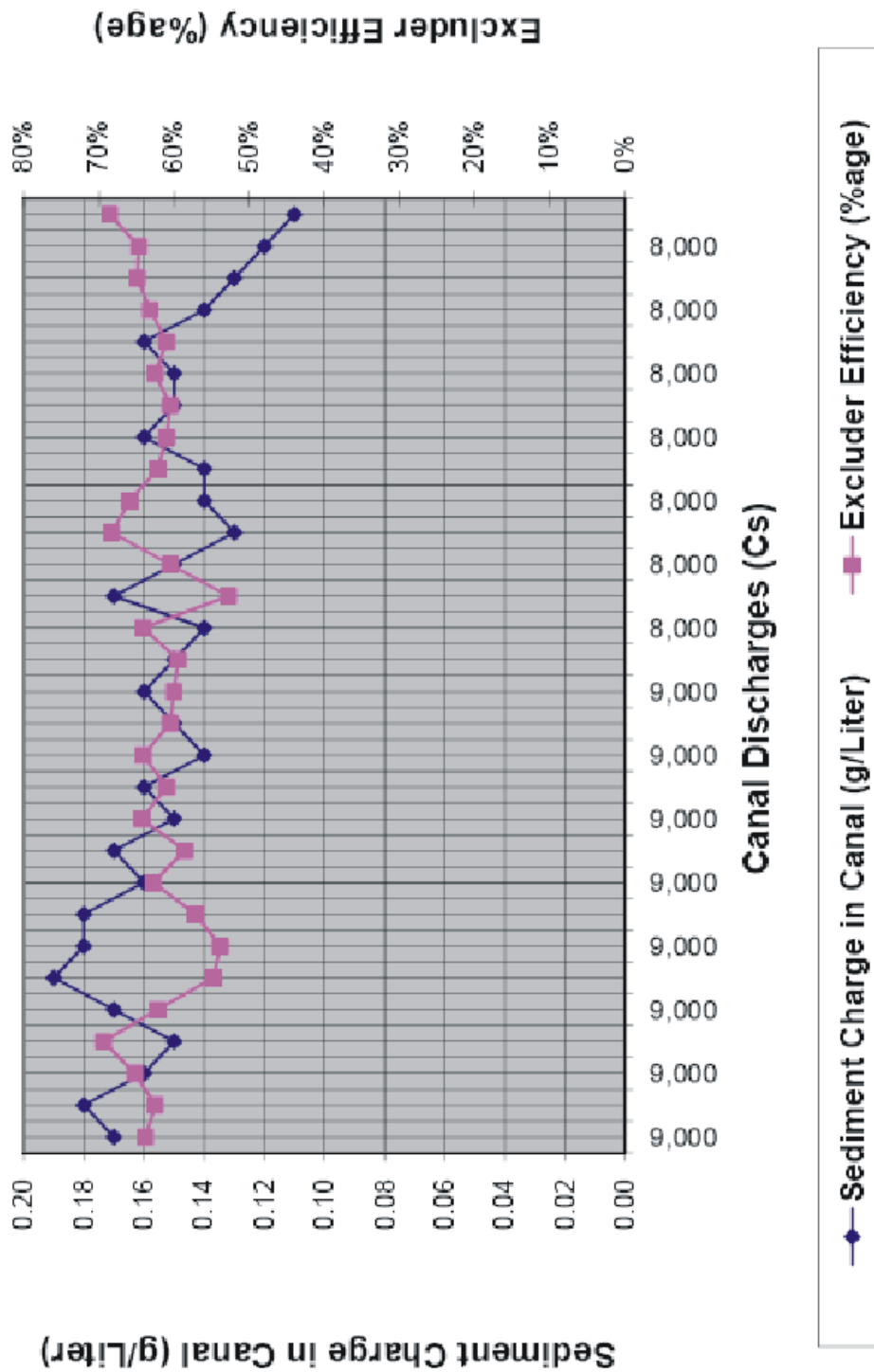
| <b>Date</b> | <b>Discharge (Cs)</b> | <b>Sediment Charge (g/Liter)</b> | <b>Excluder Efficiency in %age</b> | <b>Remarks</b> |
|-------------|-----------------------|----------------------------------|------------------------------------|----------------|
| <b>1</b>    | <b>2</b>              | <b>3</b>                         | <b>4</b>                           | <b>5</b>       |
| 1-Sep-09    | 9,000                 | 0.17                             | 64%                                |                |
| 2-Sep-09    | 9,000                 | 0.18                             | 63%                                |                |
| 3-Sep-09    | 9,000                 | 0.16                             | 65%                                |                |
| 4-Sep-09    | 9,000                 | 0.15                             | 69%                                |                |
| 5-Sep-09    | 9,000                 | 0.17                             | 62%                                |                |
| 6-Sep-09    | 9,000                 | 0.19                             | 55%                                |                |
| 7-Sep-09    | 9,000                 | 0.18                             | 54%                                |                |
| 8-Sep-09    | 9,000                 | 0.18                             | 57%                                |                |
| 9-Sep-09    | 9,000                 | 0.16                             | 63%                                |                |
| 10-Sep-09   | 9,000                 | 0.17                             | 59%                                |                |
| 11-Sep-09   | 9,000                 | 0.15                             | 64%                                |                |
| 12-Sep-09   | 9,000                 | 0.16                             | 61%                                |                |
| 13-Sep-09   | 9,000                 | 0.14                             | 64%                                |                |
| 14-Sep-09   | 9,000                 | 0.15                             | 61%                                |                |
| 15-Sep-09   | 9,000                 | 0.16                             | 60%                                |                |
| 16-Sep-09   | 8,000                 | 0.15                             | 59%                                |                |
| 17-Sep-09   | 8,000                 | 0.14                             | 64%                                |                |
| 18-Sep-09   | 8,000                 | 0.17                             | 53%                                |                |
| 19-Sep-09   | 8,000                 | 0.15                             | 61%                                |                |
| 20-Sep-09   | 8,000                 | 0.13                             | 68%                                |                |
| 21-Sep-09   | 8,000                 | 0.14                             | 66%                                |                |
| 22-Sep-09   | 8,000                 | 0.14                             | 62%                                |                |
| 23-Sep-09   | 8,000                 | 0.16                             | 61%                                |                |
| 24-Sep-09   | 8,000                 | 0.15                             | 61%                                |                |
| 25-Sep-09   | 8,000                 | 0.15                             | 63%                                |                |
| 26-Sep-09   | 8,000                 | 0.16                             | 61%                                |                |
| 27-Sep-09   | 8,000                 | 0.14                             | 63%                                |                |
| 28-Sep-09   | 8,000                 | 0.13                             | 65%                                |                |
| 29-Sep-09   | 8,000                 | 0.12                             | 65%                                |                |
| 30-Sep-09   | 8,000                 | 0.11                             | 69%                                |                |





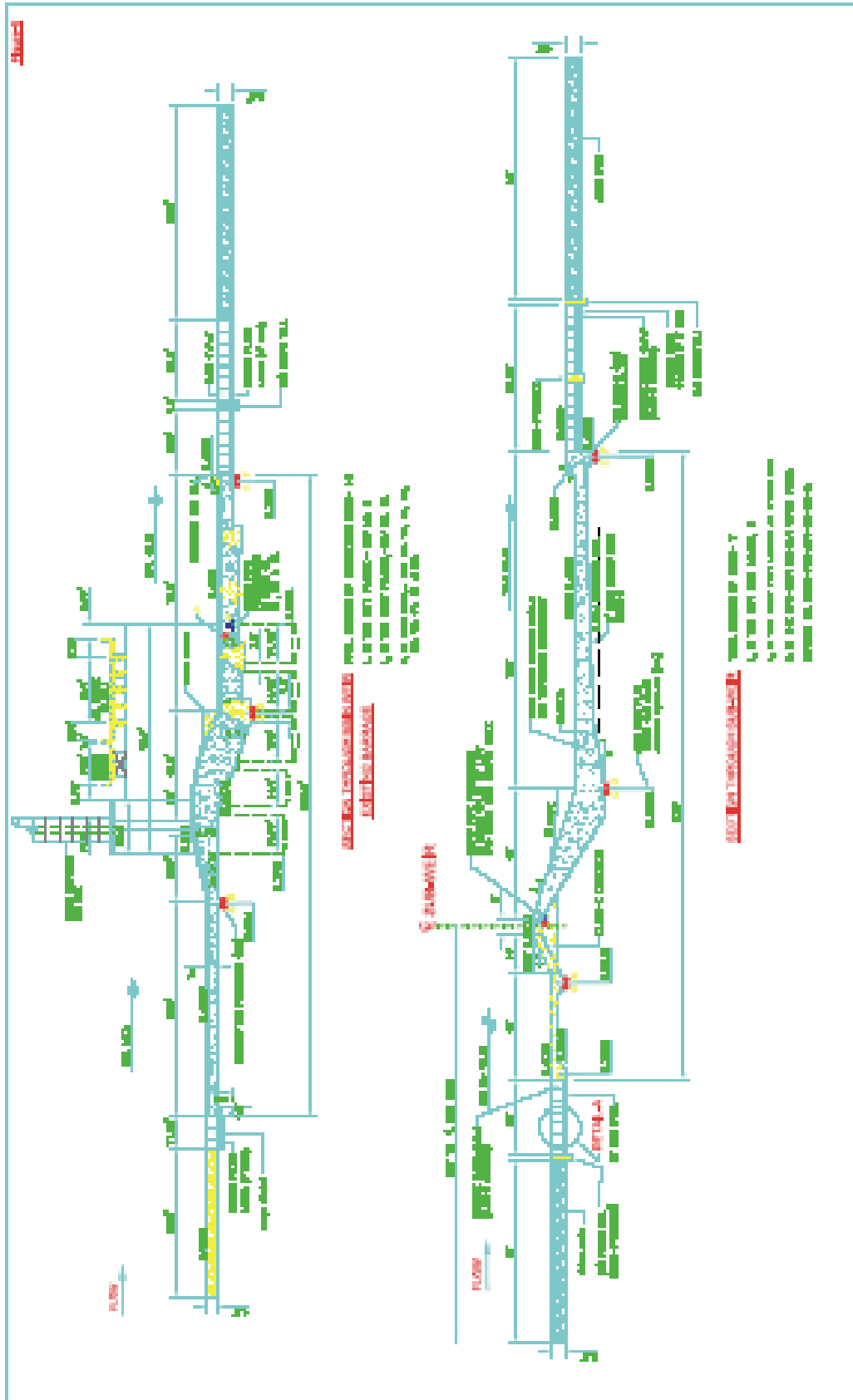
**GRAPHICAL PRESENTATION OF SEDIMENT CHARGE AND SILT EXCLUDER EFFICIENCY FOR VARIOUS DISCHARGES IN DG KHAN CANAL**

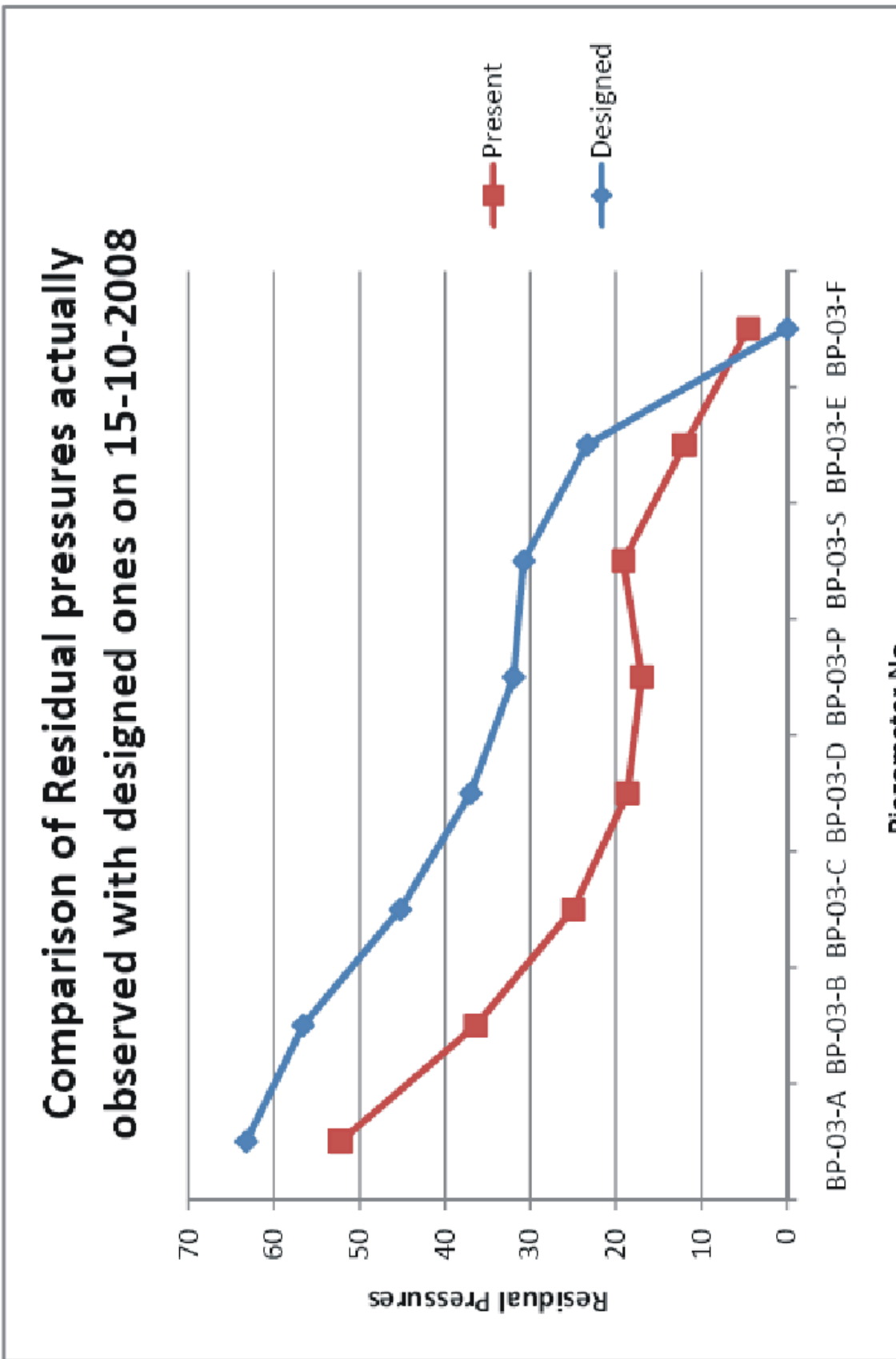
**SEPTEMBER 2009**



**TABLE 6**  
**PIEZOMETRIC DATA OF TAUNSA BARRAGE**

| Pond Level (ft) 447.85 |                           | D/S Guage (ft) 429.3 |                             | Head Across (ft) 18.55 |          |
|------------------------|---------------------------|----------------------|-----------------------------|------------------------|----------|
| Sr. No.                | Present Piezometric Level | Head Loss (Ft)       | $\phi$ Values in Percentage |                        |          |
|                        |                           |                      | Piezometer No.              | Present                | Designed |
| 1                      | 438.99                    | 8.86                 | BP-03-A                     | 52                     | 63       |
| 2                      | 436.05                    | 11.80                | BP-03-B                     | 36                     | 57       |
| 3                      | 433.94                    | 13.91                | BP-03-C                     | 25                     | 45       |
| 4                      | 432.76                    | 15.09                | BP-03-D                     | 19                     | 37       |
| 5                      | 432.45                    | 15.40                | BP-03-P                     | 17                     | 32       |
| 6                      | 432.85                    | 15.00                | BP-03-S                     | 19                     | 31       |
| 7                      | 431.52                    | 16.33                | BP-03-E                     | 12                     | 23       |
| 8                      | 430.14                    | 17.71                | BP-03-F                     | 5                      | 0        |
| 1                      | 435.82                    | 12.03                | BP-27-A                     | 35                     | 63       |
| 2                      | 434.39                    | 13.46                | BP-27-B                     | 27                     | 57       |
| 3                      | 434.14                    | 13.71                | BP-27-C                     | 26                     | 45       |
| 4                      | 433.34                    | 14.51                | BP-27-D                     | 22                     | 37       |
| 5                      | 433.62                    | 14.23                | BP-27-P                     | 23                     | 32       |
| 6                      | 433.55                    | 14.30                | BP-27-S                     | 23                     | 31       |
| 7                      | 431.89                    | 15.96                | BP-27-E                     | 14                     | 23       |
| 8                      | 430.35                    | 17.50                | BP-27-F                     | 6                      | 0        |
| 1                      | 438.60                    | 9.25                 | BP-64-A                     | 50                     | 63       |
| 2                      | 435.90                    | 11.95                | BP-64-B                     | 36                     | 57       |
| 3                      | 434.00                    | 13.85                | BP-64-C                     | 25                     | 45       |
| 4                      | 432.50                    | 15.35                | BP-64-D                     | 17                     | 37       |
| 5                      | 432.30                    | 15.55                | BP-64-P                     | 16                     | 32       |
| 6                      | 432.60                    | 15.25                | BP-64-S                     | 18                     | 31       |
| 7                      | 431.40                    | 16.45                | BP-64-E                     | 11                     | 23       |
| 8                      | 430.40                    | 17.45                | BP-64-F                     | 6                      | 0        |





### Comparison of Residual pressures actually observed with designed ones on 15-10-2008

