Evaluation of Options for Remodelling of Upper Jhelum Canal, Pakistan

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***Abstract*-**The paper develops and implements remodeling approach for alluvial irrigation channels. The approach mainly includes in-depth analysis of original/existing design parameters, identification of existing condition of channel and hydraulic structures along with their problems, evaluating different options and finalizing the remodeling parameters by emphasizing hydraulic, structural and economic consideration. Upper Jhelum canal in Pakistan was selected as case study channel. The condition survey of channel was conducted which showed that it was facing multiple problems i.e. excessive silt deposition, erosion of banks, inadequate freeboard, side embayment and widened channel section. The channel was unable to run at the design discharge and therefore required remodelling. The reasons for multiple problems were diagnosed during the study. The analysis showed that the viable approach for remodeling of subject canal is at enhanced design parameters. Different options were developed by varying different hydraulic parameters and possible economical solutions were analyzed using different approaches to suggest the most suitable remodelling strategy for UJC. The existing parameters with minimum change became basis for re-designing of the channel by different approaches i.e. Lacey's regime theory, Manning's formula and Tractive force method. Sensitivity analysis was also carried out to finalize the design parameters emphasizing hydraulic, structural and economical consideration. The remodelling of UJC as per recommended parameters will ensure increased agriculture and power benefits and enhance conveyance efficiency.

***Keywords*-**Upper Jhelum Canal, Remodelling, Alluvial Channel, Canal Problems

I. INTRODUCTION

Remodelling of irrigation channels is a process of restoring or modernization of existing system including all hydraulic structures at same/modified design parameters. Food and Agriculture Organization (FAO) [i] discussed that detailed diagnosis including the performance, present condition, original design and other deficiencies are very important for remodelling and modernization of any irrigation system. Shakir and Khan [ii] critically investigated the previous structural interventions for their viability and effectiveness for Marala Ravi Link Canal in Pakistan. The enhancement of crest level was also checked and found that it was effective in reducing sediment intake of MR Link Canal to some extent but did not make any impact in reducing the sediment entry to its offtakes including Upper Chanab Canal. The sediment management problems of Marala Barrage were also reviewed in the study. Different operational scenarios of Upper Swat Canal (USC) were investigated and quantified based on fixed frequency operation. Tariq and Latif [iii] suggested operating the channel at 8090% of the design discharge during May to July, and 7590% of the design discharge from August to April to reduce water losses due to high water allowance.

The important parameter for remodelling of irrigation channels change in concept, structure and design. It considers modification in technology, techniques and future consideration of future needs of operation and maintenance [iv]. The provision of food and fibre requirement of people is one of the challenges of this century. To fulfill these basic needs of rapidly growing population water resources and irrigation system to efficiently take water up to fields are utmost important. The Indus Basin Irrigation System (IBIS) being the largest contiguous irrigation system of the world, comprises of 12 inter river link channel, 45 canal systems, about 100,000 tertiary channels, 16 barrages and 3 major reservoirs including Mangla, Tarbela and Chashma. The IBIS commands cultural command area of 14 million hectares. Total length of primary, secondary and tertiary channels are 56128 km. IBIS utilizes 51.3 billion cubic meter (BCM) groundwater pumped through more than 800,000 tube-wells to add-on the canal supplies [v].

The importance of efficient use of irrigation water is necessarily increasing as the world population is increasing. At this stage the country would need more food and fibre to meet the needs of growing population. This shortfall can be met either by constructing new reservoirs or irrigation water management at canal command level [vi]. Irrigation water management includes improvement of physical infrastructure for distribution of water from source to the crops and water management at the farm level [vii]. Shakir et al. [viii] suggested optimization measures for improving water management in Lower Jhelum Canal command in Pakistan which includes enhancing productivity by using crops having higher values and yields, enhancing conveyance efficiency, adopting conservation techniques including bed-furrows, laser land leveling, zero tillage and on-farm water management. The structural measures identified for improving canal management includes rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal along with its hydraulic structures, restoration of prism, raising and strengthening of canal banks and lining of distributaries and minors may lead towards optimization of irrigation system of LJC command.

FAO [ix] presented detailed methodology for modernization of medium to large irrigation canal systems for improving performance. The strategy was developed for analyzing channel optimization on the basis of Mapping System and Services for Canal Operation Techniques (MASSCOTE). During the process of remodeling and modernization, the expectations and achievements had to be kept at realistic and practical level. The most economical and easy-to-implement options were selected to start the process of modernization. Irrigation system management includes equitable and efficient distribution of water. Computation of irrigation demands and matching water supplies are also very important for successful irrigation system. In addition, irrigation system should be kept in operating condition throughout the season to achieve the desired objectives. Shakir and Nasir [x] reviewed the problems of Upper Chenab Canal in Pakistan. Water availability studies were carried out to ensure the reliability of enhanced water for irrigation, power and other benefits. It was suggested that the economical solution for remodelling of the channel was by increasing its water depth instead of enhancing the bed width. It will reduce the cost of remodelling of hydraulic structures of UCC. The opinion of users through Farmer Organizations (FO) should be considered for devising and implementation of remodelling projects [xi]. FO participation should be ensured while computing design of outlets, constructing and remodelling channels along with their commissioning for monitoring and ensuring equitable distribution.

Pakistan has one of the largest contiguous irrigation systems of the world. The rehabilitation and remodelling of irrigation canals along with their hydraulic structures have always been an ongoing process for Pakistan and other countries of the world. Some theories of designing of irrigation channels are available in literature i.e. Lacey's regime method, Tractive force method and Manning's formula. However, the topic of remodelling and rehabilitation of alluvial channels also desires practical and hands on experience of problems solving and does not much available in literature. The objectives of this study are i) to develop approach/methodology for remodeling of irrigation channels by consulting literature and practical experience and ii) to apply the developed approach to remodelling of Upper Jhelum Canal, Pakistan (case study channel).

II. APPROACH/METHODOLOGY FOR REMODELING OF IRRIGATION CHANNELS

The approach developed for remodelling of alluvial irrigation channels is as follows:

- In-depth analysis of original/existing design approaches and parameters
- Conduct condition survey to access the existing condition of channel along with hydraulic structures and access the reasons for developing problems
- Develop and evaluate different options for remodeling
- Selection of parameters for remodelling of irrigation channel including design discharge, longitudinal slope and water levels, bed width and depth
- Design of irrigation channel by different methods and sensitivity analysis to finalize the design parameters
- Finalize the remodeling approach based on hydraulic, structural and economic consideration

III. CASE STUDY OF UPPER JHELUM CANAL (UJC)

Upper Jhelum Canal (UJC) offtakes from Mangla head works of Jhelum River. It was designed in 1904 and commissioned in 1915 primarily as a feeder channel to supplement the supplies of Khanki headworks at Chanab River for Lower Chanab Canal system. It has total length of 142 km and original design discharge was 12800 cusecs. Its gross and culturable command areas are 642447 and 603749 acres respectively. However, the channel was redesign in 1941. It also supplies water for two Hydro power stations namely Rasul and Shadiwal having power potential of 22 and 12 MW respectively, constructed later on. UJC also fulfils the water requirements of Khanki headworks of River Chanab during low flows in river Chanab. After commissioning of Mangla Dam and Mangla Powerhouse, a new channel Bong Canal having designed capacity of 49,000 cusecs, was constructed. The Bong canal offtakes from Mangla Powerhouse for feeding irrigation requirements of UJC and the downstream water requirements at Rasul barrage. The UJC head regulator is located at 8.4 km (RD 27+500 feet).

IV. Site Visit to Conduct Condition Survey of UJC

The site was visited during flow and closure periods of the canal to observe existing condition of the channel and hydraulic structures. Some problems observed during the site visit include but are not limited to:

- Excessive silt deposition and scouring
- Erosion of banks
- Inadequate freeboard
- Side embayment and widened channel section
- Deteriorated condition of super structure of some hydraulic Structures

Excessive Silt Deposition and Scouring

The channel bed was found slightly scoured in few head reaches up to RD 244+000. However, excessive silt deposition was observed through the entire reach of the channel from RD 244+000 to 418+000 (Tail). The silt deposition was measured at some locations and found in the range of 3-5 ft. The longitudinal section of the channel shows that the head reach was constructed by cutting local soils whereas middle and tail reaches were constructed in filling of local soil. A typical photograph of excessive silt deposition of UJC is shown as Fig. 1.The channel was found widened oddly in tail reaches and became nonoperational at design discharge.

Fig. 1. Excessive silt deposition at 109.73 km of UJC

Erosion of Banks

The banks of the channel were found eroded in several reaches throughout the channel and especially in the tail reaches. Apparently banks seem to be made of local soils having less cohesive particles. Excessive bank erosions have also caused excessive water losses, less efficiency of canal system and canal breaches. The erosion of banks is also one of the problems which do not allow the canal to be operated at its design discharge. Figure 2 shows erosion of banks at typical location of UJC.

Fig. 2. Erosion of banks downstream at 99.02 km of UJC

Inadequate Freeboard

During condition survey, the water marks on the banks confirmed that recommended freeboard of 3 ft was not available in some reaches of the channel because of bank erosion, weather action, less maintenance and widened sections. It resulted in canal operation at lesser discharges compared with the design discharge. The canal has been run at even less than 50% of its design discharge since last 10 years. The freeboard was also found short at the upstream of some hydraulic structures. Fig. 3 depicts typical inadequate freeboard of UJC.

Fig. 3. Inadequate freeboard at 97.61 km of UJC

Side Embayment and Widened of Channel Section

The side embayment was observed at downstream of hydraulic structures of Upper Jhelum Canal. The channel was constructed by fluming the channel width at hydraulic structure to reduce the construction cost. The transition provided for divergence and convergence of flowing water at downstream and upstream was found unproductive. The Fig. 4 shows the excessive side embayment and widened section of UJC resulting in non operation at its required design discharge. The currents generated downstream of these structures traveled long distances along the canal before merging into normal depth of streamline flow. The undulating flow pattern generated channel instability and side embayment.

Fig. 4. Side Embayment and Widened section at 97.61 km of UJC

Deteriorated Condition of Super Structure of Few Hydraulic Structures

The channel has more than 100 hydraulic structures including bridges, falls, level crossings, siphons, cross-regulators and head regulators of offtaking channels. Most of the hydraulic structures are as old as the canal. Silt deposition was found on the upstream (u/s) and downstream (d/s) floors of the structures. Apparently the hydraulic performance of the structures was found satisfactory. However, the superstructures including deck slab of some hydraulic structures need repair and replacement. The trend of energy dissipation arrangement of the hydraulic structures was found effective as no scouring of bed and major side embayment were observed at their downstream. As such, the present condition of piers and foundations was found satisfactory. The water marks on piers shows that 2 - 3 ft free board is available near the hydraulic structures.

Fig. 5. Damaged Deck Slab and parapet of bridge at 122.6 km of UJC

The possible reason for high silt deposition in the tail reaches and scouring in the head reaches is the entry of silt free water after the commissioning of Mangla reservoir in 1967. From historic operation of the channel, it has been observed that less discharge and less velocity have also facilitated the silt deposition and bank erosion. The reason for less discharge may be due to less availability of water or less demand for UJC. Proper maintenance of the channel and hydraulic structures have not been carried out. The operation of canal at substantially less discharge than its design discharge, deferred maintenance and monitoring seems to be the reasons for the said problems. All the above mentioned factors lead to reducing the efficiency and enhancing conveyance losses of UJC.

V. DESIGN DISCHARGE FOR REMODELING OF UJC

The original design discharge of the channel was 12800 cusecs (as of 1915). The channel was redesigned for 8893 cusecs due to less availability of water in 1941 according to Manning's formula. There was no provision of supplies for two power houses namely Rasul and Shadiwal when the canal was designed in 1915 and 1941. During last 10 years, the channel has been operated at less discharge. It has been noticed that only 116 m^3/s has passed downstream khokhra (77.77 km of UJC) against the allocated discharge of 185 m^3/s during last several years. The possible reasons for less discharge are: i) the less availability of water and ii) inability of the channel (middle and tail reaches) for safely carrying the original design discharge. The current authorized head and tail discharges of the UJC are 255.7 m^3/s (9030 cusecs) and 222.8 m^3/s (7868 cucecs).

The design discharge of an irrigation channel is usually based on culturable command area (CCA) and sanctioned water allowance. The design discharge for remodeling may be enhanced by assuring the additional water through water availability studies. Pakistan Drainage Consultants (PDC) [xii] discussed that perennial irrigation channel should be atleast designed at reliability of 80% available water. The increase in CCA and commissioning of power houses necessitates updating the design discharge for the remodeling. The raising of Mangla Dam in 2009 has enhanced its live storage capacity from 4.51 to 7.39 MAF. The Mangla reservoir has 2.88 MAF additional storage available which may be used for acquiring power and agriculture benefits. The additional water may be utilized for enhancing the discharge of UJC as per Water Apportionment Accord among the provinces of Pakistan. Punjab Irrigation Department (PID) [xiii] proposed the revised capacity of UJC by computing the discharges of all offtakes, power houses and losses as follows:

Discharge for offtakes of Azad Kashmir = 1.5 m^3/s
Discharge for Rasul Power House = 102.6 m^3/s
UJC Internal (Gujrat Branch & other offtakes) = 57.7 m^3/s
Shadiwal Power House = 220.9 m^3/s
Approximate conveyance losses = 38.3 m^3/s
Total Revised Capacity of UJC = 420.51 m^3/s

VI. Evaluation of Possible Options

The possible options for remodeling are as follows:

I. To remodel the canal for existing discharge of 255.70 m^3/s at existing hydraulic parameters and fulfill the needs of Shadiwal power house and Khanki headworks at Chanab River for Lower Chanab Canal system through some alternate route including developing new channel.
II. To remodel the channel for increased discharge of 420.51 m^3/s by minimum variation of existing parameters i.e. bed and water levels, longitudinal slope, water depth and bed width

The 1st option for remodeling was analyzed technically and economically. The present condition indicates that the bed width of the channel has substantially increased from 230 to 330 ft in the middle and tail reaches and full supply has reduced from 10.2 to 5 ft. Moreover, recommended freeboard of 3 ft was not available. The width to depth (B/D) ratio of the channel has been enhanced upto 55. The channel does not provide the desired velocity and results in high conveyance losses and sediment deposition. The existing condition of the channel presents the view of a natural river. The existing dimensions and parameters of the channel including water depth, bed with, velocity and others are not considered hydraulically feasible for remodeling of UJC at 255.7 m^3/s. The development of new channel would involve cost of acquiring new land, constructing several hydraulic structures, availability of good soil and construction material (cement, sand, crush, steel etc) including engineering services which seems to be very expensive. The acquiring of land is also very complicated and time consuming process. The site visit indicated a few problems in technical design of the new channel in setting its alignment due to physical constraints including displacement of roads and other infrastructure. The cost of this option will be much higher as compared to the 1st option not considered technically and economically feasible.

The 2nd option of remodeling of the UJC at enhanced discharge seems to be feasible. The channel was originally designed for discharge more than 362.5 m^3/s (12800 Cs). The enhanced discharge is only about 15% more than the original discharge of 1904. The original design, modified design and existing dimensions of the channel are shown in Table I. Two reaches indicating entire length of UJC have been shown in Table 1 and developed on the basis of significant difference in discharge and other hydraulic parameters. The channel was originally designed in 1904 on the basis of Manning's formula. The approved L-Section shows that the basis of redesign in 1941 was again on Manning's formula by keeping the roughness coefficient (n) of soil as 0.0225.

Critical review of different design approaches including Lacey regime method, Tractive force method and Manning's formula have been carried out for their suitability of redesign of UJC. These methods proposed change in bed width, full supply depth and longitudinal slope of whole channel. The change in these parameters would require re-construction of UJC along with its hydraulic structures which will increase the remodelling cost. It would also require the cost of land acquisition and construction of diversion channel. The preliminary investigation indicated that remodeling of UJC at existing parameters along with enhanced depth would be economical solution. In this case only earthwork of banks would only be desired. However, to bring the existing bed width (260 m 330 m) to original bed width of 220 m would involve huge earthwork along with removing of earthwork. The remodeling of channel at existing bed width and longitudinal slope and by changing depth will reduce the remodeling cost to a great extent. However, the increased existing bed width of the channel does not provide stable and efficient design.

TABLE I
Design and Existing Parameters of Upper Jhelum Canal (UJC)

Design Parameters	Original Design (1904)	Design (1941)	Average Existing Parameter	
			Head Reach upto 74.4 km	Tail Reach 74.4 - 127.4 km
Discharge, Q (Cs)	12800	8893	7700	4100
Bed Width, B (ft)	228	223	240	270
Full Supply Depth, (ft)	13	10.2	9.5 - 11.5	5 - 7
Side Slope	1.5	1.5	1.5	1
Longitudinal Slope (I/slope)	6667	6667	6667	6667
Bed width to Depth (B/D) ratio	17.54	21.86	20 - 25	38 - 55

The average existing width to depth ratio (b/d) has been enhanced to 55. The increase in b/d ratio of the channel is associated with accelerated bank erosion rates, excess deposition/aggradation processes and over-widening. The re-design of the channel at such high B/D ratio does not seem to be efficient. The data of existing alluvial channels in the same region having similar topographic characteristics and discharges as of UJC, the maximum suitable range of B/D ratio of 16-23 was found. Therefore it is suggested to slightly decrease the bed width and increase the depth to get the B/D ratio within the specified range of efficient and stable design. The existing slope may also be considered as constraint to be kept same for remodeling of UJC. The hydraulic parameters computed by different design approaches for remodeling of UJC are provided in Table II.

Lacey's regime method is most extensively used method for hydraulic design of alluvial irrigation channels. Functioning of these channels depicts regime canals designed with Lacey's parameters. The suggested depth by different design approaches by allowing minimum reduction in existing bed width and keeping other existing parameters. Lacey's design parameters are recommended for remodelling of UJC as they would require less deviation from existing dimensions and its successful implementation for alluvial channel design in Pakistan. The new depth is compatible with the original design.

There are more than hundred hydraulic structures on UJC and preliminary investigation indicates that the most of the structures will safely pass the increased discharge as per new proposal. The clear waterway, fluming ratio and afflux for the structures were found satisfactory. However, the freeboard was found slightly deficient as compared to standard of 3 ft for remodelling parameters. The need of raising of deck slab of some hydraulic structures was observed to safely pass the discharge and to achieve the desired freeboard. The scouring depth was found 4 ft and 3 ft below the channel bed for the head and tail reaches respectively by taking FOS of 1.25 (for straight reach). The foundations of hydraulic structures were also found safe as being placed lower than the scouring depth. To achieve the desired bed width, a new centre line of the UJC be established and accordingly the banks should be reconstructed. The strengthening of newly constructed banks from earthen material by stone pitching along with apron are advised for the canal in filling reaches, curved portions and upstream and downstream of structures. To cater for hydraulic grade line as per new proposal, pushta may be provided in some reaches. However, a detailed study is recommended to finalize and verify the findings of preliminary investigation of this study regarding hydraulic structures and suggested parameters for remodelling. The availability of design discharge throughout the year must be ensured prior to remodelling of the channel and for sustainable solution.

TABLE II
PROPOSED HYDRAULIC PARAMETERS FOR REMODELLING OF UJC BY DIFFERENT METHODS

Design Parameters	Average Existing Parameters		Proposed Design by Lacey Method		Proposed Design by Manning Formula		Proposed Design by Tractive Force Method	
	Reach 8.4- 74.4 km	Reach 74.4 - 127.4 km	Reach 8.4- 74.4 km	Reach 74.4 - 127.4 km	Reach 8.4- 74.4 km	Reach 74.4- 127.4 km	Reach 8.4- 74.4 km	Reach 74.4- 127.4 km
Q (Cs)	7700	4100	14850	8500	14850	8500	14850	8500
B (ft)	240	270	240	230	240	230	240	230
Depth (ft)	9.5 - 11.5	5 - 7	13.55	9.47	13.7	10.1	13.9	10.3
Side Slope	1.5	1	1.5	1	1.5	1	1.5	1
Longitudinal Slope (I/slope)	6667	6667	6667	6667	6667	6667	6667	6667
B/D ratio	20 - 25	38 - 55	17.71	23.12	17.58	22.77	17.39	22.33

VII. CONCLUSIONS & RECOMMENDATIONS

1. Upper Jhelum Canal is unable to operate at its design discharge due to multiple problems and enhanced conveyance losses. Some major problems identified in the study are excessive silt deposition in middle and tail reaches, scouring in head reach, erosion of banks, inadequate freeboard, side embayment and widened channel section.
2. The existing width to depth ratio of UJC is not suitable to achieve parameters of regime channel. The option of remodelling of UJC at enhanced depth and slight decrease in bed width to achieve B/D ratio within permissible limit.
3. The enhanced discharge for remodelling of UJC has been considered suitable on the basis of preliminary study. The increased discharge favors

continuous and more benefits of power generation and agriculture.

4. It is recommended that detailed study including hydraulic evaluation of the UJC and its hydraulic structures i.e. cross regulators, bridges, inlet, syphon and falls at enhanced discharge is necessary to finalize remodelling approach. The study highlights the typical problems of alluvial channels and their solutions on the basis of practical experience in addition to following latest theories and trends. The strategies proposed for remodelling of Upper Jhelum Canal have been recommended for their application to other alluvial channels.

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