Optimization Strategies for Improving Irrigation Water Management of Lower Jhelum Canal

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Abstract-The paper includes computing crop water requirement, identification of problems and optimization strategies for improved irrigation water management of a canal command. Lower Jhelum Canal (LJC) System was selected as a case study. Possible strategies for optimization are enhancing irrigation water productivity by high value and high yield crops, adoption of resource conservation interventions (RCIs) at the farm level, improving irrigation system efficiency and its management. Estimation of daily reference evapotranspiration of LJC command was carried out by Penman Montieth - 2000 method and metrological data of Sargodha for the period 1999 to 2010 was used. Crop water requirements were computed from reference evapotranspiration, crop coefficients and periods of crops for existing cropping pattern. The comparison of the crop water requirements and available water supplies indicated shortage of more than 51% in Kharif and 54% in Rabi seasons. The gap between requirements and supplies is fulfilled by groundwater in the command. The structural measures identified in the present study for improving canal management include rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling, zero tillage, and bed-furrow irrigation method. Adopting proper cropping systems considering land suitability and capacity building of farming community in improved soil, crop and water management technologies would enhance the water productivity in an effective and sustainable manner.

Keywords-Irrigation Management, Optimization Strategies, Reference Evapotranspiration, Canal Water Management, Lower Jhelum Canal

I. INTRODUCTION

Irrigation is essential in Pakistan due to its larger share of 24.1% in country's gross domestic product (GDP) [i]. The significance of managing irrigation water, its practices, standards and scope differ to large extent depending on its economic growth and water scarcity in a country. Effective irrigation management ensured sustainability in farming and productivity. Irrigation management provides extent of sustainable farming and reduces poverty, hunger and starvation [ii]. Presently, irrigated agriculture enterprise in semi-arid and arid regions of the world is confronted with major challenge of addressing the interactive triangle of food security, environmental sustainability and poverty alleviation by improving the livelihood of the farming community. Also, competition among different water uses and users is increasing with time, especially under the water scarcity situation. This reflects water management by bringing more area under agriculture, increasing cropping intensity along with increased land and water productivity, sustaining land and water quality and improving farm economic returns. Wheat is the most extensively grown / consumed cereal food for 35 % of world's population. Moreover, it contributes over 45% of wheat production in the developing world [iii, iv]. Resource conservation interventions (RCIs) including laser land levelling (LLL), zero tillage (ZT) and bed and furrow (BF) have prime role to achieve sustainable agriculture output, reducing crop inputs and enhancing the resources' efficiency. It was concluded that these interventions enhanced the agriculture yield and water saving. Irrigation water saved by RCIs was upto 771 m^3/acre in the selected irrigated areas of Punjab, Pakistan [v].

II. LOWER JHELUM CANAL (LJC): A CASE STUDY

Lower Jhelum Canal (LJC) off takes from river Jhelum at Rasul head-works and irrigates areas of Chajj Doab in Districts Sargodha, Mandi Baha-ud-din and

Jhang in Punjab, Pakistan. The gross command area (GCA) of LJC is 0.657 million hectares (1.635 million acres), culturable command area is 0.610 million hectares (1.518 million acres) and cropping intensity is 121% [vi]. The command area of LJC is shown in Fig. 1. LJC was opened in 1901 with original design discharge capacity of 102.03 cumecs (3600 cusecs). Its capacity was increased to 156 cumecs (5500 cusecs) in 2002 due to increasing demand. Provincial Irrigation department has proposed further increased discharge carrying capacity to 187.0 cumecs (6600 cusecs) for which remodeling of the canal is being done. The length of canal is about 60 Km. Fig. 1 shows location of LJC command.

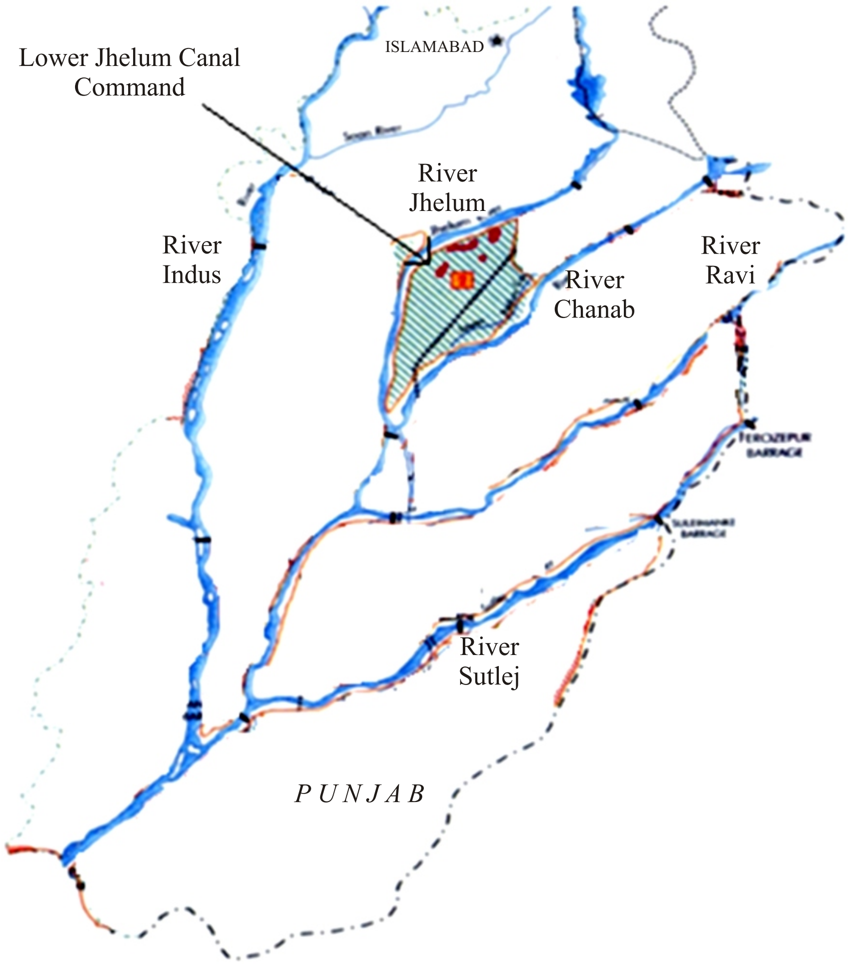


Fig. 1. Location of LJC command Area

III. DATA USED

The following data has been used in the study:

3.1 Climatic Data

Sargodha is the only meteorological station estimating climatic parameters in the LJC command. Daily values for maximum and minimum temperature, wind speed, humidity, daily sunshine hours from 1999 to 2010 were collected for the case study from Regional Meteorological Centre (RMC) Lahore (RMC, 2010, unpublished data). Average monthly values of humidity, wind speed, maximum and minimum temperatures, sunshine hours and rainfall for Sargodha Meteorological Station, Pakistan are shown in Table I.

TABLE I
HUMIDITY, WIND SPEED, MAXIMUM AND MINIMUM TEMPERATURES, SUNSHINE HOURS AND RAINFALL AT SARGODHA METEOROLOGICAL STATION, PAKISTAN

Sr. No.	Month	Mean Monthly Relative Humidity (%)	Mean Monthly wind speed (m/s)	Mean Monthly Max. Temperature (°C)	Mean Monthly Min. Temperature (°C)	Total Monthly Sunshine Hours (h)	Total Monthly Rainfall (mm)
1	January	73.8	0.87	18.29	5.1	162.2	25.2
2	February	62.6	1.35	22.95	8.4	197.2	27.4
3	March	56.6	1.81	28.18	13.6	249.0	21.0
4	April	41.2	2.11	35.39	19.8	262.7	23.3
5	May	36.5	2.41	40.24	24.8	270.6	38.6
6	June	43.4	2.88	40.86	27.3	264.4	37.2
7	July	60.7	2.84	38.08	27.9	228.0	129.0
8	August	65.2	2.27	37.26	27.4	243.5	108.7
9	September	61.6	1.74	36.09	25.0	260.3	40.6
10	October	60.3	1.03	32.94	19.0	254.8	12.3
11	November	64.6	0.54	27.25	11.8	198.4	9.2
12	December	70.5	0.55	21.84	6.4	197.4	16.4

3.2 Cropping Pattern / Intensities for LJC System

Cropping pattern is obtained by averaging crop reporting data available with Punjab Agriculture Department and Punjab Irrigation Department for the period 1998 to 2010 (unpublished data). Analysis of cropping data indicates the intensity of 59% and 62% for Kharif and Rabi seasons respectively with average annual cropping intensity of 121% for LJC command area. The cropping pattern and intensities of LJC system are shown in Fig. 2a and 2b.

3.3 Crop Coefficients, Kc

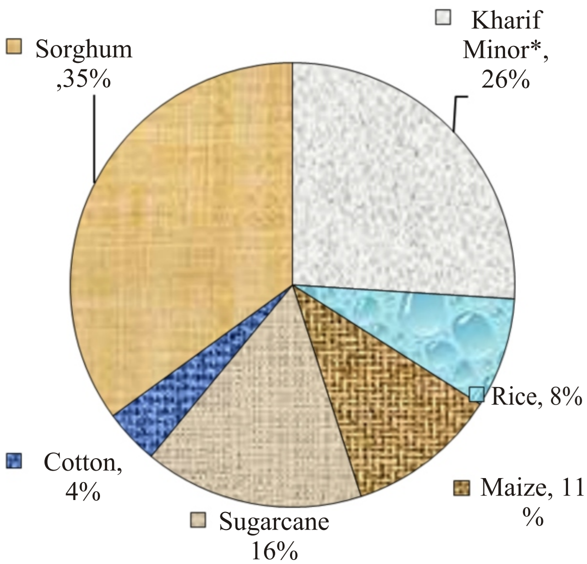
A study was conducted by [vii] to find out the crop coefficients Kc of different crops based on state of the art procedure described in FAO Irrigation and Drainage paper No. 56 (Food and Agriculture Organization (FAO)) [viii]. Same values for crop coefficients Kc of the crops cultivated in LJC command have been used in the analysis. Kc curves of two major crops i.e. wheat and sorghum in the study are shown in Fig. 3a and 3b.

3.4 Lower Jhelum Canal Discharge

Actual average 10 daily discharges of LJC for 19992010 have been collected from (Punjab Irrigation and Power Department (PID), 19992010, unpublished data). The allocated discharges are those given in the Water Apportionment Accord 1991 document. The comparison indicates that available supplies are 10% lesser than the allocated water supplies. The allocated and supplied average 10 daily discharges of LJC are shown in Fig. 6.

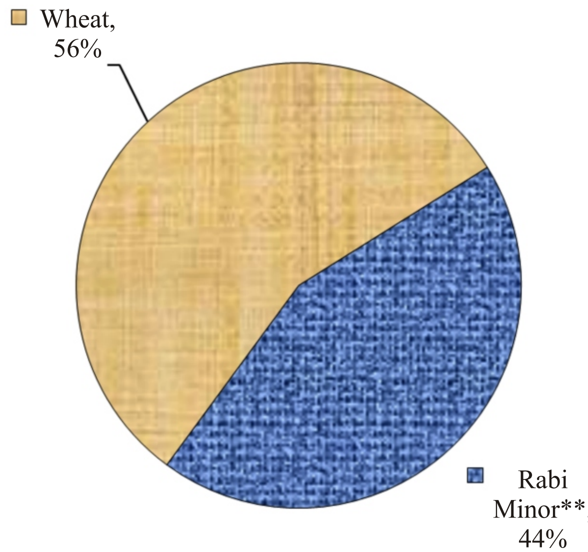
3.5 Irrigation Efficiency

Irrigation looses from head of canal to the root zone of crops in the fields are high and must be included in analysis. Several studies have been carried out in the Indus Basin to estimate conveyance losses upto field level. The findings of some studies have been summarized in Table II. ACE [ix] discussed that the existing efficiency of canal, distributaries/minors, water courses and field is 88%, 83%, 75% and 70% respectively. The overall efficiency reported by ACE [ix] was 38.25%. Directorate of Land Reclamation (DRL) [x] estimated 16.8% losses in main canals, 20% in watercourses, and 25% field losses which leaded to an overall efficiency of about 40%. To compare the crop water requirements and the availability of the canal command it is essential to find out the efficiency of the system. In this study the efficiency of 38.25%, as used by DLR has been used for LJC command.



* Kharif Minor Crops includes mainly jawar, chari, garden, rouni and oil seeds.

Fig. 2a Pattern and intensity for Kharif Crops



** Rabi Minor Crops includes mainly barley, mixed grains, grams, fodders, garden and rouni

Fig. 2b: Pattern and intensity for Rabi Crops

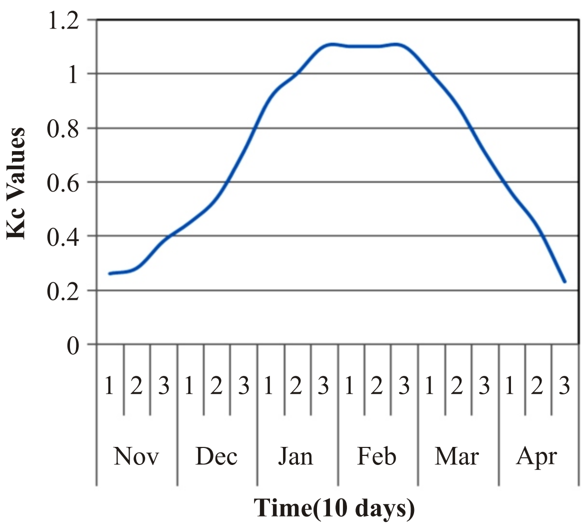


Fig. 3a Kc curve for wheat crop

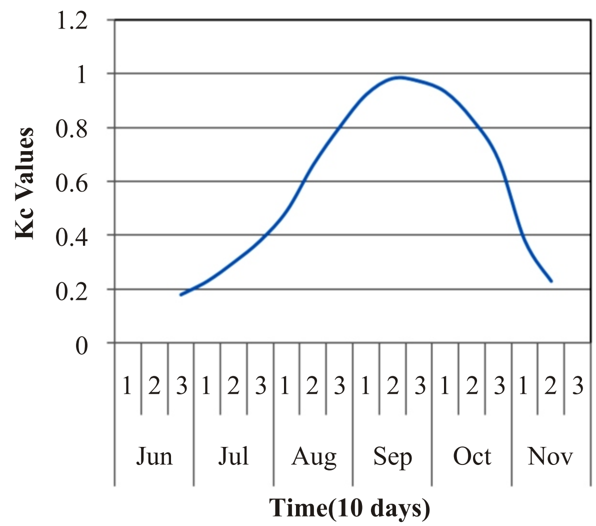


Fig. 3b Kc curve for sorghum crop

IV. Estimating Crop Water Requirements

Evapotranspiration (ET) is required for estimating volume of irrigation water necessary for satisfying seasonal as well as short term irrigation water needs of farms, fields and projects. It is one of the important parameter for designing, planning and operating irrigation/water resources system. The wrong computation of the requirements leads to failure of performance and wastage of water resources. For planning and design purposes, irrigation water requirement has to be studied with respect to the magnitude and variability of the seasonal and peak period irrigation water requirements [xiii].

TABLE II
Efficiencies and Losses of Canal Systems by Different Studies

Sr. No.	Source	Losses (%)	Efficiency (%)
1	ACE[ix]	61.75	38.25
2	DLR [x]	61.75	38.25
3	Ministry of water and Power [xi]	60	40
4	Federal flood commission (FFC) [xii]	60	40

4.1 Estimation of Reference Evapotranspiration (Eto)

Different methods are available in literature to estimate Reference Crop Evapotranspiration (ETo). These methods were reviewed to find out the method that gives best estimated results for Reference Crop Evapotranspiration (ETo). As discussed by Walter [xiv] in ASCE task committee report, "Based on an intensive review of reference evapotranspiration calculated for 49 sites throughout the United States, ASCE Standardized Penman Montieth - 2000 found to be reliable and recommended its use for calculating reference evapotranspiration (ETo), crop evapotranspiration (ETc) and developing new crop coefficients (Kc)". So the same method has been used in the present study. The daily (ETo) of LJC command was estimated using metrological data for the years 1999 to 2010 of Sargodha (the only station falling in this canal command) obtained from Regional Meteorological Centre (RMC) Lahore (unpublished data). Estimated 10-daily average ETo for the station using the Penman Montieth - 2000 is given in Figure 4 and annual ETo works out to be 1646 mm.

4.2 Crop Evapotranspiration (Etc) for LJC System

Estimation of crop evapotranspiration (Etc) of crops cultivated in LJC command area were obtained by multiplying ETo by the crop coefficients, Kc (Etc = Kc x ETo). The values of crop evapotranspiration (Etc) are given in Fig. 4 for the crops cultivated in LJC command. The requirements on 10-daily basis were estimated using Crop Evapotranspiration and reported cropped area. The water requirements at the canal head for the Rabi and Kharif crops are estimated considering 38.25% system efficiency, which has been taken from draft report of National Water Policy [ix] and are shown in Fig. 5.

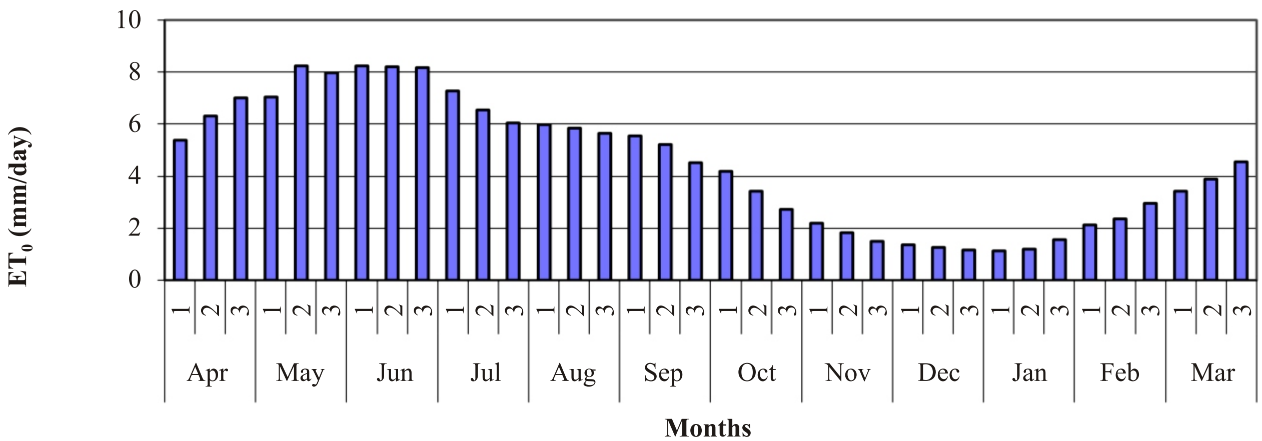


Fig. 4. Average Reference Evapotranspiration (Eto)

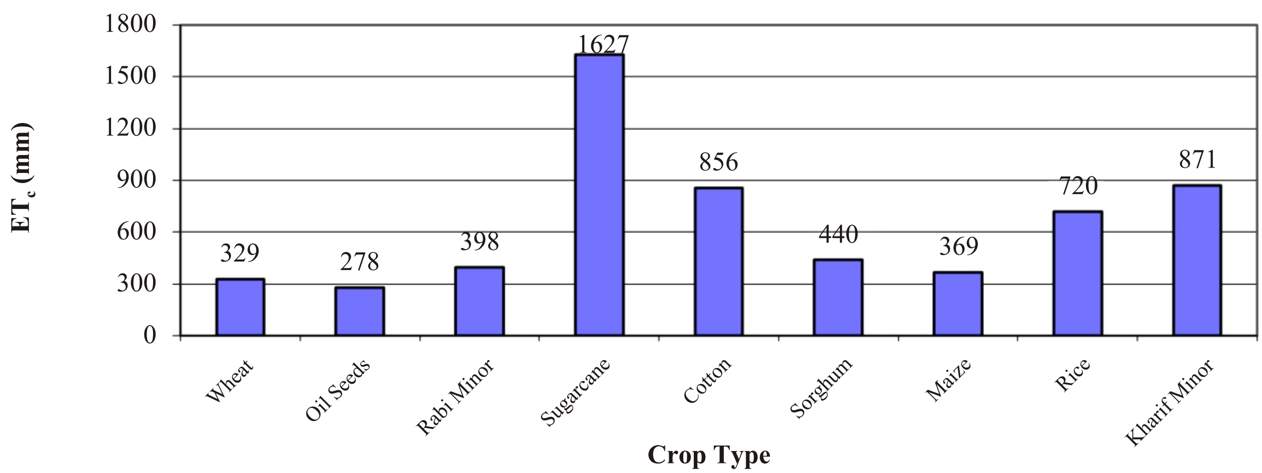


Fig. 5. Etc values for different crops cultivated in LJC command areas

4.3 Comparison of Crop Water Requirements and Availability

The crop water requirements are compared with available canal water supplies at canal head for Rabi and Kharif seasons and are shown in Fig. 6. The comparison of irrigation crop-based requirements has been estimated at 38.25% efficiency. The analysis has also been carried out excluding and including rainfall to find out how 10-daily crop water requirements vary with rainfall. The analysis shows that the shortage of crop water requirements and available water supplies is reducing, as the efficiency of the system increases. The results reveal total crop based irrigation requirements of about 2.7 BCM and shortfall of about 45% for the scenario of 38.25 % system efficiency including rainfall. The shotfall further increases to about 59 % by excluding rainfall in the analysis. Fig. 6 depicts larger deficit during the months of July, August and September in Kharif season and February and March in Rabi season.

It also shows that available surface water supplies cannot meet the crop water requirements and groundwater is abstracted to abridge the gap between demand and supply. The groundwater of LJC command is of marginal quality. The excessive use of groundwater for irrigation reduces the crop yields and increases salinity. The conjunctive use of canal and groundwater in optimized proportion has been suggested to get maximum crop yields and reduces the trend of increasing salinity.

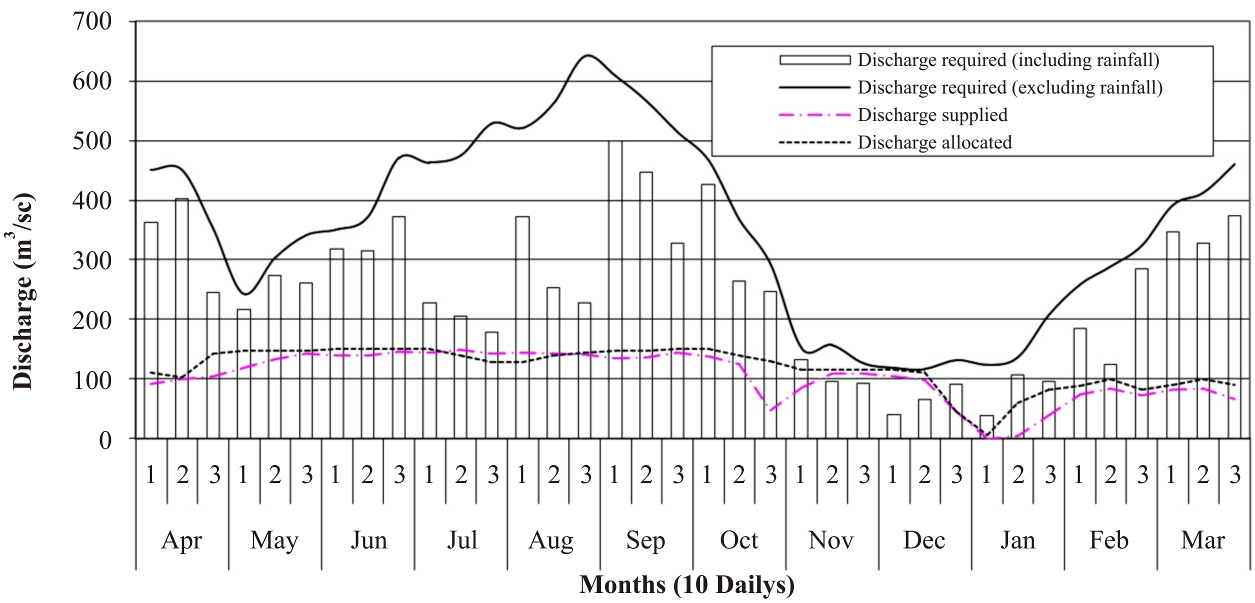


Fig. 6. Comparison of water required, supplied and allocated on 10 Daily Basis at Canal Head

V. ISSUES OF LOWER JHELUM CANAL COMMAND

LJC has served its useful life of 100 years, with minor repair and maintenance. With the population growth, stress irrigation and adoption of modern farming and techniques, vast tracts of barren land was brought under cultivation for which the capacity of LJC was increased. Upto 2008, LJC was badly deteriorated. The banks of the channel were in a worn out state and inadequate freeboard was available in many reaches. All the hydraulic structures, being more than 100 years old, had been deteriorated and were generating undulating flow on downstream side in the channels. The channel prism had widened and a lot of cattle ghat sites have rendered the prism in a wild shape. Gates and gearing machinery being as old as the LJC system itself had eroded badly. Most of the channels were running in a precarious condition and these are unable to convey the required discharge. Breaches occurred very frequently, which interrupted supplies to farmers. Also inefficient water application methods (wild flooding techniques), improper land leveling, poor condition and layout of water courses were observed. As such, the water conveyance and water application losses had been increased and the system was losing efficiency day by day. In the circumstances as explained above, a project for Rehabilitation of Lower Jhelum Canal was executed from 2005 to 2008 to rectify all the problems as discussed above. The remedial measures implemented include but not limited to the following: i) earthwork to achieve the desired channel section, ii) earthen banks strengthening by stone pitching along with apron, iii) rehabilitation of hydraulic structures along with stone pitching and apron at their upstream and downstream iv) provision of pushta to cater for hydraulic grade line. Moreover, concrete lining of distributaries and minors were also started in 2008 and it is in progress.

VI. Possible Scenarios for Optimization of Irrigation Water Management

The possible strategies of optimization are enhancing productivity of water by high value and high yield crops, increase efficiency, applying RCIs, improving irrigation system and on-farm water management. Reference [xv] discussed that developed countries are shifting the trend from water productivity and crop yield to high value crops. The profitability of high value crops is much higher than the low value crops. Other economic indicators like IRR of high value crops are also higher than other crops. The high value crops like fruits, vegetables can also sustain in drought season.

High value/yield crops can provide huge economic return. For example olive plantations and modern vineyards needs less than 2,500 m^3/ha of water and their water productivity is equivalent to cotton or sugar having three times more evapotranspiration [xvi]. Fig. 7 shows road map for improving the irrigation water management at canal command level.

VII. Improving Irrigation System and On-farm Water Management Strategies

The structural measures identified in the present study for improving canal management and conveyance efficiency of the LJC system, include rationalization of canal capacities in keeping with the current water requirements and availability, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. For rehabilitation and remodeling of canal involves improving the channel prism to cater for enhanced discharge, raising and strengthening of canal banks, providing cattle ghats, upgrading hydraulic structures had been suggested. Suggested water management measures are regular water flow measurements to ensure adequate, reliable and equitable water distribution at different levels of LJC irrigation system and participation of farmers in the operation and maintenance of canal system using the ongoing reforms framework, whereby the farmers are being empowered for management of the distribution network.

An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling, zero tillage, and bed-furrow irrigation method. Adopting proper cropping systems considering land suitability and capacity building of farming community in improved soil, crop and water management technologies would enhance the water productivity in an effective and sustainable manner.

Resource conservation interventions (laser land leveling, bed & furrows and zero tillage) can save 50% water and increase the crop yield upto 25% [xvii]. Reference [xviii] concluded that laser land leveling (LLL) can enhance crop yield from 20 to 35% and save 25% irrigation water. The use of RCIs can save 20 to 30% irrigation water [xix] . Reference [xx] evaluated the impact of resource conservation techniques on water and land productivity. These techniques were tested on 200 acres of land (Mona Reclamation Area) in LJC command. It was concluded that average yield/acre for wheat crop in case of laser leveling was the highest with 1856 kg/acre followed by zero tillage with 1812 kg, bed & furrow with 1673 kg and conventional farms with 1615 kg/acre. On an average 0.30 AF of water per acre could be saved by adopting zero tillage technology besides saving a pre-sowing irrigation. Moreover, significant quantity of water could be saved by adopting laser land leveling & bed and furrow method of wheat sowing.

Reference [i, xxi] recommends increase in irrigation system efficiencies to 45%. While there may be uncertainty as to whether this can be achieved, there is significant scope for this modest increase, through farmer education in water application in the field and through on-farm water management in the form of lining watercourses. The use of RCIs has proved several benefits to wheat farmers. Water can also be saved upto 34% by using ridge furrow of 660cm wide [xxii, xxiii].

The demand side management by optimized cropping pattern can improve crop productions and reduce the pressure of water shortage to some extent. The growth of high delta crops should be avoided. The crops grown in LJC command need to be rationalized so that the pattern of crops provides high water productivity and crop yield. The traditional pattern of wheat-rice has resulted better economic return. The sugarcane crop has resulted poor water productivity and allocation of resources. Awareness should be created among the farmers to discourage the growth of sugarcane. The water productivity of Orchards is very high and also these are high value crops. The area is also very famous for oranges, which is liked all over the world. Key crops identified in the study for LJC command are wheat and orchards for Rabi season and rice, cotton and orchards for Kharif season. The cropping intensity of these crops may be increased so as to make the cropping pattern optimized. Reference [xxiv, xxv] suggested that several organizations are involved in management and distribution of water, on farm water management and revenue collection at canal command levels in Pakistan. Generally there seems to be lack of coordination and overlap of activities among the agencies causing poor overall performance. It may be advisable to provide a single

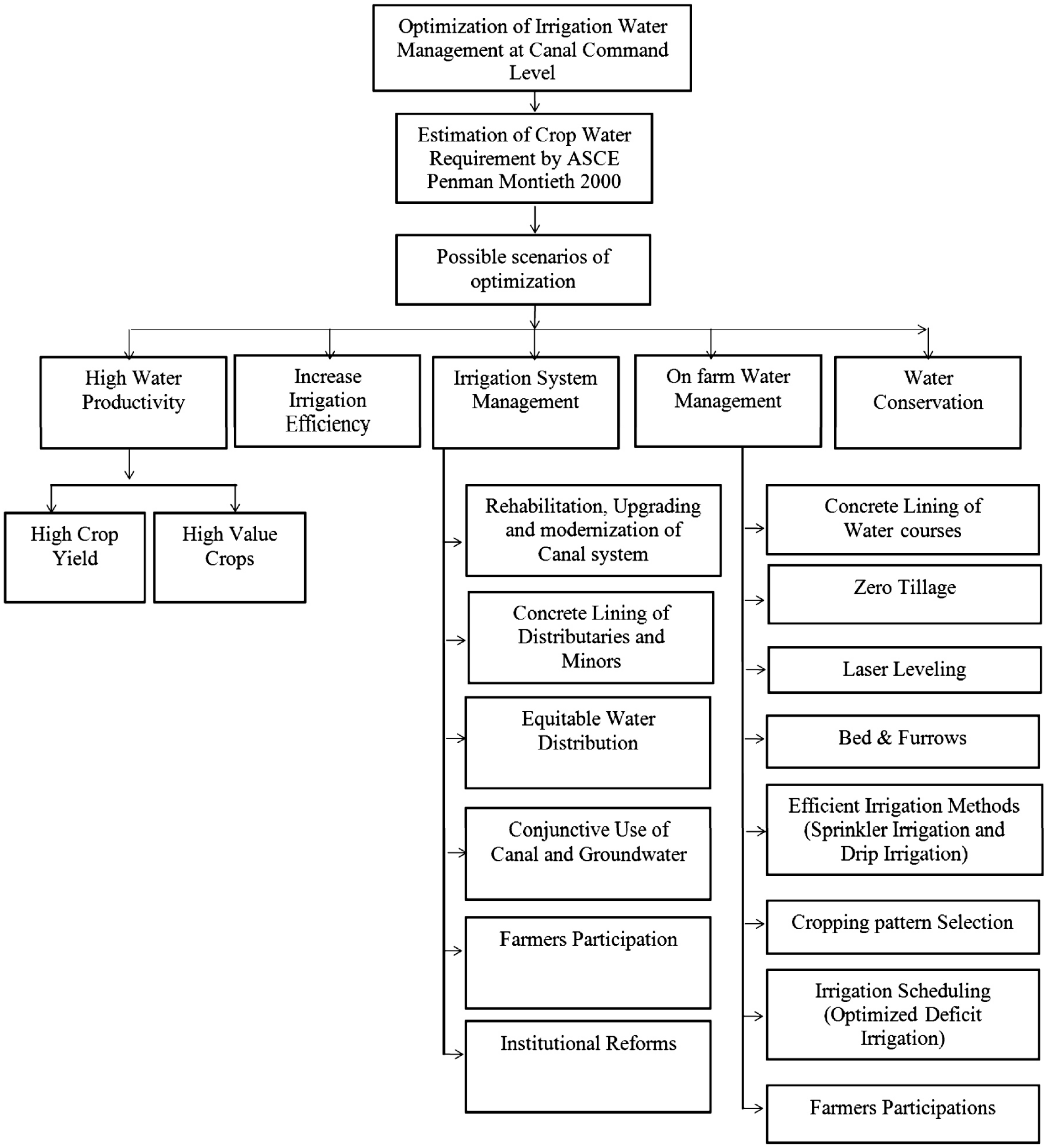


Fig. 7. Schematic Diagram of Optimization of irrigation water management at Canal Command Level

administrative unit bringing together all stakeholders. The last but not the least, the participation of farmers in management needs to be enhanced in real terms to create within them a sense of owner ship of the system. The results of the present study of 45% shortfall at 38.25% efficiency are compatible with the findings similar study conducted by [xxv] for canal water management of Upper Chanab Canal (UCC) in Pakistan. The crop based irrigation water requirements of UCC computed was 2 BCM leading to shortfall of more than 40% on an annual basis at 40% overall system efficiency. The prospective measures identified in the study for reducing shortfall included enhancement in canal supplies, change in cropping pattern, canal lining and on farm water management.

The constraints for implementing the optimization strategies identified in the study include: physical constraints due to poor operation and maintenance of the system and inadequate water control structures. Institutional constraints due to public sector monopoly, lack of coordination among different institutions and agencies, limited specialization and skilled staff, limited involvement of farmers in irrigation management. Financial and economical constraints due to inadequate cost recovery and provisions for operation and maintenance of irrigation system.

VIII. CONCLUSIONS

The following conclusions may be drawn from the present study:

1. The comparison of actual crop water requirements and available water supplies indicates a shortage of more than 50% for LJC system on annual basis.
2. The shortfall in availability and requirements is met by pumping groundwater of marginal quality. A comprehensive study is needed for optimized conjunctive use of surface and groundwater to minimize the ill effects of increasing salinity.
3. The possible strategies of optimization are enhancing the water productivity by high value/yield crops, improving irrigation system and on-farm water management/efficiencies and adoption of resources conservation interventions. An array of measures and practices identified for improved water management at the farm level include: improvement and lining of watercourses, proper farm design and layout, adoption of resource conservation technologies involving laser land leveling (LLL), zero tillage (ZT), bed-furrow (BF) irrigation method.
4. The structural measures for improving canal management include rationalization of canal capacities, rehabilitation and remodeling of canal network and lining of distributaries and minors in saline groundwater areas. Suggested water management measures are regular water flow measurements to ensure adequate, reliable and equitable water distribution at different levels of LJC irrigation system and participation of farmers in the operation and maintenance of canal system

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