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HYDRAULIC SIMULATION OF LOWER BARI DOAB CANAL (LBDC) PUNJAB PAKISTAN

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SYNOPSIS:

The hydraulic simulation of Lower Bari Doab Canal, off taking from left flank of river Ravi is accomplished using hydrodynamic simulation irrigation canal model SIC. Hydraulic simulation models are used for improving the performance of the irrigation systems by studying the flow behavior under a variety of design and management practices. The Model was calibrated and validated under steady state conditions. The model was applied between head RD 0 to RD 69.345 KM (RD 211+452) for simulating flow in a series of linearly connected reaches. The different boundary conditions modeled were discharge hydrograph at the source node(s) and stage hydrograph, rating curve, uniform flow, and discharge hydrograph at the terminus node(s). The model was set for handling different hydraulic structures such as weirs, sluice gate, falls, outlets, and imposed discharge. The model allowed computation of gate opening for a given full supply level and discharge at the head/cross-regulator and off taking points, respectively. The simulated discharges and observed hydraulic daily data were in close agreement for the studied reaches. The comparison of simulated and observed discharges showed that the model performed satisfactorily for most of the irrigation events. The SIC model can be considered a tool for understanding the operational aspects for improving system efficiency.

1.1 INTRODUCTION

The hydraulic computer simulation is an attempt to model a real irrigation system so that it can be studied to see how the system works. By changing variables, predictions can be made about the behaviour of the system. With advanced technological innovation, irrigation has become efficient and provides more per unit volume of water. The poor performance of aged irrigation system in developing countries like Pakistan produces low delivery and application efficiencies. As a result, the existing cropping intensities don't fulfill the present day requirements of irrigated agriculture. Due to increasing demand for irrigation water, efforts have been made to improve efficiency of irrigation system through improved management and operation. The hydraulic simulation models are appropriate tools for understanding the hydraulic behavior of system as a whole. The 2D hydrodynamic computer model Simulation of Irrigation Canal, SIC (Authorized Version 4.27a purchased from CEMAGREF, France) has been selected

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for use on LBDC irrigation system. This model is robust from numerical stability point of view. It can accommodate irregular shape of canal cross sections and simulate flow for a very long canal system with several off take points and in-line control structures.

For simulation of canal system, the data sets are classified into three broad categories, namely hypothetical, model canal system, and full scale operating canal system. The real canal systems are more complex and face practical constraints and limitations. For efficient operation and management, there is growing need to test the simulation of models for the complex irrigation system. For this, the SIC model has been tested on Lower Bari Doab Canal System (LBDC) from Head RD 0 to 69.324 km (RD 227+454), a century old historical system in the Indo Pak Sub Continent. The present study aims at using SIC model in improving the operation and management of a large and complex canal network.

1.2 LBDC COMMAND SYSTEM

The Lower Bari Doab Canal (LBDC) Command System is situated in the East-South of Punjab Province of Pakistan. It is located in the Bari Doab between the rivers Ravi and Sutlej and bounded by river Ravi in North and Sukh Beas Drainage channel in the South. The LBDC off takes from left bank of river Ravi at Balloki Headworks with the design discharge of 278.70 m^3/sec at its head and flows for some 201.372 km along the length of command area of about 0.676 million hectares. There are 65 distributaries off taking from main canal and 24 in–line canal cum regulators /falls in addition to 14 direct outlets in the LBDC main system. The FIG.-1 shows the boundary map of Lower Bari Doab Canal irrigation system along with the network of the main and branch canal systems and its distribution system. After completion of Mangla Dam in 1967 under Indus Basin Treaty (1960), most of the water to the canal is supplied from the Chenab and Jhelum rivers by transfer through Rasul-Qaderabad and Qaderabad-Balloki link canals which put the area in direct command of Mangla reservoir. During summer, flood supplies of Ravi are also diverted into LBDC. Most of the area receives perennial supplies except about 17,250 hectares of non-perennial area which mainly comprises of forest plantation. Groundwater is being used in the project area, mainly for irrigation purposes through private tube-wells of about 20,000 supplementing canal irrigation supplies, contribute more than 34 percent of the crop water requirements at crop root level account for more than 44 percent of the total available supplies at the head. The study is confined to the main canal from RD 0 to 69.324 km (RD 227+452). The Model is calibrated and validated under steady state conditions.

1.3 HYDRAULIC PROBLEMS

The main sources of irrigation supplies to the command area of Lower Bari Doab Canal (LBDC) are (i) canal water, (ii) groundwater, and (iii) Rain water. The canal water supplies average to an annual figure of 4.86 MAF plus share of flow supplies during the flood period. Total annual groundwater abstraction of 2.2 MAF is used to supplement surface water canal water. Average annual rainfall varies from about 366 mm to 249 mm contributing to an annual average of about 1.06 MAF. There exists inequity in distribution of Irrigation water. As per prevailing intensities of irrigation, canal supplies only meet 44% of crop water requirements in the LBDC Command area and by the use of groundwater; it is about 34%, leaving a deficit of about 22% of the crop water requirements which is practiced as "Stressed Irrigation". Due to the shortage of water in the river system and limited transfer capability, the area faces severe water shortages especially during critical periods of cropping seasons. The physical delivery efficiency is quite low about 40% from barrage to the root zone. The area lies in the cotton-wheat zone, with cotton being major crop in Kharif and wheat in Rabi. The traditional warabandi system is being implemented in the system. A fixed duration, variable discharge, and variable frequency delivery scheduling are practiced. The duration of water supply per irrigation is seven days. All the irrigation system in the country are designed to be operated at, or near full supply capacity. The LBDC operational flow system significantly below the design capacity leads to inequity in the geographic distribution of water.

1.4 REHABILITATION OF LOWER BARI DOAB CANAL SYSTEM

For the improvement of the historical Lower Bari Doab Canal Irrigation System, Asian Development Bank and Government of Punjab have together launched the Lower Bari Doab Canal Improvement Project to maintain and enhance the water supply up to 0.676 million hectares in the districts of Kasur, Okara, Sahiwal and Khanewal. This Project comprises of the rehabilitation and up-gradation of Balloki Barrage Complex, On Farm and Ground Water Management, implementation of Institutional Reforms and environmental issues of the area. The total cost of the LBDCIP is Rs. 17,176 million, out of which 77% is the share of ADB, while rest of the amount is shared by Punjab Government. The project is at initial stage of implementation.

1.5 MODEL DESCRIPTION

The SIC hydrodynamic model is a mathematical simulation model that allows users to simulate the hydraulic behavior of irrigation canal in steady and unsteady flow conditions. The SIC model is divided into three units. Unit I is designed to create the topographic files used for program calculations of Unit II and Unit III. It is a menu driven unit and programs have user friendly interface. These files contain the characteristics of the system (topology, geometry, and branches). A file is created by topographical file data editor that contains all topographic, geometric and graphical data of canal system. The Unit II is designed to perform calculations in steady flow. It allows users to study the profile for any combination of flow or off take position (gate opening, weir level, or width). This unit permits the user to determine the required openings for the off takes and adjustable gates so as to satisfy the given water rotation schedules while maintaining a set target water levels in the canal. Unit III is used to make calculations in unsteady flow. This allows users to test various water rotations schedules, different manipulations on the head gate and regulation structure details.

1.6 MODEL SET UP

For hydraulic model set up, the canal cross sections, main canal network layout, falls control data, head and cross regulators, upstream and downstream initial and boundary conditions and seepage losses were defined. The details of input data are depicted in Table-1 and Table -2.

1.6.1 Data Requirement and Collection

The necessary information / data of hydraulic structures cross sectional details of canal, longitudinal sections, location and geometry of off takes and canal inflow and discharge observation data were collected from the offices of Irrigation and Power Department, Punjab.

1.6.2 Cross-Sections Data Definition

The reach geometry was defined by the cross section profiles. The cross-sections survey data were available at discrete points along the canal system. Each point was input in terms of its cross–wise abscissa and its elevation. The sections were introduced from the left bank. The elevations were indicated with reference to the unique datum in order to compute local slopes. Every cross section was defined by canal name, topographical identification, and chainage in metric system. At cross regulators and falls, the cross sections were defined upstream and downstream. A singular section was that section in which one or more hydraulic structures are defined. A reference elevation was defined for each cross section. All elevations were stored in absolute value in the geometry file. The model based layout details is depicted in FIG.-2. The topographical information, upstream and downstream connections, cross sectional distance was required for channel network definitions.

1.6.3 Hydraulic and Regulating Structures Definition

The main canal under study consisted of 25 off take channels, 2 no. meter flumes, 3 cross devices, one fall structure and 7 direct outlets and two inlets. The details are shown in Table-1. The discharge was controlled at Head Main Canal Regulator, meter flume at RD 8.28 km and at meter flume 69.324 km (RD 211+452). These cross devices were controlled according to the discharge at the particular location. The hydraulic parameters at these control points such as location, gate type, number and width of bays, sill level / crest level and type of structure were defined in the topographical / topological module of the model.

1.6.4 Initial and Boundary conditions

The initial conditions were defined as global values of water levels and discharges for the entire canal network. The boundary condition at node points and structures were given. The values of canal flow depth and discharge or time varying values were entered as boundary conditions. The boundary condition, the daily discharge data at the system source, and water level at the end points were defined in the time series data file. For downstream conditions, the calculation of water surface profile was initiated at the downstream end of a reach and preceded upstream. Therefore a relationship between water surface elevation and discharge was needed as a downstream boundary condition in order to begin the calculations.

1.6.5 Simulation parameters

The simulation period, simulation time step and storage time was identified as simulation parameters. The simulation period was specified by the start end dates defined by the year, month, day, hour, and minute. The model checked the actual time and read all data given as a time series during the simulation. The Courant number was considered for selecting the time step, which checked and controlled the whole simulation process.

1.7 RESULTS AND DISCUSSION

1.7.1 Model Calibration

For modeling the main canal head reaches, the gate contraction coefficient, hydraulic parameters of falls/meter flumes/cross regulators were defined as model calibration parameters. The resistance number was identified as reciprocal of the Manning's roughness coefficient (also known as Strickler's Coefficient). At control point such as fall / cross regulators or meter flume, the discharge value was taken as control parameter for the operation of the gate in the structure. For initial run of the model, the resistance number and gate contraction coefficient were considered. For simulation, the data of Kharif period 2008 (April to September) and Rabi period 2008-09 (October to March) were used. The different time steps were selected. Thereafter, a comparison was made between the observed and simulated supply levels and discharges at different control points and off taking head regulators along the length of the canal. During the process of comparison, the model parameters were adjusted till the observed and simulated discharges were in close agreement. FIG-3 shows the observed and simulated supply line of said reach.

1.7.2 Model Validation

The comparison between the observed and simulated discharges at the selected locations along the main canal for the validation period of 2008-09 was carried. The results indicated that the model computed discharges were in close agreement with the observed values for the reach under study. Based on the results of validation for the irrigation even under study, it was concluded that the model performs well with high validity.

1.8 SUMMARY OF RESULTS

- The Saint-Venant equations were widely used to describe water discharge in a canal. The simulations were carried out using the software simulation of irrigation canals (SIC), which implemented a semi-implicit Preissmann scheme to solve the nonlinear Saint-Venant equations for open-channel one-dimensional flow. LBDC was viewed and modeled as delay systems since it took time for the water released at the upstream end to reach located downstream.
- The simulation has indicated capacity problem for the design conditions. While operating at full supply, the short of supply was observed about 17% from the design supply (Ref. FIG-3). This has shown that existing prism

section of canal could take full supply authorized discharge. The field observed data also confirmed that during the past decade, LBDC main canal have never been operated at full design supply, the actual performance of the structures were also not available.

- The canal structures have not been calibrated yet. Some structures are model calibrated. (Ref. Table-3). However, the design rating curves for cross - regulators and estimated rating tables for head regulators were used.
- Model calibration was achieved by adjusting hydraulic parameters in order to adjust how the model operated and simulated the process.
- Model verification was achieved by obtaining output data from the model and comparing it to what was expected from the input data.
- The validation of the model was done by comparing the results with what's expected based on historical data from the study reach. Ideally, the model would produce similar results to what has happened historically.
- Simulation on the data of 2005-06 has indicated a reduction of canal capacity by 17% in a stretch between 33.201 km to 69.324 km.
- The cross regulators (gated/karries) were operated to create backwater effect and a maximum upstream level was maintained even during low delivery events.
- Almost all of the off taking distributaries in the studied reaches were operated as submerged to feed maximum design discharge. The downstream influence was quite high on these regulators.
- In practice, it was difficult to obtain good data for comparison of simulated versus actual hydraulics because of the uncertainties of actual flow rates, canal dimensions and roughness, and water levels.
- The simulation of actual main canal and its distribution system is a complex phenomenon. The study shall be extended up to tail RD 201 km of Main LBDC.
- This research would serve as a decision support tool for the system managers to formulate effective and responsive control operation strategies under varying flow scenarios.
- This research study shall provide an in-depth analysis of the hydraulic behaviour of the canal network.

1.9 CONCLUSIONS

The figures and discussion above give a brief glimpse of the research. The points below summarize conclusions from that glimpse, plus provide a few additional insights to research results. The points include:

a) The present delivery hydrograph of main canal showed that the actual demand curve of the area was different in quantities and patterns. As the system was operating very near to the demand based, the calibration and validation values indicated that the Simulation model for LBDC Main Canal performed satisfactorily. The results showed that the model computed discharges were in close agreement with the observed values for the said study reach. Based on the results, it was concluded that the model performed well with high validity.

b) Most of the major irrigation command areas in Pakistan suffer from problems of inadequate and unreliable water supply, having wide gaps between irrigation potential created and utilized. This leads to temporal imbalance of water demands and supplies, excessive seepage losses and rise of ground wavetable, resulting in problems of water logging and salinity. Simulation models are used as a tool to verify engineering problem if calibrated properly. Once satisfactory estimates of the parameters for model have been obtained, the model was checked to assure that it adequately perform the functions for which it is intended. The validation process established the credibility of the model by demonstrating its ability to replicate actual flow patterns. The importance of model validation underscored the need for careful planning, thoroughness and accuracy of the input data. For the said study, the efforts were made to ensure collected data was consistent with expected values.

c) All these problems exist due to inadequate attention paid to the assessment of water availability, non matching of canal water releases with rainfall, crop water requirements and change in the cropping pattern from what has been envisaged at the time of planning. While short-term imbalances between water supplies and demands are inevitable, it is possible to reduce these considerably, if not totally, through development and adoption of appropriate water-management techniques like simulation through computer softwares and policies that take into account rainfall, changing cropping pattern and crop water demands.

d) The LBDC canal water-release is supply-based and does not meet the actual water requirement of the existing cropping pattern and under actual level of groundwater exploitation. The simulation model is developed for providing existing large complex system to reduce the gap between the demands and supplies. This simulation model once completed, shall provide operational guidelines, make more efficient, and work on several assumptions.

e) The simulation model was run for maximum operative discharge with seepage losses and roughness coefficients. The canal reaches were calibrated using Manning's relations and the design discharge in each reach. The simulated water levels were compared with the design levels. The simulated water surface matched with the designed water surface with adjusted Manning's value. At full supply, all off takes can obtain the maximum design discharge. The canal has in-sufficient free board to operate at design authorized discharge and face capacity problems. Field calibrated results indicated that adjusted water surface profile was obtained to match the designed water surface.

f) This research would serve as a decision support tool for the system managers to formulate effective and responsive control operation strategies under varying flow scenarios. This research study shall provide an in-depth analysis of the hydraulic behaviour of the canal network. The equity, adequacy, dependability, and efficiency are key performance indicators adopted for evaluation of irrigation water delivery system. Hydraulic simulation of full length of main canal RD 0 to 201372 m using survey data of 2009 shall be completed. Calibration & validation of inline and off-takes structures for performance assessment shall be taken up. Trends of sedimentation behavior shall also be incorporated in research work. This study uses the hydrodynamic computer simulation model for improving irrigation system management and operation.

1.10 ACKNOWLEDGEMENT

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1.11 REFERENCES

1. The 2D hydrodynamic computer model Simulation of Irrigation Canal, SIC, Version 4.27a CEMAGREF, France.
2. Lower Bari Doab Canal, Historical Data, Feasibility Reports, Project Reports, etc.

Photo # 1: View of Head Regulator of Main Canal RD 0 (LBDC)

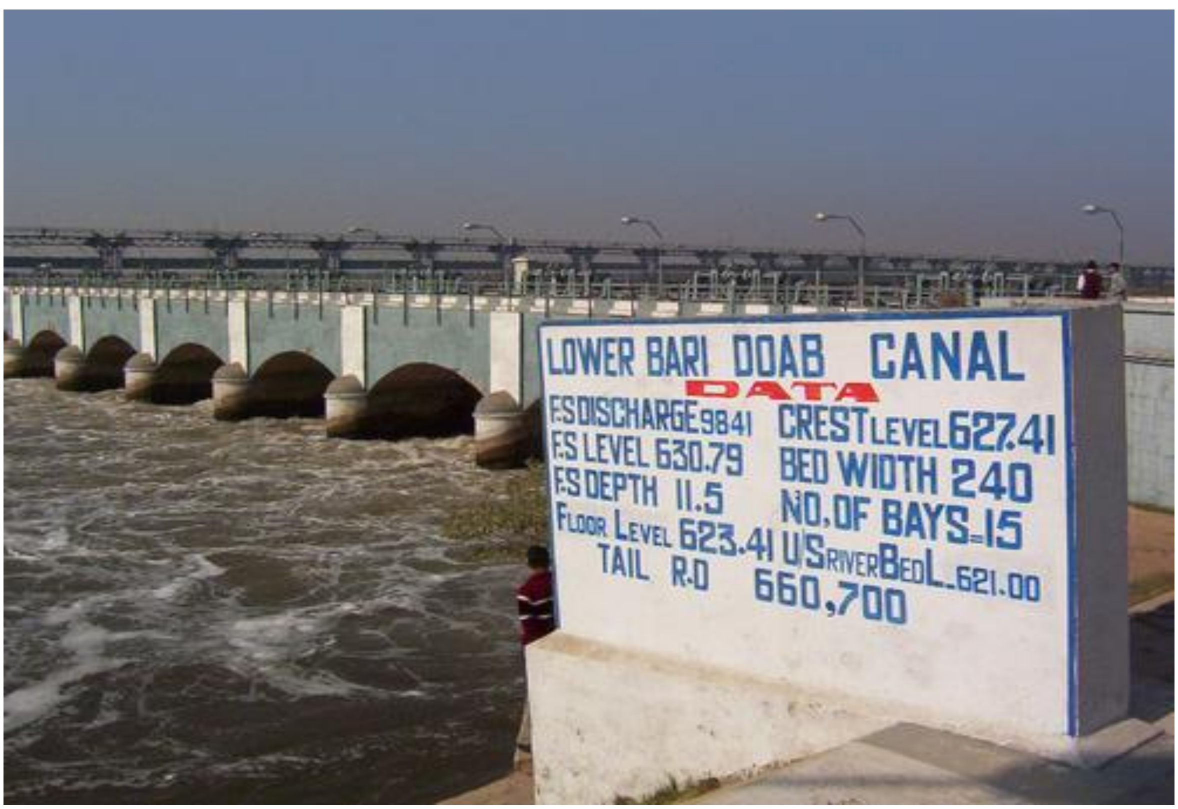

Photo # 2: View of Head Regulator of Main Canal RD 0 (LBDC)

Photo # 3: View of downstream of Fall structure RD 19.11 km Main Canal (LBDC)

Photo # 4: View of Upstream of Fall RD 59.815 km Main Canal (LBDC)

Table-1: DETAILS OF STRUCTURES CALIBRATED REACH
Head RD 0 to 69325 m (Rd211+452) LBDC (MAIN CANAL)

Discharge at Head	278.70 cumecs
Length of calibrated reach	69325 m
No. of off take Head Reg.	25
No.of Direct Outlets	7
No. of Meter Flumes	2
No.of Cross regulators	2
No of Canal falls	3
No. of inlets	2
Discharge at RD 69325	210.45 cumecs

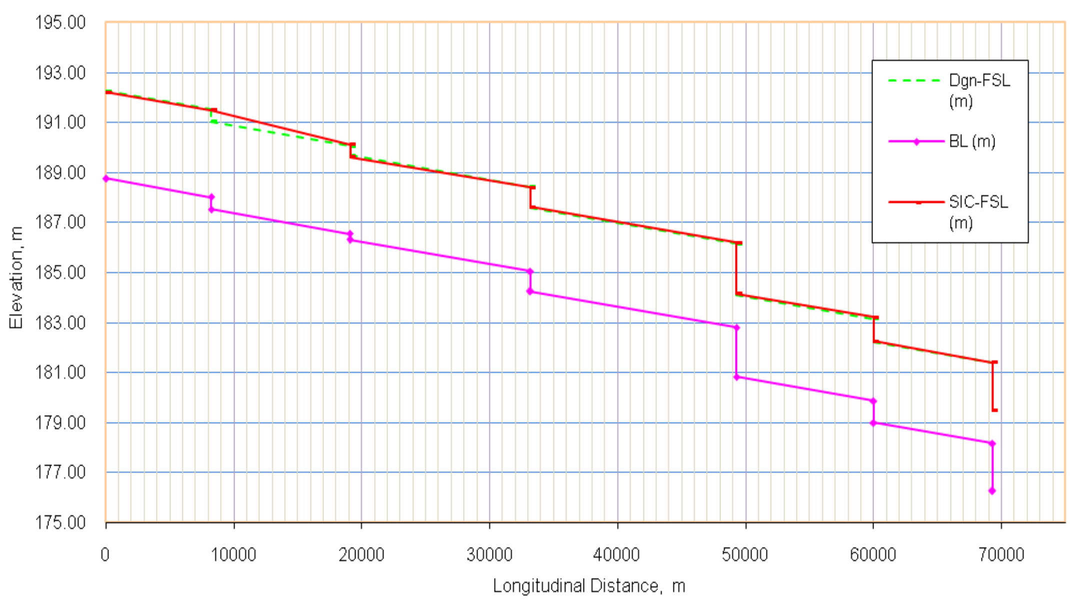

Figure-3: Simulated vs design F. supply line of LBDC RD 0 to RD 69.324 km

Table-2: Simulated roughness for reaches from RD 0 to RD 69.324 km

ach No	RD (m)	Inflow (m^3/sec)	Outflow (m^3/sec)	USD (m)	DSD (m)	Simulated Roughness	Standard Roughness values range
1	0-8282	255	250.5	4.419	3.505	0.0212	"Natural channels with regular sections of and little weed growth" range 0.02-0.0225 (Chow, 1959; Brater & King 1976; French 1985)
2	8282-19114	250.5	223.91	3.5	3.383	0.0215	
3	19114-33201	223.91	210.29	3.322	3.261	0.0223	
4	33201-49300	210.29	199.17	3.23	3.2	0.0221	
5	49300-59815	199.17	188.04	3.18	3.14	0.022	
6	59815-69324	188.04	184.25	3.11	3.06	0.0206	

Table-3: Details of in-line structures from RD 0 to RD 69324 km

Structure type	RD (m)	No. of BAYS	Bay width (m)	Simulation	USD (m)
Head	0	15	6.096	Calibration	3.505
Meter Flume	8282	7	8.914	Calibration	3.383
				Validation 1	
				Validation 2	
X-REG (stop logs)	19114	11	5.729	Calibration	3.261
				Validation 1	
X-Reg (Gated)	33201	9	6.476	Calibration	3.2
				Validation 1	
Fall (weir)	49300	7	6.476	Calibration	3.14
				Validation 1	
X-REG (stop logs)	59815	7	6.746	Calibration	3.06
				Validation	
Meter Flume	69324	7	6.171	Calibration	3.06
				Validation 1	
				Validation 2	

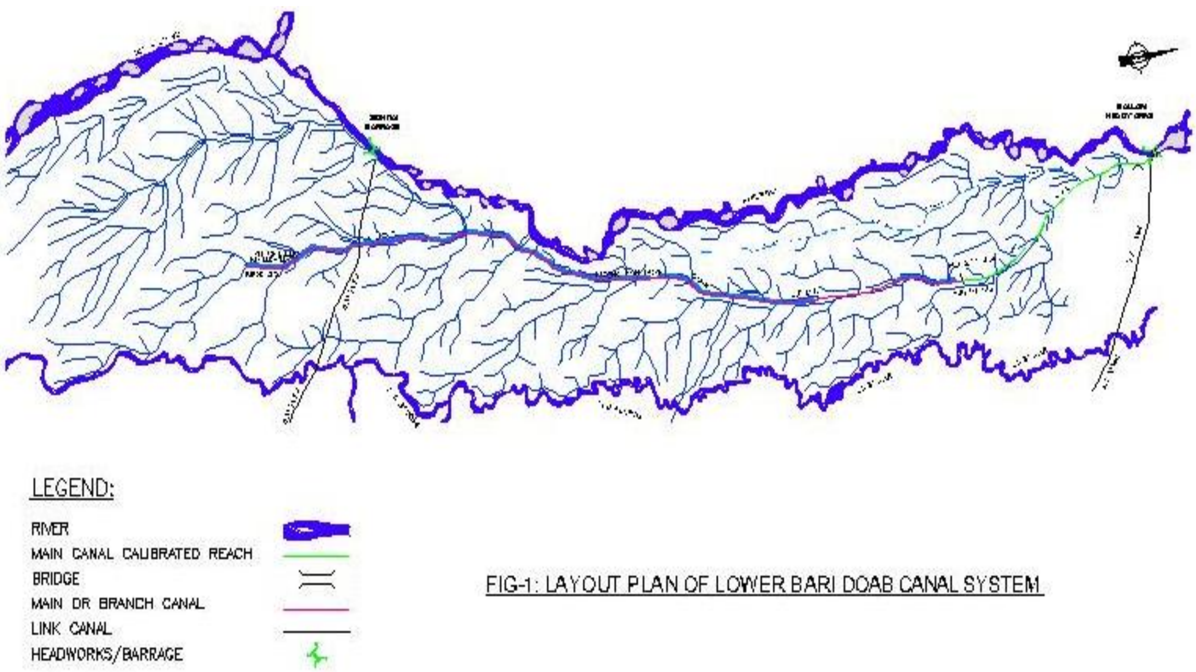

FIG-1: LAYOUT PLAN OF LOWER BARI DOAB CANAL SYSTEM

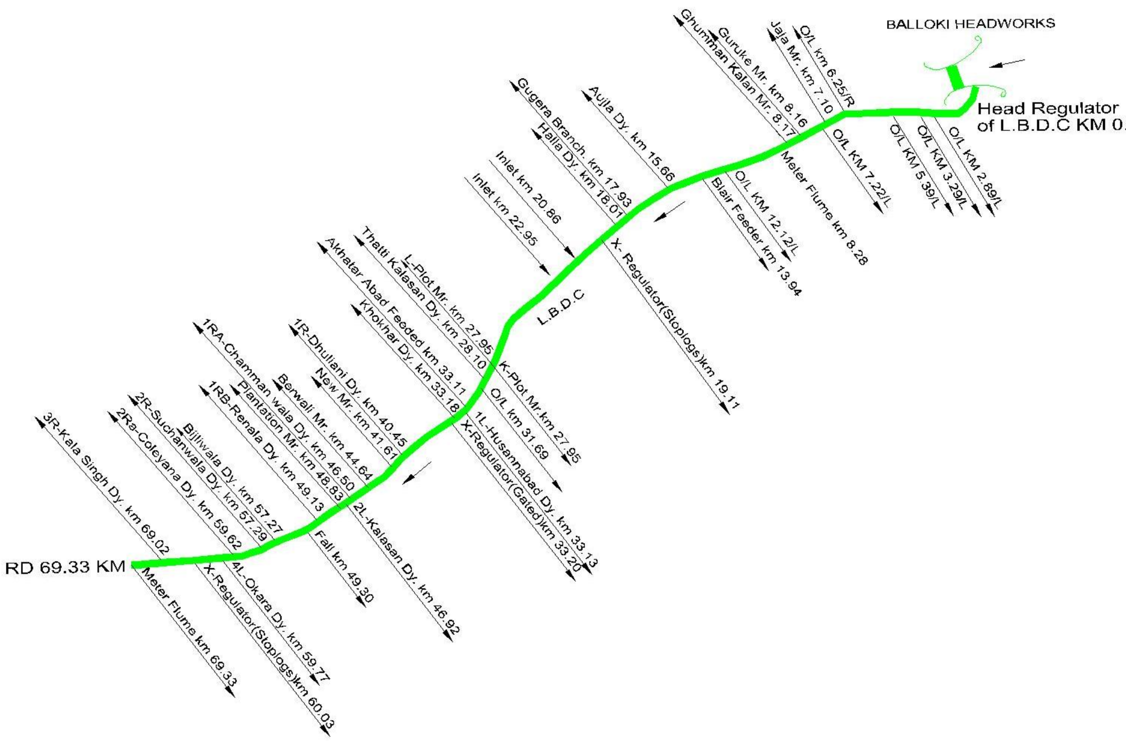

Figure-2: Studied reach main canal LBDC RD 0 to RD 69.324 KM