INVESTIGATION OF PERFORMANCE AND SEDIMENT TRANSPORT OF LOWER BARI DOAB CANAL

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ABSTRACT

Economy of many countries world-wide depends upon irrigated agriculture. The performance of irrigation system having large network of canals fed from rivers is influenced by many parameters. Inequitable water distribution, Shortage of water during peak crop water requirements, tempering of insufficient funds for proper maintenance and high sediment loads in canals are worth mentioning issues. In this paper the performance of Lower Bari Doab Canal with emphasis on sediment transport analysis has been investigated using field data. The performance of canal has been discussed using delivery performance ratio (DPR) a well known performance indicator. The sediment laden water flow problem may be described by three equations; the one dimensional equation of motion (momentum-equation) and the flow and sediment-continuity equations. All the three equations are partial differential equations and may be solved by the finite difference method. Numerical models can be used for this purpose. SETRIC model has been used in this paper. The sediment deposition and erosion in time and space along the canal has been simulated. The relevant data were obtained from Punjab Irrigation and Power Department Lahore. It is observed that sediment deposition and erosion is a significant problem being faced by the canals in Punjab.

KEYWORDS: *Sediment, Punjab, Irrigation, Model, Erosion, Deposition.*

INTRODUCTION

Irrigated agriculture acts as back bone for sustainability and poverty alleviation. About 32 million tones of food is produced annually only in Pakistan. There is annual growth of nearly 57million tons of cash crops in the country[1]. Pakistan has a prestigious network of canals fed from the rivers. Rivers in the country contain heavy sediment flows which are diverted into canals also. Sediments in the range of 5,000 m^3 to 64,000 m^3 per day are being diverted in canal at distributary level[1]. Some canals get sediment flows more than this amount even. Management and operational problems are being faced due to heavy sediment flows in canals. Maintenance of irrigation canals requires huge funds from a poor country. Some cheap solution through research is required. Experimental studies and physical modeling to solve a variety of problems is done time to time at various research stations. Such studies however are costly. A cheap alternative for analysis of sediment transport may be the use of numerical models. This paper has investigated sediment transport by application of computer models. These models find solution of three partial differential equations of continuity and momentum for water and sediment flows. Only a few studies are found in past which have addressed the sediment issues in canals. Embaye et al.[2] have studied sediment issue in canals due to spate irrigation in Africa. They have investigated the effectiveness of design of canals with regards to the non-uniform cross-sections and different slopes for better performance. Munir et al.[3] have investigated crop based irrigation operations (CBIO) for keeping the distribution of water as equitable one. They have studied the reducing of canal-sedimentation as well. The system under consideration was the demand based semi-automatic. The discharge of main canal in their study was automatically controlled whereas the flows in secondary canals were operated manually. Other studies have investigated problems related to water flow, design and performance of canals without considering the sediment flows.[4-8] The problem of sedimentation of canals of Khaiber Pakhtoon Khah Province has been investigated by Munir[1] with the help of numerical models. There are three classes of sediment transport models. The three and two dimensional models are mainly used for the unsteady flows of sediment in rivers and reservoirs. However

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sediment flow investigations in irrigation canals is normally to predict bed level changes over a time period of several of irrigation seasons. So the one dimensional models can be used to study the sediment flow issues in canals. Many one dimensional numerical models are available.[1,9-14] One dimensional numerical model namely SETRIC (Sediment-Transport in Irrigation-Canals) was chosen in present study. This model was developed by Mendez[15] in 1998. There are broad based choices for selecting hydraulic roughness in this model.[1,15-17]

STUDY AREA

Lower Bari Doab Canal (LBDC) was selected for investigating the sediment related problems. The location map showing the canal under study is given in Figure1.

This Canal originates from Balloki Barrage situated on river Ravi about 65Km from Lahore on south-west constructed about 100 years ago. Its cultivable commanded area is about 0.6879 million hectares. The authorized discharge is nearly 278.6 m^3/s. There are 6000 outlets. The main canal is about 207 km having 2272 km long distributaries and minors. The command area includes the Districts of Kasur, Okara, Sahiwal and Khanewal. The major crops grown are rice, wheat, cotton, maize, sugarcane, fodder, vegetables, flowers and other orchard crops. LBDC feeds very important and progressive agricultural area in Punjab where there is high potential for increasing the crop productivity per unit area. Sediment flows are in the range from of 300 to 5000 ppm. Due to the sediment flows the system is facing severe mainte-

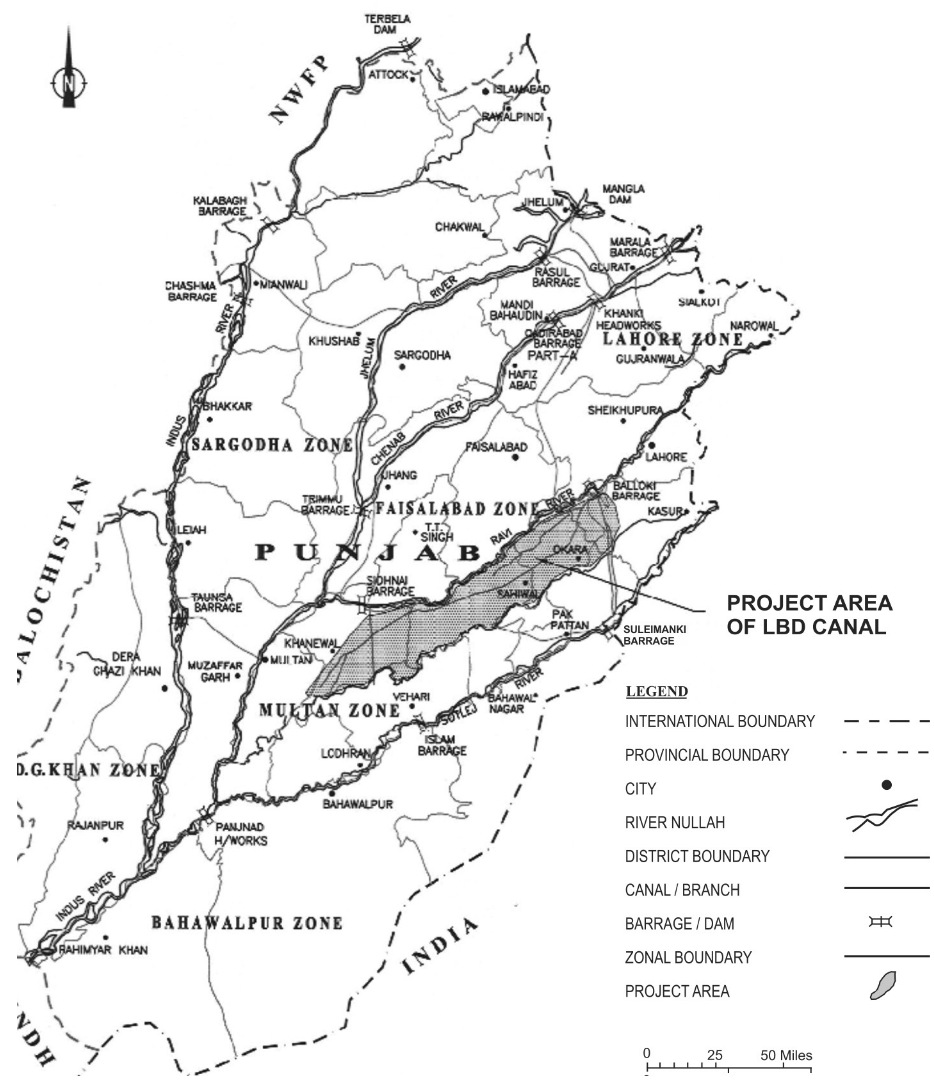

Figure-1: Location Map of LBDC

nance and operational difficulties. The capacity of canal has been reduced and the authorized discharge hardly can pass through the canal. Hence the investigations were taken in this paper to find an appropriate value for equilibrium sediment flow so that there is no further sedimentation or erosion of the canal.

PERFORMANCE OF CANAL

The measured supply and demand for the canal under study is shown by Figure 2. This Figure was prepared using the average values of data taken for crop-water requirement and canal discharges during year 2011. The supply in this case is less than the requirements during mid February to the end of February. The same situation prevails during September to October and on the other hand proper growth of the crops also depends upon the situation during this period.

The existing condition of 7 sample outlets regarding outlet discharges is shown by Figure 3 to Figure 15. The performance based upon the parameter delivery-performance-ratio (DPR) is shown by Figures 16 to 28. DPR is defined as the ratio of the actual discharge to the target discharge of an outlet. The performance of outlet at location 1 is very bad. Its delivery performance ratio is noted as 1.8 showing that this outlet is getting 80 percent more water than that of its requirements. At the same time some other outlets are getting only 60 percent of their requirement. The outlets of tail reach of the canal are facing problem of shortage of water as the crop water requirements are not being met adequately. DPR of outlet number 7 is unexpectedly more than one during eight months of the year. The reason for this may be the tempering of outlet and fault in design as well. In brief as described above the tail reaches of the canal are facing shortage of supply as the crop-water-requirements are higher than the supply.

The irrigation canals, which were constructed with huge financial investments, are not functioning up to expected levels particularly in respect of equity and efficiency. Fluctuations are observed in the initial water levels and final water levels of the canal (LBDC). Lower discharges and artificial backing-up at distributaries is the problem as usual. The performance of LBDC Canal is not satisfactory. Canal banks are seriously eroded and freeboard is not adequate in several reaches. The condition of the Distribution system is far worse than the Main Canal, with severe bank damage due to buffalo trespass, varying supply at canal head, and sedimentation. Further working has been carried out on sediment modeling in this paper. The monthly sediment concentration is given in Figure 28.

SEDIMENT TRANSPORT MODEL:

The one dimensional equations which may govern the sediment movement in canals can be expressed in form of equation of continuity for sediment, flow continuity equation and dynamic equation of motion. These are written as follows:

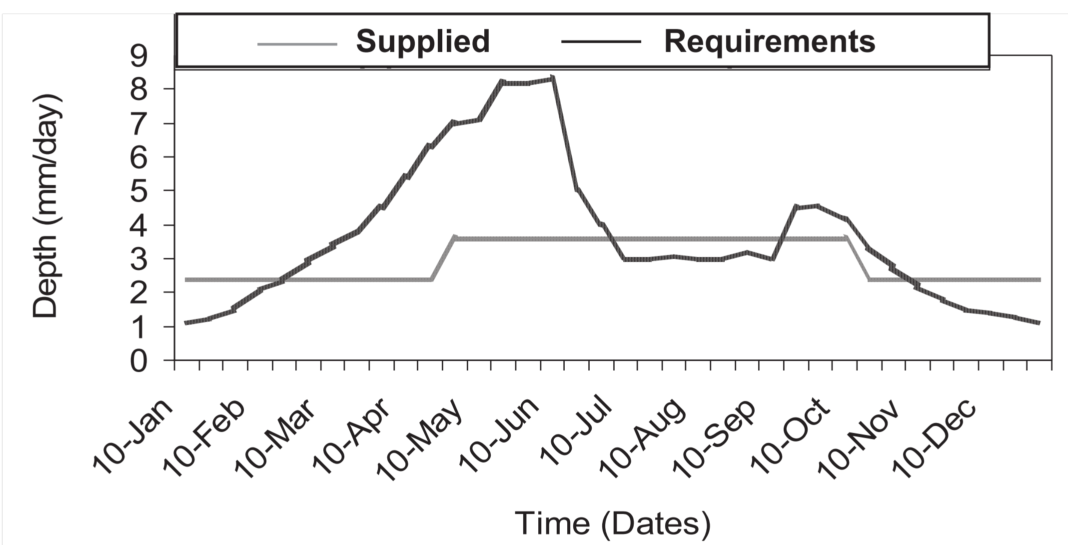

Figure 2: Crop Water Requirement for LowerBari Doab Canal

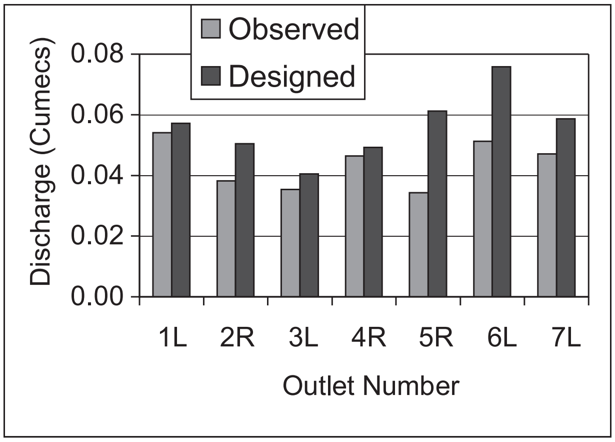

Figure 3: Comparison of observed and design discharge for the month of July

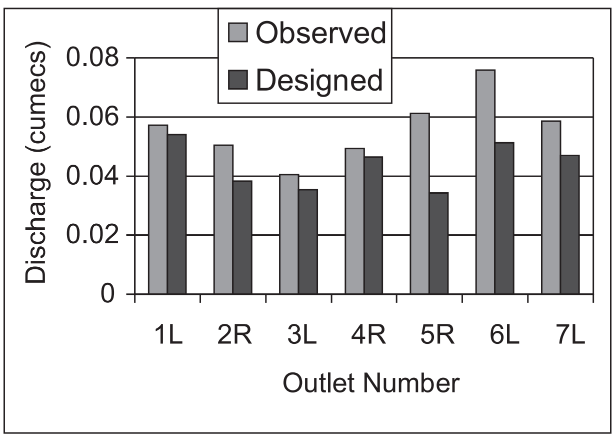

Figure 4: Comparison of observed and design discharge for the month of August

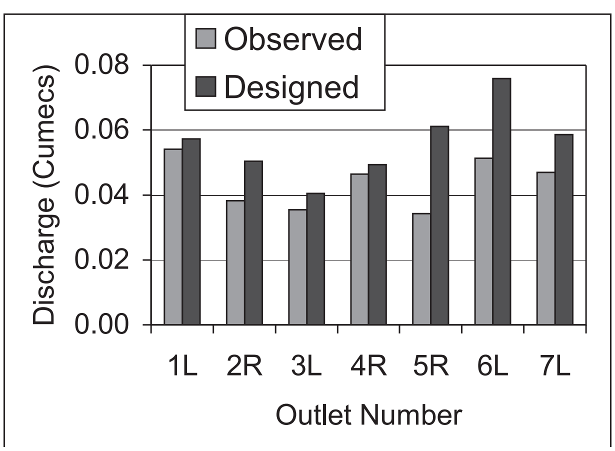

Figure 5: Comparison of observed and design discharge for the month of Sept.

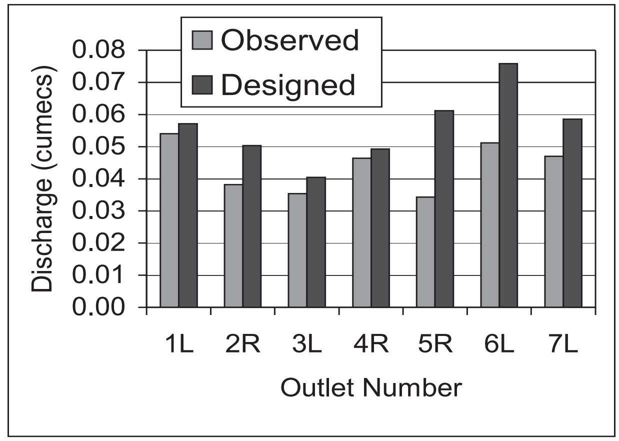

Figure 6: Comparison of observed and design discharge for the month of October

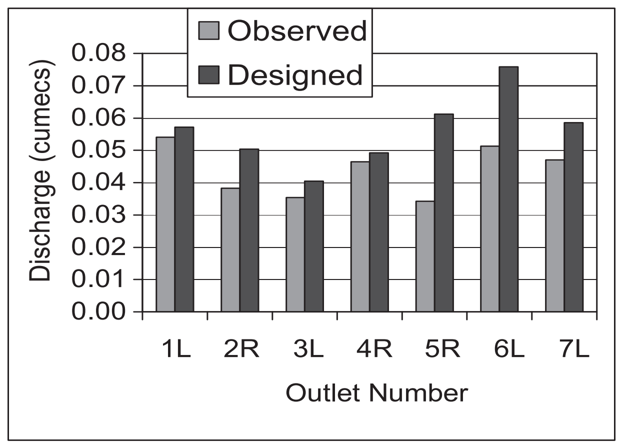

Figure 7: Comparison of observed and design discharge for the month of Nov.

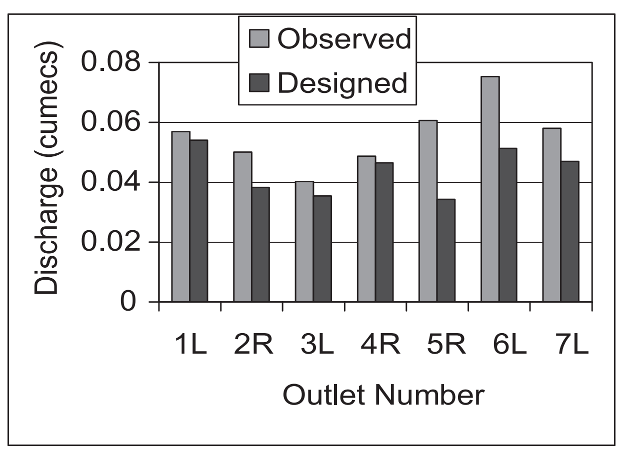

Figure 8: Comparison of observed and design discharge for the month of Dec.

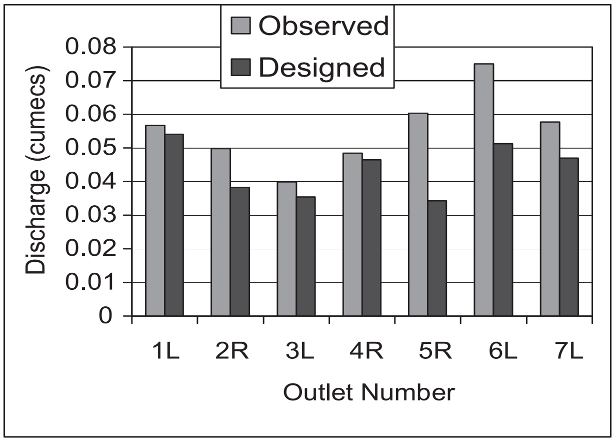

Figure 9: Comparison of observed and design discharge for the month of Jan.

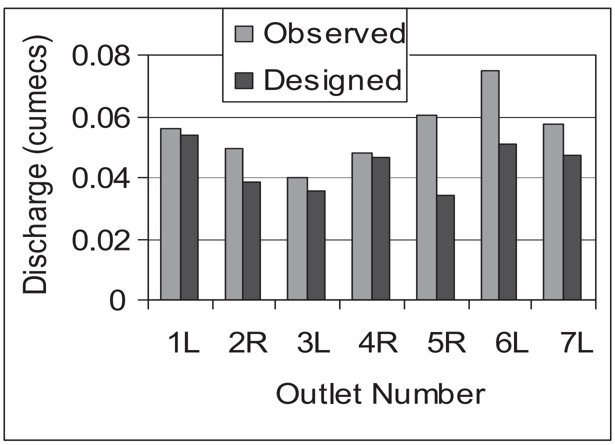

Figure 10: Comparison of observed and design discharge for the month of Feb

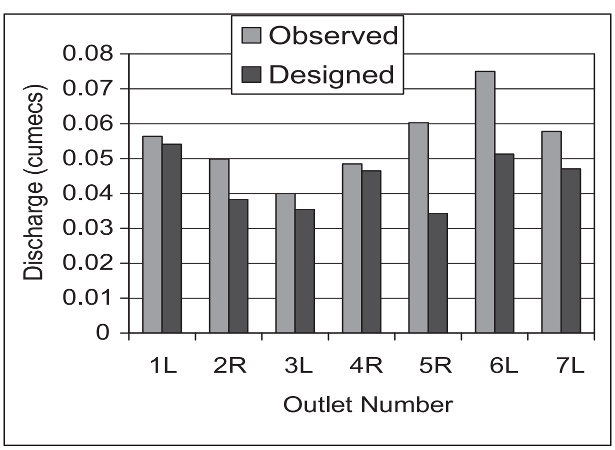

Figure 11: Comparison of observed and design discharge for the month of March

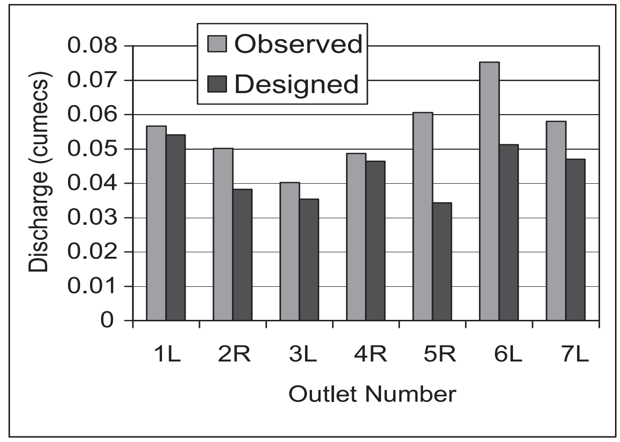

Figure 12: Comparison of observed and design discharge for the month of April

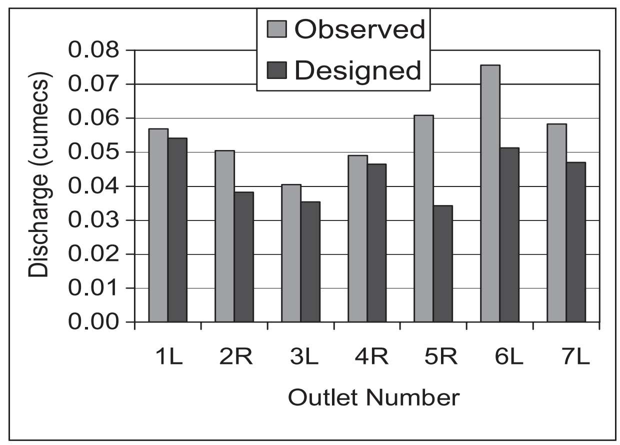

Figure 13: Comparison of observed and design discharge for the month of May

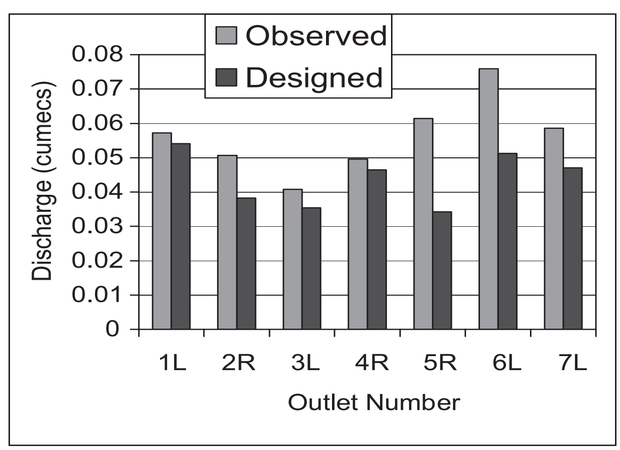

Figure 14: Comparison of observed and design discharge for the month of June

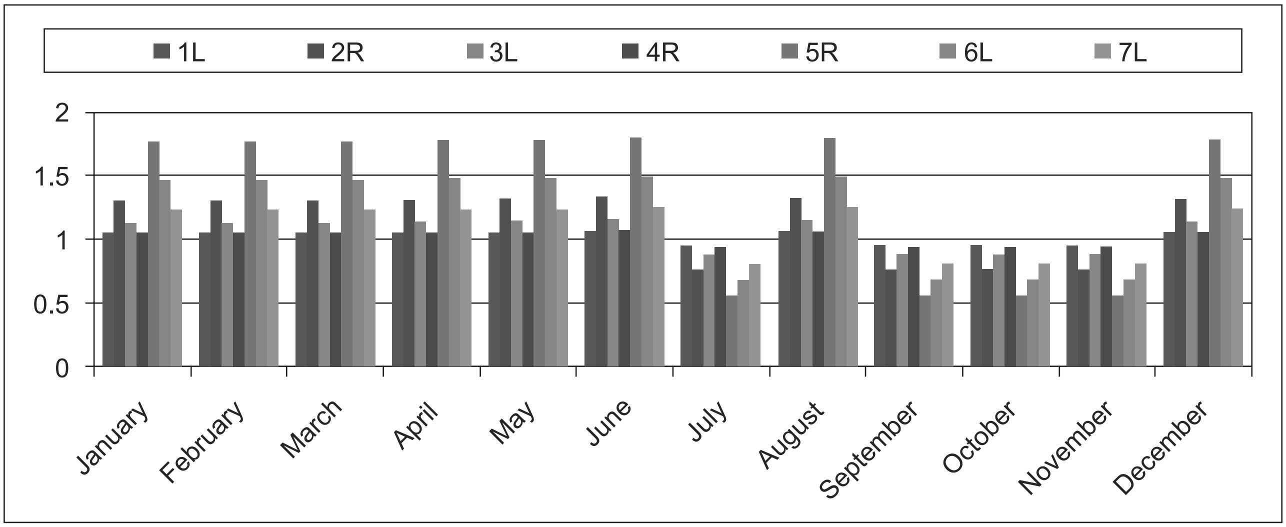

Figure 15: Comparison of the delivery-performance-ratio for 7 outlets on LBDC System under present conditions.

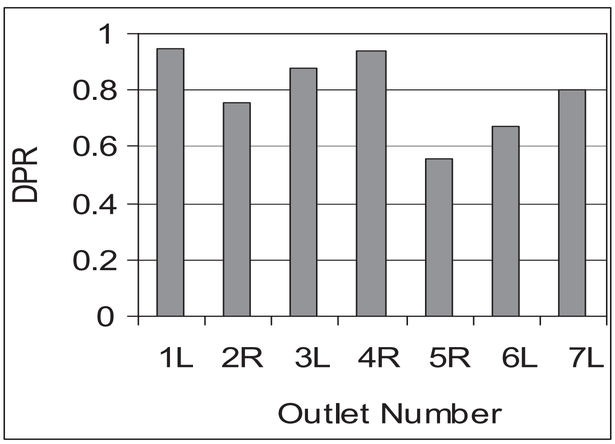

Figure 16: DPR for the month of July

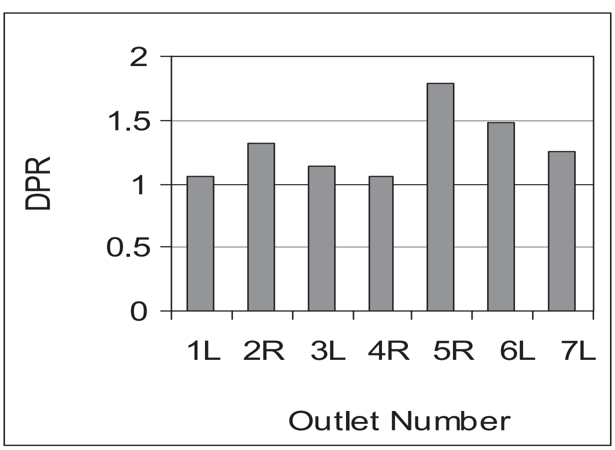

Figure 17: DPR for the month of August

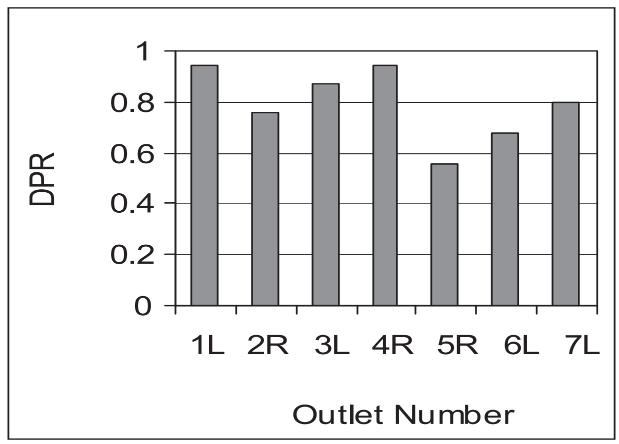

Figure 18: DPR for the month of Sept.

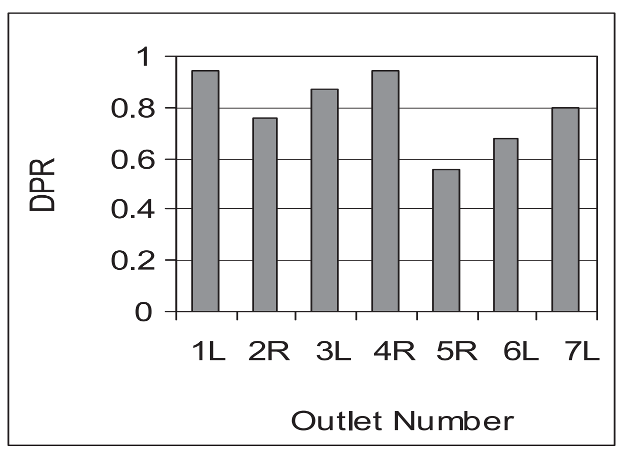

Figure 19: DPR for the month of October

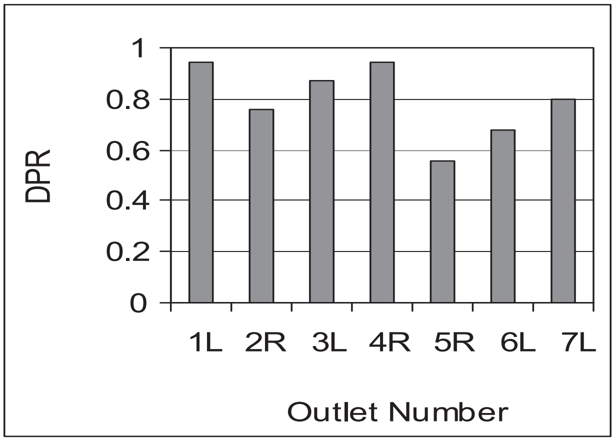

Figure 20: DPR for the month of Nov.

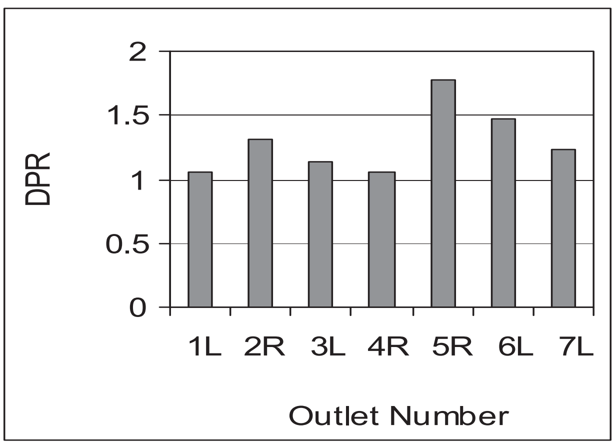

Figure 21: DPR for the month of Dec.

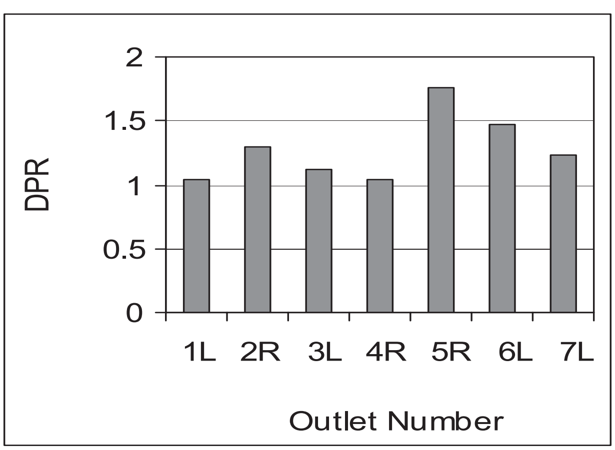

Figure 22: DPR for the month of Jan.

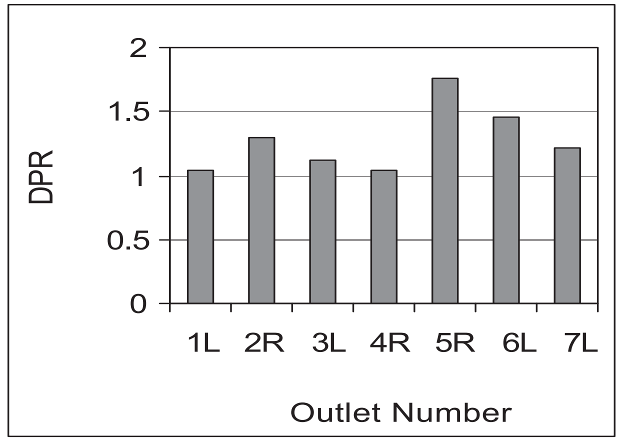

Figure 23: DPR for the month of Feb.

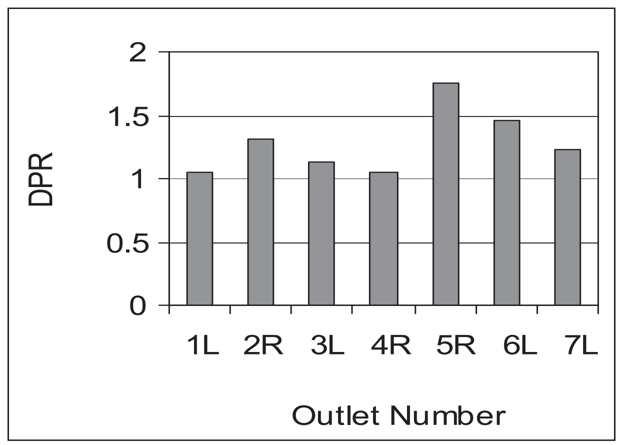

Figure 24: DPR for the month of March.

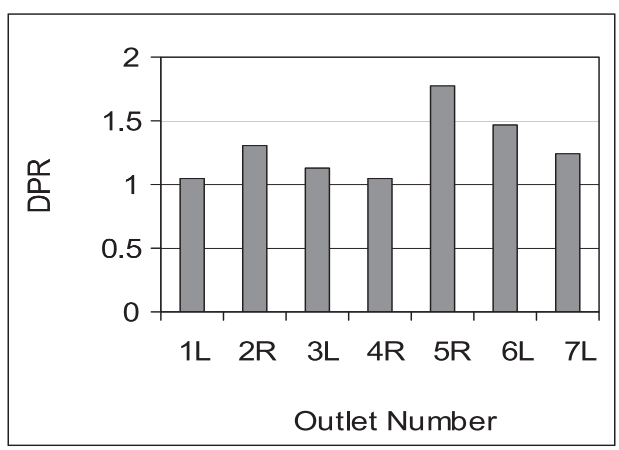

Figure 25: DPR for the month of April.

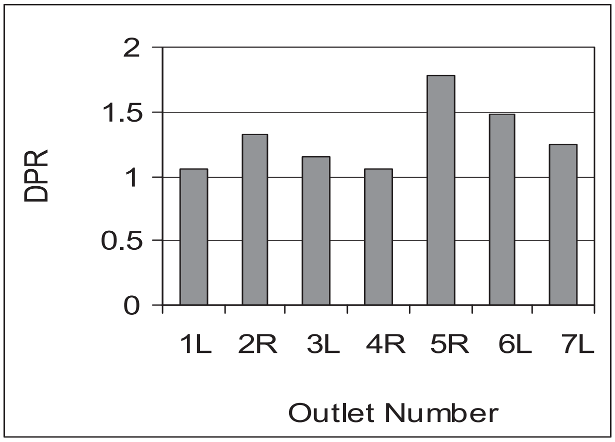

Figure 26: DPR for the month of May.

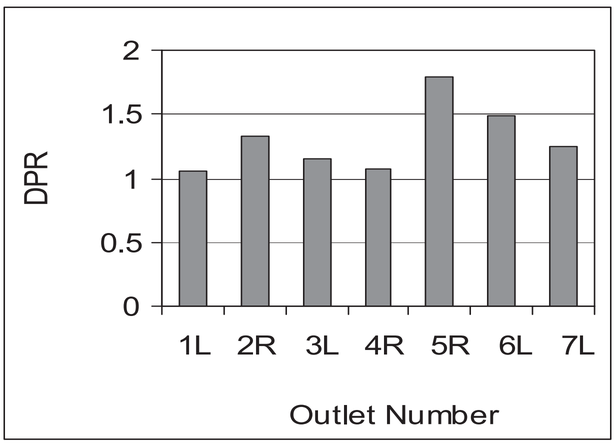

Figure 27: DPR for the month of June

$$\frac{\partial Q_s}{\partial x} + p\frac{\partial V}{\partial t} + \frac{\partial (ACs)}{\partial t} = q_{ls} \qquad 1$$

$$\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} + \frac{\partial V}{\partial t} = q_l \qquad 2$$

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x}\left(\frac{Q^2}{A}\right) + g\frac{A}{T}\frac{\partial A}{\partial x} - gA\left(S_o - S_f\right) - q_l\frac{Q}{A} + \frac{Q}{A}\frac{\partial V}{\partial t} = 0 \qquad 3$$

Here Q = discharge(m^3/s), A is area of cross-section of flow, V is sedimentation (in volume units) per unit length of the channel, x = distance(m) along the flow; t is time; q_l is lateral flow; g = acceleration due to gravity; T is top-width of channel; S_o is bed-slope, S_f is energy-line-slope, Q_s is sediment flow(m^3/s), C_s is ratio of sediment discharge to the water discharge, p is the volume of sediment in unit volume of bed layer and q_{ls} represents the lateral sediment flow.

The Equations 1 to 3 need two more equations for their solution. One equation is needed for estimation of frictional slope S_f and the second equation is required for the sediment discharge Q_s.[18,19]

These equations can be given as follows:

$$S_f = \left(\frac{n^2 Q^2}{A^2 R^{(4/3)}}\right) \qquad 4$$

In this equation R is hydraulic radius and n is roughness constant of Manning

$$Q_s = cQ\left(\frac{F_{gr}}{A} - 1\right)^m d_{35}\left(\frac{V^m}{yV^{n_1}{}_*}\right) \qquad 5$$

The above equations 1 to 3 can be solved by the methods which can be divided in to several types. The term, ∂V/∂t in equations 1 2 and 3 is the rate of change of bed-levels. If it is ignored from the flow continuity equation 2, the sediment continuity equation 1 is un-coupled from equations 2 and 3. Still there is coupling through the bed slope and frictional relationships. So there are two main categories of sediment transport models namely coupled and un-coupled. In uncoupled solution equations 2 and 3 are solved for discharge or velocity and area of flow or depth, followed by a separate solution of equation 1 to find volume of sediment. In fully coupled solution, equations 1 to 3 are solved simultaneously to give discharge or velocity, area of flow or depth and volume of sediment per unit length together, however uncoupled solutions are not capable of satisfying arbitrary boundary conditions like a constant stage, Wormleaton and Ghumman.[9] The model SETRIC is an uncoupled type of model.

MODEL-CALIBRATION

The CanalMan was run for actual steady flow of 278.6 m3/s for the months of low sediment concentration. The measured and calculated water levels are shown in Figure 29. As the flow was steady the sediment concentration was low so there was a minute difference between the simulated and observed water-levels.

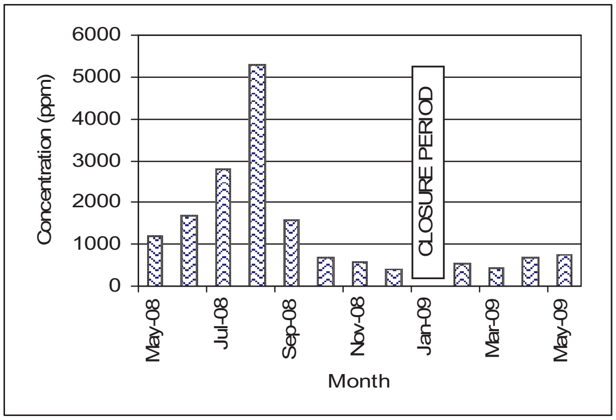

Figure 28: Sediment Concentration.

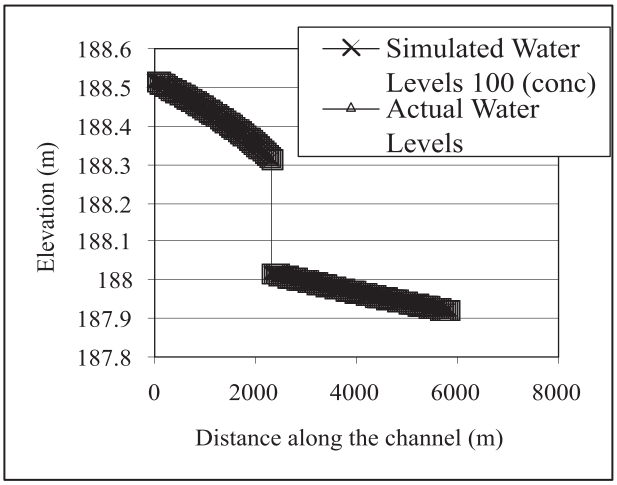

Figure 29: Calibration results

RESULTS AND DISCUSSIONS FOR SEDIMENT FLOW SIMULATIONS.

Results from the model are compared with the field data taken for initial conditions as given in Figure 30. The simulated results show that the bed level changes are affected significantly with the decrese in sediment concentration resulting decrese in deposition. The model was run to find the concentration at which the deposition on bed of the channel are minimum. The best equilibrium concentration is found to be 100 ppm. Although, the SETRIC Model is uncoupled but it has produced reliable results for steady flows. The reason behind is that the uncoupled solutions for bed level changes, differ in the treatment of the terms which are non-linear in this system of equations. It also differ in treating the frictional-slope. On the other hand the linearization of the some terms like $\partial AC_s/\partial t$ and gASo are also a cause of the difference between the coupled models. This implies that the difference will be magnified in uncoupled methods only when the variation in depth and discharge is large with respect to space or time. Irrigation canals mainly have steady flows so the uncoupled models also produce plausible results.

CONCLUSION

The performance of Lower Bari Doab Canal in Pakistan is not satisfactory. Fluctuations in the water levels of the canal (LBDC) have been found from observed data.

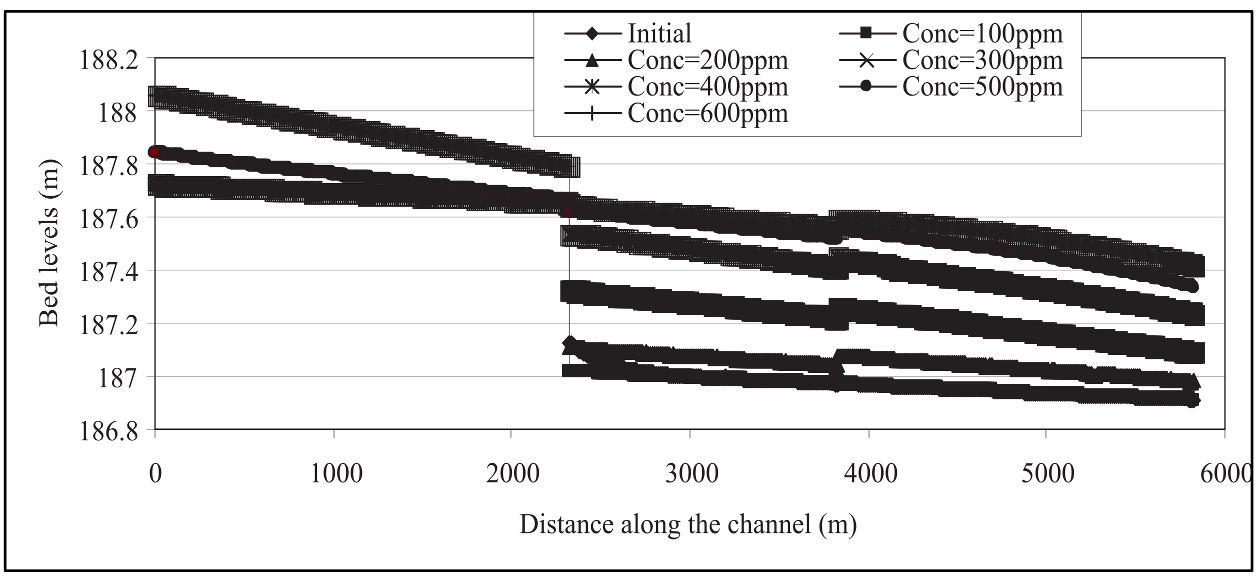

Figure 30: Comparison of initial and simulated bed levels for different sediment concentrations

It is noticed that DPRs of outlets have gone as high as 114 % and as low as 55%. The sediment concentration was higher in the months of April to September whereas it was low during rest of the months.

The base line work for simulation of sediment transport using SETRIC Model has been developed. The bed level changes with time and water levels have been simulated. The bed level changes simulated by uncoupled models differ in the handling of the frictional-slope in the momentum equation and non-linear terms $\partial(Q^2/A)/\partial x$ and $gA/T(\partial A/\partial x)$. The difference will be ignorable in uncoupled methods when the flow is steady.

The equilibrium concentration for LBDC is found to be 100 pm. The sedimentation will be negligible for 100 pp sedimentation concentration.

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