RE-DESIGNING AND OPERATIONAL ANALYSES OF THE SEDIMENT TRANSPORT CONTROL IN IRRIGATION CANAL NETWORK

Saman Shahid[1], Shahid Ali[1], Muhammad Abdullah Ahmad[1], Sarfraz Munir[2]

ABSTRACT

The purpose of this research was to improve the existing design of the irrigation canals in Punjab. The design of an entire canal network is a tiresome and laborious work, where engineers spend months to design canals. Over the years, engineers and agriculturists in the Punjab have been trying to find a solution to the sediment transport problem which occurs in existing irrigation system. To address these problems, the canals can be analyzed to point out the flaws in design and operation mechanism. This study used a Physics based mathematical model, which can aid the engineers to design and analyze the canals on scientific basis. The research evaluated the existing design of BRBD link canal using SETRIC (Sediment Transport in Irrigation Canals) model based on Saint Venant shallow water equation and also, compared the sediment deposition's result under various maintenance conditions for both Brownlie and Engelund Hansen predictor methods. The data related to BRBD canal, including its cross-sectional properties, hydraulics and sediment parameters were acquired from the Irrigation Department, Lahore. The paper also described the problem which exists in design and operation of the canal by comparing it with original field data. The BRBD canal achieved a regime condition in 1.5 years. The results of sediment deposition produced by Brownlie predictor were more accurate than Engelund Hansen. The sediment deposition volume for Reach 2 was about 593084 m3, whereas for Reach 1 Brownlie method predicted a sediment deposition of 26675 m3 and it was discovered that this large volume of sediments were deposited due to cross-sectional anomalies along the canal such as the geometry of Reach 2 varied abruptly; at one section the width was 21.54 m and the very next section it faced a contraction and reduced to 16.46 m and at RD 372+638, the width of channel expanded to 45.72 m, which then reduced to 43.28 m. Thus, to make possible efficient flow of water in BRBD Link canal and to decrease the sediment volume, the canal's cross-sections were redefined. After this, the canal was remodeled on SETRIC by providing gradual changes in geometry rather than abrupt changes, which showed positive results, and sediment deposition was reduced by 35.25 %. If further modifications are made in the geometry of BRBD canal, the sediment deposition can be minimized which can help in saving billions of tax payer money spent on "Bhal Safai" and maintenance.

KEYWORDS: *Irrigation Canal Design, Sediment in Irrigation Canal, Physics Based Canal Design, Canal Operation and Maintenance, SETRIC (Sediment Transport in Irrigation Canals), BRBD (Bambawali Ravi Bedian Dipalpur)*

INTRODUCTION

Pakistan has the largest contiguous irrigation canal network in the whole world, which contributes a major chunk to Pakistan's economy. Therefore, it signifies the importance of the system. This irrigation system is a network which consists of 3 reservoirs, 12 link canals, 44 main canals and 107000 water courses that covers whole Pakistan (mainly the areas of Punjab). The efficiency of any irrigation canal system immensely depends on the concentration and properties of sediment. The hydraulic efficiency gets affected by the quantity of sediments which is carried along the canal and deposited on the bed. The irrigation canal system of Punjab had been designed and analyzed over the years without considering the effect of sediment which resulted in the lower efficiency of the system. There are numerous softwares which are used for managing the flow rates in rivers, canals, distributaries, etc. In these software, either the sediment transport factor was neglected or given less importance to the sedimentation, which produced such results that were not assimilating in real life conditions. In order to overcome this problem, a Physics based SETRIC (Sediment Transport in Irrigation Canals) model was introduced which considers the factor of sediment traveling along with the flowing canals. The results obtained from the model were sound, authentic and similar to the real-life conditions as compared to other software. Therefore, this program has been a success which can be used to analyze an existing canal system as well as

1 Department of Sciences & Humanities and Department of Civil Engineering, National University of Computer & Emerging Sciences (NUCES), Lahore Pakistan
2 Dapartment of Natural Resources Engineering (Water), University of Kurdistan Hewler (UKH) Erbil, Iraq

design a new canal system.

Pakistan contiguous canal irrigation system's canals have not been designed or analyzed properly regarding the factor of sediment transport and the system needs to have a program like SETRIC for canal design and analysis. The main objective of this research was to analyze an existing canal system in Pakistan, which involves the sediment transport and to design a canal network with minimum erosion/deposition. These sediments should be either deposited at some specific locations or transported to fields. We studied and analyzed the sediment load in a network via. program SETRIC. The basic aim of this research was to give a detailed analysis, which involves physical and mathematical descriptions of the behavior of sediment transport in the irrigation canal system and to discuss the mathematical based model which predicted sediment transport in canals, as well as deposition and the entertainment rate for different flow conditions. This model is favorable and best suited for the simulation of sediment transport under certain conditions where the control structures are used to control and determined the sediment transport and flowing condition. This research incorporated the sediment related problem in BRBD (Bambawali Ravi Bedian Dipalpur) link canal which is located on the eastern side of Lahore, Pakistan. The BRBD canal was examined with the stance of better management of sediments by enhancing the canal design and improving the operation of the irrigation canal system. This canal begins at Wazir Abad Nandipur canal and ends at the Sutlej River. It is the source of the Lahore's canal which runs westwards to the city of Lahore. The sedimentation data of this canal was taken from the Silt laboratory of Irrigation Department located at Head Marala, which included average particle size and sediment inflow rate. The BRBD link canal which has been under subject starts from RD 178+000 to RD 435+000 with over 35 different control structures installed across it. These control structures are of various types, which include head regulator, escape regulator, outfall and inlet. The study further emphasized that a hydrodynamic behavior of the downstream controlled irrigation canals is affected spontaneously by the sediment and hence, the hydraulic capacity of the canals is affected. Sediment transport and canal operations have been discussed throughout the study and also the relationship that exists among them was studied. In the downstream controlled channel design, variations were observed and after remodeling the channel, operation for controlling this high influx of sediments have been recommended. In recent times, new canal operating techniques with the aim to minimize the deposition and erosion problem to full extent have been formulated and tested. Hence, canals can be operated at the desired hydraulic efficiency. The study and simulation of hydrodynamics and sediment behavior in canals are now possible using mathematical models like SETRIC and SIC (sediment in canals).

MATERIALS AND METHODS (STUDY AREA)

General Information about Pakistan

Pakistan has a world's Largest Irrigation System. This irrigation system fulfills the need of 14.4 million hectors of cultivated land. The irrigation system lives on water from the Indus River and the main features of the system are its three major storage reservoirs, which are Tarbela & Chashma on the River Indus & Mangla on the River Jhelum (FBS, 2001; Ragab, 2006; Ali, 1993). Pakistan's irrigation system consists of 19 barrages, 12 inter-river link canals and 43 independent irrigation canals, which spread to the total length of 58,500 km in the form of main canals (FBS, 2001; Ragab, 2006). There is an additional 1.6 million kilometers of farms and field ditches. The 43% of the total working population has an occupancy of farming and these farmers produce crops of about 47.03% of the land. Almost 4 million acres of land are irrigated by the world's largest irrigation system on which wheat, rice, fruits, vegetables and sugarcane are grown. Due to this reason, on the river Sindh other than the Tarbela dam, there are 85 small embankments, 19 barrages, 45 canals, 12 link canals and 7 lakh tube wells on it. There are four types of canals in Pakistan according to the perennial conditions of the canals (Ali, 1993). The study area for the research was decided to be the BRBD Link canal and the data for this canal was collected from the concerned departments. This study area was selected as it was accessible and data collection was easy.

Bambawali Ravi Bedian (BRBD) Link Canal

The BRBD canal starts from the Wazir Abad Nandipur canal and ends at the Sutlej River. It is located on the east of the city of Lahore, Punjab, Pakistan. It runs westwards to the city and is the source of Lahore Canal (Fig. 1).

There is only one barrage i.e., Marala Barrage in Lahore irrigation zone, which is located at a distance of 26 Km North-West of Sialkot on River Chenab and 6 miles below the entrance point of River from Indian occupied Jammu & Kashmir. The old barrage was constructed during 1905-1912 on River Chenab to irrigate the 32,20,000 acres of Cultureable Command Area (CCA) acre area of Sialkot Narowal, Gujranwala, Sheikhupura, Nankana, Lahore, Kasur, Depalpur, Okara and Pakpattan. The Marala Barrage also passes the surplus supply through Balloki Head Works at River Ravi. Depalpur Canal off-taking from River Sutlej from Ferozepur Head works and CBDC (central Bari-doab canal) System off-taking from Kadhupur Headwork on River Ravi were cut off by the Indians. Supply to the cut off area were arranged through BRBD link canal and accordingly the diversion capacity of Marala Barrage was increased to 11,00,000 Cs, by remodeling the Marala Barrage during 1965-1968 by Ed Zublin Ac DUISBERG of West Germany under supervision of West Pakistan Water and Power Authority through the Indus Basin Project. In order to supplement supply to the River Sutlej at Sulemanki, Marala Ravi Link Canal and B.S Link Canals were also constructed during 1955-1967 in order to supplementary supply to the River Sutlej at Sulemanki through Marala Ravi Link and B.S Link Canals which were constructed during 1955-1957 (Punjab irrigation and power, 2008).

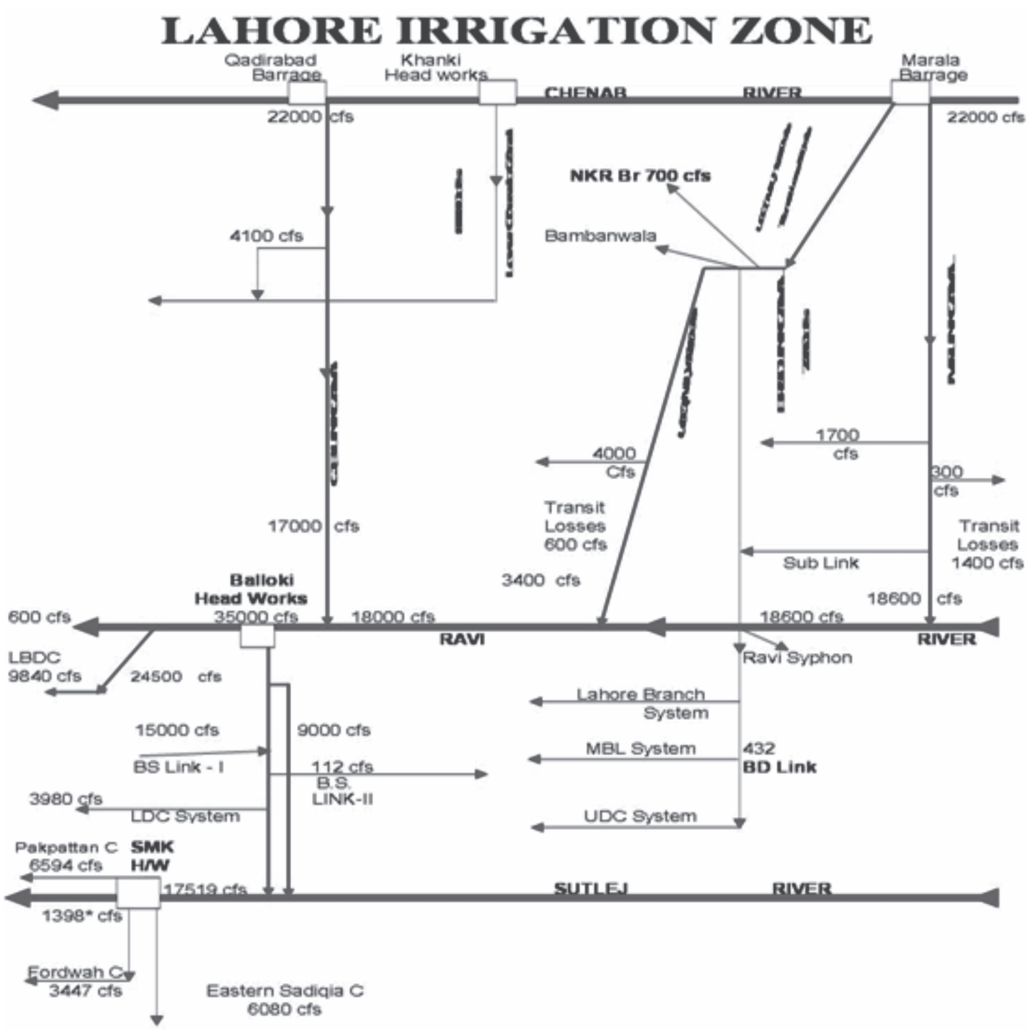


Fig. 1: Detail of Lahore Irrigation Zone (Punjab irrigation and power, 2008)

SETRIC (Sediment Transport in Irrigation Canals)

MATHEMATICAL MODEL FOR SEDIMENT TRANSPORT IN IRRIGATION CANALS

Canal-design's objective is to ensure that the deposition of sediments or the erosion of sediments which occur in the canal network should be least. The influx of sediment in the canal arranges ought to be either transported to the field or stored in particular areas. This objective is very exigent to achieve for irrigation canals transporting an acute sum of silt and advancing through alluvial soils, indeed amid relentless and uniform stream conditions. For this purpose, in order to design the canal network in such a way that the sediment transport should be minimum, a new model is selected to study which is called SETRIC model (Sediment Transport in Irrigation Canals). The SETRIC is a Physics based model in one-dimension. In this model, the flow of water in the irrigation canals has been contrived in a quasi-steady and gradually varied flow (Méndez, 2002; Depeweg and Paudel, 2003).

Working principle

The equation of mass balance and the Gallapatti's depth model play a vital role in the working of the SETRIC model (Méndez, 2002). The equation of mass balance is solved using the Lax's method (modified). The solution was performed by accepting the steady condition of the silt concentration for the entire sediment transport in the entire Reach. To predict the equilibrium concentration, the model permits the user to use any of the three indicators: i.e., Brownlie Method, Engelund and Hansen Method or Ackers and White strategy. Roughness within the bed and sides of the canal is calculated independently. The roughness within the sides is affected by weed development, disintegration within the banks and other exercises while the unpleasantness within the bed depends upon the water stream and sediment characteristics. The show calculates the roughness within the bed utilizing the van Rijn method, which is based on the conditions of the stream and depends upon the bed shape and grain related parameters as bed frame length, tallness and silt estimate. At that point, the equivalent roughness was computed taking under consideration the sidewall impact as predicted by Méndez in 1998 (Méndez, 2002; Boss, 1989; Paudel et al., 2014). This one-dimensional stream condition was solved by the predictor-corrector strategy. The Gallapatti's depth coordinates model for sediment transport has been utilized to foresee the real silt concentration at any point beneath non-equilibrium conditions. The Galappatti's model is based on the 2-D convection-diffusion condition (Paudel et al., 2014).

Governing equations

There are different equations used in this model in order to simulate the water flow as well as sediment transport, hence, the equations for water flow and sediment transport is different which is stated as follows (Chen *et al.*, 2006)

Water flow equations

In a waterway or a canal section, one dimensional unsteady stream can be solved by two subordinate factors, the h (depth of water) and the Q (discharge in the Reach). To find the liquid stream state, two conditions are required, which are explained from mass balance, energy balance and momentum balance. De Saint-Venant equation provides assistance in the conservation of mass and momentum:

$$\frac{\partial h}{\partial t}+V\frac{\partial h}{\partial x}+h\frac{\partial V}{\partial x}=0 \tag{1}$$

$$\frac{\partial \mathrm{V}}{\partial \mathrm{t}}+V\frac{\partial \mathrm{V}}{\partial \mathrm{x}}+g\frac{\partial \mathrm{h}}{\partial \mathrm{x}}+g\frac{\partial \mathrm{z}}{\partial \mathrm{x}}=-gS_f \tag{2}$$

Under the conditions, that the alteration in the unsteady stream flow conditions is slower than the steady flow state and also the time required for any noteworthy alterations in the bed morphology, and the changes on bed are expected to be constant, the equation gets to be:

Equation 1 becomes:

$$V\frac{\partial \mathrm{h}}{\partial \mathrm{x}}+h\frac{\partial \mathrm{V}}{\partial \mathrm{x}}=0 \tag{3}$$

$$\frac{\partial(\mathrm{Vh})}{\partial \mathrm{x}}=0 \therefore q=constant \tag{4}$$

Equation 2 becomes:

$$V\frac{\partial \mathrm{V}}{\partial \mathrm{x}}+g\frac{\partial \mathrm{h}}{\partial \mathrm{x}}+g\frac{\partial \mathrm{z}}{\partial \mathrm{x}}=-gS_f \tag{5}$$

Considering a canal section which has constant geometry throughout, has bed slope that is small and the velocity distribution is uniform (Chow, 1983), above equation can be written as:

$$\frac{dh}{dx}=\frac{\left(S_o-S_f\right)}{\left(1-Fr^2\right)} \tag{6}$$

With Froude number

$$\mathrm{Fr}=\sqrt{\frac{\mathrm{Q^2B_s}}{\mathrm{gA^3}}} \tag{7}$$

Where,

A = Water flow Area (m^2), B = Width of water surface (m), g = Gravitational Acceleration (m/s^2)

h = Depth of Water (m), Q = Discharge (m^3/s), S_o = Slope of channel's bed ($-\partial z / \partial x$)

S_f = friction slope, V = Velocity of water flow (m/s), z = bed level above datum (m)

Sediment equations

When the water starts moving it, applies some force on the sediments as a result of which there comes a critical force at which it starts moving, the bed sediments begin to travel after this threshold. To understand the threshold, condition critical for the incipient motion of the sediments on the bed, three parameters can be used: shear stress (drag force), average velocity and flow rate (Depeweg and Mendez, 2014). Shields' equation for drag force is given by

$$\theta_{cr}=\frac{u_*^2}{\left(s-1\right)gd_{50}}=\frac{\tau_{cr}}{\left(s-1\right)\rho gd_{50}}=f\left(\frac{u_{*,cr}d_{50}}{v}\right) \tag{8}$$

Where,

d_{50}= size of material on the bed (m), s = specific gravity of bed load, θ_{cr} = critical mobility parameter,

u_*= shear velocity (m/s), $\tilde{i}_{cr}$ = critical shear stress (N/m^2), v = kinematic viscosity (m^2/s)

Equation 8 represents that in the beginning of the grain's motion on channel bed, the Reynold's number (Re_*) of grain is a function of the ratio of drag force acting on the channel bed on grain to its weight (Braban, 1990). Upon further experimentation involving the sediments of various specific gravities, Shield was successful in determining the value of the function *f* shown in equation 8 and used these results to form a graph, commonly known the Shield's diagram (Fig. 2).

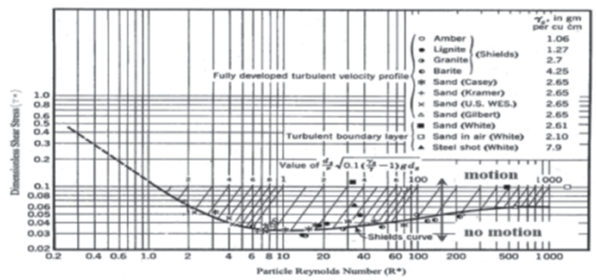


Fig. 2: Shields Diagram (after Simons, et al. (1992) [6]

While finding a solution through Shields' diagram, a trial and error procedure is to be followed, because the parameter u_* occurs in both axes of the diagram. It was then realized that this all can be avoided by using the Yalin's (1977) equation (Bos, 1989; Brownlie, 1981).

$$D_*=\frac{R_{e*}^2}{\theta}=\left(\frac{(s-1)g}{v^2}\right)^{\frac{1}{3}} d_{50} \tag{9}$$

Once D_* is known, the van Rijn (1993) (Bos, 1989; Méndez, 2002) relationships can be used to determine the value of θ_{cr} and solve equation 8 for τ_{cr} .

$$\theta_{cr}=0.24D_*^{-1} \quad \mathrm{for} 1<D_*\leq 4 \tag{10}$$

$$\theta_c r=0.14D_*^{(-0.64)} for 4<D_*\leq 10 \tag{11}$$

$$\theta_{cr}=0.04D_*^{-0.1} \qquad \mathrm{for} 10<D_*\leq 20 \tag{12}$$

Where,

D_* = dimensionless grain parameter, s =specific gravity of sediment, $\tilde{i}_{cr}$ = shear stress (N/m^2)

$u_{*.cr}$ = critical shear velocity (m/s), v = kinematic viscosity of water (m^2/s)

OPERATIONAL SCHEME AND DATA ACQUISITION

BRBD Link Canal's Operational Scheme

The water in the BRBD link Canal usually comes from the Marala Barrage and a silt trap is located, where the canal offtakes from the barrage. At the off-taking point of the canal, there are undershot types of gate and the outgoing water flow of the silt trap. As the water moves in the downstream direction, usually broad crested weirs are used as the control structures. The BRBD's operation is constant where the control structures at upstream are utilized for the controlling the flow. It is upon the discretion of Irrigation Department (Zone Level) to make decisions on the water allocation. As per design, the entire canal service a large area of more than 15,000 ha. In its length, the canal passes through a number of small towns and villages and a large number of secondary (distributary) canals off to take from this mammoth structure. In these large areas, the farmers grow a large variety of crops ranging from crops that require more water such as Sugar cane, Potatoes, Wheat and Cotton. The farmers also tend to grow crops which require less water, such as Barley, Corn and Maze. Due to this, much difference in the crop water requirements, the needs of framers are met by the Department of Irrigation by using the control structures at the upstream. In one year, there are two cropping seasons in Pakistan, (1) Rabi Season (October to March) in which farmers grow Wheat, Gram, Barley, Potato, Fodder, Oil seed and Berseen. During the same season, the Monsoons falls, which is the rainy season. The second season of cropping in Pakistan is the (2) Kharif Season (April to September) in which farmers grow crops such as Cotton, Maize and Rice.

Field Data Acquisition

The data to be modelled was gathered and collected from various departments of the Punjab including the Irrigation Department of the Punjab and the Mineralogy Department of the Punjab. The data for the longitudinal section of BRBD link canal was acquired from the Irrigation office located at Dharampura, Lahore. Also, it is very crucial to mention that the exact data of the sediments deposited in this canal was not available in the Irrigation Department. The data regarding the sediment size and concentration was collected from the field and then utilized to run the model.

Suspended Load

The lab results, after the analysis of the sample gathered from the field, showed that there is about 1000 ppm concentration of sediments.

Particle Size Analysis

About 4 samples were collected from the depositions on channel bed. These samples were collected from various sites through the entire Reach. After that, the analysis was done to determine the particle size distribution in the entire Reach. The results showed grain size of different diameters, the mean value of came out to be 0.20 mm and was used in SETRIC model.

Maintenance Data

Major maintenance works for BRBD link canal include the maintenance of the slope for gravity flow, berm cutting, vegetation removal and the maintenance of the side slopes. The most important of all is to make sure that the water flows under the gravity and for this, the canal operation is to be halted for months so that the slope or bed level can be maintained by removing the sediments or by filling where scouring has occurred the term used in Pakistan for this is the "Bhal Safai". The process causes the canal operation to be stopped for 2-3 months, which enables farmers to use tube wells and other sources to provide water to the crops. The use of tube wells is quite common which happens to be expensive as they require electricity for working and they draw out the ground water, which is already very low. The cutting and filling are costly as this technique is used throughout the canal system of Punjab and funds worth of millions of rupees used to spend on it and these funds are generated from the taxpayer money (Punjab Irrigation and Power, 2008).

CANAL INPUT DATA

1-Reach 1 (Before Ravi Syphon)

This Reach of canal starts at RD 177+174 near the Fall and Head Regulator. In this Reach, there are 8 laterals, one Sub-Link outfall at 188+500 and two Escape Regulators; one at RD 204+800 L and the other at RD 279+500 R as shown in Fig. 3.

2-Reach 2 (From Ravi Syphon to RD 435+000)

This Reach of canal starts at RD 285+000 after the Ravi Syphon. In this Reach, there are 6 laterals and two fall structures one at RD 337+144 (15893 m) and the

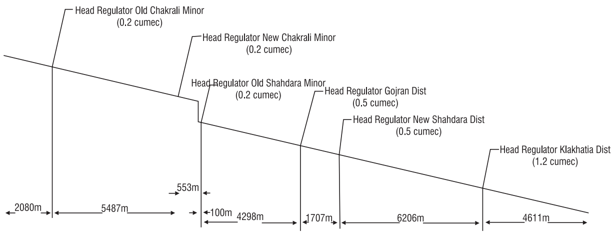


Fig. 3: Main Canal Longitudinal Section Reach 1

other at RD 400+000 (35051 m). This Reach ends in Bedian at the RD 435+958 and at the end two distributary canals offtake with discharges 1532 Cs and 2035 Cs as shown in **Fig. 4** (L section of Reach 2).

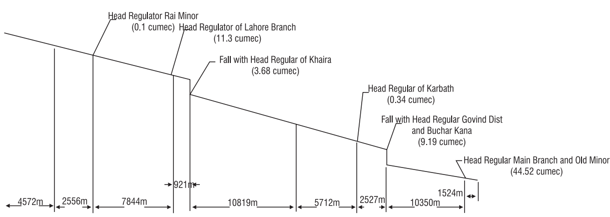


Fig. 4: Main Canal Longitudinal Section Reach 2

MODULATION OF DATA IN SETRIC

The discharge and sediment data, which is used as an input in the model are the average values from the data collected from the concerned departments. The proposed value of discharges written on the L- Section was provided by the department were averaged and the average value of 154 m^3/sec was used in the model for Reach 1. Similarly, for Reach 2, the average value of proposed discharges which comes out to be 137 m^3/sec was used. For the sediment concentration in the Reach 1 and Reach 2, same method was used by taking the mean value of concentration data collected on various time intervals. The simulation was done by keeping in mind that when the channel comes into regime, there is no silting and scouring on the channel bed and equilibrium state is achieved, which means that the sediment volume entering into the Reach leaves without any deposition or scouring.

The simulation of Reach 1 was done for 40 days with the time step of 5 days each and the trend was noted for both sediment transport capacity predictor, Brownlie and Engelund-Hansen. The whole canal as mentioned earlier was divided into two Reaches because of the Ravi Syphon which passes along the way. The simulation of Reach 2 was done for 2 years with the time step of 180 days and the trend of sediment deposition was noted for both sediment transport capacity predictor, Brownlie and Engelund-Hansen.

Sediment Transport Capacity Predictor

In SETRIC, three different sediment concentration predictors are installed. The question here arises is what method or predictor can be employed, it depends on the conditions these methods were developed. The method of Engelund-Hansen is suitable for D50 range of 0.19 mm to 0.93 mm, while Ackers-White method has a grain size limit that the particle size should be greater than 0.4 mm (Ackers, 1999) and the water depth of 0.4 m, whereas, the sediment deposited in BRBD has grain size of 0.20 mm, which rules out this method. Furthermore, upon experimentation, it was realized that the Brownlie and Engelund-Hansen methods would give the best result in predicting the volume of sediment transport in irrigation canals. As our particle size is 0.20 mm, which is in the range of D50 for which Engelund- Hansen was developed, therefore, more accurate results can be expected from it which will be discussed later on (S.K., 2005).

Control structures

In this main canal reaches, there are 3 structures and 12 lateral nodes. The details are as follows:

1− **Structure 1 at 204+800 RD; between lateral node 2 and 3 (Reach 1):**

At RD 204+800, there is a broad crested weir. This kind of control structure which is a broad crested weir is very common in the Punjab irrigation system. In SETRIC model, this type of weir is represented in an overflow type of structure as a broad crested weir. The weir installed has a crest level of 222.8 m and width of 60 m. The lateral at the node 2 is the secondary branch to the right/east direction named New Chakrali Minor (RD 202+000), and the lateral at the node 3 is the secondary branch to the left/west named Old Shahdara Minor (RD 204+800). These secondary canals are treated as lateral number 2 and 3 in the SETRIC lateral input.

2− **Structure 2 at 337+144 RD; between lateral node 2 and 3 (Reach 2):**

At RD 337+144, there is a broad crested weir which is commonly used as water level control structures in the Punjab irrigation system. In SETRIC model, this type of weir was represented in an overflow type of structure as a broad crested weir. The weir installed has a crest level of 215.5 m and width of 19.8 m.

3− **Structure 3 at 400+000 RD; after lateral node 4 (Reach 2):**

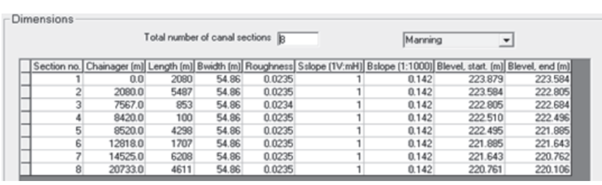
At RD 400+000, there is a broad crested weir. In SETRIC model, the broad crested weir was represented in an overflow type of structure. The weir installed had the crest level of 213.9 m and width of 44.2 m (S.K. 2005).

Weed information

This tab consists of information related to weed factors, which includes the constant parameters like water viscosity and gravity, weed growing time, maintenance interval periods and sediment related parameters. The values of weed factor were obtained from tables, which depends on the various types of vegetation. When working in the field, the weeds are generally grouped into 'Low' which has a weed factor value ranging from 1.25 to 1.5. The time step for the model is set for 1 hour and length step of 1000 m.

Starting the Simulation

Some changes were made in the model for Reachs 1 and 2 and simulated on SETRIC. As the software auto corrected and the data that was obtained from the Irrigation department, so the cross-sectional data for Reach 1 and Reach 2 had to be modified a little bit and was entered in metric units.



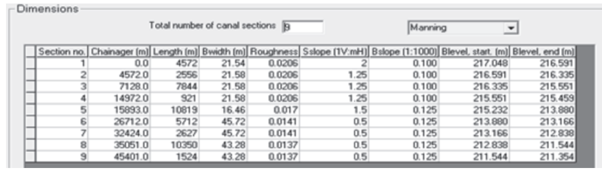
Dimensions

Total number of canal sections 8 Manning

Section no.	Chainager (m)	Length (m)	Bwidth (m)	Roughness	Sslope (1V:mH)	Bslope (1:1000)	Blevel, start. (m)	Blevel, end (m)
1	0.0	2080	54.86	0.0235	1	0.142	223.879	223.584
2	2080.0	5487	54.86	0.0235	1	0.142	223.584	222.805
3	7567.0	853	54.86	0.0234	1	0.142	222.805	222.684
4	8420.0	100	54.86	0.0235	1	0.142	222.510	222.496
5	8520.0	4298	54.86	0.0235	1	0.142	222.495	221.885
6	12818.0	1707	54.86	0.0235	1	0.142	221.885	221.643
7	14525.0	6208	54.86	0.0235	1	0.142	221.643	220.762
8	20733.0	4611	54.86	0.0235	1	0.142	220.761	220.106

Fig. 5: Simulating the Cross-sectional Data for Reach 1 in SETRIC

It is evident from Fig. 5 and 6, that both the Reaches have been entered separately and from each Reach, the chainage of section 1 has been kept 0.00 m. In SETRIC,



Dimensions

Total number of canal sections 9 Manning

Section no.	Chainager (m)	Length (m)	Bwidth (m)	Roughness	Sslope (1V:mH)	Bslope (1:1000)	Blevel, start. (m)	Blevel, end (m)
1	0.0	4572	21.54	0.0206	2	0.100	217.048	216.591
2	4572.0	2556	21.58	0.0206	1.25	0.100	216.591	216.335
3	7128.0	7844	21.58	0.0206	1.25	0.100	216.335	215.551
4	14972.0	921	21.58	0.0206	1.25	0.100	215.551	215.459
5	15893.0	10819	16.46	0.017	1.5	0.125	215.232	213.880
6	26712.0	5712	45.72	0.0141	0.5	0.125	213.880	213.166
7	32424.0	2627	45.72	0.0141	0.5	0.125	213.166	212.838
8	35051.0	10350	43.28	0.0137	0.5	0.125	212.838	211.544
9	45401.0	1524	43.28	0.0137	0.5	0.125	211.544	211.354

Fig. 6: Simulating the Cross-sectional Data for Reach 2 in SETRIC

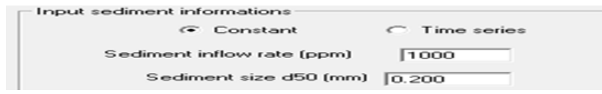


Fig. 7: Data of sediment concentration for both the reaches

the location of laterals was to be put in the form of distance from the very first chainage. If not, then this would lead to an error and the simulation will not be successful. The data of sediment concentration for both the Reaches was entered to be 1000 ppm (Fig. 7). As this value was determined from lab results and same value had to be used in both the Reaches. So, kept the sediment condition same throughout.

RESULTS AND DISCUSSION

The simulated results are discussed here for both Reaches and in the light of the design for the optimum channel cross-section which maintains equilibrium. After the simulation, two different kinds of sediment transport predictor were used and the three different field conditions were used such as ranging from 'No Maintenance of The Canal to Canal', being 'Well Maintained', and towards the 'Ideal Maintenance'.

The analysis of BRBD Link Canal Reach 1

As mentioned earlier that the reach 1 was simulated for 40 days and using 5 days interval, the results of that simulation are as follows.

The Table 1 shows the result of the Reach 1 and it can be seen that the values of accumulated sediments for both predictors is same for each maintenance condition. This shows that the sediment accumulation was not affected by the maintenance condition. Whereas, it is evident that both predictor gave different results. The sediment deposited amount as predicted by Engelund Hansen was more than the sediment deposited amount as predicted by Brownlie.

Table 1: Comparison of Results for Reach 1

		Accumulated Sediments (m3)					
		No maintenance		Well maintenance		Ideal maintenance	
		Predictor		Predictor		Predictor	
Reach	Days	Brownlie Method	Engelund-Hansen	Brownlie Method	Engelund-Hansen	Brownlie Method	Engelund-Hansen
1	5	16334.001	26598.462	16334	26598.46	16334	26598.46
	10	22917.933	44138.167	22917.93	44138.17	22917.93	44138.17
	15	25548.921	54711.247	25548.92	54711.25	25548.92	54711.25
	20	26612.782	60595.917	26612.78	60595.92	26612.78	60595.92
	30	26675.327	65052.687	26675.33	65052.69	26675.33	65052.69
	35	26675.327	65702.387	26675.33	65702.39	26675.33	65702.39
	40	26675.327	65702.387	26675.33	65702.39	26675.33	65702.39

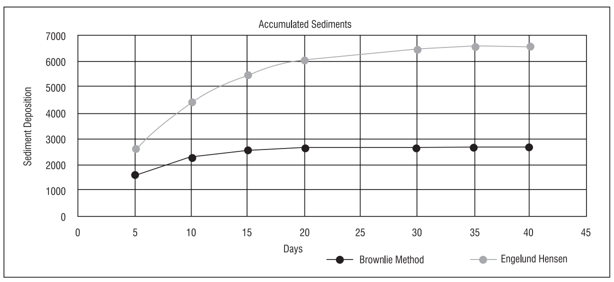


Fig. 8: Trends for Sediment Deposition of Reach 1

From Fig. 8, it is quite evident that as the number of canal operational days increase, the sediment deposition increases in the canal, meaning that the silting is taking place. It can be observed, as per Brownlie Method of sediment transport predictor, the Reach 1 of BRBD link canal comes to regime after 20 days, meaning that within 20 days of operation, the reach 1 has managed to achieve the regime condition of non-silting and non-scouring. The amount of sediment deposited in 20 days remains the same to the value of 26675 m^3 even on the 40th day of canal operation. Whereas, from the results obtained from the Engelund-Hansen predictor, it can be seen that the canal comes into regime after 35 days. And, after 35 days, it is observed that the total sediment deposition on the bed of Reach 1 was 65702 m^3, which is about 146% more than the total volume deposited as proposed by Brownlie. It is because the Engelund-Hansen predictor over predicts the sediment concentration. That is why, it shows an increase in the total volume of sediment deposition and an increase of 15 days of operation for achieving regime state. The graphical output was generated by the SETRIC, such as Actual and Accumulated Sediment Deposition, Initial and Modified Bed Levels and of Hydraulic data profile in the respective Reach.

Sedimentation Using Brownlie Method for Reach 1:

The results on the 20th operational day for Reach 1 was generated by the SETRIC are discussed below. It can be observed from Fig. 9 that after 20 days, the initial and final bed level were almost same. The final bed level was raised upstream of the fall due to silting as explained earlier. It can be seen in Fig. 9 that the initial bed level of 223.73 m at 1080.0 m from start (or after the Head regulator at 177+174 RD), was modified to 224.05 m. A total rise of 0.32 m or 32 cm will be experienced to achieve regime condition. It was assumed that this deposition distributed evenly in the canal, hence up to the length of 1000 m. It was also observed that at 2080.0 m (184+000 RD) from the start from where Head Regulator Old Chakrali Minor takes off, the initial bed level of 223.58 m modified up to 223.84 m. It was inferred from this Fig. 9, that at 2080.0 m from the start the sediment height of the canal is 0.26 m, which means that the canal bed will be raised by 0.26 m or 26 cm. Also, if observed closely, it can be seen that on the downstream side of the fall there is slight increase in the height of canal bed from 222.51 m to 222.61 m. It was realized that at as the regime condition approaches, the sediment deposition occurs at the upstream and downstream side of the fall structure. At the downstream side of the fall, there is a total deposition of 0.10 m which results in the sediment deposition of 586.768 m^3.

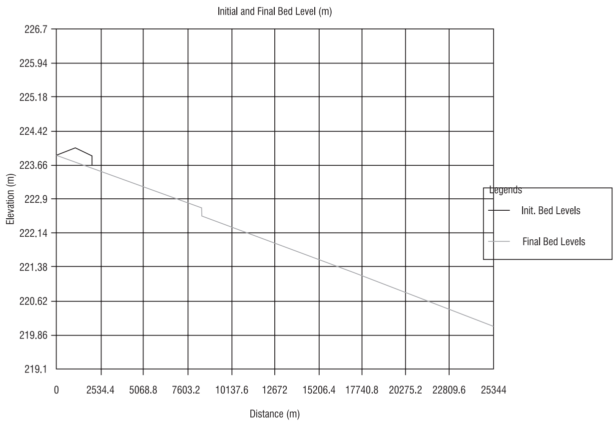


Fig. 9: Graph of Initial and Final Bed level on the day 20

Analysis of BRBD Link Canal Reach 2

The Reach 2 was simulated for 3 years with the interval of 180 days. The results obtained from the simulations are discussed below. In Table 2, the result for Reach 2 shows that the values of accumulated sediments for both Brownlie and Engelund-Hansen predictors were same for each maintenance condition. It can be inferred from the Table 2 that the conditions of maintenance have nothing to do with the sediment deposition as it remains the same. Whereas, it was very much evident that both the predictors gave different values and that the value of sediment deposited by Engelund Hansen was less than the value of sediment deposited given by Brownlie.

It can be observed in Fig. 10, that sediment deposition shows an increasing trend as the number of operational days are increased. It is quite evident that the Reach 2 of BRBD link canal comes to a non-silting and non-scouring stage after 455 days or 1.5 years of operation as per Brownlie, whereas if the other method of Engelund Hansen is considered, the Reach 2 comes into regime after 2 years or 760 days. From the graph in Fig. 10, it is inferred that in one and a half year a total deposition of 593084 m^3 occurs in Reach 2 as per Brownlie Method and this value remains the same after 2 and 3 years showing that the channel has achieved regime state.

Table 2: Comparison between Brownlie and Engelund- Hansen Predictor for Reach 2

		Accumulated Sediments m3					
		No maintenance		Well maintenance		Ideal maintenance	
		Predictor		Predictor		Predictor	
Reach	Days	Brownlie Method	Engelund-Hansen	Brownlie Method	Engelund-Hansen	Brownlie Method	Engelund-Hansen
2	180	265530.58	167460.08	265530.58	167460.08	265530.58	167460.08
	365	461375.90	349770.33	461375.9	349770.33	461375.90	349770.33
	455	593084.54	512736.15	593084.55	512736.15	593084.55	512736.15
	760	593084.54	552521.81	593084.55	552521.81	593084.55	552521.81
	1095	593084.54	552521.81	593084.55	552521.81	593084.55	552521.81

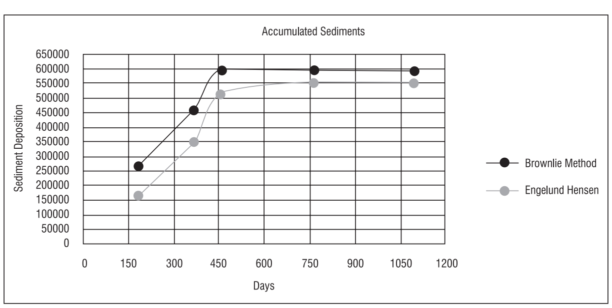


Fig. 10: Comparison of Trends of Sediment Deposition for two predictors.

Whereas, the results of Engelund Hansen show that the channel will come to regime after 2 years and has an accumulated silt deposition of 552521 m^3, which is about 6% less than the results shown by Brownlie Method. Hence, both methods are converging up to one value of the accumulated sediment deposition. It can be observed that the Engelund Hansen overpredicts the results, therefore, only Brownlie Method was discussed.

Brownlie Method Results for Reach 2

After 1.5 years, the canal achieves regime state and results which were generated by the SETRIC are discussed below. The volume of sediment deposition was about 4036 m^3 at 0 RD and at 7057 m^3 at the 572.00 m from 0+000 RD (Fig. 11). This sediment deposition occurred on the upstream side of the fall structure and on the downstream side of the Ravi Syphon. At 26712.00 m or 372+638 RD, the channel bed width changes from 16.46 m to 45.72 m along with the side slope of 1:1.5 to 1: 0.5. There is a sharp increment of sediment deposition on the downstream side of the 2nd fall structure at 337+144 RD and the upstream side of the 3rd fall structure 400+000 RD. The silt deposited here was 34522 m^3, which increased to 57218 m^3 at 31424.00 on the upstream side of the Head Regulator Karbath, which is located at 391+380 RD.

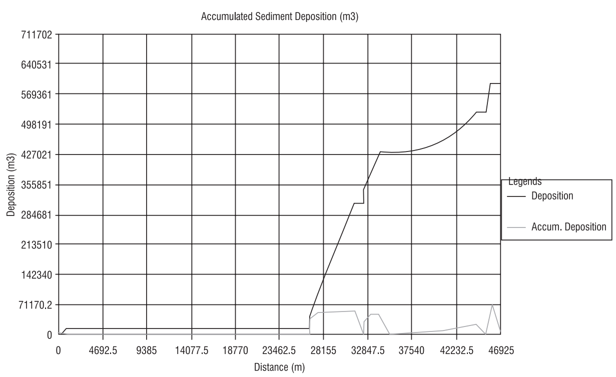


Fig. 11: Actual and Accumulated Sediment Deposition for Reach 2 by Brownlie Predictor

On the upstream side of the Head Regulator, the accumulated sediment deposition was 310000 m^3 (Fig. 11). At the downstream side of the regulator, a silt of volume 28386 m^3 is deposited. At the upstream of the fall at 400+000 RD, the accumulated sediment deposition was 427021 m^3. At the fall there is no deposition, but on the downstream of fall to the upstream of Head Regulator (Old minor) at 433+958 RD, there will be total deposition of 91414 m^3, which leads to a total accumulation of 523378.499 m^3 (Fig. 11). On the downstream side of Head Regulator (Old minor) and Head Regulator Main Branch, there is a deposition of 69706 m^3 due to which the total sedimentation volume on the downstream of this reach 2 will be 593084 m^3 (Fig. 11).

The modified bed levels given by the SETRIC are quite useful. They help in determining that how much bed level is increased from the initial bed level at which the canal is designed. At 572 m from the 0+000 RD, the bed level is increased from 216.99 m to 217.61 m accounting for 0.62 m or 62 cm increase in the sediment height (Fig. 12). This sediment deposition occurs at the upstream side of the fall structure and at the downstream side of the Ravi Syphon. It can be observed from Fig. 12 that from here to the upstream side at RD 372 + 638 or 26712.0 m there is no modification in the bed level. Whereas, on the downstream side, there is a sudden expansion in the width and the side slope which changes from 1:1.5 to 1:0.5. The bed level was also modified and changed from 213.88 m to 214.90 m. A total of 1.02 m the bed rises due to the irregular geometry of the canal. It can be observed from Fig. 12 that the bed level after the operating time of 1.5 years is raised to about 1 m or 100 cm. At the downstream of Head Regulator of Karbath, the bed level is raised to 214.13 m from 213.17 m. Therefore, for a reach of 2627 m, the height of sediment (assumed distributed evenly) is 0.96 m. It is also visible that on the downstream of the fall, the modified bed level begins to decrease and matches the initial bed level. At the tail of the Reach 2 on the downstream of Head Regulator of Old Minor and Head Regulator of Branch canal at 45925 m from the start the bed level is raised by 1.5 m, which accounts for heavy silting before the regime.

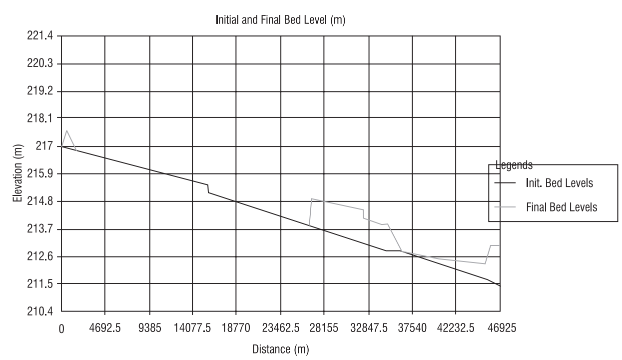


Fig. 12: Graph of Initial and Final Bed level after 1.5 years for Reach 2

SETRIC also provides the information with the output for the hydraulic parameters such as Actual Water Level, Normal Water Level and Critical Water Level in the canal. The channel cross-sectional properties changes near RD 372+638 which causes this anomaly in the sediment deposition. This sediment deposition and the changes observed in the bed level of the channel in regime condition can also be accorded to the varying hydraulic conditions in the channel. These conditions have been simulated by the SETRIC and have been plotted as a graph (Fig. 13). The graph basically shows how the hydraulic conditions change along the Reach 2. As can be inferred from Fig. 13, the critical water level is below the actual water level, which mean that the flow in the channel is in sub critical stage. The graph shows that when the canal reaches the regime condition after 1.5 years of operation, the normal water level and critical water level at 26712 m or RD 372+638 show an abrupt rise due to the varying channel cross-sectional properties at this point (which have been discussed earlier and can be seen in Fig. 6).

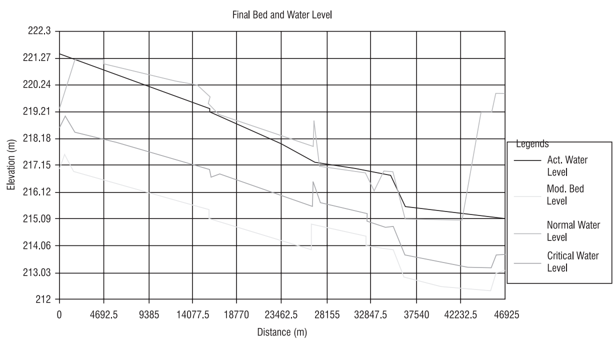


Fig. 13: Hydraulic Parameters in Reach 2

From the results of SETRIC, it can be observed that the normal water level in the downstream of fall structure 3 is lower than the Actual Water Level, whereas the normal water level is higher than the Actual Water Level at the tail of the Reach 2, this can be due to the two Head Regulator here at RD 433+958 which cater the Old Minor and the Branch canal. Due to these hydraulic characteristics of the water in the channel, the silt deposition in BRBD's Reach 2 is of much greater quantity than the Reach 1. This Reach starts at the downstream of the Ravi Syphon from RD 285+000. It has two control structures and throughout its length it contracts and then expands. Therefore, it will exhibit this kind of hydraulic character when the channel achieves regime condition. The deposition of so much silt at the upstream of RD 372+638 is due to the varying cross-sectional data. It can be explained by the Fig. 14 as to maintain the equilibrium condition at that point, that much deposition had occurred. The concentration of sediment at the upstream side of fall and head regulators is 1000 ppm, which drops to 365.7 ppm at 572.0 m to meet the equilibrium condition. At the fall RD 337+144 (15893 m), the equilibrium concentration also shows a dip, but the actual concentration of sediment remains the same at 213.13 ppm. At the upstream side of fall structure 3 at RD 400+000, it is observed that the equilibrium concentration and the actual concentration become somehow equal to achieve the regime condition. At the tail of Reach 2, where two laterals offtake and two head regulators are present, there the difference between the concentrations of sediment is only of few ppm. Such as at RD 433+938 or 45401 m, the difference in actual concentration (of 49.6 ppm) and equilibrium concentration (of 57.6 ppm) is of 8 ppm. In the end, at 46925 m, the equilibrium and actual sediment concentrations are 34.2 ppm that can be viewed in the Fig. 14.

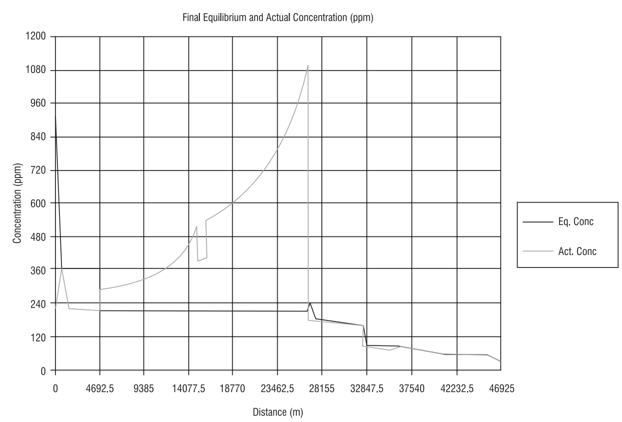


Fig. 14: Comparison of Equilibrium and Actual sediment Concentration in Reach 2

DESIGN OF CANAL USING SETRIC

Design Discussion

The BRBD link canal is an unlined channel. The flow and sediment transport analysis was performed using SETRIC model. The current canal design parameters, hydraulic and sediment transport characteristics were evaluated. The analysis showed that the canal achieved the regime conditions after 1.5 year operation. A considerable amount of sedimentation occurred because of cross-sectional variation which altered the bed level and affected the performance of the canal. The location of falls and head regulators also affect the sedimentation. The design of the canal, using Physics based SETRIC model results a stable cross-section and minimizes sedimentation and scouring. This model can be used to design an efficient canal cross-section. If the present geometry of the canal is modified by back calculating the dimensions of the canal from the deposited sediment on channel bed, efficient and stable canal cross-section can be achieved. If the canal is simulated from a Physics based mathematical model, then that operational time period can be determined which will be required to achieve regime state. With the help of these simulated results, the geometry of the canal can be modified. The BRBD canal was commissioned in 1968 and has achieved its regime state. However, it has lost a major percentage of its deliverance capacity and to remove the excessive silt the canal operation is to be halted for 1 month which puts a huge burden on the national exchequer. By remodeling the BRBD canal's Reach 2 and increasing the width of its section 5 (Fig. 6) from 16.4 m to 35 m (Fig. 15), so that there is no abrupt expansion as the width at section 6 is 45.72 m. It is observed that using the updated geometry, there was less sedimentation at RD 372+638 or 26712 m (Fig. 16). Fig. 16 shows that that the equilibrium concentration increases upstream of fall at RD 337+144. This is because that there is an abrupt change in cross sectional properties between section 4 and section 5 as shown in Fig. 15.

Dimensions

Total number of canal sections 9 Manning

Section no.	Chainager (m)	Length (m)	Bwidth (m)	Roughness	Sslope (1V:mH)	Bslope (1:1000)	Blevel, start. (m)	Blevel, end (m)
1	0.0	4572	21.54	0.0206	2	0.100	217.048	216.591
2	4572.0	2556	21.58	0.0206	1.25	0.100	216.591	216.335
3	7128.0	7844	21.58	0.0206	1.25	0.100	216.335	215.551
4	14972.0	921	21.58	0.0206	1.25	0.100	215.551	215.459
5	15893.0	10819	35.00	0.017	1.5	0.125	215.232	213.880
6	26712.0	5712	45.72	0.0141	0.5	0.125	213.880	213.166
7	32424.0	2627	45.72	0.0141	0.5	0.125	213.166	212.838
8	35051.0	10350	43.28	0.0137	0.5	0.125	212.838	211.544
9	45401.0	1524	43.28	0.0137	0.5	0.125	211.544	211.354

Fig. 15: Remodeling of Reach 2

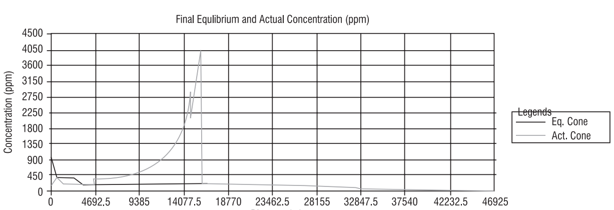


Fig. 16: Comparison of Actual and Equilibrium Sediment Concentration in Remodeled Reach 2

If the canal is remodeled again and the geometry of section 1 up to section 4 is modified by increasing the width from 21.58 m (Fig. 6) to 32 m (Fig. 17) so that there is a gradual change in the width of the canal rather than an abrupt change. As the geometry corrected, there were gradual changes in geometry as shown in Fig. 17. Due to which the accumulated sediment volume was low. From the comparison of Fig. 11 (which shows the simulation result for sediment deposition after 1.5 years of operation when original data was modeled) and Fig. 18 (which shows the simulation result for sediment deposition after 1.5 years of operation when modified data was modeled using SETRIC), it was realized that when the cross-sectional properties were corrected for Reach 2, the total accumulated sediment deposition was reduced from 593084 m^3 to 384000 m^3. The total reduction in sedimentation was about 35%. The canal with modified geometry showed better results regarding the equilibrium condition met throughout the Reach 2.

We can conclude that the whole irrigation System can be remodeled using SETRIC. The evaluation of the entire irrigation system can be performed and the geometry of the designed canals can be modified.

Dimensions

Total number of canal sections 9 Manning

Section no.	Chainager (m)	Length (m)	Bwidth (m)	Roughness	Sslope (1V:mH)	Bslope (1:1000)	Blevel, start. (m)	Blevel, end (m)
1	0.0	4572	32.00	0.0206	2	0.100	217.048	216.591
2	4572.0	2556	32.00	0.0206	1.25	0.100	216.591	216.335
3	7128.0	7844	32.00	0.0206	1.25	0.100	216.335	215.551
4	14972.0	921	32.00	0.0206	1.25	0.100	215.551	215.459
5	15893.0	10819	35.00	0.017	1.5	0.125	215.232	213.880
6	26712.0	5712	45.72	0.0141	0.5	0.125	213.880	213.166
7	32424.0	2627	45.72	0.0141	0.5	0.125	213.166	212.838
8	35051.0	10350	43.28	0.0137	0.5	0.125	212.838	211.544
9	45401.0	1524	43.28	0.0137	0.5	0.125	211.544	211.354

Fig. 17: Remodeling of Reach 2

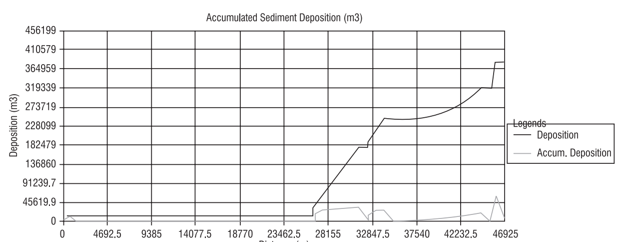


Fig. 18: Accumulated Sediment Deposition for Remodeled Reach 2

CONCLUSIONS

The agriculture-based economy of Pakistan heavily depends upon its massive irrigation system. The maintenance of this system requires huge budgets, which are to be allocated by the Government of Pakistan. The maintenance of this system requires de-sedimentation of the channel bed (Bhal Safai), maintenance of the slope for gravity flow, berm cutting, removal of vegetation and maintenance of the side slope. Sediment deposition is one of the main factors which causes hindrance in the canal operation and maintenance. In maintaining a canal bed, the silt or sediment removal is the expensive and laborious work, and also the canal operation has to be halted. The farmers during this halting operation has to use the ground water extracted from the tube well, which is expensive and not a suitable approach. Sediment transport in the irrigation canal (SETRIC) is a mathematical model which can be used to model the canal and provide analysis of the existing hydraulic and sediment conditions. By using this model, the existing canal can be simulated and the simulation can be performed for the required operational days. The end simulation results reveal whether a canal achieves a regime state. The analysis of the results can help us to calculate the volume of the sedimentation and it can also help us to design a canal in which at the start no silting or no scouring condition is achieved, which means that the equilibrium is attained in that cross-section, i.e., the amount of sediment which will enter will equal the same of sediment it will leave the canal.

The problem statement included the analysis of already existing BRBD Link Canal using SETRIC model and to come up with a better design solution to cater the problems that exist in the current design. The analysis of BRBD existing design was performed by modeling the canal from RD 177+174 to RD 282+760 in one reach (namely Reach 1) and modeling the canal from RD 285+000 to RD 435+000 in the other reach (namely Reach 2). These two reaches were then simulated on SETRIC and the results were analyzed and comments on design were made. The sediments in the entire reach of BRBD Link had an average size of 0.20 mm. Therefore, the sediments in the flowing canal were found to be in between the coarse sediments and medium sediments. The sediments in the Reach could be cohesive sediments. It was observed that the whole BRBD canal from RD 177+174 to RD 435+000 achieved the regime condition in one and half year when the Brownlie sediment transport predictor was used. The Fig. of 1.5 years is a collective Fig. as the Reach 1 achieved a regime state in 20 days, whereas the Reach 2 achieved a regime state in 1.5 years.

This study included a comparison between Brownlie and Engelund- Hansen sediment transport predictor for the Reach 1. The channel comes to the regime in 20 days of operation as per Brownlie, whereas it came to the regime in 35 days of operation from Engelund- Hansen predictor. It was observed that Engelund- Hansen predicted 65702.387 m^3 of sediment will be deposited in Reach 1 for 35 days of operation, which was 146% greater than the amount of sediment volume predicted by Brownlie (which predicted 26675 m^3) in 20 days of operation. The results of Brownlie were given more importance as they were representing physical conditions and the values predicted by the other predictor were far away from reality.

Similarly, when Reach 2 was modeled on SETRIC, the results it showed helped to determine the total duration in which the entire reach of BRBD will come into the regime and also the total volume of sedimentation in the BRBD canal which has been accumulated. Reach 2 was also simulated for both predictors and the results which SETRIC showed were different from Reach 1. The Engelund Hansen Method predicted that the total volume of deposited sediments (552521 m^3) will be 6% less than the result shown by Brownlie Method (593084 m^3). Upon comparison, it was realized that the channel comes to regime after 2 years if the Engelund Hansen Method is used and for the Brownlie predictor method the channel comes to regime after 1.5 years. The results shown by the Brownlie Method were more reliable. The geometry of reach 2 varies very abruptly at one section, the width is 21.54 m and the very next section it faces contraction and reduces to 16.46 m, and at RD 372+638, the width of channel expands to 45.72 m, which then reduces to 43.28 after 8339 m. Due to this change of geometry the hydraulic and sediment conditions in the channel show abnormal behavior. Due to this sudden expansion at 372+638 RD, the flow velocity reduces as the area increases. This flow velocity became lesser than the critical velocity, and the sediments begin to deposit. Also, it can be observed that when the width further reduces, the sediment deposition was found lesser. In Fig. 12, it is quite visible that due to this reduction of velocity, there is a tremendous increase in the sediment deposition and due to which on the downstream of fall structure 2 and the upstream of fall structure 3, there are heavy deposits of sediments and the bed level is raised by 1.2 m or 120 cm for the length of 8339 m.

Based on the analysis made on BRBD's current design and working, it is understood that the design of BRBD Link Canal is not an efficient one. A total of 619759 m^3 of sediments has been deposited on the bed of channel after 1.5 years of operation and after that the channel managed to achieve regime condition. Afterwards, when there is a slight fluctuation in the discharge, there are more changes in this deposition and also some scouring can be expected. For the design purpose, again SETRIC expertise was used to seek that efficient design in which the equilibrium stage is achieved from the start and there existed no deposition and scouring. The new cross-sections were designed by keeping the existing design and its problem regarding sedimentation in mind. The main problem in the design of Reach 2 is the abrupt change in geometry, so during the remodeling this section was under consideration and it was decided to increase the bed width of the section at RD 337+144 (upstream of fall structure 2). The width of this section (shown in Fig. 15.) increased to 35 m from 16.46 m as the section at RD 372+638 was 45.72 m wide. This increase in width was made to provide a gradual change rather than abruptly changing geometry. By doing this modification, the value of sedimentation dropped and the now excessive sedimentation was not observed at RD 372+638 as shown in Fig. 16. Now, the excessive sedimentation can be seen at the upstream of the weir at 337+144 RD (153893 m), because again there was an abrupt expansion at this point such as the width of upstream section is 21.58 m and the bed width at this section of RD 337+144 is 35 m.

Now, to overcome this situation the bed width of 4 sections (from RD 285+000 or 0 m to 337+144 RD or 153893 m) was increased from 21.58 m to 32 m (as shown in Fig. 17). This modification along with one made earlier showed better results than the last modification, as the reach now had no abrupt changes in geometry but rather smooth and gradual changes can be seen. By doing this complete modification, the total sedimentation in the BRBD canal was seen to be reduced from 593084 m^3 to 384000 m^3 about 35.25% lower volumes of sediment deposition shown in Fig. 18. This was no doubt a big step as this whole process of remodeling and re analyzing give the opportunity to design an efficient canal system. If supposedly, SETRIC was not used in this whole process, it would have taken years to analyze BRBD and draw conclusion regarding the sediment deposition and to find the time in which it comes to regime. SETRIC has been very much helpful as it enables the mathematical modeling of the entire canal and gave results which were logical and close to reality. This analysis and design helped to understand various characters that must be kept in mind while designing the canal which were usually ignored at the time these canals were constructed due to which there existed a lot of discrepancies in this irrigation system.

Recommendations

Modification in SETRIC Model: This can be further improved if we divide the Reaches in small intervals and then gradually change the bed width and other adjoining properties. Also, a modification in the software can be performed which might help in the modelling of other constraints which the current software does not consider.

REFERENCES

1. *Ackers, P., (1999), "Sediment transport: new approach and analysis", Journal of Hydraulic Engineering, ASCE, Vol 99(11).*

2. *Ali, I., (1993), "Irrigation and Hydraulic Structures, Theory, design and practice, Karachi, Pakistan: Institute of Environmental Engineering and Research", NED University of Engineering and Technology.*

3. *Bos, M. G., (1989), "Discharge measurement structures (Third ed.)", Wageningen, The Netherlands: International Institute for Land Reclamation and Improvement.*

4. *Braban, T., (1990), "Workshop on Sediment Measurement and Control, and Design of Irrigation Canals", Wallingford, United Kingdom: Hydraulic Research.*

5. *Brownlie, W. R., (1981), "Prediction of flow depth and sediment discharges in open channels", California: California Institute of Technology.*

6. *Chen, C. N., Tsai, C. H., Tsai, C. T., (2006), "Simulation of sediment of yield from watershed by physiographic soil erosion-deposition model", Journal of Hydrology..*

7. *Chow, V. T., (1983), "Open channel hydraulics", Tokyo, Japan.: Mc Graw Hill International Book*

Company.

8. *Depeweg, H., (1993), "Lecture notes on applied hydraulics", gradually varied, Delft, the Netherlands: IHE.*

9. *Depeweg, H., Mendez, V. N., (2014), "A new approach to sediment transport in the design and operation of irrigation canals", Delft, the Netherlands: CRC Press,Taylor & Francis Group.*

10. *Depeweg, H., Paudel, K.P., (2003), "Sediment transport problems in Nepal evaluated by the SETRIC model", Irrigation and Drainage.*

11. *Federal Bureau of Statistics, (2001), "Pakistan Statistical Yearbook 2001, Statistics Division", Govt of Pakistan.*

12. *Méndez, D. H., (2002), "Sediment Transport Applications in Irrigation Canals", Irrigation and Drainage, Vol 51, pp. 167–179.*

13. *Paudel, K. P., Schultz, B., Depeweg, H., (2014), "Design of non-wide canals for sediment transport. Case study of sunsari morang irrigation scheme Nepal", Irrigation and Drainage.*

14. *Punjab Irrigation and Power, (2008), Lahore, Punjab: Office of the Chief Engineer.*

15. *Ragab, R., (2006), "Proceedings of the International Workshop on Water Saving Practices in Rice Paddy Cultivation, Malaysia", Centre for Ecology & Hydrology, Wallingford, UK.*

16. *Sherpa, K., (2005), "Use of the Sediment Transport Model Setric in an Irrigation Canal MSc Thesis", the Netherlands: UNESCO-IHE.*