International Journal of Science and Research (IJSR)
ISSN: 2319-7064
Impact Factor 2024: 7.101

Canal Optimisation of Longa Irrigation Project

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Abstract: ***In an irrigation project, canals play a major role. As India depends upon agriculture for its livelihood and it involves usage of water to a large extent, focusses are made on irrigation. It is seen that there is water stress in many parts of country due to climate change, and hence efficient utilization of water becomes a matter of concern. In the present study, non-linear optimization models are developed for canal section as well as cost of construction since the main conveyance of water to the field are irrigation canals. In this study, the approach used is Microsoft GRG solver. Rectangular and trapezoidal cross-sections are optimized considering the constrains on the velocity, flow conditions, width, depth, most economical cross section and discharge. However, the depth of canal and width of canal are taken as the variables during study and thus cost of construction of optimized section is computed.***

Keywords: Assam, Non-linear optimization, canal, rectangular and trapezoidal cross section.

1. Introduction

India depends on agriculture for its living since times immemorial and it is the primary source of livelihood. About 14% of a country's GDP depends on agriculture. About 51% of agricultural land depends on irrigation. However, 84% of the total water is used for irrigation. (S et al., 2021.) There is a huge scarcity of fresh water due to increased demand for agriculture as most of the freshwater is consumed by agriculture. Therefore, there should be an efficient utilization of water. (Gangwar et al., 2017.) Farmers use the traditional approaches of farming leading to huge loss of water. Moreover, they provide more watering to the crops which is also a reason of losses of water. The amount of water supplied should be in accordance to the water demand. And therefore, the farmers should be facilitated with the know-how on Crop water requirements (Kumar et al., 2020.) It is also seen that there are water losses due to seepage, evapotranspiration, infiltration losses, etc. when water passes through an earthen irrigation canal. Hence, the seepage losses contribute to reduced irrigation. The major losses occur due to seepage and therefore proper lining should be provided in order to combat the losses (Zhang et al., 2016, Barkhordari and Hashemy Shahdany,2022). Therefore, the design of canal should be in a way to obtain an optimal section which would ultimately results to an economical cost of construction of the canal section. In order to obtain such results, the specific energy plays a vital role. The specific energy is almost vertical at the critical condition. And a small change in specific energy could bring depth of channel to higher or lower position. And so, critical condition is treated as most unstable zone. Moreover, there occurs a hydraulic jump too when Froude's no. attains a value of 1.2. Hence, subcritical zone is considered convenient for design of canal section. (Rajiv Bhattacharjee, 2006.)

It is observed that water threats led to focus on irrigation scheduling of the crops which in turn brought best practices of water management and irrigation planning. Genetic algorithm works well in irrigation scheduling (Peng et al., 2012).However, various optimizers were used in order to improve the irrigation scheduling and also new optimizing techniques were developed to optimize the usage of water at the fields. (Shahverdi & Maestre, 2022). Incorporating fuzzy sarsa AI in MATLAB while developing a HEC-RAS model has brought a lot of improvements in the water distribution indicators, energy generation, and reduction in CO_2 emission, which has not only resulted to economic viability but also causing significant benefits to the environment (Kazem Shahverdi and Jose Maria Maestre,2023). In order to minimise the cost of construction, various researchers developed optimising models with the help of several approaches such as sequential quadratic programming (Rajiv Bhattacharjee, 2006), genetic algorithm (Wang, 2022),MATLAB programming considering the flow discharge as main constraint in addition to minimum permissible velocity and flow condition etc.(Rezapour Tabari et al., 2014)

In the present study, Microsoft GRG solver is used to frame the non-linear optimization where the inputs such as discharge data is obtained using CROPWAT 8.0 for the crops Sali, Rapeseed, Vegetable (Sweet Melon) and Jute and other parameters are considered using IS standards.

2. Study Area

A flow irrigation project is taken for the study. Longa Irrigation Project is located in the district Kokrajhar of Bodoland territorial council. The headwork of the project is located at latitude 26.548096^{0}N longitude 90.162317^{0}E. The scheme has a barrage of length 86.58 meters and the canal system will be provided mainly on the right bank of river Longa. The Right Bank canal system of the scheme proposed of one main canal M1 and six numbers of branch canal. The left bank canal system has only one main canal M2 of length 600m without any branch canal. Initially the Scheme was proposed and sanctioned as Medium Irrigation project with proposed Canal Length of 34.60 Km with CCA of 3672.43 Ha. The soil in the region is recognized as light(sand) as stated in FAO standards. Major crops cultivated include Sali, Rapeseed, Jute and Vegetables (sweet melon)

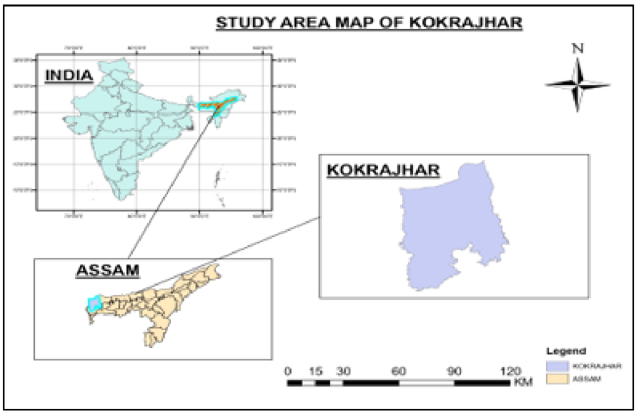

Figure 1: Location map of Longa Irrigation Project

Figure 2: District map of the study area

3. Materials and Methodology

This study uses CROPWAT 8.0 and CLIMWAT 2.0 to determine the crop water requirement. With the help of crop water requirement, the required discharge of the canals are found out. The required discharge of canal section as given by Eq.1, constraints on the velocity, flow conditions, width, depth, most economical cross section are the inputs to the Microsoft GRG solver in order to obtain optimized canal section.

Required Discharge by the canal $= Annual\ Irrigable\ Area\ x \frac{Max.CWR\ per\ decadal}{10\ x\ 24\ x\ 60\ x\ 60}\ x\ \frac{10000}{1000}$ m^3/s….Eq.1

3.1 Crop water requirement

This study utilizes the Food and Agriculture Organization (FAO) CROPWAT 8.0 model, developed by the Department of Land and Water Resources of FAO. CROPWAT 8.0 is a computer program designed for computing crop water requirements (CWR), irrigation water management, and irrigation scheduling (Smith, 1991). With the calculated CWR which is influenced by climatic conditions, crop characteristics, soil type, growing season, and crop production frequencies, following the FAO-approved Penman-Montieth method for estimating reference evapotranspiration (ETo), crop evapotranspiration (ETc), and irrigation water management, required discharge is obtained considering the maximum discharge per decadal. ETc reflects the water lost through evapotranspiration, while CWR represents the amount of water to be applied (Allen et al., 1998,Smith, 1991).

ETc=ETo x Kc where, ETo-Reference evapotranspiration, ….Eq.2

Kc -crop factor

In the present study, the climatological data, rainfall data were extracted from CLIMWAT 2.0 for the nearest station Dhubri, soil and crop data were taken as per FAO standards. Table 3 showing the discharge required by each canal using the formula. Table 1 showing the computed crop water requirement which is obtained using CROPWAT 8.0. Table 2 showing the Maximum Crop water Requirement and Table 3 represents the discharge required by the canal.

Table 1: Crop water requirement

Name of Crop	Crop Water Requirement(mm/dec)
Sali	515.2
Vegetable (Sweet Melon)	338.4
Jute	380.5
Rapeseed	226.4

Table 2: Maximum Crop Water requirement

Name of Crop	Maximum Crop Water requirement (mm/dec)
Sali	45.3
Vegetable	50.7
Jute	47
Rapeseed	38.5

Table 3: Discharge required by the canal

Name	Designation of canal	Type of crops grown and net irrigable area (ha)	Annual irrigable area (in ha)	Discharge required by the canal (m^3/s)
Main Canal	M1	Sali=1145 Rapeseed=1145	2290	1.1
Branch Canal	M1S1	Sali=200 Ha Rapeseed=200	400	0.193
	M1S2	Sali=200.22 Veg=200.22 Jute=200.22	600.66	0.3
	M1S3	Sali=500 Veg=500 Jute=500	1500	0.83
	M1S4	Sali=336	336.00	0.176
	M1S5	Sali=360	360.00	0.188
	M1S6	Sali=250 Rapeseed=250	500	0.2

3.2 Model formulation

Let us consider a rectangular channel section as shown in the figure 3. The Manning's roughness coefficient, flow depth, width of the channel, thickness of canal lining and free board of the channel are (n, Y, B, t, f). Cement concrete is used as a lining material; hence roughness coefficient for cement concrete is used.

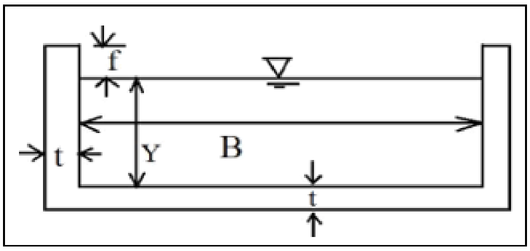

Figure 3: Rectangular channel cross-section

Let A_f and P_f are the cross sectional area and wetted perimeter of the channel with free board f.

$$A_f = B(Y+f) \qquad \text{Eq.3}$$

$$P_f = B+2(Y+f) \qquad \text{Eq.4}$$

Similarly A, P, R, T, D,V and F_r are the area, wetted perimeter, hydraulic radius, top width, hydraulic depth, velocity of flow in the channel and Froude's no of the channel without freeboard. These parameters can be written as

$$A = B \times Y \qquad \text{Eq.5}$$

$$P = B+2Y \qquad \text{Eq.6}$$

$$T = B+2ZY \qquad \text{Eq.7}$$

$$D = A/T \qquad \text{Eq.8}$$

$$R = A/P \qquad \text{Eq.9}$$

$$Fr = V/\sqrt{gD} \qquad \text{Eq.10}$$

Now, consider a trapezoidal channel section as shown in the figure 4 with Manning's roughness coefficient 'n', flow depth 'Y', width of the channel 'B', thickness of canal lining 't', free board 'f' and side slope in the ratio of 1:Z (V:H) = 1:1 on both the sides.

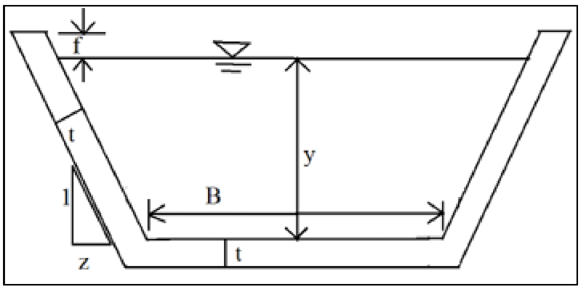

Figure 4: Trapezoidal Channel Cross-section

Let A_f and P_f are the cross sectional area and wetted perimeter of the channel with free board f.

$$A_f = (B+Z(Y+f)) \times (Y+f) \qquad \text{Eq.11}$$

$$P_f = B + (2(Y+f)\sqrt{1+Z^2}) \qquad \text{Eq.12}$$

Similarly A, P, R, T, D, L, V and Fr are the area, wetted perimeter, hydraulic radius, top width, hydraulic depth, length of slanting side, velocity of flow and Froude's no of the channel without freeboard. These parameters can be written as

$$A = (B+ZY) \times Y \qquad \text{Eq.13}$$

$$P = B + 2Y\sqrt{1+Z^2} \qquad \text{Eq.14}$$

$$T = B + 2ZY \qquad \text{Eq.15}$$

$$D = A/T \qquad \text{Eq.16}$$

$$L = Y\sqrt{1+Z^2} \qquad \text{Eq.17}$$

$$R = A/P \qquad \text{Eq.18}$$

$$Fr = V/\sqrt{gD} \qquad \text{Eq.19}$$

The free board (f) value for both the section is considered as per IS: 10430-1982. The thickness for canal lining is considered as per Table 4 which is as per IS 3873:1993.

Table 4: Thickness of Canal Lining

S. No	Discharge(m^3/s)	Depth of Water(m)	Thickness (cm)
1	0-5	0-1	50-60
2	5-50	1-2.5	60-75
3	50-200	2.5-4.5	75-100
4	200-300	4.5-6.5	90-100
5	300-700	6.5-9.0	120-150

The manning's equation for uniform flow in a open canal is written as follows-

$$Q = A \times \frac{1}{n} \times R^{\frac{2}{3}} \times S^{\frac{1}{2}} \qquad \text{Eq.20}$$

Where, Q=design discharge, S= longitudinal slope of canal, R= Hydraulic depth of canal.

Longitudinal slope is considered as 1/3000 for all canal section.

3.3. The Nonlinear Optimization Model:

3.3.1 Objective Function:

The objective function of the Nonlinear Programming (NLP) model comprises the excavation and lining costs, aimed at minimizing the overall construction expenses for the Longa Irrigation project canal.

Min Z=Cost of excavation + Cost of lining
= C1 x Cross-sectional area of the canal+ C2 x Cross sectional area of lining
= C1 x B x (Y+f) + C2 x (B+2 x (Y+f)) x t

Where, z = Minimum cost of construction of canal per running meter.
C1 = Cost of excavation per cubic meter.
C2 = Cost of lining per cubic meter.

The values of C1 (Item no. 6.1(A)) and C2 (Item no. 18.4) are taken as per Schedule of rates for the year 2023-24 of the Irrigation department of Govt. of Assam.

3.3.2 Constraints:
The various constraints of the optimization model are listed below:

1) Discharge in the canal: The discharge calculated from Manning's formula for the canal is greater than or equal to the design discharge for the canal.
2) Froude number: The Froude number calculated for the canal section should be less than 1(one) to maintain the subcritical flow condition and to avoid hydraulic jump in the canal.
3) Condition of most economic rectangular canal section: The condition for most economic rectangular canal section is $Y=\frac{B}{2}$. So, B=2Y is considered as a constraint to get the most economical canal section.
4) Width of the channel: The width of the channel cannot be negative, i.e. B > 0. Considering the construction point of view, let the minimum width of the channel be 0.1m.
5) Depth of the channel: The depth of the channel cannot be negative i.e. Y > 0. Let the minimum depth of the channel be 0.1m.
6) Limiting velocity: The limiting velocity for the canal is considered as per IS: 10430-2000 and for cement concrete lining it is 2.7 m/s.
7) Critical velocity: According to IS: 10430-2000, the critical velocity obtained by any formula should be less than the velocity of the canal obtained by Manning's formula. The critical velocity obtained by Kennedy's formula i.e. $V_0= 0.546 \text{ X } D^{0.64}$ should be less than the velocity in the canal obtained by Manning's formula.
8) Top width: The top width for main canal and branch canal are 3.6m and 3m respectively.

3.3.3 Variables:
The optimization model is subjected to two variables. They are: i. Bed width of the canal. ii. Depth of the canal

4. Results and Discussion

A nonlinear optimization model has been applied to the canal network of Longa IP considering rectangular and trapezoidal sections, yielding optimal dimensions and construction costs per meter for the canal sections. The optimal dimensions and costs for the main canal M1 and its branch canals are tabulated at Table 5. For the entire canal system, adopting a rectangular section results in a total minimum construction cost Rs.7,20,83,602 (Rupees Seven Crore Twenty Lakh eighty three thousand six hundred two only) and for trapezoidal section it will be Rs 9,28,49,549 (Rupees nine crore twenty eight lakh forty nine thousand five hundred forty nine only).

Table 5: Optimum costs of construction for rectangular and trapezoidal section

S no.	Name	Discharge(m^3/s)	Rectangular Section			Trapezoidal Section		
			Optimum Width B(m)	Optimum Depth Y(m)	Optimum cost of construction per running meter (Rupees)	Optimum Width B(m)	Optimum Depth Y(m)	Optimum cost of construction per running meter (Rupees)
1	M1	1.1	1.766	0.883	3021.605	0.562	0.927	4043.204
2	M1S1	0.193	0.919	0.460	1439.227	0.273	0.451	1818.818
3	M1S2	0.3	1.085	0.542	1671.03	0.322	0.532	2068.286
4	M1S3	0.83	1.589	0.794	2428.75	0.472	0.779	2880.492
5	M1S4	0.176	0.888	0.444	1396.361	0.264	0.436	1772.63
6	M1S5	0.188	0.910	0.455	1426.842	0.270	0.446	1805.476
7	M1S6	0.2	0.931	0.466	1456.271	0.277	0.457	1837.181

5. Conclusion

This paper presents two non-linear models, one is rectangular cross section and the other is a trapezoidal cross section, which is then solved based on Microsoft GRG solver. Table 5 represents the optimized canal section which consequently minimises the costs of construction. It is seen that this method of obtaining minimum costs of construction for the optimized canal section does not involve any complexity and hence it can be easily handled by the field engineers, unlike other optimizing technique such as Grey Wolf optimization, MATLAB etc, which requires adequate knowledge as well as costly softwares. Hence, MICROSOFT GRG SOLVER easily solve the non-linear models. Engineers very often fail to adopt proper optimizing technique due to the lack of infrastructures in the departments. This paper aims to describe how easily design of an optimized canal section could be obtained at MS Office platform, which is at everyone's fingertips.

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Paper ID: SR25402121733 DOI: https://dx.doi.org/10.21275/SR25402121733

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