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Original Article

Economic Design of Combined Gravity and Pumped Water Transmission Main

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Abstract - *A water transmission system is designed to supply treated water from the Water Treatment Plant (WTP) to the storage reservoirs located in the city's different zones in urban areas or different villages in a grouped water supply scheme. In the case of a grouped water supply scheme, the cost of the transmission network is quite high as the villages are generally located far from each other. Such a transmission system is planned as a direct pumping or a combined gravity and pumped type system. Recently, in the CPHEEO Manual, a methodology for the economic design of such systems is suggested that involves minimizing the cost of pipes, cost of pumps, Master Balancing Reservoir (MBR) cost (if required), and capitalized energy cost. A Linear Programming (LP) based model is suggested to design the network. The LP model provides two pipe sizes for some of the links, which is sometimes not favored by field engineers. Herein, a methodology based on a single pipe size for each link called the Modified Marginal Cost Increase Head Gain Ratio (MMCH) method, is suggested. The present work focuses on developing software using Python code. Initially, it is tested with a single-source, single-destination pumped transmission main, which is used to pump water from the sump of a WTP to MBR. Later, an economic analysis of a combined gravity and pumped transmission network is considered. The example network from the manual is considered, and it is observed that the overall difference in cost is 1.04 % when each link consists of a single size in the transmission network.*

Keywords - *Transmission system, Pumped transmission main, MMCH method.*

1. Introduction

A water transmission network is a paramount element of a water supply system. A transmission network could be defined as a network of pipes that transmits raw/clear water from one component to another in a water supply scheme. For urban as well as rural water supply systems, treated water, usually is pumped to an MBR and then to several Elevated Service Reservoirs (ESRs) under gravity. There are three types of transmission mains systems:

- Gravity System,
- Pumped System, and
- Combined Gravity and Pumped System.

When the source of the transmission network is at a higher elevation, and the flow of water is from high to low head, such a system is called a Gravity System. When the source of the transmission main is located at a lower elevation, additional heat is generated at the source using pumps. At times, even when the source of the transmission main is at a higher elevation, the available head may not be sufficient to supply water by gravity, and a pump is required to transmit water. Such systems are called Pumped systems. Generally, it is observed that the source of clear water (WTP) is at a lower level, and water is usually pumped to a highly elevated MBR from the source. Further, from the MBR, water is transmitted to the Village Reservoirs (VRs) under gravity. Such systems involve the combined action of pumping and gravity in the same network and hence are called Combined Gravity and Pumped Systems. The designing of a water transmission network with different components and their complexities is a cumbersome task due to the non-linear relationship between the pipe discharge and head loss and the fact that the nature of the decision variables, i.e. pipe sizes, is discrete and not continuous. The cost of transmission takes up an appreciable portion of the capital outlay, thus requiring economic design.

2. Literature Review

As stated earlier, a transmission system can be considered into three major types. Different researchers have attempted to solve the issue of calculating the economic system cost. A brief literature review is prepared herein, showing the existing methods for finding the economic/optimal system cost.

2.1. Pumped Systems

Various researchers have suggested several methods for the economic analysis of pumped transmission networks. A concise overview of the same is provided here. Swamee (2001) developed a methodology for the optimal design of multi-stage pumping mainly using geometric programming with a unit degree of difficulty, which was dependent upon the estimation of friction factor, f. This iterative process was very time-consuming. Also, the diameter of the pumping main was assumed to be a continuous variable, and hence, the diameter obtained as the optimal solution would have to be rounded off to the nearest available size. This would result in a loss of optimality and may not satisfy pressure constraints at demand nodes, if any. Mahar et al. (2013) suggested optimization of pumping mains by considering various pump characteristics. A non-linear optimization model is developed to design a pumping main for the desired hydraulic and economic parameters. The model reports the optimal diameter of the pumping main using pump efficiency for a given discharge. The model takes into account the future cost of components and energy. However, this approach also does not report the discrete diameters of pipes.

Patil et al. (2020) used the Lagrange Multiplier Technique to obtain the optimal cost of the transmission network. A flow path algorithm and dynamic programming are developed to report the optimal diameters. The design is based on the Hazen-Williams equation. It is then analysed in EPANET.

The results of the analysis were used to check the obtained design values. The cost was calculated for various heads. The total cost includes the pipe cost and pumping cost. The pumping cost was calculated using the cost function parameter for the power required and energy consumed. However, discrete pipe diameters were not obtained in the optimization process, leading to a loss of optimality when the diameters were rounded off.

A method to carry out an economic analysis of a single source, single destination pumped transmission main is suggested in CPHEEO (2024). The method considers the total cost of the pumped transmission main dependent on the head loss occurring in different candidate pipe sizes considered in the analysis. Different stages are considered depending on the design period of the system's different components (pipe and pumps). The system's total cost is calculated by adding the pipe cost, pump cost and energy cost for these stages for different candidate pipe sizes. The pipe size having the least total Present Worth (PW) for the system is then selected as the economic size of the pumped transmission main.

2.2. Gravity Systems

As a gravity transmission system is just a simple branch network, different optimization techniques that are valid for optimization of Water Distribution Networks (WDN) are applicable to Water Transmission Networks **(**WTN). Various deterministic, heuristic, and metaheuristic techniques are available in the literature to obtain the minimum pipe cost (Sarbu & Adam, 2014; Kumar & Yadav, 2022). Each technique has advantages and limitations in its applicability to obtaining a solution. Deterministic and heuristic techniques are observed to converge at a local optimum but offer savings in overall computation time. Metaheuristic techniques, while computationally expensive, are observed to converge to better solutions compared to the other two techniques (Kumar & Yadav, 2022).

Practitioners often rely on trial error/heuristic approaches to find the solution. In the present work, heuristic approaches are considered to obtain a solution as they are easy to understand and implement with the least calculation efforts. Bhave (2003) developed a methodology akin to Rasmusen's (1973) marginal cost approach, referred to as the 'Marginal Cost Increase Head Gain Ratio (MCH) Method'. All pipes in the network are initially assigned the smallest possible size, not any random pipe size. Then, the network is analyzed to calculate the available pressure heads.

The most pressure-deficient node is called the critical node. The most suitable pipe to mitigate this deficiency in pressure at the critical node is decided using the MCH ratio. Each link's pipe size is then increased to the next higher size one by one, and an MCH ratio is obtained. The link size with the minimum ratio is changed to the higher one. This process of analyzing the network, identifying the critical node and adjusting pipe sizes is repeated until all nodes in the network satisfy the criteria of the required pressure heads.

The author proposed some changes to the MCH method and called it the MMCH method. The first adjustment involves altering the MCH ratio from a cost-to-head gain ratio to a head gain-to-cost ratio. The second adjustment focused on selecting multiple pipes in each iteration, with constraints based on both the number of pipes and the MCH ratio. It is proposed that 10% of all the pipes be increased to a larger size, with the condition that their MCH ratio must exceed 50% of the greatest MCH ratio. This reduces the time required to execute the code and the number of hydraulic analyses in EPANET. However, selecting more than one pipe simultaneously could lead to some sub-optimal choices. To address this, the third modification involved reviewing potential sub-optimal selections at the end. The suggestion was to select one size lower than the one obtained at the end and repeat the process.

2.3. Combined Gravity and Pumped Systems

'JalTantra' (Hooda and Damani, 2019) is a freeware system for the optimal design of branched networks developed by the CSE Department of IIT Bombay. It can be used for all types of WTNs, i.e., gravity, pumping, and combined pumping and gravity networks. In the case of a combined pumping and gravity WTN, JalTantra allows the sizing of the pumped transmission main, pump, ESR, and gravity mains simultaneously.

However, JalTantra considers a constant flow for the entire design life of 30 years instead of varying flow with population change. Herein, as per the recommendation in the manual (CPHEEO 2024), varying discharge with the provision of pumps in two stages of 15 years is considered.

3. Research Gap and Study Objectives

The design period for the pump is considered based on the life of the pumping machinery and the suitable impact of wear and tear during operation. Hence, an overestimation of pumping capacity is observed in the case of solutions obtained from JalTantra. Further, as Jal Tantra reports, a split-size solution based on LP optimization is mostly discouraged by practicing engineers/departments.

Herein, an attempt is made to overcome the aforesaid limitations of the existing solutions obtained using JalTantra. To cope with this limitation, a Python code is developed to calculate the energy cost for each pumping stage and estimate the PW energy cost accordingly for a combined pumping and gravity network. For calculating suitable pipe sizes, a heuristic method named MMCH, as developed by the author. The novelty of this work is an attempt to combine deterministic and heuristic methods to obtain a solution for combined gravity and pumped systems. Economic analysis of a pumped transmission main, as suggested in CPHEEO (2024) and MMCH method, as suggested by author, is combined with having a solution for the minimum system cost.

4. Methodology

A Python program is developed to obtain the minimum cost of combined gravity and pumped systems for WTNs. The code is designed in two stages: 1) Calculate the economic size of the pumped transmission main, as explained in CPHEEO (2024). 2) Calculate the cost of the gravity network using the MMCH method. The stage-wise procedure is elaborated in the subsequent sections.

4.1. Economic Size of Pumped Transmission Main

The economic diameter of the pumped transmission main can be calculated based on the methodology shown in Figure 1. A Python program has been developed for the same. The detailed procedure for calculating the economic diameter of the pumped transmission main is provided in Annexure 6.1 of the CPHEEO Manual (2024).

The cost of pumping the network at different heads is calculated by varying the static head in terms of the FSL of MBR.

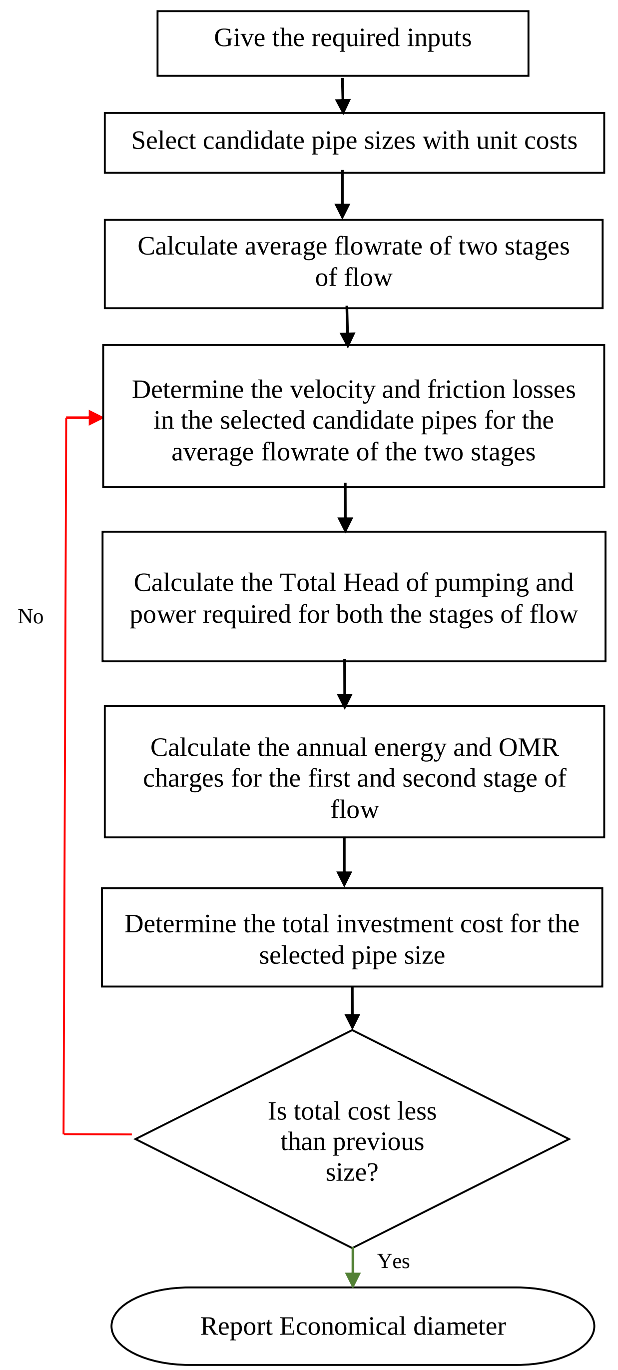

Fig. 1 Flowchart showing the method as per the CPHEEO manual to find the economic size for a single-source, single-destination pumping main

4.2. Optimization of the Gravity Transmission Network

As explained earlier, the MMCH method is used to obtain the cost of the gravity network emerging from the MBR.

The head at the MBR is varied, and the total cost of the network for different staging heights is obtained.

4.3. Total Cost of Combined Gravity and Pumped System

The total system cost is inclusive of includes cost of the network, the cost of MBR, the cost of the pumps and the energy cost over the period. To obtain the optimal solution, the staging height of the MBR is considered as a design variable. Different feasible staging (in multiple of 3, 4 or 5) are considered for MBR. The MMCH method is used to obtain the pipe sizes for various links for each of the staging heights. Once the appropriate pipe sizes are determined, the total cost of the transmission network can be estimated. Next, the optimal size of the pumping main is obtained by considering pipe diameter as a decision variable for different staging heights. It can be observed that the cost of the pumped transmission main increases with the increase in the staging height, whereas the cost of the gravity transmission network reduces with an increase in the staging height. Staging height that results in minimum total cost is adopted.

5. Data Considered in Present Work

A combined gravity and pumped transmission network, as depicted in Figure 2 (CPHEEO 2024), is used for the present work. The water is pumped from the WTP to MBR, which is 5 kilometers away from WTP. The MBR supplies water to the Zonal Balancing Reservoir (ZBR) and six ESRs by gravity. The node and link data are provided in Table 1. The unit cost of pipe given in Table 2, energy charges, etc., are considered as provided in the Manual (CPHEEO 2024). The lowest water level in the MBR is considered the sole decision variable. With the known Lowest Supply Level (LSL) of the MBR: (i) the cost of the gravity network is minimized, (ii) the economical diameter of pumped transmission main and the associated cost of pumps and energy is obtained, (iii) MBR cost is obtained.

5.1. Design of Gravity Network

The gravity network consists of six ESRs and one ZBR. Each of them has a minimum pressure requirement of 3 meters. The total head for the system is determined by adding the Ground Level (GL) at the MBR to the height provided by staging. As can be observed from the elevations at different villages, ESRs vary from 7.9 to 11.39 m, and the ground elevation at the MBR is 50 m, which indicates the possibility of underground GSR. Considering a depth of tank as 5 m, the LSL at the MBR (i.e. source head) are considered as 45, 48, 50, 52, 55, 58 and 60 m, as shown in Table 3. The MMCH method is used to design the network with different LSLs. The obtained costs are also shown in Table 3.

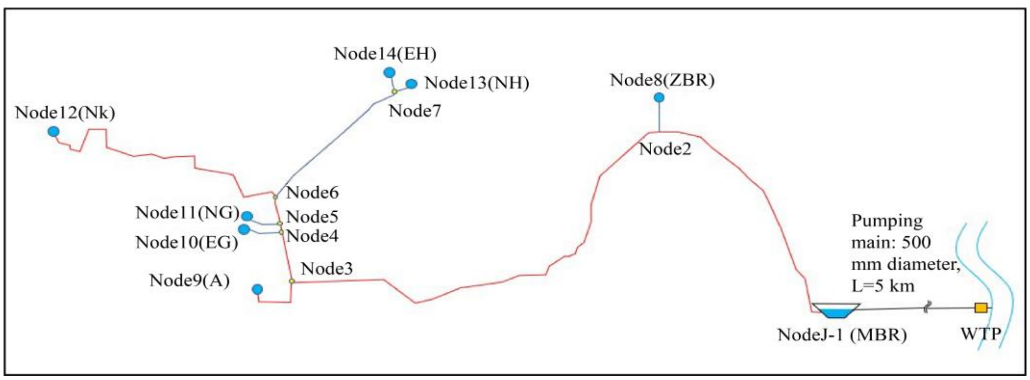

Fig. 2 Diagram of the WTN (CPHEEO 2024)

Table 1. Node and pipe data of gravity network

Node ID	Elevation (m)	Demand (LPS)	Pipe ID	Start Node	End Node	Length (m)
2	7.9	-	1	1	2	2,200
3	11.39	-	2	2	3	7,123
4	7.9	-	3	3	4	651
5	7.9	-	4	4	5	15
6	7.82	-	5	5	6	356
7	9.97	-	6	6	7	1,859
8	34	69.44	7	7	13	78
9	25	12.59	8	7	14	63
10	26	7.94	9	2	8	114
11	26	23.36	10	3	9	660
12	27	9.44	11	4	10	136
13	26	37.22	12	5	11	104
14	18	18.7	13	6	12	3348
	Total	**178.69**				

Table 2. Commercial pipe data

Diameter (mm)	Roughness	Cost (Rs/m)
80	140	750
100	140	952
150	140	1,383
200	140	1,870
250	140	2,485
300	140	3,106
350	140	3,919
400	140	4,558
450	140	5,560
500	140	6,405
600	140	7,495
700	140	9,105

Table 3. Total cost of WTN using MMCH method with the cost of MBRs at various stagings

Source Head (m)	Gravity Network Cost (Lakh Rs.)	Staging Height of MBR (m)	Cost of MBR (Lakh Rs.)	Static Head-on Pump(m)
45	736.00	0	67.34	51
48	662.36	0	67.34	54
50	643.77	0	67.34	56
52	625.39	2	75.76	58
55	603.35	5	87.33	61
58	598.15	8	96.80	64
60	598.15	10	101.01	66

5.2. Staging Height of MBR and Cost

The staging height of MBR is obtained by considering a ground elevation of 50m, as shown in Table 3. Considering the 2-hour capacity of designed demand, the MBR capacity works out to be 1286 m3. The cost of MBR as per SOR (MJP SOR, 2023) is calculated for different staging, as shown in Table 3. In the SOR, the base rate for ESR is provided for the staging height of 12 m. This cost is increased/decreased for an increase/decrease in staging height. Herein, the maximum staging is 10 m. The percentage decrease in cost per m is 2% from 12 to 8 m in staging, 3% per meter from 8 m up to 4 m staging, and 4% per meter from 4 m upto 0 m. For 0 m staging a total decrease of 8% (=2%/m x 4 m) + 12% (=3%/m x 4 m) + 16% (=4%/m x 4 m) = 36% decrease over the base rate is considered. Hence, the cost of MBR for 0 m staging will be 105.218 x 0.64 = Rs. 67.34 Lakhs.

5.3. Details of Pumped Transmission Main

The water demands vary over the period of time. At the initial stage, the demand is 10 Million Liters Per Day (MLD), which increases to 12 MLD at the intermediate stage and finally increases to 15.44 MLD at the ultimate stage. The pumped transmission main is 5000 meters long. An 8% interest rate is considered for the economic analysis. The pumps having a design life of 15 years are considered for each stage of 15 years separately. These are designed to operate 24 hours a day at the end of each stage. The cost of pump sets is considered as Rs. 25,000 per kilowatt (kW), and the energy charges are taken as Rs. 7 per kWh. The average hours of pumping are calculated as 22 hours for the first stage and 21.33 hours for the second stage. The Hazen-Williams coefficient is taken as 140 for all pipes. The depth of water in the MBR is 3 meters. The candidate diameters, along with their unit costs considered for both the pumped transmission main and gravity network, are given in Table 2.

For the different staging heights, a static lift of the pump is obtained by considering the HGL at the MBR as LSL plus 3 m water depth and 3 m of residual head and subtracting the ground level at the sump bottom level. These heads are the same for both pumping stages, as shown in Table 3. As the optimal diameter of the pumped transmission main is independent of static lift, the economical diameter calculations are shown for only one head, i.e., a source head of 48 m. The economic diameter calculations are shown in Tables 4 to 6. It can be observed that the economical diameter is 500 mm. The energy costs for different heads are obtained, as shown in Table 7 (Appendix). The total cost of the pumped transmission main, including energy costs, MBR cost and gravity main network cost, is obtained for different HGL values at MBR, as shown in Table 8 (Appendix). It can be seen that at HGL of 48 m, the overall cost is minimal. The link-wise diameters obtained from the JalTantra and MMCH methods are shown in Table 9.

6. Results & Discussions

The most economical diameter of the pumped transmission main is found to be 500 mm. With any increase in LSL at MBR, the optimal diameter remains the same, and the pump capacity requirement changes, leading to an increase in pump cost and associated energy cost. However, the cost of the gravity main network decreases. The optimal LSL of MBR is obtained as 48 m. The MMCH method employed in this study consistently provided only one pipe size for each link in the network, as opposed to the LP approach used in JalTantra. The network cost, along with capitalized energy cost, is also obtained to compare it with that presented in the manual, in which gravity network cost is obtained through JalTantra. This cost is given in the last column of Table 8 (Appendix). As can be seen, the optimal HGL at the MBR is the same as 48 m.

Table 9 shows the pipe-wise diameter details of the gravity main design through MMCH and Jal Tantra for the optimal HGL of 48 m. The most cost-effective solution of Rs. 17.978 Cr is obtained with a source head at 48.0 meters. Economic analysis of the network, as performed in Annexure 6.6 of CPHEEO (2024), considered the cost of the gravity network as obtained by Jal Tantra and energy charges only. The cost of the pumped transmission main, the cost of MBR, and the cost of pumps were not considered in the calculation; maybe it was just to explain the procedure by fixing some of the parameters. In the present work, we have considered the system's total cost. Further, to have a common ground for comparison, we have calculated the cost of the gravity network and energy charges separately for the MMCH method. For the most cost-effective solution at 48.0 m source head, the combined cost of gravity network and energy charges as per CPHEEO manual and MMCH method is obtained as Rs. 13.588 Cr. and Rs. 13.729 Cr. respectively. This difference is majorly due to less cost of split pipe size solutions provided by the LP method of JalTantra for the gravity network.

6.1. Sensitivity Analysis

Sensitivity analysis of the pumped transmission main is carried out by varying the dependent parameters required to obtain the economic size. These parameters are identified as energy charges, interest rate and unit pipe cost. For a 10% variation in the above-mentioned parameters, considering one parameter at a time for economic analysis, no change in the size of the pumped transmission main is observed. The results of the sensitivity analysis that were obtained are tabulated in Table 10.

Table 4. Head Loss and velocity for different pipes to calculate the economic diameter of the pumping main

Candidate Diameter (mm)	Stage 1					Stage 2				
	Unit Frictional Head Loss (m)	Velocity (m/s)	Frictional Head Loss for 5000 (m)	Minor Head Loss (m)	Total Pumping Head (m)	Unit Frictional Head Loss (m)	Velocity (m/s)	Frictional Head Loss for 5000 (m)	Minor Head Loss (m)	Total Pumping Head (m)
300	10.29	1.96	51.46	5.15	105.61	16.42	2.53	82.08	8.21	139.28
350	4.86	1.44	24.29	2.43	75.72	7.75	1.86	38.74	3.87	91.62
400	2.54	1.11	12.68	1.27	62.95	4.04	1.42	20.22	2.02	71.24
450	1.43	0.87	7.14	0.71	56.86	2.28	1.12	11.39	1.14	61.53
500	0.86	0.71	4.28	0.43	53.7	1.36	0.91	6.82	0.68	56.50
600	0.35	0.49	1.76	0.18	50.94	0.56	0.63	2.81	0.28	52.09
700	0.17	0.36	0.83	0.08	49.91	0.26	0.46	1.32	0.13	50.46

Table 5. Kilowatts of power and cost of pump sets required for different pipe sizes

Candidate Diameter (mm)	Stage 1			Stage 2			Cost of pipe unit per length (Rs in thousand/m)	Cost of pipe for 5000 m (Rs in thousand)
	Total Head (m)	Total working kW	Pump Cost (Rs in thousand)	Total Head (m)	Total working kW	Pump Cost (Rs in thousand)		
300	105.61	205	5135	139.28	349	8715	3106	15530
350	75.72	147	3681	91.62	229	5733	3919	19595
400	62.95	122	3059	71.24	178	4458	4558	22790
450	56.86	111	2767	61.53	154	3850	5560	27800
500	53.71	104	2611	56.50	141	3535	6405	32025
600	51.0	99	2475	52.0	130	3259	7495	37475
700	50.0	97	2427	50.0	126	3157	9105	45525

Table 6. Comparative statement of overall cost of pumping main for different pipe sizes

Stage 1				Stage 2				Grand Total of Capitalized cost for 30 years (Rs in thousand)	Candidate Diameter (mm)
Cost of pump sets (Rs in thousand)	Annual Energy and OMR cost (Rs in thousand)	Capitalized Cost of Annual Energy and OMR (Rs in thousand)	Total Capitalized Cost (Rs in thousand)	Cost of pump sets (Rs in thousand)	Annual Energy and OMR cost (Rs in thousand)	Capitalized Cost of Annual Energy and OMR (Rs in thousand)	Initial Capital investment for pump sets, energy and OMR charges (Rs in thousand)		
5135	11547	98834	119489	8715	18994	162576	53998	173487	300
3681	8279	70863	94134	5733	12494	106944	35520	129654	350
3059	6882	58907	84747	4458	9715	83155	27619	112366	400
2767	6217	53211	83786	3850	8391	71821	23855	107641	450
2611	5872	50264	84884	3535	7705	65950	21905	106789	500
2475	5569	47668	87618	3259	7103	60802	20195	107813	600
2427	5457	46712	94662	3157	6881	58900	19563	114225	700

Table 9. Comparison of the configuration of pipe diameters for each link obtained for source head of 48.0 m using JalTantra and MMCH method

Pipe ID	By JalTantra		By MMCH Method	
	Length of link (m)	Diameters (mm)	Length of link (m)	Diameters (mm)
1	1972.61	400	2200	400
	227.39	450		
2	7123.00	400	7123	400
3	651	400	651	400
4	15	350	15	350
5	356	300	356	300
6	154.55	250	1859	200
	1704.45	300		
7	78	250	78	100
8	16.44	100	63	500
	46.56	80		
9	114	150		150
10	209.91	100	660	200
	450.09	150		
11	136	80	136	100
12	56.64	100	104	350
	47.36	150		
13	919.07	150	3348	150
	2428.93	200		

Table 10. Results of sensitivity analysis of pumped transmission system using dependent parameters

Description	Economical Diameter Reported (mm)
interest rate increased by 10%	500
interest rate decreased by 10%	500
pipe cost increased by 10%	500
pipe cost decreased by 10%	500
energy charges increased by 10%	500
energy charges decreased by 10%	500

7. Conclusion

Designing a transmission network becomes challenging when the energy cost of the system is taken into consideration. Researchers in the past have suggested different methodologies to calculate the cost of pumped systems and gravity systems. An attempt to optimize the total cost in the case of a combined pumped and gravity transmission network is presented herein, considering a sample network as given in the CPHEEO Manual.

It is observed that the total cost is dependent on the head considered at the source. The total cost is calculated for different heads at MBR and compared with the values provided in the CPHEEO Manual in Table 8 (Appendix). The cost of the network obtained by using JalTantra, which is based on LP and may result in spilt pipe diameters, is lesser than that obtained by the MMCH method, but the overall performance and operation of the network being better in the latter due to single pipe size being provided for each link, as no pipe reducers are required which indirectly increases network cost.

This has not been considered in the JalTantra software. Further, pump and energy cost for different stages is also not considered in the JalTantra. This limitation is addressed in the present work.

7.1. Future Work

A similar methodology could be developed to find the economic cost for the remaining types of Transmission Networks (Direct Pumping/Gravity). The results could be compared with different optimization methods and the most suitable amongst them could be suggested as a solution for such type of WTN problems.

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Appendix

Table 7. Pump cost and PW of energy costs

Source head (m)	Stage 1						Stage 2							Total PW Energy Cost (Rs.)
	Head Loss (m)	Total Head (m)	Pump Power (kW.h)	Pump Cost (Rs.)	Average Annual Energy Cost (Rs.)	Capitalized Annual Energy Cost (Rs.)	Head Loss (m)	Total Head (m)	Pump Power (kW.h)	Pump cost (Rs.)	Average Annual Energy Cost (Rs.)	Capitalized Annual Energy Cost (Rs.)	Initial Investment for Energy Cost (Rs.)	
45	4.71	50.71	98.64	2466056	5544363	47456855	7.5	53.50	133.9	3347566	7295805	62448287	19686305	67143160
48	4.71	53.71	104.48	2611948	5872367	50264399	7.5	56.50	141.41	3535280	7704916	65950064	20790211	71054610
50	4.71	55.71	108.37	2709209	6091036	52136095	7.5	58.50	146.42	3660423	7977656	68284577	21526146	73662241
52	4.71	57.71	112.26	2806470	6309706	54007791	7.5	60.50	151.42	3785565	8250397	70619097	22262085	76269876
55	4.71	60.71	118.09	2952362	6637710	56815335	7.5	63.50	158.93	3973279	8659507	74120866	23365988	80181323
58	4.71	63.71	123.93	3098253	6965714	59622879	7.5	66.50	166.44	4160993	9068618	77622642	24469894	84092773
60	4.71	65.71	127.82	3195514	7184383	61494575	7.5	68.50	171.45	4286136	9341358	79957155	25205830	86700405

Table 8. Total cost of WTN MMCH method vis-a-vis JalTantra

							By MMCH Method		By JalTantra
Source head (m)	Network Cost by MMCH Method (Cr. Rs.)	MBR Cost (Cr. Rs.)	PW of Energy Cost (Cr. Rs.)	Cost of Pumping Main of 500 mm diameter (Cr. Rs.)	Pump Cost for Stage 1 (Cr. Rs.)	Capitalized Pump Cost for Stage 2 (Cr. Rs.)	Total Cost (Cr. Rs.)	Pipe Cost and Energy Cost (Cr. Rs.)	Pipe Cost and Energy Cost (Cr. Rs.)
45	7.360	0.673	6.714	3.203	0.247	0.106	18.302	14.074	13.611
48	6.624	0.673	7.105	3.203	0.261	0.111	17.978	13.729	13.588
50	6.438	0.673	7.366	3.203	0.271	0.115	18.066	13.804	13.654
52	6.254	0.758	7.627	3.203	0.281	0.119	18.241	13.881	13.776
55	6.033	0.873	8.018	3.203	0.295	0.125	18.548	14.052	14.000
58	5.981	0.968	8.409	3.203	0.310	0.131	19.002	14.391	14.220
60	5.981	1.010	8.670	3.203	0.320	0.135	19.319	14.652	14.368