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Water Network Optimization of Lift Irrigation System Using Computer Simulation

M.E. Sutharsan[1*] and Sunoj Vijayatharshini[2]

[1]National Water Supply and Drainage Board, Sri Lanka
[2]Department of Irrigation (NP), Sri Lanka

[*]Corresponding Author: edsutharsan@yahoo.com

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***Abstract*—**Supplying water to paddy, and crops at the required quantity is the prime purpose of any lift irrigation system. In this study, a lift irrigation network model was built using WaterGEMS V8i computer simulators and hydraulic analyses were conducted to optimize the lift irrigation scheme in the Kilinochchi area of Sri Lanka. A series of steps such as; selection of models, network representation, calibration, problem identification, model application, and results analysis were carried out by developing and analyzing the simulation model. The analysis was carried out by using the Hazen-Williams friction method under steady state simulation. The result revealed that all of the nodes in the system are operating above the threshold pressure limit. Since the pressure at the end delivery nodal point is slightly high, this system is optimized by reducing the pump capacity and reducing the pipe sizing. After several simulation trials, the pump is optimized to the capacity of 24.3 kW from 33.7 kW, which account for 28% capacity reduction, when operating with 80% of pump efficiency. The original pipe network with nominal diameters of 300 mm, and 250 mm was reduced to 225 mm, and 200 mm respectively through pipe optimization. This system has the potential for further extension to a certain extent with the existing pumps and pipe diameter.

***Keywords*—**Lift irrigation, WaterGEMS, Optimization, Hydraulic analyses, Hazen-Williams formula

I. Introduction

Freshwater is categorized as a limited and vulnerable resource that is crucial for maintaining the life cycle, nation's development and therefore the setting on earth. Water inadequacy may be a regionally, domestically and seasonally specific drawback. Therefore, it's necessary to avoid wasting water and use it sparingly in a sustainable manner. Sri Lanka is primarily an agriculture-based country. Based on the statics of the Department of Census and Statistics, agriculture is one of the four major components of the economy; which has contributed its share of Sri Lanka's GDP by 7.8 percent in the first quarter of 2021 (Department of Census and Statistics, 2021).

The conventional canal system is used to supply water from sources to the demand areas under the gravity flow. However, science is advanced and contributed to innovation the agricultural techniques like lift irrigation, sprinkler, mechanical device and drip, which created rapid strides in the twenty-first century in terms of production efficiency, overall cost and efficiency in water usage.

The present study aims to simulate, compare and optimize the lift irrigation system by maintaining adequate flow, pressure head and velocity at the Iranamadu lift irrigation scheme in the Kilinochchi district of Sri Lanka.

A. Study Area

The area for modelling of optimized lift irrigation scheme is at Iranamadu in the Kilinochchi area in the Northern part of Sri Lanka as shown in Figure 1. The lift irrigation scheme was established in the left bank canal of the Iranamadu tank since the left bank was in an abandoned condition. The full lift irrigation system was rehabilitated by considering the future peak water demand of 0.66 cum/sec to supply 480 hectares of irrigable area.

Figure 1: Study area map

The irrigation sector plays a vital role in developing the nation. Irrigation has been practiced in Northern Province since the ancient period and is almost exclusively used for paddy cultivation. Irrigation schemes in Northern Province have storage reservoirs which assure supplementary irrigation during dry spells in the Maha season and assure the limited water supply during the Yala season. Iranamadu irrigation scheme, which is the largest irrigation scheme in Northern Province, gets water from the largest provincial river basin Kanakarayan Aru, starting from Chemamadu, Vavuniya and running through Mullaitivu and impound water completely within Mullaitivu district. However, the entire facilities lie in the Kilinochchi district (LTD *et al*., 2017).

A lift irrigation system shall be hydraulically analyzed through computerized simulation techniques and simulated for the different scenarios to optimize the pipe diameters and pump capacity. The appropriate function of a lift irrigation system is vital to supply a sufficient quantity of water to crops, paddy, vegetables, etc. Hence, the principles of designing lift irrigation systems need to be well understood (Shiyekar Patil, 2017).

B. Lifted Irrigation

Gravitational force is used to irrigate the irrigable areas which are topographically situated below the water level. Furthermore, this kind of gravity-based irrigation is a convenient method for the reason that it requires less workforce and low cost. But in the case of a region which is located above the water level, gravitational force cannot be used to carry water to that region or land. Lift irrigation is the solely way to supply water to such regions under irrigation. In lift irrigation, pumps are utilized to lift water from the neighbouring water source and followed by distribution to the crop (Shiyekar Patil, 2017). This technique of lifting water using pump installation and afterward supplying it to the area is defined as lift irrigation. The two parts of the mechanism under lift irrigation systems are; the pumping mechanism, which is used to carry the water to a chamber which is existed at an altitude higher than the land which is to be irrigated, and the distribution mechanism is the process properly circulates this water to the crop planted in the land. Entirely this distribution happens by the force of gravity (the gravitational method manages the distribution) (Francis *et al*., 2021).

C. WaterGEMS Simulator

A user-friendly interface to analyze, design and optimize water distribution networks such as lift irrigation is provided by WaterGEMS V8i software. There are a few important attributes namely; hydraulic analysis, water quality analysis, extended period simulation, and steady state simulation. Simplified model building, water quality modelling, fire flow analysis, optimization and scenario management are some benefits of WaterGEMS V8i over other software (Sonaje Joshi, 2015).

II. Materials and Methods

The total peak demand for the lift irrigation system was taken as 0.66 cum/sec by considering the future water requirements. There are 06 nos of centrifugal pumps installed in 6 nos of pipelines to supply the full demand. As such, the peak demand for one pumping system is considered as 0.11 cum/sec for the modelling in this study.

The layout of lift irrigation system is exhibited in Figure 2. The lift irrigation pipe network model was created with the relevant elements such as pipes, nodes, bends, valves, and pumps as shown in Figure 3. This is a simple system fed by one centrifugal pump. Next, pipe data was created with the followings; pipe length, pipe material, internal diameter, and Hazen-Williams friction coefficient. The node data was input with demand, demand pattern, and elevation above the given datum. The friction method namely; Hazen –Williams's formula (1) is shown in the equations below, which is a widely used friction method in many simulation software.

$$\frac{H_{\mathrm{L}}}{L} = \frac{10.67 Q^{1.852}}{C^{1.852} D^{4.8704}} \tag{1}$$

where:

Q = Fluid flow rate (m^3/s),
C = Dimensionless HW roughness constant
D = Pipe internal diameter (m)
H_{L} = Head loss (m)
L = Pipe length (m)

The hydraulic analysis is carried out by using the Hazen-Williams friction method with steady state simulation in this study. The model system is consist of a centrifugal pump with a head of 25 m and a flow of 0.11cum/sec and a 60m length of steel pipe network with different nominal diameters of 300 mm, and 250 mm which have an internal diameter of 281.6 mm, and 231.6 mm respectively.

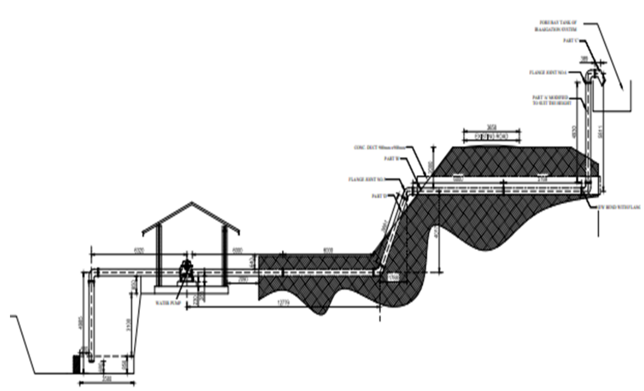

Figure 2: Layout of lift irrigation system

The modal validation is a vital part in any research, in order to confirm the capability of software used for modelling and to confirm whether the researcher has enough knowledge on the modelling. Hence, the proposed model was validated by using the study done by (Revelli & Ridolfi, 2002) from the idealized water distribution network. The deviation in the flowrate between the results of this study and the previous study was observed to be 1.98%.

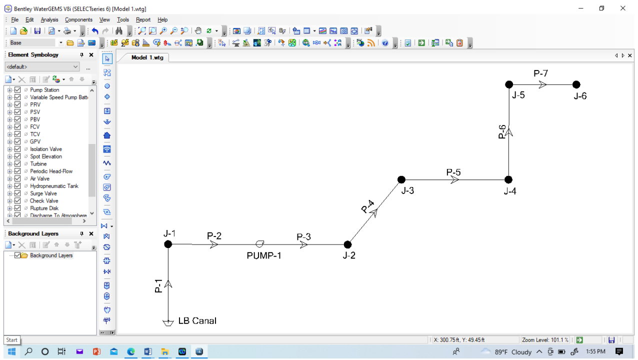

Figure 3: Water GEMS network model

III. Results and Discussion

There are few significant output parameters required to analyze the optimizing options to design the pipe network for lift irrigation system, in terms of investment cost, operational efficiency and operation cost. Those output parameters mainly nodal pressure, flow rate and flow velocity were extracted from Water GEMS V8i simulation models and discussed in this chapter.

A. Nodal Water Pressure

The nodal water pressure at the peak in the system is shown in Figure 4. The pressure at the end delivery nodal point is recorded as 7.7m H_2O. This end pressure is satisfied the minimum pressure required to supply water to the feeding tanks. The pressure in the lift irrigation water distribution network mainly depends on pipe diameter, roughness coefficient of pipe material, and elevation.

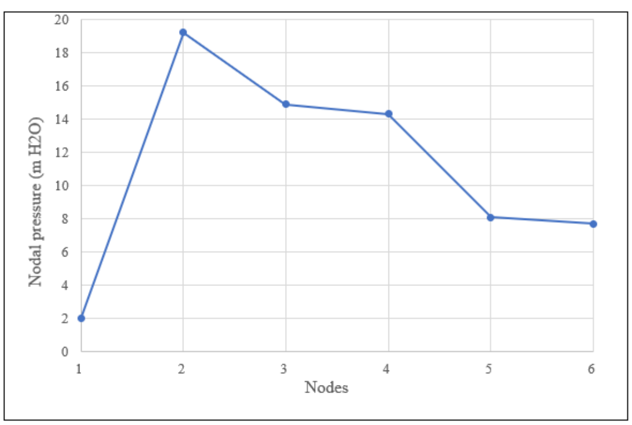

Figure 4: Pressure head of nodal junctions

The result indicates that the nodal pressure within the system is above the minimum level and adequate for the effective performance of the lift irrigation system. However, in general, a positive pressure head is sufficient to feed the feeding tanks since the feeding tank is located below the endpoint. Since the pressure at the end nodal point is 7.7m H_2O, it shall be treated as a higher value. Further, the system shall be optimized by reducing the pump capacity or reducing the pipe sizing or reducing both.

B. Optimizing the Pump capacity

The pump is optimized to obtain the positive minimum pressure at the end delivery point. Figure 5 shows the original pump definition before optimizing. The original pump is designed for 0.11 cum/sec as flow rate and 25 m head, with the capacity of 33.7 kW when operating with 80% of pump efficiency.

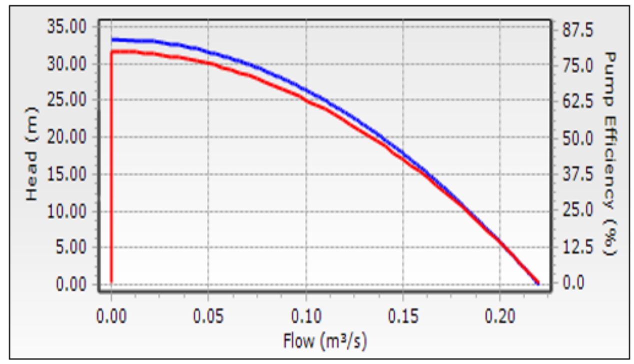

Figure 5: Pump definition before optimization

However, after several simulation trials, the pump is optimized to have a flowrate of 0.11 cum/sec, a head of 18m, and a capacity of 24.3 kW when operating with 80% of pump efficiency. It can be observed that the pump capacity is reduced by 28% by optimizing. Figure 6 shows the comparison of the nodal pressure in the pipe system before and after the optimization of the pump. The pressure at the end delivery point is obtained as 0.7 m H_2O, which sufficient enough to function the system.

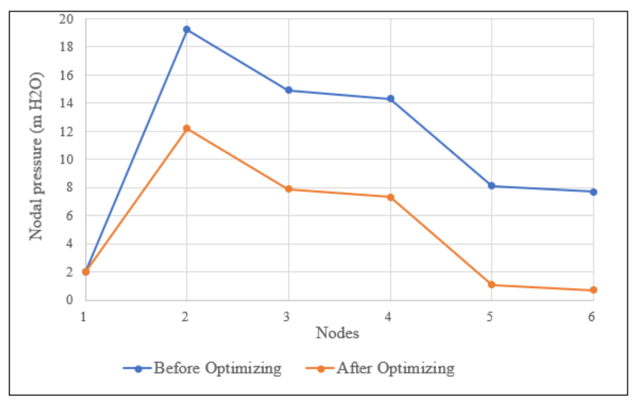

Figure 6: Nodal pressure before and after optimizing

C. Optimizing the Pipes

The pipe size is optimized to obtain the positive minimum press at the endpoint. Figure 7 shows the comparison of the nodal pressure before and after optimization of the pipe sizes. The pressure at the end delivery point is obtained as 0.9 m H_2O, which is sufficient enough to function the system.

The diameter of the pipes was reduced by two steps down during the optimization as shown in Figure 8. The pipe network with different nominal diameters of 300 mm, and 250

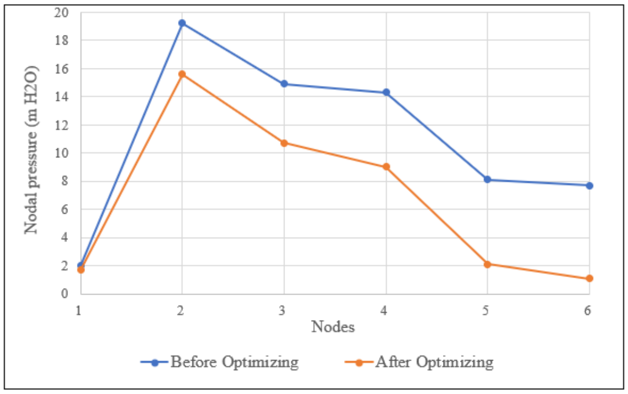

Figure 7: Nodal pressure before and after optimizing

mm which have the internal diameter of 281.6 mm, and 231.6 mm respectively before in the original system. However, the pipe sizes were the optimized nominal diameters of 225 mm, and 200 mm which have the internal diameter of 206.6 mm, and 181.6 mm respectively.

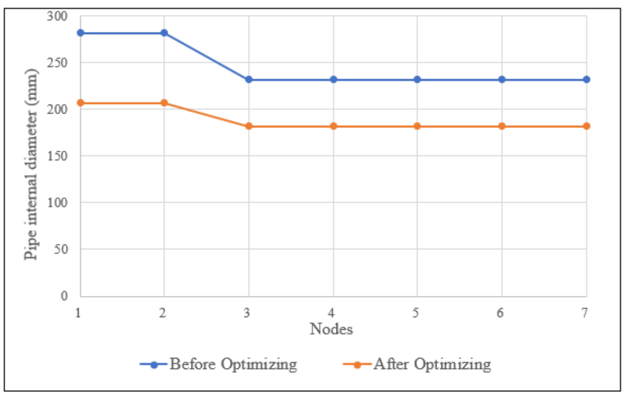

Figure 8: Pipe internal diameter pressure before and after optimizing

IV. Conclusions

Based on this study, the vital output parameters such as the water flow in all the pipes and nodal pressure at all the nodes are sufficient enough to supply water as per the water requirement in the study area. The designed and optimized pipe sizes of the lift irrigation system are adequate to meet the future demand and peak water demand while maintaining adequate pressure in the system. WaterGEMS V8i simulation technique is one of the efficient tools to analyze the existing lift irrigation pipe network system and optimize the system. Since the pressure at the end delivery point is slightly high, this system is optimized by reducing the pump capacity and reducing the pipe sizing. The Computer-aided network simulation techniques provide great advantages over conservational computations in terms of optimization, results in accuracy, monitoring of the system during operation, time consumption and room for future modification.

V. Acknowledgement

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