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REHABILITATION OF EXISTING INTERMITTENT WATER SUPPLY NETWORK UNDER FUND CONSTRAINTS USING MARGINAL INCREASE IN RESILIENCE TO MARGINAL INCREASE IN COST METHOD

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Abstract

The battle of intermittent water supply posed a tough challenge by jointly considering a problem related to analysis, design and operation of water distribution networks (WDNs). A methodology is needed which could summon all the inefficiencies of the existing network on a single platform to achieve the different stated objectives (Indicators) under some technical and financial constraints. The main targets are: (1) reduction in losses by repairing leaks, and/or replacing pipes, (2) to increase consumer satisfaction by meeting the demands at required pressure. A multi-stage methodology is proposed to suggest a solution to the given problem. Initially, demand nodes are clustered to form District Metering Area (DMA) by considering the locations of existing valves. The methodology of Sharma et al. (2022) consists of identification of clusters and their boundaries by considering the location of existing valves. Out of the several ways of improving the network performance in desired 5-year periods with limited budget in each year, the leak detection and repair, pipe replacement with same or higher size, and valve installation to reduce excess pressure are proposed to be targeted primarily. A fast greedy algorithm, similar to that used by Gupta and Bhave (1996) for design of WDN and Agrawal et al. (2007) for strengthening and expansion of WDN, is proposed to be used. The iterative methodology starts with DMA formation in existing network. Benefits in terms of improvements in both head and outflows at demand nodes due to change in any option will be calculated along with increase in cost for that option. All the options will be considered one by one. Out of several options at any stage few best will be selected. The iterative process of selection for any year will be repeated till the available fund for that year are exhausted. Final solution for the first year will become, initial solution for the next year. Solution for all the five years will be obtained. Finally, the performance of network would be assessed using suggested parameters and the results will be reported.

Keywords
Design, Optimization, Rehabilitation, Strengthening, Water Supply, Water Distribution Network

1 INTRODUCTION

Water distribution networks (WDNs) are designed for supply of required quantity of water of desired quality with adequate pressure at consumer location throughout its design period. Only a continuous supply can achieve this goal. Poor maintenance is one of the main reasons for shifting mode of water supply from continuous to intermittent. Impacts of poor maintenance are not noticed in the beginning of the design period as the pipelines are new and the network inherent redundancy considering that the population is less. However, with the increase in water demand and deterioration of network due to poor maintenance, high leakages and shortfall in supply are noticed. To resolve the problem, new pipelines, tanks and sources are added, and problem of poor maintenance still persists. This ultimately leads to change in mode of water supply from continuous to intermittent, so that available water can be distributed to all the consumers. In case of intermittent mode of supply, the water supplied may not be potable, and the consumer drinking straight from the tap may expose himself to the risk of water-borne diseases and infections. Even though sufficient quantity of water may be available at consumer end, expensive coping strategies that include installing underground storage tanks, pumps to lift water to overhead tanks, household filters/disinfection system are required. This cost of ensuring potable water is borne entirely by the individual. Therefore, intermittent mode of water supply is not at all desirable. This battle of water networks envisages solution to a problem of converting an intermittent mode of supply to its original continuous mode under the fund constraints.

The improvement options consist of repairing leaks, replacing pipes, installation of new pumps, expansion of the tank capacity. Improvement in hours of water supply, number of users with continuous supply, supply pressure and reduction in supply deficit, volume leaked and energy consumption is required. These improvements are planned to be assessed through various service indicators. A solution to the problem is obtained and provided in this paper. The remainder of the paper includes the strategy and the methodology adopted to obtain the solution.

2 DMA FORMATION

A reliable estimate of water losses is important for the management of any WDN. Formation of District metered areas (DMA) helps in detection of under registration problems and maintenance cost reductions, hydraulic efficiency audits (Di Nardo et al. 2014), network rehabilitation and work planning (Muhammed et al. 2017). The water losses can be recovered with sustainable expenditures by planning and implementing the required actions. A network is partitioned by placing isolation valves and flow meters at the boundaries of each DMA. It represents a complex problem. This is because closing certain pipes for defining fixed boundaries would reduce the looped nature of the network, thereby reducing its performance. Several clustering techniques have been applied to solve the DMA design problem. Herein, methodology of Sharma et al. (2022) is used to form DMA that make use of existing valves. Herein, DMA for supply of water from well W3_AB was formed separately by providing 8 additional isolation valves at locations L1314, L2949, L2948, L1332, L3244, L1133, L1923 and L2973. This DMA was separated and proposed to be supplied from pumps installed at W3_AB as it was containing some higher elevation nodes and supply from original source node was observed difficult.

3 DESIGN STRATEGY AND METHODOLOGY

3.1 DESIGN STRATEGY

There are several options for improvement of the performance of the network, each having different benefits and costs. It is observed that for the example networks there are several pipes with single and multiple leakages. Pipes having multiple leakages may be better to be replaced than repaired as the cost of repairs would be more than cost of replacement. While, pipes having single leakage may be better to be repaired. Therefore, initially it was decided for each pipe having leakages that whether the same is to be repaired or replaced depending on the total cost of repairs and total cost of replacement.

As the network was originally satisfactory to meet the consumer demands on its own, it was thought appropriate to remove all additional pumps and tanks and water sources except that at W3_AB. The contribution from other sources was found to be meagre and also there was addition recurring cost associated with it. The main strategy was therefore to reduce leakages that will improve pressure and also increase the served demand.

As the effect of the leakages to be modelled at the specific location provided would not significantly change the hydraulic results, the leakages were assumed to be concentrated on the nodes and were modelled using pressure dependent emitter coefficients in excess to the base demand. For the selection of nodes and clubbing the coefficient values at any node, the methodology used by demand allocation by unit line method was adopted. In this methodology, it is assumed that demand contributed by half of the length of the pipes connected to any node will be concentrated at that node. Likewise, here the methodology was applied on the leak coefficient and the value of emitter coefficient for all the nodes in the network were calculated and provided.

All the options of performance improvements were not considered simultaneously. In the first 3 years priority was given to reduce the leakages and improve the demand satisfaction of the system. Hence, options of only pipe replacement and repairs were considered. In the last 2 years, priority was given to pressure improvement and equitable supply by increasing the pipe sizes and also by zoning of the networks into sub zones. PRV's were installed to control excess pressure.

The isolation valves were modelled in the EPANET file as closed pipes as interpreted from the BIWS instructions. The same methodology was adopted while installing isolation valves in the system. The pipe status was closed in the EPANET and it was assumed that the isolation valve is installed just at the downstream of the node as directed in the BIWS Instructions. However, for modelling PRV in the network, an additional node and pipe (if necessary) were considered. The details of which has been provided the BIWS Template sheet. The elevation of the node was considered as the elevation of the nearest node and the Base Demand for the node were put as zero. In the peak hours, the setting of the installed PRV's were changed using the option of Simple Controls in EPANET.

For the initial operation of the network, DMAs were formed using the Initially installed valves and closed pipes in the network. The status of the valves was not changed throughout the analysis period and kept open. The details of the pump used in the Initial Operation are provided in the Template.xlsx submitted along with the INP files of each year.

3.2 METHODOLOGY ADOPTED

Using the above strategy, available options in different years were limited. Further, to choose the bast from available options at any stage, a method of marginal improvement in the values of the performance indicators to marginal increase in cost was adopted. BIWN has indicated nine performance indicators. However, consideration of all in evaluating the performance with different options increases the computational efforts. Therefore, to simplify the solution methodology few performance indicators were selected. For the first 3 years, out of 9, following 4 indicators were selected for performance improvement.

Indicator I_1 : Proportion of the number of the effective hours a subscriber is served.

Indicator I_2 : Proportion of subscribers with continuous service

Indicator I_3 : Volume of water leakage

Indicator I_4 : Proportion of volume of water supplied to users.

However, for the remaining two years, apart from the above-mentioned indicators, 3 more indicators were selected for improvement.

Indicator I_5 : Level of pressures at consumption nodes

Indicator I_6 : Percentage of users supplied continuously

Indicator I_9 : Level of equity in supply.

It was observed that the improvement of selected indicator also resulted in improvement of other indicators not selected.

For the first 3 Years, the indicators related to pressure, demand satisfaction and leakage reduction were selected to be improved. To reduce the computational efforts, pipes to be improved were arranged on the basis of their Emitter Coefficient values from higher to lower along with the cost. Ratio of marginal increase in performance indicators to marginal increase in cost for first 100 pipes from the list. The best and those providing improvement of about 70 percent were improved with the restrictions on cost and numbers that not more than 10% of selected option are improved at a time. The selected elements were then improved and their effect on the system was studied.

For the next year, the leakages were again modelled in the similar way as foretold. The coefficient values were increased as provided by the equation in the BIWS instructions. However, for the pipes which were repaired, the coefficient value was considered as zero.

4 DESIGN SOLUTION

As per the BIWS Instructions, a total of 650000 € per year could be invested at the start of each year for carrying out the following actions:

1- Detecting and Repairing Leaks
2- Completely replacing a pipe with new one
3- Install new valves in the network
4- Increase the capacity of the network tanks
5- Replacing existing borehole pumps by pumps with better performance
6- Installing frequency inverters on the existing pumps

However, among the different options, only first three options namely detecting and repairing leaks, completely replacing a pipe with new one and install new valves in the network are only used as investments in the considered approach.

The details of year wise investment are submitted in the Template file as required and the cost summary of each year are presented in Table 1 as shown below:

Table 1. Year wise cost summary of investments

Year	Nos of Pipe Repaired	Total Cost of Repair	Nos of Pipe Replaced	Total Cost of Replacement	Nos of Isolation Valves Installed	Total Cost of Installation of Isolation Valves	Nos of PRV Installed	Total Cost of Installation of PRV	Total Cost Invested
Year 1	45	120823.03	174	480185.45	8	48819.07	0	0	649827.53
Year 2	64	295959.28	88	354025.81	0	0	0	0	649985.09
Year 3	74	355203.26	117	291341.30	0	0	1	3299.78	649844.34
Year 4	131	459583.52	21	148533.80	2	504.94	8	41156.66	649778.92
Year 5	30	146977.45	42	429416.80	16	8143.88	14	65380.02	649918.15

As it could be seen from the above table, the cost is restricted under the allocated cost as per the BIWS instructions. In the first year, major expenditure was on replacement of leaky pipes. 174 pipes were replaced and only 45 were repaired. Few isolation valves were installed for DMA formation. In the beginning of 4th year, major expenditure was on repairing of pipes. A total of 131 pipes are proposed to repaired and only 21 replaced. PRV's and isolation valves were mainly considered in the 4th and 5th year for improving the pressures and have equality in supply.

5 PERFORMANCE AFTER IMPROVEMENTS

BIWS proposed 9 Service indicators for evaluating the performance of the system. In this study, 7 service indicators were selected and their performances were improved using the proposed methodology. The initial values of performance indicators and their year wise improvement in the values are provided in Table 2.

Table 2. Year wise improvement in Service Indicators

Year	I1	I2	I3	I4	I5	I6	I9
Initial Operation	0.9022	0.9022	0.6926	0.3362	0.4499	0.7036	0.5484
Year 1	0.9004	0.9004	0.5913	0.3473	0.447	0.6928	0.5576
Year 2	0.918	0.918	0.3918	0.4939	0.5713	0.7635	0.638
Year 3	0.9195	0.9195	0.3375	0.5285	0.6112	0.7846	0.6588
Year 4	0.9247	0.9247	0.2488	0.5791	0.6438	0.8088	0.7306
Year 5	0.9305	0.9305	0.2102	0.6083	0.6454	0.8182	0.7712

The above results are calculated for the simulation time of 168 hours for each year. For the calculation of the indicators, the expressions provided in the BIWS instructions have been used. Following can be observed from the Table 2:

1. As all the small sources of water except well W3_AB were removed initially, there was a decrease in the pressure in the network resulting in decrease in the I1, I2, I5, I6, and I9. As the losses are also pressure related leakage volume (I3) has decreased and volume supplied increased.
2. All the indicators improved gradually from year to year. Leakages (I3) which were around 69% in the beginning are reduced to 21% in the fifth year. On the other hand, served demand (I4) that was only 33% in the beginning has increased to 60%.
3. Addition of PRVs and isolation valves in the 4th year shows improvements in pressure and equity related indicators.

6 CONCLUSIONS

A methodology based on the ratio of marginal increase in performance indicator to marginal increase in cost is used for improving a leakage effected network. Decision on pipe repair or pipe replacement is taken on the basis of combined cost of leak detection and repair against cost of replacement. The effects of various improvement options on improving the service indicators are studied at the beginning of each year. An iterative methodology selects pipes to be repaired and the pipes to be replaced in that year. Options of PRV installation and isolation valve placement were considered in the beginning of 4th and 5th year, as leakage losses were appreciably reduced in first 3 years, It can be concluded that as leakages are directly dependent on the value of leak coefficient and pressure, the repairs should be performed on the basis of the values of coefficients. As far as equity is concerned, using PRV to control pressure and forming sub zones having minor variation in elevation in the zones using isolation valves should be encouraged.

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