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Applying a heuristic approach for a minimum-cost operating strategy for tap water

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ABSTRACT

A water supply system with multiple water purification stations supplying tap water to different clients in the district has to satisfy water pressure requirements as the rule of thumb. Water allocation combined with pipeline network hydraulic analysis has not been applied to obtain the minimum total operating costs of all water purification stations. In this study, we developed a heuristic approach to gradually adjust water yield of each water purification station, network hydraulic analysis is executed to check the pressure requirements after each adjustment. Under the conditions satisfying to pressure requirements, this approach gradually and effectively adjusts water yields of all water purification stations until overall operating costs cannot be further reduced. Additionally, we adopted a brute-force search method to verify the above results. Under limited water source of every purification station, this method developed all feasible water yield combinations of purification stations in which the total water supply is equal to the total demands. The pipe network hydraulic analysis is performed for every yield combination to check whether the hydraulic head of each node is satisfied. Further, head required at the purification station need to be lower than the elevation of each station to ensure the water supply via gravity only. If the heads of all nodes are satisfied, then the operation cost of this combination is compared with the minimum cost of previous combination, and the smaller cost combination is reserved for further screening of minimum cost combination. Subsequently, this method screens out the minimum cost water yield combination of all purification stations. Finally, we found that both the heuristic approach and the brute-force search method both obtained same minimum operating cost, but the heuristic approach significantly reduces the computation burden.

KEY WORDS: heuristic method; minimum cost; operation strategy

INTRODUCTION

Owing to different methods of water extraction, the raw water coming from a tap can be divided into three categories: surface water, groundwater, and hyporheic water. Raw groundwater has the best water quality and the cost of dosing in subsequent water purification procedures is the lowest, but sites for groundwater extraction are mostly located in low-lying places, so its power cost is the highest. Raw surface water has the worst water quality and it is vulnerable to increasing rainfall-induced turbidity and to man-made pollution with poor stability. The cost of subsequent dosing is the highest. Meanwhile, the relevant characteristics of hyporheic water lie somewhere in between these two.

After the raw water is extracted, a water purification plant needs to decide the subsequent dosing treatment procedure according to the water quality characteristics of the raw water and to drinking water quality standards. Finally, depending on the elevation of the water purification plant’ s location, the clean water will be sent to the water supply area by gravity or dynamic compression. As described above, the operating costs of a tap water supply system include the raw water charges, power costs, chemical costs, personnel costs, depreciation charges, mechanical equipment maintenance costs, interest, etc. Of these, the raw water charges, power costs, and chemical costs will have different operating costs owing to different water source positions, elevation, water yields volume, and water quality situations.

In a water supply system with multiple water purification plants, to meet the water pressure needs of different clients within the water supply area, it is necessary to distribute the water outputs of each water purification plant appropriately. However, different operators do not have the same distribution methods because of different preferences. In order to improve operational performance, this study explores the operating strategies for water purification plants for minimum water source cost in a tap water supply system, under different water source restrictions and minimum pressure requirements at the water-use side.

LITERATURE REVIEW

Among the optimization studies related to distribution network systems, linear programming, dynamic programming, neural networks, genetic algorithms, and other methods are often applied to determine the the optimal design for the network, such as in the study of Bi and Dandy (2014). However, few have discussed the best operation for a network system. The research outcomes of relevant scholars are as follows.

Bagirov et al. (2013) took the energy consumptions of pumps in a water distribution network system as an objective function, developed a set of algorithms based on a combination of the grid search method and the Hooke–Jeeves pattern search method, and used EPANET software to conduct network hydraulic analysis to determine the optimal operating time for the pumps. Kurek and Ostfeld (2014) took the energy consumptions of pumps and the water quality in a water distribution network system as objective functions, and used EPANET to conduct network hydraulic analysis, using multi-objective genetic algorithms to determine the optimal operation modes for pumps and dosing.

Kuo (2006) adopted the water supply operation of the Tainan area of Taiwan. as a case study. Its water sources are extracted mainly from Zengwen Reservoir and Nanhua reservoir. Considering that both reservoirs supply the tap water of the Chiayi and Kaohsiung areas, Kuo drafted eight different types of water extraction strategies. Through simulations of water dispatching (supply), Kuo explored timings for more economical water storage and water overuse during wet, normal, and dry hydrological years to increase the operating performance. Chen (2009) adopted the water supply operation of the Hsinchu area as a case study, applied linear programming, and used LINGO software to analyze the raw water, purified water, and water supply costs of major water purification plants, in order to explore the optimal water allocation for water supply costs.

RESEARCH METHODS

To develop operating strategies for minimizing water source cost in a tap water system, the analysis methods include distributing and adjusting the water outputs of water purification plants, as well as performing network hydraulic analysis to examine and verify the water pressures at the water-use sides. Under the assumption that the water-source sides supply water only through gravity, this study adopted the EPANET software to conduct network hydraulic calculations. It also developed a heuristic method and used an exhaustive method to adjust the water outputs of the water purification plants in order to find an operating strategy for minimal water cost.

Heuristic Method

First, under the conditions of the maximum available volume of water supply and a gravity-fed water supply at the water source, performing the network hydraulic calculation yields the initial volume of water output for each water purification plant. Then, based on the cost level of the unit water output, the aim is to reduce the volume of water output starting from the water purification plant with the highest cost. Under the condition that the total water supply volume equals the total water volume required, the water volume that is reduced from the water purification plant with the highest cost must be complemented by the increased volume of water output from the other water purification plants with lower costs. However, it is necessary to examine and verify that the volumes of water output from each water purification plant are not greater than the maximum available volume of water output, and the water pressure at the demand side needs to meet the minimum acceptable water pressure. If these two conditions are both met, then we continue to reduce the volume of water output until we find the minimum volume of water output when the water purification plant with the highest cost is in line with the two conditions mentioned above. This type of water-volume adjustment method can effectively reduce the cost of a water source. Subsequently, it is used again to reduce the volume of water output from the water purification plant with the second-highest cost for a water source, based on the aforementioned process. Deduction through this process can continue to reduce the total cost of the water source. Therefore, the alternative water output method based on reducing the cost can determine an operating strategy with minimal total cost. The detailed process is shown in Fig. 1.

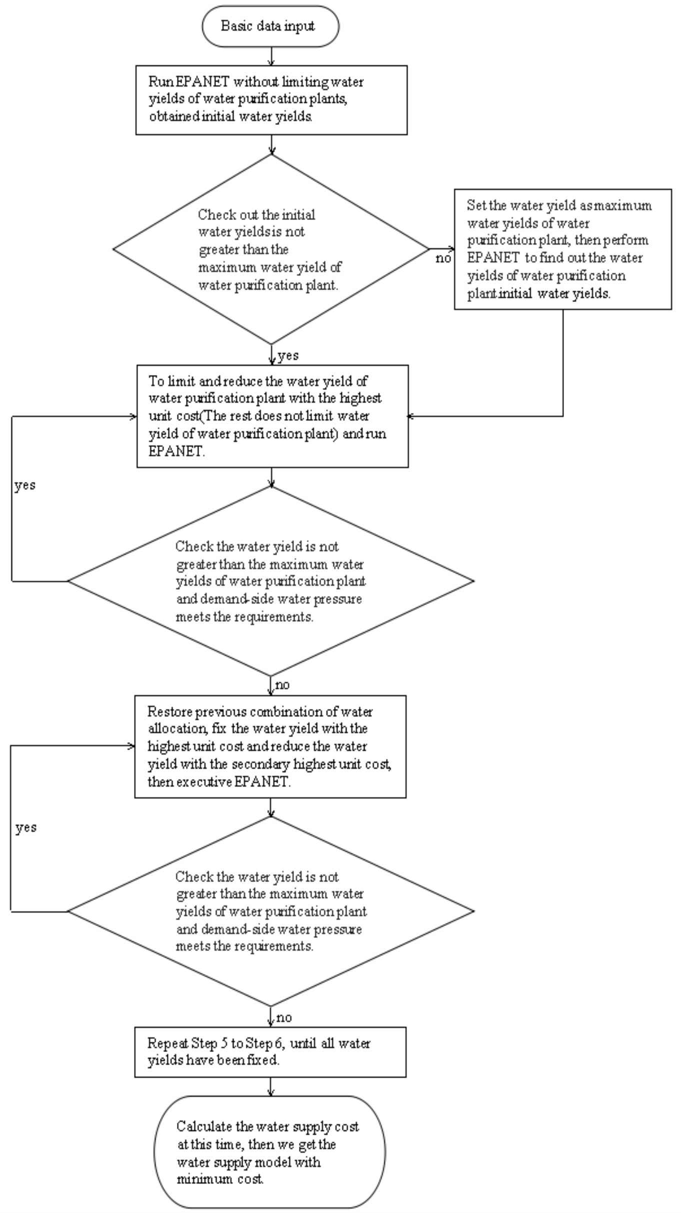

Fig. 1 Flowchart of the heuristic method

Exhaustive Method

In this study, we also employed an exhaustive method to search the range of configurations of water sources with minimum cost. This method first takes the volume increment of water output from each water purification plant as 10 cubic meters per day (CMD) and then sorts and combines all water source volumes of each water purification plant in the system from 0 to the maximum volume of water output. The combinations of water source volumes that are in line with the total water use volume at the demand side are retained, and then network hydraulic calculations are conducted on every combination to obtain the hydraulic head of each node and the required hydraulic pressure head at the water-source end. The aim is to examine and verify that the hydraulic head of each demand side is greater than the minimum required pressure and that the required hydraulic head at the water-source end is lower than the elevation of the water purification plant. The aim is then to filter out the water source combinations that can supply water merely through gravity. Finally, the aim is to compare and determine the combination of water source volumes with the minimum cost, which is the optimal solution. The detailed process is shown in Fig. 2.

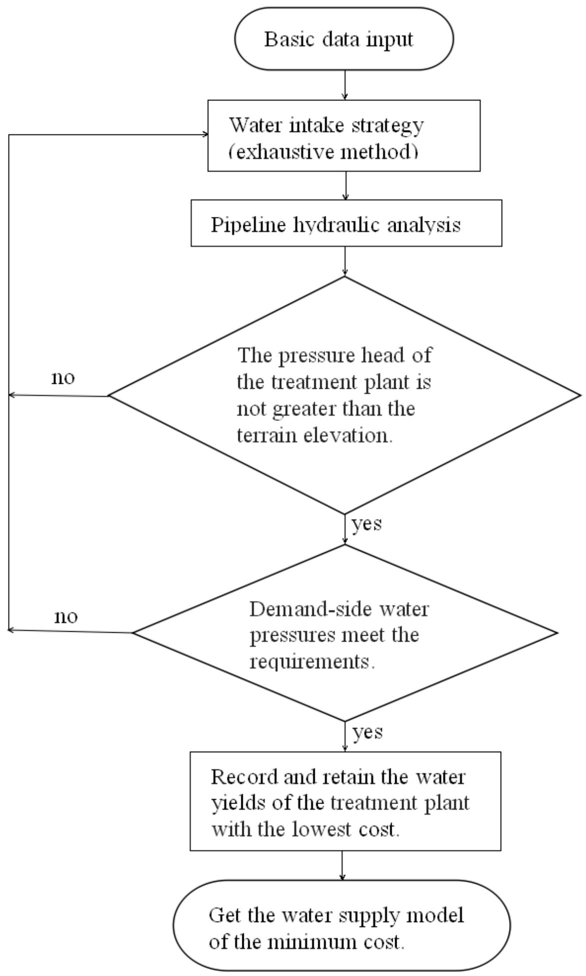

Fig. 2 Flowchart of the exhaustive method

RESULTS AND DISCUSSION OF CASE STUDY ANALYSIS

The case study for analysis is defined to be a network system with multiple sources of water supply. There are a total of four water sources and twelve demand nodes. The required water volume for each node is 300 CMD, all the elevations are 0, all the pipeline diameters of L1 – L17 are 100 mm and all the pipeline diameters of L18 – L21 are 200 mm. The system configuration map is shown in Figure 3, the pipeline lengths are shown within the map with units of meters and V22 – V25 are the flow control valves used to distribute volumes of water output from each water purification plant. For the maximum available volume of water output, terrain elevations, and unit costs of water output of each water purification plant, please refer to Table 1.

Table 1 Maximum volume of water output and unit cost of water output for each water purification plant

Node no. of the water purification plant	Maximum water output (CMD)	Elevation (m)	Unit cost (NT$)
R13	1,800	30	1.2
R14	1,200	20	1.5
R16	500	15	2.0
R15	1,200	20	1.0

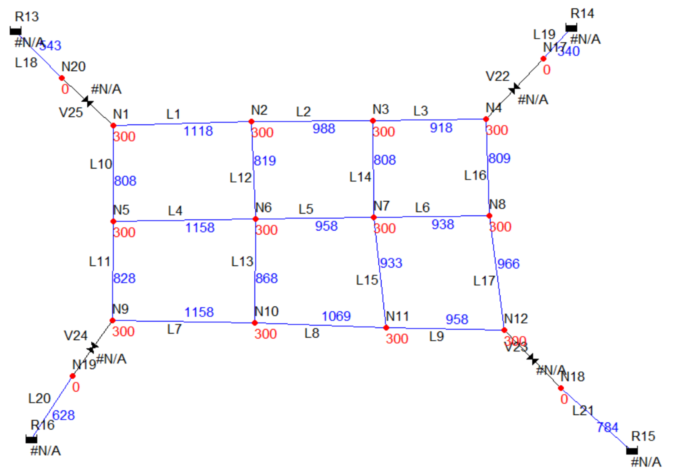

Fig. 3 System layout

When conducting network hydraulic analysis, we adopted the Hazen-Williams equation (in SI units) for the calculation of hydraulic head loss. All the C values for each pipeline are 100. The equation is shown as:

$$h_L = 10.666 * L * Q^{1.85} * C^{-1.85} * D^{-4.87} \quad (1)$$

where h_L is the head loss (m), L is pipeline length (m), Q is the flow (CMS), C is the roughness coefficient and D is the pipeline diameter (m).

Assuming that the system has no leakage loss and has a gravity-fed water supply, the volume of water output from each water purification plant cannot be greater than the maximum available volume of water output and the hydraulic head of the demand node must be at least 10 meters. The results of analysis using the heuristic method and exhaustive method are shown in Figure 4 and Figure 5, respectively. The node numbers are the hydraulic head heights and the line numbers are the flows. The results of analysis for both cases are listed in Table 2.

Table 2 Comparisons of the water output costs of each water purification plant

Node no. of the water purification plant	Maximum water output (CMD)	Unit cost (NT$/CMD)	Water output by heuristic method (CMD)	Water output by exhaustive method (CMD)
R13	1,800	1.2	1539	1540
R14	1,200	1.5	1023	1020
R16	500	2	57	60
R15	1,200	1	981	980
		Cost Subtotal	4476.3 NT$	4478 NT$

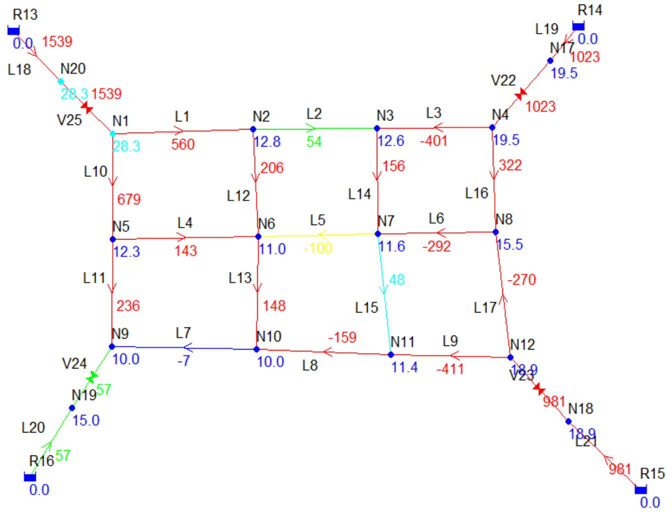

Fig. 4 Map of the hydraulic network analyzed using the heuristic method.

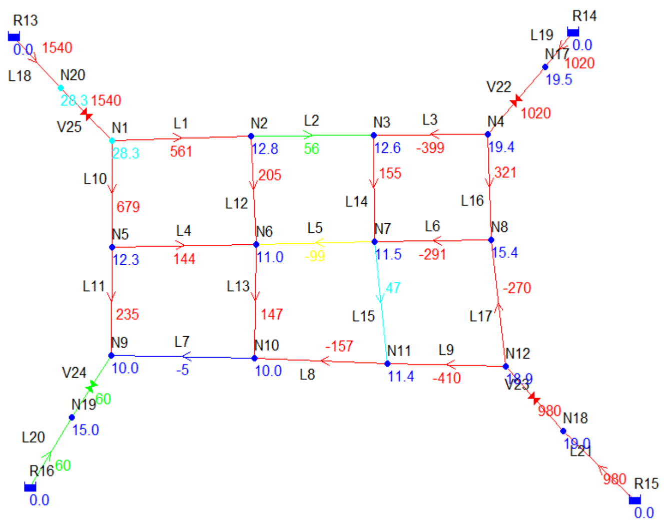

Fig. 5 Map of the hydraulic network analyzed using the exhaustive method.

As shown in Table 2, the minimum water source cost and the water output of each water purification plant obtained using the heuristic method and the exhaustive method are found to be almost the same. For this case study, the heuristic method can be used sequentially to fine-tune the water output of the water purification plant with the highest water source cost to 1 CMD, whereas the exhaustive method takes 10 CMD as the smallest unit for a thorough search to find all configurations that are in line with the restrictive conditions and then select the configuration with the lowest cost. If the heuristic method and the exhaustive method are required to have identical accuracy, then calculations will take a very long time, or will be impossible under the restriction of a lack of sufficient computing equipment. From the results of the exhaustive analysis, node N9 with minimum pressure had 9.98 meters of hydraulic head height. The difference from the case with 10 meters under restrictive conditions is minimal.

CONCLUSIONS AND RECOMMENDATIONS

The minimal cost of water resources in the system obtained using the heuristic method proposed in this study produced almost the same results as that using the exhaustive method, which validates the heuristic method. The heuristic method can significantly reduce the number of calculations compared to the exhaustive method. Hence, applying the heuristic method to the system in this case study can allow the water volume of the source to be adjusted very efficiently, yielding an operating strategy for the minimum total cost of a water source.

The case study for analysis assumed that the system has four water sources each with different unit costs of water output. If there are more water resources in the network system, and the unit costs of water output of some of the water source units are similar or even identical, then the analysis results of using the heuristic method to adjust the water volume in accordance with the cost level may produce multiple sets of water source distribution methods. Therefore, it is recommended to consider other case studies of different scenarios for in-depth analysis.

REFERENCES

Bagirov, A. M., Barton, A. F., Mala-Jetmarova, H., Al Nuaimat, A., Ahmed, S. T., Sultanova, N., Yearwood, J. (2013). An algorithm for minimization of pumping costs in water distribution systems using a novel approach to pump scheduling. Mathematical and Computer Modelling 873-886.

Bi, W., Dandy, G. C. (2014). Optimization of Water Distribution Systems Using Online Retrained Metamodels. J. Water Resour. Plann. Manage.140.

Chen, Yu-Kuei. (2009). Cost analysis and discussion of optimized deployment of a water supply system – A case study of the Hsinchu system. Dissertation for Master of Engineering, Chua Hua University.

Kuo, Der-Luh. (2006). Investigating the least cost water withdraw policy of the Tainan metropolitan. Dissertation for Master of Engineering, Department of Hydraulic and Ocean Engineering, National Cheng Kung University.

Kurek, W., Ostfeld, A. (2014). Multiobjective Water Distribution Systems Control of Pumping Cost, Water Quality, and Storage-Reliability Constraints. Journal of Water Resources Planning and Management ASCE / february 184-193.