A PRAGMATIC MODELLING APPROACH FOR INTERMITTENT WATER SUPPLY

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Abstract

Traditional water distribution modelling theory gives primacy to demands over pressures, thereby making demands the fixed and independent input variable, and pressures becoming the dependent output variable. This approach is very convenient for systems without any pressure limitations so that demands are always met. However for pressure-constrained systems the models do not give sensible results as they do not demonstrate the fact that with declining pressures, flows will also correspondingly decline in reality. In order to carry out more realistic modelling, it is important to divert from the traditional demand-driven approach and inculcate methodologies that recognize the relationship between flow and pressure, also called the head-driven approach. This paper applies both methodologies to an intermittent water supply system and demonstrates that in cases where pressures are insufficient, traditional demand-driven models should be substituted with head-driven models.

Key Words

Demand Driven Analysis, Head Driven Analysis, Water Distribution Networks, Modelling, Simulation, Pressures, Flows.

INTRODUCTION

In the traditional design of water distribution systems, pressures are assumed constantly available to satisfy demands defined throughout the networks, thus models for analysing water distribution networks consider nodal demand as a primary model input while pressure is regarded as a primary output. This demand-driven approach (DDA) to modelling water distribution is well developed and valid for scenarios in which pressures in a system are adequate for delivering required nodal demands. It gives realistic results when network pressures are high enough to meet demand, however, should pressures fall substantially, unrealistic and meaningless results are obtained, such as very low or negative pressures (Chandapillai, 1991; Ang & Jowitt, 2007; Wu et al., 2009)**.**

Intermittent water distribution networks involve periodic low and no pressure events and to simulate these in a realistic way a new approach, different from demand-driven analysis is required. This has led to development of analysis that incorporates a relationship between demand and pressure, also called pressure/head driven analysis (PDA/HDA), which has resulted in desirable solutions by showing compensation among nodal demands and available pressures (Cheung et al., 2005). Using HDA, a modeller is able to determine nodes with insufficient supply and the respective magnitudes of the shortfalls. Primacy is given to pressures and a node is supplied its demand fully only if a minimum required supply pressure is satisfied at that node. If the minimum pressure requirement cannot be met, then the fraction of the nodal demand satisfied is determined by recognition of a relationship between nodal head and nodal outflow. Many researchers have attempted to predict behaviour of water distribution systems under pressure-deficient conditions (Chandapillai, 1991; Hayuti et al., 2007; Ang & Jowitt, 2007; Wu et al., 2009) and have demonstrated that under conditions of insufficient pressures, the amount of water that can be supplied at a node directly depends on the pressure available at the node.

In this paper, the authors carry out a comparative analysis of performance of demand-driven and head-driven approaches to water distribution modelling using a case study of the Rubaga subsystem of the Kampala Water Supply Network (KWSN), Uganda. In KWSN, there are sections which experience severe pressure shortfalls brought about by inadequate production, inadequate distribution and unplanned and excessive network expansions, leading to several cases of very low or no flow at all and this directly limits supply (Nyende-Byakika et al, 2010; 2011). In such situations, traditional methods of analysis have limitations; demands in this case are not only a function of time but of pressure as well and consequently, demand driven analysis alone fails when abnormal conditions prevail (Hayuti et al., 2007). Using HDA, an iterative method that uses a pressure-flow relationship is employed, that adjusts both demand and pressure in order to yield an optimum solution that represents equilibrium of a water distribution network and certainly, the reality on the ground.

METHODS

Methods that were employed in the study included characterisation of the Rubaga subsystem, development of a model of the Rubaga subsystem and analysis of response of the network under various scenarios. Data collected on the Kampala water supply network included water produced and supplied, pipe layout, pipe sizes and elevations, pipe lengths and materials, valves, reservoirs, pumps, consumption patterns (estimation of nodal demands) and pressures, heads and flows at strategic sections, well supplied zones and poorly supplied zones. The second step entailed building a model of the Rubaga network in the EPANET2 hydraulic solver (Rossman, 2000) using the network data obtained under the demand driven approach. The modelling process involved network schematisation, model building, testing and problem analysis. Principal hydraulic input parameters for pipes are start and end nodes, diameters, lengths and roughness coefficients for determining head loss. Computed outputs for pipes included flow rate, velocity and headloss. The hydraulic head lost by water flowing in a pipe due to friction with the pipe walls was computed using the Darcy-Weisbach formula.

The Rubaga subsystem was modelled to comprise of 22 pipes and one 4000 m^3 reservoir. A model of the schematised water distribution network of the Rubaga subsystem showing node and link identification numbers (IDs) is shown in Figure 1.

In order to use the developed model to obtain the study objectives, two broad scenarios were considered as follows:

i. Normal operating systems in which pressures are assumed sufficient to meet the demand throughout the network. This scenario involved monitoring the response and performance of the model during ideal flow conditions i.e. periods and sections when pressures are sufficient, in order to find out system behaviour and pressures, heads and flows at various sections. This provided a control and benchmark to the subsequent scenarios.
ii. A constrained system which was created by imposing excessive demand loadings, insufficient supply and inadequate pipe sizes.
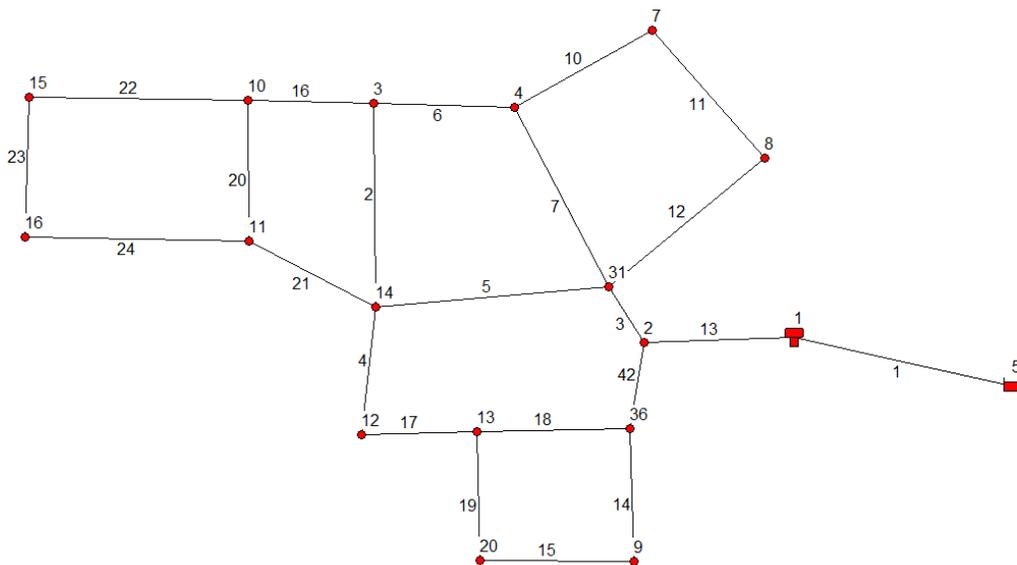
Figure 1: Model of Rubaga Subsystem showing Node and Link IDs

Having carried out demand driven analysis (DDA), nodes at which pressures were insufficient to fully supply their demands were identified. As already discussed, since demands are fixed under DDA while pressures vary, a nodal pressure value was considered insufficient if it was less than the pressure threshold, a situation that would result in less water supply than is required. The threshold value for each node can be approximated by the expected maximum outlet level in the locality served by that node represented by the height of the tallest building that can be agreeably supplied by the service provider without extra pumping (Tanyimboh, 2000). A threshold value of 10 m was used in this study. When lower nodal pressures are obtained then only a fraction of the original demand is met. There is then the need to determine the available flows at the identified pressure deficient nodes using the modifications summarised below (Ozger, 2003; Mays, 2004).

i. New node elevation = Original node elevation + Threshold pressure head
ii. Set demand to zero
iii. Connect an artificial tank to the node by an infinitesimally short pipe that allows flow only from the node to the reservoir
iv. Artificial tank elevation = New node elevation

RESULTS AND DISCUSSION

Demand Driven Analysis: Pressure Response to Demand

In this section we looked at the response of nodal pressures to changing demand. Plots of variations of demand with pressure at node 16 were done at 16 00 hours (Figure 2) at peak demand. Demands were shown to be met at different pressures in a relationship of inverse proportionality i.e. the higher the demands the lower the pressures at which the demands are fulfilled. At 29 l/s, negative pressures were exhibited. This showed that the model at this point was malfunctioning, since not all nodes could supply water.
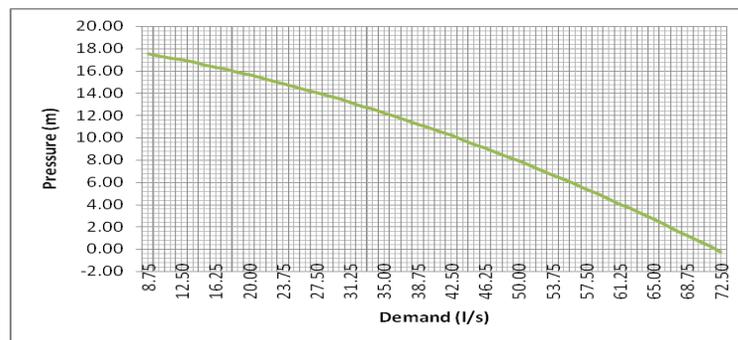

Figure 2: Plot of Demand vs Pressure at Node 16 at 16 00 hours

Figure 3 shows initial pressures at 16 00 hours (peak demand hour) and Figure 4 shows pressures after higher demand loadings are made. It can be observed, as is expected of demand-driven analysis, that lower pressures arise from higher demand loadings. It is particularly observed that negative pressures develop at junction 16 highlighted in Figure 4, which implies an inability to meet the demand at that node.

At junction 16 the pressure required to satisfy a demand of 37.5 l/s is negative which is logically interpreted to mean that at this demand value, no supply is possible at this node. This is computational result, however in reality some water will come out of this node at a discharge less than 37.5 l/s, in proportion to the prevailing pressure at the node and this further underlies the chief weakness of demand-driven analysis for water distribution networks. Using head-driven analysis however, it can be worked out that the demand that can be met at node 16 is 9.73 l/s at midnight and 0.4 l/s at the peak hour.
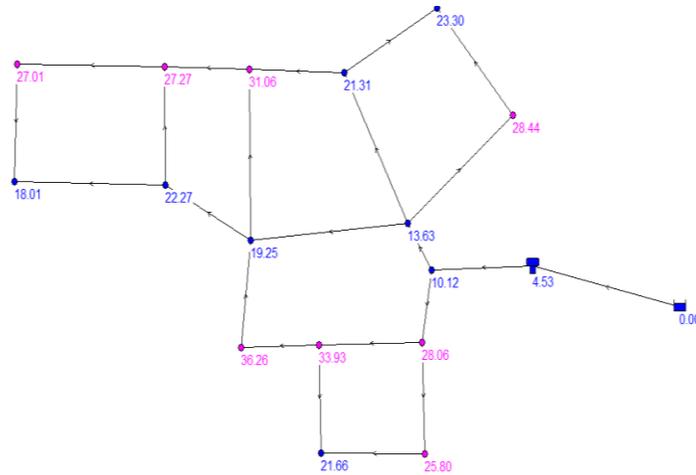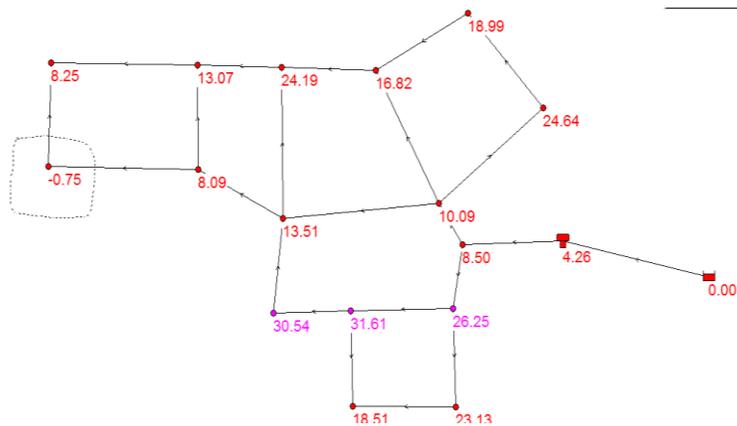
Figure 3: Initial pressures at 16 00 hours

Figure 4: Pressures after higher demand loadings are made

Head Driven Analysis: Demand Response to Pressure

In this section, we looked at the response of water supplied to pressure when pressure is the driving factor/independent variable while demand is the dependent variable. Figure 5 shows variation of pressure with water supply at node 16 in the model at 16 00 hours. It can be seen that when pressure is the determining factor of system performance, then the higher the pressure in the system the more the water supplied.
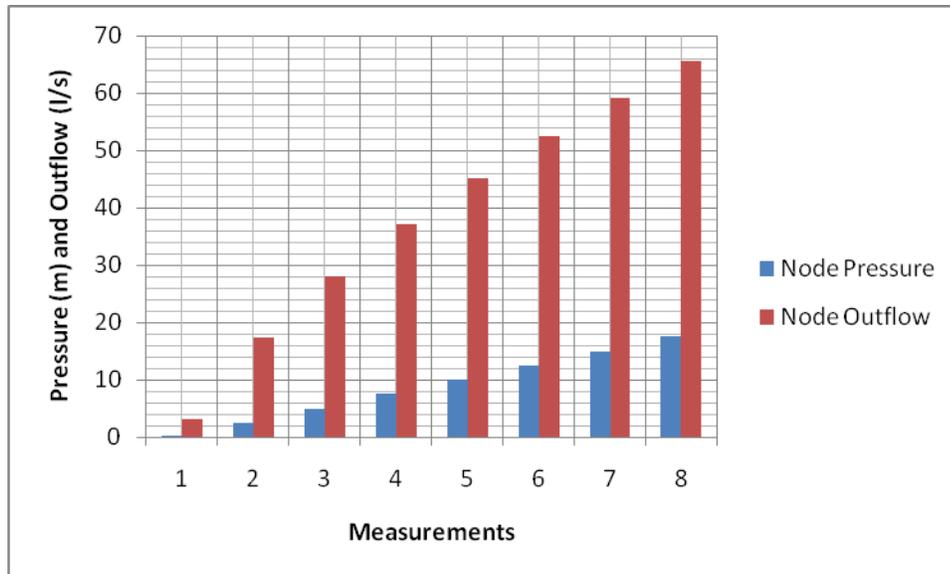
Figure 5: Response of Available Supply to Changing Pressures at 16 00 hours

It is important to realise that in financially viable economies characterised by satisfactory water supply system performance, all customers are expected to receive the amount of water they need and pressure is a key performance indicator whose non-fulfilment attracts penalties to the service provider. In low developed and water scarce regions, pressure is a luxury with flow becoming the more critical performance indicator. In these regions it is good enough that some water can run through faucets. In these areas the notion of "some for all rather than all for some" strongly holds. Focus then shifts from supplying water at pressures above a pre-established threshold figure to supplying some water to all, at whatever pressure. This means that while we cannot achieve the desired pressures, we need to maintain some flows to the populations and this makes the demand driven approach along which traditional water distribution models are designed less helpful where supply pressures are deficient.

CONCLUSION

In demand driven analysis, the higher the outflow the lower the pressure while in head-driven analysis, the higher the pressure, the higher the outflow. Current water supply modelling philosophy assumes a demand driven approach which may not be applicable in networks experiencing low pressure situations. The models are thrown into chaos during pressure shortfalls when the required demands are shown to be satisfied in all circumstances, including periods of inadequate pressure, which is unrealistic. In reality, when pressures are low, water is supplied in accordance with the available pressures, that is, the lower the pressure the less the water supplied, which concept is the selling point for application of head-driven analysis.

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