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Water Distribution Network's Modelling and Calibration

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Abstract

Water is an inestimable natural resource and is essential for all life on the planet. But the natural resources have been exploited, mistreated and contaminated and hence management of water is a really challenging task in developing countries to make sure every customer is getting sufficient and good quality of drinking water. Increases in population and climate change are main reasons for an ever increasing demand on water supply system. Since water resources are definite, it requires proper management and supply.

This paper focuses on modelling and calibration of water distribution network which can be used for further analysis like pressure optimization, growth studies etc. A trial and error process is used for the calibration of network. The paper describes the path followed through the hydraulic model build up to final calibrated model, including importing of the assets, the definition of network zones and measures taken for the calibration using EAPNET tool.

Keywords: Calibration, Critical point, District metering area, High performance polyethylene pipe, Hydraulic model build, Pressure reducing valve, Water distribution network.

Introduction

Water distribution system is a hydraulic infrastructure consisting of elements such as pipes, tanks, reservoirs, pumps and valves etc. Effective design is very important for a new water distribution network and expansions of existing network, so as to provide drinking or potable water to the end customers. Water distribution modelling plays an important role in the design and operating water distribution system. It is capable of serving water to the community trustworthily, safely and economically. Because of the availability of user friendly and sophisticated models these goals comes into reality than ever before. Before starting any modelling project, it is necessary that the water utility agrees upon the need for the model and purposes for which the model will be used in both short term and long term. In utilities, a model consists of pipes, pumps, demands, etc. These components in the system are represented in maps and drawings of those facilities. The maps are converted to a model that represents the facilities as links and nodes. The behaviors of the links and nodes are described in the form of mathematical equations. The model equations are then solved, and the solutions are typically displayed on maps of the system or as tabular output.

For those involved in design, construction and maintenance of public water distribution system, computation of flow and pressure in a complex network is a great challenge. Earlier, many methods have been used to compute flows in pipe network which involves graphical method, mathematical model and physical analogies. Development and implementation of these methods using a computer have been used over the last fifty years. The Hardy Cross method is adopted from the moment of distribution method, developed by Hardy Cross. This method is used to determine the moments in indeterminate structures. In later stages these methods were obsolete after the development of computer solving algorithms employing Newton-Raphson method and other solution methods. These algorithm methods removed the need to solve nonlinear systems of equations by hand. In certain cases it has been found that the Hardy Cross method

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converges very slowly or not at all. This leads to suggest special measures to improve convergence and a constrained model for the minimum cost design of water distribution networks.

Hardy Cross proposed the use of mathematical methods for calculating flows in complex networks. This manual, iterative procedure was an epoch-making advance in the water distribution system calculation and used throughout the water industry for almost 40 years, even extended to the early stage of computer age. The machine implementations of Hardy Cross methodology were developed and were in widespread use by the 1980s. The usability of these models was greatly improved in the 1990s with the introduction of the public domain EPANET model and other Windows-based commercial water distribution system models.

Most of researchers studied water networks calibration methodology thoroughly but it is almost evaded by practitioners. Due to less number of measurements and high uncertainty in real networks makes the calibration problem more challenging. Walski et al. (2003) states that "simulation is a process where mathematical representation of the real WDN used to compute the systems performance, in order to reproduce the responses of real systems for the same input conditions". This procedure is called as model calibration. Shamir and Howard (1977) defines that calibration "consists of determining the physical and operational characteristics of an existing system and determining the data [that] when input to the computer model will yield realistic results". Cesario (1995) states that calibration as "the process which involves fine-tuning a model until it is able to simulate the field data for a particular time horizon (e.g. the scenario peak time consumption), with a degree of accuracy pre-established". Walski et al. (2003) states calibration as "the process of comparing the model results with the field data. If necessary, adjust the model data until the predicted model behaviour matches with the field behaviour for a wide range of operating conditions". In Straightforward manner Calibration is defined as the comparison between simulated data vs. measured data. The calibration methods typically alters system demands, roughening or smoothing of the pipe and modifies pump operation characteristics until satisfactory match is obtained between measured and modelled data".

Walski, Bhave, Ormsbee and Wood, Boulos and Wood states that several techniques of model calibration involves trial and error procedure. From point of view of model's hydraulic calibration it is important to make sure that both flow values (which contains systems inflows and outflows as well as network's flow) and pressure values (or level in the reservoirs) are simulated correctly. Inputs and outputs of the network are the important sectors in the measurement of total system demand.

Depending on the optimisation technique and their dynamics (static/transient) calibration methods are classified as (1) Iterative methods which is based on trial and error procedures; (2) Explicit methods, which solve the extended set of steady-state mass balance and energy equations; and (3) Implicit methods, which are formulated and solved using an optimisation technique coupled with a hydraulic solver. To solve the uncertainties associated with estimated parameters and model predictions some efforts have been attempted. To estimate the uncertainty First-Order Second-Moment (FOSM) approximation and Bayesian recursive optimization approach have been applied instead of random sampling approach.

Walski in 1983, proposed a trial and error methodology by using a fire flow test in a pipe network to adjust both demands and roughness. Another iterative methodology is proposed by Bhave in 1988, where the network was divided in zones to adjust the total demand and the resistances in the pipe network is adjusted too. Solving the basic network equations explicitly, Ormsbee and Wood in 1986 formulated the calibration algorithm in terms of head loss coefficients. However, implicit methods were user-friendly and used most of the time. The problem that deals with the calculation of the pressure and flow distribution in the network is described by Datta and Sridharan in 1994. This solves the problem of determining resistance coefficient (Hazan Williams coefficient) by means of weighted least squares (WLS) method. In 1996 Reddy et al. estimated the roughness using Weighted least squares method based on the Gauss-Newton minimization technique. More references of calibration techniques to identify most reliable method of calibration are reviewed by Savic et al in 2009. When input data is inaccurate it is important to calculate estimated parameter values as well as reliable of estimation. Bargiela and Hainsworth in

1989 compared Monte Carlo simulation. Monte Carlo simulation is used for confidence limit analysis. It is an optimisation and sensitivity-based approach. Enable the hydraulic operation of a study area, aiming A WDN's model construction using EPANET contribute a more feasible method.

Case Study

Water distribution network Characterization

For the effective water distribution network analysis, Gulbarga city in the state of Karnataka, India is considered. The population of the town as per the data available from the statistics department is taken as 430,000. For the study purpose, one zone with the population of 4000 is considered. The study area contains only domestic population with the no major large industrial or commercial consumers. Households are now consuming an average of 91 litres per person per day, which is sufficient to enable the maintenance of hygiene standards as well as to meet most convenience needs.

The WDN is 10km long pipeline mainly in HPPE with a diameter of 63mm. The pipe age is about 5-6 year. The DMA is feeding via inlet meter with the PRV and contains two pressure monitoring point and critical point.

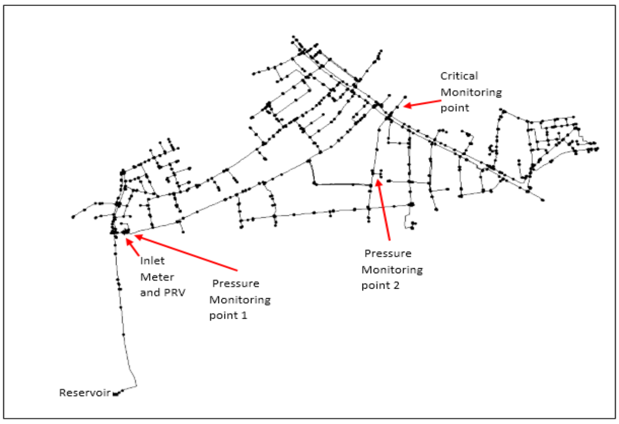


Figure 1: Water distribution network under analysis

Water distribution network model build

The first step to the WDN's model construction contains analysis of the historic network data. WDN model requires network data, water data and operation data.

The model for water supply system establishes the computer simulation, including the following parts: junctions, pipes, valves, pumps, reservoirs, hydrants. The pipe network contains lot of information about pipes, junctions, pumps, valves, etc. as well as the properties of the components. Pipeline network properties, the formation of these parts and other databases can effectively simulate and managed by EPANET.

The distribution network was present in the GIS and imported to the EPANET. The simplified DMA network in GIS format are transformed to the pattern in EPANET and water supply terminal of DMA is expressed as reservoir, as shown in Fig. 1. The basic information in the model should include: node flow, node elevation and pipe roughness, pipe diameter and so on for hydraulic analysis. For the pipes, Hazen-Williams formula for the calculation of unit head loss with the roughness coefficient of K=140 (The lengths were assigned automatically from the GIS) is considered. The node flow is obtained by demand of the consumers at the node multiplied by diurnal pattern. The model must be verified after the import, to check the connectivity of the network at intersections and reservoir nodes.

The relevant flow and pressure data at the inlet meter, pressure monitoring point and the critical point of DMA is obtained by the SCADA data at the interval of 15 min.

Taking in to account the inlet meter flow profile, diurnal pattern (dimensionless) of this area can be obtained from the actual measuring value.

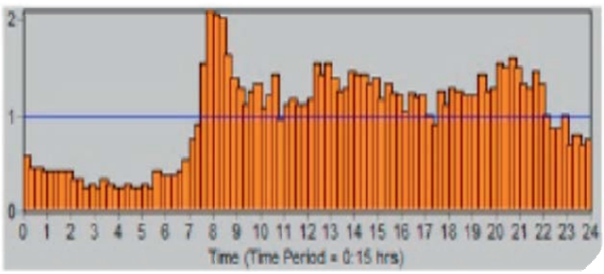


Figure 2: Demand Pattern

The extended period simulation is used for hydraulic modelling based on Hazen Williams's equation, and litre per second as the flow unit and meter as the pressure unit.

Model calibration

After the hydraulic model construction proceeded its calibration. For the calibration the SCADA data of flows and pressure at the inlet meter, pressure monitoring point and critical point are used. To analyse the accuracy of the model, it is necessary to give input of actual measuring data into the file for comparison. The comparative graph between computed flow and observed flow at the inlet of DMA is shown in Figure 3 and the relation between computed pressure and observed pressure at the pressure monitoring point 1 is shown in Figure 4

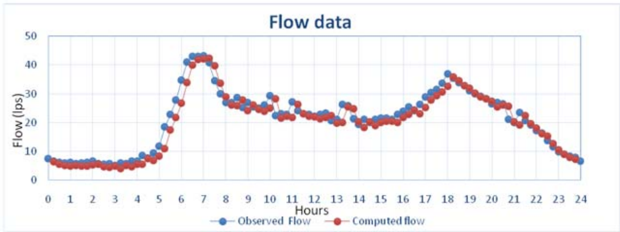


Figure 3: The computed and observed value of inlet meter flow

As obtained from Fig. 3, the average computed inlet flow during a day is 20.95 L/S, and the mean observed value is 21.13 L/S, with an absolute error of 0.85%. From the above results, flow calibration of the zone with absolute error of 0.85% is acceptable.

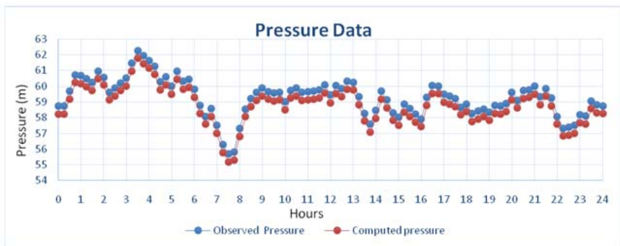


Figure 4: The computed and observed value of pressure data at inlet meter

As known from Figure 4, pressure at the inlet meter during 24 hours, the average computed value of pressure is 58.78m and the observed mean value is 59.28 m, with an absolute error of 0.84%. Therefore it is concluded that source of modelling error mainly includes pipe age, pipe roughness, influence of water consumption pattern.

The pressure data in the study area is measured at inlet meter, pressure monitoring points and at the critical point.

Calibration methodology

Calibration of WDS is necessary to predict the water distribution network models behaviour under different condition and to plan their expansion in future. Calibrated models of WDS are used for future growth studies. Before a network model is used for further studies, it needs to ensure that the model would predict, with reasonable accuracy with the field data. The behaviour of the network should reflect the field conditions. Such a process is called as "calibration" of the model. The accuracy of a hydraulic model depends on calibration methods and how well it has been calibrated. Hence Before a model is used for any future studies or decision-making purposes calibration analysis should always be carried out. Calibration is the process which compares the model results against field observations. Calibration actions focuses on the adjusting the model hydraulic conditions until model-predicted performance reasonably matches with measured system performance over a wide range of operating conditions.

Following steps are involved in the calibration of the model:

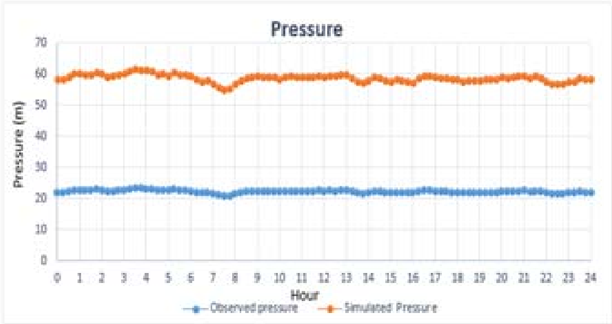
1. ***Head at source node***

The head at source nodes can be determined based on the head loss difference between the reservoir head and pressure monitoring point immediate downstream of the inlet meter. The water elevation in the reservoirs and the head supplied by the pumps can be measured with SCADA system.

2. ***Manual calibration approach***

The manual process or trial-and-error method of calibration generally involves the modeller's estimates to change pipe roughness values and nodal demands, conducting the simulation, and comparing simulated results against observed results. Until a satisfactory match is obtained between simulated and observed values the process is carried out iteratively. When model is not able to show satisfactory match, it is considered as the model is not a true representation of the part of the real system where discrepancies remain. In such cases, to identify discrepancies between the model and the real system further site investigations are usually carried out. Incorrectly modelled valve settings and unrecorded connections can be reason of the discrepancies. The process of calibration may include changing system demands, smoothening or roughening of pipes, throttling of the valve, changing pump operating condition, and adjusting other model attributes that affect simulation results.

Calibration Actions



(a)

(b)

Figure 5: Simulated and observed value of pressure monitoring point 1: (a) Before Calibration; (b) After Calibration

From the above observed and simulated values (Fig.5a) pressure variation at pressure monitoring point 1 is about 40 m. Hence model needs to be calibrated. Therefore to calibrate the pressure, Pressure reducing valve present at the d/s side of inlet meter, set to the pressure of 22m. From Fig.5b pressure at pressure monitoring point 1 during 24 hours, the average simulated value of pressure is 22m and the observed mean value is 22.2 m, with an absolute error of 0.9%.

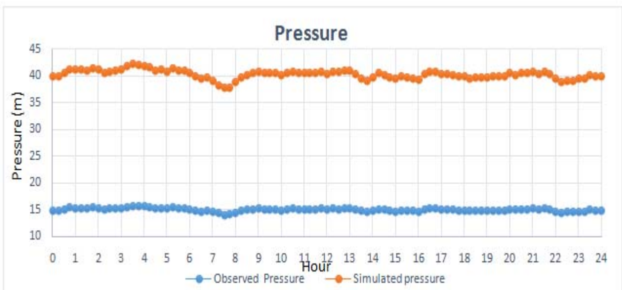
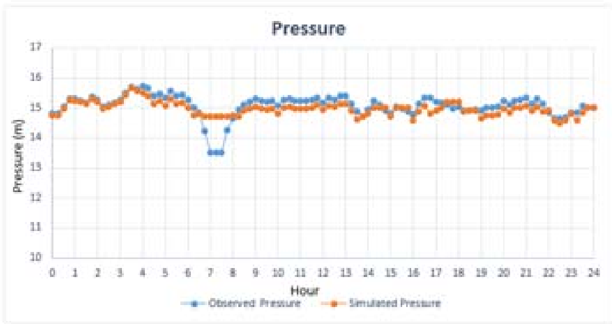


Figure 6: Simulated and observed value of pressure at pressure monitoring point 2 before calibration

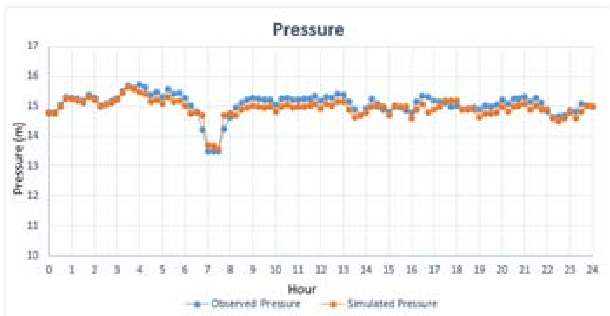
From the above observed and simulated values, pressure variation at the pressure monitoring point 2 is 25 m before calibration.

After the setup of PRV, the pressure at the monitoring point 2 is matching at the minimum night flow time but head loss of 2m/km is occurring at the peak time between 7 am to 8 am. Hence to calibrate the head loss, The K value of HPPE pips is decreased from 140 to 120. In the below image pipes with changed roughness are heighted in the pink colour.

Figure 7: Pipe roughed to calibrate head loss



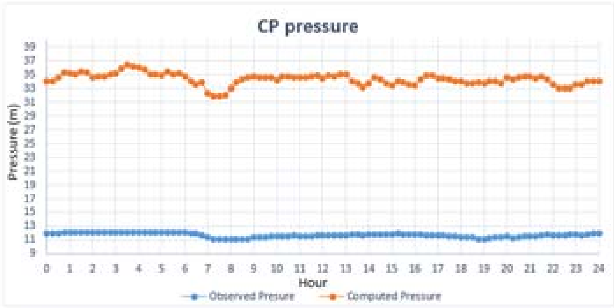
(a)



(b)

Figure 8: Simulated and observed value of pressure at monitoring point 2: (a) before changing the pipe roughness; (b) After changing the pipe roughness

From Fig. 8b, pressure at pressure monitoring point 2 during 24 hours, the average simulated value of pressure is 14.94m and the observed mean value is 15.07 m, with an absolute error of 0.86%



(a)

(b)

Figure 9: Simulated and observed value of pressure at CP: (a) Before Calibration; (b) After Calibration

From Fig. 9b, the average computed pressure at Critical point is 11.64 m and the mean observed value of pressure is 11.73m, with an absolute error of 0.76%. Hence from the fig. 5, 8, 9 it is concluded that model is calibrated and it is used for the further analysis.

Conclusion

The hydraulic model of DMA is established by EPANET, and can be used for further analysis like pressure optimization, growth studies, leakage modelling etc.

For the calibration of the model, the existing PRV pressure is set to 22m. From inlet flow meter data, the variation trends of water supply and water consumption of DMA are as per the diurnal pattern is considered. The leakage in the system is higher than the water consumption from 0:00 to 04:00 and the water consumption is greater from 07:00 to 08:00. Because of higher water consumption between 07:00 to 08:00 head losses of 2m/km occurring in the system. These head losses are calibrated by changing the K value of HPPE pipe from 140 to 120.

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