Calibration Guidelines for Water Distribution System Modeling

by
Engineering Computer Applications Committee

Hydraulic network simulation models are widely used by planners, water utility personnel, consultants, and others involved in the analysis, design, operation, and maintenance of closed-conduit hydraulic systems. Quite possibly the largest application of hydraulic network models lies with the municipal water supply industry. The results of network models have been used to assist in long-range master planning, short-term project design, fire flow studies, daily operations, emergency response, energy management, rehabilitation, troubleshooting, operator training, and water quality investigations. Clearly multi-million dollar decisions can be and have been based on the results provided by hydraulic network models. Consequently the results from the model must bear close resemblance to the actual performance of the hydraulic system. In other words, the computer model must be calibrated. The purpose of this paper is to present guidelines for network model calibration. The degree of accuracy needed for model calibration will be discussed within the context of the intended use of the model. For example, a higher degree of calibration is necessary for a model that is used to examine daily operations than is needed for a model used in long-range planning studies. The paper will also discuss calibration approaches and testing procedures that can be used to aid in the calibration effort.

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Introduction

A computer model of a water distribution system is a valuable tool which can assist engineers and planners in analyzing the hydraulic performance of water delivery systems. Computer models of water supply systems are constructed for a variety of uses including:

1) Identifying system deficiencies,
2) Analyzing the impacts of proposed development or long-term growth within the system,
3) Determining the ability of the system to deliver adequate fire flows,
4) Sizing pipes, selecting pumps, locating tanks,
5) Evaluating operating strategies,
6) Assessing pipeline rehabilitation methods,
7) Developing emergency response plans,
8) Training new operators,
9) Estimating the quality of water throughout the system.

A computer model of a water distribution system is a mathematical representation of a real physical system. Data describing the physical characteristics of the system as well as loading conditions and boundary information are supplied to a computer program that simulates the behavior of the real system. Physical data includes information such as pipe length, diameter and roughness, pump characteristics and minor loss coefficients. Loading conditions reflect demands that are placed on the system while boundary information describes reservoir and tank levels, valve settings and pump on/off status. The computer program uses this information to develop a set of equations which is then solved by the program. The solution to the set of equations provides information on pressures and flows throughout the system. Information on pressures and flows can then be used to aid in decision-making.

It is not unusual for the results provided by a computer simulation model to be used in capital projects involving several million dollars. As a result, it is imperative that the results provided by the model bear close resemblance to reality. If this is not the case, then the results provided by the model will be of limited value. Consequently, the model must be calibrated. Computer model calibration can best be defined as the process of adjusting data describing the mathematical model of the system until observed performance, typically pressures and flow rates, are in reasonable agreement with computer-predicted performance over a wide range of operating conditions.

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There have been a number of papers published on the subject of hydraulic network model calibration. These papers generally discuss errors that contribute to discrepancies between observed and computer predicted performance, provide detail on data collection and testing methods and provide some insight into what should be adjusted to achieve a suitable match. However a void exists in the United States network modeling community dealing with an acceptable accuracy of the calibration effort. In other words, when is the model calibrated well enough?

The purpose of this paper is to provide a little deeper background on the various sources of error that will produce differences between measured and computed system performance. Armed with a strong understanding of the errors inherent in a network model, we will briefly discuss the level of effort that can be involved in performing a comprehensive network calibration. Finally we propose some calibration guidelines and attempt to establish some criteria indicating a suitable level of calibration based upon the intended use of the model. The purpose of this paper *is not* to establish standards for model calibration. Rather members of the Engineering Computer Applications Committee hope that the proposed criteria presented here will foster meaningful discussion among the United States modeling community regarding the need and validity of calibration standards.

Sources of Error

Before discussing how accurately a computer model should be calibrated, it is valuable to closely examine why a computer model might not exactly match the field performance of a real hydraulic system. With a computer simulation model we are trying to reproduce the behavior of a real system that acts continuously over space and time. We do so by supplying data that depicts the physical characteristics of the system and by providing information that, to some degree, represents the continuous loads (system demands) placed on the system. Calibrating a hydraulic network model involves more than just adjusting pipe roughness values and nodal demands. True model calibration is achieved by adjusting whatever should be adjusted within the model until a reasonable agreement between model-predicted behavior and actual field behavior is obtained.

Errors in Input Data

In computer modeling, *any* data that is supplied to the model is a candidate for adjustment. There are two sources of error that can be directly associated with input data: 1) typographical errors and 2) measurement errors. Generally speaking, typographical errors are more easily corrected than measurement errors assuming, of course, that they can be identified. An example of a typographical error would be typing in a value of 2250 ft for a 250 ft pipe segment. A measurement error, on the other hand, might occur because of the limited precision of measuring devices combined with the scale used on system maps. For instance, all else being equal a length measurement on a map having a scale of 1”=50’ would have more precision than a length measured from a map having a scale of 1”= 2000’.

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A critical piece of information required of all computer simulation models is the diameter of system pipes. Many times modelers ask the question “Which pipe diameter should be used – the actual diameter or the nominal diameter?” Nominal diameters have values like 6”, 8”, 12”, etc. The actual pipe diameter must be measured in the field. For older pipes such as unlined cast iron it is likely that the actual internal diameter will vary along the length of pipe.

Consider the pipe shown in Figure 1. Notice the build-up, called turburculation, on the interior pipe walls. The actual diameter of this pipe might be closer to 5 ½” or 5 ¼” instead of 6”. Because the build-up on the pipe walls is totally random and irregular, it is highly doubtful that the actual diameter, regardless of what it is, will remain the same throughout the pipe length. Generally speaking it is usually best to use the nominal diameter in a computer model and adjust pipe roughness values to achieve calibration.

Unknown Internal Pipe Roughness Values

In the paragraph above it was stated that it is usually best to supply the nominal pipe diameter and adjust pipe roughness values until a suitable match is obtained. But what roughness values should be used? There are a number of tables in various texts that provide estimates of pipe roughness, usually Hazen-Williams C-Factors, as a function of pipe material, size and age. However pipe roughness is also a function of water quality [1]. In other words, there is no guarantee that the internal roughness of a 12” 40-year old unlined cast iron pipe in New York City will be the same as the internal roughness of a 12” 40-year old unlined cast iron pipe in Seattle.

Simulation models require a value for pipe roughness for each individual pipe segment. This can result in quite a bit of information if one considers that it is not unusual for a model of a moderately sized system to contain 500-1,000 pipes with larger systems incorporating 2,000 or more pipelines. Certainly observed pressures can point the modeler in the correct direction with regard to pipe roughness values. Nonetheless compensating errors could cause incorrect pipe roughness values to be used.

Consider the simple parallel pipe system shown in Figure 2. Suppose that pressure measurements have been taken at the node on each end of the pipe segment and the flow through the system is known. The unknowns are the internal pipe roughness values for each pipe. Table 1 shows the results of a simple analysis performed on this system. Column 1 represents an assumed internal roughness for Pipe #1. Column 2 is the resulting flow due to the measured head loss, the pipe characteristics and the assumed roughness. Column 3 is the flow in Pipe #2 assuming a total system flow of 1,350 Gpm. Finally column 4 represents the pipe roughness in Pipe 2 that is due to the head loss, the pipe characteristics and the pipe flow.

Clearly there are multiple values of pipe roughness in pipes 1 and 2 that produce the same head loss across the system. So the real question becomes which is the correct set of pipe roughness values? The only way this question can be answered is to measure the flow in one of the pipes. With the flow known the correct roughness values can be established. Frequently in the United States actual pipeline flows throughout the system are not

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