CHAPTER 15

OPERATION OF WATER DISTRIBUTION SYSTEMS

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15.1 INTRODUCTION

A water distribution system, like any large complex system, must be operated properly so that it performs at an acceptable level of service. Many water utilities use human operators whose primary function is to monitor the pulse of the water distribution system and provide system control when needed. When the characteristics of the water supply system begin to change—for example, when tank levels increase or pressures fall—the operator initiates an action to ensure that the system operates within reasonable bounds. For example, when tank water levels fall in a particular part of the system, the operator may place a pump into service. When pressures within another part of the system get too high, the operator may turn off a pump that serves the area. For complex systems, operators may even operate valves and regulators within the system so that pressures, flows, and tank levels are kept within acceptable limits.

This chapter details the general nature of water distribution system operations for water utilities across the United States. Of course, each water supply system will have its own unique characteristics that require special consideration from an operational perspective. The role of operations with regard to water quality and emergency response are detailed as well. Most water utilities now use some form of Supervisory Control and Data Acquisition (SCADA) systems in their daily operations. This chapter presents the nuts and bolts of SCADA. The use of SCADA systems in monitoring and controlling a system's behavior also is discussed.

The chapter does not discuss the role of maintenance in distribution system operations. Although preventive and emergency maintenance certainly is crucial to proper operation of any water distribution system. The chapter also does not discuss operations in water treatment plants that actually could require an entire chapter by itself. Instead, this chapter focuses on the actions that take place to ensure that sufficient volumes of water are delivered throughout the distribution system at an acceptable level of service.
As more and more water utilities become comfortable with technology and the use of technology in their daily operations, more and more water utilities may investigate the possibility of unattended operations. Unattended operations are discussed in this chapter, as are the advantages and disadvantages associated with automatic control. New technology also offers the ability to manage energy consumption and reduce the cost of operating the system. In this chapter, the role of optimal control models within the framework of system operations is presented.

Most simulation models capable of predicting the hydraulic, energy consumption, or water-quality characteristics of a distribution system require information about the system itself. Such information typically includes boundary conditions, such as tank levels, pump on/off status, and valve settings. Much of this information can be obtained from a SCADA system. In fact, there has been a significant amount of activity linking SCADA systems with analysis and control models. This chapter also discusses the fundamentals of linking analysis and control models with SCADA systems to assist with and improve operations.

There is a movement within the water works industry away from housing pockets of fragmented data used only by a single department toward using a centralized database shared by all departments within the utility. This so-called data centric approach has the distinct advantage of ensuring that the most up-to-date information is used for a particular application. The use of a centralized database in water distribution operations will be discussed in this chapter. Finally, future trends in water system operations will be presented.

### 15.2 HOW SYSTEMS ARE OPERATED

Conceptually speaking, operating a water distribution system is not that difficult. All one needs to do is keep an eye on measurements of system performance whether the measurements are in the form of pressure, flow, or tank water levels. If a system operator notices that a quantity, such as pressure, is not within acceptable limits, appropriate action is taken to remedy the situation.

However, consider that the system may have four or five pressure zones and that each pressure zone may have multiple storage tanks or multiple pumping stations. Also consider that the zones may be hydraulically connected so that actions taken in one pressure zone may have an effect on other zones. Finally, consider that water system operations are inherently time-dependent and one may quickly agree that although the operations of a water distribution system appear to be simple, they can require a great deal of skill, especially if a system is large and complex.

Water distribution systems can be operated either manually or automatically. Many small systems in the United States have been operated automatically for years. Typically, operations are based on tank water levels. For example, a liquid-level switch senses the water level in a water storage tank. Field instrumentation sends a signal to a controller that will either turn a pump on or off, depending on the water level in the tank. Larger systems, because of their higher degree of complexity, normally have human operators whose primary function is to monitor the pulse of the system and initiate actions based on system behavior. The criteria that the operator uses to indicate whether the system is operating properly largely depends on what is measured throughout the system. Put another way, for many systems in the United States, the quantities that factor directly into operator decision-making will be measured.

#### 15.2.1 Typical Operating Indexes

Water distribution systems are usually operated on the basis of pressure, flow rate, tank water levels, or combinations of the above. For an operator to know if he or she is
operating the system in an acceptable manner, the parameters or indexes that form the basis of operations need to be measured. Accordingly, in many systems, instruments and equipment are used to measure, record, and store systemwide pressures, flows, and tank water levels. Other quantities, such as pump vibration or motor temperature, also can be measured, but they typically do not factor directly into system operations as it relates to an acceptable level of service.

In the United States, flow measurements are generally taken at only a few selected locations, including water treatment plants, pump stations, and boundaries with other systems. Some systems do not even record plant and pump-station discharges. Like flow, pressures also are recorded at a few key locations, usually at pump stations. In addition, pressures may be recorded at the highest and lowest elevations within the system or at sites within a pressure zone to determine the lowest and highest pressures in the system. Almost all water systems in the United States record tank water levels.

Many European systems, on the other hand, take pressure and flow rate measurements throughout the entire system. In Paris, for example, pressures and flows are measured at more than 30 locations, (Gagnon and Bowen, 1996). Not only can comprehensive systemwide measurements assist in system operations, but these data can be used to help calibrate computer models of hydraulics and water quality in a distribution system.

### 15.2.2 Operating Criteria

For systems whose operations are based on pressure, operators typically operate pumps and possibly valves so that systemwide pressures are maintained within acceptable limits. Although what is considered to be acceptable may vary from system to system, pressures in most cases should be kept above 207 kPa (30 psi) and below 689 kPa (100 psi) during normal operations. Pressures much greater than 689 kPa (100 psi) tend to waste water through leaks and could damage residential and commercial plumbing systems or possibly cause main breaks. A pressure of 207 kPa (30 psi) allows water to be supplied to the top floors of a multistory building.

During emergency conditions, such as a fire, pressures should be maintained above 138 kPa (20 psi) throughout the entire system. The 138 kPa minimum for fire flows is a generally accepted rule of thumb and provides enough pressure to supply the suction side of pumps on a fire pumper truck. More important, pressures of 138 kPa can help prevent contamination of the potable supply from cross-connections. During main breaks, when the pressure can drop below 138 kPa, it is not uncommon for the water utility to issue a “boil water” advisory because of the possibility of system contamination from cross-connections. In an effort to protect public health, many states and communities have adopted minimum pressure requirements.

Depending on the nature of the water supply system, minimum pressures greater than 207 kPa (30 psi) may have to be maintained at certain locations within the system. For example, certain industries or hospitals may require a minimum pressure above 207 kPa so that equipment within the facility will function properly. If the water system sells bulk amounts of water to an adjacent community, that community may require the water to be supplied at a minimum pressure of 345 kPa (50 psi) or higher. Operators must consider such unique circumstances in their operating decisions.

Flow also can be used as a parameter to control a water distribution system. Many systems measure flow at pumping stations and at interconnections with other systems. What constitutes an acceptable range of flows generally is be dictated by the nature of the water distribution system. For example, if the purpose of the system is to sell bulk amounts of water to neighboring communities, operators need to ensure that sufficient
volumes of water are delivered to the system's customers. In addition, the water may have to be delivered at or higher than a specified pressure.

Flow and pressure are directly related to one another. When the flows in a pipeline increase, the pressure at the end of the line will decrease. Therefore, although some operators may operate the system according to pressure, one also can think of those operators as operating the system according to flow. In other words, when the pressure in part of the system falls below acceptable limits, it does so because the usage in that part of the system is most likely to be high. Consequently, flows and pressures into that part of the system must be increased by placing a pump into service. Operators also can control valves to direct water to areas where it is needed, but this usually is not done in municipal water distribution systems.

Among the more important parameters that an operator monitors is perhaps the water level in system tanks. Tank levels can provide an indication of the overall pressure throughout a pressure zone or even the entire system. Generally speaking, the higher the tank level, the higher the system pressure. In fact, operations in many systems are based solely on tank levels. For example, over time an operator may have developed an intrinsic feel for systemwide pressures as a function of the level in one or more storage facilities.

Operators must ensure that sufficient volumes of water are stored in tanks at all times in the event of an emergency, such as a fire, power failure, or source outage. In fact, common operating practice in the recent past (and possibly even today in some systems) was to keep storage tanks as full as possible at all times. However, for the most part, operators now recognize the relationship between storage tank water levels and the water quality in the tank. As a result, they usually try to provide some change in tank levels over the course of a day.

15.2.3 Water Quality and Operations

Within the past decade, there has been a much greater awareness of water quality within water distribution systems. This increased awareness has been driven in part by new federal regulations mandating that water-quality standards must be met at the customer's tap. Although hydraulic performance remains the primary basis by which operators make their decisions, more and more attention is being paid to water-quality behavior in the distribution system.

Operations provide a great opportunity to affect water quality in existing distribution systems. For example, through their actions, operators can directly influence tank water levels and pumping operations. Through these actions, they may be able to bring fresh water from a treatment plant and direct it toward a certain part of the service area. Operators in the United States generally do not operate valves within the system to direct water to specific parts of the system. However, in the future such an approach may offer more control than traditional means of operating water distribution systems.

In the near future, more water supply systems may consider using in-line booster disinfection stations or possibly even mini in-line treatment plants in an effort to improve overall water quality in the system. Because these elements are located within the distribution system, their operation will become the system operator’s domain. Chemical feed rates would be monitored and controlled by the operator to maximize water quality.

15.2.4 Emergency Operations

Possibly, the real reason that human operators are used in larger systems is to respond to such emergencies as fires, main breaks, source contamination, source outage, or power
failures. Operators must be able to respond to any emergency that arises and ensure that system performance remains at an acceptable level of service.

During fires, operators may place more pumps into service to deliver higher rates of flow out into the system. During a power failure one of the operator's tasks may be to place a diesel or natural gas generator into service so that pumps can continue to operate. For many systems, however, backup generators automatically enter into service when a power failure occurs. During contamination of a source, the operator may have to close valves to isolate part of the system. Needless to say, emergency operations are an extremely important component of the operator's duties.

15.3 MONITORING OF SYSTEM PERFORMANCE WITH SCADA SYSTEMS

As discussed above, water utilities typically use human operators to monitor the pulse of the water distribution system. To do their job, operators need information about tank levels, pressures, flows, and so forth. For most utilities, SCADA systems—also called telemetry—provide this information. A SCADA system is a collection of field instrumentation, communications systems, and hardware and software systems that permit a system's behavior to be monitored and controlled, typically from a remote site (ASCE, 1991). The following example provides a quick summary of the functionality of a SCADA system.

Suppose that we have been asked to operate a water supply network that utilizes a SCADA system to provide monitoring and control. We have a computer screen in front of us that we use to view the status of the distribution system and its components. For example, we can cause the SCADA system to display current water levels in each elevated or ground-storage tank. Because some systems use touch screens, we might even be able to touch a tank on the screen and the SCADA system would draw a chart showing the water levels in the tank for the past 24 h.

Suppose that during our shift, we notice that the water level in a particular tank falls below half full. We know from experience that whenever water levels in this particular tank fall below half full, pressures in some parts of the pressure zone served by the tank are unacceptably low. So from our control panel, we place a booster station into service by pressing the "On" button for this pump station. In short order, we can see that the tank water level has begun to rise and, as a result, the pressures in the pressure zone are kept within acceptable levels.

Of course, the use of SCADA systems is not limited to the distribution system, nor is it limited to the water works industry. Some water utilities have SCADA systems that provide process monitoring and control for both the water treatment facilities and the water distribution system. In fact, SCADA systems are used wherever there is a need to monitor or control a process. This spans many other industries, including other utilities. The common theme is to monitor the behavior of a process or a system and to feed that information back to a central location where decisions can be made and actions can be taken.

Much of the boundary information for a water distribution system hydraulic model can be obtained from a SCADA system. Such information might include tank water levels, pump on/off status, pump speed, and valve status. If a utility wishes to conduct realtime simulations, in support of an emergency response, for example, then up-to-date boundary information can be obtained from the SCADA system quickly and easily. Another valuable use of the information provided by a SCADA system is model calibration. Since many SCADA systems archive data for some period of time, historical information can be obtained.
15.3.1 Anatomy of a SCADA System

As mentioned above, a SCADA system typically consists of field instrumentation, communications, and hardware and software systems that allow remote monitoring and control. Figure 15.1 presents a general schematic of the individual elements found in a typical SCADA system used in water distribution. The purpose of the field instrumentation is to collect information on the state of the hydraulic system. Such instrumentation may include programmable logic controllers (PLCs), remote terminal units (RTUs), liquid-level switches, or other instruments (AWWA, 1983). These devices are capable of measuring and recording system indexes, such as pressure, flows, or tank water levels. In some cases, these devices are capable of providing localized control in the event of a communications failure.

In the past, RTUs generally were used to collect field data and to send these data to a central computer. The on-site control capabilities of RTUs were limited. PLCs, on the other hand, typically were used to provide some type of localized control, but they had limited data collection and storage features. Today, because the capabilities of RTUs and PLCs are merging, they provide similar functionality. Current RTUs can be programmed to provide some localized control, whereas current PLCs can store data and exchange this information with a central computer. An example of an RTU is shown in Fig. 15.2.

Regardless of whether control is maintained at the local level or from a central location, or no matter whether data are transmitted to a master computer or kept at a local site, quantities must be measured in the field. Quantities that typically are measured in water distribution systems include pressure, flow, and tank water levels. Therefore, some type of measuring device such as a pressure transducer, a flow transducer or a liquid-level

![FIGURE 15.1 Elements of a SCADA system.](image-url)
sensor must be installed. Figure 15.3 shows an example of a pressure transducer, and Fig. 15.4 shows an example of a device that collects flow data. Flow data also can be collected using Venturi tubes connected to pressure transducers.

The next link in a SCADA system is transmitting information collected by the field units to a central location. Communications can be accomplished using telephone lines, fiber optics, microwave, radio, or satellite. Each type of communication has features that make it suitable for a particular application. For example, microwaves may be more

FIGURE 15.4 Example of flow measuring device (Courtesy of ATSI, Inc.).
FIGURE 15.5  Schematic of a SCADA system using radio-based communications. (Courtesy ATSI, Inc.)

reliable than telephone lines. However, microwaves may not be suitable for systems having significant elevation differences since the transmitter, receiver, and relay stations must be in visual contact with one another. Figure 15.5 shows some of the components of a radio-based SCADA system.

Information that is transmitted by the communications system is generally sent to a central location where the operations staff reside. For digital SCADA systems, the information is collected by a receiver and is delivered directly to a computer system. For analog systems, the data must somehow be provided to the computer system. Software on the computer system provides the man-machine interface (MMI), which enables operators to monitor the system visually, typically from a central console. The MMI also provides functionality to allow system operators to control field units. In systems using analog monitoring and control, the information received from the field usually is delivered to circular charts or strip charts.

Because the SCADA system is such a vital component of the overall operations of a water distribution system, reliability is extremely important. Many water utilities recognize this and use redundant systems. Frequently, two computer systems are used: One functions as the primary SCADA computer and the other supports some monitoring and control features. If the primary computer fails for whatever reason, the secondary computer takes its place.

The water works industry is certainly moving toward digital monitoring and control; in fact, a large number of utilities control their systems using digital SCADA systems with personal computers. The information is often displayed in a graphical format that makes it easier for operators to visualize what is going on throughout their system.
An equally important component to the monitoring portion of the SCADA system is the ability to control field elements from a central location. If a pump needs to be placed into service or a valve must be closed, the operator initiates the action at a central location sending a signal through the communications link back to the remote site. Field units receive and interpret the signal and implement the requested action.

Another common feature of SCADA systems involves alarm recording. Many elements in the system may fail, but the failure may not be catastrophic. For example, when a storage tank overflows, the system continues to operate. Of course, an overflowing storage tank is undesirable; therefore, the SCADA system sounds an alarm indicating a problem with the tank. An operator can then take corrective action. Some SCADA systems even have the ability to telephone specified individuals, such as the director of operations, and notify them of an alarm condition.

15.3.2 Data Archiving

Many of today's SCADA systems offer data retrieval features that allow historical information describing the performance of the system to be displayed. For example, data describing tank levels, pump status, and system pressures during a main break that occurred several weeks ago might be able to be displayed on the console with the push of a button. Storing historical SCADA information can require a tremendous amount of data storage. Consider a large system that may have as many as 100 individual elements that must be monitored. Now consider that data on each element may be delivered to the central location every 30 s. One can see that a large amount of information can be generated even for a single day.

Data archiving can be a valuable asset when training operators, or hindcasting and possibly for litigation. For instance, the actual response of the operations staff can be cataloged and retrieved at a later date to determine whether the appropriate course of action was taken. Similarly, information about the behavior of the system in response to a particular emergency can be used to train new operators. Finally, data on system performance can be used to calibrate mathematical models that simulate system performance.

15.4 CONTROL OF WATER DISTRIBUTION SYSTEM

Several items in a water distribution system can be controlled by an operator, but by far the most common elements are system pumps. Pumps can be placed on-line or be taken out of service at high-service pump stations or smaller booster stations. High-service pump stations generally deliver water from water treatment plants, or possibly from ground reservoirs, out into the distribution system. They act as a point of entry for water into the distribution system. Booster pumps, on the other hand, are usually in-line pumps whose function is to boost pressures or flows to a particular location in the system. A common application of booster pumps is at the interface between two pressure zones.

Another common element that is controlled are valves—usually those on the discharge side of pumps. Although pumps are commonly started against closed valves, some units are started with the discharge valves open. Check valves usually are used in these cases to prevent backflow through the pumps. Pump discharge valves must be opened slowly to prevent line surges or waterhammer from occurring. Operators also can operate valves to control the flow into or out of storage facilities.
15.4.1 Control Strategies

Several methods of controlling water distribution systems are available, each representing an increasing level of automation. The American Water Works Association Research Foundation (AWWARF) recently supported a study for water treatment facilities that identified three levels of control (Younkin and Huntley, 1996). The three levels of control also can be adapted to water distribution systems, as described in the following sections.

15.4.1.1 Supervisory control. Many water utilities in the United States are operated today by supervisory control. A human operator monitors the behavior of the water distribution system 24 h a day, 7 days a week to make certain the system is operating properly. The operator makes decisions based on his or her knowledge and experience—sometimes gained over a long period. These decisions are then implemented manually by adjusting controls or pressing buttons.

15.4.1.2 Automatic control. This type of control represents the case where instrumentation and control equipment are used to control the distribution system automatically. Such control can be implemented either locally at the facility or throughout the system. Typically, simple operating rules are used to determine which component is operated and how it is operated. An example of automatic control described earlier is the use of liquid-level switches in tanks to control a pump’s on/off status.

Coincident with automatic control is the idea of unattended operations. As the name implies, unattended operations have no human operator on duty. Smaller systems have used unattended operations for some time. In these cases, the on/off status of a pump usually is controlled by the water level in a storage tank. Because of their relatively simple nature, unattended operations seemed to be the natural way to operate small systems.

Automatic control is not limited to unattended operations. Human operators may be on duty 24 h a day, 7 days a week even though the system is operating automatically. In these cases, automatic control generally describes the use of computers and control logic to run the system while human operators remain on standby.

15.4.1.3 Advanced control. Systems that rely on advanced control use optimization algorithms, decision support systems, artificial intelligence, or control logic to control the distribution system. Usually, the methodologies used to develop control logic are much more complex and sophisticated than are those used in automatic control. Chapter 16 discusses the fundamentals of control models that can be used in operations. The use of advanced control and automatic control can be combined with one another, with the advanced-control algorithms supplying operating rules and the automatic-control features implementing the rules.

Given the capabilities of today’s computer and control technology, a number of water utilities are investigating the possibility of completely automated and advanced control. Although process-monitoring and control technology has become increasingly reliable over the past several years, the primary driving force behind more sophisticated operations is cost reduction.

Personnel costs are the single largest item in the budgets of most water utilities. In fact, it may cost as much as $400,000 annually to staff even a small facility, (Younkin and Huntley, 1996). The next highest budget item after personnel costs are pumping costs. Automatic control can reduce staff requirements, thus reducing costs associated with personnel. Advanced control can reduce operating costs even further through the use of optimized pumping or operating schemes.

A disadvantage associated with automatic control is the perceived lack of control. Water utility operators in the United States seem to be extremely cautious. For the most
part, they seem unwilling to allow a computer to operate their system. In some measure, this reluctance has hindered the development and subsequent use of advanced control. However, the AWWARF recently funded a study to establish a set of standards for software that will be capable of enabling advanced control.

### 15.4.2 Centralized Versus Local Control

Water distribution systems can be operated in one of two modes: from a central location or locally with control originating at the facility. Many systems implement a combination of the two methods in which centralized control is in place most of the time. Under emergency conditions such as a power or communications failure, localized control governs the system. Centralized control can be automated, although for many water distribution systems in the United States, humans oversee control of the systems.

In the case of *centralized control*, all decisions are made at a single location. Of course, all system parameters must be delivered to the central location to aid in decision making. Centralized control is straightforward because all control decisions usually are made by human operators. Alternatively, system elements may automatically be placed into or taken out of service according to predefined operating rules.

In the case of *localized control*, all control at a facility, such as a pump station or storage tank, takes place at the facility. Typically, control logic is built into the controllers so that appropriate action occurs. For example, suppose that the pressure at a booster pump station falls below a prescribed value. Furthermore, suppose that all pumps at the station are off. Controller logic at the station might cause the largest pump to be placed into service. If pressures at the pumping station continue to be unacceptable, the next largest pump can be placed into service and so on until pressures are within acceptable limits. Control logic can be specified to address such operational and maintenance constraints as pumps that are unavailable for service or pumps that have recently completed a cycle of operation.

### 15.5 LINKING OF SCADA SYSTEMS WITH ANALYSIS AND CONTROL MODELS

A recent development in the waterworks industry that will certainly see greater usage in the near future is the linkage of SCADA systems with other analysis and control models or decision support systems. Analysis and control models, such as hydraulic network, optimal control, and water-quality models, can be used by operations staff in a variety of ways, including operator training, emergency response, energy management, and water-quality behavior. (Chapter 16 describes control models in greater detail and discusses how they can be used in operations.)

- Operator Training
- Emergency Response
- Energy Management
- Water Quality Behavior

Hydraulic network, optimal control, and water-quality models require information on the current state of the system, usually in the form of boundary conditions and system loadings. Boundary information, such as tank levels, pump status, and valve settings, can be obtained directly from the SCADA system. Loading conditions describe the demands
placed on the system. Although this information may not be available directly from the
SCADA system, information provided by SCADA can be used to estimate system loads.

15.5.1 Data Requirements of Analysis and Control Models

The particular data needs of the analysis and control models will, of course, depend on
what the model ultimately computes. In the case of hydraulic network models, distribution
of pressure and flow throughout the hydraulic network is determined. This includes flows
into and out of storage tanks and the operating characteristics of system pumps and valves.
Many hydraulic models are capable of performing time simulations indicating that the
performance of the system over a specified time horizon, such as 24 h.

Optimal control models can be used to indicate what pumps should be run and when
they should be operated so that energy use and operating costs can be minimized. It is
important to note that even though energy costs are reduced, the system must be operated
at an acceptable level of service. An optimal control model should consider acceptable
operating characteristics in its problem formulation.

Water-quality models can predict the concentrations of specified water-quality
constituents throughout the distribution system. For example, these models can be used to
determine the concentration of chlorine at various locations in the system. Other water-
quality parameters of interest that these models can determine include the age and amount
of water delivered from individual storage tanks and treatment plants. A hydraulic
network model can supply much of the information needed by optimal control or water-
quality models. In fact, many control and quality models are integrated with hydraulic
network models.

A decision support system used by system operators can include a number of
components, including hydraulic network models and optimal control models.
Alternatively, a decision support system may consist only of general operating rules
developed over many years of operating the distribution system. The difficulty with using
general operating rules is that new pump station or tank construction could make the
operating rules obsolete.

Information that can be supplied by a SCADA system and used directly in a hydraulic
network model include tank and reservoir levels, pump on/off status, pump speed, valve
status, and valve setting. Estimates of total system use also can be extracted from a
SCADA system using a mass balance approach. If the SCADA system monitors high-
service pump station flows and tank water levels, the total usage of system water can be
determined from the expression below. Notice that this expression considers that multiple
pumps can deliver flow into multiple storage tanks.

\[
Q_{sys} = \Sigma Q(j)_{pump} + \Sigma \left( \text{Level} (k)_{t+\Delta t} - \text{Level} (k)_{t} \right) \ast \text{Area} (k) / \Delta t
\]  

(15.1)

where \( Q_{sys} \) = average system over time step \( \Delta t \), \( Q(j)_{pump} \) = average discharge of pump \( j \)
over time step \( \Delta t \), \( \text{level}(k)_{t+\Delta t} \) = water level in tank \( k \) at time step \( t + \Delta t \), \( \text{level}(k)_{t} \) = water
level in tank \( k \) at time step \( t \), and \( \text{area}(k) \) = average area of tank \( k \) over time step \( \Delta t \).

As mentioned above, most available hydraulic network models can perform a time
simulation that represents the temporal nature of the distribution system. When
performing a time simulation, system demands at various times of the simulation must be
supplied. For example, estimates of system demand may need to be supplied every hour
during a 24 h simulation. A combination of the mass balance approach and a curve-fitting
procedure can provide these estimates.
If one were to plot system demands over the course of a day, one would find that they are generally smooth and continuous. In other words, there would be no "kinks" in the plot of system demand. At any hour, estimates of system demand could be computed using a mass balance approach, as described above, once pump-flow and tank-level data have become available.

Assuming that demands are indeed smooth and continuous, a curve could be fitted through demand estimates of the past 3 or 4 h. This curve can then be used to extrapolate demands for the next time step. Figure 15.6 graphically shows this approach. Of course, as soon as estimates of actual system demands are available, they should be used to update the curve.

An alternate approach is to use an areawide demand adjustment (Schulte and Malm, 1993). Assuming that meters are placed on key mains within the distribution system and that this information is supplied to the SCADA system, a simple mass balance can be performed. Figure 15.7 illustrates the concept. The measured outflow in pipe P3 is subtracted from the measured inflows through pipes P1 and P2. The flow difference represents the usage in the area, which could be an entire pressure zone.

Another approach would be to use so-called "smart meters" at interconnections with other systems or at points of high water use. Telemetry located in the meter pit would transmit data on real-time water use back to a central location; the information also could be recorded on-site for later retrieval.

15.5.2 Establishment of the Link

Clearly, data that can be used by analysis and control models resides on the SCADA system. The question therefore is, how can data from the SCADA system be transferred
to the analysis and control models? Similarly, how can results from the analysis and control models be sent back to the SCADA system? This latter step is necessary for comparison purposes or for implementation of automatic control.

Most if not all SCADA systems use databases to store information. A database is nothing more than a collection of information that may or may not be related. Possibly, the most common means of exchanging data stored in a database with other applications is to use the Open Database Connectivity (ODBC) interface. Roughly, ODBC consists of a set of software drivers that allow a computer program to exchange data with ORACLE, Microsoft Access, dBASE, Microsoft Excel, Microsoft FoxPro, Borland Paradox, or other software that uses the ODBC interface. Data are not actually exchanged between programs. Instead, programs that use the ODBC interface are capable of accessing the same database generated by the SCADA system.

Applications can manipulate the databases using Structured Query Language (SQL), a set of statements and commands supported by various programming languages, such as Visual Basic, C/C++, and others. A program can be written using SQL to perform a variety of functions on the data stored in the database.

For example, a database containing information on the behavior of the distribution system can be generated by a SCADA system. A hydraulic network model can access the database using ODBC. Using SQL statements built into the hydraulic network model the database can be manipulated to find the date representing maximum water use: that is, the maximum daily condition of the water distribution system. Again, using SQL, the hydraulic network model can extract the boundary conditions on the given date. The network model can then be executed to determine systemwide pressures and flows. This information can in turn be used to train operations staff about the expected behavior of the system during periods of high demand.

An alternate means of transferring data between a SCADA system and other applications is through the use files. Files adhering to a standard format are shared between the SCADA system and other software. Such an approach can be rigid and inflexible, especially if the SCADA system does not allow files to be generated in a user-specified format. A unique format usually is necessary for each piece of software that needs to supply data to the system measuring performance. In addition, if upgrades to new software are made, it is possible that a new format between programs will have to be established.
Within the past decade, there has been a movement within the waterworks industry away from a fragmented data-management structure toward a data-centric approach in which all data are housed in a central database or data repository. The advantage of housing all data in a central database is obvious. Different software applications that use similar data can share the information. For example, both a hydraulic network model and a pipeline inventory program might require information about the size and length of water mains in the system. Similarly, both a SCADA system and a hydraulic model may use information describing tank water levels.

Housing information in a central location can ensure that the most recent data describing the water supply system are available to all users who may need it. Consider a design engineer making changes to as-built drawings that reflect modifications made to the distribution system as part of constructing a large industrial park. Because the as-built drawings depict what is in the ground, this information is extremely valuable to the modeling engineer in the planning department. Unless the modeling engineer is aware of the new pipe that was placed in the ground, there is no guarantee that the most recent network topology will be used in the hydraulic model.

A data-centric approach typically involves a client-server computer arrangement, as illustrated in Fig. 15.8. A single computer called a server houses all databases and also may contain the applications that use the data. Other computers called clients or host computers access the data from the server. Thus, multiple users may be able to access and modify the same database at the same time.
15.7 WHAT THE FUTURE HOLDS

The future of operations in water distribution offers exciting potential, in large measure as a result of the rapid growth of monitoring and control technology as well as the use of advanced control in operations. The following paragraphs describe some of the developments the water distribution system operators may see in the not-to-distant future.

Several water utilities in the United States are using hydraulic network models in their operations, but few systems are actually allowing system operators to use the models. In the future, more and more distribution system operators will use hydraulic network models to assist them in their daily operations and in responding to emergencies. The key to more widespread use of simulation models by system operators is the availability of an easy-to-use graphical interface where operators can specify the “what-if” conditions. More and more systems will link analysis and control models with SCADA systems to permit real-time simulation and control of distribution systems. This linkage can address the need for a graphical interface described above. Much of the data exchange between the SCADA system and the analysis and control models can be transparent to the system operator.

More and more utilities will investigate the benefits associated with optimal control. The increased interest will be driven in part by deregulation of the electrical industry. These control models will allow the development of efficient operating strategies that can reduce energy consumption and associated operating costs. Improvements in control technology will make it easier to implement automatic control, thereby increasing the numbers of unattended operations.

REFERENCES


