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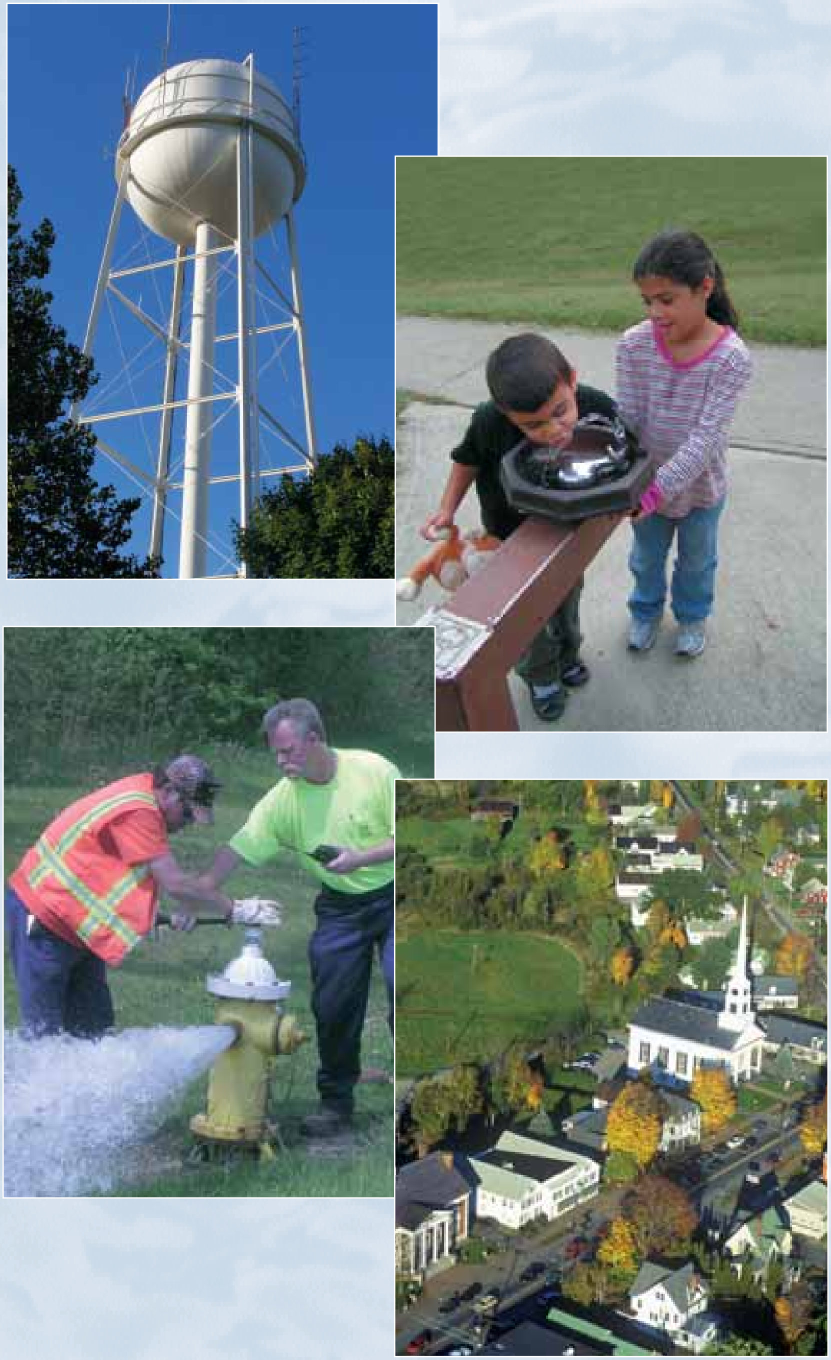
Water Quality in Small Community Distribution Systems

A Reference Guide for Operators



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Water Quality in Small Community Distribution Systems

A Reference Guide for Operators

U.S. Environmental Protection Agency

Office of Research and Development
National Risk Management Research Laboratory
Water Supply and Water Resources Division
Cincinnati, Ohio

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Notice

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Disclaimer

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Foreword

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Sally Gutierrez, Director
National Risk Management Research Laboratory

Abstract

The U.S. Environmental Protection Agency (EPA) has developed this reference guide to assist the operators and managers of small- and medium-sized public water systems. This compilation provides a comprehensive picture of the impact of the water distribution system network on distributed water quality. This reference guide provides information on the following topics:

- Water supply and distribution process overview
- Distribution system infrastructure
- Drinking water regulations
- Distribution system water quality issues
- Distribution system monitoring, control and security
- Operational, financial and management strategies to address distribution system water quality

In addition, to make this document appeal to a diverse group of small system operators and managers, graphical elements such as pictures, tables, blue sidebars, and cartoon illustrations have been used throughout the document. Although every water distribution system is different (in terms of specific layout and operations), all water distribution systems generally have the same components and operate under similar principles and operational strategies. To illustrate solutions to some of the common issues faced by the small community distribution system operators, an example of a small water distribution network (SmallWater, USA) has been included in this document. At the end of many chapters, one or more SmallWater problem scenario(s) are presented along with some guidance on resolving these problems.

Other related EPA reference guides in this area include the following:

- Small Drinking Water Systems: State of the Industry and Treatment Technologies to Meet the Safe Drinking Water Act Requirements. EPA Publication Number: 600-R-07-110
- Water Distribution System Analysis: Field Studies, Modeling and Management – A Reference Guide for Utilities. EPA Publication Number: 600-R-06-028
- Small Drinking Water Systems Handbook: Guide to “Packaged” Filtration and Disinfection Technologies with Remote Monitoring and Control Tools. EPA Publication Number: 600-C-03-041

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Acronyms and Abbreviations

AM	Asset Management
AMR	Automatic Meter Reading
ANSI	American National Standards Institute
AOC	Assimilable Organic Carbon
ARC	Appalachian Regional Commission
ASTM	American Society for Testing Materials
AWWA	American Water Works Association
AwwaRF	American Water Works Association Research Foundation
BAT	Best Available Treatment
BDOC	Biodegradable Organic Carbon
CaCO3	Calcium Carbonate
CADD	Computer-Aided Design and Drafting
CCR	Consumer Confidence Report
CDBG	Community Development Block Grant
CWA	Clean Water Act
CWS	Community Water System
DBP	Disinfection Byproduct
D/DBPR	Disinfectants/Disinfection Byproducts Rule
DWSRF	Drinking Water State Revolving Fund
EDA	Economic Development Administration
EPS	Extended Period Simulation
ERP	Emergency Response Plan
EPA	United States Environmental Protection Agency
FBRR	Filter Backwash Recycling Rule
fps	Feet per Second
GIS	Geographic Information System
gpm	Gallons Per Minute
GPS	Global Positioning System
GWR	Ground Water Rule
GWUDI	Ground Water Under Direct Influence (of Surface Water)
HAA	Haloacetic Acids
HDPE	High-Density Polyethylene
HPC	Heterotrophic Plate Count
IESWTR	Interim Enhanced Surface Water Treatment Rule
IDSE	Initial Distribution System Evaluation
IHS	Indian Health Service
I/O	Input/Output
IOC	Inorganic Compounds
IRS	Internal Revenue Service
LCR	Lead and Copper Rule
LOS	Level of Service
LRAA	Locational Running Annual Average
LSI	Langelier Saturation Index
LT1ESWTR	Long-term 1 Enhanced Surface Water Treatment Rule
LT2ESWTR	Long-term 2 Enhanced Surface Water Treatment Rule
MCL	Maximum Contaminant Level
MCLG	Maximum Contaminant Level Goal
MCPSD	McDowell County Public Service District
µg/L	Micrograms per Liter
mg/L	Milligrams per Liter
NDWC	National Drinking Water Clearinghouse
NIPDWR	National Interim Primary Drinking Water Regulations
NKWD	Northern Kentucky Water District
NMEFC	New Mexico Environmental Finance Center
NPDES	National Pollutant Discharge Elimination System
NRWA	National Rural Water Association
NSDWR	National Secondary Drinking Water Regulations
NTNCWS	Non-Transient Non-Community Water System
O&M	Operation and Maintenance
OSHA	Occupational Safety and Health Administration
PD	Positive Displacement
POE	Point of Entry
POU	Point of Use
PRV	Pressure Reducing Valve
PVC	Polyvinyl Chloride
PWS	Public Water System
RAA	Running Annual Average
REM	Roentgen Equivalent Man
RTU	Remote Terminal Unit
RUS	Rural Utilities System

SBREFA	Small Business Regulatory Enforcement Act
SCADA	Supervisory Control and Data Acquisition
SCWIE	Small Community Water Infrastructure Exchange
SDWA	Safe Drinking Water Act
SMF	Standardized Monitoring Framework
SOC	Synthetic Organic Compounds
SSCT	Small System Compliance Technology
STEP	Simple Tools for Effective Performance
SWTR	Surface Water Treatment Rule
TCR	Total Coliform Rule
THM	Trihalomethanes
TMDL	Total Maximum Daily Load
TNCWS	Transient Non-Community Water System
TOC	Total Organic Carbon
TT	Treatment Technique
UF	Ultrafiltration
UL	Underwriters Laboratory
USDA	U.S. Department of Agriculture
U.S.	United States
USA	United States of America
VA	Vulnerability Assessment
VOC	Volatile Organic Compounds
WV	West Virginia

Acknowledgements

The principal authors of this document, titled “Water Quality in Small Community Distribution Systems - A Reference Guide for Operators,” were: Mr. Srinivas Panguluri, P.E., Dr. Walter M. Grayman, P.E., Dr. Robert M. Clark, P.E., D.E.E., Mr. E. Radha Krishnan, P.E., Ms. Lucille M. Garner, Mr. Craig L. Patterson, P.E., and Mr. Roy C. Haught.

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Small town picture – Aerial view of Stowe, Vermont – Royalty-free image from American Spirit Images purchased from www.fotosearch.com
Operators flowing a hydrant – Montgomery County Sanitary Engineering Department Operators – photograph by Dr. Walter M. Grayman.

Chapter 1
Introduction

In the United States, there are thousands of miles of water distribution pipes which convey drinking water to consumers. However, there are many changes that occur within a distribution system that may result in degraded water quality. Suspended and/or dissolved solids in finished water can settle under low-flow conditions and can be re-suspended during high-flow conditions. Various disinfection agents (e.g., chlorine, chlorine dioxide, and chloramines) can react with organic matter contained in the source water and generate potentially harmful byproducts to which consumers are exposed. In addition, microorganisms can attach to pipe surfaces, producing a complex microbiological environment known as “biofilm.” Contaminants may infiltrate a distribution system during pipe breaks or through finished water storage facilities. Some of these undesirable water quality changes result in taste, odor or red-water problems that can be detected immediately. Potential contamination by pathogens (e.g., *E. coli* or *Salmonella*) may only be identified by sampling and analysis after a contamination event or following a waterborne disease outbreak. In order to minimize the degradation of water quality within distribution systems, the United States Environmental Protection Agency (EPA) publishes drinking water regulations. It is important that water distribution system operators and water utility managers understand changes occurring in water distribution systems, the related water quality concepts, and associated regulations in order to maintain a high degree of water quality within a distribution system. As emphasized in this document, proper operation and management of distribution system components is essential to protect the customer against both aesthetic and public health threats that may result due to undesirable water quality changes in the distribution system.

1.1 Purpose and Scope of the Document

EPA has developed this reference guide to assist operators and managers of small- and medium-sized public water systems (PWSs). It presents a compilation of information designed to provide small- and medium-sized water utility operators with a comprehensive picture of the water distribution system network. Because the technical background level of the target audience (small- to medium-size system operators and decision makers) varies widely, some very basic concepts have been included in this document. For the purposes of this reference guide, PWSs are interchangeably referred to as water utilities.

1.2 Graphical Elements and Cartoon Illustrations

To make this document appealing to a wide audience, graphical elements (pictures, tables and blue sidebars) and cartoon illustrations have been used throughout the document. Many of these graphical elements and cartoons are borrowed or adapted from existing publications (as referenced). Others were developed exclusively for use in this reference guide. Many of the cartoons were developed to illustrate basic distribution system concepts in a humorous manner but bear no relation to any real individuals or organizations. Figure 1.1 shows a “rogue’s gallery” of the characters that populate this

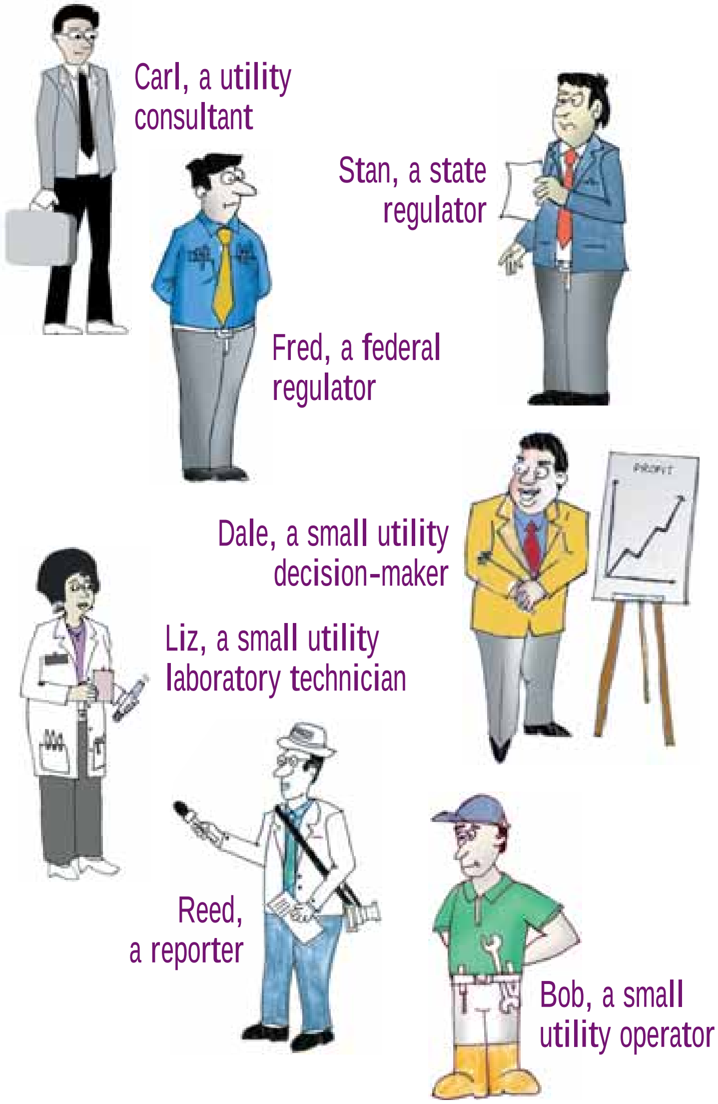


Figure 1.1 “Rogue’s Gallery” of fictional characters used in this reference guide.

manual and their roles. In addition to these fictional characters, other "stand alone" cartoons are also used throughout the document as necessary. None of the cartoon illustrations are meant to provide any "real-world" solutions. The sole purpose of the cartoon illustrations is to provide humor without offending any race, nationality, gender, politics, or religion.

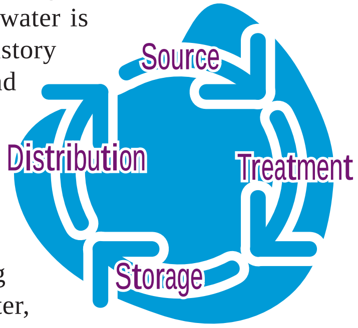
1.3 SmallWater, USA - Problem Scenarios

Every water distribution system is different in terms of specific layout and operations. However, water distribution systems generally have the same components and operate under similar principles and operational strategies. SmallWater, USA is an example of a water distribution system, utilized in this document to illustrate a drinking water utility serving a small- to medium-sized town. This example system includes all of the components that are typically found in the majority of small- and medium-sized PWSs and is used to illustrate many of the issues and potential problems facing a small water utility. SmallWater, USA problem scenarios are used throughout this reference guide to explore a number of water quality, operational, regulatory/compliance, and institutional problems faced by many of the small- and medium-sized utilities in the nation. At the end of each chapter, one or more SmallWater problem scenario(s) are presented along with some guidance on how to address these problems.

1.4 Content Development and Description

Between January and February of 2007, during the initial stages of development of this reference guide, several of the authors met with the staff at three small water utilities to discuss their operational and management procedures. The various utility staff members were very helpful in discussing their approaches to solving common problems. The authors also met with various state regulatory agency personnel to get their perspective on the critical issues facing small-community water utility operators and managers. In addition, the authors consulted with several technical and editorial reviewers to refine the material presented in the document to make it suitable for the target audience. These individuals are listed in the Acknowledgement section immediately preceding this chapter. The following is a brief description of the content in each of the subsequent chapters of this reference guide.

Chapter 2 provides an overview of the water supply and distribution process with an emphasis on how the distribution system impacts the quality of water supplied to the consumer. First, the concept of "water cycle" is illustrated along with strategies employed by EPA to protect source water quality. Subsequently, the process for treating, storing and distributing water is described. A brief history of water treatment and water quality regulations is provided as it relates to protecting water quality. Summary statistics documenting the size, source water, and ownership of PWSs is presented. Finally, a listing of common problems faced by small- and medium-sized water utilities is presented along with the description of SmallWater, USA.



Chapter 3 describes distribution system infrastructure and how each component can potentially impact water quality. Each of the major distribution system components is discussed in this chapter. The first subsection of this chapter discusses distribution system pipes and how their functionality varies with connectivity, placement and configuration. Pipe types and material are also discussed along with common problems, as well as troubleshooting and pipe repair techniques. Options for minimizing pipe leaks and water loss during distribution system line breaks are also presented. This is followed by a discussion on distribution system pumps, storage facilities (tanks), valves, and hydrants. Common problems associated with each of these components, along with troubleshooting and suggested maintenance techniques for these components, are also presented. Finally, the distribution system asset management concept is presented along with a SmallWater, USA problem scenario.

Chapter 4 presents a summary of the drinking water regulations. The highlights of the 1974 Safe Drinking Water Act (SDWA) and its subsequent amendments are discussed. The regulations to control microbial and chemical contaminants are tabulated. Public notification and consumer confidence rules under the SDWA are discussed. Two SmallWater, USA regulatory problem scenarios are presented.


Safe Drinking Water Act

Chapter 5 summarizes various distribution system water quality issues such as taste, odor, and color. The concept of “biofilm” is presented, along with the factors contributing to biofilm growth and operational factors that could inhibit the growth of biofilm. Subsequently, distribution system water quality issues such as disinfection byproducts (DBPs), nitrification, pH stability and scale formation are discussed. These sections are followed by a discussion on contamination events including cross-connections, permeation/leaching, intrusion/infiltration and reservoir/storage facility contamination. Finally, the concept of hydraulic modeling is introduced followed by two SmallWater, USA regulatory problem scenarios.

Water Quality

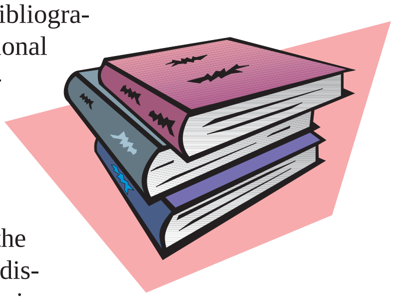
Chapter 6 provides a summary of the available methods for monitoring, controlling, and securing distribution systems. The physical state of the distribution system changes over time and techniques for monitoring parameters such as flow, velocity, and pressure are presented. Distribution system water quality monitoring techniques and methods for controlling a distribution system are discussed. Common control automation equipment such as Supervisory Control and Data Acquisition (SCADA) instrumentation, SCADA hardware, SCADA interface, and SCADA communication media are presented. This is followed by a discussion on distribution system vulnerabilities, operational responses, and emergency response mechanisms. Finally, two SmallWater, USA problem scenarios related to monitoring, control and security are presented.


Water Distribution Automation

Chapter 7 contains a summary of operational, management and financial strategies to address distribution system water quality issues. Operational strategies such as reducing water age, adapting operations to meet demand, initiating or changing disinfectants, and controlling corrosion are presented. Financial strategies such as obtaining loans and grants through various government and private sources are discussed. Management strategies such as regionalization and change in ownership are presented. Finally, two SmallWater problem scenarios are presented.


Strategy

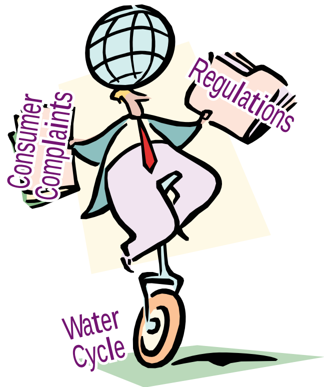
Chapter 8 includes a bibliography for this reference guide. Some of the documents included in the bibliography are referenced within the text of this guide. The references in the bibliography contain additional detailed information and provide valuable reading material for readers who wish to pursue any of the specific topics discussed in this guide in greater detail.


Additional Information and Bibliography

In the development of this reference guide, care has been taken to keep the guide simple, short, and concise. The guide contains additional references for supplementary reading material (as necessary and appropriate). Acronyms and abbreviations used in each chapter are defined in a separate listing as well as at their first occurrence in each chapter. In addition, to help explain many of the concepts, a variety of graphic illustrations, crossword puzzles and example problem scenarios have been utilized throughout the document.

Chapter 2
The Supply, Distribution, and Quality of Water: An Overview

Water is a renewable resource that is in continuous movement at the earth's surface (e.g., rivers, streams, and oceans), below the ground in aquifers and in the atmosphere. The natural movement of water is powered by the sun and the earth's gravity. This natural continuous movement of water is called the hydrologic cycle or the "water cycle." In this cycle, water precipitates as rain and falls onto surface storage areas such as lakes, rivers, streams, and oceans. The water on the land and these surface storage areas infiltrates and recharges underground sources called aquifers. Additionally, the water from the surface sources and plants evaporates to form rain-bearing clouds. Figure 2.1 is a graphical representation of the natural water cycle.



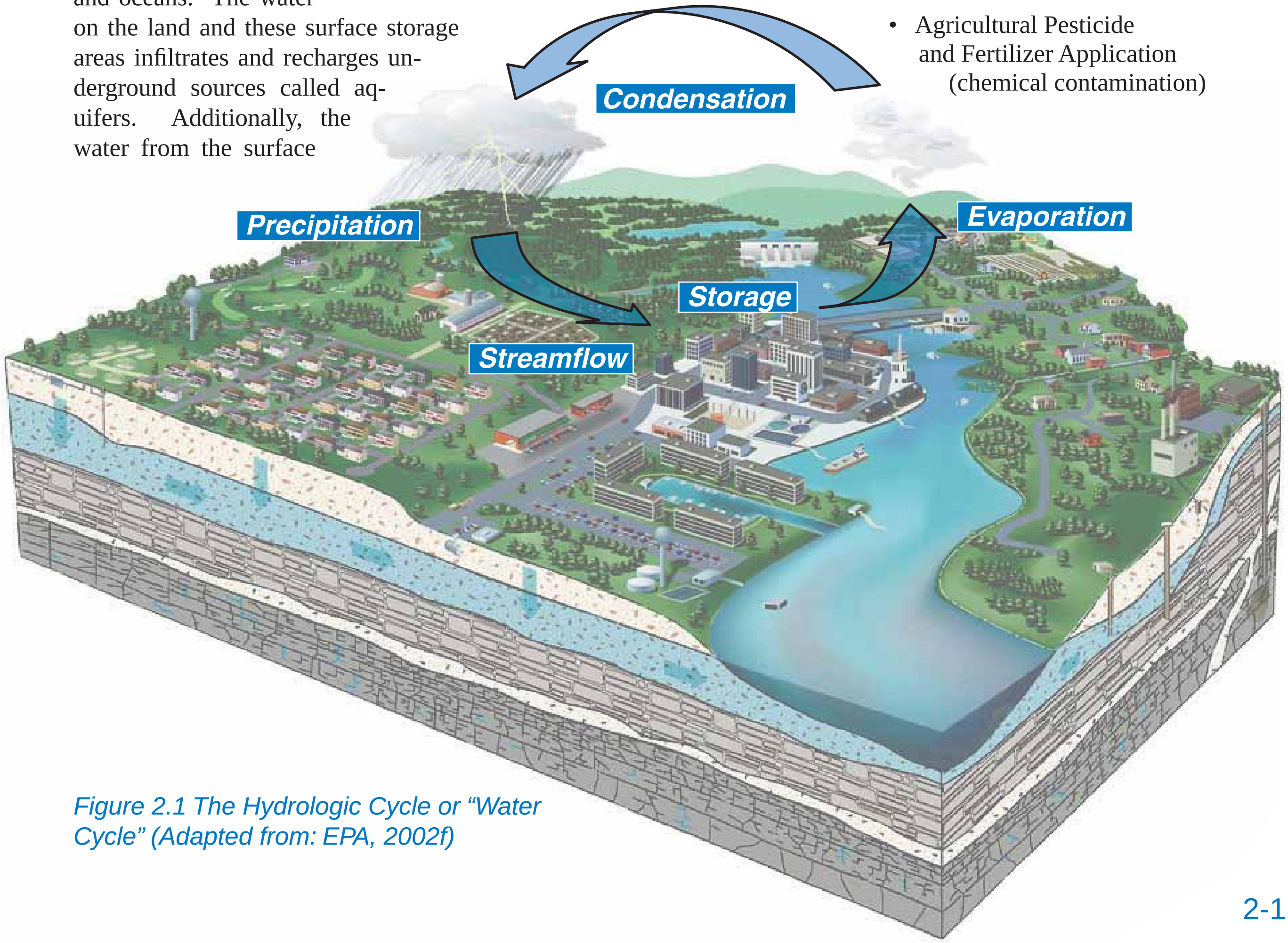


Figure 2.1 The Hydrologic Cycle or "Water Cycle" (Adapted from: EPA, 2002f)

Aquifers (ground water) and rivers (surface water) are the main sources of water for utilities in the United States (U.S.).

2.1 Protecting Source Water Quality

During the natural cyclic movement and storage of water in both surface and subsurface sources, water may be exposed to a variety of natural or human activity-related contaminants. Depending upon the location, the source water may be exposed to surface or subsurface sources of physical, chemical, biological and/or radiological contamination. Examples of contamination sources include:

- Rain water run-off collected by storm sewers (physical and/or chemical/biological contamination)
- Concentrated Animal Feeding Operations (biological and chemical contamination)
- Agricultural Pesticide and Fertilizer Application (chemical contamination)

- Septic Systems and Leaking Sewers (biological contamination)
- Construction Activities (chemical contamination)
- Wastewater and Industrial Discharges (chemical and biological contamination)
- Mining Wastes (chemical and radiological contamination)
- Naturally occurring chemical and radiological material in contact with underground water resources (chemical and radiological contamination)

These multiple risks to public health, illustrated in Figure 2.2, are only a few of the potential sources of contamination that can threaten both surface and ground water supplies used by the water utilities. EPA mandates various water quality standards and regulations that are designed to serve as barriers to the risk of source water contamination.

If the amount (or concentration) of the contaminant material present in the source water supply exceeds drinking water standards, water utilities are required to treat the source water to reduce (or eliminate) the contaminant material to the required standard levels prior to distributing the water to their customers.

2.2 Water Treatment, Supply and Distribution

Source water is often treated by unit processes such as coagulation, filtration, and disinfection to remove/reduce the contamination, to meet the maximum contaminant levels (MCLs). These treatment processes are generally not considered to be part of the distribution system. The finished water may be directly delivered to the consumer through the distribution system or temporarily stored in underground/elevated tanks before it is delivered to the consumer through the distribution system to faucets in their homes or work places. Figure 2.3 is a graphical representation of a typical water supply system that uses a surface water source.

A drinking water distribution system is a complex network of pipes, tanks and reservoirs that delivers finished water to consumers. The consumers of water include: residential households, commercial businesses, industrial users, and agricultural users. Collectively, water distribution system infrastructure consists of a variety of equipment such as pumps, pipes, tanks, valves, hydrants and meters, that are built to deliver water from the surface (e.g., river) and/or subsurface source (e.g., wells drilled into aquifers) to the customer. Figure 2.4 shows a schematic representation of a generic water distribution system.

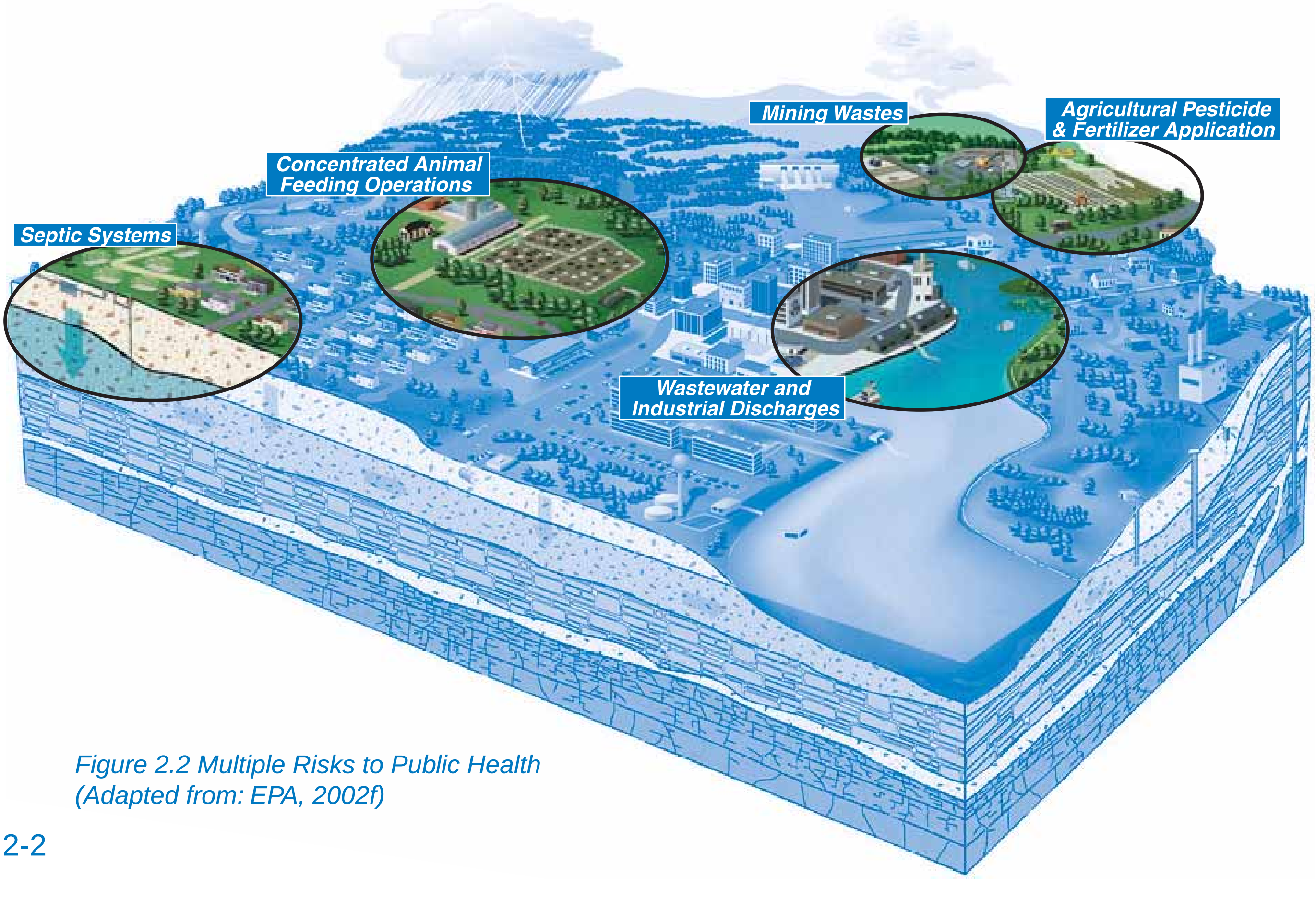


Figure 2.2 Multiple Risks to Public Health (Adapted from: EPA, 2002f)

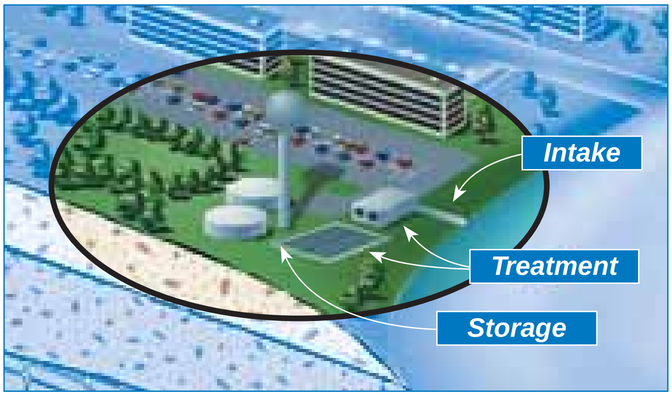


Figure 2.3 A Typical Water Supply System Using Surface Water as Source (Adapted from: EPA, 2002f)

A more detailed discussion of the distribution system components is presented in Chapter 3.0 of this report.

2.3 History of Water Supply and Treatment in the United States

The first water supply utility was established in the U.S. in Boston, Massachusetts in 1652, for the purpose of providing domestic water and fire protection. Other cities followed Boston's example and established water utilities for fire protection and to provide commercial and residential water service. The first water treatment plant in the U.S. was constructed in Richmond, Virginia in 1832 and the second was constructed in 1855 in Elizabeth, New Jersey. The water treatment system in Elizabeth consisted of a small charcoal sand and gravel filter. By 1860, only 136 water systems had been constructed in the U.S. Because most of the early utilities supplied water from springs low in turbidity and relatively free from pollution, they were also relatively problem-free. By the end of the nineteenth century, however, waterborne disease had become a serious problem in industrialized watersheds. For example, during one year in the 1880s, the typhoid death rate was 158 deaths per 100,000 in Pittsburgh, Pennsylvania. This led to the more routine use of water treatment; by 1935, the typhoid death rate had declined to 5 per 100,000. Another study of typhoid case rates and associated death rates in the City of Cincinnati between 1898 and 1928 shows a significant decline in these rates after the city initiated filtration in 1907, and after implementation of chlorination in 1915. Water treatment in the U.S. has proven to be a major benefactor to the nation's public health. The use of chlorine in particular has been recognized as a breakthrough in public health.

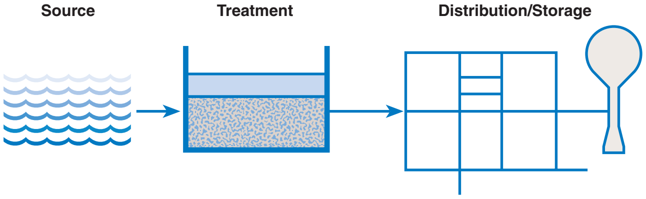
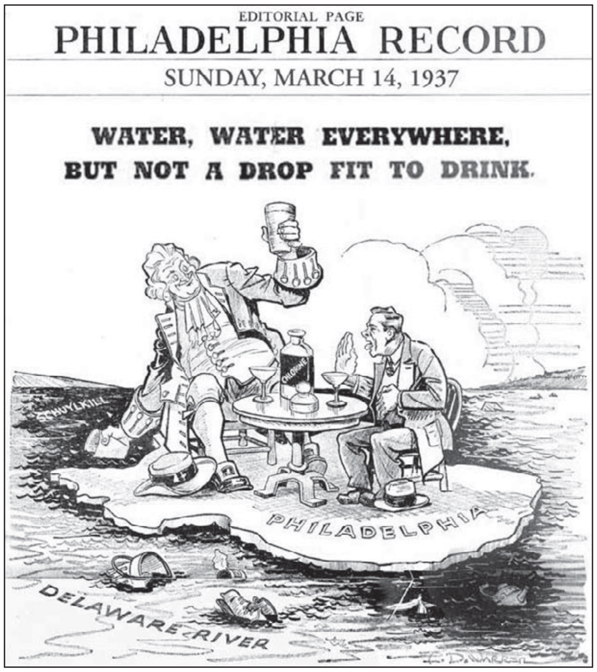


Figure 2.4 A Schematic Representation of a Water Distribution System

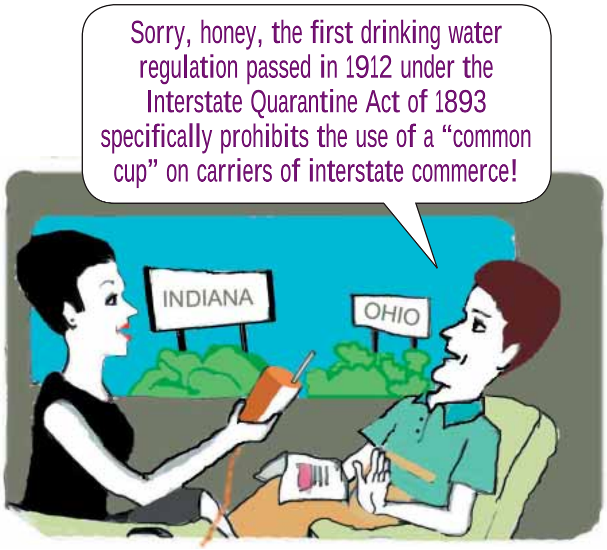
2.4 History of Water Quality Regulations and Standards in the United States

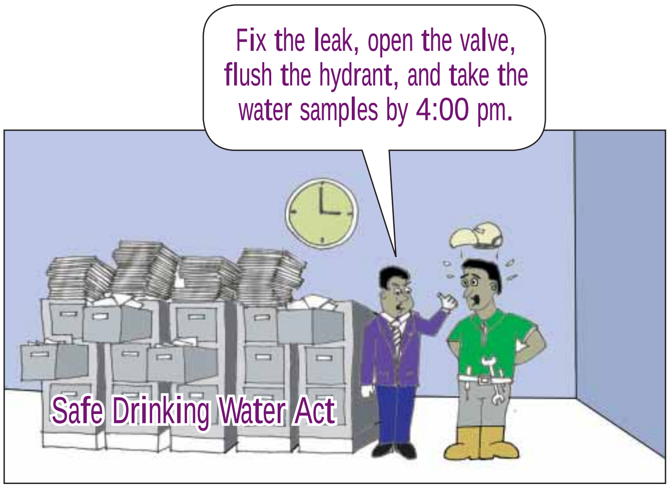

EDITORIAL PAGE
PHILADELPHIA RECORD
SUNDAY, MARCH 14, 1937

WATER, WATER EVERYWHERE,
BUT NOT A DROP FIT TO DRINK.

(Courtesy: PWD, 2007)

The first federal drinking water regulation was promulgated in 1912 under the Interstate Quarantine Act of 1893. At that time, interstate railroads provided a common cup for train passengers to share for drinking water while on board. The Act prohibited this practice. By 1962, several sets of federal drinking water standards





had been issued, but they applied only to interstate carriers. By the 1960s, each of the states and trust territories had established its own drinking water regulations, although there were many inconsistencies among them. Reported waterborne disease outbreaks had declined from 45 per 100,000 persons in 1938-40 to 15 per 100,000 persons in 1966-70. However, the annual number of waterborne disease outbreaks had stopped declining around 1951 and may have actually increased slightly. These conditions, in part, led to the passage of the Safe Drinking Water Act (SDWA) of 1974.

The SDWA defines drinking water quality as a measure of its suitability for human consumption, based on selected physical, chemical, and biological characteristics. The regulations established under the SDWA became the first set of national drinking water regulations. These regulations require that utilities meet specific guidelines and/or numeric standards for drinking water quality. The SDWA defines a public water system (PWS) as a system that provides water for human consumption through pipes or other constructed conveyances, provided that such a system has at least 15 service connections or regularly serves an average of at least 25 individuals daily for at least 60 days out of the year. The SDWA established two types of numeric standards. The first is an enforceable standard commonly referred to as an MCL. The other (non-enforceable) standard is referred to as a maximum contaminant level goal (MCLG). MCLGs are set at a level at which no known or anticipated adverse human health effects occur.

Water quality in the distribution system has been of major interest to regulators and drinking water utilities. Maintaining a high level of water quality in the distribution system can pose a major challenge to some drinking water utilities because of the age and type of pipes used in their system. Corroded and decaying pipes may deteriorate water quality significantly during transportation of water through the distribution system. Contaminants that can potentially increase in a distribution system include lead, copper, disinfection byproducts (DBPs), and coliform. Cross-connections are another major source of distribution system contamination.

Where it is not economically or technologically feasible to determine the MCL for a contaminant, an enforceable treatment technique (TT) is prescribed by EPA instead of an MCL. For example, *Giardia lamblia* is a microbial contaminant that is difficult to measure. To ensure proper treatment, experimental work has been conducted by EPA and others to establish optimum treatment conditions. EPA and other researchers have identified treatment technologies for ensuring proper treatment. Therefore, the TT describes a specified pH, temperature, and disinfectant concentration along with a specified length of “contact time” to achieve a specific level of inactivation (or microbial kill). EPA has also set operational conditions that systems must meet to demonstrate removal by physical removal processes (e.g., rapid granular filtration, membranes).

The major rules and requirements of interest to small- and medium-system operators are discussed in Chapter 4 of this document.

EPA has identified several Best Available Technologies (BATs) under SDWA for the treatment of drinking water. The identified BATs include: Activated Alumina, Coagulation/Filtration, Direct Filtration, Diatomite Filtration, Electrodialysis Reversal, Corrosion Control, Granulated Activated Carbon, Ion Exchange, Lime Softening, Reverse Osmosis, Polymer Addition, and Packed Tower Aeration. Note that using BAT is not the same as employing specified TT. However, BATs can be used for requesting the issuance of variance or exemption.

2.5 Public Water System

There are nearly 160,000 water utilities in the U.S. These water utilities vary greatly in size, ownership, and type of operation. The SDWA defines PWSs as consisting of community water systems (CWSs), transient non-community water systems (TNCWSs), and non-transient non-community water systems (NTNCWSs). A CWS is a PWS which serves at least 15 service connections used by year-round residents or regularly serves at least 25 year-round residents. An NTNCWS is a PWS that is not a CWS and it regularly serves at least 25 of the same persons for more than six months per year. A TNCWS is a not a CWS and it does not regularly serve at least 25 of the same persons for more than six months per year. Figure 2.5 shows examples of this classification.

2.5.1 Type and Size of Systems

Of the nearly 160,000 water utilities in the U.S., 33 percent are classified as CWSs, 55 percent are classified as TNCWSs, and 12 percent are classified as NTNCWSs. PWSs serve 297 million residential, transient, and

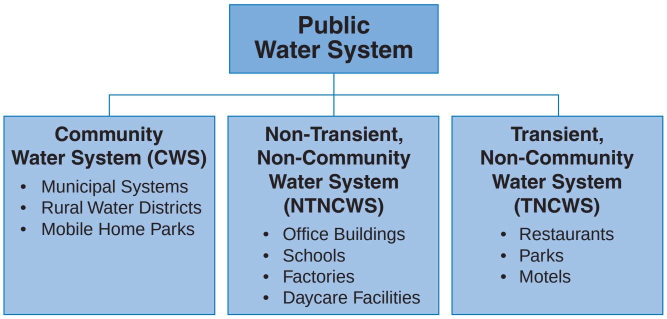


Figure 2.5 Classification of PWSs in the U.S.

commercial customers. PWSs serving fewer than 3,300 people are categorized as small systems and those serving 3,300 to 10,000 people are categorized as medium systems. Although a vast majority (98 percent) of systems are categorized as small and medium, they serve only about a quarter of the U.S. population. Other size classifications such as that specified by the Small Business Regulatory Enforcement Act (SBREFA) generally define small systems to include all distribution systems that serve less than 10,000 people. Figure 2.6 shows a distribution of PWSs by size in the U.S.

"Consecutive systems" are those PWSs that receive some or all of their finished water from one or more wholesale systems. Delivery may be through a direct connection or through the distribution system of one or more consecutive systems.

As shown in Figure 2.6, a very large number of the PWSs in the U.S. are represented by small- and medium-size water utilities. The large number of small and medium utilities creates a major administrative and oversight challenge for state and federal water supply regulatory agencies.

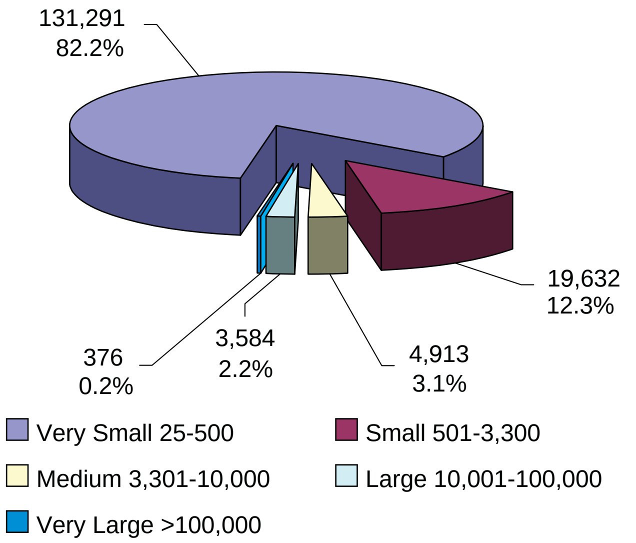
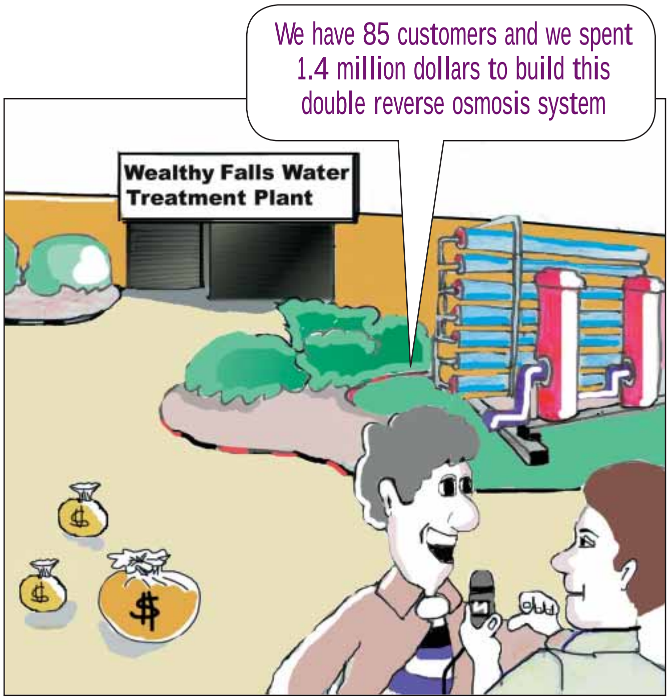
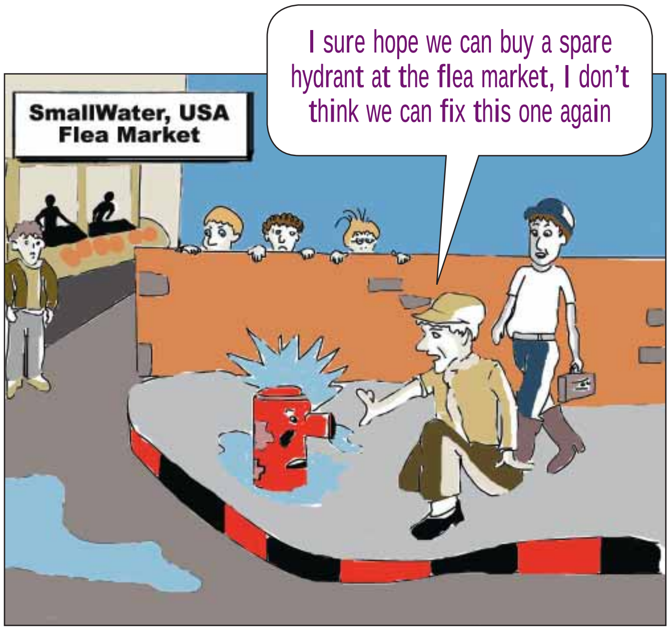


Figure 2.6 Distribution of PWSs by Size (EPA, 2007a)





2.5.2 Type of Source Water Used

Some utilities rely primarily on surface water supplies, while others rely primarily on ground water. Surface water is the primary source of 22 percent of the CWSs, while ground water is used by 78 percent of CWSs. Of the TNCWSs and NTNCWSs, 97 percent are served by ground water. In addition, many systems serve communities using multiple sources of supply such as a combination of ground water and/or surface water sources. In these systems, the mixing of water in the distribution system poses a challenge for managing water quality. Figure 2.7 shows a distribution of PWSs by primary source of water used.

As shown in Figure 2.7, the vast majority of small and medium water utilities in the U.S. use ground water.

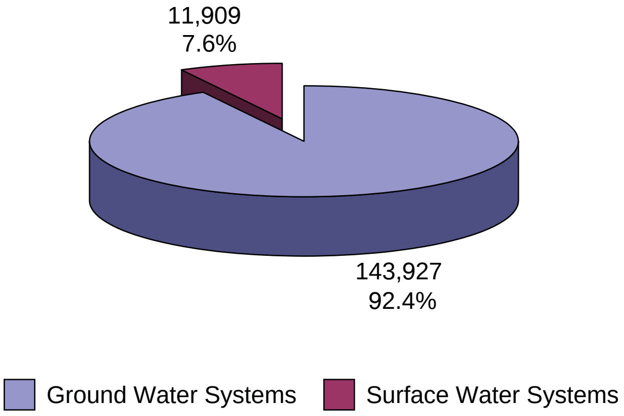


Figure 2.7 Distribution of Small- and Medium-Sized PWSs by Source of Water Used (EPA, 2007a)

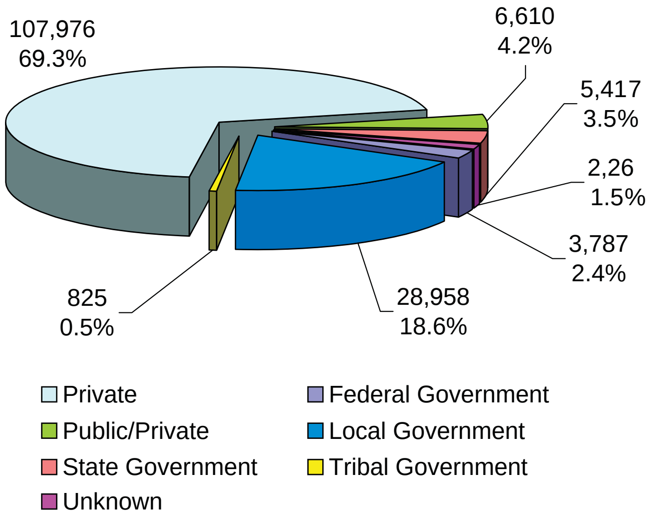


Figure 2.8 Distribution of Small- and Medium-Sized PWSs by Ownership (EPA, 2007a)

2.5.3 Type of Ownership

The ownership of water utilities in the U.S. is also diverse and has a long history of local government control over operation and financial management, with varying degrees of oversight and regulation by state and federal government. The water utilities serving cities and towns are generally administered by departments of municipalities or counties (public systems) or by investor-owned companies (private systems).

Public systems are predominately owned by local municipal governments, and serve approximately 78 percent of the total population. Approximately 82 percent of urban water systems (those serving more than 50,000 persons) are publicly owned.

About 33,000 privately owned water systems serve the remaining 22 percent of people served by CWSs. Private systems are usually investor-owned in the larger population size categories, but can include many small systems as part of one large organization. These investor-owned utilities are in business to generate profit for their shareholders. In the small-and medium-sized categories, the privately owned systems tend to be owned by homeowners, associations, or developers.

Other types of system owners include several classifications of state-chartered public corporations, quasi-governmental units, and municipally owned systems that operate differently from traditional public and private systems. These systems include special districts, independent non-political boards, and state-chartered corporations. Figure 2.8 shows the distribution of PWSs by ownership.

Figure 2.8 indicates that the vast majority of small and medium water utilities in the U.S. belong in the private ownership category, followed by the local government category. The difference in financial structure between the government and private entities makes the management of small system operations challenging.

2.6 Common Problems Faced by Small and Medium Utilities

The problems faced by operators of a small- and medium-sized utility are as diverse as the system statistics presented in Section 2.5. However, for the purposes of this document, the common problems have been broadly categorized as follows:

- Water Quality Problems
- Operational Problems
- Regulatory/ Compliance Problems
- Institutional Problems

Key considerations associated with the management of these problems for small-and medium-sized utilities will be the focus of this document.

2.6.1 Water Quality Problems

Water quality issues faced by small-and medium-sized utilities are geographically diverse and complex. The common consumer-reported problems include taste, odor, and color. These problems generally do not have an immediate impact on consumer health or result in regulatory non-compliance. However, they must be addressed quickly to retain customer support for the system. Examples of taste and odor issues reported by the customers include:

- earthy smell
- chlorine smell
- rotten egg smell
- petroleum smell
- fishy smell
- metallic taste

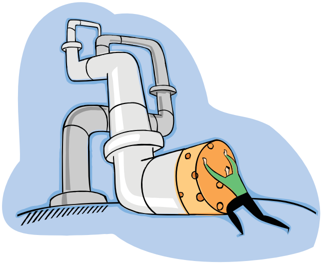
Examples of common color issues reported include:

- red water
- green water
- black water
- milky water

2.6.2 Operational Problems

Common operational problems faced by small-and medium-sized utility operators include:

- pressure problems
- main breaks, leaks
- valve problems
- excessive sediments in pipes and reservoirs
- cross-connection and backflow
- replacement and/or repair of tanks and water mains
- network and supply expansion
- adequate fire flow



2.6.3 Regulatory/Compliance Problems

Common regulatory and compliance issues faced by small-and medium-sized utilities include:

- Monitoring and reporting problems
- MCL exceedances (e.g., elevated lead, copper, and arsenic levels)
- Treatment technique violations
- Loss of disinfectant residual

2.6.4 Institutional Problems

Common institutional issues faced by small-and medium-sized utilities include:

- money constraints (small population and low water rates)
- limited asset management
- poorly trained and low-paid operators (even volunteers)
- inadequate metering
- unaccounted-for water loss
- lack of system security

To focus on these problems and to evaluate potential solutions, a hypothetical example of a community with a small water utility called "SmallWater, USA" has been developed. The problems and solutions discussed and presented in this document will be related to SmallWater, USA. The following section presents a brief overview of SmallWater, USA.

2.7 SmallWater, USA Scenario

SmallWater is a hypothetical rural town in Midwestern U.S. The current population is about 2,700 with a small commercial downtown area and a small industrial park. The original water system was installed in the 1930s using cast iron pipe and was served by a well field on the western edge of the town and an adjacent standpipe. The town grew with additional development in the 1970s to the north of the original town using asbestos-cement pipe. In the 1990s, the well supply became inadequate and an alternate source was developed in the form of an interconnection to the surface water supply for a larger system located to the southeast. The well field was maintained as a supplemental and emergency supply. At that time, additional development also occurred in the form of a subdivision at the eastern edge of the town and on the ridge to the north of the town. A pump station was built to serve this high zone (ridge) and a small elevated tank was constructed. A commercial development (shopping center) was also added to the system and served via a pressure-reducing valve (PRV) from the high zone. Polyvinyl chloride (PVC) pipe was used for these modifications. Figure 2.9 is a schematic of the water system in SmallWater, USA.

SmallWater, USA purchases finished water from the adjacent system via the interconnection. Well water is chlorinated without any additional treatment. At the current time, the town uses an average of 210,000 gallons/day with approximately 70 percent of that total attributed to residential use and the remainder for commercial, industrial, and institutional use. Maximum daily usage is approximately 400,000 gallons. Total revenue for the water utility is approximately $250,000/year. The water system is run by the town water board. Employees include a full-time clerk, a full-time water director and a part-time assistant.

The SmallWater, USA scenario will be used in this reference guide to explore a number of water quality, operational, regulatory/compliance, and institutional problems faced by many small- and medium-sized utilities in the U.S.

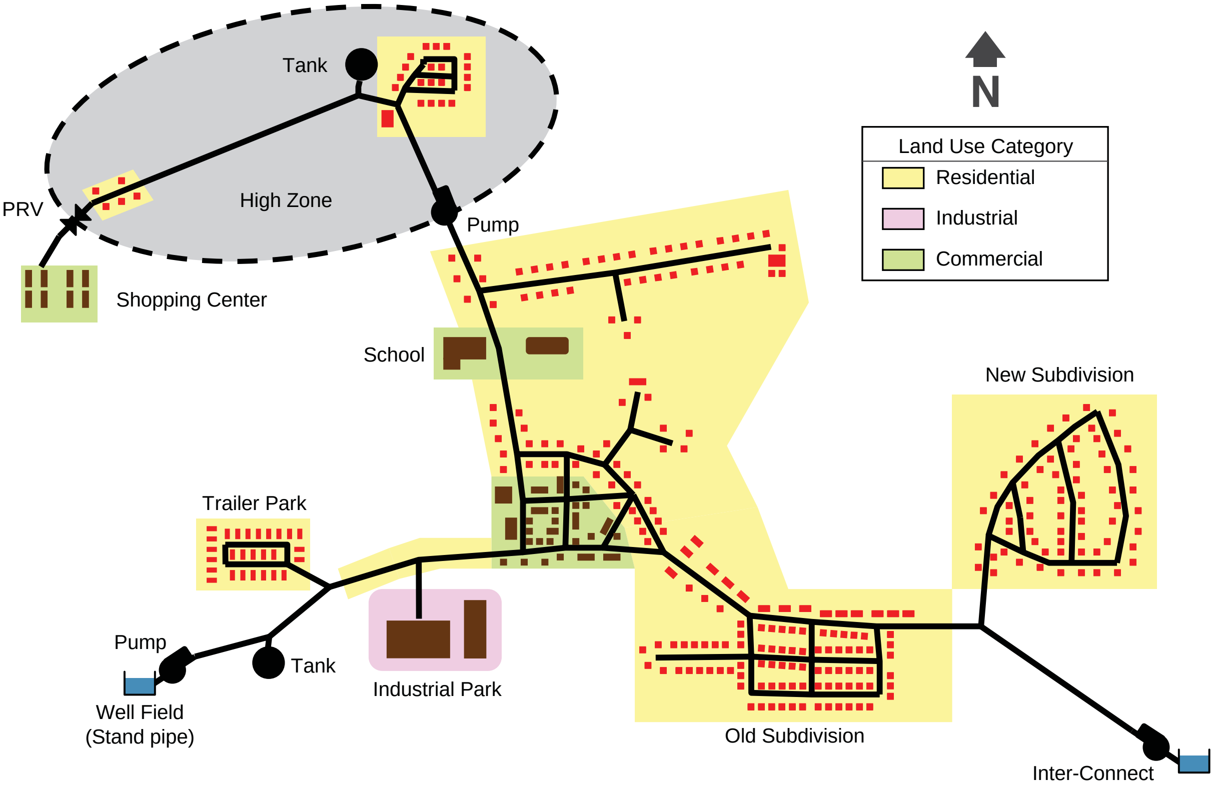
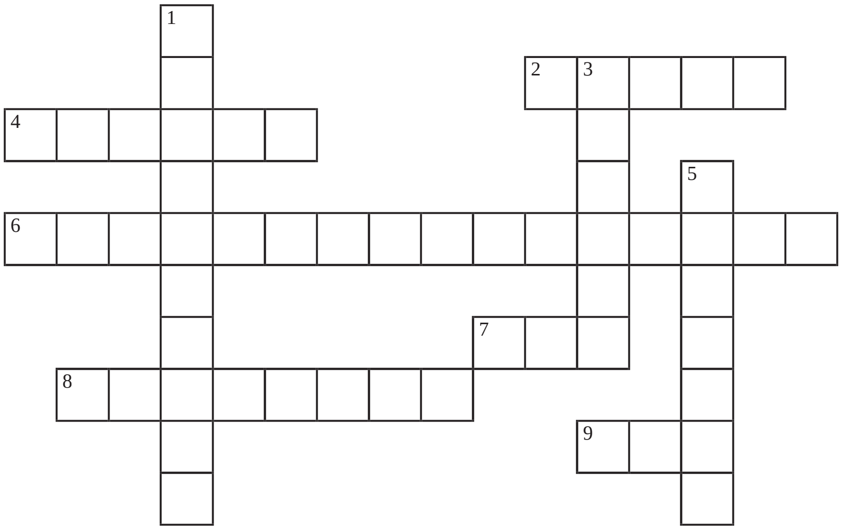


Figure 2.9 SmallWater, USA –Schematic Layout

Crossword
The Supply, Distribution, and Quality of Water: An Overview



ACROSS

2 Regulatory acronym for water system serving restaurants, parks, motels that serve different customers
4 U.S. City where first water utility was established
6 Term for preventing source water contamination
7 Regulatory acronym for utilities serving 25 or more people year round
8 U.S. City where first water treatment plant was established
9 Regulatory acronym for expressing the enforceable limits for a particular contaminant

DOWN

1 Term for natural movement of water from rains, to lakes and streams, and evaporation
3 Regulatory acronym for water system serving schools, hospitals and factories that have their own water supply and serve the same people for at least six months in a year.
5 Term for microbial organisms that attach to interior pipe surfaces

Crossword solution:
1) Water cycle, 2) TNCWS, 3) NTNCWS, 4) Boston, 5) Biofilm, 6) Source Protection, 7) CWS, 8) Richmond, and 9) MCL

Chapter 3 Distribution System Infrastructure

Distribution system infrastructure consists of a network of pumps, pipes, tanks, valves, hydrants, and meters through which finished water is supplied to customers. This infrastructure is designed to deliver water to the customer. The physical integrity of the distribution system, from entry point to the customer's faucet, is a primary barrier against the entry of external contaminants. Figure 2.4, in the previous chapter, showed a schematic representation of a typical water distribution system.

A variety of components and materials make up a drinking water distribution system. These include: (1) pipes, including mains and service lines; (2) fittings and appurtenances such as crosses, tees, ells, hydrants, valves, and meters; (3) storage facilities including reservoirs (underground, open, and covered), elevated storage tanks, ground level storage tanks, and standpipes; and (4) backflow prevention devices.

Table 3-1 provides examples of the infrastructure components and the common materials of construction. These components serve as a physical barrier to protect the distribution system water quality from external contamination threats. For example, the piping material and fittings serve to protect the water from external contamination sources such as soil, ground water, sewer exfiltration, surface runoff, human activity, animals, insects, microbial pathogens, and other life forms. The premise plumbing and storage facilities are designed to protect from air contamination, rain, algae, surface runoff, human activity, animals, birds, insects and other sources of non-potable water.

3.1 The Impact of Distribution System on Water Quality

Although water entering the distribution system may meet the regulatory standards, water quality may degrade during transportation within the distribution system before reaching the consumer. Some of these undesirable water quality changes such as taste, odor or red-water problems can be detected immediately, whereas others may only be identified by sampling and analysis. A waterborne outbreak caused by organisms such as *E. coli* or *Salmonella*, for example, may be later traced back to accidental contamination of water in the distribution system. A variety of components make up the physical barrier that protects against the deterioration of water quality in a distribution system. In addition, the proper management of these components is essential to protecting the customer against both aesthetic and public health threats to distribution system water quality. This chapter presents an overview of the key distribution system infrastructure components, the common problems associated with these components, and some potential solutions to these problems. Specifically, the following infrastructure components are discussed in this chapter:

- Pipes
- Pumps
- Storage facilities
- Valves
- Hydrants
- Water meters and service lines

Table 3.1 Infrastructure Components (NRC, 2006)

Component	Common Materials of Construction
Pipe	Asbestos cement, reinforced concrete, steel, lined and unlined cast iron, lined and unlined ductile iron, polyvinyl chloride (PVC), polyethylene and high-density polyethylene (HDPE), galvanized iron, copper, polybutylene, and lead
Pipe wrap and coatings	Polyethylene, bitumastic, cement-mortar
Pipe linings	Epoxy, urethanes, asphalt, coal tar, cement-mortar, plastic inserts
Service lines	Galvanized steel or iron, lead, copper, chlorinated PVC, cross-linked polyethylene, polyethylene, polybutylene, PVC, brass, cast iron
Customer building plumbing	Copper, lead, galvanized steel or iron, iron, steel, chlorinated PVC, PVC, cross-linked polyethylene, polyethylene, polybutylene
Fittings and appurtenances (meters, valves, hydrants, ferrules)	Brass, rubber, plastic
Storage facility walls, roof, cover, vent hatch	Concrete, steel, asphalt, epoxy, plastic
Backflow prevention devices	Brass, plastic, stainless steel
Gaskets and joints	Rubber, leadite (a lead substitute), asphalt, plastic

The U.S. Federal Communications Commission in March 2005 made 811 the universal number for coordinating location services for underground public utilities. This was required by the Pipeline Safety Improvement Act of 2002.

3.2 Distribution System Pipes

Pipe materials used by the water utilities have changed greatly over time. Cast iron pipe (lined or unlined) has been largely phased out primarily due to its susceptibility to both internal and external corrosion. Early on, ductile iron pipe (with or without a cement lining) took its place because of its durability, strength and good resistance to external corrosion from soils. However, ductile iron pipe also needs corrosion protection in certain soils and may require multiple types of joints. Subsequently, concrete, asbestos cement, and polyvinyl chloride (PVC) plastic pipe were used to replace metal pipe because of their relatively good resistance to corrosion. More recently, high-density polyethylene (HDPE) pipe is being used as a replacement because of its ease of installation, toughness, flexibility, and corrosion resistance.

3.2.1 Pipe Connectivity, Placement and Configuration

Distribution system pipe networks consist of water "mains," also called "primary feeders" or "trunk lines." The mains are generally 12 inches or greater in diameter (for small systems, the mains may be only 6- to 8-inches in size), and carry water from the treatment plant to the local service areas where they are connected to smaller-diameter "branches" also called "secondary feeders." The branches that are tied into the mains are usually greater than six inches in diameter. At the other end, the branches are tied to other smaller diameter pipes (4, 6 or 8 inches) that connect with service connections to customers (residential, commercial, and industrial). Water pipes are typically placed three to six feet below ground level to protect them from traffic, freezing, damage from excavation and construction activities. These pipes are placed within the public right-of-way so that workers can install service connections for all potential water users.

Branch and grid/loop are the two basic configurations used by most water distribution systems. A branch system is similar to a tree where smaller pipes branch off larger main pipes (similar to a tree trunk) throughout the service area. This type of system is most frequently used in rural areas, and generally in this type of system, water has only one pathway from the source to the consumer. A grid/loop system consists of interconnected pipe loops throughout the area to be served. In this type of system, there are several pathways that the water can follow from the source to the consumer. A grid/loop system is the most widely used configuration in medium-and large-sized utilities. The grid/looped systems provide a high degree of reliability should a line break occur, because the break can be isolated with little impact on customers outside the immediate area. Figures 3.1 and 3.2 depict a branched and grid/looped distribution system, respectively.

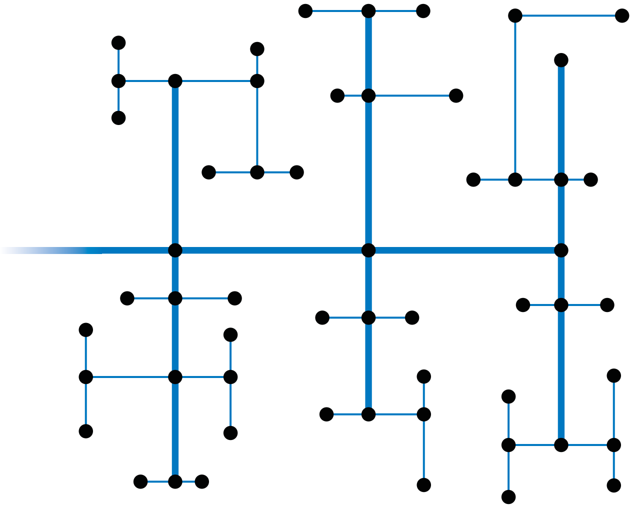


Figure 3.1 A Branched Distribution System

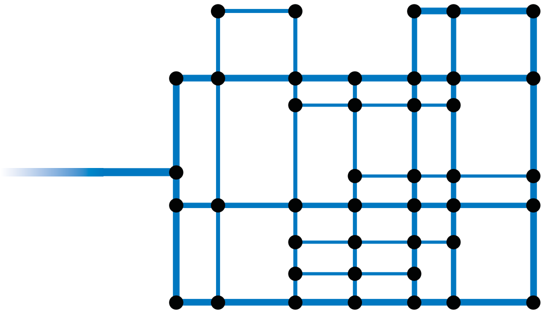


Figure 3.2 A Grid/Looped Distribution System

3.2.2 Pipe Material

Distribution system pipes are generally made of asbestos cement, unlined cast iron, cement-mortar-lined cast or ductile iron, plastic (PVC, HDPE), reinforced concrete, steel or fiberglass. Pipes used in water systems must be approved for potable water use. NSF International, American National Standards Institute (ANSI), American Society for Testing Materials (ASTM), and Underwriters Laboratory (UL) are among the organizations that test and approve pipe for potable water applications. Figure 3.3 shows the NSF potable water use approval depicted on a PVC pipe.

Figure 3.3 NSF-Approved PVC Pipe for Potable Water Use

The condition of pipe, source water quality, and the soil conditions around the buried pipe can negatively impact the water quality. Degradation of plastic (PVC or HDPE) pipes located in soils contaminated with organic compounds may result in softening of the pipe wall and subsequent permeation of organic matter through the pipe wall, leading to contaminated water. Table 3.2 presents a summary of potential negative impacts to water quality based on pipe material and changes in source water quality.

As presented in Table 3.2, depending upon the pipe material and relative changes in source water quality, the pipe wall interactions may negatively impact the water quality. Figure 3.4 depicts the various pipe wall interactions that may adversely affect water quality.

Additional Information

Pipe Material Voluntary Standards

AWWA - M9, Concrete Pressure Pipe, Second Edition, 1995

AWWA - M11, Steel Pipe—A Guide for Design and Installation, Fourth Edition, 2004

AWWA - M23, PVC Pipe—Design and Installation, Second Edition, 2002

AWWA - M41, Ductile-Iron Pipe and Fittings, Second Edition, 2003

AWWA - M55, PE Pipe—Design and Installation, First Edition, 2006

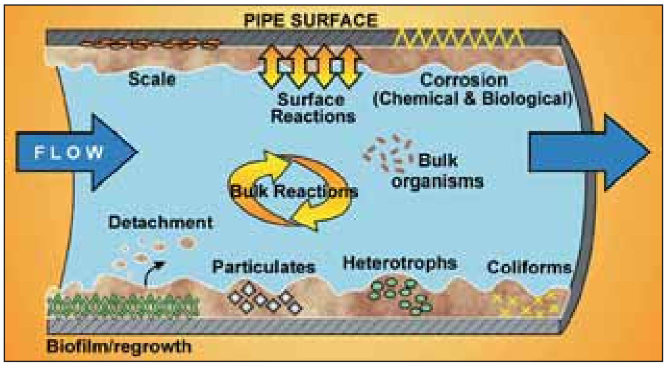


Figure 3.4 Pipe Wall Interactions that Affect Water Quality (Adapted from: MSU, 2005)

Table 3.2 Potential Negative Impacts to Water Quality Based on Pipe Material and Changes in Water Quality (Adapted from AwwaRF, 2005)

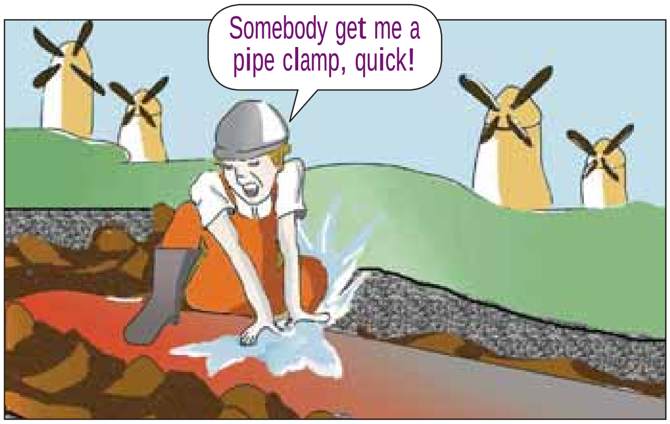
Pipe Material	Changes in Water Quality	Potential Negative Impacts
Unlined cast iron, steel, or old galvanized steel	1) pH increase or decrease, or 2) Alkalinity decrease, or 3) Dissolved oxygen increase or decrease	May result in discolored water
	Chlorine residual increase	May mobilize iron and/or manganese oxides and result in discolored water
Cement-mortar lined ductile iron	1) pH decrease, or 2) Alkalinity decrease	May trigger localized pH and alkalinity increases with associated negative impact of discolored water
Asbestos cement (Transite)	1) pH decrease, or 2) Alkalinity decrease	May trigger localized pH and alkalinity increases and increased levels of asbestos fibers in water
All pipe types including fiber glass	Chlorine residual decrease	May result in increase in microbiological population such as HPC[a] and possibly coliform[b] levels

[a] Heterotrophic Plate Count —A bacterial counting procedure used to estimate bacterial density in a water sample. Other names for the procedure [within the water industry] include total plate count, standard plate count, or plate count.

bColiform - A specific class of bacteria found in the intestines of warm-blooded animals and people. The presence of coliform bacteria in water indicates that there is a possibility, but not a certainty, that disease-causing organisms may also be present in the water.

3.2.3 Common Problems, Troubleshooting and Pipe Repair

Excessive scale buildup, corrosion, pipe leaks and main breaks are the most common pipe-related problems faced by water utilities. Excessive scaling in pipe results in loss of delivery capacity over time. Internal corrosion of pipes can result in discolored water or high lead and copper levels. For example, reddish-brown water is the result of corrosion of iron pipes, bluish stains on fixtures are the result of corrosion of copper lines, and black water generally results from sulfide corrosion of copper or iron lines, or can be the result of precipitation of natural occurring manganese in water. External corrosion leads to pipe leaks and water main breaks. There are several types of leaks, including valve leaks and service line leaks, but in most cases the largest amount of water is lost through water main leaks. Leaks occur due to factors such as pipe material, pipe composition, pipe age, finished water quality, temperature, pressure, and pipe joining methods. External conditions, such as contact with other structures (that can cause movement or electrical current flow), stray electric currents, traffic load, aggressive soils, vibrations, and frost conditions can also contribute to leaks. Pipes also break due to factors such as water freezing, traffic load, and corrosion. In addition, pipes may be defective, installed improperly, or simply not strong enough to handle pressure surges.



Pipe Leak Management by a Small System (EPA, 2002c)

Gallitzin, a small town in western Pennsylvania (population ~2,000), services approximately 1,000 connections. The system was experiencing water losses exceeding 70 percent. In November 1994, the system was using an average of 310,000 gallons per day. Gallitzin experienced a peak usage in February 1995 of 500,000 gallons per day. The water authority identified five major problems in the system: 1) high water loss, 2) recurring leaks, 3) high overall operational costs, 4) low pressure complaints and 5) unstable water entering the distribution system.

The water utility decided to implement a comprehensive program for water leak detection. For this purpose, the utility first developed accurate water production and distribution records using 7-day meter readings at the plant and pump station. A system map was then created to locate leakage. Through the use of a leak detector, the utility was able to identify approximately 95 percent of its leaks. Thereafter, the utility initiated a leak repair program and a corrosion control program at the Water Treatment Plant. Gallitzin was one of the first systems to receive technical assistance from the Pennsylvania Department of Environmental Protection Small Water Systems Outreach Program. The training helped the authority repair distribution system leaks, replace inaccurate meters, and improve customer billing. Accuracy of water meters is critical for determining water loss as part of a good leak management program. By November 1998, 4 years after implementation of the program, the system delivered an average of 128,000 gallons per day to the town—down from 310,000 gallons per day in November 1994. Unaccounted-for water dropped to only 9 percent. The financial savings from the program have been highly beneficial. The city saved $5,000 on total annual chemical costs and $20,000 on total annual power costs between 1994 and 1998. The significant savings helped the utility keep water rates down.

3.2.3.1 Minimizing Leaks and Water Loss

Leakage results in loss of revenue to a utility. Larger leaks are usually detected faster, because they usually lead to water reaching the surface which results in quick identification, isolation and repair. Small undetected leaks can often lead to large amounts of water loss over time. Leak detection methods usually involve sonic or ultrasonic leak-detection equipment, which identifies the sound of water escaping a pipe. These devices include pin-point listening devices that make contact with valves and hydrants, or geophones that listen directly to sound moving through the ground. In addition, there are other devices that can listen at two locations simultaneously to correlate "leak" sounds and determine the exact leak location. Leak detection efforts should focus on the portion of the system where the greatest problems are expected. These problem areas generally include areas with excessive leak and break rates, high-pressure areas, and areas where pipes are old. As a general guideline, a water conservation and leak detection

Additional Information

Leak Detection and Water Loss

A National Drinking Water Clearinghouse (NDWC) Tech Brief on leak detection and water loss control can be obtained online from: http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/TB_LeakDetection.pdf

AWWA - M36, Water Audits and Leak Detection, Second Edition, 1999 program should be implemented when the “unaccounted-for” water (water produced – metered water usage at customer locations) exceeds 15 percent.

3.2.3.2 Distribution System Line Breaks

Distribution system pipes can break for a variety of reasons such as excessive traffic load, extremely cold temperatures, accidents during excavation/construction activities, pressure surges, and corrosion. Procedures for dealing with major main breaks are usually outlined in a utility’s emergency response plan (ERP). If a utility suffers a major main break, law enforcement, fire protection, and city officials should be notified since the leak may pose significant hazard to life or property. Affected customers should be notified since valves must be shut off to isolate the break and to perform needed repairs. For smaller leaks, it is preferable to perform the repair without shutting off the water service. Allowing a line to remain under pressure prevents back siphoning and back pressure that can cause contaminants to enter into the pipe. In some cases, nearby hydrants can be opened to lower the water pressure to facilitate the repair. If the pipe break is small, it can be repaired using a pipe clamp or sleeve that serves as a “bandage.” For larger breaks, portions of pipe are cut off and replaced by new sections. As a general rule when conducting repairs, safety precautions are necessary with regard to trenching and shoring, in addition to following proper procedures for pipe installation and repair.

Additional Information

Line Repair and Rehabilitation

A NDWC Tech Brief on repairing distribution line breaks can be obtained online from: http://www.nesc.wvu.edu/ndwc/articles/OT/SP04/TechBrief_LineBreaks.pdf

AWWA - M28, Rehabilitation of Water Mains, Second Edition, 2001

AWWA - M22, Sizing Water Service Lines and Meters, Second Edition, 2003

Table 3.3 summarizes some of the common problems that lead to pipe failures for pipes of differing materials. These include some of the principal factors, but they are not the only factors that act individually or in combination to cause a main break. Other factors could include a street excavation that accidentally disturbs a water main or the misuse of fire hydrants.

3.3 Distribution System Pumps

Within a distribution system, pumps are used to discharge water under pressure to the pipe network, to boost pressure within a system and also to lift water to a higher elevation where it can then be delivered by gravity (e.g., elevated water storage tanks). Pumps can be classified into two basic groups: positive displacement and variable displacement pumps. A positive displacement pump delivers the same volume or flow of water against any “head” within its operating capacity. Head is the vertical distance between a pump and water outlet, usually measured in feet or converted and expressed in equivalent pressure scale. Examples include: piston pumps, screw pumps, diaphragm pumps and gear pumps. Variable displacement pumps deliver water with the volume or flow varying inversely with the operating head (i.e., the greater the head, the less the volume of the flow). Examples include: centrifugal pumps, jet, and airlift pumps. Appropriate pumps are selected based on the desired application.

Centrifugal pumps are used widely in water distribution systems because of several advantages including: 1) low cost and small footprint for a given capacity, 2) a rotary mechanism that allows for adaptability to high-speed driving mechanisms such as electric motors and gas engines, 3) simple mechanism, easy for operations and repair, and 4) safety against damage from high-pressure because of limited maximum pressure that can be generated.

Table 3.3 Common Problems that Lead to Pipe Failure for Various Pipe Materials (NRC, 2006)

Pipe Material (common sizes)	Common Problems
PVC and Polyethylene (4−36 in.)	Excessive deflection, joint misalignment and/or leakage, leaking connections, exposure to sunlight, high internal water pressure or frequent surges in pressure, exposure to solvents, manufacturing flaws
Cast/Ductile Iron (4−64 in.) (lined and unlined)	Internal corrosion, joint misalignment and/or leakage, external corrosion, leaking connections, casting/manufacturing flaws
Steel (4−120 in.)	Internal corrosion, external corrosion, excessive deflection, joint leakage, imperfections in welded joints
Asbestos-Cement (4−35 in.)	Internal corrosion, cracks, joint misalignment and/or leakage, small pipe can be damaged during handling or tapping
Concrete (12−16 to 144−168 in.) (prestressed or reinforced)	Corrosion in contact with ground water high in sulfates and chlorides, pipe is very heavy, alignment can be difficult, settling of the surrounding soil can cause joint leaks

Many brands of centrifugal pumps are available in the U.S. with capacities ranging from a few gallons per minute (gpm) to several thousand gpm. Working heads can range between 5 to 700 feet, but the efficiency of each pump is limited to a narrow range of discharge flows and head. Careful consideration must be given to these factors prior to pump selection.

3.3.1 Common Problems, Troubleshooting and Maintaining Pumps

During startup, centrifugal pumps require "priming." Priming is a procedure in which the pump is filled with water before turning the switch on. The unit does not operate efficiently if it is not properly primed. In general, pumps have an adjacent priming chamber that draws water when the pump is turned on to keep the impeller submerged. After priming, the pump must be started with the discharge valve fully closed. Thereafter, the discharge valve must be opened slowly to allow any air in the system to escape and prevent water hammer or pressure surges. A surge of pressure occurs when a valve is suddenly closed or opened. This surge can cause the pipes to vibrate or create a hammering noise. Also, at shutdown or during power failures, the discharge valve must be programmed to close in order to avoid backflow and prevent the impellers from running in reverse.

Because of the variety of pumps available, individual procedures for proper operation of each pump vary by manufacturer. A utility operator should refer to manufacturer instructions while operating and troubleshooting the pumps. Centrifugal pumps require regular inspection and maintenance. Bearings on the motor may become worn and must be checked and kept well-lubricated. The packing seals must be examined for wear due to friction that can result in pump leakage. Bearing and motor temperature must be monitored for excessive heat. If a surface is substantially hotter than normal, the unit must be shut down and examined for the cause. Any unusual noises or vibrations from the pump should also be thoroughly investigated by shutting down the unit first. Prior to performing any maintenance activity on the pump, the pump must be shut down and drained of all liquids before servicing. Electrical safety procedures must also be followed while servicing motors. All safety instructions provided by the manufacturer must be followed during the performance of maintenance activities.

Additional Information

Pumps

AWWA - Water Transmission and Distribution: Principles and Practices of Water Supply Operations, 3rd edition, 2003

AWWA- Design and Construction of Small Water Systems, 2nd edition, 1999

3.4 Distribution System Storage Facilities

Distribution system storage facilities (tanks and reservoirs) are necessary to accommodate peak flow (equalizing storage), emergency demand, and firefighting capabilities. In addition, they help maintain uniform pressure and allow for reduction in the size of distribution mains that would otherwise be much larger to accommodate peak flow requirements. Storage also reduces pumping costs under peak energy periods. Generally, these storage facilities are designed and located such that they can provide water at the required pressure to the farthest location in the service area.

3.4.1 Types of Storage Facilities

Ground level reservoirs and tanks, elevated tanks and hydro-pneumatic tanks are designed for multiple uses including: equalizing storage, maintaining pressure in the system, and providing firefighting capabilities. Equalizing storage is necessary when the source pump capacity is less than the peak system demand. This storage is also essential for water production facilities to run at a constant rate. Smaller distribution systems with wells and relatively flat topography may use a hydro-pneumatic tank to maintain water pressure. A hydro-pneumatic tank is an air-pressurized water tank. The air in the tank acts as a cushion that can exert or absorb pressure as required. The two common methods employed for air-charging the tanks are: motor-driven air compressors and hydraulic-powered air chargers.

The storage volume requirements for tanks are classified by function: operating, equalizing, fire and/or emergency, and dead storage volume. The typical minimum municipal fire flow requirement for a single-family residential area is 500 to 1,000 gpm for two hours, which is equivalent to a minimum storage requirement of 60,000 to 120,000 gallons. For commercial and industrial areas, the fire flow requirement ranges between 2,000 and 8,000 gpm for several hours which is equivalent to a storage requirement of ~500,000 gallons to over a million gallons. Some local fire and state agencies allow for combining fire and emergency storage requirements. Figure 3.5 illustrates the typical storage tank volume design parameters.

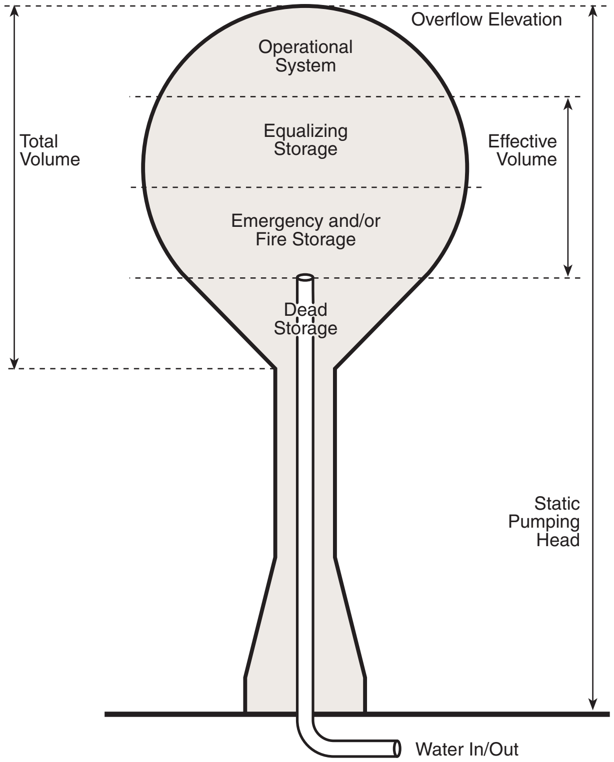


Figure 3.5 Storage Tank Volume Design Requirements

Depending upon the size and location-specific requirements, tanks may be constructed using steel (welded or bolted, carbon or stainless), concrete, fiberglass, or plastic (polyethylene, polypropylene). The type of material used for the tank depends upon many factors including: 1) location of the water tank (indoors, outdoors, above ground or underground), 2) volume (larger tanks are generally made of steel), 3) temperature and wind in the area where water will be stored (concern for freezing and structural strength requirements). In addition to selecting appropriate tank material, all piping, joints and fittings should conform to regulatory design specifications. Steel tanks are most widely used by water utilities in the U.S. Steel tanks are required to be painted and to have cathodic protection to resist corrosion.

Additional Information

Storage Tanks

AWWA - M25, Flexible-Membrane Covers and Linings for Potable-Water Reservoirs, Third Edition, 2000

AWWA - M31, Distribution System Requirements for Fire Protection, Third Edition, 1998

AWWA - M42, Steel Water-Storage Tanks, First Edition, 1998

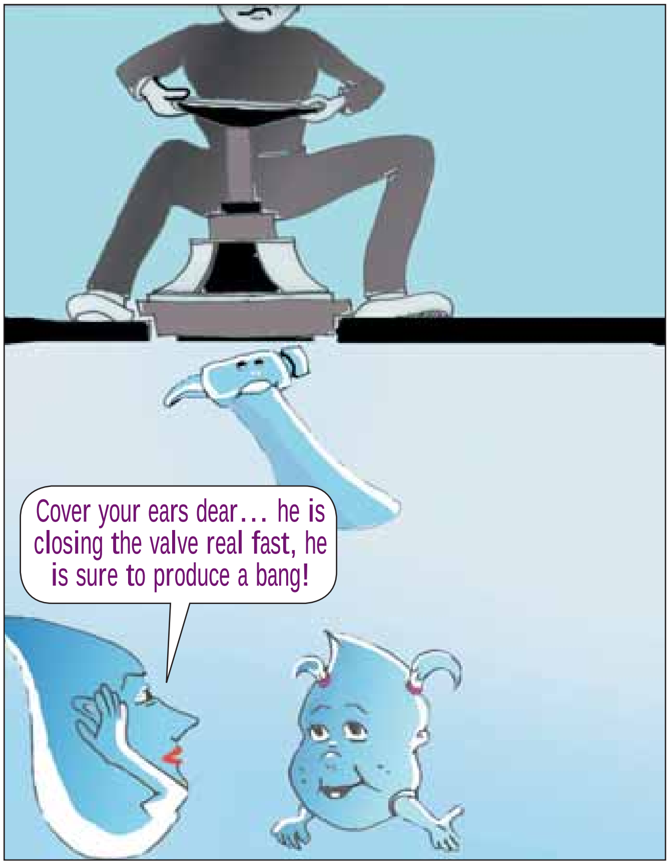
3.4.2 Common Problems, Troubleshooting and Maintaining Tanks

Water storage facilities (tanks) must have covers or hatches that keep out birds, rodents, insects, dust and surface runoff. They must also have a screened vent which allows air to enter and leave as the water level drops or rises in the tank. Outside access to the storage facility must be lockable and weather-tight. Lack of proper hatches and vents may result in dead animals and/or birds floating in the tank which can create serious health problems. Tanks should be routinely inspected (for corrosion and structural integrity) and cleaned. Water tanks are confined spaces and a confined-space warning label must be placed on tank access. Confined-space entry procedures must be followed by anyone entering the tank. For larger tanks, commercially trained divers and/or remotely controlled underwater robotic systems can be used for inspection and/or cleaning. The use of divers and/or robotic devices requires special precautions and procedures, especially if the tank is allowed to remain in service during inspection/cleaning procedures.

Tanks that are improperly operated can lead to excessive “aging of water” or areas of poor circulation. Excessive storage time can lead to a loss of disinfectant residual (chlorine/chloramine) which can result in bacterial regrowth. In addition, the disinfectant can react with naturally occurring organic matter to form greater levels of undesirable byproducts that may pose long term health problems. Poor circulation can lead to "dead" or static zones where the water may be much older than the average age in the storage facility. Stratification is an example of poor mixing where the water age and characteristics vary in the vertical direction in the tank. This is most common in tall standpipes and in tanks where there is insufficient energy in the inflow during the fill cycle to create a well-mixed tank. Water aging can be reduced by changing the tank operation so that there is a greater exchange of water between the tank and the distribution system. Mixing problems can frequently be relieved by modifying the inlet-outlet configuration and/or increasing the inflow rate and velocity.

3.5 Distribution System Valves

Valves are critical for management of the distribution system. Valves control flow/pressure, and isolate portions of the water distribution system for servicing. If valves are properly placed, distribution system pipe repairs and maintenance can be conducted with minimal loss of service to the customer. Most valves require some mechanical or externally devised system to open/close or change the position of the valve. Manually operated actuators, or electromechanically actuated mechanisms are installed on valves to allow proper operation.



In newer installations, it is common to use automatic valves. The valve types generally used in water distribution systems include: gate, butterfly, check, control, pressure reducing, pressure relief, altitude, and air-and-vacuum relief. A brief overview and general function of the most commonly used valves are presented in the following sections.

3.5.1 Gate Valves

Gate valves are used to isolate distribution system sections. A sliding gate is moved up or down to block the flow. The purpose of the valve is to completely stop the flow and not to regulate it. These valves should not be opened or closed too rapidly. Rapid valve operation can cause a phenomenon known as "water hammer" or pressure surge that can seriously damage distribution system components. Water hammer is caused by the sudden increase in pressure of water caused by the conversion of the kinetic energy of the water in motion to static energy when it is forced to stop. Under extreme conditions, this pressure surge may cause the pipes to vibrate and/or create a hammering noise. Figure 3.6 illustrates a gate valve.

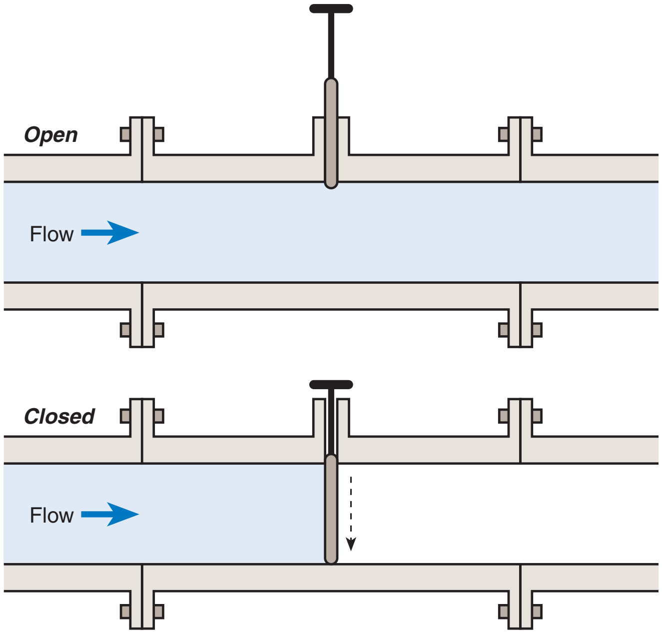


Figure 3.6 Gate Valve (side view)

3.5.2 Butterfly Valves

A butterfly valve consists of a round disk attached to a shaft in the pipe. Rotating the shaft by 90 degrees (one quarter turn) opens or closes the valve. In the open position, the disk is parallel to the flow of water. These valves are commonly used for larger diameter pipes. Similar to gate valves, these valves should not be opened or closed too rapidly in order to avoid water hammer. Figure 3.7 illustrates a butterfly valve.

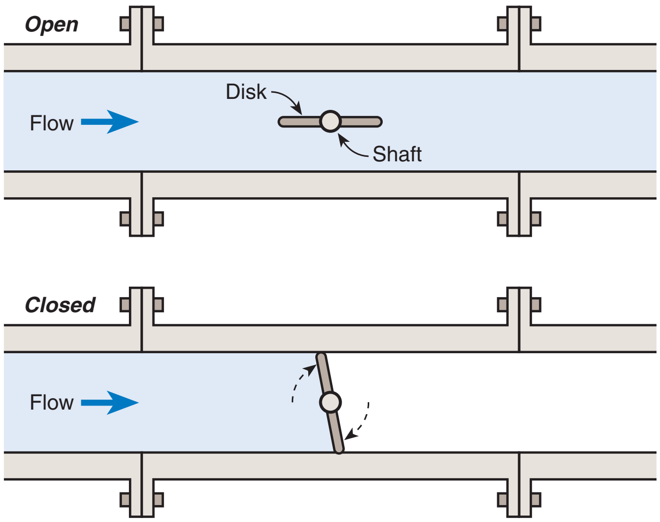


Figure 3.7 Butterfly Valve (top view)

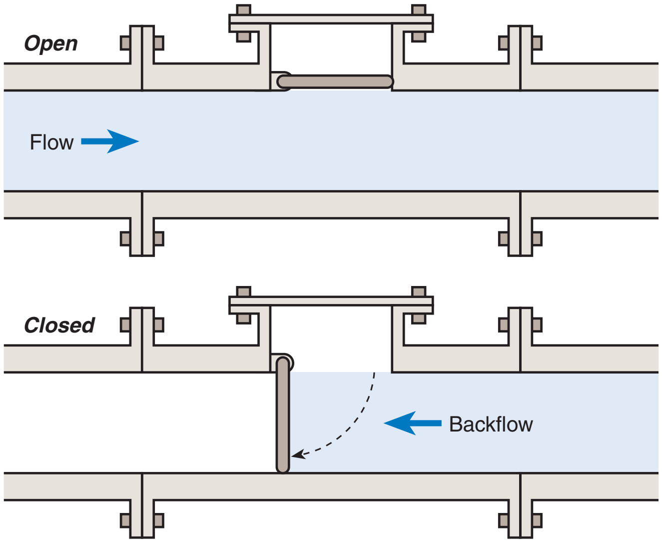


Figure 3.8 Swing Check Valve (side view)

3.5.3 Check Valves

Check valves are designed to allow flow in only one direction. One common application of this valve is on the discharge side of a pump to prevent backflow when it is shut down. A variety of devices (e.g., weights, springs, motors) are available to dampen the closing of valves to minimize water hammer. Figure 3.8 illustrates a swing check valve.

3.5.4 Other Valves

Control valves are used to regulate flow between a fully opened and a fully closed position. Control valves are almost always equipped with some sort of actuator mechanism to provide ease of operation.

There are many types of pressure regulating and flow control valves. For example, a pressure sustaining valve tries to maintain a constant upstream pressure, whereas a pressure reducing valve maintains a constant downstream pressure. An altitude valve is a self contained pressure regulating valve that is used to control the flow into a tank in order to prevent water overflow. These valves are balanced to use the line water pressure as the operating motive. For example, when the tank level rises to a specified upper limit, the valve closes to prevent any further flow from entering, thus eliminating overflow. When the flow trend reverses, the valve reopens. In some places, high- and low-level tank indicators are also used to control flow.

Pressure relief valves are installed to relieve excessive internal pressures (such as surge pressures) in a hydropneumatic tank as the excessive pressure may lead to ruptures.

Air and vacuum valves, commonly referred to as air release/vacuum breaker valves, are used to remove air from system components. For example, deep-well pumps are equipped with air release valves to exhaust large quantities of air very rapidly from a deep-well pump column when a pump is started.

3.5.5 Common Problems, Troubleshooting and Maintaining Valves

Valves in constant use have parts that wear out and require routine maintenance. In addition, valves that are not used regularly may not function when the need arises. Valves can stick (due to deposition or rust formation and growth of biofilm on the operating surface) and even break (weakened by corrosion) if neglected. A valve exercise program is a necessary part of water distribution system maintenance.

In cases where there is a high-pressure drop through a valve, it can lead to a number of immediate problems such as cavitation, flashing, choked flow, high noise levels and vibration. Over the longer term, it degrades system efficiency and results in higher pumping costs.

Additional Information

Valves

A NDWC Tech Brief on valves can be obtained online from: http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/OT_TB_Su02.pdf

AWWA - M44, Distribution Valves: Selection, Installation, Field Testing, and Maintenance, Second Edition, 2006

AWWA -M49, Butterfly Valves: Torque, Head Loss, and Cavitation Analysis, First Edition, 2001

AWWA - M51, Air-release, Air/Vacuum and Combination Air Valves, First Edition, 2001

3.6 Distribution System Hydrants

Two types of hydrants are used in a distribution system: flush hydrants and fire hydrants. Flush hydrants are generally installed in a pit and have nothing projecting above ground. These hydrants are placed at the end of lines to remove accumulated corrosion products from dead-ends. Flush hydrants should also be installed throughout the system to provide for periodic flushing to maintain high water quality. Sometimes, flush hydrants are mistaken for fire hydrants. Fire hydrants are larger in size. Fire hydrants are classified into two basic categories: wet barrel and dry barrel. Wet barrel hydrants are designed to be used only in areas of the country where the temperature never drops below freezing, since these units are always charged with water. Dry barrel hydrants are predominantly used in the U.S., and designed to automatically drain water after the water is turned off. Figure 3.9 illustrates a dry barrel hydrant.

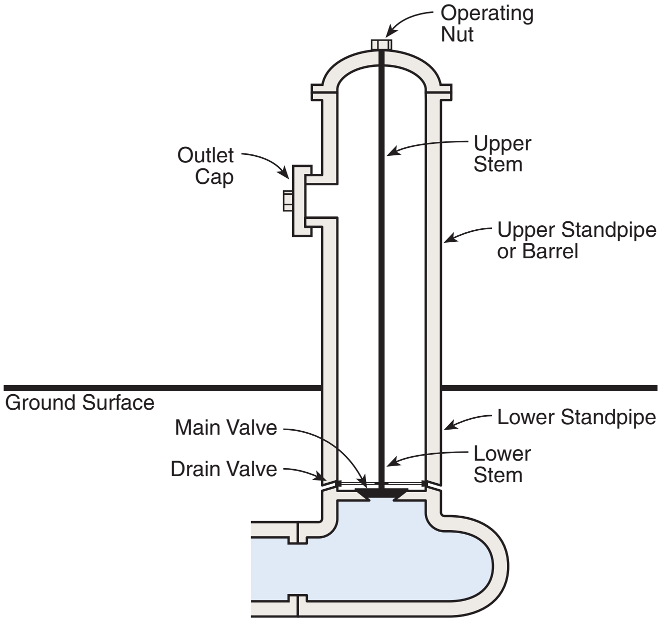


Figure 3.9 Dry Barrel Hydrant

Fire Hydrant History (Adapted from Rader, L. undated):

In colonial America, cisterns were used to store water for early fire fighting purposes. Around the time of the American Revolution, several American communities had built water distribution systems. These early systems used wooden main lines that workers had built using bored-out logs. The logs were fitted together and buried. When fire fighters needed water, they uncovered the wooden line and bored a hole in the pipe wall. They used the water that collected around the pipe for fighting the fire. After the fire was put out, a tapered wooden plug was driven into the hole in the pipe wall and the location of the hole was marked with the "fireplug." Later, when cast iron became the material of choice for water lines, it became harder to bore the hole. However, water systems installed tees with wooden plugs at convenient locations and the wooden fireplug continued for several more years. The hydrant's evolution included a standpipe that fire fighters shoved into the tee after they removed the fireplug. It conveyed water above ground to a hose connection and a ball valve, and it finally made the wooden plug obsolete. This setup was the forerunner of the dry-barrel compression hydrant. Cisterns continued to be used even after the introduction of the hydrant in many cities. As late as 1861, the city of Louisville, Kentucky employed 124 cisterns but no fire hydrants. Cisterns are still used today for firefighting.

3.6.1 Common Problems, Troubleshooting and Maintaining Hydrants

Hydrants should be opened and closed slowly to avoid water hammer effect. Dry barrel hydrants should always be fully opened because operation of the drain mechanism is linked to the main valve. A partially opened hydrant causes water to leak through the base which can cause erosion around the base of the hydrant. Dry barrel hydrants need a supply of air to drain properly. Therefore, the caps should not be tightened until the unit finishes draining. Hydrants should be inspected on a routine basis for operability and leaks. Many different brands and models are available in the U.S. It is important that parts provided or recommended by the manufacturer be used for servicing each unit. Hydrant

Additional Information

Hydrants

A NDWC Tech Brief on how to begin a fire hydrant operation and maintenance program can be obtained online from: http://www.nesc.wvu.edu/ndwc/pdf/OT/TB/OT_HowTo_f02.pdf repair requires specialized tools that are available from the manufacturer; using other tools may result in unnecessary damage and lead to the early failure of the unit.

3.7 Water Meters and Service Lines

Water meters are generally considered to be the last connection in the portion of the distribution system owned by a utility before water is delivered to the customer. They are extremely important because they measure the customer's water usage and are the basis for billing customers for money to support the utility's operation. In larger utilities, wastewater charges are frequently based on water meter readings. A service line carries water from the main to the water meter and/or curb stop or to a customer's building plumbing. Meters are generally the property of the water utility, but there are wide differences across the country with regard to the ownership of service lines. Residential or building plumbing is almost always the property of the home or building owner.

3.7.1 Water Meters

A water meter is a device used to measure the volume of water usage. Water meters are used at the service line inlet to a residential and commercial building in a PWS. Water meters can also be used at the water source, well, or throughout a water system to determine flow through that portion of the system. Water meters in the U.S. typically measure and display total usage in cubic feet, or U.S. gallons on a mechanical or electronic register. Water meters are also used to generally define ownership and responsibility. For example, maintenance and repair of pipes on the "street side" of the water meter is the responsibility of the PWS, and the customer/property owner is responsible for the maintenance and repair of pipes and plumbing on the "customer side" of the water meter.

There are several types of water meters in common use. Selection is based on different flow measurement methods, the type of end user, the required flow rates, and accuracy requirements. In U.S., standards for manufacturing of water meters are made by the American Water Works Association. Positive Displacement (PD) meters are most commonly used and are generally very accurate at low to moderate flow rates typical of a residential user and a small commercial user. Common PD meters are sized between 5/8 and 2 inches. Because these meters rely on water flowing through the meter to "push" the measuring element, they are generally not practical in large commercial applications requiring high flow rates or low pressure loss. See Section 6.2.1 for other types of flow meters.

PD meters normally have a built-in strainer to protect the measuring element from rocks or other debris that could stop or break the measuring element. PD meters normally have bronze, brass or plastic bodies with internal measuring chambers made from molded plastics and stainless steel. Most meters in a typical water distribution system are designed for cold potable water only. There are other water meters manufactured for specific uses. For example, hot water meters are designed with special materials that can withstand higher temperatures. Meters for reclaimed water have special lavender register covers to signify that the water is non-potable and should not be used for drinking.

Water meters are generally owned, read, and maintained by the PWS. In some cases, an owner of a mobile home park, apartment complex or commercial building may be billed by a utility on one meter, and the cost of the bill is shared among the tenants. In these cases, the complex owner may purchase private water meters to separately track usage of each unit in what is called submetering.

3.7.2 Service Lines

A service line carries water from the main to the water meter and/or curb stop. A curb stop box refers to the enclosure which houses a valve. In case of an emergency or service disconnection, this valve is used to shut-off water service to the individual customer. Most curb stop boxes are not boxes, but cast iron housings with a pipe that extends to the ground level with a removable cover. The valve is accessed with a special wrench which is slid down the pipe and turns the valve off and on. A meter stop is a valve placed on the street side of the water meter to isolate the water meter for installation or maintenance. Many codes require a gate valve on the customer side of the meter to shut off water for performing customer plumbing repairs.

3.7.3 Common Problems, Troubleshooting and Repairs

Water meters are generally well built, and require minimal maintenance if installed correctly. If a meter is in need of repair, it will generally under-register rather than over-register the customer's water use. Because they are very accurate, they can be used to identify leaks in a customer's plumbing. For example, if a customer reports excess usage bill, the first step would be to shutoff all water use in the building and observe if the meter is still moving. In case the meter registers usage, it is very likely that the customer plumbing contains a leak. The customer should be recommended to obtain the services of a licensed plumber to isolate and correct the problem. Even small leaks over time can result in significant water loss and resulting cost to the customer.

The majority of water leaks in a distribution system occur in service lines, service fittings, and connections including ferrules, curb stops, valves and meters. In addition, customer's plumbing and service lines have longer residence times, more stagnation, lower flow conditions and elevated temperatures than normally found in distribution systems and can have a negative effect on the quality of water supplied to the customer.

Therefore, service lines and their fittings provide the greatest potential for intrusion and subsequently for outside contamination to enter the distribution system. Compared to the main water distribution systems, less is known about the types and causes of service-line failures than for other components of the distribution system. Some possibilities include:

- Internal and external corrosion
- Poor installations such as improper backfilling techniques and materials
- Damage during handling
- Improper tapping

Many times during landscaping of the home, the curb stop access is buried or damaged. The cover lid can also be damaged, allowing debris to block access to the valve. Locating and marking the curb stop on a customer's property line can save time and money during an emergency when water needs to be shut off. The curb and meter stop valves are not designed for frequent use and can be ruined in a short time if used very frequently.

Because of the wide variation in ownership service lines, it is difficult to identify the party that should take responsibility for their maintenance. This lack of clear responsibility can complicate the extent to which service lines are inspected, replaced, and repaired. In most cases, a drinking water utility only assumes responsibility for the quality of water delivered to the curb stop or water meter. For the portion of the service line owned by customers, the responsibility and cost of repairs falls on the customer.

Service Line/Water Meter Repair (NRC, 2006)

A recent report published by the National Research Council of the National Academies highlighted the issue of service lines and residential plumbing and their contribution to the deterioration of water quality. A waterborne disease outbreak that occurred in Cabool, Missouri, in the winter of 1989-1990 was partially attributed to the need to replace a large number of water meters in the distribution system at the same time as the sewage overflow occurred. The town had a population of approximately 2,100 people. A total of 243 cases of *E. coli* O157:H7 was reported, with 32 hospitalizations and four deaths. It was the first documented waterborne outbreak of *E. coli* O157:H7 ever reported.

3.8 Distribution System Asset Management

Distribution systems typically represent a water utility's largest capital investment. In order for a distribution system to operate at peak performance, its status must be continuously assessed. The Asset Management (AM) concept has emerged as an important mechanism for tracking and evaluating distribution system operation and maintenance (O&M) needs. The key focus of asset management is to minimize the amount of money necessary to own, operate, and maintain a distribution system asset (e.g., pumps, pipes, hydrants, and tanks) over its useful life. One key feature of an AM system is to track the installed life of a distribution system asset.

Asset Management (NMEFC, 2007)

In 2005, the New Mexico Environmental Finance Center (NMEFC) conducted an AM study for the Arenas Valley water distribution system in New Mexico. The Arenas valley water system purchases finished water from Silver City. The primary distribution system assets included: relatively new PVC pipe installed in the 1980's (approximately 20 miles of pipe), approximately 430 service connections, 25 hydrants and 100 valves. When the study was initiated, the utility was concerned that a substantial portion of the system's PVC pipe had degraded/failed and needed replacement. During the process of developing a comprehensive AM database, a pipe break event map was created depicting the 26 breaks previously recorded. Figure 3.10 shows the pipe break event map, which indicates that the majority of the breaks were service-line leaks and two of the 26 breaks were caused by a service-line tap. This pipe break map allowed the utility board to see that these pipes were not degrading as originally suspected, and therefore did not need replacement. Also, a better grasp on assets and Level Of Service requirements allowed the utility board to see that it was more valuable to install new pipe that would create some loops in the distribution system, improving both service and possibly water quality.

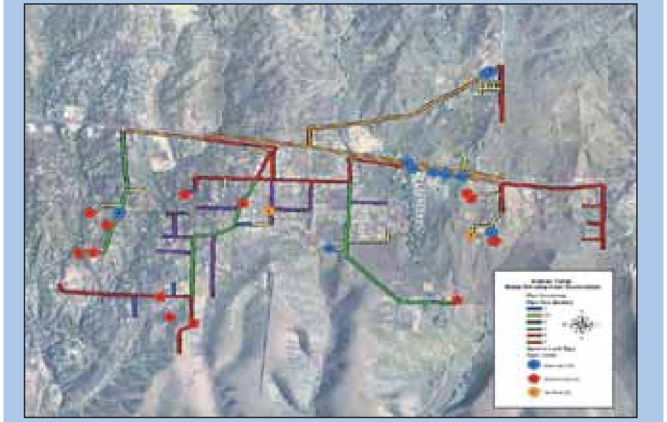


Figure 3.10 Arenas Valley Pipe Inventory and Main Break Map

The "expected useful lives" of distribution system components are theoretically known and depend upon construction material, location, and environmental conditions. For example, the expected useful life of distribution system components is as follows: pipes – 35 to 50 years; hydrants – 40 to 60 years; valves – 35 to 40 years; storage tanks – 30 to 60 years; pumps – 10 to 15 years. Though these are typical values for expected useful life, there are always exceptions and it is not unusual, for example, to find some 100-year old pipes that are still in good condition. Generally speaking, when a specific asset begins to exceed its "useful life," it needs to be inspected periodically and reevaluated for replacement. For example, if the average age of the hydrants is documented as 50 years in the AM database, it is likely that a majority of the hydrants are near the end of their useful lives and would need to be replaced fairly soon or evaluated on a regular basis. Basically, a good AM system contains a comprehensive equipment inventory, and is closely linked to the Level of Service (LOS) concept. LOS clearly defines performance goals and can be periodically used to define where, when, and how resources must be expended. The LOS defines a utility's commitment to the customer and its goals must be measurable. For example, a water utility might define its LOS as follows:

- Main breaks will be repaired within 8 hours of initiation of repair 90 percent of the time.
- Regulatory water quality requirements will be met 100 percent of the time.
- Monthly water losses will be kept to less than 15 percent .
- Customer complaints will be responded to within 24 hours.

These LOS requirements make it possible for a utility to prioritize its O&M activities in order to meet these goals. For example, if monthly water losses average greater than 20 percent, the utility would initiate some type of water audit and leak detection program.

The heart of any utility AM system is a complete inventory of the pipes, tanks, pumps and other facilities that make up the distribution system, coupled with a system for recording and tracking the status of those assets. Historically, information on distribution system assets has been kept in the form of maps and paper records. In recent years, many larger water utilities have moved to computerized mapping and database management systems. Commercial AM software packages are now readily available. However, most small- to medium-sized water utilities continue to use paper records as the primary method for tracking assets. In many cases, electronic AM takes a backseat to other utility functions such as electronic billing and electronic reporting (which may be required by regulations). Expenditures for commercial AM software packages and their associated labor costs are generally perceived as being too expensive for most small- and medium-sized systems. The resulting lack of effective tracking often results in a delay or deferment of needed repair and maintenance of distribution systems.

An economical solution to AM inventory and record-keeping is the use of general spreadsheet or database management software typically available on most personal computers. These systems can be augmented by mapping software (Geographic Information System [GIS] or Computer Aided Design and Drafting [CADD]). As an alternative, a utility may continue to use paper-based maps.

CADD and GIS are more advanced geographic-based computer systems that allow the user to store, display and analyze spatial data. Historically, CADD packages have been used by engineers and draftsmen in the design of facilities. GIS grew out of the planning and mapping fields as a means of constructing maps and analyzing spatial data. The two fields have moved closer together in terms of concepts and software and both are used today as a basis for designing, analyzing and displaying water distribution systems.

Table 3.4 provides a listing of the popular low-cost CADD and GIS mapping software.

3.9 Distribution System Modeling

Distribution systems are designed to provide customers with needed flow at an acceptable pressure level. Some questions frequently asked regarding the design and operation of a distribution system are as follows:

Table 3.4 Listing of Low-cost CADD and GIS Application Software

CAD Mapping Software				GIS Mapping Software					
Product	Virtual Drafter V2.2	IntelliCAD	TurboCAD Deluxe V14	GRASS V6.2	JUMP V1.2	Map Window GIS V4.4	Forestry GIS V1.0	Manifold System V6.5	Tatuk GIS Editor V1.8
Vendor	Softsource	IintelliCAD Technology Consortium	IMSI/Design	GRASS Technology Consortium	Vivid Solution	Map Window Open Source Team	Forest Pal	Manifold.Net	TatukGIS
Web site	http://www.vdraft.com/vdraft.html	http://www.intellicad.org/	http://www.turbocad.com/	http://grass.itc.it/	http://www.vividsolutions.com/	http://www.mapwindow.org/	http://www.forestpal.com/Toolbox.html	http://www.manifold.net/	http://www.tatukgis.com/products/Editor/Editor.aspx
Cost	$250	Basic - $149, w/ Service Contract $249 Pro Version - $349	Deluxe - Price Varies from $100-$150	Free (Open Source)	Free (Open Source)	Free (Open Source)	Free; Version of software is frozen in time	Personal - $245/$295; Professional - $295/$345	$350, Free Viewer Available
Ease of Use	Medium	Easy/Medium	Easy/Medium	Difficult	Difficult	Medium/Hard	Medium	Medium/Hard	Medium/Hard
Operating systems supported	Microsoft Windows 95, 98, ME, NT, 2000 and XP	Microsoft Windows 2000, XP and Vista	Microsoft Windows XP and Vista, Macintosh 10.4+	Microsoft Windows 2000, XP, Mac 10+, Linux	Microsoft Windows 2000, XP, Mac 10+, Linux	Microsoft Windows 95, 98, ME, NT, 2000 and XP	Microsoft Windows 95, 98, ME, NT, 2000 and XP	Microsoft Windows 95, 98, ME, NT, 2000, XP and Vista	Microsoft Windows 95, 98, ME, NT, 2000, XP and Vista

- How is a distribution system designed and operated to satisfy the acceptable flow and pressure objectives?
- How can one determine the flow available to fight a fire in a particular neighborhood on a hot summer day?
- How can one determine the consequences of taking a tank out of operation to perform maintenance activities such as painting?
- If an extension to the water system is built to serve a new development, what will be the pressure and will there still be an acceptable chlorine residual in the water delivered to the new service area?

Computerized network models can assist in providing answers to these questions. These models are also referred to as distribution system models or hydraulic and water quality models. Computerized network models perform calculations based on mathematical descriptions of flow and pressure. The basic formulation of these models dates back to the work of Professor Hardy Cross in the 1930s. Today, these models are packaged in an interactive graphical format that makes the data entry and analysis of results relatively easy. Figure 3.11 is a computer screen shot depicting the results of an analysis of the SmallWater distribution system using the EPANET software package (available from EPA). Color coding and arrows are displayed in order to show flow magnitude and direction, and pressure at junctions.

A distribution system is represented as a network model of links and nodes. Links represent pipes, while nodes represent junctions, sources, tanks or reservoirs. Valves and pumps are represented as either nodes or links depending on the specific software package. In order to "build" a network model, the location and connectivity between each network component must be known. Additionally, the following basic information is required for the various types of components:

- Pipe: length, diameter, roughness
- Junction: elevation, water use
- Tank: diameter or dimensions, elevations
- Reservoir: water level

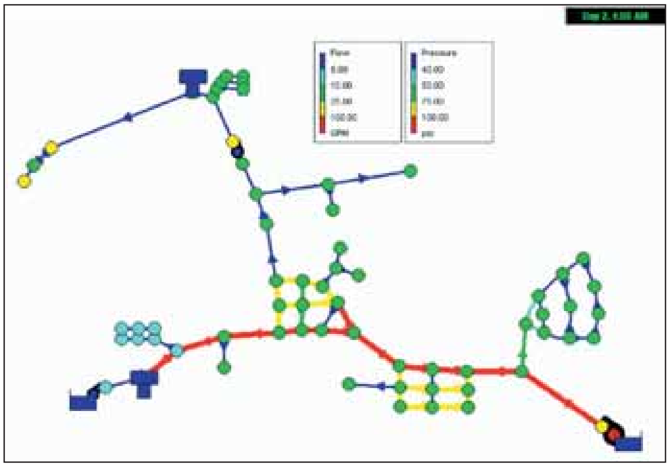


Figure 3.11 Screen-shot Showing the Results of an Analysis for the SmallWater Distribution System

- Pump: head-discharge curve, intial status
- Valve: type, settings

There are two types of hydraulic analyses that may be conducted using a drinking water distribution system network model: steady-state and extended period simulation (EPS). In a steady-state analysis, all water demands and operations are treated as constant over time and a single solution is generated. Steady state analysis is useful for assessing a distribution system under a particular set of circumstances. For example, a steady state model could be used to estimate the amount of water available to fight a fire and the resulting pressures in a particular neighborhood on a hot summer day.

In the EPS mode, variations in demand, tank water levels and other operational conditions are simulated by a series of steady-state analyses that are linked together in order to represent the changes in flows and pressures over time. EPS can be used to investigate distribution system operation, study the behavior of tanks and pumps, assess energy usage, and serve as the basis for water quality modeling. Figure 3.12 illustrates plots from an EPS model of SmallWater showing the variation in tank water levels and flow in a water main over a 2-day period. EPS models are "built" starting with a steady-state model. Additional information that is needed for an EPS model include: variation in water use (demands) over the course of a day, operating rules that describe how pumps and valves are operated and minimum and maximum allowable water levels for tanks.

Water quality models use the output from hydraulic models in conjunction with additional inputs to predict the temporal and spatial variability of a variety of constituents within a distribution system. These constituents include:

- the fraction of water originating from a particular source

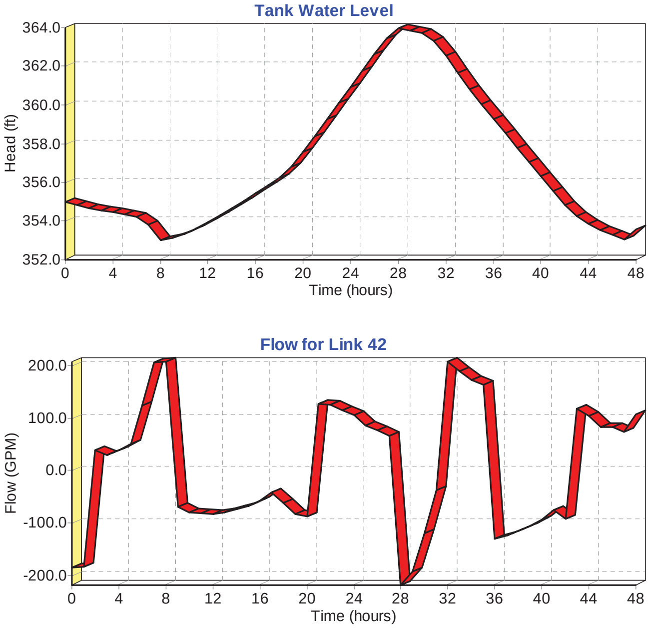


Figure 3.12 EPS Plots of Tank Water Levels and Flow in a Water Main Over a 2-Day Period.

- the age of water (i.e., duration since leaving the treatment plant)
- the concentration of a non-reactive tracer compound either added to or removed from the system (e.g., fluoride or sodium)
- the concentration of a reactive compound including the concentration and loss rate of a secondary disinfectant (e.g., chlorine or chloramines) and the concentration and growth rate of disinfection by-products (e.g., trihalomethanes [THMs])

EPANET was initially developed in 1993 as a distribution system hydraulic-water quality model to support research efforts at the EPA. The development of the EPANET software has also satisfied the need for a comprehensive public sector hydraulic/water quality distribution system model. It has been a key component in providing the basis for water quality modeling incorporated into many commercial models and has been used by many utilities throughout the country. In addition to EPANET, there are several commercial software packages that are widely used in the United States and internationally. Many of these packages are based on the EPANET formulation and include value-added components that increase the capability of the software. Table 3.5 provides a summary listing of available commercial software and a Web link where additional details may be obtained on specific features, current versions, availability and pricing.

Table 3.5 Available Hydraulic-Water Quality Network Modeling Software Packages

Network Modeling Software	Company	Website
AQUIS	7-Technologies	http://www.7t.dk/company/default.asp
EPANET	U. S. EPA	http://www.epa.gov/ORD/NRMRL/wswrd/epanet.html
InfoWater H2ONET/H2OMAP	MWHSoft	http://www.mwhsoft.com
InfoWorks WS	Wallingford Software	http://www.wallingfordsoftware.com/
MikeNet	DHI	http://www.dhisoftware.com/mikenet/
Pipe2000	Univ.of Kentucky	http://www.kypipe.com/
PipelineNet	TSWG, SAIC	http://www.tswg.gov/tswg/ip/PipelineNetTB.htm
STANET	Fisher-Ulrig Eng.	http://www.stanet.net
SynerGEE Water	Advantica	http://www.advantica.biz/
Wadiso	GLS Eng. Software	http://www.wadiso.com
WaterCAD/WaterGEMS	Bentley Systems	http://www.bentley.com

3.10 SmallWater, USA – Asset Management Problem Scenario

SmallWater has been experiencing a rapid turnover of operators. Often, during these personnel changes, one operator has left before another is fully trained. Consequently, much of the on-duty operator's time has been spent in locating seemingly misplaced maintenance records. Repair problems seem to be increasing. The utility's managers are increasingly concerned that the loss of trained operators, personnel turnover and misplaced records are jeopardizing the utility's ability to meet long-term water quality goals, to develop an O&M plan, and to meet their overall LOS requirements.

Issues to Consider

SmallWater does not have an AM system in place. It has limited finances to purchase commercially available AM software and is limited in its ability to provide training to operators for developing an in-house AM system.

Guidance

In order to solve these problems, it is recommended that the utility investigate the use of a simple spreadsheet- or database-based AM system. Prior to selecting an AM system to track inventory and event data, the utility staff should examine its needs and determine which AM system provides the best fit. If utility personnel are not familiar with the use of spreadsheet or database management software, there are many readily available resources that can help provide training. These resources include local software specialists, community colleges, and vendors. Also, there are many books that can provide a good overview of available software packages. Once data are entered into a spreadsheet or database management system, the data can be sorted or filtered and custom reports can be generated. To be effective, this system should be viewed as a means for efficient O&M, not merely a recordkeeping tool.

The key to successful inventory and recordkeeping is the identification of all distribution system assets and assignment of a unique identifier to each separate asset component. Figure 3.13 shows the SmallWater distribution system with each component color coded. Each component type is assigned a letter (or letters) and within that component type, individual items are assigned a unique number. For example, T-2 refers to tank number 2 and P-30 refers to pipe number 30. Individual pipes are categorized as continuous "runs" between junctions, where pipe characteristics (diameter or material) may (or may not) change at other important locations such as a tank, pump or major water users.

For each component, additional information of interest can be collected and stored in the database. For example, the following information would likely be stored for pipes:

- Pipe number
- Street name
- Diameter
- Length
- Material
- Date installed or replaced

Other types of information could easily be stored. For example, in addition to the components shown in Figure 3.13, inventory data on hydrants and isolation valves could be kept. Figure 3.14 shows the location of hydrants in parts of SmallWater and the accompanying Table 3.6 contains useful hydrant inventory information. This type of data could be useful and provide the basis for an inventory of assets. It is usually referred to as static data since it remains relatively constant over time.

Other data that can be collected and stored in a data base include information on pipe breaks, valve exercising, hydrant flushing, hydrant flow tests, water quality events such as "red water," or any other distribution system events or activities of interest. This type of O&M information is especially useful for evaluating the performance of assets and making decisions on future repair and

Table 3.6 Hydrant Inventory Information

Hydrant No.	Year Installed	Address	Pipe No.	Available Flow (gpm)	Notes
H014	1996	202 Main St.	P-3		
H015	1996	224 Main St.	P-5		
H016	1996	248 Main St.	P-17	1100	
H017	1996	286 Main St.	P-17		
H043	1952	140 Spring St.	P-16		
H044	1952	110 Spring St.	P-9	375	
H045	?	78 Spring St.	P-8		
H046	?	95 Spring St.	P-8		
H047	2005	112 Lincoln St.	P-12		
H048	1968	82 Lincoln St.	P-13	420	

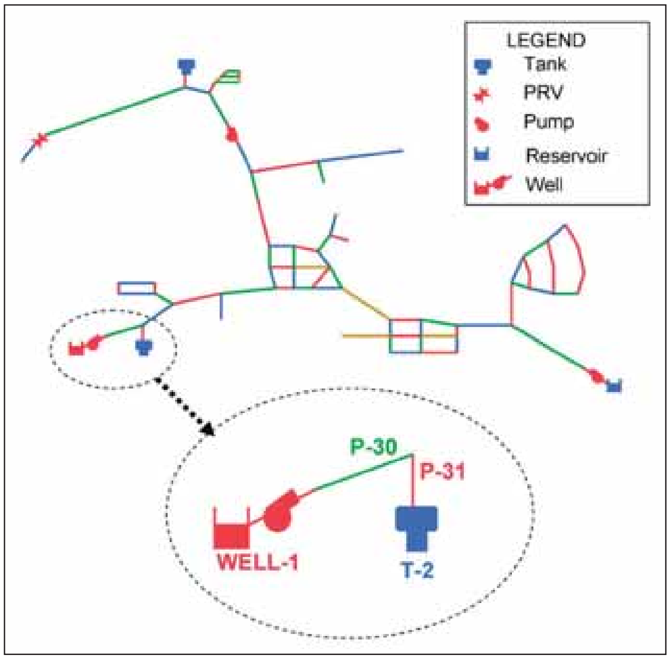


Figure 3.13 Components in the SmallWater Distribution System

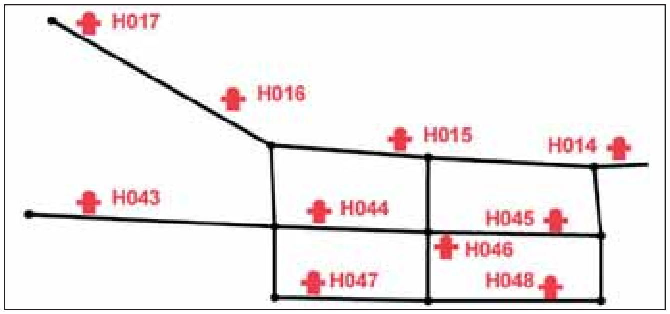


Figure 3.14 Hydrant locations in part of SmallWater

replacement programs. Table 3.7 shows a portion of an event table for SmallWater.

The inventory and event tables serve as a permanent repository for information on all actions taken related to the distribution system. Figure 3.15 presents an example schema (structure) that can be used to design such a system within a spreadsheet or database management system. The solid boxes show the elements in the water system. The dashed boxes refer to maintenance events for various elements, and the dashed lines show the relationship between the elements and the maintenance events. This schema can be modified, based on the specific needs of the utility. Some types of information may not be of immediate interest to some utilities and other data may be added as needed.

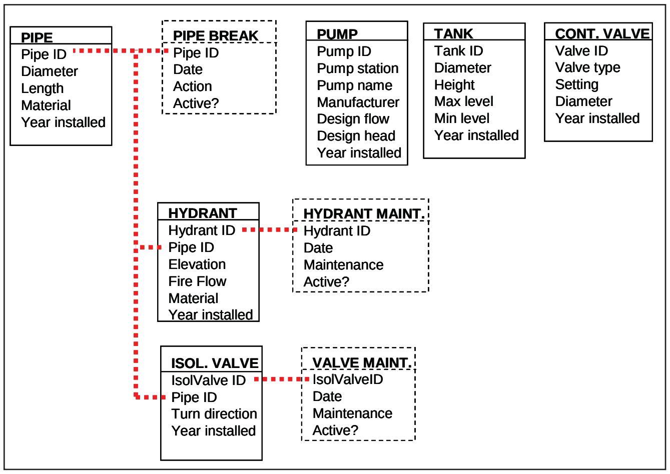
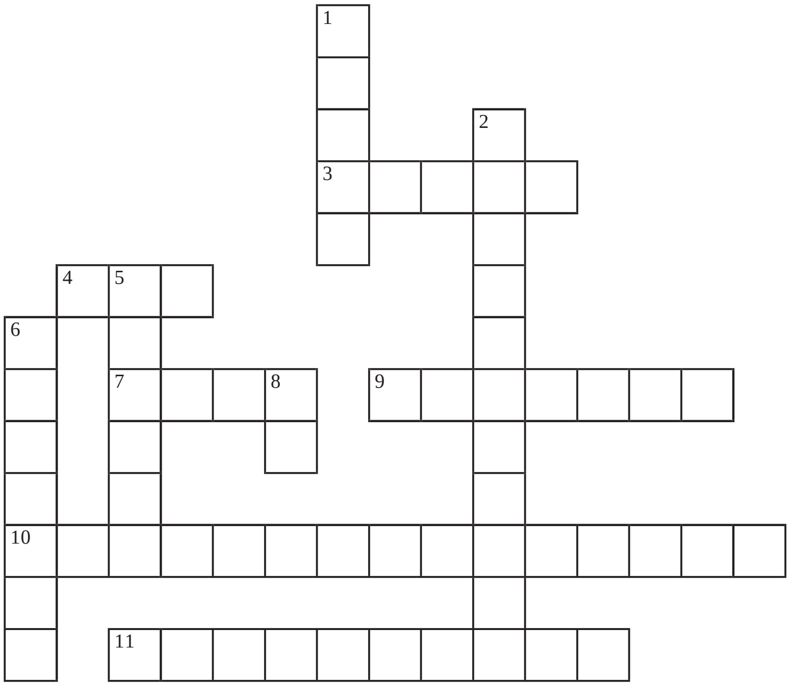


Figure 3.15 Sample Asset Management Database Design or Schema

Table 3.7 Event Table

Component Type	ID	Date of Event	Type of Event	Notes
Pipe	P-4	2/5/03	Break	
Valve	V-55	2/5/03	Flow Test	Valve cannot be closed
Valve	V-55	6/14/03	Replaced	
Hydrant	H016	8/07/06	Flush	
Hydrant	H047	9/12/06	Replaced	

Crossword
Distribution System Infrastructure



ACROSS

3 The longest components of a distribution system infrastructure

4 Abbreviation for a commonly used plastic pipe in U.S. water distribution systems

7 Configuration of distribution system that provides a higher degree of reliability of service to customers in case a main break occurs

9 Centrifugal pumps require this at startup

10 Term for keeping an inventory of distribution system components

11 Type of valve that allows flow in one direction only

DOWN

1 Mechanical device that moves water from surface to elevated storage tanks

2 Types of pumps most commonly used in distribution systems

5 Can be a “turn on” or a “turn off” for water utilities

6 Provides a water connection for fire-fighters

8 Two letters of the NSF logo designating pipe approved for potable water use

Crossword solution:
1) Pumps, 2) Centrifugal, 3) Pipes, 4) PVC, 5) Valves, 6) Hydrant, 7) Loop, 8) PW, 9) Priming, 10) Asset Management, 11) Check valve

Chapter 4
Drinking Water Regulations

Drinking water regulations are designed primarily to protect public health. As discussed in Section 2.4, the Safe Drinking Water Act (SDWA) was passed by the U.S. Congress in 1974 to protect public health by regulating the Nation's drinking water supplies. The 1974 SDWA and its amendments established the following four key elements:

- a framework (including schedule and procedures) for developing drinking water standards
- drinking water standards designed to include health-based goals, known as Maximum Contaminant Level Goals (MCLGs)
- technically achievable enforceable standards known as Maximum Contaminant Levels (MCLs)
- use of treatment techniques (TTs) instead of the MCLs (as necessary)

The SDWA works in conjunction with the Clean Water Act (CWA), which controls the discharge of pollutants into lakes, rivers and streams. The CWA regulations are designed to protect the source water, whereas SDWA regulations are designed to protect water quality supplied to the general public (consumer) by public water systems (PWSs).

Even though CWA and SDWA generally work in conjunction with each other, some conflicts may arise between the two acts as they have separate and distinct measures of water quality. As mentioned previously, the CWA prescribes Total Maximum Daily Loads (TMDLs) for different pollutants based on the designated use of a water body, whereas the SDWA prescribes MCLs.

Clean Water Act (EPA, 2002a)

The 1977 amendments to the Federal Water Pollution Control Amendments of 1972 are commonly known as the CWA. The goal of the CWA is to eliminate the releases of toxic amounts of pollutants into waters of the United States (e.g., rivers, lakes, streams). The CWA established the following three major programs:

- National Pollutant Discharge Elimination System (NPDES) Program – A system for granting and regulating discharge permits which regulates both point (industrial) and non-point (agricultural) discharges into waters of the U.S.
- Total Maximum Daily Load (TMDL) Program – A TMDL is the sum of the allowable loads of a single pollutant from all contributing point and non-point sources to a water body (e.g., river, stream, lake). The TMDL calculation includes a margin of safety to ensure that the receiving water body can be used for the state-designated purposes (e.g., drinking water supply, swimming, fishing). The TMDL calculation also accounts for seasonal variation in water quality.
- State Water Pollution Control Revolving Fund – To assist municipalities in creating wastewater treatment plants that were capable of meeting the standards, the CWA established a system to provide federal financial assistance. Initially, funding was provided in the form of construction grants. This mechanism was modified several times and later replaced by the State Water Pollution Control Revolving Fund in 1987.

In response to the CWA, EPA finalized effluent guidelines that regulate water pollution from 56 industrial categories. It also established pretreatment requirements for industrial users contributing wastewater to Publicly Owned Treatment Works. It is estimated that these EPA regulations are responsible for preventing the discharge of nearly 700 billion pounds of pollutants each year.

From a compliance perspective, PWS operators who discharge wastewater and/or storm water (during construction activities) from their facilities need to ensure that the applicable requirements of CWA are met. However, the focus of this reference guide is distribution system water quality; therefore, only SDWA-related regulations are discussed in this chapter. A summary of the evolution of federal drinking water regulations since the passage of the 1974 SDWA is presented in Figure 4.1.

The regulations presented in Figure 4.1 are designed to: control microbiological contamination, control chemical/radioactive contamination, and establish procedural requirements for meeting MCLs. The following three factors determine if a specific regulation or rule applies to a utility's operations:

- classification and size of the utility
- type of source water used (e.g., surface water, ground water, or ground water under the influence of surface water)
- type of water treatment used by the utility (e.g., filtration, disinfection)

Based on these factors, if it is determined that a particular rule applies, the utility must then meet the sampling, monitoring, reporting, treatment, and management practices as outlined in the regulation. These applicability decisions are typically made by the state regulatory agencies. Failure to meet these requirements

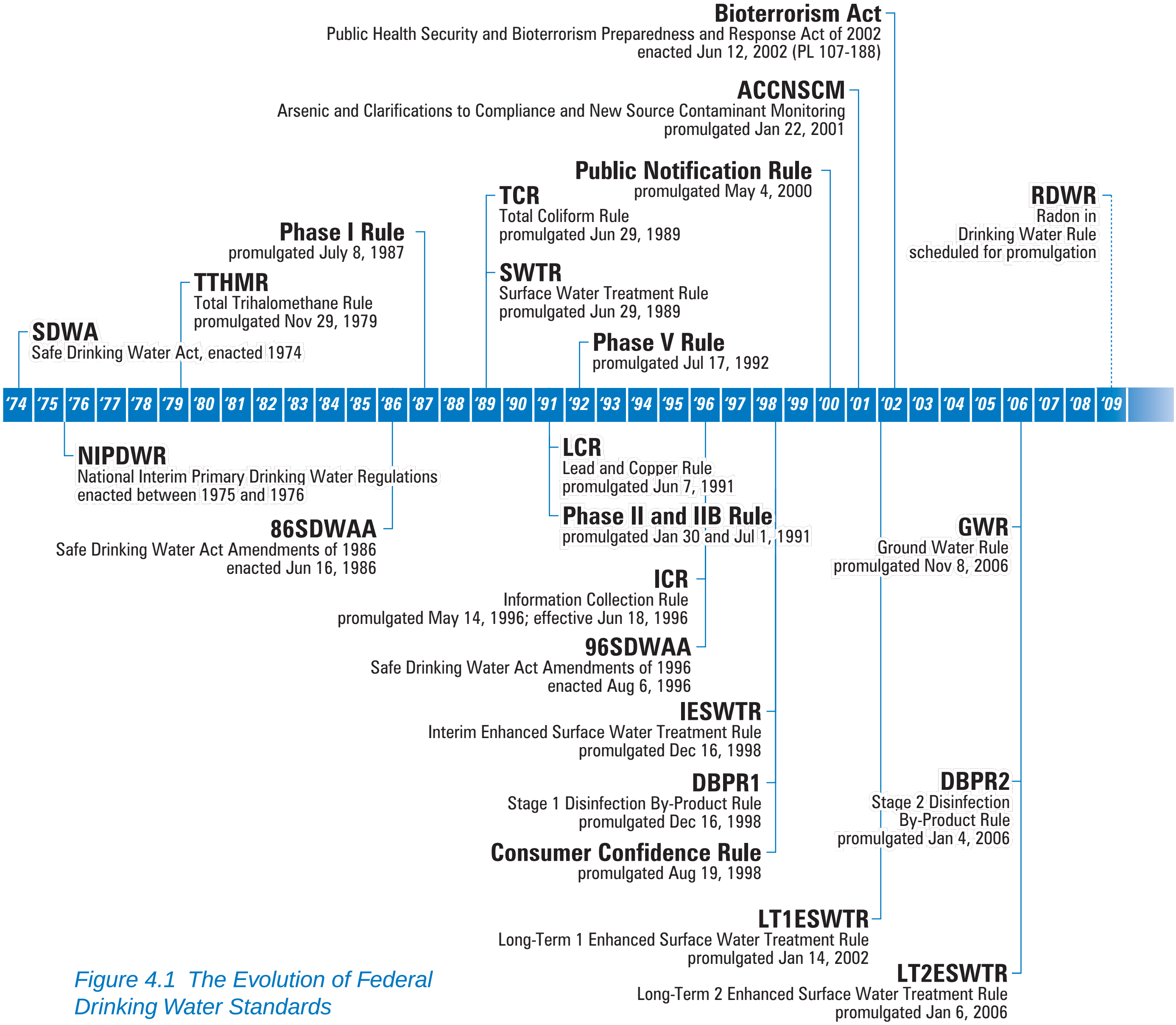


Figure 4.1 The Evolution of Federal Drinking Water Standards (Adapted from EPA, 2005a)

constitutes a violation under the SDWA and can lead to enforcement actions and penalties. The following sections present a summary of the key regulations that apply to small- and medium-sized utilities.

4.1 Highlights of 1974 SDWA and its Amendments

Between 1975 and 1976, EPA adopted a set of National Interim Primary Drinking Water Regulations (NIPDWR). The NIPDWR provided the basis for the first national drinking water standards. These standards included limits for ten inorganic chemicals, six organic pesticides, turbidity and five radionuclides. In addition, the NIPDWR established standards for microbiological contamination based on total coliform organisms. In order to ensure that the water quality supplied to the public met these standards, the SDWA required that utility operators routinely monitor drinking water by sampling and testing the water entering the distribution system for most contaminants and in their distribution system for other contaminants. The SDWA also required utilities to notify their customers if the standards or sampling requirements were not met. State regulatory agencies were given the primary enforcement responsibility ("primacy") over their water supply systems, provided the individual State program met the national criteria. Furthermore, the SDWA required EPA to assume the enforcement responsibility in case a State was unable or unwilling to do the job of enforcing the national standards.

4.1.1 1986 Amendments to SDWA

In 1986, the SDWA was amended and the NIPDWR standards were declared to be final. In addition, the 1986 amendments required EPA to:

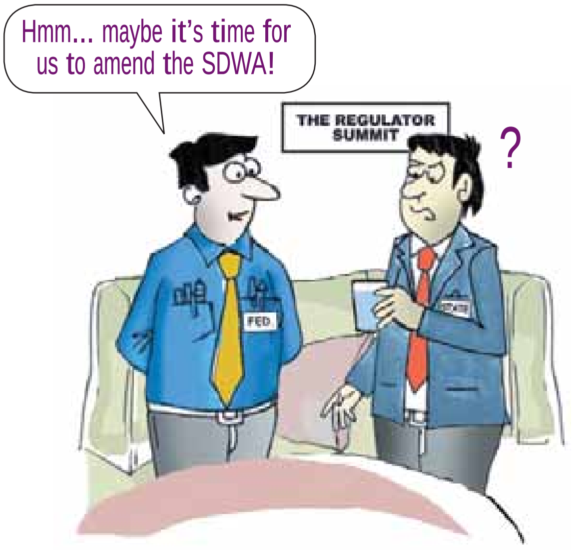
- regulate 83 contaminants within three years after enactment
- regulate an additional 25 contaminants every three years
- mandate disinfection for all PWSs
- mandate filtration for surface water systems
- designate best available technology for each contaminant regulated
- allow for TT instead of MCL

The non-community water systems were subdivided into transient and non-transient systems. States with primacy were required to adopt these regulations and begin enforcing them 18 months after they were published by EPA.

4.1.2 1996 Amendments to SDWA

The SDWA was amended again in 1996 to address these concerns and provide funds for PWS infrastructure and state program management. The 1996 amendments made the following changes to the SDWA:

- allowed EPA to establish a process for selecting contaminants to regulate based on scientific merit and eliminated the need to regulate an additional 25 contaminants every three years
- established the Drinking Water State Revolving Fund (DWSRF) to help PWSs finance the costs of drinking water infrastructure needs
- added an emphasis on source water protection and enhanced water system management
- allowed for flexibility of regulations and monitoring for small systems
- required EPA to conduct cost-benefit analyses of new regulations and analyze the likely effect of the regulations on the viability of the utility to implement them cost-effectively
- provided all systems additional time to come into compliance, plus allowed up to two more years if capital improvements were required
- established consumer confidence reporting requirements



4.1.3 Variances and Exemptions

Each drinking water regulation includes provisions for states to issue variances and exemptions. Affordability-based variances are available for small-to-medium systems (serving fewer than 10,000 people) that allow utilities to deviate from MCL or TT requirements under

The EPA Regulatory Process (EPA, 2003b)

To continually increase the effectiveness of the multiple barrier approach and protect drinking water customers, EPA develops regulations as new scientific or health information becomes available. Each new regulation strengthens or adds a needed barrier at one or more stages of the water supply process. After an extensive review of scientific and health information, EPA works with stakeholders and concerned citizens to draft a proposed regulation. The proposed regulation is published for public comment. EPA considers all comments and revises the regulation, if appropriate. A final regulation is then published. A listing and details on specific current and proposed standards can be found on the EPA website at: http://www.epa.gov/safewater/standards.html

certain conditions. Exemptions are designed to give utilities additional time to comply with the new regulations. To use these variances and exemptions, the utility must first prove that the requested variance or exemption does not pose an unreasonable risk to public health as determined by EPA. Also, variances and exemptions are not allowed for meeting the regulatory requirements for controlling microbial contaminants.

General Variance A general variance from meeting an MCL requirement can be requested if the utility cannot comply with the MCL because of the characteristics of the source water. This variance is granted only if the utility has already installed the EPA-designated Best Available Technology (BAT) for treatment to remove the contaminant for which the MCL is being exceeded. In addition, the variance should not result in an unreasonable risk to public health, and the state agency must prescribe a schedule for compliance when granting this variance.

Small System Variances States can grant small-system variances to systems serving fewer than 3,300 people without EPA approval. However, they must get EPA concurrence for variances to systems serving between 3,300 and 10,000 people. EPA needs to identify affordable variance technology for each regulation based on affordability criteria. As of 2005, no such small-system variances have been granted because EPA has not identified any affordable small-system variance technology.

Exemptions States may exempt PWSs from an MCL or TT requirement if the following three conditions are met:

- The utility is unable to comply because of compelling factors, which may include economic factors.
- The exemption must not result in unreasonable risk to public health.

- The system was in operation as of January 1, 1989, or, if it was not, no reasonable alternative source of drinking water is available to the new system.

In summary, the variances and exemptions are temporary. Only under an extreme condition should a utility consider these as options.

4.2 Regulations to Control Microbial Contaminants

Disease-causing microbial contaminants such as fecal coliform (e.g., *E. coli*), *Giardia*, and *Cryptosporidium* are frequently found in surface waters and groundwaters under the influence of surface water. Figure 4.2 shows microscopic photographs of the disease-causing microorganisms *E. coli*, *Giardia*, and *Cryptosporidium*. Some of the major rules that are intended

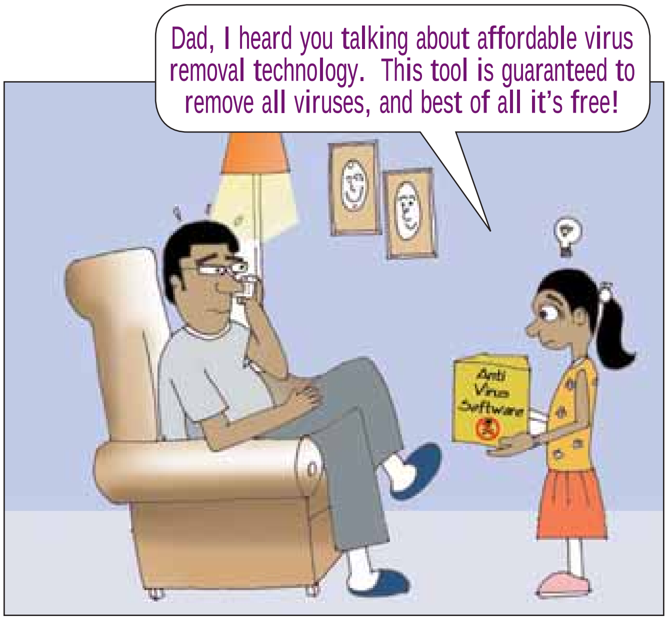


Figure 4.2 Disease-Causing Microorganisms - E. coli, Giardia and Cryptosporidium (not to scale)

to control these microbial contaminants include:

- Total Coliform Rule (TCR)
- Surface Water Treatment Rule (SWTR)
- Interim Enhanced SWTR (IESWTR)
- Long-term 1 Enhanced SWTR (LT1ESWTR)
- Filter Backwash Recycling Rule (FBRR)
- Long-term 2 Enhanced SWTR (LT2ESWTR)
- Ground Water Rule (GWR)

Table 4.1 presents a summary overview of each of these regulations and its applicability to small- and medium-sized systems, along with the associated monitoring, treatment, and management practice requirements. The information presented in the table is only meant to provide a general overview of the regulation. EPA has developed many regulation-specific factsheets and guidance documents that are much more thorough and cover the nuances of each regulation.

4.3 Regulations to Control Chemical Contaminants

Some of the major rules under the SDWA that are intended to control chemical contaminants include:

- Arsenic Rule
- Lead and Copper Rule (LCR)
- Stage 1 Disinfectants/Disinfection Byproducts Rule (Stage 1 D/DBPR)
- Stage 2 Disinfectants/Disinfection Byproducts Rule (Stage 2 D/DBPR)
- Radionuclides Rule
- Radon Rule

Table 4.2 presents a summary overview of each of these regulations and its applicability to small- and medium-sized systems, along with the associated monitoring, treatment, and management practice requirements. The information presented in the table is only meant to provide a general overview of the regulation. EPA has developed many regulation-specific factsheets and guidance documents that are much more thorough and cover the nuances of each regulation.

Additional Information

Regulatory Guidance Documents

EPA has prepared many rule-specific guidance documents for public use. In addition, EPA has prepared the following guides which are tailored for small system operators:

1. Small Systems Guide to Safe Drinking Water Act Regulations: The First STEP to Providing Safe and Reliable Drinking Water - One of the Simple Tools for Effective Performance [STEP] Guide Series.
2. Complying with the Ground Water Rule: Small Entity Compliance Guide - One of the Simple Tools for Effective Performance (STEP) Guide Series.

These and the other rule-specific regulatory guidance documents can be downloaded for free from the EPA website at: http://www.epa.gov

4.4 Public Notification and Consumer Confidence Rules

Public notification is intended to ensure that consumers will know if there is a problem with their drinking water. PWSs must notify their customers if: the level of a contaminant in the water exceeds EPA/state drinking water regulations; there is a waterborne disease outbreak or any other situation that may pose a risk to public health; the water system fails to test its water as required; or the system has a variance or exemption from the regulations. Depending on the severity (tier) of the situation, PWSs have a time limit of 24 hours to one year to notify their customers. The three EPA designated tiers are as follows:

1. Tier 1, for MCL violations and situations with significant potential to have serious adverse effects on human health as a result of short-term exposure. Notice is required within 24 hours of the violation. A consultation with the state agency is also required within 24 hours.
2. Tier 2, for other violations and situations with potential to have serious, but not immediate, adverse effects on human health. Notice is required within 30 days, or as soon as possible, with extension of up to three months for resolved violations at the discretion of the state or primacy agency.

Table 4.1 Summary of Regulations Designed to Control Microbial Contamination (Adapted from AWWA, 2006a)

Rule/Applicability to Small-and-Medium Systems	Rule Overview/Objective	Related General Monitoring Requirements	Related Treatment Requirements	Related Management Practice Requirements[a]
Total Coliform Rule – Applies to all PWSs.	Coliforms are abundant in the feces of warm-blooded animals. In most instances, coliforms themselves are not the cause of sickness, but they are easy to culture and their presence is used to indicate that other pathogenic (disease-causing) organisms of fecal origin may be present which can cause serious illnesses.	Sampling is required. The number and frequency of samples is based on population served by the PWS and results of the sanitary survey. Repeat samples are required within 24 hours if a positive total coliform sample is found. Furthermore, the positive samples must be analyzed for *E. coli* (a fecal coliform). Certain strains of *E. coli* are known to cause illness in humans.	The rule does not mandate any specific treatment. However, if monitoring indicates the presence of coliform, treatment may need to be added or modified as necessary to resolve the issue.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet the problems uncovered during monitoring.
Surface Water Treatment Rule – Applies to all PWSs that use surface water or ground water under the influence of surface water.	Disease-causing microorganisms such as *Giardia* and *Legionella* are present in most surface waters. This rule establishes criteria for determining if both filtration and disinfection are required for removal of these organisms.	Unfiltered systems need to monitor turbidity every 4 hours (source water), residual disinfectant concentration continuously (finished water), maintain distribution system disinfectant residual, and the total coliform levels (source water) 1-3 times per week, depending upon the population served. Filtered systems need to monitor turbidity at least every 4 hours and residual disinfectant concentration continuously (finished water).	Systems may avoid filtration if they have low coliform and turbidity in source water and meet other site-specific criteria. Systems that do not meet this criteria must install filtration treatment and the state must determine that filtration in combination with disinfection achieves the desired *Giardia* (99.9% removal) and virus (99.99% removal) removal/inactivation efficiency.	Unfiltered systems are required to meet source water quality criteria and maintain a watershed control program. They are also subject to annual inspection and watershed control program evaluation.
Interim Enhanced SWTR and Long-term 1 Enhanced SWTR.	This regulation builds upon the SWTR to address Cryptosporidium - a microorganism that can spread due to contamination of water from human or animal feces leading to severe diarrheal illness.	Continuous turbidity monitoring is required for each conventional and direct filtration process, with values recorded every 15 minutes. States are required to perform sanitary surveys.	Combined filter effluent must be $\leq$ 0.3 NTU for 95 percent of monthly readings and may at no time exceed 1.0 NTU.	Systems requiring compliance must establish disinfection profile and benchmark. Any changes to disinfection practice must be approved by the state.
Long-term 2 Enhanced SWTR – Applies to all PWSs that use surface water or ground water under the influence of surface water.	This regulation builds upon the SWTR, IESWTR and LT1ESWTR to address *Cryptosporidium* - a microorganism that can spread due to contamination of water from human or animal feces leading to severe diarrheal illness.	Required to initially monitor *E. coli* for a year and if the annual mean concentration in the source water exceeds specified levels, *Cryptosporidium* monitoring is required.	Depending upon the initial monitoring results, the PWS is further classified into four "bins" (Bin 1 $<$ 0.075 oocyst/L, Bin 2 - between 0.075 and 1.0 oocyst/L, Bin 3 - between 1.0 and 3.0 oocyst/L, and Bin 4 $>$ 3.0 oocyst/L). Each bin (except Bin 1) requires the PWS to install a treatment technology and establish a monitoring schedule based on contamination levels in the source water. The treatment options range from improving watershed control, reducing influent concentrations and additional pre-treatment to membranes and advanced oxidation.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet the problems uncovered during monitoring.
Filter Backwash Recycling Rule – Applies to all PWSs that use surface water or ground water under the influence of surface water; if they employ conventional or direct filtration, and recycle spent filter backwash water, thickener supernatant, and liquids from dewatering process.	Spent filter backwash water, thickener supernatant, and liquids from dewatering process can contain microbial organisms such as *Cryptosporidium*. This rule minimizes the risks associated with recycling these types of water.	The FBRR requires utilities to submit a plant schematic showing recycle flow and plant flow to the regulatory authority. They must also retain any records on recycle practices to document that the recycling of the regulated streams is performed correctly.	The recycle streams must be sent to a point where they will pass through all the treatment process steps before entering the distribution system. The PWSs can request approval for an alternate location.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet requirements of the regulation.
Ground Water Rule – Applies to all PWSs that use ground water.	This rule is designed to protect the consumers of ground water from bacteria and viruses. It also seeks to identify defects through sanitary surveys in water systems that could lead to contamination.	Systems not achieving mandated level of microbial removal/inactivation must, after a positive total coliform result, take a source water sample and conduct further tests (e.g., for *E. coli*, enterococci, or coliphage). States also conduct hydro-geological assessments to identify if a particular source is sensitive to such contamination in which case further monitoring requirements are applicable.	Systems that detect fecal contamination would be required to take corrective action that may include disinfection, removal of the contamination source, or switching sources.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet deficiencies noted in the sanitary survey requirements of the regulation.

[a] All of the rules have recordkeeping and reporting requirements associated with the monitoring, treatment and/or management requirements.

Table 4.2 Summary of Regulations Designed to Control Chemical Contamination (Adapted from AWWA, 2006a)

Rule/Applicability to Small-and-Medium Systems	Rule Overview/Objective	Related General Monitoring Requirements	Related Treatment Requirements	Related Management Practice Requirements[b]
Arsenic Rule – the revised rule is called -Arsenic and Clarifications to Compliance and New Source Contaminants Monitoring Rule. All CWSs and NTNCWSs.	The revised Arsenic Rule reduced the MCL from 0.05 mg/L to 0.01 mg/L. Arsenic is shown to cause cancer and other health effects.	The rule makes monitoring requirements of arsenic consistent with those for other inorganic compounds (IOCs) regulated under the standardized monitoring framework (SMF)‡.	The rule specifically lists BATs and small system compliance technologies (SSCTs). The SSCTs including Point-of-Use (POU)/Point of Entry (POE) technologies most likely to be used by small systems include: activated alumina treatment, reverse osmosis, and modified lime softening.	The rule does not mandate any specific management practices. However, systems employing treatment for the first time to meet the MCL need to focus and develop appropriate technical, managerial and financial capacity. Systems employing POU/POE systems must maintain excellent customer relationship.
Lead and Copper Rule – All CWSs and NTNCWSs.	This rule establishes a 90th percentile action level for lead at 15 micrograms/L (µg/L) from the 50 µg/L previous level and copper action level of 1.3 mg/L. Lead is a toxic metal that can cause a range of health effects including learning disabilities in children. Long-term (more than 14 days) exposure to copper in drinking water at levels higher than 1.3 mg/L may cause kidney and liver damage in infants.	The number of samples required (ranging between 5 and 60 for small- and medium-sized systems) depends upon the system size. Sampling frequency is annual, every 3 years, or every 9 years (depending upon the system size and previous monitoring results). If lead or copper concentrations exceed the specified action levels in more than 10% of customer taps sampled, the PWS must undertake a number of additional actions to control corrosion.	Corrosion control treatment is required unless the monitoring data indicates levels below the action level for two consecutive 6-month sampling periods. Source water monitoring and treatment may be required if the action levels are exceeded because of elevated levels in source water. If the service lines are the cause of the exceedance and the problem is not corrected by corrosion control, service lines must be replaced.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet the problems uncovered during monitoring.
Stage 1 Disinfectants/ Disinfection By-products (D/DBPs) Rule – All CWSs and NTNCWSs that add chemical disinfectant to water during the treatment process. Certain requirements apply to TNCWSs that use chlorine dioxide.[a]	DBPs result from a reaction between the disinfectant (such as chlorine) and the organic and inorganic compounds present in water. The rule sets MCLs for haloacetic acid 5 (HAA5) at 0.060 mg/L, chlorite (chlorine dioxide by product) at 1.0 mg/L, bromate (ozone byproduct) at 0.010 mg/L, and total trihalomethanes (TTHMs) at 0.080 mg/L. It also sets maximum residual disinfectant levels (MRDL) for chlorine (4.0 mg/L), chloramines (4.0 mg/L) and chlorine dioxide (0.8 mg/L). DBPs can potentially cause cancer and impact reproductive health of humans.	For small and medium systems, 1 sample per plant annually are required for THMs and HAAs, generally in the warmest month, or quarterly. Plants using ozone are required to monitor monthly, and chlorine dioxide plants are required to monitor daily at the entrance to distribution system and monthly within the distribution system. For systems using conventional filtration, monthly sampling is required for total organic carbon (TOC) and alkalinity which are precursors that impact the DBP formation.	Systems that use surface water or ground water under the influence of surface water and employ conventional filtration must remove a specified percentage (15 to 50%) of TOC using either enhanced coagulation or enhanced softening. The specific % requirement depends upon TOC concentration and alkalinity of source water.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to balance the need for disinfection while minimizing the potential for DBP formation.
Stage 2 D/DBPs Rule – All CWSs and NTNCWSs that add chemical disinfectant (other than UV light) to water during the treatment process or deliver water that has been disinfected.[a]	The rule builds upon the Stage 1 D/DBP Rule. The covered PWSs are required to perform an initial distribution system evaluation (IDSE) to identify monitoring locations for eventual compliance with the current standards for TTHM and HAA5. Very small systems (serving fewer than 500 people) may seek waiver from IDSE. The other option is to obtain a "40/30" certification. The term "40/30" refers to a system that under the Stage 1 D/DBP monitoring shows all samples $\leq$ 0.040 mg/L for TTHMs and 0.030 mg/L for HAA5.	The IDSE determines the monitoring site locations. The frequency of monitoring is based on both source water type and system size. Generally, for small to medium systems it is 2 samples per quarter or year.	Changes in treatment may be required to remove the DBP precursor (TOC) for the reduction of DBP concentrations. Systems should explore operational changes, distribution system modifications, and alternative disinfection strategies as necessary.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to balance the need for disinfection while minimizing the potential for DBP formation.
Radionuclides Rule – All CWSs	This rule builds upon the MCLs for combined radium-226/228 of 5 pico curies/liter (pCi/L), gross alpha particle activity 15 pCi/L, and beta particle and photon activity of 4 millirem†/year. It adds a uranium MCL of 30 pg/L. These radionuclides are known to cause cancer and death at elevated levels of exposure.	Monitoring of the radionuclides other than beta particle and photon emitters is consistent with the SMF‡. Monitoring is required at each entry point to the distribution system. Monitoring of beta particle and photon emitters is not required for most CWSs. If the system is designated by the state as "vulnerable" or "contaminated," monitoring of beta particle and photon emitters is required.	The small system compliance technologies listed in the rule are green sand filtration, co-precipitation with barium sulfate, electrodialysis, activated alumina and ion exchange POU/POE devices. Special consideration for spent media or cartridge disposal may be required.	The rule does not mandate any specific management practices. However, management practices may need to be adjusted to meet requirements of the regulation.

[a] Stage 1 D/DBP Rule compliance is based on running annual average (RAA), monitoring is plant-based. Stage 2 D/DBP Rule compliance is based on locational running annual average (LRAA), monitoring is population-based.

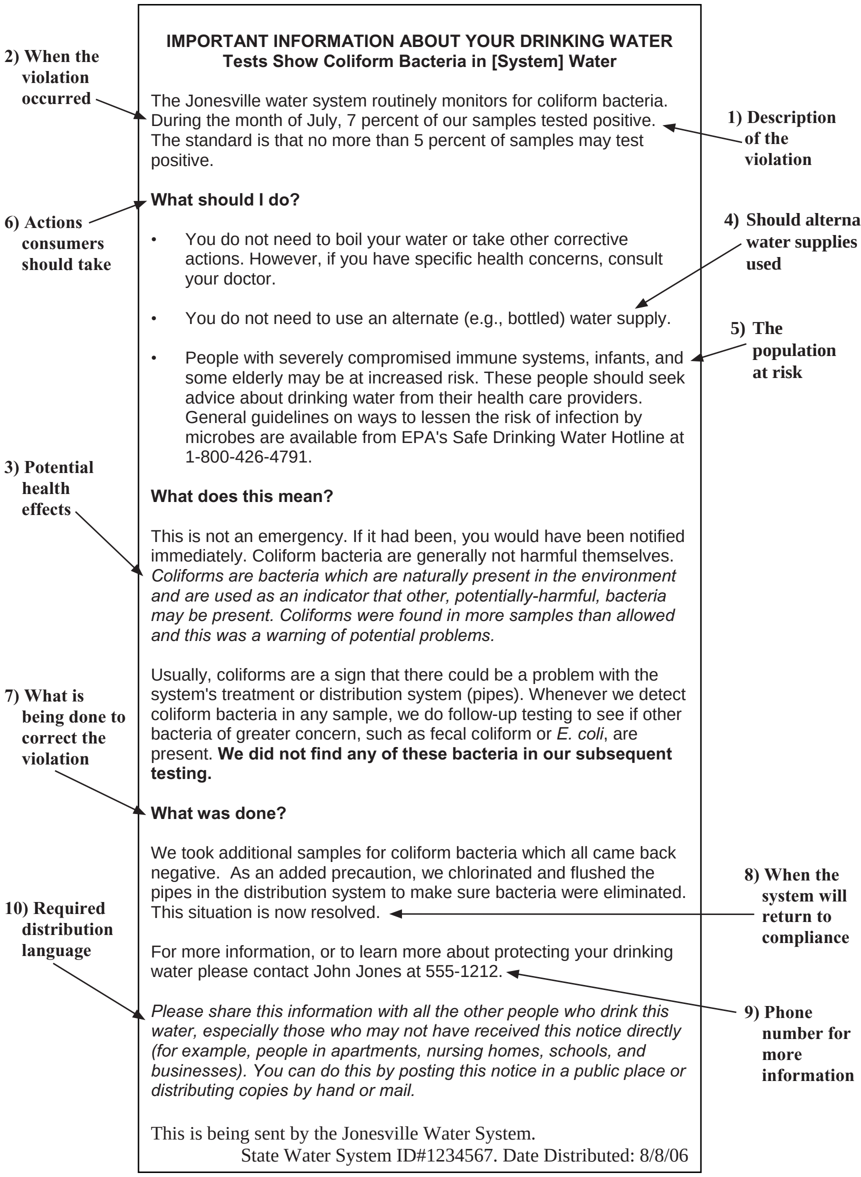
[b] All of the rules have recordkeeping and reporting requirements associated with the monitoring, treatment and/or management requirements.

‡ The Standardized Monitoring Framework (SMF) was finalized by EPA in 1991 to simplify and consolidate monitoring requirements across contaminant groups. The SMF increases public health protection by simplifying monitoring plans and synchronizing monitoring schedules leading to increased compliance with monitoring requirements. The SMF reduces the variability within monitoring requirements for chemical [inorganic compounds (IOCs), volatile organic compounds (VOCs), and Synthetic organic compounds (SOCs)] and radiological contaminants across system sizes and types. Monitoring for asbestos, fluoride, nitrate and nitrite are different from monitoring requirements for other IOCs because these chemicals have unusual characteristics. The SMF established a 9-year "compliance cycle" composed of three 3-year "compliance periods." Newly regulated contaminants will be subject to the SMF. During the initial monitoring period, the rule requires PWSs to sample four consecutive quarters for each contaminant at each entry point to the distribution system. Depending upon the results, systems may be able reduce their monitoring frequency to annually or once every 3, 6, or 9 years. The SMF allows states to waive all monitoring requirements for all contaminants except nitrate (MCL of 10 mg/L) and nitrite (MCL of 1 mg/L).

† millirem is a unit of radiation dose equivalent to one-thousandth of a rem. Roentgen equivalent man (rem) - A unit used to express different types of ionizing radiations on a common scale to indicate its relative biological effects. For beta and gamma radiations: Exposure to 1 Roentgen delivers a dose of 1 Rad, which is equivalent to 1 Rem.

3. Tier 3, for all other violations and situations not included in Tier 1 and Tier 2, such as monitoring and reporting violations. Notice is required within 12 months of the violation, and may be part of a single annual report, including, in some cases, the annual consumer confidence report (CCR) already required by EPA.

EPA sets strict requirements on the form, manner, content, and frequency of public notices. Figure 4.3 contains a sample public notice. Public notification is provided in addition to the annual water quality report (or CCR), which provides customers with a more complete picture of drinking water quality and system operations for the preceding year. The annual CCR informs consumers what is in their water, where it comes from, and where they can obtain additional information.



IMPORTANT INFORMATION ABOUT YOUR DRINKING WATER
Tests Show Coliform Bacteria in [System] Water

The Jonesville water system routinely monitors for coliform bacteria. During the month of July, 7 percent of our samples tested positive. The standard is that no more than 5 percent of samples may test positive.

What should I do?

- You do not need to boil your water or take other corrective actions. However, if you have specific health concerns, consult your doctor.
- You do not need to use an alternate (e.g., bottled) water supply.
- People with severely compromised immune systems, infants, and some elderly may be at increased risk. These people should seek advice about drinking water from their health care providers. General guidelines on ways to lessen the risk of infection by microbes are available from EPA's Safe Drinking Water Hotline at 1-800-426-4791.

What does this mean?

This is not an emergency. If it had been, you would have been notified immediately. Coliform bacteria are generally not harmful themselves. *Coliforms are bacteria which are naturally present in the environment and are used as an indicator that other, potentially-harmful, bacteria may be present. Coliforms were found in more samples than allowed and this was a warning of potential problems.*

Usually, coliforms are a sign that there could be a problem with the system's treatment or distribution system (pipes). Whenever we detect coliform bacteria in any sample, we do follow-up testing to see if other bacteria of greater concern, such as fecal coliform or *E. coli*, are present. **We did not find any of these bacteria in our subsequent testing.**

What was done?

We took additional samples for coliform bacteria which all came back negative. As an added precaution, we chlorinated and flushed the pipes in the distribution system to make sure bacteria were eliminated. This situation is now resolved.

For more information, or to learn more about protecting your drinking water please contact John Jones at 555-1212.

Please share this information with all the other people who drink this water, especially those who may not have received this notice directly (for example, people in apartments, nursing homes, schools, and businesses). You can do this by posting this notice in a public place or distributing copies by hand or mail.

This is being sent by the Jonesville Water System.
State Water System ID#1234567. Date Distributed: 8/8/06

Figure 4.3 Sample Public Notice (EPA, 2007c)

Sanitary Surveys (EPA, 1999)

A sanitary survey is an on-site survey of the water source, facilities, equipment, operation, and maintenance of the PWS for the purpose of evaluating the adequacy of such source, facilities, equipment, operation, and maintenance for producing and distributing safe drinking water. They are used to prevent and correct sanitary deficiencies and are indispensable for ensuring the delivery of safe water on a sustainable basis. When conducted properly and with appropriate follow-up, sanitary surveys fulfill the following objectives:

- Reduce the risk of waterborne disease;
- Provide an opportunity to educate system operators;
- Identify systems needing technical or capacity development assistance; and
- Identify candidates for enforcement action.

Sanitary surveys have been a critical component of state drinking water programs for decades. States regulatory agencies are required to complete sanitary surveys for all surface water systems and systems using ground water under the direct influence of surface water (GWUDI) on the following schedule:

System Type	Minimum Frequency
Noncommunity water system	Every 5 years
Community water system	Every 3 years
Community water system with outstanding performance based on prior sanitary surveys	Every 5 years

The recent ground water rule extends sanitary survey requirements to ground water systems. Sanitary surveys may also be required when compliance problems arise. The PWSs are required to cooperate with their regulatory agency and provide supporting information when requested by the agency. Sanitary surveys can be very useful for small utilities and provide them outside assistance to identify weaknesses in the system before they cause serious problems. They can also help the utility regain control and resolve current weaknesses and avoid repeat compliance problems. Sanitary surveys help evaluate the following issues:

- The capability of the PWS to monitor and manage water quality data
- System management and operational weaknesses
- Regulatory compliance weaknesses
- The integrity of supply sources
- Treatment adequacy and operational weaknesses
- Potential impacts of pumping
- Integrity of storage facilities, and
- Distribution system weaknesses

After the sanitary survey is completed, the inspector generally provides a follow-up report addressed to the PWS manager or chief operator. The purpose of the report is to summarize any problems that have been identified, as well as recommendations for necessary improvements. The report generally discusses each of the items listed above in detail and provides dates by which the deficiencies (if any) should be corrected. Sanitary surveys can be a preventive tool, helping water utilities address weaknesses.

4.5 SmallWater, USA – Regulatory Scenario Problems

Problem #1 Scenario

As previously presented in Section 2.7, in the 1990s, the well (ground water) supply in SmallWater became inadequate. Therefore, an alternate source was developed in the form of an interconnection to the surface water supply from a larger system located to the southeast. The well field was maintained as a supplemental and emergency supply. What regulations would currently apply?

Issues to Consider

1) Is the source considered a surface water source from a regulatory standpoint because it has switched supply from ground water wells to purchased surface water?

2) If the ground water source is used for supplementing for peak summer demand, what compliance issues are raised?

3) Since SmallWater is buying treated surface water from another source which is in compliance with all surface water source requirements, does SmallWater have any compliance requirements?

Regulatory Guidance

SmallWater should first contact its state (primacy) regulatory authority and present the entire operating scenario. From a regulatory standpoint, SmallWater is considered as the supplier to the customers who live in the SmallWater service area. At the point where the bulk purchase takes place, it is SmallWater's responsibility to ensure that the water quality supplied to the consumer meets the surface water requirements mandated by the SDWA.

If ground water is used as a supplement to meet summer demand, the supplier has to comply with both ground and surface water treatment requirements. SmallWater should consult the state regulatory agency to make sure the mixed water supply meets all regulatory requirements.

Problem #2 Scenario

Last July, one of the three required monthly routine total coliform samples in SmallWater showed positive results. This triggered a series of actions including notification to the state, additional testing, and public notification.

Issues to Consider

1) What is the procedure to identify if contamination is isolated to the plumbing system of an individual building from where the routine sample was drawn, or if contamination was in the distribution system itself?
2) What should be done if a repeat sample is total coliform-positive?
3) How is the overall monitoring schedule affected by this event?

Regulatory Guidance

In response to the notification of positive total coliform sample, SmallWater was required to take action within 24 hours. This response includes collection of a set of three repeat samples to assess the extent of the problem. For water systems that collect one or fewer samples per month, a fourth repeat sample is required. One of the repeat samples must be collected from the original sample tap, one within five service connections upstream, and one within five service connections downstream. This pattern of repeat sampling helps to determine the extent of contamination and potential cause of the positive sample. If a repeat sample is total coliform-positive at the same service connection, but negative at upstream and downstream service connections, the state may investigate to determine if it is appropriate to waive the total coliform-positive sample as being a plumbing system problem in the individual building.

If any routine or repeat sample is total coliform-positive, the positive sample is tested either for the presence of fecal coliforms or *E. coli*. The test is done automatically by the lab and does not require an additional sample. A potential urgent health risk exists if any sample, routine or repeat, tests positive for fecal coliform/*E. coli*. When notified by the laboratory that one of the samples tested positive for fecal coliforms or *E. coli*, SmallWater was required to notify the state by the end of the day. This notification is required on or before the end of the next business day if the state office is closed. The occurrence of a positive routine and repeat sample in conjunction with a positive fecal or *E. coli* sample creates an acute violation of the MCL. In addition to notifying the state, SmallWater is also required to notify the public within 24 hours by television, radio, hand delivery, or other methods approved by the state, and consider advising their customers to boil their water.

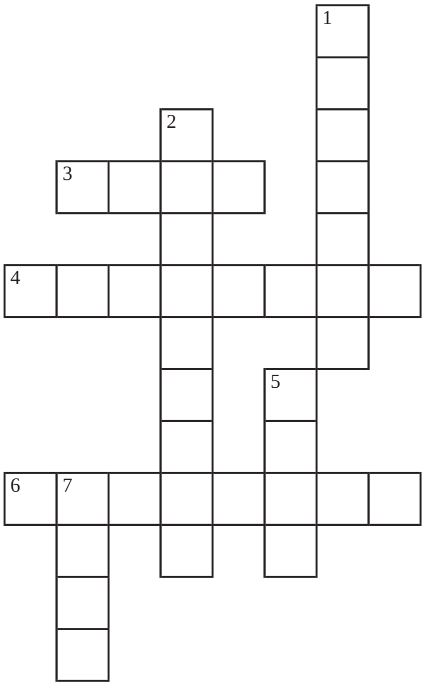
A less serious but still significant potential health risk exists if more than one sample (routine and/or repeat) in a month is total coliform-positive. This creates a monthly MCL violation. When SmallWater is notified by their laboratory of the repeat or second routine total coliform-positive sample results, they are required to notify the state by the end of the next business day and to notify the public within 30 days by mail, hand delivered notices, or other methods approved by the state.

In the month following detection of total coliforms in any routine or repeat sample, SmallWater is required to collect five routine samples. If none of these tests are positive for the presence of total coliforms, they may resume collecting their usual three routine samples the next month. A total coliform-positive sample is cause for concern. However, if a set of repeat samples that month and five routine samples the next month are all negative, and their other multiple barriers to contamination are adequate, SmallWater should have confidence that their water is safe.

Beyond the strict requirements for responding to a positive coliform sample, SmallWater may also consider the following progressive steps to avoid further problems.

1. The sample-tap and sample collection procedures should be examined and reviewed. Coliform bacteria can come from unclean faucets, biofilm in the premise plumbing, and poor sample collection and handling procedures such as sample bottles sitting in melted ice in a cooler. Sample collectors may need to take more care in the collection process and sample faucets may need to be repaired and sanitized.
2. Local water main conditions should be reviewed. If the water system is chlorinated, chlorine test results should be evaluated to ensure that there is adequate chlorine residual. Local main breaks, flushing, unusual flow reversals, valve and hydrant operations can all stir up or dislodge coliforms from sediments or biofilms.
3. Storage facilities that influence the water provided to the sample location from which the positive coliform sample was taken should be checked for possible contamination.

Crossword
Drinking Water Regulations



ACROSS

3 The action level for this compound is 15 µg/L under the Lead and Copper Rule
4 A microbial contaminant that is used as a general indicator of the presence of other disease-causing organisms
6 Acronym for the regulation designed to control *Cryptosporidium* in drinking water

DOWN

1 Time period within which a notice is required to the regulatory agency in case of a Tier 1 violation
2 Term for special allowances by the regulators to exempt small systems from meeting the regulatory MCL or treatment technique requirements
5 Abbreviation for the act passed by congress to protect drinking water in 1974
7 Acronym for the sum of four disinfection byproducts formed due to reaction of chlorine with naturally occurring organic matter

Crossword Solutions
1) 24 hours, 2) Variances, 3) Lead, 4) Coliform, 5) SDWA, 6) LT2ESWTR, 7) TTHM

Chapter 5
Distribution System Water Quality Issues

Drinking water exiting the water treatment plant enters a distribution system which is a complex network of pipes, tanks and reservoirs designed to deliver finished water to consumers. Although water entering a distribution system may meet drinking water standards, the quality of the transported water may degrade within the distribution system before it reaches the consumer. Some of these undesirable changes such as objectionable taste, odor or color can often be detected immediately, whereas other changes in quality such as the intrusion of dangerous pathogens may only be noticed after a waterborne disease outbreak. Some of these pathogens include *Salmonella* and *E. coli*. Therefore, proper distribution system management is essential to protect consumers from both aesthetic and public health threats due to deteriorating water quality. The following sections in this chapter discuss common water quality issues faced by water utilities, including small- and medium-sized systems. These issues include taste, odor, and color; biofilm formation; disinfection and disinfection byproducts (DBPs); nitrification; pH stability and scale formation; and contamination events.

5.1 Taste, Odor, and Color

In most cases, taste and odor do not pose a public health threat, and color in water can stain household appliances and plumbing fixtures. These aesthetic problems can result due to various factors including the following: poor source water quality, inadequate treatment, initiating disinfection of well with iron or manganese, changes in water quality in the distribution system, and external contamination events. The Safe Drinking Water Act (SDWA) established National Secondary Drinking Water Regulations (NSDWR or secondary standards) that are non-enforceable guidelines regarding contaminants that may cause cosmetic effects (such as skin or tooth discoloration) or aesthetic effects (such as taste, odor, or color) in drinking water. EPA recommends secondary standards for water systems, but does not require these systems to comply. However, states may choose to adopt them as enforceable standards and may require monitoring and reporting.

All customers want their water to look, taste and smell good; therefore, the utility operator should investigate customer complaints and try to resolve these issues. When complaints are filed, as a first step, the utility operator should try to identify if the water quality problem has occurred in the customer's plumbing or is due to poor source water quality or treatment and/or changes in the distribution system that can be controlled by the utility operator. If more than one customer has reported similar problems, it is likely that the issue is related to source water, inadequate treatment or distribution system problems. The following sections discuss typical customer concerns, their most common causes and basic troubleshooting techniques.

5.1.1 Taste and Odor Problems

Petroleum, gasoline, turpentine, fuel or solvent odor Generally, the source of these types of odors is external contamination (e.g., leaking underground fuel storage tanks). Therefore, it is recommended that the utility perform on-site investigations to isolate and remediate the problem. Contaminated soil or ground water can enter a well or it can permeate through plastic pipe buried in a contaminated area. Small systems that lack resources and expertise for tackling this problem should notify the state agency.

Sulfur or rotten egg odor These types of odors are commonly caused by bacteria growing in a sink drain or in a water heater in the customer's home. In some cases, the smell may be caused by naturally occurring hydrogen sulfide. As a first step, it is recommended that the utility ask the customer to collect a small amount of water in a cup, step away from the odor-causing sink, swirl the water around inside the cup and smell it. If the water has no odor, the likely source is bacteria in a sink drain. If the water continues to have an odor, a possible source is the customer's water heater. This problem can occur 1) if the hot water has not been used for a long time, 2) if the heater has been turned off for a while, or

3) if the thermostat on the heater is set too low. If the sink drain and the water heater have been eliminated as the potential source of the problem, additional investigations will be needed. Sulfur odors can also originate from unmaintained household water treatment devices and from stagnant plumbing. Sulfur odors can appear in dead-end mains or through a backflow event and the distribution system piping may require flushing to remove the odor-causing material. If the problem is system-wide, additional water treatment (such as carbon filtration) prior to distribution may be necessary to eliminate organic compounds in the source water that may be causing the problem.

Moldy, musty, earthy, grassy or fishy odor These odors can also be caused by bacteria growing in a sink drain or stagnant water. As indicated in the previous section, the customer should be requested by the water utility to collect a small amount of water in a cup, step away from the tap, swirl the water around inside the container and smell it. If the water has no odor, the likely cause is bacteria in the sink drain. If the water continues to have an odor, the source is most likely algal bloom in the main water. Although generally harmless, it may result in abnormal odor at very low concentrations. Temporarily, this problem can be alleviated by flushing (running the faucet for several minutes). However, it is possible that the distribution system may require flushing to remove the odor-causing material. If an algal bloom in the surface water source is determined to be the cause, additional water treatment (such as ozonation or carbon filtration) prior to distribution may be necessary to eliminate the problem.

Chlorine, chemical or medicinal odor These types of odors are usually caused by the presence of excess chlorine in the water. Chlorine odors can result from disinfection of new pipe installations or due to poor control of chlorine residual. Chemical or medicinal odors may occur due to the interaction of excess chlorine with organic matter present in source water or the distribution system piping. If the organic matter in the source water is not a problem and there are no nearby customers reporting similar problems, it is recommended that the customer contact a licensed plumber and have the building pipes cleaned or replaced. If organic matter in the source water is found to be causing the problem, additional water treatment (such as carbon filtration) prior to distribution may be necessary to resolve the issue.

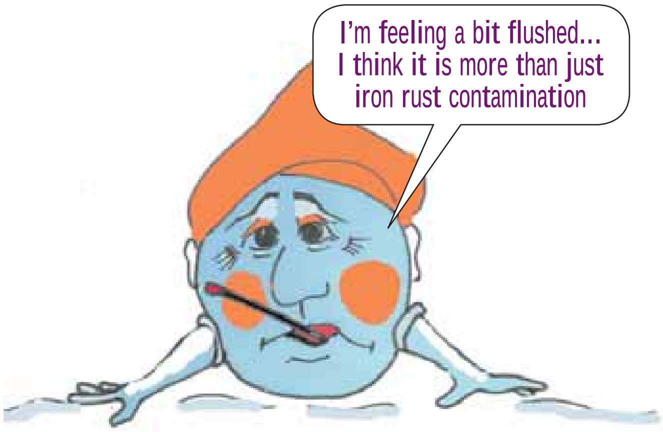
Salty taste This type of taste is usually caused by naturally occurring sodium, magnesium or potassium compounds that are present in a coastal area where sea water may be affecting the fresh water supply. Naturally occurring high levels of total dissolved solids (e.g., Colorado River water) can also cause this problem. A utility should work with the state, and additional site investigation may be required to isolate and remediate the problem.

Metallic taste Metallic tastes may be caused by metals, such as aluminum, zinc, iron, copper or manganese that leaches from distribution system piping as corrosion byproducts, or arise from the source water, or a residual chemical contaminant from water treatment. Possible sources of these tastes are treatment process chemicals (e.g., coagulants or corrosion inhibitors) or the source water. The corrosive potential of the finished water must be evaluated to determine if the distribution system piping could be a source (see Section 5.5, pH Stability and Scale Formation, for additional details). Appropriate sampling and analysis may be required to isolate the problem. Once the problem is identified, corrective techniques can be applied which may include modification of the treatment process.

5.1.2 Color Problems

Green or blue water Corrosion of copper plumbing will frequently cause a bluish-green stain on porcelain fixtures. The cause of this problem is generally in the customer's piping or due to corrosive water supplied by the utility. Copper corrosion can sometimes appear in new building plumbing. Also, backflow of carbon dioxide or other corrosive chemicals can cause copper corrosion in plumbing. The corrosive potential of water should be checked and, if necessary, adjustments need to be made during treatment such that the water supplied is not corrosive. Phosphate is commonly added to reduce corrosion in the distribution system. If the water supplied by the utility is not corrosive, the customer should contact a licensed plumber and possibly have the residential pipes replaced. A short-term acute exposure (above the maximum contaminant level (MCL) of 1.3 mg/L) can cause gastrointestinal distress. Long-term acute exposure can result in liver or kidney damage. People suffering from Wilson's disease should consult their doctor if the copper in their water exceeds the MCL.

Brown, red, orange or yellow water Rusty water can cause brown, red, orange or yellow water due to corroding galvanized iron, steel or cast iron pipes in building plumbing or in the distribution system pipes. Local water main conditions (valve operating, flow reversals, and flushing) can upset corroded iron mains and stir up rust. While unpleasant and potentially damaging to clothes and fixtures, iron in drinking water is not an immediate human health concern. The SDWA has a (non-enforceable) secondary standard of 0.3 mg/L for iron. The corrosive potential of water should be checked by the utility and, if necessary, appropriate adjustments should made during treatment. Phosphate addition and pH adjustment are commonly used to reduce corrosion in the distribution system.



Black or dark brown water Manganese or other pipe sediment can cause a black or dark brown color but generally clears up without further action after the sediment settles in the water main. Flushing of cold water faucets and toilets is recommended. Manganese does not pose a threat to human health. The SDWA has a (non-enforceable) secondary standard of 0.05 mg/L for manganese. The utility should investigate to determine if the household is located in an area with chronic low-flow issues that could lead to pipe sediments and deposits. If the problem is caused by the presence of manganese in source water, additional treatment prior to distribution may be required to resolve the problem.

Milky white or cloudy water Entrapment of air bubbles can result in milky or cloudy water. The customer should fill a clear glass with water and set it on a flat surface. If the water starts to clear at the bottom of the glass first, the cloudy or white appearance is a natural occurrence. Presence of air bubbles is not a health threat and should clear in about five minutes. If the water does not become clear, additional studies should be conducted to isolate and remediate the problem. Galvanized pipe (zinc coating) or aluminum oxide can also make the water appear milky.

Figure 5.1 depicts a taste and odor wheel that can assist troubleshooting activities.

5.2 Biofilm

Biofilm consists of microbial organisms that attach to the interior surfaces (e.g., pipes, tanks) of water distribution system pipes and tanks. These organisms excrete a slimy glue-like substance that allows them to adhere to the piping or other water distribution system components. Figure 5.2 shows a picture of biofilm growth inside a pipe. Generally, biofilm in distribution system piping contains various species of bacteria: most commonly coliforms, heterotrophic and nitrifying bacteria. However, biofilm can contain fungi, algae, protozoa, dead cells, corrosion products, organic, and inorganic matter. Typically, biofilms are benign and do not cause health problems. However, in many cases, their excessive growth leads to various types of problems and requires control. For example, biofilms can shield disease-causing microorganisms such as mycobacteria, aeromonads and *Legionella* from residual disinfectants. In addition, biofilms can allow the growth of bacteria to reach a level that interferes with total coliform compliance testing or support the growth of coliform organisms to a level that jeopardizes compliance with the total coliform

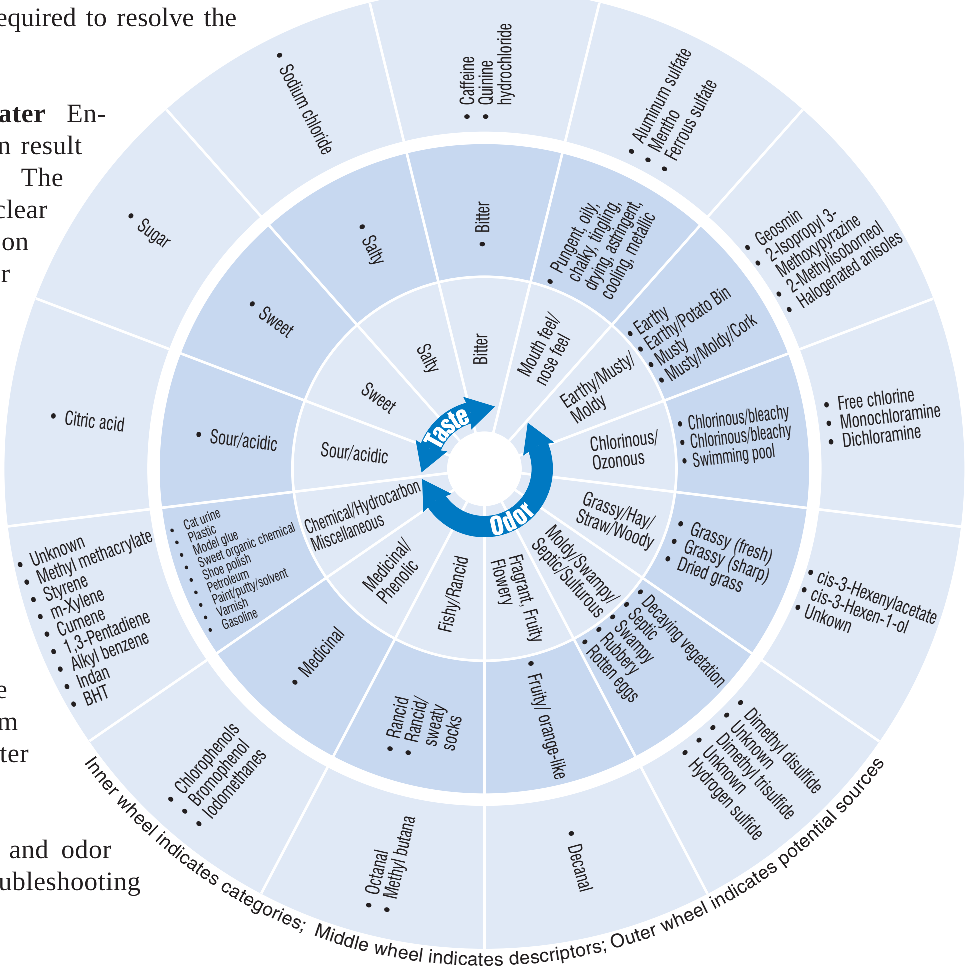


Figure 5.1 Drinking Water Taste and Odor Wheel (adapted from AWWA, 2004)

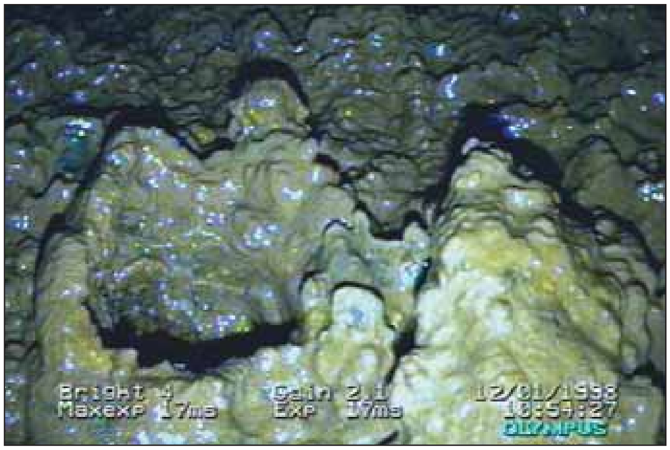
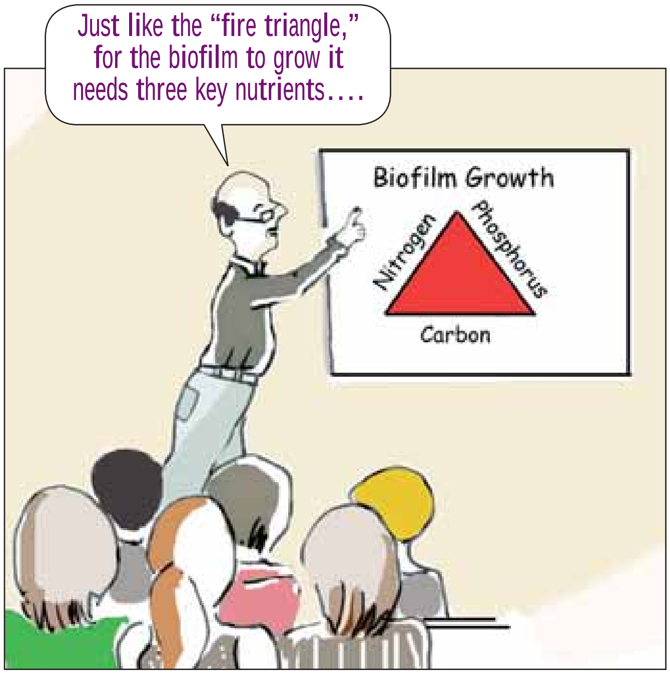


Figure 5.2 Biofilm Growth Inside the Pipe

monthly standard. Furthermore, biofilms can also produce taste- and odor-causing compounds, especially after initiation of disinfection, leading to consumer complaints. Therefore, it is important to understand the factors that promote biofilm growth and the operational techniques that can be employed to minimize biofilm growth as discussed in the following subsections.

5.2.1 Factors Aiding Biofilm Growth

Drinking water is not sterile. Thus, bacteria in water will form biofilm as water always has enough nutrients (carbon, nitrogen and phosphorous) to allow biofilm growth to occur. However, the rate of biofilm growth is influenced by the finished water quality and other contributing factors such as disinfectant type, residual disinfectant concentration, pipe material, system hydraulics, corrosion activity and distribution system maintenance practices. The basic process begins with the seeding of the microbial organism in the system and the growth rate is a function of nutrient availability and other contributing factors which are discussed in this section.



The overall composition of the biofilm in a distribution system depends upon the organisms that initiate the growth. For example, water main construction and repair activities can create an opportunity for some undesirable organisms to enter the system and act as "seeds" for growth. Thereafter, the availability of nutrients in the finished water is a key factor in biofilm growth. The key nutrient that impacts biofilm growth is total organic carbon (TOC) in water. Some research has pointed to specific components of TOC, notably assimilable organic carbon (AOC) and biodegradable organic carbon (BDOC), as the key factors in influencing biofilm growth. However, there is still much uncertainty associated with the biofilm growth process.

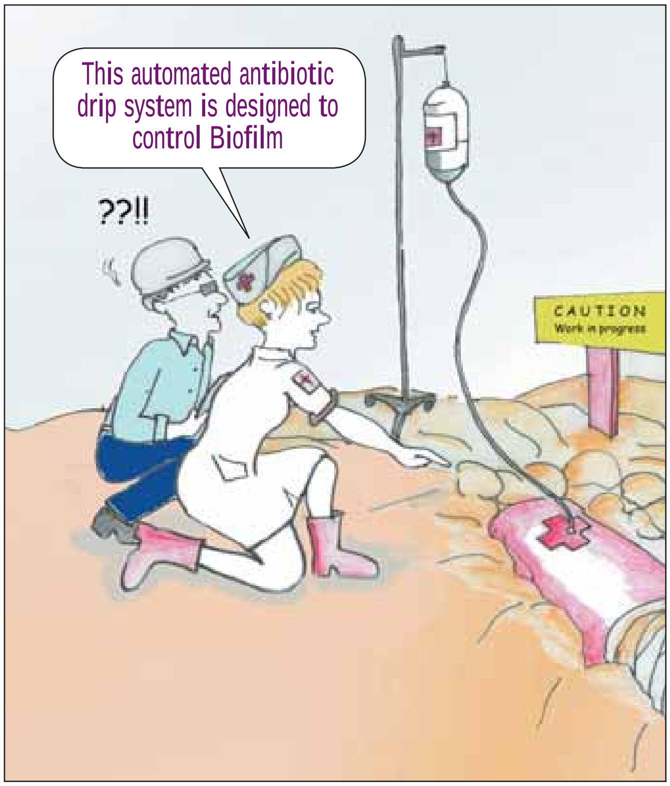
Biofilm growth is amplified by factors such as flow, high temperature, corrosion, and low residual disinfectant levels. In general, low flow conditions tend to favor formation of biofilms. Higher temperatures favor the development of biofilms and increase the diversity of microorganisms present in the biofilm. A rule-of-thumb is that water temperature at or above 15°C (~60°F) tends to experience greater bacterial activity. Corroded pipes are more supportive of biofilm growth than non-corroded pipes, because the corrosion deposits and tubercles (blister-like growth of iron oxides) can act as a shelter to the organisms to protect them from the disinfectant. Most disinfectants are effective in controlling the organisms that comprise a biofilm provided that it comes in contact with the organisms. However, the dead cells, extra cellular molecules, and other components of a biofilm react with the disinfectant to limit their destructive ability. The type of disinfectant used can also affect biofilm growth. In some instances, the use of chloramines may yield better biofilm control.

5.2.2 Operational Factors Inhibiting the Growth of Biofilm

Biofilm growth in distribution system piping is inevitable, given that small quantities of microorganisms are always present in source water and pass through treatment or can be introduced accidentally during construction and repair activities. Operational techniques can be implemented to inhibit biofilm growth by the following: reducing available nutrients, optimizing disinfectant dosage, controlling corrosion and periodic flushing.

Reducing nutrient availability As mentioned in the previous section, TOC is usually the key nutrient that impacts biofilm growth in drinking water systems. Utilities should consider treatment techniques such as enhanced coagulation and/or activated carbon filtration in conjunction with source water protection measures to reduce the overall TOC levels in water. For some utilities, another option is to move the point of disinfection (to a point after the filtration process). This allows bacteria to grow in the filter media and consume the biodegradable fraction of TOC, even though the overall TOC levels are not significantly reduced. In some systems, nitrogen may be the limiting nutrient factor. Ammonia, nitrate or nitrite removal technologies may be employed by the operator to reduce nitrogen availability. For systems using chloramines, careful control of ammonia addition may help to reduce residual free ammonia in the finished water.

Optimizing disinfectant dosage Disinfectants can reduce the growth of biofilm in a distribution system. However, residual disinfectant must be available throughout the distribution system. In many cases, it may not be practical to maintain residual levels based on disinfection at one central location. Distributed booster chlorination stations may be more effective in maintaining residual levels in areas of low-flow and stagnation, especially during warmer water temperature months.

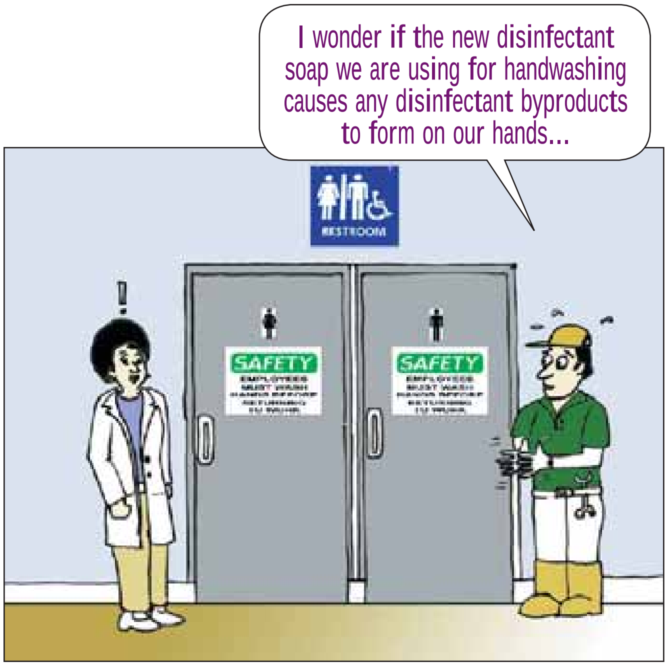


Corrosion control As discussed previously, corrosion deposits and tubercles can act as a shelter to help protect biofilm from a disinfectant. In moderate to severely corroded iron pipes, the exposed surface may take up a vast majority of the available disinfectant. Proactive corrosion control practices may result in better control of biofilm growth. Water main rehabilitation or replacement is another option.

Flushing Flushing at velocities greater than 2 feet/second can physically remove some biofilm by scouring. Flushing can also remove accumulated debris and corrosion products that shield the biofilm from disinfection. Flushing is only a temporary measure; the underlying conditions that support biofilm growth need to be addressed simultaneously.

5.3 Disinfection and Disinfection Byproducts

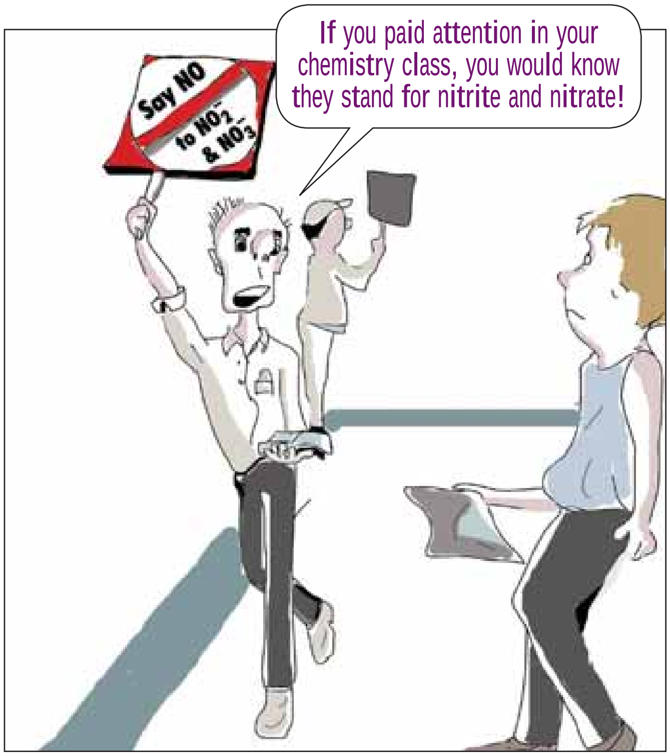
All utilities using surface water sources are required by EPA to disinfect the water prior to delivery to their consumers. The intent of this requirement is to provide a barrier against disease-causing microorganisms. The process which destroys or removes disease-causing organisms is termed “disinfection.” Chlorine and chloramines are the most commonly used disinfectants in the U.S. Furthermore, it is necessary that a residual disinfectant be maintained throughout the distribution system. Loss of disinfectant residual is one of the most common water quality concerns. The availability of a disinfectant residual is a function of time and rate of decay or loss caused by consumption of disinfectant at the pipe wall and in the bulk water. Excess disinfectant levels lead to undesirable changes in water quality when the disinfectants react with naturally occurring organic matter or compounds, such as TOC or bromide, in the source water/distribution system to form DBPs.



Although studies are ongoing to determine the long-term health effects of exposure to DBPs, EPA has already set monitoring requirements and MCLs for some of the more common DBPs including: trihalomethanes (THMs), haloacetic acids (HAAs), bromate, and chlorite. If DBPs are a problem, the utility should carefully evaluate the key variables that impact their formation including: residual disinfectant levels, water age in the distribution system, TOC concentration, pH, and water temperature. A DBP problem scenario is described in Section 5.7 at the end of this chapter.

5.4 Nitrification

Nitrification in drinking water distribution systems is the transformation of ammonia to nitrate. In this process, ammonia is first transformed to nitrite by bacteria and subsequently, nitrite is transformed to nitrate as a bacteriological process or simply in the presence of oxygen. Nitrifying bacteria are slow-growing organisms, and nitrification problems usually occur in large reservoirs or low-flow sections of distribution systems. Ammonia is present in drinking water through either naturally-occurring processes or through the addition of ammonia during disinfection to form chloramines. Given similar levels of TOC and temperature in the source water, chloramines form less DBPs than chlorine. Therefore, chloramine use is expected to increase as a direct result of more stringent DBP MCLs associated with the Stage 1 and Stage 2 D/DBP Rules (see Chapter 4).



Nitrate and nitrite levels in water are required to be monitored at the entrance to the distribution system. If the levels are greater than one-half of the MCL, additional proactive monitoring and troubleshooting should be performed. Nitrate and nitrite have direct health implications. Nitrate is transformed to nitrite in the human digestive system. The nitrite ion oxidizes iron in the hemoglobin of the red blood cells to form methemoglobin, which lacks the oxygen-carrying ability of hemoglobin. This creates the condition known as methemoglobinemia (commonly referred to as “blue baby syndrome”), in which blood lacks the ability to carry sufficient oxygen to the individual body cells causing the veins and skin to appear blue. Infants under 6 months of age and older persons with genetically impaired enzyme systems are unable to reduce toxic methemoglobin to oxyhemoglobin. Therefore, ingestion of nitrite and nitrate can be fatal in these susceptible population groups. To protect the susceptible population, EPA has mandated the MCL for nitrate to be 10 mg/L (measured as nitrogen) and 1 mg/L for nitrite (measured as nitrogen). Most individuals over one year of age have the ability to rapidly convert methemoglobin back to oxyhemoglobin.

It is important to recognize that nitrate and nitrite may come from sources other than nitrification. It has been found that 93 percent of all U.S. water supplies contain less than 5 mg/l nitrate, but these values may be changing as a result of the increased use of nitrate-containing fertilizers that enter source waters. Increased use of chloramination may also result in higher levels of nitrate in drinking waters because of partial nitrification in the distribution system. The nitrification process in a distribution system can be controlled by utility operators by controlling the presence of ammonia, minimizing the low-flow areas in distribution systems and controlling the growth of biofilm that may contain the nitrifying bacteria.

5.5 pH Stability and Scale Formation

It is important to maintain a stable pH as part of maintaining distribution system water quality. Excessive changes in pH can lead to water quality problems. For example, low pH values (less than 7.0) can accelerate the internal corrosion of metallic pipes, and can lead to leaching of lead and copper in pipes and plumbing fixtures. Therefore, a certain level of scaling in metallic pipes is helpful in passivating the pipe by depositing a protective carbonate layer on it. However, higher pH (greater than 9) can cause excessive scale formation which can significantly reduce the carrying capacity of a pipe and provide a shelter for biofilm growth. Scales in pipes are formed due to the precipitation of mineral constituents in water onto the pipe walls. Scale formation is a complicated process that depends on a variety of system-specific physical and chemical conditions and pH is only one of the factors. Scale-forming potential is often measured by the Calcium Carbonate Precipitation Potential or the Langelier Saturation Index (LSI).

Langelier Saturation Index (LSI) (CD, undated)
In order to calculate the LSI, it is necessary to know the alkalinity (mg/l as calcium carbonate [$CaCO_3$]), the calcium hardness (mg/l Ca^{2+} as $CaCO_3$), the total dissolved solids (mg/l), the actual pH, and the temperature of the water (°C).

$LSI = pH - pH_s$

Where: pH is the measured water pH and pH_s is the pH at saturation in calcite or calcium carbonate and is defined as:
$pH_s = (9.3 + A + B) - (C + D)$

Where:
$A = (\text{Log}_{10}\,[\text{total dissolved solids}] - 1) / 10$
$B = -13.12 \times \text{Log}_{10}\,(°C + 273) + 34.55$
$C = \text{Log}_{10}\,[Ca^{2+} \text{ as } CaCO_3] - 0.4$
$D = \text{Log}_{10}\,[\text{alkalinity as } CaCO_3]$

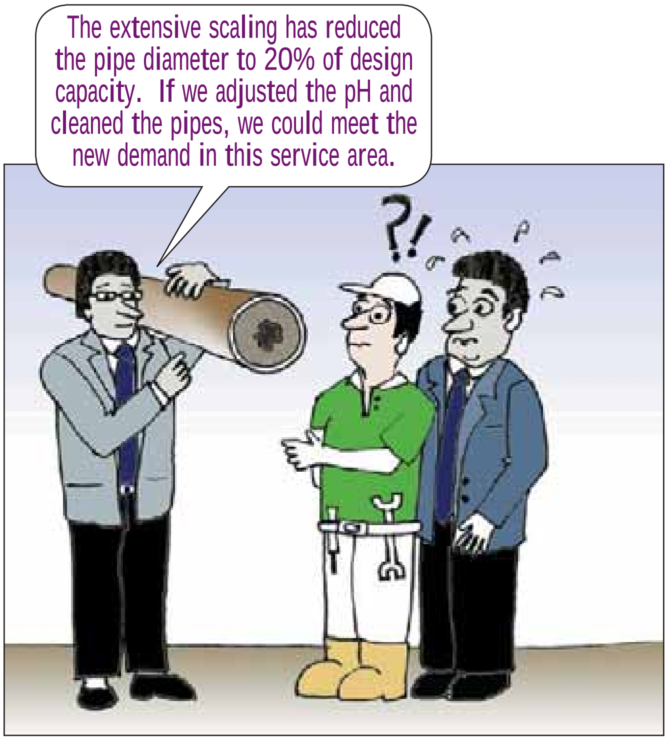
A negative LSI value indicates that there is no potential for scaling to occur, the water will dissolve $CaCO_3$. A positive LSI indicates that scaling can result from $CaCO_3$ precipitation. An LSI close to zero is the desirable in most cases.

5.6 Contamination Events

Drinking water distribution systems are vulnerable to external contamination from cross-connections, permeation/leaching, intrusion/infiltration and reservoir/storage facility contamination. These problems are briefly discussed below.

5.6.1 Cross-connections and Backflow

Almost all distribution systems contain locations where accidental cross-connections between potable drinking water and non-potable water can occur. These cross-connections can provide a pathway for backflow of non-potable water (i.e., contaminated water into potable supplies). Backflow occurs either because of reduced pressure in the distribution system (termed backsiphonage) or due to the presence of increased pressure from a non-potable source (termed backpressure). Backsiphonage may be caused by a variety of circumstances, such as main breaks, flushing, pump failure, hilly terrain, limited pumping capacity, high demand by consumers, or emergency firefighting water drawdown. Backpressure can occur when heating/cooling, waste disposal, or industrial manufacturing systems are connected to potable supplies and the pressure in these external systems exceeds the pressure in the distribution system. In both cases, the direction of water flow is reversed, causing non-potable and potentially contaminated water from industrial, commercial, or residential sites to flow back into the distribution system through a cross-connection.



The risk posed by cross-connection and backflow can be minimized. For example, it can be prevented by installing backflow prevention devices and assemblies and through formal programs to seek out and correct cross-connections within the distribution system. Some water systems have programs to identify cross-connections or the potential for cross-connections in individual service connections. Some corrective measures include activities such as flushing and cleaning a distribution system after an incident.

There is no easy way to detect and monitor for the occurrence of cross-connection and backflow. Also, there are no national reporting requirements for backflow incidents, and no central repository exists for backflow incident information. Some states have detailed requirements and other states have minimal requirements for cross-connection control. The number of reported incidents is believed to be a small percentage of the total number of backflow incidents that actually occur in the U. S. There is a lack of general awareness about the threat posed by cross-connections and backflow through illegal and unprotected taps. PWS operators should be aware that there is a potential for intentional contamination of a distribution system through such cross-connections.

5.6.2 Permeation and Leaching

Permeation of piping materials and non-metallic joints is defined as the passage of contaminants external to the pipe, through porous, non-metallic materials, into the drinking water and is generally limited to plastic and other non-metallic materials. Volatile organic compounds present in the ground can permeate plastic piping and gaskets.

Leaching is defined as the dissolution of metals, solids, and chemicals into drinking water. Leaching from cement linings can occur in soft, aggressive, poorly buffered waters. Under static conditions, metals such as aluminum, arsenic, barium, chromium, and cadmium can leach from cement linings, even when NSF-approved materials are used and linings are applied according to AWWA standards. Vinyl chloride can leach from PVC pipe manufactured prior to 1977. The SDWA has established an MCL of 0.002 mg/L (2 µg/L) for vinyl chloride; however, no instances of MCL violations have been cited in connection with PVC pipe manufactured after 1977.

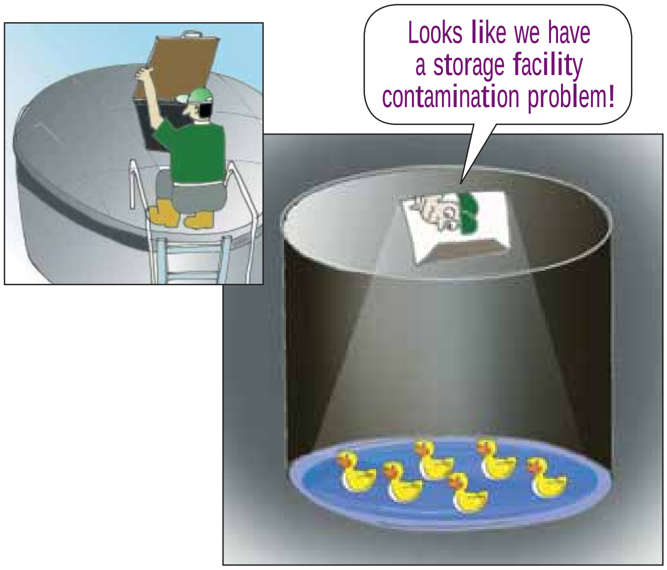
Permeated plastic piping must be replaced since the piping retains its swollen porous state after permeation. Operators of small PWSs using non-metallic pipes should be aware of permeation and leaching problems and address them appropriately. Operators should avoid placing plastic pipes (mains or service lines) in soils and ground water environments that may be contaminated with organic solvents and petroleum products.

5.6.3 Intrusion and Infiltration

A pressure transient in a drinking water pipeline caused by an abrupt change in the velocity or direction of water can cause a surge or "water hammer." When a valve is closed rapidly, it suddenly stops water flowing in a pipeline and the associated pressure energy is transferred to the valve and pipe wall. Similar action can occur when a pump is shut off rapidly, as may happen with a power outage. Shock waves circulate within the distribution system and pressure waves sometimes produce a banging noise as it travels back and forth. A less severe form of water hammer is called a surge where a slow motion mass oscillation of water is caused by internal pressure fluctuations in the system. If these pressure transients are not controlled, they can damage pipes, fittings, and valves, causing leaks and shortening the life of the system. The production of this transient low- and negative-pressure creates the opportunity for contaminated water to intrude and infiltrate the pipe from outside. Such pressure transients can back-siphon environmental water in soil (or flooded valve and meter pits) into the mains through leaking joints or cracks.

5.6.4 Storage Facility Contamination

Reservoirs and neglected finished water storage facilities such as reservoirs and tanks can be a dangerous source of contamination. When unchecked, animals, birds and pests can inhabit and contaminate these facilities. If these facilities are improperly maintained, they can quickly spread the contamination throughout a distribution system. Storage facilities should be thoroughly inspected on a regular basis.



Storage Tank Contamination (Clark et al., 1996)

In December 1993, a *Salmonella* outbreak was identified in the Gideon, Missouri, municipal water system. This outbreak affected around 486 of the 1,104 residents and caused seven deaths among nursing home residents. Ensuing EPA investigations supported by other federal, state and local authorities concluded that all the affected residents had consumed municipal water. The investigations revealed that a large municipal storage tank was in a state of disrepair with bird parts and other floating debris which was determined to be the source of contamination. During November 1993, the residents of Gideon reported objectionable tastes and odors in the drinking water supply. The utility superintendent initiated an aggressive and comprehensive flushing program and flushed the hydrants in the system. Unfortunately, the flushing program resulted in water being drawn from the municipal tank that was severely contaminated with *Salmonella* which dispersed throughout the network. This preventive action led to a major waterborne disease outbreak. Initially, it was suspected that the sediments in the tank owned by the private company also connected to the distribution system and was the source of the outbreak. However, a pressure test confirmed that the backflow prevention valve connecting the private tank to the Gideon network was functioning properly. A modeling analysis confirmed that the earliest reported cases of disease were found to be from areas receiving water predominantly from the contaminated municipal tank.

Additional Information

Taste, Odor, Flushing, DBP, Nitrification and Cross-connection

NESC. Tech Brief: Taste and Odor Control. 2006.

AWWA. Water Supply Operations: Flushing and Cleaning - DVD. 2006.

AWWA. Cost and Benefit Analysis of Flushing. 2004.

EPA. Technologies and Costs for Control of Disinfection By-Products. October, 1998

EPA. Nitrification. August 15, 2002.

EPA. Cross-Connection Control Manual. February, 2003.

5.7 SmallWater, USA – Water Quality Problem Scenarios

Problem #1 DBP Scenario

SmallWater purchases water from another supplier and has discovered a compliance problem with DBPs (particularly THMs and HAAs) in its purchased water. The supplier chlorinates the water and the long travel time to SmallWater and within the SmallWater distribution system frequently leads to the formation of excess DBPs.

Issues to Consider

Elevated DBP levels can be a difficult problem to alleviate. This is especially true in this situation where SmallWater purchases most of its water from another utility and has little control over the source water and treatment process. Issues that should be considered include:

- Does the water comply with DBP levels in the new Stage 2 DBP Rule?
- If it is not in compliance, what are the primary causes for the elevated DBP levels? Potential problems could be high levels of DBP precursors in the source water coupled with insufficient or incorrect treatment, long travel times for the finished water to reach the town, and/or excessive travel times from the entry points into the town until the water reaches the town's customers.

Regulatory Guidance

The initial question that SmallWater should address is whether or not the elevated DBP levels are due primarily to the characteristics of the source water and treatment. Another question is whether or not excessive water age has led to high levels of DBP formation during the time when the water is traveling to SmallWater and within the SmallWater distribution system.

Sampling data showed that THM levels at the point of entry to the town were in compliance and typically averaged around 40 to 50 µg/L while samples within the SmallWater distribution system frequently exceeded 80 µg/L and, in some cases, exceeded 100 µg/L. This suggested that THM formation within the town was the primary cause of the elevated DBP levels. A quick calculation of the travel time for the water from the treatment plant to the town for the purchased water showed that, under average conditions, it took about 20 hours. This was compared to the map of maximum water age (from the entry points to the town) that the town's consultants produced from their hydraulic model.

Figure 5.3 indicates that maximum travel times within the town were typically in the range of 1 to 5 days. This far exceeded the 20-hour travel time for the purchased water to reach the town. Both the sampling data and the travel time calculations clearly indicated that the primary problem leading to excessive DBP levels was the operation of SmallWater's water distribution system rather than the source water/treatment. SmallWater's consultant was asked to work with the town's water staff to determine operational changes for reducing the water age within the town.

Problem #2 Contamination Scenario

SmallWater has received several sporadic complaints over the past year from the residents in the trailer park in the southwestern part of town about water that occasionally tastes and smells bad. The water system operator has visited the area on a few occasions and has not found any obvious problems. There haven't been any positive coliform samples in the town for the past year. Recently, one resident mentioned that both their children and elderly mother have experienced severe stomach aches.

Issues to Consider

The patterns of complaints in the trailer park suggest that there may be some intermittent contamination occurring in the distribution system serving this area. Since the complaints are from more than a single residence, it is likely that the location of the contamination is in the distribution system itself or possibly within the customer's plumbing that has then migrated through the distribution system. Also, since the trailer park is served by a single connection to the main part of the distribution system, it is likely that the contamination usually will stay in the trailer park piping rather than move more widely into the distribution system. There are no Total Coliform Rule (TCR) sampling sites in the

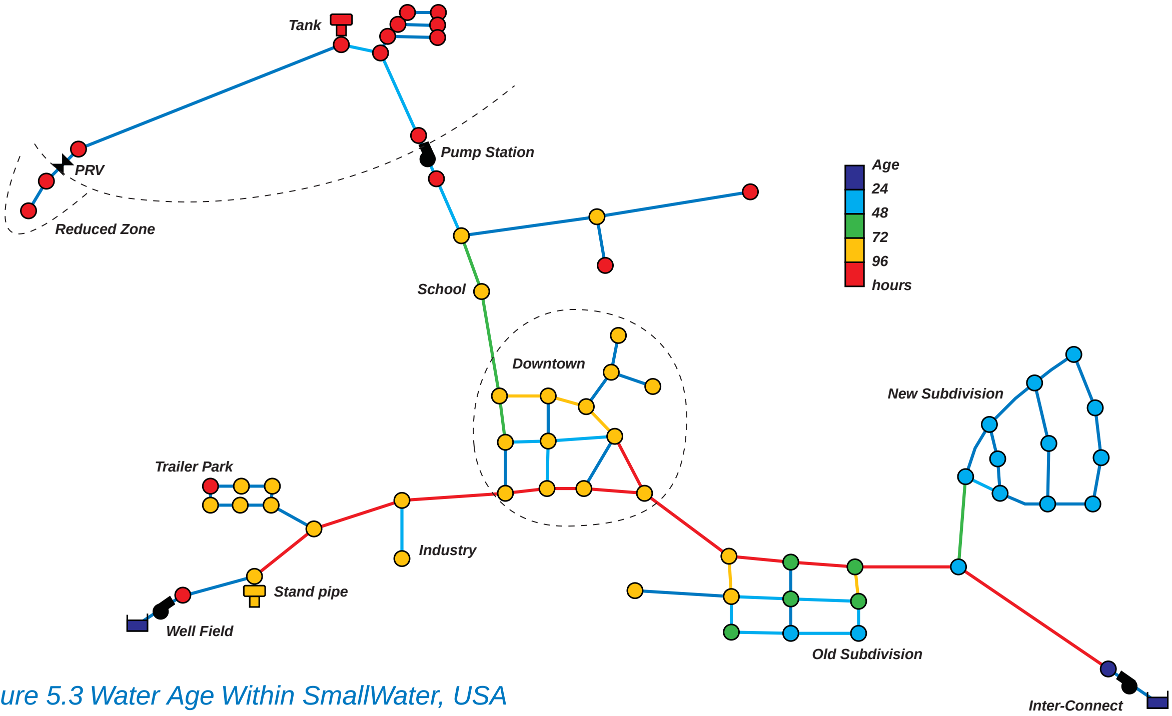


Figure 5.3 Water Age Within SmallWater, USA

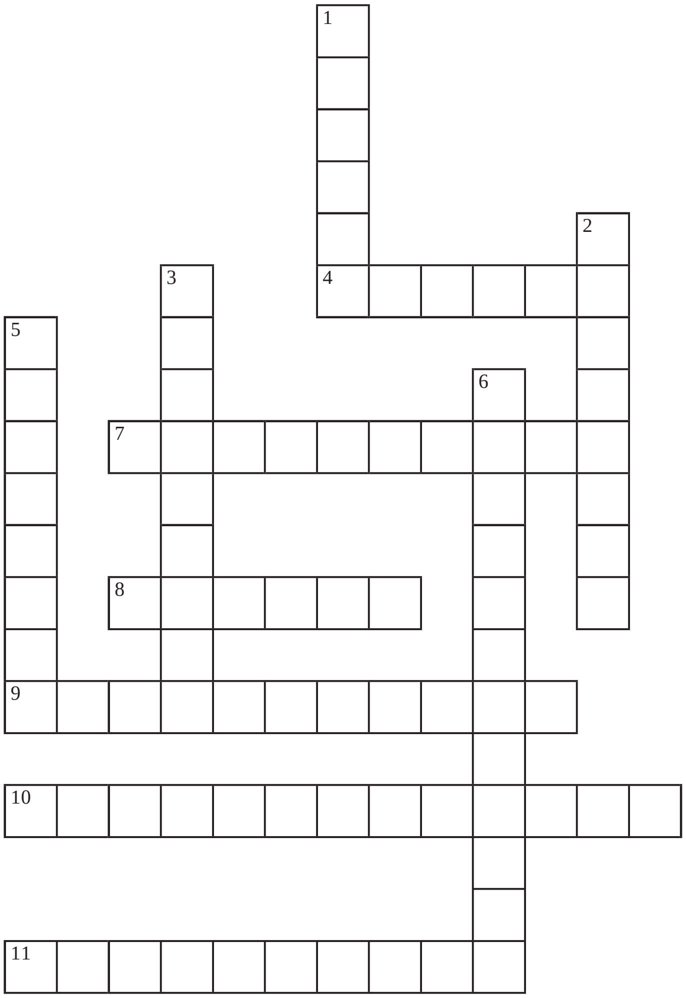
trailer park which may explain why there have been no positive coliform readings.

Regulatory Guidance

The town has fulfilled the sampling requirements associated with the TCR and has not experienced any positive readings. However, the repeated complaints within a small area and especially the recent indications of possible gastrointestinal illness should alert the town to a potential serious problem. SmallTown officials should contact the state primacy and health agency and solicit its assistance. Other activities should include (1) a cross-connection investigation in the trailer park area; (2) additional coliform sampling in the trailer park area; and (3) medical testing of the sick residents for possible exposure to disease-causing coliforms such as *E. coli*.

Crossword

Distribution System Water Quality Issues



ACROSS

4 Odor commonly caused by bacteria growing in a sink drain

7 Plastic pipes are susceptible to contamination from surrounding soils when this occurs

8 Water appearance caused by entrapment of air bubbles

9 Shock-waves caused by abrupt changes in velocity and direction of water

10 Technical term for process that converts ammonia to nitrate in distribution system

11 Water colors associated with manganese or other pipe sediments

DOWN

1 Forms due to precipitation of minerals in water on to the pipe walls

2 Water colors associated with corroding iron pipes

3 Water colors associated with corrosion of copper plumbing

5 A result of a cross-connection where nonpotable water contaminates drinking water distribution system

6 Common technique used for biofilm control which can sometimes lead to undesirable byproducts

Crossword Solutions

1) Scales, 2) Brown Red, 3) Green Blue, 4) Sulfur, 5) Backflow, 6) Disinfection, 7) Permeation, 8) Cloudy, 9) Water Hammer, 10) Nitrification, 11) Black Brown

Chapter 6

Distribution System Monitoring, Control, and Security

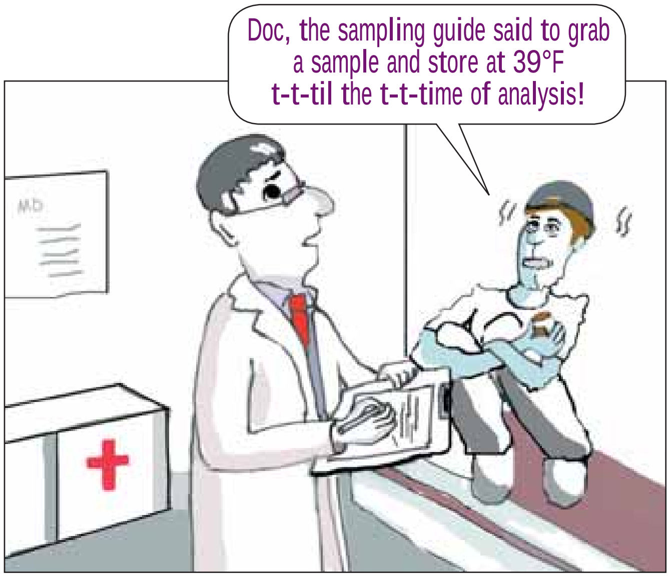
There are many questions that arise when attempting to monitor, control and/or secure a distribution system. Some of these questions include the following:

- What is happening at any moment in the underground pipes, elevated tanks, pump stations and other components that make up the distribution system?
- Are pressures sufficient to meet customer demands, prevent infiltration, and provide fire flow?
- Is there sufficient chlorine residual to protect the water in the distribution system?
- Is there enough water in the tank in case of a major fire?
- Has a contaminant entered the water system that could lead to a waterborne disease outbreak?
- When opening a hydrant, how much flow is available?
- Does the distributed water quality meet the standards set by EPA and the state regulatory agency?

In order to answer these questions with some degree of accuracy and reliability, data must be collected and reviewed periodically by the utility personnel from a variety of sources. If any problems are observed, corrective actions must be taken by the utility personnel. Utility managers may want to consider automated monitoring for operating and controlling a distribution system. Automation assists in obtaining a continuous set of records that can be examined for improving system operations. A distribution system is one of the most vulnerable aspects of a water utility because its components are geographically dispersed, making it difficult to ensure physical integrity. However, some key distribution system components, such as finished water storage tanks, can be adequately secured. Automation may therefore help improve the overall security of the distribution system. This chapter discusses options for monitoring, controlling and securing a distribution system.

6.1 Monitoring a Distribution System

Monitoring can be broadly categorized as measuring the hydraulic state of the water in a distribution system, or measuring water quality parameters. These two aspects of distribution system monitoring are discussed further in Sections 6.2 and 6.3. Hydraulic state monitoring includes: measuring flow rate, water pressure, velocity and/or water levels within a tank or reservoir. Water quality monitoring involves measurement of the intrinsic characteristics of the water. For example, a representative sample of water may be analyzed for temperature, conductivity, and pH. In addition, the water can be analyzed for specific water quality parameters such as chlorine residual and coliform.



Specific monitoring procedures may range from simple manual sampling to a highly automated process of sample collection and analysis. In manual sampling, a water sample is taken from the distribution system and is either analyzed in the field (Figure 6.1) or transported for analysis in the laboratory. Automated monitoring typically requires more sophisticated and costly equipment, but provides savings in labor costs and the added benefit of a greater number of measurements. Historically, small water utilities have generally relied upon manual sampling procedures in order to avoid the capital investments associated with automated equipment. However, as technology costs decrease, there are many cases where automated monitoring equipment is cost-effective for smaller utilities. Figure 6.2 shows an example schematic of an automated sampling unit that measures and analyzes the sample in the field and sends the information back to a central office for assessment.

Figure 6.1 Manual Water Quality Sampling and Field Testing

Since monitoring activities are expensive, they are usually performed to meet a specific objective or multiple objectives. These objectives may include:

- Regulatory requirement – Taking samples of water to determine if it meets the requirements established by federal or state agencies
- Process control requirement – Providing real-time information that assists in operating the system
- Baseline data collection – Establishing normal ranges for data values from the system
- Contaminant identification – Detecting the presence of a contaminant that has intentionally, accidentally or naturally entered the water system
- Computerized model calibration – Collecting hydraulic or water quality data to be used in adjusting a hydraulic and/or water quality model of the distribution system

Figure 6.2 Automated Water Quality Monitoring (GCWW, 2007)

- Improving system performance – Collecting real-time information that may be used to understand and improve system performance

In the following sections, various available options for distribution system state and water quality monitoring are discussed.

6.2 Distribution System Hydraulic Monitoring

As water moves through a distribution system and its various components, hydraulic characteristics such as flow, velocity, and pressure change over time. In order to understand a system's operation, to identify potential problems, or to operate the system more efficiently, it is useful to monitor these characteristics. Measurements may be made continuously at key locations using automated monitors (if affordable) or be measured manually at selected locations and times.

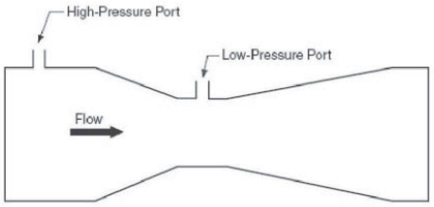
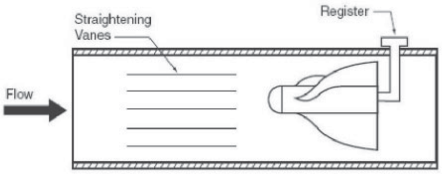
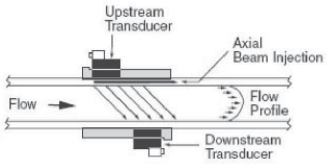
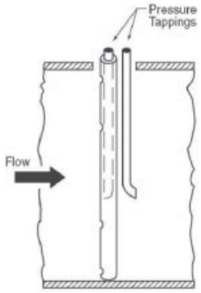
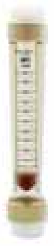
6.2.1 Flow and Velocity Monitoring

Flow is an important factor in understanding the operation of a distribution system. Low flows in some pipes may indicate a constriction or closed valve. High flows can result in high velocities which cause large friction losses and even damage to the pipe. Water sold to customers is typically billed based on flow. Therefore, understanding flow is important to the proper operation and maintenance of a water distribution system.

Meters are used to measure flow rates and velocities in an open channel or closed pipe. They may be permanently placed in the distribution system or in a treatment plant to provide continuous measurements. They may also be temporarily installed as part of a testing program to provide measurements over a period of a few days or weeks. They may also be used manually to measure flow from a hydrant as part of a system calibration or fire flow analysis. Flow meters can provide continuous flow measurements and/or totalized volumes over a period between readings.

There are several different types of flow meters. Most meters can be broadly classified based on the following operating principles: differential pressure, positive displacement (PD), velocity measurement and level measurement. Differential pressure meters and velocity meters are most commonly used in the water industry. Within each of these categories, there are alternative methods for achieving these measurements. Table 6.1 illustrates several different types of flow meters and the basic principle upon which each is built. More detail on the limitations and advantages of each type of meter can be found in American Water Works Association's (AWWA's) M33 Manual of Water Supply Practices "Flowmeters in Water Supply" (second edition published in 2006).

Table 6.1 Flow Meters (Partially adapted from AWWA, 2006b)

Meter Type	Diagram	Principles of Operation
Venturi Meter		A constricting section is placed in the pipe causing an increased velocity and corresponding pressure drop. Pressures are measured at the upstream end of the constriction and within the constriction. Flow is calculated from the square root of the measured pressure differential multiplied by a meter factor that accounts for dimensional units and discharge coefficient.
Turbine and Propeller Meters		In turbine and propeller flowmeters, flowing water strikes rotor blades that rotate at a rate proportional to the flow velocity. The turbine wheel of a turbine meter generally fills the cross-section of the pipe and is mounted to spin freely between two central bearings supported in the pipe wall. The propeller of a propeller meter is mounted on bearings at the downstream end of the pipe and does not fill the meter cross-section.
Transit Time Ultrasonic Flow Meter		A pair of transceivers is positioned diagonally across the meter body. The transceivers transmit and receive an ultrasonic pulse in the direction of flow, followed by a return pulse against the direction of flow. The time difference between the two pulse transmissions through the stream is a function of fluid velocity and, by computation, the rate of flow.
Averaging Pitot Flow Meters		Multiple ports in an insertion tube face upstream into the flow to provide sampled pressures at selected points along the vertical pipe diameter to provide an averaged pressure over the pipe cross-section while ports facing downstream register static pressure. The device produces a differential pressure reading which is used to calculate velocity (proportional to the square root of the pressure differential).
Insertable Averaging Magnetic Flowmeter		Multiple magnetic fields are generated by electromagnetic coils placed inside a sensor inserted in the pipe section through a tap connection. Water passing around each sensor encounters the magnetic field, which induces a small electric charge that is proportional to the velocity of the water in the magnetic field. The electric charge is sensed by multiple pairs of electrodes in contact with the water adjacent to each of the electromagnets. Each coil and pair of electrodes becomes an electromagnetic velocity sensing point along the sensor.
Variable Area Flow Meter		Also known as a rotameter, the area through which the liquid flows is permitted to vary so that a constant differential pressure is maintained. The basic elements are a vertical conical tube and a cylindrical float that is free to rise and fall in the tube. The greater the entering volumetric flow, the larger the required flow through area, and the higher the float rises. Therefore, the rise of the float is proportional to the rate of flow.

Flow measurements may also be taken at hydrants and used to estimate fire flow availability (or as part of a distribution system model calibration study). Pitot gages are typically used to measure hydrant flow and are available in three forms: hand held, clamp-on, or in combination with diffusers (see Figure 6.3). They are all based on the principle that virtually all of the velocity head in the hydrant flow is converted to pressure head that is read by the pitot gage. Pressure measurements can then be converted to hydrant discharge rates based on the diameter of the hydrant port, the characteristics of the port and the specific instrument.

(a) Hand-held

(b) Clamp-on

(c) Integrated with diffuser

Figure 6.3 Hydrant Flow Gages

Water Meters and Automation

Positive displacement (PD) water meters are normally used to measure usage in residences and commercial buildings. Other types of flow meters can also be used at specific locations in a distribution system to determine flow through that portion of the system. These flow meters utilize a variety of flow measurement methods and are generally selected for specific use based on the type of end user, the required flow rates, and accuracy requirements.

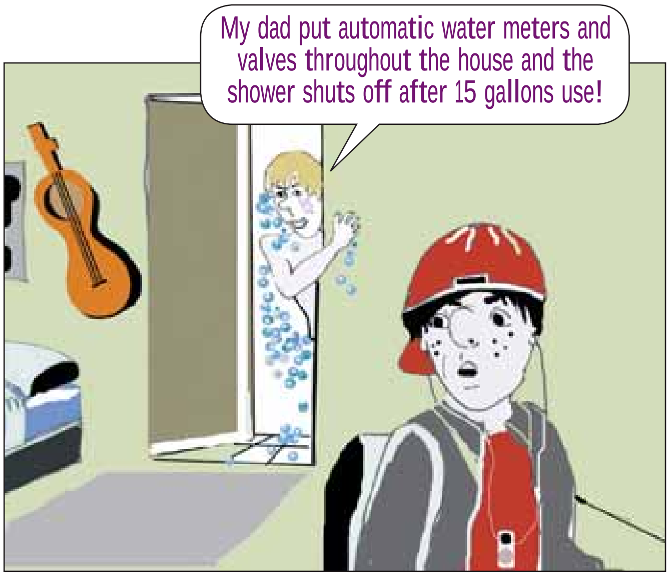
PD meters employ oscillating pistons or a nutating disk to measure flow. Both methods rely upon the physical displacement of the measuring element in direct relation to the amount of water passing through the meter. The piston or disk moves a magnet that drives the register. PD meters are generally very accurate at low to moderate flow rates typical of residential and small commercial users, and are common in sizes from 5/8 to 2-inch pipe-size. However, this measuring methodology is not practical in large commercial applications that experience high flow rates or low pressure loss. A velocity type meter is commonly employed for higher flows where the velocity is converted into volume. Common velocity-based meters include: jet meters (single-jet and multi-jet), turbine meters, propeller meters, and magnetic meters.

Manufacturers have now developed pulse or encoder registers to produce electronic output for radio transmitters, reading storage devices, and data logging devices that are employed with Automatic Meter Reading (AMR). In AMR technology, the usage data is automatically collected from customer water meter and transferred to a central database for billing and/or analyzing. AMR systems provide customers and utilities a more accurate way of tracking and billing of actual water usage rather than depending on a flat rate system or an estimate. AMR technologies include handheld, mobile and network technologies based on wired, wireless, or radio frequency transmission.

6.2.2 Pressure Monitoring

Pressure measures the amount of internal energy within water at any location in the distribution system. Most importantly, pressure serves as an important indicator of how a water system is operating and is closely related to hydraulic integrity. Routine low pressures in a distribution system indicate design deficiencies or operational problems in the system. Unusually low pressures may indicate a problem such as a main break, closed valve or low water levels in a tank. Therefore, pressure is frequently monitored to assess system operation and integrity.

Pressure can be monitored continuously using pressure meters installed in the system or can be measured manually at hydrants or any faucet in the distribution



system. Permanently installed continuous monitors are frequently connected to a Supervisory Control and Data Acquisition (SCADA) system (See Section 6.4 for an overview on SCADA and automation). These pressure values are transmitted to a central control room. Pressure meters may also be used to measure tank water levels. Figure 6.4 shows a pressure gage attached to a fire hydrant. Figure 6.5 shows typical SCADA readouts of the distribution system hyraulic measurements.

6.3 Distribution System Water Quality Monitoring

Water utilities strive to deliver water that meets or is better than the Safe Drinking Water Act (SDWA) standards and is aesthetically acceptable. Other goals may include minimizing treatment costs and delivering a product that is consistent in quality for all uses. Water quality monitoring serves as the mechanism for measuring how well the utility meets these goals and may serve multiple purposes including:

1. Satisfying regulatory compliance requirements
2. Assisting in process or operational control
3. Identifying contaminants in the water
4. Characterizing the water quality for use in future decisions

Because water quality monitoring can be expensive, most small utilities emphasize its use only in meeting regulatory compliance requirements. However, additional monitoring can frequently pay off in terms of an improved product and lower treatment and chemical costs. Routine or automated online monitoring can also assist in screening for the possible occurrence of: loss of disinfection residual, pathogen contamination, disinfectant byproduct formation, nitrification, metal accumulation, and intentional (e.g., terrorist) contamination.

Design of a monitoring or sampling program involves the following decisions:

1. What constituents should be monitored?
2. Where should the monitoring locations be placed?
3. What type of sampling (continuous, composite or grab) should be employed?
4. How often should sampling occur?
5. What type of analytical procedures should be used?
6. Is the sampling routine, seasonal, or being conducted for a special study?

Figure 6.4 Digital and analog pressure meter attached to fire hydrant

Figure 6.5 Readout meters for flow, water level and pressure from a SCADA system

For compliance monitoring, the answers to most of these decisions are spelled out in the regulations and operating permits. However, for other types of monitoring, the water utility is responsible for designing the monitoring program that meets its specific needs and fits within its budget.

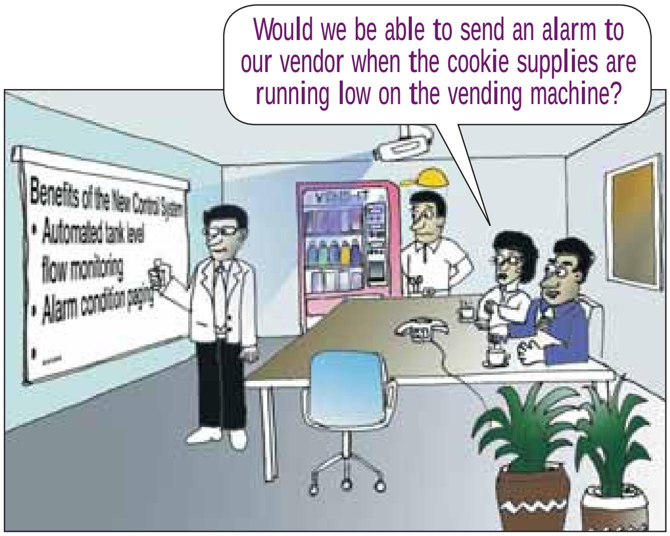
6.4 Controlling a Distribution System

The smaller utilities have historically limited the use of SCADA to control the treatment process. However, SCADA is routinely employed by larger utilities to monitor and control distribution system operations. A SCADA system consists of three components: instrumentation and hardware, a software program or operator interface, and communication media. In the past, most small systems could not afford SCADA systems because the initial equipment cost was high and it required a highly trained technical person to effectively operate the SCADA on a routine basis. However, with more sophisticated technology updates, costs have become more reasonable. Furthermore, the degree of sophistication (and customization of the programming) allows for a less skilled person to operate the system effectively. The implementation of appropriate automation and control technology (e.g., SCADA) can greatly enhance operations and maintenance activities for small utilities. The key components of SCADA systems, along with some basic selection criteria, are described in the following subsections.

6.4.1 SCADA Instrumentation and Hardware

Instrumentation and hardware are generally the most expensive components of a SCADA system. In order for an instrument to be connected to a SCADA system, it must generate an output signal that the SCADA can read. Sophisticated monitoring instruments generally have a local display and an optional standard external analog or digital output. The analog output is usually a direct current output of 1 to 5 volts or 4 to 20 milliamperes which can be interfaced with standard SCADA input/output (I/O) hardware. Through calibration, this signal can then be directly related to the instrument reading, such as chlorine concentration in milligrams per liter or turbidity in nephelometric turbidity units. Similarly, a pump's operating state would have a predefined digital output (e.g., 1 or 0) where the value returned would directly correspond to the operating state of the pump (i.e., 1 = off and 0 = on, or vice versa).

Information also travels in the opposite direction through the SCADA system. In this case, the central system sends an analog or digital signal to the instrument in order to initiate some action by the instrument. The digital signals are used to control all system components from relays to motor starters. The analog signals are used to control variable frequency drives and other variable speed pumps and motors.



The analog and digital I/O values are aggregated, computed and communicated by field SCADA devices such as programmable logic controllers or micro-processor based remote terminal units (RTUs). Field RTUs may be connected to other master RTUs or computing devices such as a personal computer that contains customized software which provides the human machine interface or the SCADA operator interface. The cost of the RTUs can range between $200 and $20,000, depending upon the features and complexity desired.

6.4.2 SCADA Operator Interface

The price of commercially available customizable SCADA software usually depends on the number of I/O channels licensed for use along with the number of computers or workstations from which the system is operated. The cost of SCADA software has decreased over the past few years and the ease of customizing SCADA software has improved dramatically. The most sophisticated packages, designed to work with a variety of hardware, are relatively expensive (between $1,000 and $20,000 for a utility with I/O channels numbering between 50 and 1,000) and generally require a trained programmer for the initial setup. For less complicated uses, such as by a small water utility with minimal staffing, a package arrangement (where the software is included with the hardware and basic programming setup) is usually sufficient.

6.4.3 Communication Media

Generally, SCADA equipment that is located within a treatment plant is hard-wired. Distribution system components, such as tanks and pumps that are scattered throughout the distribution system, need alternative communication media such as leased lines or wireless transmission capability. Small systems that are relatively compact should explore the use of standard industrial wireless radio modem connectivity where possible. Other hard-wired and wireless options available to commercial carriers (such as the phone company) require a monthly fee that may range between $20 and $200 per month, depending upon the selected solution and required data bandwidth requirement.

6.4.4 Selection of SCADA Systems

If a small system operator is considering the installation of a new SCADA system, the following factors should be carefully considered:

- Does the treatment and distribution system justify the need for a SCADA system (is it spatially dispersed and are its various components difficult to access)?
- Is the treatment plant and the distribution system amenable to automation?
- What types of communication media can be used (phone, radio, cellular, etc.) at the critical locations in the system?
- How much existing automation and control instrumentation is available in the system that could be incorporated into the SCADA system?
- What type of SCADA system is needed (is the goal to monitor and /or control operations)?
- How many parameters need to be monitored and/or controlled?
- Are there any specific regulatory monitoring and reporting requirements that can be met by using a SCADA system?
- Can the selected SCADA system be made compatible with existing or future use of AMR?

Remote Monitoring – Coalwood, West Virginia (EPA, 2003d)

In 1992, EPA, in collaboration with the McDowell County Public Service District (MCPSD), installed a prefabricated semi-automated ultrafiltration (UF) drinking water treatment package plant in Coalwood, West Virginia (WV). The UF system was located approximately 12 miles from the MCPSD office in the Appalachian Mountains. The UF system has been in operation since 1992, and has been providing water of good quality to the community. However, upon completion of the two-year project, it became apparent that the MCPSD would be unable to meet the WV Department of Health monitoring and reporting guidelines. These regulations require that the treatment operator(s) maintain daily records of specific operating and treatment parameters. Routine monitoring of the water distributed from the UF treatment process was resulting in significant costs for associated time and travel. Furthermore, during inclement weather conditions, completion of these routine tasks became extremely difficult. Similar monitoring requirements at other remotely located sites also required MCPSD to dedicate a considerable amount of staff time to complete these routine tasks. Therefore, in 1998, the EPA extended the research project by installing and testing an off-the-shelf user-friendly Windows-based SCADA system. The SCADA system selected was fairly inexpensive, smart, user-friendly and scalable. The total cost for the hardware and software for setting up the SCADA system at the WV test site was $35,000. Table 6.2 provides a breakdown of the SCADA system costs:

Table 6.2 Cost of SCADA Implementation at Coalwood, WV.

Computer, Instrumentation, Software, and Upgrades	$6,000
Communication Modem and Phone Line	$1,000
Data Collection and Transportation Terminal	$5,200
Instrumentation for Monitoring and Control	$21,000
Setup and Installation	$1,800
Total Capital Cost	$35,000

The remote capability allowed the utility to save on labor and mileage for performing daily monitoring. A simple cost-benefit (return-on-investment) analysis showed the advantages of such a system. The site was approximately 24 miles round trip from MCPSD headquarters and it took the operator one hour per day to perform this task. The annual labor savings (based on an operator labor rate of $15/hour) amounted to: $15 per hour X 1 hour/day X 365 days/year = $5,475. In addition, the vehicle cost savings at the rate of $0.40 per mile amounted to: $0.40 per mile X 24 miles/day X 365 days/year = $3,504. In total, a minimum of $8,979 in annual savings to the utility was achieved immediately for this site. A direct payback, based on cost savings to satisfy daily monitoring requirements, was achieved in less than 4 years. This simplified cost model was based on direct operating costs only and assumed that the cost of upkeep of monitoring instrumentation was similar to other laboratory devices used by the operator. Additional benefits included the ability to maximize the efficiency of the water treatment operations, creation of an advanced knowledge of the systems condition prior to performing any site visits for troubleshooting and repair, improving the security of the system, and improving regulatory monitoring compliance.

- Can the SCADA system be classified as a capital improvement project and acquired through outside sources of funding such as grants and interest-free loans?
- What is the return-on-investment or labor cost savings resulting from installing a SCADA system?

Considering these factors will help a utility determine the need, affordability, and the basic design of a SCADA system. These factors will also help to determine if the SCADA system will complement general utility operations. Retrofitting a treatment and distribution system for a SCADA system can be cost-prohibitive because many currently operating small utilities were not originally designed for remote operations. Therefore, they have little or no existing electronic instrumentation or hardware that can be integrated into a SCADA system, and the cost of upgrading the utility for remote operations could be significant. It is essential that a cost-benefit analysis be performed prior to such implementation.

6.5 Securing a Distribution System

The Public Health Security and Bioterrorism Preparedness Act of 2002 mandated that drinking water utilities serving more than 3,300 persons conduct vulnerability assessments (VAs) and develop emergency response plans (ERPs). EPA provided funding or training assistance to utilities to assist in compliance with the Act. The compliance schedule was staggered based on system size. The last scheduled date for preparing a certified ERP was December 31, 2004, for systems serving between 3,300 and 50,000 persons. For systems serving fewer than 3,300 persons, EPA developed a guidance document titled, “Drinking Water Security for Small Systems Serving 3,300 or Fewer Persons.” There are a variety of guidance documents and tools available on the Internet for addressing small systems security that were collaboratively developed and funded by a variety of organizations including: EPA, state environmental agencies, Department of Homeland Security, National Rural Water Association, and the Rural Community Assistance Program. Small water utilities are strongly encouraged to use these sources as much as possible.

The VA process identifies the critical water utility assets that may be subject to potential threats. If these assets are successfully targeted, the consumer’s health could be compromised or there could be severe infrastructure and economic damage. The ERPs address the risks associated with these vulnerabilities and contain procedures that eliminate, minimize, and/or manage these security breaches. An overview of distribution system vulnerabilities, operational and emergency response mechanisms is presented in the following subsections.

6.5.1 Distribution System Vulnerabilities

Distribution systems and their components are vulnerable to two types of attacks. In one scenario, the system component could be physically destroyed or disabled; in the other scenario, the component may be contaminated with a chemical and/or biological threat agent. In

addition to security threats, distribution system components are vulnerable to aging and corroded pipes. Pipes located below the water table provide an opportunity for intrusion of water and contaminants (e.g., animal and human wastes) if low or negative pressure conditions occur. Maintaining the hydraulic integrity (positive pressure) of a water distribution system is important, given that insufficient pressure can lead to infiltration or backflow through cross-connections (see Chapter 5). Infiltration or backflow can occur during fluctuating water use patterns (e.g., fire prevention activities/fire hydrant use, power outages, and flushing exercises).

Post-treatment contamination can occur during the storage of drinking water. Storage facilities are particularly vulnerable to contamination due to the failure of protective covers or barriers, or open hatches and vents. Birds, insects, animals, rain, and microorganisms can even contaminate covered finished water storage tanks. Routine inspections and maintenance are necessary to address this vulnerability.

6.5.2 Operational and Emergency Response Mechanisms

EPA strongly recommends that utilities develop a formal ERP that contains the following eight core elements:

1. System-Specific Information – At a minimum, identify the utility staff and contact person(s) with the location of critical documents, such as distribution system maps, as-built drawings, site plans, source water locations, current equipment inventory and operations manual(s).

2. Community Water System Roles and Responsibilities – The plan should designate an Emergency Response Lead with an alternate. This person should be designated as having the responsibility for evaluating incoming information, managing resources and staff, and deciding on appropriate response actions. This person should also have the lead responsibility of coordinating emergency response efforts with first responders.

3. Communication Procedures: Who, What, and When – The plan should clearly identify communication channels for utility staff and personnel, external non-utility entities (such as other city, state and federal agencies), and the public/media. The plan should contain internal and external notification lists with information on all appropriate entities to be contacted, including their names, titles, mailing addresses, e-mail addresses, all applicable land line and cellular phone numbers, and pager numbers. These lists should be updated as necessary.

4. Personnel Safety – During an emergency, personnel may be at risk of harm, injury, or even death. Therefore, protecting the health and safety of the utility, first responders, and the surrounding community should be a key priority. An ERP should provide direction to personnel on how to safely implement a variety of response actions.

5. Identification of Alternate Water Sources – The plan should contain information on the amount of water needed to address both short-term (hours to days) and long-term (weeks to months) outages. The ERP should identify potential alternate water supplies that can be quickly mobilized during both types of outages.

6. Replacement Equipment and Chemical Supplies – The plan should identify the location of the current equipment inventory that contains the listing of equipment, repair parts, and chemicals that would be needed to respond adequately to a particular vulnerability. The utility should consider establishing mutual aid agreements with other nearby water utilities to address any deficiencies. These agreements should identify the equipment, parts, and chemicals available to the utility under the agreement.

7. Property Protection – Protecting the utility facilities, equipment and vital records at the utility is essential to restoring operations once a major event has occurred. Therefore, the ERP should identify measures and procedures that include: “Lock down” procedures; access control procedures; establishing a security perimeter following a major event; evidence protection measures for law enforcement (should the major event also be declared a crime scene); securing buildings against forced entry; and other property protection procedures and measures.

8. Water Sampling and Monitoring – The ERP should clearly identify water sampling and monitoring requirements. To the extent possible, the ERP should identify and address special water sampling and monitoring issues that may arise during and after a major event. Some water sampling and monitoring issues to consider include: identifying proper sampling procedures for different types of contaminants; obtaining sample containers; determining the quantity of required samples; identifying who is responsible for taking samples; identifying who is responsible for transporting samples (in time-sensitive situations); confirming laboratory capabilities and certifications; and interpreting monitoring or laboratory results.

An ERP containing these eight core elements provides the necessary information to effectively coordinate and respond to an emergency event. In addition, the utility staff should be trained on procedures and conditions that necessitate the activation of the ERP. Thereafter, operational actions must be implemented to identify the source of contamination, to isolate the source (if possible), and to determine the operational changes necessary for containing the damage to public health and the distribution system. Finally, steps must be undertaken to discharge or transport the contaminated water to a location where it can be effectively treated for disposal. An ERP should be viewed as a "living document" that is frequently updated as changes are made in the system, its operation and its personnel.

6.6 SmallWater, USA – Monitoring, Control and Security Problem Scenarios

Problem #1 Monitoring and Control

Water samples from the distribution system indicate that SmallWater has had trouble maintaining residual chlorine levels in the distribution system. Residual chlorine levels were frequently near zero at the most distant locations (supplied by the elevated tank) in the distribution system. SmallWater is considering booster disinfection at the tank and installing a continuous chlorine monitor to collect data for optimal disinfectant dosage and to control the chlorine dosage rate.

Issues to Consider

Maintaining adequate residual disinfectant levels is essential from a compliance perspective and to ensure a safe water supply. However, the cost of installing a booster chlorine station and an online chlorine monitor with an analyzer can be quite costly. Costs may range between $1,000 and $2,000 for the monitor and connecting it to a SCADA interface to control the booster dosage of chlorine will require additional funds (new SCADA remote terminal unit ~$2,500, installation and testing ~$3,000). Additional funds are required for the chlorine storage unit and the injection pump.

Guidance

In order to take better advantage of the costs associated with the booster chlorination station, other uses of the SCADA at this location should be investigated. The utility may achieve some operational efficiency if the operation of the tank can be optimized by using the tank level indicators and integrating them with the SCADA system for booster chlorination. Understanding tank hydraulics and mixing processes within the tank and their potential impact on loss of chlorine residual may result in further efficiencies and better performance. Online residual chlorine data are also useful if there is a great deal of variation in the regular weekday, weekend and seasonal data.

Problem #2 Security Scenario

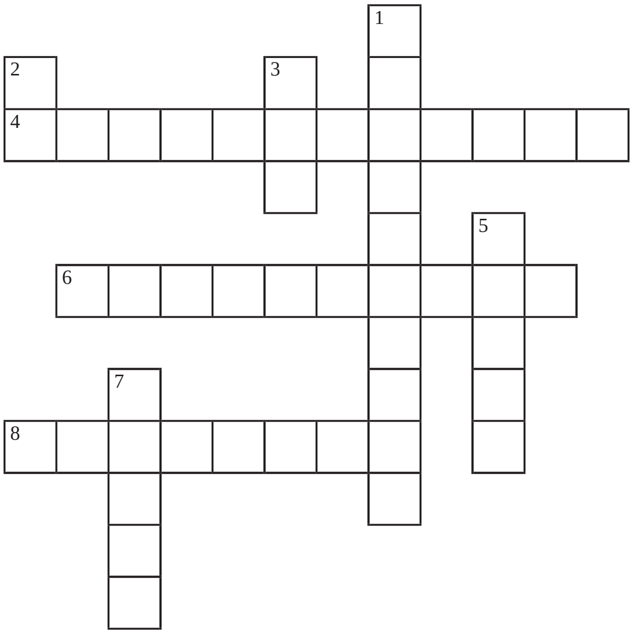
Security at the elevated tank has been an ongoing issue. The tank property is not fenced and has been broken into several times. Birds, animals and insects have periodically contaminated the tank and dead species have been found in traps at access locations.

Guidance

First and foremost, the tank access must be physically secured. Barriers (e.g., doors, wire mesh or iron bars) and locks must be placed on all hatches, vents, gates, and other points of entry to prevent access by unauthorized personnel, birds, animals and insects. Dead bolt locks and lock guards are fairly inexpensive and provide additional security at minimal cost. A daily check of critical system components enhances security and ensures that there has been no unauthorized entry. Doors to critical facilities, and their hinges, should be constructed of heavy-duty reinforced material. Hinges on all outside doors should be located on the inside.

To further enhance security, SmallWater should consider installing access alarms on all points of entry utilizing the SCADA system (see Problem #1). Integrating SCADA with security and monitoring/compliance requirements is extremely cost-effective.

Crossword
Distribution System Monitoring, Control, and Security



ACROSS

4 Type of commonly used pressure-based flowmeter

6 Flowmeter using sound waves to measure flow

8 A term for protecting utility property from tampering

DOWN

1 Term for periodic measurement of water quality in distribution system

2 Abbreviated term for most commonly used water meters for residential applications

3 Acronym for a plan to address risks associated with vulnerabilities

5 Recommended number of core elements of an Emergency Response Plan

7 Acronym for Supervisory Control and Data Acquisition System

Crossword Solutions

1) Monitoring, 2) PD, 3) ERP, 4) Differential, 5) Eight, 6) Ultrasonic, 7) SCADA, 8) Lockdown

Chapter 7
Strategies to Address Distribution System Water Quality Issues

In the U.S., a concept called the "multiple barrier approach" (as discussed in Chapter 2) has been applied widely to drinking water treatment. This includes the use of both disinfection and filtration to treat surface water prior to supplying it to the consumer. However, under the Safe Drinking Water Act (SDWA) and its amendments, this concept has been expanded by EPA to include source water protection and distribution system integrity. The 1996 Amendments to the SDWA emphasized source water protection; more recently, EPA has focused on drinking water distribution systems. The most recent "report card" issued by the American Society of Civil Engineers addressing the nation's drinking water infrastructure reveals that distribution system infrastructure improvements will require a tremendous investment if they are to provide an effective barrier in protecting the nation's drinking water.

Many small- and medium-sized distribution systems built prior to World War II (especially those serving rural areas) have received little or no recent capital investment. Some of these systems are facing water quality problems that are associated with aging infrastructure. In addition, some utilities are experiencing a higher rate of pipe failures and problems with specific pipes manufactured during a certain period of time, or when they are subjected to certain environmental conditions. Common problems include: corrosion, biofilm growth, frequent breaks and leaks, and difficulty in minimizing disinfectant loss and disinfection byproduct (DBP) levels. Cross-connection and backflow issues are also frequently observed in these systems. To address these issues and find long-term solutions, small- and medium-sized utilities need to step back from a "crisis management mode" and engage in strategic planning. For example, when a water quality problem is discovered and the cause isolated, the utility must address immediate problems related to public health. However, utility mangers should also explore strategies that address long-term issues. Some of these changes may require long-term, phased infrastructure investment. This chapter provides an overview of these operational, financial and management strategies.

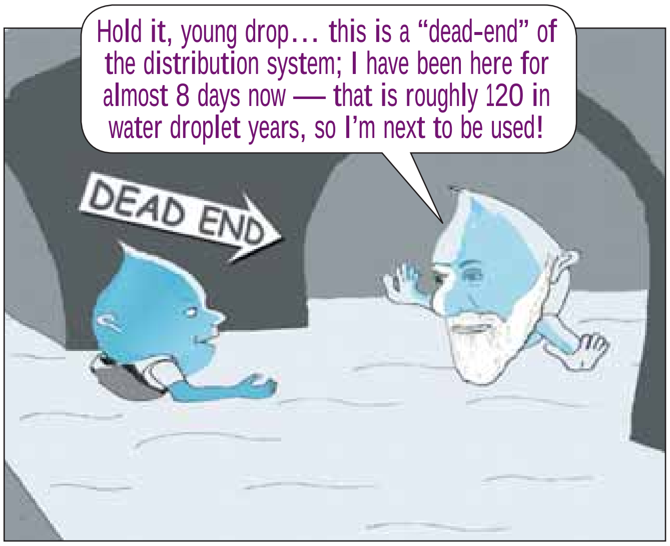
7.1 Operational Strategies

Operational changes are generally less expensive and easier to implement than changes that require significant infrastructure investment. For example, if DBPs are an issue, the utility should consider actions that minimize DBP formation in the distribution system. The utility might consider reducing water age and/or changing disinfectants (e.g., chlorine to chloramine) or both. Switching disinfectants to chloramine will likely require some capital investment. In some cases, these operational changes may only provide temporary relief and eventually an infrastructure investment may be necessary. The utility may need to find an alternative source of water or treat the water in such a way as to lower the total organic carbon (TOC) content in the finished water. A summary of available operational strategies is presented in the following sections of this chapter. Some of these operational strategies are not presented in detail here as they have been previously described within various chapter-specific problem scenarios (see Chapter 4 and 5).

7.1.1 Reducing Water Age in the Distribution System

There are several indicators of excessive water age including: taste and odor complaints, discoloration, low disinfectant residual concentration, elevated DBP level, elevated bacterial count, and elevated nitrite or nitrogen levels. "Old" water, especially in warm environments, promotes the growth of microorganisms. Such microorganisms impart taste and odor issues or enhance nitrification. Low-flow and dead-end areas within a distribution system generally accumulate sediments; during high-demand periods, these sediments may be stirred up, resulting in discolored water.

From an operational perspective, tanks, valves, main size and pumping rates have a direct impact on water age. Finished water storage facilities may exhibit poor mixing conditions because tank turnover is limited by minimum fire-fighting capacity requirements. Tank mixing can also be optimized either by cycling the tanks periodically or installing mechanical devices, such as diffusers and nozzles to achieve higher velocities which results in better mixing. Valve settings and pumping rates determine water velocities and flow direction. Velocity, in turn, impacts hydraulic pathway and retention time. In some cases, operators can adjust system pressures and position the valves in such a way as to induce flow within the distribution system in a direction that can minimize water age. The utility can also initiate flushing programs to displace "old" water.



7.1.2 Adapting Operations to Meet System-Specific Water Demands

Water demand is a driving force that affects all public water system (PWS) operations. However, water demands vary significantly and system operators must have a good understanding of the amount of water being used, where it is being used, and how this usage varies with time. For example, for most PWSs, the ratio of daily average to daily maximum water demand ranges from 1.2 to 3.0, and the ratio of the daily average to the peak hourly demand ratio may vary between 3.0 and 6.0. Seasonal variations may make these ratios even more extreme. Fortunately, these demand values are system-specific and can be quantified based on experience. Demands are generally classified as follows:

- Baseline demands - Corresponds to consumer demands and unaccounted-for water associated with daily average operating conditions.
- Seasonal Demand - Water use typically varies over the course of the year with higher demands occurring in the warmer months, due to watering of lawns and recreational use (e.g., swimming pools).
- Fire demands – Typically, the most important consideration for water system design.
- Diurnal (daily) demand variations - Continuously varying demands which are inherent in a PWS and typically increase during the daytime hours.

As discussed previously, water distribution systems are basically a networked conveyance mechanism in which pumps move water through the system, control valves allow water pressure and flow direction to be regulated, and storage facilities such as reservoirs and tanks smooth out the effects of fluctuating demands (flow equalization). Storage facilities also provide reserve capacity for fire suppression and other emergencies. Generally, pumping operations are optimized based on cost of electricity and demand requirements. A utility might consider operational changes based on overriding demand type in an attempt to minimize water age. For example, a storage tank might normally be cycled to only 50 percent of its capacity because of fire-fighting needs. The utility could consider a change in strategy in which it cycles the tank to utilize 65 percent of its capacity and then make arrangements to meet the additional 15 percent fire-fighting demand from alternate sources such as other tanks, or even the purchase of bulk water from a nearby utility.

7.1.3 Changing Disinfectants

If DBP formation or nitrification is a problem, the utility could consider switching disinfectants on a periodic or permanent basis. For example, a drinking water utility that normally uses chloramines might temporarily switch to free chlorine as a preventative nitrification control measure. This switch to chlorination would be accomplished system-wide by simply turning off the ammonia feed facilities. However, to switch to free chlorine in an isolated pressure zone or storage facility, enough chlorine must be added to exceed the breakpoint and thereby achieve a free chlorine residual. If strategies such as adjustments in chlorine to ammonia ratio, increased turnover, or flushing have not solved the problem, breakpoint chlorination is a commonly utilized approach in storage tanks.

Utilities that normally chlorinate could consider a temporary switch to chloramines. Recently, many utilities have switched from chlorine to chloramines because chloramines are more stable and associated DBP formation is lower. Whether disinfectant changes are long- or short-term, utilities should be aware that these changes may have implications for protecting public health, especially during an intrusion event. Chloramine is a less powerful disinfectant than chlorine and may be inadequate for protection against microorganisms entering the distribution system. *Giardia* cysts and enteric viruses are known to be less easily inactivated by chloramines than chlorine. However, any significant intrusion event will likely overwhelm either types of residual disinfectant. In addition, the utility should inform dialysis centers that chloramines are being used so that they can have their water treatment system enhanced to remove chloramine. In addition to chloramines, other substances found in tap water can also interfere with dialysis. For example, copper, fluoride, sulfate, nitrate, zinc and aluminum also impact dialysis operations. Remember, chlorine and chloramines are both toxic to fish. Generally, the operators of dialysis centers and fish breeders know that disinfectants in tap water must be removed before being used in their facilities. Therefore, utilities changing disinfectant techniques must notify the public of the change, contact kidney dialysis facilities, and fish breeders. Disinfection changes may also cause a change in pH levels in a distribution system resulting in temporarily elevated lead or copper levels.

7.1.4 Implementing Corrosion Control

Corrosion in drinking water systems can be controlled by adjusting pH, alkalinity or by introducing corrosion inhibitors. Increase in pH is one of the effective methods for reducing lead and copper corrosion. According to research studies, the optimal pH for lead and copper control falls between 7.5 and 9.5 (the value depends upon the system and inhibitor used). The higher pH level can also help reduce iron concentrations. However, high pH can also result in precipitation and scale on the pipe that significantly impact the hydraulics of a distribution system.

Increasing alkalinity can also assist in corrosion control, and the optimal alkalinity for lead and copper control lies between 25 and 75 mg/L as calcium carbonate. Higher alkalinity levels (>60 mg/L as calcium carbonate) are favorable for controlling iron corrosion and result in better buffer intensity, which in turn provides a stable pH.

Phosphate- and silicate-based corrosion inhibitors are often used by water utilities. The most commonly used inhibitors include orthophosphate, polyphosphate and sodium silicate, with or without zinc. Orthophosphate and zinc orthophosphate have reportedly been successful in reducing lead and copper levels; polyphosphates are reported to prevent iron corrosion. Sodium silicate has been shown to reduce lead and copper levels. It should be noted that sodium silicate is basic and always results in pH increases. Therefore, it is difficult to determine if reductions in lead or copper are due to the use of sodium silicate or higher pH levels. Nevertheless, sodium silicate has been shown to be an effective inhibitor. Utilities using inhibitors should periodically monitor the inhibitor concentration within the distribution system.

Use of corrosion inhibitors and pH and/or alkalinity adjustments to control lead, copper and/or iron levels in drinking water should be employed with caution. Pilot studies should be conducted to determine the effectiveness of a specific control method.

Changing Disinfectants (AwwaRF, 2006b)

In November 2003, the American Water Works Association Research Foundation (AwwaRF) sponsored a project to evaluate the long-term effects of disinfection changes on distribution system water quality. The research team evaluated 19 utilities that had changed their primary and/or secondary disinfectants. Specifically, seven utilities changed from chlorine to chloramines, six changed from chlorine to ozone, two changed from chlorine to chlorine dioxide, two changed from chlorine to ultraviolet disinfection, and two added booster chlorination. The study concluded that, in general, the results were positive. The following specific improvements in the distribution system water quality were observed as a result of changing disinfectants:

- Better microbial quality - lower coliform levels and heterotrophic plate counts
- Lower DBPs - reduced levels of trihalomethanes and haloacetic acids
- Reduced numbers of customer complaints regarding red water or discolored water
- Reduced numbers of customer complaints regarding tastes and odors

Despite the positive effects of changing disinfectants, there was one participating utility that experienced an increase in lead levels. Therefore, a utility should carefully evaluate the effect of making such changes.

7.1.5 Preventing Sedimentation and Scale Formation

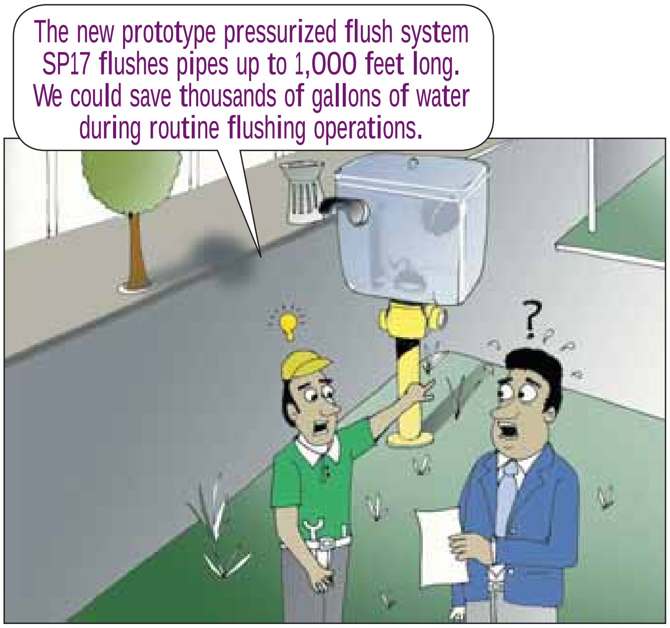
Under low velocity conditions, suspended solids may deposit on the pipe surface. Scale and mineral deposits may accumulate on pipe surfaces if the mineral content in the water is high and the pH/alkalinity of the water is supportive of scale formation (as addressed previously in Section 5.5). The accumulated sediment and scale reduces the carrying capacity of the pipe and can also create a more favorable environment for microbial growth. Although sediments and scales themselves do not necessarily pose a serious health risk, they can cause water quality deterioration, taste and odor problems, or discoloration. Furthermore, the deposited solids may be re-suspended by sudden changes in flow. Significant changes in flow (velocity and direction) can scour sediments, tubercles, and scale deposits from pipe walls and result in degradation of water quality. It is possible that these re-suspended particles may contain adsorbed contaminants such as arsenic and other metals that originated in the source water. Rapid changes in velocity and flow direction can occur during main breaks, when service reservoirs are being filled or drained, when pumps are going on or off line, or during hydrant flushing activities.

As metal pipes corrode, roughness tends to increase, and cross-sectional area tends to decrease. Microbial slimes can also result in a decrease in the hydraulic carrying capacity of water mains. This loss in carrying capacity can result in a water system that cannot deliver necessary fire flow. Increases in pumping rates may be necessary to overcome the increasing friction losses and local deficiencies in system pressure. These increased pumping requirements can overload motors and result in a significant increase in energy consumption, and in operating and maintenance costs. Furthermore, the additional pressure can over-pressurize weaker portions of the distribution system, potentially increasing the number of leaks and breaks. To avoid these negative consequences, utilities should operate their distribution systems in a manner that minimizes sedimentation and scaling by maintaining appropriate flow and water chemistry (e.g., pH and alkalinity levels) throughout the distribution system.

7.1.6 Implementing a Flushing Program

Flushing involves moving water through the distribution system at a high rate, and then discharging it through hydrants or blow-off ports. A flushing program is designed with one or more specific objectives such as replacing aged water, removing loose deposits and sediments, and/or scouring internal pipe surfaces. Utilities typically implement a flushing program in response to consumer complaints. Terms such as “directional flushing” or “unidirectional flushing” are used to describe the operation of valves during a flushing program to maximize velocity and control flow direction, starting with the largest mains and moving to the smallest. Flushing is usually accomplished by opening one or more hydrants in a planned pattern. A good rule of thumb for flushing is to start at the location with “best“ water quality in the system and move outwards.

Residual disinfectant concentration in a distribution system can be reestablished or stabilized by displacing “old” water and replacing it with fresh water containing a measurable residual disinfectant. Flushing can also remedy or prevent nitrification in systems that utilize chloramines for disinfection. Water that has elevated levels of ammonia is replaced with water containing a higher disinfectant residual. However, flushing is not required by all state agencies. Of 34 states responding to a survey by the Association of State Drinking Water Administrators, only 11 require flushing/cleaning/pigging, with 20 others encouraging the practice.



Flushing Velocities (AwwaRF, 2004b)

AwwaRF sponsored a project to evaluate a range of site-specific flushing velocities. The study report indicates that utilities which had previously never flushed their systems benefited significantly from a high velocity (~5 feet per second [fps]) unidirectional flushing program. Utilities that had flushed within the last 4 to 6 years could receive approximately the same benefit (and save water) by flushing at a lower velocity (2 to 4 fps). The AwwaRF study also determined that loose particles, including corrosion particles, iron sludge, sand, and iron floc, are removed from smooth or slightly tuberculated pipes at lower flushing velocities (2 to 4 fps). In most cases, distribution system lines should be flushed until the water is clear.

Some systems may choose to clean pipelines that are suspected of contributing to the decay of disinfectant residuals in finished water. A variety of cleaning methods are available which include:

- swabbing
- scraping
- pigging
- chemical cleaning, and
- jet flowing

Swabbing, scraping, and pigging refer to methods that remove scale and deposits from the inside of the pipes. Chemical cleaning involves the injection of chemical cleaners. Jet flowing uses a high-pressure method to wash the inside of the pipe. Each technique has its benefits and disadvantages and should be tailored to a specific site. In addition, depending upon the age of the pipes, some utilities may want to consider pipe lining or replacement.

7.1.7 Infrastructure Replacement and/or Treatment Upgrades

Proper treatment methods, tailored to the utility's source water characteristics, can also solve potential problems in the distribution system. If optimum treatment is employed, it can greatly improve the biochemical stability of the finished water. Biochemical stability is closely related to the amount and kind of organic matter present in the water. Problems associated with the formation of DBPs increase with the amount of organic matter left in the water. Treatment to remove organics, inorganics, and turbidity will also curb chlorine decay. The most effective treatment methods for maintaining biochemical stability include:

- enhanced coagulation
- biological filtration
- ultrafiltration/nanofiltration
- granular activated carbon treatment

Water main breaks commonly occur in older or in poorly designed systems. Main breaks are disruptive and expensive to fix. Furthermore, for rusting and aging pipes and finished water storage facilities, replacement may be the only viable option. Therefore, utility operators and managers must develop a long-term strategy for timely maintenance and replacement. However, these types of infrastructure replacement and treatment upgrade projects require a significant amount of financial resources and time. Possible financial strategies designed to accomplish these goals are discussed in the next section of this document.

7.2 Financial Strategies

Small- and medium-sized systems face unique financial challenges because they cannot take advantage of the economies of scale associated with larger drinking water systems. For example, in a small system, a piece of equipment costing $1,000 may be spread over a customer base of 100 to 1,000 customers. In a larger system, the cost of this same piece of equipment may be spread over 10,000 to 100,000 customers. Simply put, any capital investment for smaller systems is generally higher on a per customer basis or per capita basis than in a larger system.

Financial Strategy (EPA – EFAB, 2005)

In rural and developing areas, back-end loading could be used in financing water projects where hook-up fees and user charges only begin to flow after a project is completed. Infrastructure projects in such areas are often judged unaffordable because the debt associated with the capital investment needed for new facilities cannot be immediately serviced by user charges. In fact, new hook-ups/connections often occur slowly. As connections are made and the service area rate base increases, user charge revenues grow to support debt repayment. Back-end loading can enable projects to proceed because it solves immediate environmental needs by deferring financial issues of "affordability" of debt repayment to a later time.

This approach has proven to be valuable for San Benito, Texas, along the US-Mexican border. The North American Development Bank guaranteed a bond issue for San Benito with a highly skewed amortization schedule that allowed for the build-out of the system and the build-up of operating revenues to sustain long-term debt service. In this case, the new water system would enjoy the very low interest rates provided by the bank guaranty until such time as the system revenues could provide substantial debt service coverage.

In cases where the price of water cannot be simply passed on to the customer, small- and medium-sized utilities can apply for grants and low-interest loans. A grant is a form of financial assistance that is given to a utility which does not have to be repaid. Loans must be repaid along with the appropriate interest. These terms are defined more carefully in the following paragraphs:

- Grant Programs: Grants are generally awarded to states, local governments or other nonprofit organizations. The primary advantage of grants is that the recipients do not have to use their own resources to pay the costs that the grant covers. Applying for grants, however, can require a significant commitment of time by utility personnel. In addition, the availability

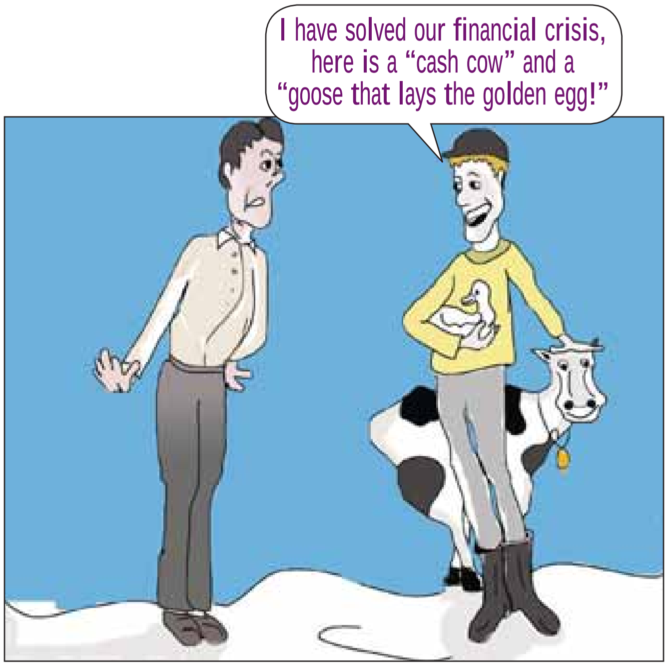
Sustainable Pricing (EPA, 2005b)

Individual customers are the most important source of revenue for a drinking water system. The income provided by customers is critical to ensuring that systems are operated properly and efficiently both in the present and in the future. Charging customers the actual cost of service ensures that water systems guarantee themselves a stable source of funds that is sufficient to cover the cost of operation (including treatment, storage, and distribution costs). This policy also allows for the acquisition of funds for infrastructure investments. Asking customers to pay for a commodity or service sends a signal about the value of the product or service they are purchasing. Fees and other charges that reflect the full cost of water service help customers recognize the value of water service. Customers also become more aware of how much water they use and how they use it. To support this approach, EPA has developed a sustainable infrastructure initiative which is based on the following four pillars:

- Better Management – Similar to asset management, environmental management systems, consolidation, and public-private partnerships can offer significant savings for small water utilities.
- Full-Cost Pricing - A key consideration in constructing, operating, and maintaining infrastructure is ensuring that there are sufficient revenues in place to support the costs of doing business. Sensible pricing can also have the added benefit of encouraging efficient water use.
- Efficient Water Use - One way to reduce the need for costly infrastructure is efficient use of water. There are many options for enhancing water efficiency including metering, water reuse, water-saving appliances, landscaping, and public education.
- Watershed Approaches to Protection - In addressing infrastructure needs for the purposes of water supply and water quality, it is important to look at water resources in a coordinated way. Directing resources towards high priorities, such as permitting on a watershed basis, and water quality trading are all means of ensuring that investments achieve the greatest benefit.

and timing of the grant award may not match the utility's needs. Most grant programs have limited funds, and usually there is significant competition for this type of funding. Grants also have project eligibility requirements, and some programs may specify that the grantee contribute a share of the total project funds.

- Loan Programs: Loans are available from governments, banks or other financial institutions and the application process can be relatively quick. Commercial interest rates are generally higher with less favorable pay back rules than government loans. State programs generally have better rates and terms for those systems that do not qualify for conventional types of financing. The terms of loans vary significantly and the utility should carefully evaluate these terms before a loan is secured.



Some of these financial options (both grants and loans) are briefly summarized in the following sections.

7.2.1 Drinking Water State Revolving Fund

Congress established the Drinking Water State Revolving Fund (DWSRF) as part of the 1996 SDWA Amendments to provide states with a financing mechanism to ensure safe drinking water for the public. EPA, through the various state agencies, administers the DWSRF in order to provide financial resources to upgrade and replace drinking water infrastructure. PWSs can receive loans with very low or zero percent interest rates with repayment periods of up to 20 years. However, in some cases, drinking water utilities in disadvantaged communities may find even low-interest loans unaffordable. In these types of cases, states can provide DWSRF funds at a negative interest loan rate, or under a principal forgiveness loan with an extended repayment period of up to 30 years. Each state has specific eligibility criteria to determine funding priorities. Funding requests under the DWSRF program are allocated based on the following order of priority:

- Requests that address the most serious health risks to consumers
- Requests necessary to comply with SDWA standards

Creative Funding (Hudson, 2007)

Recent SDWA revisions to reduce the Arsenic Maximum Contaminant Level (MCL) to 0.010 mg/L affected approximately 80 small Indiana PWSs. As a result, many small utilities needed assistance to comply with the new standard. A majority of these affected systems were rural (serving fewer than 500 people) and the Indiana DWSRF Loan Program estimated that the average arsenic remediation project would cost $44,000. Unfortunately, this amount was too small to justify a DWSRF loan. If a utility cannot justify a project under the DWSRF, these funds cannot be used for small systems. To solve this problem, the Indiana DWSRF created the Arsenic Remediation Grant Program in May 2006. By combining DWSRF set-aside funds for planning and design costs and state monies for construction costs, the DWSRF Loan Program was able to offer grants up to $100,000 to small PWSs to cover the entire cost of arsenic remediation projects.

- Requests that assist water systems which are most in need, on a per-household basis (as determined by the state affordability criteria)

Similar funding assistance is also available to Indian tribes in the U.S.

7.2.2 Community Development Block Grants

The U.S. Department of Housing and Urban Development administers a Community Development Block Grant (CDBG) program through the individual states. The program provides small communities with resources to address a wide range of needs. The program gives each state the opportunity to administer CDBG funds for "non-entitlement areas." Generally speaking, "non-entitlement areas" are cities with populations of less than 50,000 and counties with populations of less than 200,000. The primary objective of this CDBG program is to develop viable communities by providing decent housing and a suitable living environment. This general objective is achieved by prioritizing activities which benefit low- and moderate-income families or aid in the prevention or elimination of slums or blight. Under unique circumstances, states may also use their funds to meet urgent community development needs. A need is considered urgent if it poses a serious and immediate threat to the health or welfare of the community and has arisen in the past 18 months. Local governments have the responsibility to consider local needs, prepare grant applications for submission to the state, and carry out the funded community development activities. The list of eligible activities under this program includes construction or reconstruction of water and sewer facilities.

7.2.3 Rural Utilities System

One of the six basic mission areas of the U.S. Department of Agriculture (USDA) is the Rural Utilities System (RUS). Under the RUS umbrella, USDA provides a variety of water loan and grant programs. Along with EPA and other federal agencies, USDA supports organizations such as the National Rural Water Association (NRWA) and the Rural Community Assistance Partnership. The USDA's RUS issues contracts to NRWA for providing rural water circuit rider technical assistance. In addition to supporting these national organizations, USDA provides emergency community water assistance grants to rural communities that have experienced a significant decline in the quantity or quality of drinking water. Grants are provided to rural areas and cities or towns with low income and a population of fewer than 10,000. Grants can cover up to 100 percent of project costs. The maximum grant is $500,000 when a significant decline in quantity or quality of water occurred within two years, or up to $150,000, to make emergency repairs and replace facilities in existing systems.

7.2.4 Economic Development Administration

The U.S. Department of Commerce provides grants through the Economic Development Administration's (EDA) Public Works and Development Program. Applications must be submitted to the state economic development agency; states are authorized to administer the funds. A drinking water project must be located in a community or county determined to be economically distressed, and the project must be directly related to future economic development. Some restrictions apply when grants are provided in conjunction with other financial assistance. The combined funding is generally limited to 80 percent of the total project cost.

7.2.5 Other Entities and Private Foundations

Appalachian Regional Commission (ARC) ARC supports qualifying applicants in the designated Appalachian Regions of 13 states. The ARC's local development districts provide assistance in preparing an applicant's proposal. Priority funding is determined each year by the state governors, Appalachian district personnel, and ARC members. All projects that qualify for grant funding must be directly related to economic development, housing development, or downtown revitalization and improvement. Drinking water projects are among the types of projects eligible for assistance. It should be noted that ARC grants are limited to 50 percent of project costs and require the recipients to supply the other 50 percent. An exception is made for economically distressed counties, which can receive 80 percent and must supply only 20 percent. To raise the remaining 20 percent of funds, owners of small systems in distressed counties should innovatively and aggressively seek other sources of funding.

Indian Health Service (IHS) IHS is a part of the Department of Health and Human Services, and provides grants for projects undertaken by American Indians and Alaska Natives. In 1959, Congress passed the Indian Sanitation Facilities Act to provide improved health conditions by improving sanitation, sewer, solid waste, and drinking water facilities. IHS grants support public health rather than economic development or environmental preservation and do not include funding for operation and maintenance. No matching funds are necessary, and IHS grants can be consolidated with those from other agencies.

Small Community Water Infrastructure Exchange (SCWIE) SCWIE is a network of water funding officials. Under the auspices of the Council of Infrastructure Financing Authorities, a group of public and nonprofit environmental funding and technical assistance officials combined their efforts to create SCWIE.

Private Foundations Private foundations are another possible source of funding for small- and medium-sized PWSs. These are often overlooked by small PWS managers. Information about smaller foundations can be obtained from a local Internal Revenue Service (IRS) office. The IRS annually collects Form 990-PF (Return on Private Foundations) from foundations of all sizes, and compiles information about the foundations' interests, restrictions, application procedures, and deadlines.

7.3 Management Strategies

If the operational and financial strategies currently available to a utility do not have long-term sustainability, a utility should consider management and institutional changes. Some options to consider are merging with a larger utility, or changing ownership and/or management of the water utility (from private to public or vice versa).

Additional Information

More information on the DWSRF is available at: http://www.epa.gov/safewater/dwsrf/index.html

More information on state CDBGs is available at: http://www.hud.gov/local/index.cfm

More information on RUS assistance is available at: http://www.usda.gov/rus/water/programs.htm

More information on EDA assistance is available at:

http://www.eda.gov/InvestmentsGrants/Investments.xml

More information on ARC assistance is available at: http://www.arc.gov/index.do?nodeId=101

More information on IHS assistance is available at: http://www.ihs.gov/

More information on SCWIE assistance is available at: http://www.scwie.org/ContactSearch.asp

A commercial source of private foundation listing online is: http://foundationcenter.org/

7.3.1 Small Systems Working Together

In general, state and federal regulatory agencies encourage small water systems to work together if it makes financial sense. Working together generally results in a regulatory agency having more effective control over water quality and regional development. Furthermore, the economies of scale associated with working together tend to ensure the long-term financial viability of a system. One challenge in working together is the difficulty in servicing a geographically diverse distribution system from a central location. In such cases, remote monitoring and reporting is recommended to ensure prompt local service even if bulk water is purchased from a larger utility. Each manager of a small- and medium-sized utility should consider the pros and cons of working together, for developing regional water usage rates and/or centralized purchasing. In addition to concerns of financial viability, managers should consider the geographical spread and type of source water of the combined systems. The number one concern of the partners is the potential impact of the combination on the quality of the water served to the consumer. Again, remote monitoring and reporting is recommended to ensure the quality of the water in the combined distribution system. EPA's Community Water System Survey, conducted in the year 2000, indicated that there was a continued decline in the number of systems serving fewer than 3,300 people, while the number serving more than 3,300 people grew by 20 percent.

Utility Merger (KEPPC, 2006)

The Northern Kentucky Water District (NKWD) was formed in 1997 from the merger of water districts in Kenton and Campbell counties. In recent years, it has also acquired the Newport and Taylor Mill water utilities. By 2006, NKWD had 78,000 retail customers in Campbell and Kenton counties and provided wholesale water service to the Pendleton County, Bullock Pen water districts, and to the city of Walton.

In 2003, the Kentucky Public Service Commission granted NKWD a rate adjustment that equalized the water rates in the former Kenton and Campbell county districts. In 2004, PSC granted rate adjustments to equalize water rates in Newport with the rest of the district. In 2006, the PSC granted a rate adjustment to equalize the rates for customers in Taylor Mill. The 2006 rate increase was estimated to raise the quarterly bill for the average NKWD residential customer consuming 18,000 gallons/quarter, from $78.65 to $83.70 (an increase of $5.02, or 6.4 percent). It is estimated that the 2006 rate increase will increase NKWD's annual revenues from water sales by 6.8 percent, to $36.3 million.

7.3.2 Change in Ownership and/or Management

In general, there are four options to consider when changing ownership and/or management of water utilities including:

- Efficiency Improvement Program: Implementing operational and management changes to improve efficiency.
- Municipalization: The assets, operations and ownership of private water systems are transferred to a public entity.
- Privatization: The assets, operations, and ownership are transferred to a private entity
- Public-Private Partnership: In general, the public retains the ownership and control of the system, but privatizes operation and maintenance.

Private utilities are generally perceived as being profit-oriented and hence more efficient than public or municipal utilities. Because they are for-profit entities there is a perception that they may fail to invest in long-term growth which may lead to poor system maintenance and upgrade practices. Municipalities, because they are non-profit entities and represent the people, are perceived as likely to invest in the system and have a plan for long-term growth. On the other hand, because municipal systems are non-profit entities, there is concern that there are inefficiencies built into the system which may increase costs to the consumer. The general perception about public-private partnerships is that they represent the "best" of both municipal and private systems. These perceptions are generally anecdotal and based on individual cases where information is available. There are no long-term data or analyses that conclusively support any of these general perceptions.

7.4 SmallWater USA – Cell Tower Installation

Problem #1 Water Storage Tank Antenna Scenario

Several telephone companies approached SmallWater, USA officials and made financial offers to the town if they were permitted to install cell phone antennas on the top of the elevated tank in the northern part of the water system. It sounded like a good source of needed funds but the official wanted to make sure that there would not be any problems. He talked to an engineering firm that specialized in tank construction and maintenance procedures. Following is a summary of the information that he received from the engineer.

Issues to Consider

The rapid expansion of wireless communication services throughout the United States has resulted in the construction of many cellular antenna towers. To save on the cost of erecting these towers, communications companies look for existing structures that are suitable for locating their antennas. Also, in some areas, zoning restrictions have severely limited the ability of cellular companies to locate their towers. For these reasons, water storage tanks are prime sites for antennas. Existing tanks are often the highest structure in a community and usually have pre-existing Federal Aviation Authority and zoning approvals.

Leasing revenue from antenna installations has been a welcome development for hard-pressed water utility budgets. Leasing rates range from a few hundred dollars to over $1,000 per month depending on the location and suitability of the storage tank. Since tanks usually have room for multiple antenna installations, leasing revenue can be doubled or tripled by adding cellular carriers. In some cases, it is possible to pay for all future tank maintenance and painting with these revenues. While the income provided to water utilities from placement of antennas is certainly worth considering, care must be taken to avoid the adverse effects of these installations.

Guidance (Source: Gabin, I.M., 2007)

Many problems have occurred from antenna installations that were improperly designed and constructed. Many installers have viewed the tank as simply a platform for their antennas, without understanding the important function that the tank serves and the purpose of tank appurtenances. Problem areas include:

1. Structural damage
2. Coating and corrosion damage
3. Occupational Safety and Health Administration (OSHA) violations
4. Restriction of access to ladders, manholes and hatches with resultant confined space and safety concerns
5. Contamination of water supply through improperly sealed penetrations
6. Potential for interference with future painting
7. Poor aesthetic appearance

A few basic steps should be followed by storage tank owners to avoid these problems. First, the cellular company should be required to provide a drawing of its complete installation including site utilities, ground structures, equipment panels, cable routing, and antenna structures. Secondly, a qualified engineering firm experienced with both storage tanks and antenna installations should be retained to inspect the tank, and review the drawings, welding procedures and coating repair specifications. Structural analysis should be performed to ensure that the tank can safely support the antennas. Also, care must be taken that the new installation does not interfere with existing cellular or utility antennas.

Only after all necessary drawing and specification revisions are completed should the installer be allowed to begin. Keys to the tank or tank site should be returned when the project is finished. It is not recommended that antenna companies be allowed to access the tank to service their equipment without utility personnel providing authorization and access.

The final step is inspection of the completed installation. The same firm that reviewed the drawings should inspect the entire installation including the interior paint repairs. In some cases, paint repairs can only be completed during low demand times of the year. In other cases, the repairs must wait for warmer weather. This will require coordination with the cellular company to ensure that the interior paint is properly repaired.

When negotiating a lease with the cellular company, the design review and inspection services should be included in the contract at the company's expense. Most cellular companies are very cooperative in including these services in the lease. It is a minimal expense and also provides them with the assurance that their equipment will be properly installed. A number of other legal and financial considerations should be carefully evaluated including length of contract, cost of living adjustments, access, liability, exclusivity clauses, and future painting expenses. Since many utilities already have antenna installations, it would be worthwhile to inquire about their leases and hopefully benefit from their experience.

Water storage tank antennas are certainly worth investigating. By following these steps, one should be able to obtain the benefit of this new source of revenue while avoiding the problems that can be caused by deficient antenna design and installation. Figures 7.1 and 7.2 show pictures of bad and good cell-tower designs, respectively. The crowded design shown in Figure 7.1 could lead to operational, maintenance and structural problems.

Problem #2 Operational Changes to Reduce Water Quality Degradation in Storage Tank

During the past summer, SmallWater, USA officials received frequent taste and odor complaints from residents in the trailer park located near the old standpipe. Discussions with the town consulting engineer led to the likely conclusion that these taste and odor problems were probably due to water quality degradation in the standpipe. Some options for dealing with this problem were discussed and will be tried out next summer.

Issues to Consider

Because water sometimes spends a large amount of time in a storage tank, it is susceptible to degradation of water quality. Some specific forms of water quality degradation can include: loss of disinfectant residual, regrowth of bacteria, formation of DBPs, nitrification and sedimentation. In all of these phenomena, the degradation is associated with two physical processes in a tank: aging of water and mixing within the tank.

Guidance

Since it is not uncommon for water to spend several days or sometimes even weeks in a storage facility, tanks are prime candidates for potential water quality problems. There is no fixed standard for allowable water age, but some experts suggest that 3 to 5 days is a reasonable maximum residence time within a tank. Allowable water age varies based on the chemical content of the water and the type of disinfectant that is utilized. An approximate value for the average residence time can be easily calculated based on the turnover within the tank using the following equation:

$$\text{Average Residence time (days)} = \text{Average water volume in tank (gallons)} \div \text{Average daily inflow (gallons per day)}$$

Figure 7.1 Crowded Cell Tower Installation

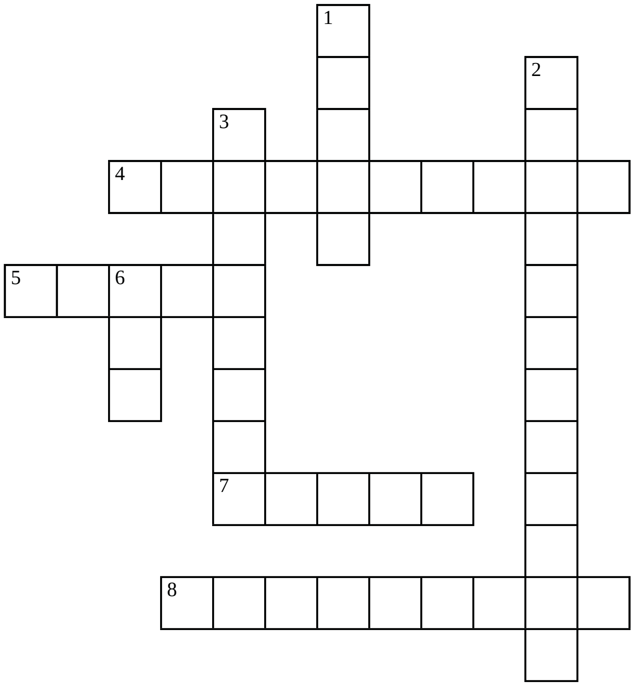
Figure 7.2 A Well-Designed and Constructed Cell Tower Installation

The standpipe typically contains about 150,000 gallons of water. Based on Supervisory Control and Data Acquisition (SCADA) records, the daily inflow is about 75,000 gallons per day. Using this equation, the average residence time in the standpipe was calculated as 150,000 ÷ 75,000 = 2 days. This was considered to be reasonable.

Mixing is another issue in tank operation and design. Distribution system storage tanks should be designed to encourage good mixing - namely, the water that is entering the tank during the fill cycle should mix well with the water that is already in the tank. A poorly mixed tank can result in zones or pockets of older, deteriorated water. In some cases, the tank may become stratified (poor vertical mixing), primarily when the inflow water is colder than the water in the tank. Tall tanks, such as the SmallWater, USA standpipe, are especially susceptible to mixing and stratification problems. Good mixing will generally occur if 1) the inflow "jet" enters at a relatively high velocity (at least 1 foot per second), 2) the inlet is oriented to encourage mixing with the water in the tank, 3) the water level in the tank is allowed to fluctuate over a range of several feet over the course of each day, and 4) the water temperature of the inflow is approximately the same as the temperature of the water in the tank. The average inflow velocity for the standpipe was calculated by dividing the average inflow rate (100 gpm) by the cross-sectional area of the 16-inch inlet. This showed a typical inflow velocity of only 0.16 feet per second (fps) - far less than the recommended velocity of 1 fps.

Based on this analysis, the engineer suggested that no modification in operations was needed but that some minor modifications in the standpipe inlet configuration should be made. The primary recommendation was that a "reducer" be placed on the inlet-outlet line where it entered the standpipe so that the effective diameter would be reduced from 16 to 6 inches. Other situations may require the addition of more complex inlet-outlet designs or the use of mechanical mixers to encourage circulation in the tank. There are a variety of modeling and monitoring procedures that can be used to assess whether there are mixing problems in a tank and to test alternative schemes for improving mixing in a tank.

Crossword
Operational, Financial, and Management Strategies to Address Distribution System Water Quality Issues



ACROSS

4 Type of disinfectant that can be more toxic to fish

5 Financial assistance that must be repaid with the applicable interest

7 Financial assistance that does not have to be paid back

8 Commonly used base-chemical for corrosion inhibition

DOWN

1 Acronym for EPA-established financing mechanism

2 Term for a publicly-owned non-profit water utility

3 Common procedure for removing loose sediments and deposits in pipes

6 Reduce "this" in distribution system to control DBP formation

Crossword Solutions

1) DWSRF, 2) Municipality, 3) Flushing, 4) Chloramine, 5) Loans, 6) Age, 7) Grant, 8) Phosphate

Chapter 8
Bibliography

The references included in this bibliography contain additional detailed information for readers who wish to pursue, in greater detail, the specific topics discussed in this guide. Many of these references (especially the EPA references) are freely available on the Internet. The references are listed alphabetically, based on the last name of the first author(s). In cases where there are two or more works by the same author (e.g., AWWA, AwwaRF, and EPA), the entries are listed by the year, with the most recent document listed first. The reverse chronological order makes it easy for the reader to look up the most recent publication first.

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