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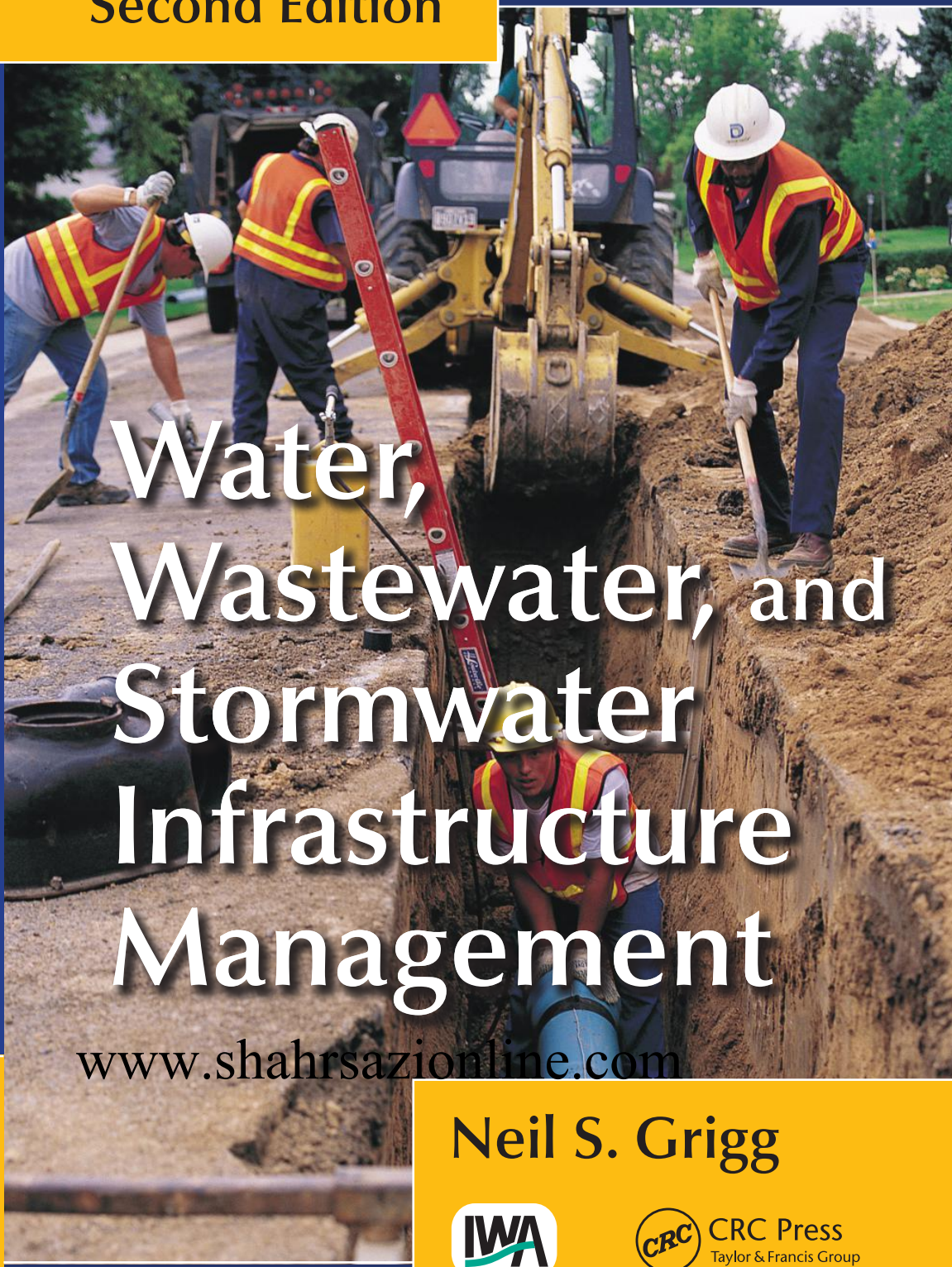

Water, Wastewater, and Stormwater Infrastructure Management

Neil S. Grigg

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Preface

Urban water services are building blocks for healthy cities, and they require complex and expensive infrastructure systems. Most of the infrastructure is out of sight and we tend to take the services for granted, but an infrastructure financing crisis looms because the systems are aging and we are behind on maintaining them.

This book aims to present clear and practical information for life-cycle management of these infrastructure systems, and it is my hope that the material will be useful to public works and utility professionals and provide a road map to valuable sources of information for all uses. Since the first edition was published in 2003, new thinking about the future of urban water infrastructure systems has emerged, and I have tried to describe it. Part of it is due to learning about what other nations are doing, and part has resulted from research and experience in the United States.

The evolution of this book begins with opportunities in the 1970s to work with the ASCE Urban Water Resources Research Program and, in particular, with Murray McPherson and Scott Tucker. In that period, my consulting partner, Dave Sellards, always kept my eye on the practical side of things as we formed Sellards & Grigg, Inc., in Denver, Colorado. As a result of those experiences, I published two books in the 1980s with John Wiley & Sons, one titled *Urban Water Infrastructure* and the other *Infrastructure Engineering and Management*.

Along the way, many other people have helped me learn about urban water infrastructure. In particular, I am indebted to Frank Blaha, who got me involved with an advisory committee of the Water Research Foundation, and Mike Woodcock of the Washington Suburban Sanitary Commission, who mentored me about managing water supply pipelines.

I thank Joe Clements, Acquisitions Editor for CRC Press, who made the publishing arrangements for this current book, and Frances Weeks of CRC Press in Boca Raton, Florida, who oversaw the production process. Both handled their duties with skill and care.

As always, I am grateful to Colorado State University for providing me with a good place to work on this research.

Neil S. Grigg
Fort Collins, Colorado

Author

Neil S. Grigg is a professor of civil and environmental engineering at Colorado State University, where he focuses on water resources and infrastructure management. At Colorado State, he has been the head of the Department of Civil and Environmental Engineering and director of the Colorado Water Resources Research Institute and Water Center. He is a graduate of the U.S. Military Academy, Auburn University, and Colorado State University and is a registered professional engineer in three states.

In addition to university work, he has been a consulting engineer and state environmental official, and he has worked on a number of government policy and advisory panels. His current research is concentrated on urban water infrastructure, especially distribution systems management. He publishes widely on topics that range across water resources and infrastructure. In addition to *Water, Wastewater, and Stormwater Infrastructure Management*, other recent books are *Water Finance: Public Responsibilities and Private Opportunities*; *Infrastructure Finance: The Business of Infrastructure for a Sustainable Future*; *Economics and Finance for Engineers and Planners*; *Total Water Management: Leadership Practices for a Sustainable Future*; *Colorado's Water: Science & Management, History & Politics*; and *The Water Manager's Handbook: A Guide to the Water Industry*.

Neil has been honored in selection for a number of important responsibilities. He is a life member of the American Society of Civil Engineers and the American Water Works Association. He is a diplomate of the American Academy of Water Resources Engineers and a charter member of the Pan American Academy of Engineering. He serves the U.S. Supreme Court as River Master of the Pecos River, and in 2011 he chaired two national flood control panels, one for the U.S. Army Corps of Engineers and the other for the National Institute of Building Sciences.

1

Urban Water Infrastructure for Healthy Cities

This book is about how to manage the infrastructure systems that enable the vital urban water services that sustain healthy, prosperous, and sustainable cities. These systems provide safe drinking water, wastewater removal and treatment, and protection from damaging storm and flood waters. When managed well, they add valuable amenities to communities and the natural environment. The urban water services can be coordinated to create an integrated and sustainable system that operates in harmony with the natural environment.

Many parts of the infrastructure systems are out-of-sight and out-of-mind, and this makes them subject to neglect. While the public is willing to pay higher rates for its electric power and cell-phone services, it resists paying full price to support water infrastructure. Reasons for this public resistance to pay vary, but they stem from lack of understanding of the complexity and cost of water services. The best remedy is good understanding of the cost of water services by professionals, followed by clear explanations to the public and policy makers.

In addition to safe drinking water, sanitation services, and protection from flooding, urban water services provide fire protection and protect rivers and streams from the abuse of urban wastes. To deliver these services, urban water utilities and their supporting construction firms, consultants, vendors, regulators, and other governmental and nongovernmental organizations employ about a million workers in the United States. The annual revenues of these systems are $100–$200 billion, and the replacement value of their infrastructure systems is around $2 trillion, according to my estimates (Grigg, 2011).

Taken together, urban water services account for about 1% of the U.S. gross domestic product on the basis of revenues and about 4% of all U.S. fixed assets. As a percentage of public fixed assets (those belonging to the government), the percentage is much higher, probably in the range of 10%–15%. The reason for this large percentage of fixed assets is that urban water systems are capital intensive, with much of their replacement value in buried pipelines and equipment. Thus, utilities must make large investments to provide their services, and their ratio of fixed-asset costs to ongoing operational costs is huge. That said, many of the fixed assets last for decades, so the annual costs to service the capital investments may not be that large, especially when the infrastructure systems are managed effectively.

The focus of this book is on managing the physical assets of these urban water systems, which have per capita replacement values of about $6,700 in the United States or close to $20,000 for a typical family of three. This $20,000 cost does not include the private water service lines, sewers, and drains that also serve properties. When added together, the full cost of water systems that serve houses and other properties rises higher and includes the premise plumbing systems. As utility financing models move toward the enterprise (user-pays) principle, most of the burden of financing the public assets is on property owners, but part remains on the general tax base due to the public-good nature of some urban water services. In total, the share of public and private fixed assets of urban water and plumbing systems is apparently between 10% and 20% of a typical $200,000 home.

As you will see, we have a problem because a lot of deferred maintenance and renewal is building up. This is evident from the fact that buried assets are being renewed at a rate of about once in 150 to 200 years, but their lifetimes are less than that. We estimate that the total replacement value of all urban water assets is in the range of $1.5 to $2.0 trillion. Assuming an average lifetime of 100 years and a current replacement cycle of 150 years, it is apparent that the annual deferred replacement cost on a national basis is on the order of $5 to $7 billion. This problem is not large enough to compete with financial time bombs such as the national debt or Social Security, and it can be handled by raising the price of water services to provide the capital needed. However, as you will see, this is not occurring, and more attention to the problem is needed.

The book blends knowledge from management fields such as facilities, finance, and maintenance with knowledge about the unique technical attributes of water, wastewater, and stormwater systems. In addition to guidelines about management topics, it describes recent research on best management practices and topics such as asset management, vulnerability assessment, and total quality management of these infrastructure systems. Managers of utilities, infrastructure managers, consulting engineers, and others involved in the management, production, design and construction, sales, or other work on urban water infrastructure should find the information in the book useful.

Water Supply, Wastewater, and Stormwater Systems

In urban water systems, water supply provides water for drinking and related purposes; the wastewater service handles used waters; and stormwater includes urban flood control as well as drainage and runoff quality control. Combined sewer and water reuse systems are also included as cross-cutting systems.

These combined services are depicted in Figure 1.1, which illustrates the water supply system with two sources: one a diversion from the stream and the other from wells. The raw water is conveyed to the treatment, then distribution, then the use system. Wastewater is collected, sent to treatment, and then discharged to the stream. Sludge (also called biosolids) is managed by dewatering, digestion, and then disposal. The stormwater system is shown as traversing the city to discharge into the receiving waters. This is a simple diagram, but it illustrates a complex set of processes.

While these systems provide different types of services, they use similar equipment and components and are often managed by the same utility and public works organizations. Water and wastewater systems cost more and employ more workers than stormwater systems do. Water supply and wastewater have different regulatory structures, but protecting public

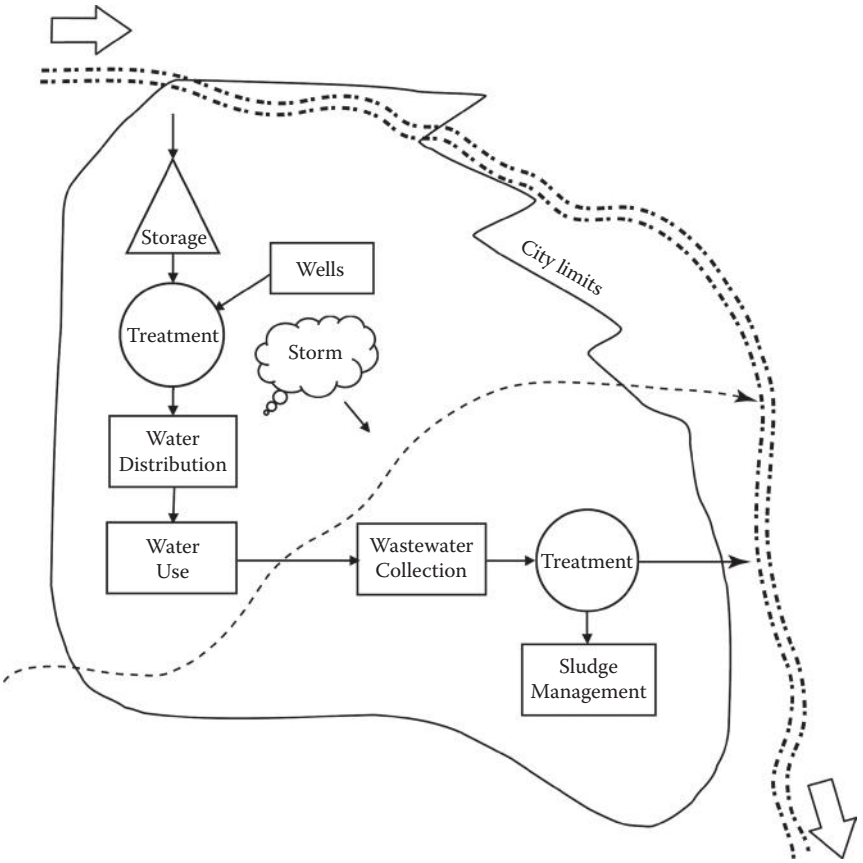

FIGURE 1.1
The integrated urban water system.

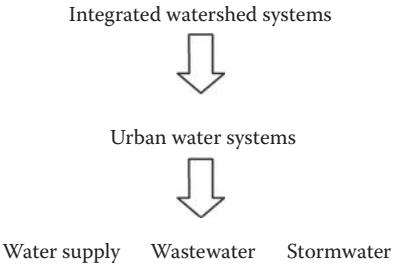

FIGURE 1.2
Water, wastewater, and stormwater within integrated systems.

health through safe drinking water systems and protecting the environment through effective total water management rate high among all the systems.

The urban water system is part of the broader water environment that involves far-flung natural and built water systems. This leads to the nested system of water systems shown in Figure 1.2, where water supply, wastewater, and stormwater systems provide specific services required in cities but are part of the larger and integrated watershed systems that also impact the broader environment. As cities expand, they have large effects on the natural environment, and some of them become megacities.

Managing the Infrastructure Life Cycle

Unlike with some equipment, you would never plan to build a water system, then discard it and replace it with a new model, although you would replace parts of it periodically. The systems are built to last and, in fact, some pipelines that are well over 100 years old remain in service. Unless the supply sources, treatment plants, pipelines, and other facilities are properly designed, constructed, and maintained over their life cycles, they cannot sustain the needed levels of service. Utility and public works managers work with their engineers and supporting resources to care for these vast and capital-intensive systems, even when they are taken for granted by a public that is often concerned with other issues. Caring for the systems is the key to their sustainability and successful performance.

To care for these capital-intensive infrastructure systems, managers and engineers need clear guidelines for life-cycle management using solid engineering and business principles. Managing them as assets will hold costs down and improve performance, and effort should also go toward increasing their efficiency and effectiveness. As the systems age, failure rates will increase, and capital needs could escalate if water, wastewater, and stormwater systems need renewal at the same time. Utility managers could face

a scenario of deteriorating systems, skyrocketing rates, and deferred maintenance becoming out of control. These can be avoided with effective management systems implemented now to extend service lives, convince policy makers to fund renewal programs, and increase public confidence.

The concept of life-cycle management is to derive the best performance from an asset at lowest cost from acquisition to disposal. As shown by Figure 1.3, it is simple at the conceptual level, but as we will see in later chapters, it is complex to implement. The basic concept is to plan, design and construct, operate and maintain, and then renew the asset. Think of your car. You plan to acquire it, you then acquire it (someone else designs and constructs it), you operate and maintain it, and then you either renew it with a major overhaul or you simply replace it. If you acquire an expensive car and abuse it, your life-cycle cost will be much higher than if you acquire an economical model, keep it a long time, and care for it well.

The sequence of life-cycle activities shown in Figure 1.3 is as follows:

- A need for infrastructure is caused by growth, desire for improvement, regulatory pressure, system failure, or obsolescence, and these create a requirement for a needs assessment (covered in Chapter 4).
- The needs assessment leads to a master plan and implementation plans (covered in Chapter 4).
- The plans are reviewed and, if approved, are implemented, requiring budget actions (covered in Chapters 4 and 6).
- Design and construction occur (covered in Chapter 5).

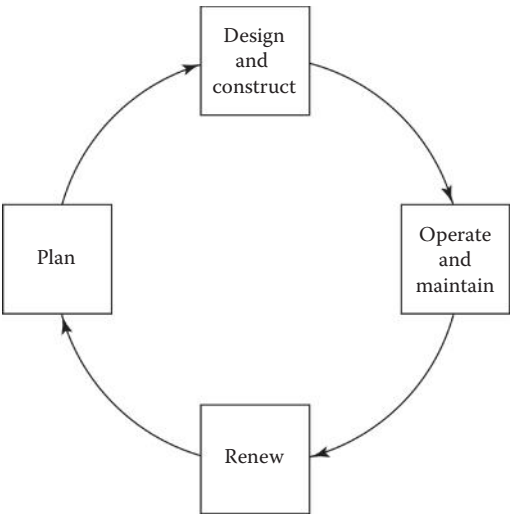

FIGURE 1.3
Phases of life-cycle management.

- The system is turned over to the O&M (operations and maintenance) department (covered in Chapters 7 and 9).
- During O&M, inspection, maintenance, and repairs occur (covered in Chapter 9).
- When the system wears out, it is rehabilitated, replaced, or decommissioned (covered in Chapters 4, 6, and 9).

During this cycle, planners and managers must understand the systems, (Chapter 2), apply aspects of law and regulations (Chapter 11), plan for risk management and emergency preparedness (Chapter 8), manage data and information (Chapter 10), and engage in overall management activities (Chapters 3 and 12).

Data-Centered Infrastructure Management

If one phrase identifies the life-cycle process, it might be "infrastructure management system." Another phrase is "asset management system," where in water, wastewater, and stormwater systems, the assets include both infrastructure and equipment, such as pipes, buildings, pumping plants, treatment trains, and other facilities. The term *asset management system* is used to describe a suite of tools for infrastructure management. Another term is *capital management*, where capital refers to something of value used to produce more value. Infrastructure is physical capital, and capital improvement programming is used for long-term investments in plant or equipment, as opposed to annual operating budgets. Chapter 3 is about infrastructure or asset management systems.

An infrastructure management system is an integrated framework for infrastructure through its life cycle from the cradle to the grave. It works across the units in an organization and coordinates functions in an integrated, data-centered approach to managing the organization's physical systems. The data-centered approach to management is shown in Figure 1.4, where four lines of activity converge on a common database that is shared by different departments. Organizations are shaped by need for and access to information, and the data-centered concept is explained further in Chapter 10, which presents an integrated view with a focus on software-based enterprise management systems.

The same data for pipe location, condition, performance, and capacity may be used by operations, maintenance, planning, engineering, and even finance staffs. As Chapters 9 and 10 explain, this is made possible by the enterprise data systems, managed centrally by information technology departments. Note in Figure 1.4 how ongoing functions that

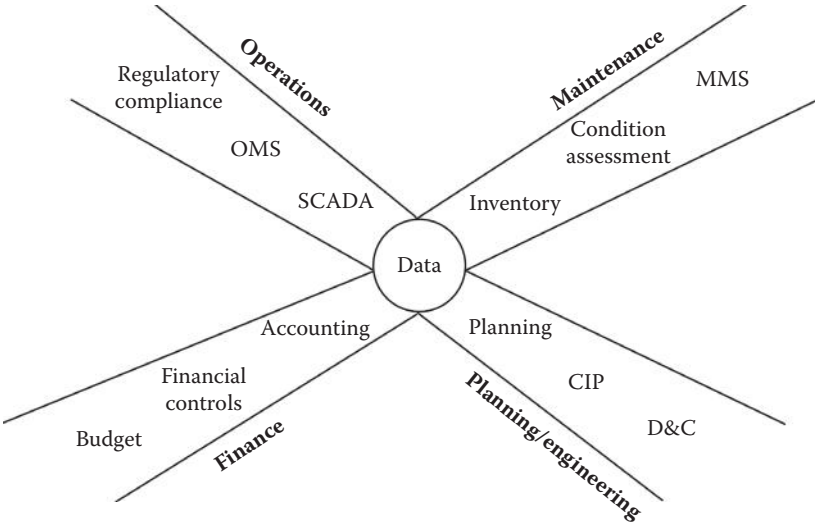

FIGURE 1.4
Data-centered infrastructure organization.

sound different, like accounting, SCADA (supervisory control and data acquisition), planning, and inventory, depend on the same data elements. The data-centered approach can increase effectiveness in programs such as capital improvement, main break response, and reliability-centered maintenance.

Elements of Infrastructure Management Systems

Chapter 3 explains the elements of asset management systems, which form a total approach to infrastructure management. The *International Infrastructure Management Manual* that was created by the Association of Local Government Engineering New Zealand, Inc., and the Institute of Public Works Engineering of Australia (2006) describes a core system and advanced system for asset management. The functions described should work within organizational management programs that include

- Capital improvement planning
- Maintenance management
- Capital and operating budgeting
- Needs assessment
- Inventory of assets
- Fixed-asset accounting

TABLE 1.1

Outline of Book

Chapter	Infrastructure Management Program Element
1	**Urban water infrastructure for healthy cities:** Needs and management systems
2	**Managing water systems and services**: Characteristics of systems; physical and management features; design parameters and constraints; how management units are organized
3	**Asset management for urban water systems:** Use of asset and infrastructure management systems as frameworks to manage capital facilities
4	**Capital improvement planning, programming, and budgeting**: Planning, programming, and budgeting for capital improvements
5	**Engineering and construction for the infrastructure life cycle**: Engineering and construction controls to provide quality infrastructure
6	**Financial management for urban water systems**: Primer on financial management for water, wastewater, and stormwater management
7	**High-performance operation of urban water systems**: Operations management for the functions of organizations
8	**Risk management and disaster preparedness**: Risk, disaster management, and safety to illustrate preparedness and how it links to capital integrity
9	**Maintenance and renewal of water infrastructure**: A comprehensive approach to data-centered maintenance management
10	**Information technology for water infrastructure**: Integrated approach to data management for infrastructure
11	**Legal and regulatory controls on urban water systems:** Legal, regulatory, and governmental processes that govern infrastructure management
12	**Managing infrastructure in the water industry**: Capstone presentation of elements of management that affect success

These are not separate, independent processes, but involve shared activities among the functional parts of organizations, especially planning, engineering, finance, operations, and maintenance. In many ways, the chapters of the book are organized to explain these processes, as seen in Table 1.1.

By applying infrastructure management systems with these elements, costs can be lowered, and the rate shocks associated with managing infrastructure for growth, deterioration, and regulatory requirements can be mitigated. Systems will last longer and service will improve. Infrastructure management systems use information-based tools to offer multiple benefits that include: better customer service; effective capital improvement programs and budgets; cost control for infrastructure management and operation; information for decision documents for capital improvements; guides for operations and maintenance practices; compliance with regulations; and higher service levels.

Measuring Infrastructure Integrity

Effective management produces large benefits for water, wastewater, and stormwater customers by focusing on the *integrity* of infrastructure. Integrity

FIGURE 1.5
Inputs to infrastructure integrity.

is an integrated indicator that measures quality of materials and original construction, as well as current condition. As shown in Figure 1.5, the inputs to integrity are quality along the planning-design-construction-O&M chain, or along the entire life cycle. The concept of integrity depends on the condition of infrastructure, but a single integrated indicator for infrastructure condition is not usually feasible.

High-integrity infrastructure produces greater reliability, greater capacity, and better overall effectiveness, which leads to improved service, lower risk and greater safety, improved public health and environmental stewardship, and protection against flood damage. Also, high-quality constructed systems last longer and perform better, and the relationship between original quality of materials and construction and current condition is easy to see.

Assuming high quality of original condition, the curve that relates condition to time and to standard of care is like that in Figure 1.6. This curve is widely used to illustrate the concept of infrastructure condition, and shows

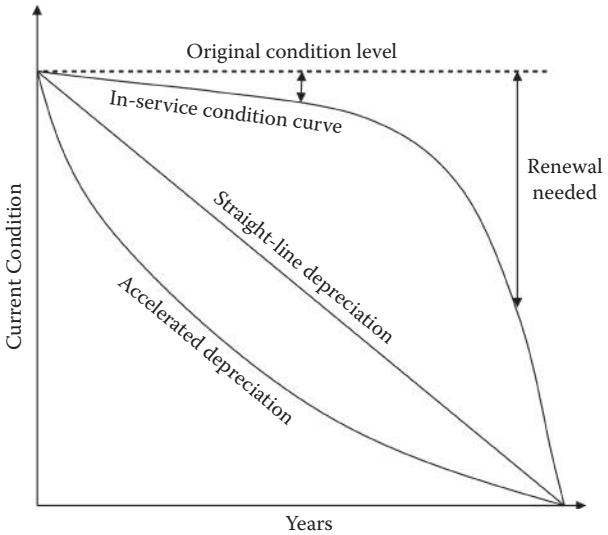

FIGURE 1.6
Infrastructure condition curve.

that the condition of a facility will normally hold up in its early years (depending on the service load), but as it ages, more maintenance and upkeep are required to prolong good condition. This type of curve is normally used to illustrate the condition of roads, but it applies equally to water, wastewater, and stormwater infrastructure systems.

The curve shows that in the early years, restoring the facility to original condition may require only a little investment, but later on, it takes much more, maybe even the full cost of demolition and replacement. In the case of pipelines, replacement may only be needed after many years and might be achieved using trenchless technologies. The figure also shows how condition relates to the financial concept of depreciation, which may not reflect the actual time history of deterioration of condition. Addressing the disparity of condition curves and depreciation curves is discussed in Chapter 3 on asset management and in Chapter 6 on financial management, which also explains differences between historical and current cost accounting and the resulting difficulties for capital planners.

The dependence of condition on the quality of original construction is easy to see when you think about a piece of equipment. If it is built well and lasts through the break-in period, it is likely to remain in good condition longer, but if the original condition is poor, the starting point on the curve is lower. This is discussed further in Chapter 5.

Condition and Investment Needs of Urban Water Systems

The aggregate replacement value of water, wastewater, and stormwater infrastructures in the United States is between $1 and $2 trillion, and their operations generate annual revenues on the order of $100–$150 billion, according to my estimates (Grigg, 2011). No central authority maintains these infrastructure statistics, but the U.S. Environmental Protection Agency (USEPA) conducts periodic studies for water supply and wastewater, and the databases are improving since the surveys began a few decades ago. Details of these estimates are presented in Chapter 2.

Because water, wastewater, and stormwater systems in the United States include so many hidden elements, it is difficult to report about their overall condition. However, since the 1980s, a number of reports have assessed their condition as poor. The first report was by the National Council on Public Works Improvement (1988), which used a report-card format to inform the public about infrastructure condition. The report-card concept was adopted by the American Society of Civil Engineers (ASCE, 2011), which has issued several Infrastructure Report Cards beginning in 1998. In the 2009 report card, ASCE gave the nation's overall infrastructure a D, including D– for drinking water and wastewater. Stormwater is not a separate category in the report card, but is reflected, to some extent, in wastewater.

About drinking water, ASCE wrote:

> The nation's drinking-water systems face staggering public investment needs over the next 20 years. Although America spends billions on infrastructure each year, drinking water systems face an annual shortfall of at least $11 billion in funding needed to replace aging facilities that are near the end of their useful life and to comply with existing and future federal water regulations.

For wastewater, ASCE wrote:

> Many systems have reached the end of their useful design lives. Older systems are plagued by chronic overflows during major rainstorms and heavy snowmelt and are bringing about the discharge of raw sewage into U.S. surface waters.

Chapter 2 presents data on investment needs, which are tricky to pin down because the levels of needs are hard to define. In any case, the 20-year drinking-water needs were some $335 billion and wastewater needs were $345 billion, when nonpoint sources and decentralized systems are included. By combining these, we arrive at some $680 billion in needs for a 20-year period. This includes stormwater needs related to clean water but not for urban drainage and flood control that do not involve water quality.

Classification System for Infrastructure Systems and Components

To get a picture of water, wastewater, and stormwater infrastructure, the systems and subsystems and components can be classified as shown in Figure 1.7. This might help explain management issues of concern to different groups. For example, at the highest level, people will discuss the issue of infrastructure to gain a perspective about national policy issues. You must drill down to the second level, however, to specify which kind of infrastructure you are discussing. There is a big difference between the problem of traffic congestion and underground water pipes, for example. At the third level you can distinguish between issues, such as drinking water or stormwater. If you are looking for a job, you might focus on the fourth level to be more specific about a sector such as a water distribution system. The fifth level is germane to products and operating problems. At this level you might focus on a pumping station or a treatment plant, for example.

Program Management within Organizational Units

Infrastructure management is normally not the sole responsibility of any single department, and it cuts across organizations. How this occurs is explained in Chapter 3, but the important point is that management programs are shared across the units. One way this can occur is explained by

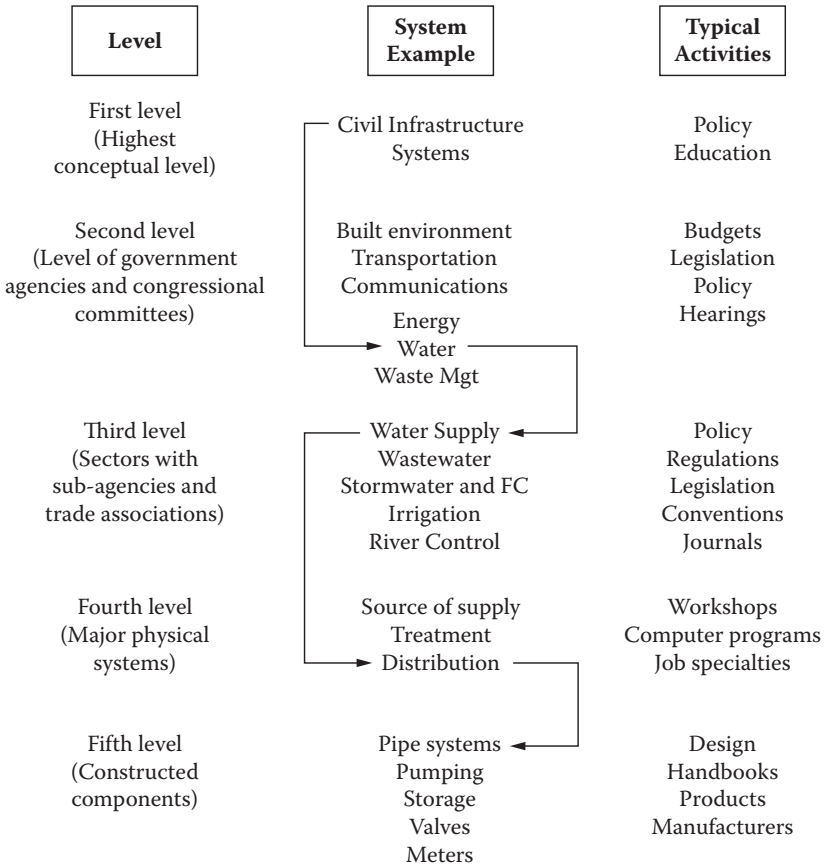

FIGURE 1.7
Levels and activities of infrastructure work.

the system shown in Table 1.2. It is well to remember that organizations can be configured in different ways, and this is only one example, although it is a common way to organize the activities.

Best Practices in Infrastructure Management

Many best practices in infrastructure management have been reported, and three good references are the American Society of Civil Engineers (ASCE, 2000), the American Water Works Association (2011), and the American Public Works Association (APWA, 2004). The practices shown in Table 1.3 are derived from sources such as these and could be used as a self-audit. Not all of these will be consensus best practices, but Table 1.3 comprises a menu to choose from. It is organized by management areas within an organization.

TABLE 1.2

Programs and Relevant Departments

Program	Department Responsible for Program
Capital improvement program (CIP)	Could be maintained by planning, engineering, or budget section
Planning	Could be an overall infrastructure planning section or in engineering planning
Needs assessment	Could be done by the planning or budget section
Design and construction (D&C)	This activity is performed in the engineering section
Asset management system (AMS)	This is an enterprise-wide activity, which might be located in the engineering section or separately
Operations management system (OMS)	This activity is handled by the operations section
Maintenance management system (MMS)	This will be located in the maintenance section, which is often combined with operations

TABLE 1.3

Best Practices in Infrastructure Management

Management Area: Policy, Management, Oversight	
Organization and policy	Centralized capital programs office tracks projects Consolidate construction-related agencies into efficient unit Capital plan involves public works, planning, and budgeting Have facilities and asset management systems in place Have policy for maintenance and limits on deferred maintenance
Authority	Program officially adopted by a board Capital projects must go through planning process
Innovation	Use design-build contracts Do not stifle innovation with too many legal requirements
Standards and goals	High expectations of contractors Decrease delays and projects done on time
Reporting	Centralized reporting of infrastructure performance
Incentives	Performance evaluations of department heads based on capital plan
Oversight	Oversight committee for capital management Require systematic process for reviewing capital proposals Post facto evaluation of projects
Management Area: Planning	
Integration	Comprehensive plan as umbrella for capital improvement plan Plan linked with city objectives and finances Cooperation among agencies and from other governments Coordination of repairs to water, sewer, electricity, streets
Prioritization	Prioritize needs based on criteria Do not favor visible infrastructure over underground systems Address equity, such as allocation to districts
Process and structure	Planning process begins early in year Have plans for specific asset categories Long-range forecasting with reasonable time horizons Assess needs frequently
Documents	Create effective documents, not wish lists Capital proposals must disclose effects on operating budget and service quality
Management Area: Asset Management	
Planning for maintenance management system (MMS)	Encourage joint maintenance work and inventory Link MMS to needs assessment and condition assessment Have clear schedule for preventive maintenance Require life-cycle analysis for major maintenance decisions
Rehabilitation and replacement	Have equipment replacement schedules Have condition monitoring and management program for major components Require new, replacement, or rehabilitated facilities to be designed for maintainability

TABLE 1.3 (*Continued*)

Best Practices in Infrastructure Management

Use of resources	When need for a facility is reduced, consider abandonment or conversion to private sector
Management Area: Finance	
Funding commitment	Annual operating and maintenance costs fully funded Have approved funding for capital improvement plan Seek sufficient funding for capital and O&M
Control	Infrastructure funding merged under the budget director Budget office prioritizes needs
Budget presentation	Agency requests supported by solid information
Methods and sources	Use pricing system to finance capital investments Use revenue bonds for capital financing Use developer contributions to finance facilities when feasible
Validity and confidence	Ensure that estimates of costs and debt are accurate Consider alternative methods for financing Consider long-term maintenance costs and use life-cycle costing
Resources	Invest when financial conditions are favorable Leverage local funds with state and federal dollars
Integration	Link operating and capital budgets
Management Area: Data Management	
Management effectiveness	Maintain comprehensive inventory of facilities Use data-centered maintenance and replacement program Use centralized monitoring and reporting
Security	Secure database to protect data
Quality	Use valid data to justify projects Use historical data on condition assessment Provide high-quality maintenance information
Coverage	Ensure clear picture of deferred maintenance
Management Area: Public Involvement	
Committees	Use public-private capital improvement advisory committee
Roles and functions	Use community input to help prioritize projects Build community support for maintenance and new projects
Surveys	Conduct periodic telephone survey of residents
Strategies	Make efforts to inform citizens Capital plan includes neighborhoods Have neighborhood ambassadors Encourage agency heads to communicate about capital budget with appointed and elected officials

Conclusion

The chapters that follow explain the details of infrastructure management systems required to sustain urban water services. Benefits of these management systems include greater effectiveness, lower costs, and elimination of surprises such as rate shocks or regulatory actions. They offer an integrated, data-centered framework for life-cycle management. Elements of these management systems discussed in subsequent chapters include the capital improvement plan, maintenance management system, asset management system, capital and operating budgets, needs assessments, and inventories.

A lot of change is on the horizon for how these management systems will work in the future. We might say that some of the change represents challenges, such as replacement needs, downsizing, higher rates and costs, and security problems. Other changes are opportunities, such as the application of new technologies for asset management and information-based management methods. Governance changes are in the works as well, including public-private cooperation. These changes will create new possibilities such as decentralized and nonconventional systems in the water, wastewater, and stormwater arenas. It will certainly be an interesting time for urban water infrastructure managers.

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2

Managing Water Systems and Services

In the water industry, regulations are often the governing force in determining how things get done. Next in line is financial capacity, which is the key factor in deciding how far a utility can go to address its needs. To consider these, along with the ever-present political factors, you must look beyond the technical issues and focus on planning and management of systems and services, with a keen eye toward public perception and customer relations.

The goal of this chapter is to present an integrated discussion about how these controls and other nontechnical factors shape the work of the water industry. The chapter blends history, experience, and technical details to provide insight into management issues. To create an overall picture, discussions from fields such as facility management, finance, and maintenance are included along with technical descriptions of the water systems.

Water, Wastewater, and Stormwater Systems

Water supply, wastewater, and stormwater are distinct industries, each with its own system type, regulatory laws, professional associations, and technical subjects. They have many similarities, but they have important differences, which are outlined in the chapter. The discussion that follows presents information about the configuration, infrastructure, and management issues of each of the separate services.

Water, wastewater, and stormwater systems have similarities, but they provide different services, have different organic laws and regulations, and are often managed by different agencies. While the systems evolved as separate services, their management is becoming more integrated, both as measured by organization within utilities and by regulatory programs. In my city, for example, Fort Collins Utilities integrated its water, wastewater, and stormwater utilities in one organization, along with electric power. However, even when integrated within an organization in this way, the services still have their own rules, associations, textbooks, and norms of practice.

The integration of water, wastewater, and stormwater systems occurs through the hydrologic cycle and through the processing of water. Figure 1.1 shows the interrelationships that occur as water travels from origins to destinations. The diversions from streams and withdrawals from wells provide

raw water supplies to the city. These proceed through a use cycle and eventually become discharges to the wastewater collection system. This wastewater is joined by stormwater in the receiving waters to connect the elements of the cycle. Water supply sources are from streams or aquifers, wastewater is returned to the same streams and sometimes the aquifers, and the stormwater flows to the streams or infiltrates to groundwater.

While physical integration occurs this way and is easy to grasp, the managerial, geographic, and political separations between the services create stovepipes in organizations and may cause management difficulties. The next section explains how this occurs by presenting a brief history of how the systems evolved into today's forms. It is followed by discussions of each separate system, and the chapter concludes with a discussion of prospects for future systems.

Evolution of Urban Water Systems

If you were to design an urban water system from scratch, you would create a more integrated system than we have today. In fact, much of today's research is about how to create integrated systems. For example, in 2011 the National Science Foundation announced approval for a research center on "Re-inventing America's Urban Water Infrastructure," to be coordinated out of Stanford University (2011). While research projects like this cannot transform our massive urban water systems overnight, they can identify ways to build on traditional forms to create new approaches incrementally.

Martin Melosi (2008) explained the evolution of urban water services in a book titled *Sanitary City*, which is an excellent historical account of the major issues that led to today's systems. He focuses on water supply, wastewater, and solid waste disposal, but does not address stormwater in the same sense as we treat it in this book. He offers three phases for the evolution of services: the Age of Miasmas, the Bacteriological Revolution, and the New Ecology, which correspond, respectively, to the epoch when sickness prevailed, the period of development of microbiology, and the emergence of the environmental movement.

Today's water systems began to take shape in ancient civilizations. Rome was famous for its water supply, which was provided by aqueducts that can still be seen today and have been studied by water industry groups. To focus on them, the New England Water Works Association published an ancient manuscript about them (Frontius, 1973). The Roman systems were developed logically because water must be transported to points of use. While there were no treatment plants or regulatory agencies, the physical layouts of these water systems showed remarkable creativity. Archeology continues to uncover such imaginative solutions to many water problems of ancient settlements, such as

the landmark work of a Denver firm, Wright Water Engineers, to delineate the design of the water systems of Native American settlements.

While drainage was always necessary in cities, the use of sewers to remove wastewater on a widespread basis is comparatively recent. Although King Minos of Greece had a latrine flushed by rainwater, it is widely believed that this standard of sanitation did not appear in Europe until the 19th century (Fair, Geyer, and Okun, 1966). However, new findings challenge this assumption. For example, Drangert, Nelson, and Nilsson (2002) showed that water and wastewater systems date to the 13th century in Swedish towns.

Early settlements had some physical systems, but they lacked the political and economic organization of today's cities. Water supply and wastewater were considered as private responsibilities and were usually found only in palaces or special places, serving the fortunate few, while the masses lived miserable lives with poor sanitation and public health. Management of water systems today is based on fair treatment to all, a concept that was not practiced much in earlier times.

Public health was poor in Europe until the Enlightenment, and their culture carried over to the United States, where water systems date back about 250 years. The first reported system using spring water forced by a pump through bored logs was built in 1754 in the Moravian settlement in Bethlehem, Pennsylvania. Philadelphia also developed an early water supply system, with combined public and private pumping facilities. The pumps were usually horse driven and were driven by steam before electric power was available (American Public Works Association, 1976).

New York City's interesting water supply story begins about 1800 with Aaron Burr and the formation of the Manhattan Water Company, and it includes John Jervis's engineering work and the construction of the Croton Aqueduct, which carried water to the city from a reservoir in upstate New York beginning in 1842 (Koeppel, 2000). New York later reached further to the Catskills and Delaware River for water.

As society advanced, communities began to develop water supply systems. However, many of them got water from nearby springs and wells that were vulnerable and easily contaminated. Waterborne disease outbreaks were serious problems until the end of the 19th century, when scientific solutions evolved and the link of sanitation to public health was explained.

People have always been willing to work hard to develop their water supplies, but they were more careless with wastewater. The history of wastewater systems derives from early storm sewers, which were convenient to use for disposal of sanitary wastes and led to today's combined sewer problem, where stormwater and wastewater are blended. Later, separate sewers were installed to remove wastewater from central cities, but this process is not complete. Wastewater treatment plants date from the early 20th century, and many were added after the advent of the Clean Water Act in 1972. A website has been created with many details of the history of wastewater (Schladweiler, 2011).

Government regulatory programs for water supply evolved from the early 20th century, when the U.S. Public Health Service (USPHS) was created, and merged later into the U.S. Environmental Protection Agency (USEPA) and the U.S. Centers for Disease Control (USCDC). Waterborne disease began to diminish with tighter public health controls. After World War II, legislation was passed that led to the management system we have today for water supply and wastewater. The Safe Drinking Water Act (SDWA) and its amendments comprise the main policy instrument for drinking water. The Clean Water Act (CWA) of 1972 was the most important legislation for wastewater, and its regulatory system continues to evolve. For the most part, stormwater remains a local issue, but growing environmental concerns about nonpoint sources have led to a stormwater regulatory program under the Clean Water Act.

Water Supply Infrastructure Systems

Configuration and Functions of Water Supply Systems

Water supply systems meet the most basic of human needs, and their infrastructure requires careful oversight. As shown in Figure 2.1, the systems require subsystems for source of supply, treatment, and distribution. The figure shows a "chains and hubs" view of how the subsystems function. The hubs are processes, and the chains display how the commodity of water being processed moves through them. The chains and hubs could also be called *links* and *nodes*, which are part of the common terminology used in the analysis of systems.

The basic requirement for water supply systems is to deliver enough water of high quality at adequate pressure for domestic, commercial, industrial, municipal, and firefighting uses. Needs must be met during peak demand

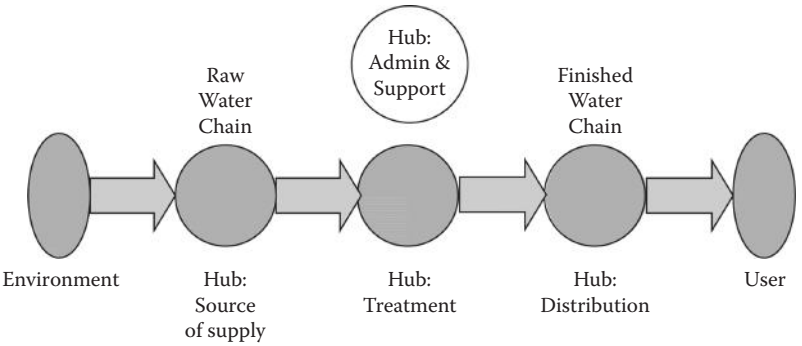

FIGURE 2.1
Subsystems of water supply service.

periods and during drought as well as during periods of average supply and demand. A percentage of the water is normally lost through leakage and other losses, and utilities work constantly to reduce these losses.

In the United States, water supply requirements are normally expressed in gallons per capita per day (gpcd). When averaged over entire cities, these requirements vary widely, from near 100 gpcd (379 liters per person per day) for an urbanized area with small yards in a humid zone to much higher for a sprawled city with lawn irrigation in a dry area. With increasing water efficiency in the United States, these levels of use have been declining since about 1980.

It is difficult to generalize about water supply requirements because they depend on different categories of uses, which vary from place to place. Taking the uses together creates a city's overall water use, which is called its *average demand* and is an aggregated indicator. In-house uses include toilet flushing, bathing, kitchen use, drinking water, washing clothes, and household cleansing. Consumption varies considerably and will be affected by conservation programs, social and economic factors such as income and lifestyle, and climate. Outdoor uses include lawn watering and perhaps car washing and other uses from the outdoor spigot. While domestic consumption might be mostly a function of income level, lawn watering depends mostly on climate and local practices. Commercial use varies by types of businesses and institutions. Industrial uses are highly variable, and many industries develop their own sources of water. Commercial and industrial uses depend on the economic character of the city, and public uses depend on practices such as frequency of water-main flushing and how many water fountains and irrigated highway medians a city has. Losses can vary widely, depending on the effectiveness of infrastructure management.

The lowest water supply demands are in low-income countries, where people may lack access to modern and safe systems and often use only minimum supplies to sustain life. At the other extreme, per capita water use has exceeded 250 gpcd (946 liters per person per day) in some western parts of the United States, even for cities without heavy water-using industries. However, these high-use levels are declining in many areas with more effort devoted toward water conservation.

The U.S. average water use in urban areas is about 150 gpcd (568 liters per day per person), which is a level reported by many utilities. This value can be estimated from the U.S. Geological Survey's (USGS, 2009) water use study, which showed for 2005 (the most recent study) that some 25,600 million gallons per day (mgd) (97 million cubic meters per day, mcm) were consumed for residential use for a population served of some 258 million people, or about 100 gpcd (379 liters per day per person). Reports by utilities are usually in the range of 150 gpcd (568 liters per day per person), but these aggregated figures include commercial and other uses. When you add uses and losses, the USGS report rises to about 147 gpcd (556 liters per day per person), which is close to the averages reported by utilities (Grigg, 2011).

There are many determinants of overall water use, such as humidity, type of city, and percentage of industry; and water use varies widely among places. A water use forecasting program (IWR–MAIN) is available to predict use in given locales, and it takes into account housing and employment, price of water, weather, plumbing codes and drought restrictions, types of use, and other variables (Baumann, Boland, and Hanemann, 1998).

Water Quality and Health

Meeting water quality requirements means that sources must be protected, and the quality of treated water must meet or exceed standards reliably. These standards are specified by regulations, mainly the Safe Drinking Water Act, which is described in Chapter 11. Keeping water quality in distribution systems safe is currently a high-priority issue, and it has gained more national attention among utilities and regulators since the 1990s.

Water quality in distribution systems depends on a number of factors and is measured by physical, chemical, and biological parameters. Chemical changes can include organic or inorganic substances, and threats from compounds such as lead in drinking water or disinfection by-products can be serious. Biological threats such as from *E. coli* can be serious and require immediate action such as boil-water notices after water systems are contaminated.

Protecting the quality of drinking water in distribution systems has become a major focus of USEPA regulatory efforts. The National Research Council (NRC, 2006) studied water quality in distribution systems and published a comprehensive report to outline the threats to drinking water. A number of infrastructure issues can threaten water quality. Among these are cross-connections, intrusions, and metal release from pipe walls or joints. The NRC report identified the actions needed to maintain the physical, hydraulic, and water quality integrity of distribution systems.

Sources of Water

Sources of fresh water supply include surface water, groundwater, and reclaimed waters. Surface water can include stored water in reservoirs or direct diversions from streams. Typical infrastructure components include dams, tunnels, outlet tubes, canals, gates and controls, spillways, and support structures. Groundwater sources include springs, wells, infiltration galleries, or aquifers that store recharged water. Infrastructure components include wells, casings, pumping systems, piping, housing, and other support facilities. Groundwater systems offer potential for water reserves, including use for aquifer storage and recovery (ASR) systems. In special cases, rainwater can be caught from roofs and stored in cisterns. This type of local supply system is found in many developing countries and in locations where centralized systems are not possible.

Desalted water is becoming more feasible because costs have come down, and reverse-osmosis (RO) plants have improved. Reclaimed wastewater also offers potential for use in dual systems and maybe for direct reuse in drinking water systems. Most scientific problems of water reuse seem solved, but concerns about economics, psychology, and public health remain. Bottled water is, of course, a popular source, and point-of-use treatment systems are becoming more popular.

Peak Rate Operations of Water Supply Systems

In addition to providing enough quantity, water supply systems must meet peak rates of demand, which vary according to time of day, day of the week, and seasonally. Peak day rates are used to plan water storage and reserves, and might be in the range of 1.2 to 4.0 times the average daily rate for the year. Peak hour rates are used for design of pumping and treatment facilities and might be 1.5 to 12.0 times the average hourly demand (computed as annual use divided by total hours). By providing storage for treated water, utilities can reduce treatment capacity needs, but treated water storage carries some water quality risks unless it is managed well. The ratios are functions of the nature of the water customer base and depend on the socioeconomic characteristics of the area.

In addition to raw water reserves for drought and other contingencies, treated water reserves are required for demand variations, emergencies, and breakdowns as well as to regulate system behavior. Treated system storage should normally be adequate for a few days of use, and raw water storage might be a year's supply or more, depending on variability of supplies. Requirements for raw and treated water storage are set locally or by state boards, and not at the national level. As an example, the Texas Board of Health has a regulation for required drinking water system storage volumes. Storage is required to ensure adequate chlorine contact time and maintain pressure during all anticipated operating conditions. For raw water, rules require safe yields to meet maximum daily demands during extended periods of critical hydrologic conditions and peak usages (Texas Water Utility Association, 1979).

Drought planning may require a system simulation study to demonstrate response of the system to stress. These might include the simulation of the worst drought of record to occur simultaneously with periods of high demand. The safe yield of the system would be evaluated for adequacy. Safe yield indicates the system, reservoir, or aquifer capacity under adverse conditions.

Drinking Water Treatment

The quality of drinking water and thus the extent of required treatment is specified by requirements of the Safe Drinking Water Act. The water supply treatment systems required to assure this quality vary from none at all

to advanced systems. Some are tiny, treating only enough water for a few homes, and some are gigantic, treating over a billion gallons per day. They depend on the quality of the source water and its intended uses and are classified as physical, chemical, and biological. Opinion in the water supply industry is that treatment requirements will become more stringent in the future. Figure 2.2 shows a large water treatment plant, the Los Angeles Filter Plant.

Unit treatment processes for water supply can be classified by main type, including: presedimentation; initial mixing; flocculation; sedimentation; filtration; disinfection; and advanced techniques to treat against inorganic, organic, and radiological compounds. AWWA's (1996) WATERSTATS database includes a detailed list of specific treatment types, such as these examples: aeration; pre- and postdisinfection (chlorine, chlorine dioxide, chloramines, ozone, potassium permanganate, UV radiation); lime/soda ash softening; recarbonation with CO_2, pH and alkalinity adjustment; conventional sedimentation or clarification; upflow clarifiers, tube settlers, and lamellar plates; dissolved-air flotation; direct filtration, microstrainer, slow sand, rapid sand, dual-/multi-media, diatomaceous earth, or pressure filtration; fluoridation, defluoridation; corrosion inhibitors; reverse osmosis, nanofiltration, ultrafiltration, microfiltration, electrodialysis; ion exchange, iron or manganese removal, manganese green sand; and granular activated carbon, powdered activated carbon, resin adsorption, air stripping, and other treatment practices.

Treatment systems are normally located in compounds and buildings, and include concrete and steel tanks; filter basins; equipment for pumping,

FIGURE 2.2
Los Angeles Filter Plant. (Courtesy of Peter Garra, Los Angeles Department of Water and Power.)

screening, chemical feed, and other mechanical operations; and electronic control systems. Management of these plumbing and chemical-handling systems requires different approaches than underground piping. Figure 2.3 illustrates aeration basins from the Los Angeles Filter Plant and shows the nature and extent of large, outdoor facilities typical of water treatment plants.

Transmission and Distribution System Infrastructure

Treated water is distributed to domestic, commercial, industrial, public, and sometimes irrigation users in different service zones. AWWA (2010) describes four types of pipelines for these and other purposes:

- Transmission lines: from source to plant or from plant to distribution system
- In-plant piping: piping located in pump stations or treatment plants
- Distribution mains: pipelines that distribute water around a community
- Service (services): small-diameter pipes from distribution mains to use points

The transmission and distribution pipelines extend over some 2 million miles in the United States. Some two thirds of the value of water supply infrastructure

FIGURE 2.3
Aeration basins, Los Angeles Filter Plant. (Courtesy of Peter Garra, Los Angeles Department of Water and Power.)

is in these systems. In-plant piping is extensive and is used in industrial plants as well as water treatment plants. The mileage of service lines is also large, and when you consider that all homes and buildings using water will require a service line, their total length will extend to more than a million miles.

Pressure and flow requirements in distribution systems govern design decisions, and there are special provisions for firefighting, with minimum pipe sizes ranging from 2 in. for minimum service locations to 6 in. and larger to ensure at least a minimum fire flow capability. Pipe sizes are not specified by national or state legislation, but are instead set by local codes to respond to fire insurance underwriter requirements. AWWA (2008) has published a manual on these requirements.

The American Water Works Association publishes practical guides about managing transmission and distribution systems, with topics such as pipe installation, maintenance, tapping, valves, fire hydrants, services and meters, cross-connection control, pumps, storage, and instrumentation and control. Additional management topics include maps, drawings, and records as well as public relations. Another text on water distribution systems explains basic processes of water distribution, including hydraulic operation (Mays, 2000).

Figure 2.4 shows a water transmission line, and Figure 2.5 illustrates one in a tunnel. Tunnels can introduce vulnerabilities in earthquake zones (see Chapter 8). Figure 2.6 shows a photo of a water line under construction.

In areas requiring high fire flows, minimum required static pressure at fire hydrants is normally 35 psi (2.4 bar), and pressure during a fire should not drop below 20 psi (1.4 bar). Ideal residential pressure would be between about 50 and 75 psi (3.4 and 5.2 bar), and users do not like pressure that is too high, as water comes out of the faucet with too much momentum. To manage pressure, distribution systems may be divided into pressure zones. In addition to the main distribution system, service storage will be incorporated in the network, and delivery systems also include local building connections and plumbing systems.

Transmission lines are normally larger than those in the distribution system, run mostly in straight lines, and have few connections or taps. Normally, delivery in distribution systems is by main lines from the treatment plant to a looped pipe network, where capacities are high enough for peak daily and fire flows.

AWWA defines layouts of systems as arterial-loop systems, grid systems, and tree systems (Figure 2.7). Major demand areas should be served by an arterial loop, with high-demand areas served by grid systems without dead ends. Critical health or fire-control areas should be connected to two arterial-loop systems wherever possible. Minor lines make up the secondary system, which serves fire hydrants and domestic and commercial customers. The tree system is not recommended because it has dead ends and is not looped.

Mains are sized to handle all demands, including fire flow. In most areas, fire flow requirements will dominate over normal service levels, although design of pipe systems also takes into account peak flows for regular use.

FIGURE 2.4
Water transmission line: 42 in. steel pipe. (Courtesy of City of Fort Collins Utilities.)

FIGURE 2.5
Water line in a tunnel: 36 in. raw-water pipe. (Courtesy of City of Fort Collins Utilities.)

FIGURE 2.6
Water line under construction. (Courtesy of Colorado Department of Transportation.)

Fire-flow requirements are set by the Insurance Services Office (ISO), representing the fire insurance underwriters (AWWA, 2008). The ISO publishes a Fire Suppression Rating Schedule for use to review firefighting capabilities of individual communities. It assigns a classification to cities of 1 to 10 based on firefighting capability (60 points for the fire department and fire alarm system) and water supply system (40 points).

Of the water supply rating, hydrant type and installation account for two points, and three points are assigned to inspection and condition of hydrants. The remaining 35 points are based on water supply system capacity. AWWA's manual contains a summary diagram of the water supply evaluation procedures. It shows a process where, for test locations, needed fire flow (NFF) and lowest system capacity are determined. Lowest system capacity is the lowest of supply works, main capacity, or hydrant capacity. NFF is then compared to system capability, and hydrant characteristics are taken into account to determine water supply credits (up to 35 points). Fire department and fire alarm credits are then added to determine the Public Protection Class, which is used to set insurance rates.

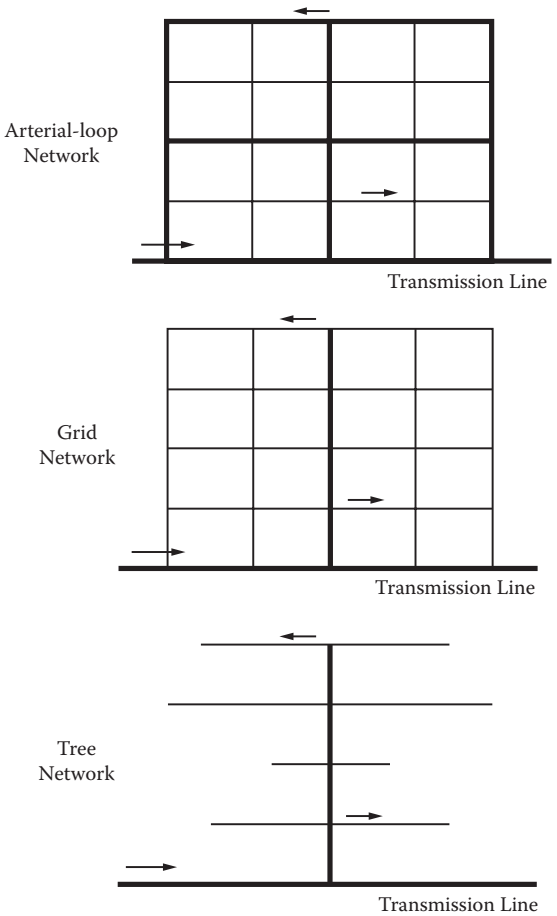

FIGURE 2.7
Water supply networks.

Design criteria include strength, durability, corrosion resistance, flow capacity, cost, maintainability, and effect on water quality. Several types of pipe materials are used in transmission and distribution systems to achieve these goals. Common materials used in transmission and distribution systems and their characteristics are given in the following list (AWWA, 2010):

Asbestos cement: Used in smaller sizes; easy to handle; might damage easily or deteriorate under aggressive soils.

Cast iron (ductile, cement-lined): More cast-iron pipe (gray and ductile cast-iron pipes) is in use in distribution systems than any other type. Cast-iron pipes are used in smaller sizes, are strong, easily tapped, and subject to corrosion.

Concrete, prestressed: Used up to very large sizes. These pipes are durable, but may deteriorate in some soils.

Concrete, reinforced: Used more for transmission lines than distribution lines. These pipes are used up to very large sizes and are durable, but may deteriorate in some soils.

Polyvinyl chloride (PVC): Used in distribution systems, PVC is lightweight, easy to install, and resists corrosion; care is required when handling.

Steel: Used more for transmission lines than distribution lines, steel pipes are found in a wide range of sizes, up to very large. They are adaptable to many conditions but are subject to corrosion.

Management of distribution systems requires the balancing of complex combinations of components. For example, pipes must be tapped to connect new services or laterals to existing lines. This means that many different people are involved with work on the pipelines. Different kinds of valves are used for diverse purposes, including shutoff, flow control, and bleeding off of air. Common valve types are gate, butterfly, globe, plug or cone, and ball valve. This creates an enormous amount of diverse hardware in the systems. Fire hydrants (Figure 2.8) are important components of distribution systems and must be exercised and protected. Meters are used to measure water flows at many locations, and these must be calibrated and managed. If gravity is insufficient to maintain system pressures and flows, pumping is used, which can create pressure changes that must be managed. Tanks of different kinds are used for in-system storage and create special management requirements (Figure 2.9).

Water Supply Statistics

As a result of extensive surveys in the last two decades by USEPA and AWWA, an extensive body of national statistics of water supply infrastructure has been produced. As the main water supply association in the United States, AWWA has published data about the industry practically from its origin during the 1880s. Beginning in 1945, the association began to conduct surveys of operating data, which included information on water production, distribution, revenues, and other business information. In the early surveys, no information was collected on the status of infrastructure systems, other than accounting data on utility book value (Seidel, 1978).

During the 1980s the concept of AWWA's Water Industry Database (WIDB) emerged, but attention to it seems to have diminished. A recommendation to develop the database was made by AWWA's Water Utility Council in 1987, and the association's strategic plan for 1989 included it with the purposes of providing information to the public, the media, and the government. AWWA received a grant from the AWWA Research Foundation (AwwaRF) to develop the concepts. AwwaRF has been renamed the Water Research Foundation

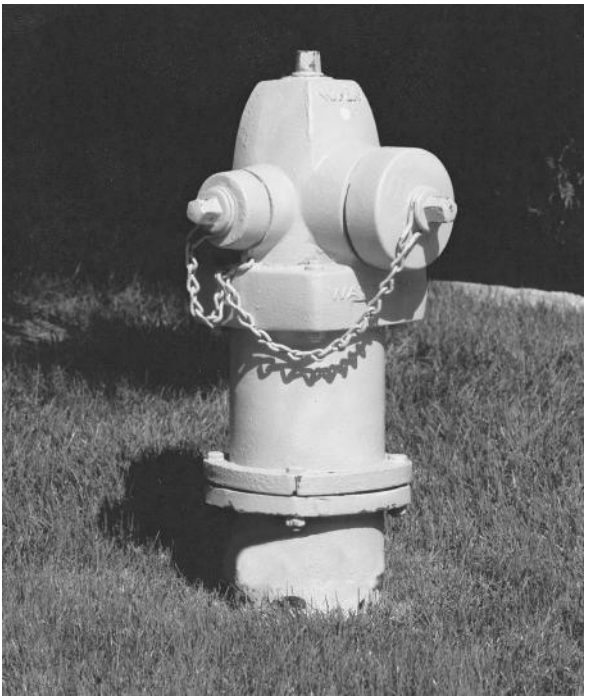

FIGURE 2.8
Fire hydrant. (From American Water Works Association. Copyright 2001. All rights reserved.)

FIGURE 2.9
Water tank for a distribution system. (From American Water Works Association. Copyright 2001. All rights reserved.)

(WaterRF). The WIDB evolved into the WATER:\STATS product, a title that has been used to label some of AWWA's products sold through the bookstore.

AWWA's 1996 utility survey and 2002 distribution survey contained large amounts of information on distribution infrastructure (Cromwell III, Lee, and Kawczynski, 1990). Now, AWWA develops periodic surveys on compensation, rates, and other business parameters, but momentum for surveys and release of water industry information seems to have shifted to USEPA because of the greater resources it is able to devote to surveys.

The 1996 survey was AWWA's (1996) most comprehensive one and the first one that included a significant amount of information about infrastructure. While the information collected in this survey is dated, it remains useful because it contains data on numerous parameters, and many of the utility attributes have changed little since that time. Of the 794 utilities providing data about water sources, 370 (47%) used groundwater systems only; 284 (36%) used only surface water; and 140 (18%) used both. Another 104 utilities provided other information. For infrastructure, AWWA included data about distribution systems: pipe material, customer service lines, fire service lines, main breaks, hydrants, maximum retention time in distribution system, and storage facilities.

AWWA's (2002) distribution survey was sent to 3,000 water utilities, with a response rate of 11%. The 337 responding utilities served 59,389,902 in population, with 14,339,261 customer service lines and 146,435 wholesale connections. Total length of pipe was 202,000 miles for the population served. Data were collected between June 2002 and April 2003 and covered pipe materials, valves, fire hydrants, finished water storage facilities, corrosion control, pumping capacity, metering, customer service lines, water auditing, leakage management, and infrastructure needs. Water audit and leakage management data is in a format developed in 2000 by the International Water Association. The data from the 2002 survey suggest that pipeline expansion and replacement slowed from the survey by Kirmeyer, Richards, and Smith (1994), but the data may not be adequate to reach this conclusion.

Data in Table 2.1 show distribution of pipeline length by pipe material, as derived from the survey. Additional detail is in (AWWA, 2007). The "all other" category includes pipe types such as: galvanized iron, high-density polyethylene (HDPE), wrought iron, black iron, copper, steel cylinder pipe, plastic, cement-stove, fiberglass, concrete-lined steel cylinder, steel, arch concrete masonry, polybutylene, and unknown.

Data from the 2002 survey show a total of 4,929 finished-water storage tanks among the surveyed utilities. The largest number (28%) of tanks was the welded ground storage type, followed by welded elevated tanks (18%). Reinforced tanks were 12%, and the other types were basins, welded standpipes, wirewound, bolted ground storage, and miscellaneous.

The total number of service lines surveyed was 14,120,646, which served a population of over 59 million, or one line for each 4.2 persons. Most were of copper (56.3%), followed by polyethylene (11.4%), galvanized (8.0%), and

TABLE 2.1

Inventory of Pipeline in U.S. Systems

Pipe Material	Miles	km	%
Ductile iron, cement mortar lined	35,118	56,517	17.4
PVC	29,835	48,015	14.8
Asbestos cement	30,484	49,059	15.1
Cast iron, unlined	37,433	60,243	18.5
Cast iron, cement mortar lined	34,039	54,781	16.8
Ductile iron, unlined	9,886	15,910	4.9
Steel	7,821	12,587	3.9
Concrete pressure	4,774	7,683	2.4
Polyethylene	1,377	2,216	0.7
All other	11,391	18,332	5.6
Total	202,158	325,343	100

polyvinyl chloride (5.8%). The data suggest that, nationally, some 2.3 million lead service lines remain in use, and this estimate compares well to the estimate by Kirmeyer, Richards, and Smith (1994). Other service line materials include steel, cast iron, asbestos cement, and smaller quantities of ductile iron, plastic, brass, HDPE, and various composites. Other equipment and appurtenances for which data was not collected include pumps, backflow preventers, system components such as blowoffs and air release valves, and meters.

Data on surface water systems from the AWWA 1996 survey illustrate the types of data and management parameters that are reported:

For surface supply and treatment: percentage of plant source water from lake or reservoir, river, or blended groundwater; plant design capacity in millions of gallons per day; average-day production in millions of gallons per day; peak-day production in millions of gallons per day; plant expansions in procurement or construction phase; expansions planned within the next 5 years in millions of gallons per day; pretreatment; permanent pilot plant availability; average chemical cost for surface water treatment per million gallons; and total costs for residuals treatment and disposal per year.

For groundwater: total number of wells; number of well fields/clusters; number of entry points to the distribution system; average-day production across all wells in millions of gallons per day; peak-day production across all wells in millions of gallons per day; capacity expansions in procurement or construction phase and expansions planned within the next 5 years; surface water effects on groundwater; wellhead protection program status; average chemical cost

for groundwater treatment per million gallons; and total costs for residuals treatment and disposal per year.

For delivered water: annual water production in millions of gallons per year for groundwater, surface water, and finished water purchased from other systems; volume of water delivered annually in millions of gallons for residential, commercial/industrial, municipal government, agricultural, wholesale, and other types not previously listed.

To illustrate infrastructure characteristics, AWWA provided the following data about distribution systems in its comprehensive 1996 survey. Data collected in the more focused 2002 Distribution Survey was similar. These are the data items collected in the 1996 survey:

- Pipe material (asbestos-cement; cast-iron [unlined]; cast-iron [cement-mortar lined]; concrete pressure; ductile-iron [unlined]; ductile-iron [cement-mortar lined]; fiberglass-reinforced plastic; polyethylene [PE]; polyvinyl chloride [PVC]; steel, galvanized, copper, or other types not previously listed)
- Customer service lines (copper pipe, lead pipe, polybutylene [PB] pipe, polyethylene [PE] pipe, polyvinyl chloride [PVC] pipe, steel pipe, cast-iron pipe, galvanized pipe, asbestos-cement pipe or other types not previously listed, and what percentage of lead pipe is replaced annually)
- Fire service lines (ductile-iron pipe, polyethylene [PE] pipe, polyvinyl chloride [PVC] pipe, steel pipe, cast-iron pipe, copper pipe, asbestos-cement pipe or other types not previously listed, and the number of dedicated fire service lines)
- Main breaks, hydrants, retention time (data for total number of hydrants, number of main breaks from 1991 to 1995, and average and maximum retention time in the distribution system)
- Storage facilities (finished water storage facilities in the distribution system and capacity in million gallons that the utility uses or plans to add within 5 years for: welded steel elevated tanks, welded steel standpipes, welded steel ground storage reservoirs, bolted steel standpipes, bolted steel ground storage reservoirs, composite tanks [concrete tower supporting an elevated steel tank], conventional reinforced concrete, prestressed concrete [wire-wound], prestressed concrete [horizontal tendons], or types not listed, and clearwell storage in millions of gallons.)

The most extensive water supply data collected by USEPA (2009) is through its Community Water Systems Survey (CWSS), which provides information on water supply finance, infrastructure, and operations to aid in

congressional policy and appropriations. These surveys date to 1976, when the first one was completed. The CWSS contains estimates of total infrastructure based on sampling from the universe of utilities.

A similar source of information is contained in USEPA's (2011a) Safe Drinking Water Information System (SDWIS), which comprises a set of databases with information about drinking water programs, including compliance data. There is a federal version (SDWIS/FED) and a state version (SDWIS/STATE) of this database. The data in the SDWIS is reported by the states. The data in the CWSS is collected by periodic surveys.

The information reported by states to USEPA includes: basic inventory and descriptive information; compliance information for each water system; enforcement information about state actions; and sampling results for unregulated and regulated contaminants. USEPA uses this information to plan regulatory actions, to evaluate program effectiveness, for policy studies, and for reporting to Congress and the public.

USEPA (2011b) uses its data sources to publish fiscal year "Drinking Water and Ground Water Statistics." In addition to compliance data, this information includes numbers and types of systems by population served. Both community and noncommunity systems are included.

The most recent CWSS from 2006 shows an inventory of about 52,000 community water systems and a larger number of noncommunity water systems that serve transient and nontransient sites (USEPA, 2009). These statistics do not change rapidly, and data for the third quarter of 2009 as contained in the SDWIS showed the distribution of systems by size for a population served of 294,339,881 people (Table 2.2).

The total inventory of water supply piping shown by the study is about 2 million miles of diverse materials and condition. Table 49 of the CWSS gives a breakdown of distribution pipe by size and miles, as shown in Table 2.3, which lists average length in miles of pipe in systems of different sizes. The data sums to more than 2 million miles (3.2 million km), reflecting differences in reporting by utilities, but it at least illustrates the relative distribution of pipe sizes. Naturally, larger utilities will have greater mileages of large-diameter pipelines.

TABLE 2.2

Numbers of U.S. Community Water Systems

Size	Very Small	Small	Medium	Large	Very Large	Total
Population	500 or less	501–3,300	3,301–10,000	10,001–100,000	More than 100,000	
No. systems	28,804	13,820	4,871	3,746	410	51,651
Population, %	2	7	10	36	46	100

Source: USEPA, 2010b.

TABLE 2.3

Pipe Length in Miles (km) by Diameter and System Size

Pipe Diameter, in. (mm)	Population Served							
	100 or less	101–500	501–3,300	3,301–10,000	10,001–50,000	50,001–100,000	100,001–500,000	Over 500,000
<6 (<150)	3.4 (5.5)	2.8 (4.5)	26.6 (42.8)	77.8 (125.2)	54.8 (88.2)	43 (69.2)	102.9 (165.6)	301.9 (485.8)
6–10 (150–250)	1.4 (2.3)	2.8 (4.5)	9.5 (15.3)	53.8 (86.6)	99.8 (160.6)	251.6 (404.8)	437.8 (704.4)	1,771 (2,849)
10–24 (250–600)	19.9 (32.0)	3 (4.8)	2.5 (4.0)	7.2 (11.6)	25.1 (40.4)	62.8 (101.0)	125.7 (202.3)	549.9 (884.8)
>24 (>600)	9.7 (15.6)	0.2 (0.3)	0.9 (1.4)	2.1 (3.4)	6.1 (9.8)	13.2 (21.2)	34.2 (55.0)	138.6 (223.0)
Total	34.4 (55.3)	8.8 (14.2)	39.5 (63.6)	140.9 (226.7)	185.8 (299.0)	370.6 (596.3)	700.6 (1,127)	2,761 (4,442)

Source: USEPA, 2010b.

For utilities, the replacement value of a system is a financial accounting value and an indicator of past investments and future needs. The parallel value is the condition of the system, which is an indicator of urgency of investments for renewal of systems. The total need for investment is determined by the cost of expansion plus the cost to remediate problems of depreciation, deterioration, and poor condition.

On a national basis, it is of interest to policy makers to know the total replacement value and condition of water supply systems across the nation. The federal government does not invest directly in water supply systems, but it provides some funding for revolving loans, and it assesses what must be done to ensure the safety of the water supply.

Replacement costs can be estimated by combining USEPA's (2006) cost models with the inventory of pipe from the CWSS. The cost models were mainly derived from the 1999 survey and adjusted for inflation. Some cost data from the 2003 survey were used to adjust them. The inflation factor used to adjust from 1999 to 2003 costs was based on *ENR* (*Engineering News Record*) construction cost indices and was 1.0977. The types of transmission and distribution projects modeled in the cost studies were

- Raw water transmission (pipe diameter and length)
- Finished water transmission (pipe diameter and length)
- Distribution mains (pipe diameter and length)
- Service lines (number of lines)
- Valves (gate, butterfly, etc.) (number and diameter)
- Control valves (pressure-reducing valves [PRVs], altitude, etc.) (number and diameter)

- Hydrants (number and diameter)
- Backflow prevention devices/assemblies (number and diameter)
- Water meters (number and diameter)
- Pump stations

Distribution mains or transmission lines were modeled by pipe diameter and project length in feet for frost and nonfrost locations. Rehabilitation was assigned an average cost per foot of $48.92 for all sizes. This may be a representative figure, but the actual rehabilitation costs may range more widely.

For a national estimate, the inventory of systems by size of population served and the total of distribution and transmission mileage by diameter can be obtained from the CWSS. If the cost was adjusted to include valves, hydrants, and pump stations the total would increase. By multiplying the mileage by the unit costs, a national replacement cost of $1.04 trillion for transmission and distribution piping is indicated, as shown in Table 2.4.

This national total can be validated independently from AWWA's (2001) study of 20 medium and large utilities, which showed that replacement costs per household (from year 2000 data) were about $10,000 for all water infrastructure facilities and about $6,300 for water mains alone. The United States currently has about 116 million households, which indicates a year 2000 replacement cost of about $730 billion for pipe and $1.16 trillion for all water supply facilities. If these are increased by the inflation factor of 1.41 (from ENR construction cost index annual average from 2000 to 2010), then the year 2010 value rises to $1.03 trillion for the pipe alone. This is probably low because the cities in the survey may have calculated only residential replacement costs, and some communities might have greater commercial and industrial costs. Also, the United States has about 23% more housing

TABLE 2.4

Estimate of National Pipe Replacement Costs

Pipe Diameter, in. (mm)	Miles (km)	Unit Cost, $/ft	Total Cost, $ Billion
<6 (150)	873,825 (1,406,290)	58.88	271.6
6 to 10 (150 to 250)	1,051,106 (1,691,230)	86.16	478.1
10 to 24 (250 to 600)	281,453 (452,858)	128.42	190.8
>24 (>600)	67,173 (108,081)	286.31	101,5
Total	2,273,556 (3,658,152)		1,042.1

Source: USEPA, 2010b.

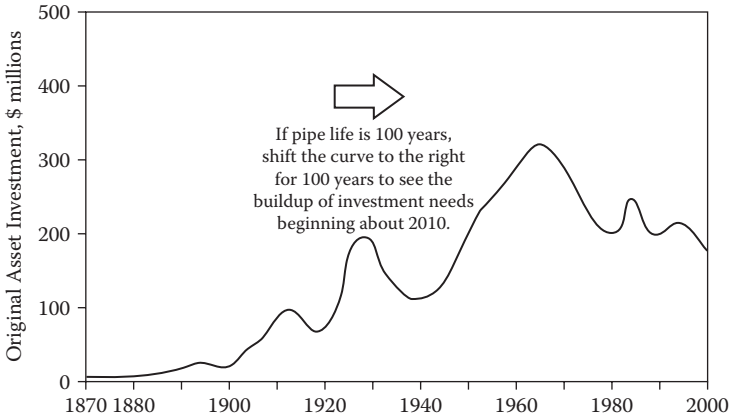

FIGURE 2.10
Investment in pipeline installation in 20 cities. (From AWWA, 2001.)

units than it has households, and these factors would increase the total replacement costs. The two sources of data (inventory of systems and total of distribution and transmission mileage) and the AWWA study both indicate a national replacement cost in the range of $1.0 trillion.

The estimate of investment needs should take into account system condition as well as replacement value. USEPA's (2009) fourth assessment of public water system infrastructure needs showed a 20-year (2007–2026) capital improvement need of $335 billion. These are needs for approximately 52,000 community water systems and 21,400 not-for-profit noncommunity water systems. The findings were based on the 2007 Needs Survey and relied on a statistical survey of approximately 3,250 community water systems that reported needs and submitted documentation. Of the $335 billion, $201 billion is for transmission and distribution facilities.

The buildup of replacement needs can be illustrated by a "Nessie Curve," which resembles the outline of the Loch Ness monster (Cromwell, Nestel, and Albani, 2001; The Nessie Curve, 2011). A display of this curve based on AWWA's (2001) "Dawn of the Replacement Era" report is shown in Figure 2.10. The data were the total cost of pipe installation in 20 cities from 1870 to 1998. By shifting the curve to the right 100 years, you see that beginning in about 2010 the replacement costs will rise rapidly.

Management Organizations for Water Supply

Most of the population is served by large systems, and a large number of small systems serve a much smaller population. The most recent USEPA CWSS indicates a significant trend toward consolidation during the last decade, and this trend will be worth watching.

Most U.S. water supply utilities are city water departments, with private water companies and special-purpose districts rounding out the total number. The publicly owned companies are usually part of a city department, a separate city department under a water board or water commission, or a separate utility district. Most systems are publicly owned, with fewer than 5% being investor owned. In addition, many self-supplied and independent installations such as mobile home communities, rest stops, and rural enterprises have their own supplies. These are called "noncommunity water systems" under the USEPA classification system.

Investor ownership can involve different forms of business organization, but the largest of the investor-owned water companies are regulated corporations similar to regulated gas, electric, and telephone utilities. A subset of the private water companies is publicly traded, and several companies, such as American Water, own large numbers of systems. The National Association of Water Companies (NAWC) lists financial and operations data for member utilities, but many private water companies do not belong to the association.

Interest Groups

Interest groups working on water supply can include government, industry, health, or environmental organizations. Many interest groups participate in this sector, but the main industry group is the American Water Works Association, located in Denver. NAWC represents private water companies, and the American Public Works Association has management improvement programs for utilities. The Association of Metropolitan Water Agencies (AMWA) represents larger water utilities. The Association of State Drinking Water Officials (ASDWO) represents state regulators. Other organizations that attract participation of engineers working in water supply include the International Water Association (IWA), American Society of Civil Engineers, and Inter-American Association of Sanitary Engineers (AIDIS). The plumbing industry has an American Society of Plumbing Engineers (ASPE) and a number of other organizations with interests in smaller-scale equipment.

Trends and Issues in Water Supply Systems

The water supply industry follows trends and driving forces closely, and AWWA reports regularly on trends. Having followed the reports for a number of years, I see the following as important trends:

- As population grows, the use per capita will continue to drop through water efficiency measures.
- Environmental pressures will increase, and the loss of threatened or endangered species will continue to be a major issue.

- Workforce challenges in utilities will continue to be an important issue.
- Use of automation and information technology will continue to expand.
- Conservation measures will continue to be pushed aggressively by multiple groups.
- Desalination technologies will continue to improve and become more feasible.
- Farmland will disappear with the growth of cities and loss of irrigation water.
- Climate change will continue as a major concern of water utilities.

These general trends lead to a list of issues that require continual attention by managers in the water supply industry:

- Improved funding will be required for capital and operations and maintenance (O&M). Higher rates will be necessary to pay for infrastructure renewal, new water sources, regulatory compliance, and other citizen demands.
- Public health concerns and health effects must be addressed by transparent and confidence-building steps. Disinfection practices and issues will remain on the radar screen. Other major concerns include bacterial regrowth in distribution systems and protecting watersheds and surface-water quality.
- Access to water and water rights will continue to tighten, requiring more attention to firming up portfolios of water supply.
- Working with public attitudes and political issues will remain high on the agendas of water utilities.
- Security and preparedness for emergencies and disasters will rise in importance as utilities confront overall risk.
- Managing small water systems will continue as a major challenge, which will be helped somewhat by industry consolidation.
- Controlling water losses and increasing water efficiency will continue as a major O&M effort.

With climate change, and as population increases and environmental water needs are increasingly recognized, it becomes more difficult to find new, untapped sources of supply, and there is much discussion today of water scarcity, especially due to climate change. For this reason, a number of innovative approaches are being used to expand and firm up water supplies. These include: conservation systems to save water; transfer of saved water from agricultural users; use of reclaimed wastewater through dual distribution systems for nonpotable applications; innovative storage, such as aquifer-storage-recov-

ery (ASR) systems; and conjunctive use, where water from different sources, such as surface and groundwater, are managed jointly and perhaps blended.

Wastewater Infrastructure Systems

Configuration and Functions of Wastewater Systems

Wastewater systems meet society's needs to dispose of used water safely and conveniently without damaging the environment. They comprise sewers from buildings, collection sewers, transmission mains, treatment plants, outfall sewers, and sludge management systems (Figure 2.11). These collect, transmit, treat, and dispose of water used by domestic, industrial, commercial, and public users.

Wastewater, or sewage, is the residual of water uses. Most wastewater, or sanitary sewage, is of municipal origin and will normally consist mainly of domestic and commercial wastewaters. Industrial wastes contain wastewater from diverse sets of industries and may or may not have been pretreated. *Sewerage* is a term that describes systems of pipes, pumping stations, and appurtenances and is somewhat synonymous with the term *wastewater infrastructure*.

Main or trunk sewers are principal sewers of systems that collect flows from lateral sewers. Interceptor sewers intercept main sewers and carry the wastewater to a treatment plant. An outfall sewer conveys wastewater to a point of disposal. Lift stations (Figure 2.12) are pumping stations that

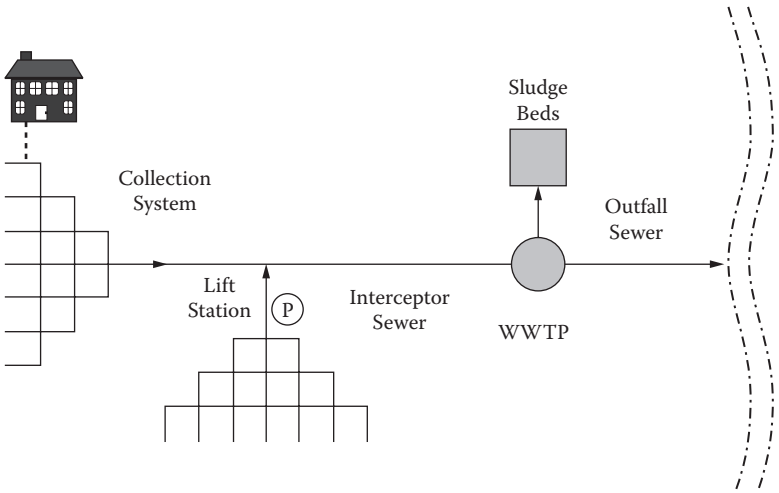

FIGURE 2.11
Wastewater system.

FIGURE 2.12
Lift station in Florida.

overcome the lack of a gravity route for wastewater. Force mains are sections of sewers under pressure, perhaps with pumping. In some cases, a pressure sewer can be used, normally where terrain prohibits gravity flow. In these cases, the solids in the wastewater are ground up, and then the mixture can be pumped.

Separate sewers transport only sanitary and industrial sewage, which may have received pretreatment. Combined sewers are systems that transport sanitary sewage and storm drainage mixed together. Combined sewers have overflow points for wet weather, when treatment plant or trunk sewer capacities are exceeded.

Whereas leaks and losses are problems with water supply systems, infiltration and inflow (I&I) are important infrastructure problems of sewers. Infiltration is wastewater that enters the system from leaking joints, cracks, breaks, porous walls, or other indirect means. Inflow refers to stormwater that enters from roof drains, catch basins, manhole covers, or other routes. Older estimates were that systems might have between 100 to 10,000 gallons per day, per inch of diameter of sewer, per mile (60 to 6,000 liters per

100 mm of diameter per kilometer) of infiltration and that I&I and roof connections and stormwater connections could add large, variable quantities to this (Linsley et al., 1992). After further review, it is clear that many different estimation methods are in use, and an overview of these was presented by Lai (2008).

Treatment plants improve wastewater to meet water quality standards, which are set by states under oversight of USEPA. Disposal systems, including wastewater and sludge, are designed to protect receiving waters and the land. Demands on wastewater systems are related to the use of water. In addition to the public water supply, however, self-supplied industrial wastewaters may also be discharged into public sewers.

Wastewater flow rates are determined by estimating the portion of water use that reaches the collection system. In the United States, the percentages range from around 60% in dry regions to around 85% in humid regions. By comparing water use and wastewater treatment records, a percentage can be determined. Percentages will vary with season and time of day.

Flow rates from indoor use in residential sources are normally 50–100 gpcd (190–379 liters per person per day). Approximate wastewater volumes such as 100 gpcd (379 liters per person per day) might be used for preliminary planning, but values depend on many factors, including infiltration and inflow. The wastewater system will also be subject to peaking factors.

Collection and Transmission Systems

Whereas water supply systems are normally looped pipes under pressure, wastewater systems are usually branched and flow under gravity because wastewater is collected and transmitted long distances to points of treatment and disposal.

As with water systems, wastewater infrastructure is normally underground and not visible. It consists of pipes that come together at manholes and junctions. In a place where wastewater is generated, appliances such as sinks, toilets, and other drain points provide entry points to indoor plumbing systems. These include mostly vertical drains with appropriate venting and lead to the building sewer, which traverses private property and leads to the public sewer.

The public sewer is usually a local collector of size 8 in. or larger that leads to manhole junctions, forming the tree configuration. These lead to progressively larger collectors and mains, eventually reaching the treatment plant. The design of the system will provide a gradual downhill grade through the system to keep the wastewater flowing at a velocity to keep sewers clean and transport material in the wastewater. Larger interceptor systems also function by gravity and collect local sewage to transmit to treatment works.

Norms of practice include minimum velocity, size, and slope for sewers and standards that determine reliability and other service parameters. Design

manuals of the American Society of Civil Engineers, the Water Environment Federation (WEF), and state associations, such as the Texas Water Utilities Association, can be consulted.

The most common collection system materials are: asbestos cement pipe; brick masonry clay pipe (vitrified); concrete pipe, plain, reinforced, pressure, and cast-in-place; iron and steel (cast iron, ductile iron, fabricated steel); and plastic pipe (ASCE and WEF, 1969).

Wastewater Treatment Systems

Wastewater utilities provide treatment so that disposed waters do not harm the environment or public health. Requirements are generally specified by regulations, mainly the Clean Water Act and state regulations, which are described in Chapter 11.

Basic wastewater treatment evolved in the period 1900–1970. Treatment systems focused on removal of suspended and floatable materials, treatment of biodegradable organics, and elimination of pathogenic organisms. After 1972, standards were raised, and treatment of nitrogen and phosphorous was introduced, mainly to protect lakes and inland streams. After 1980, more attention was given to public health and the treatment of toxic chemicals and trace compounds that might have long-term health consequences.

As they are in water supply plants, peaking factors must be considered in wastewater plants. Domestic peaks may be 2 to 5 times average flows. Commercial and industrial are not so varied, between 1.5 to 2.5. Peaks at the treatment plant range between 1.8 to 4 times average. Low flows are usually not less than 0.4. Peak ratios decline with population, as flows get evened out (Linsley et al., 1992).

Treatment systems are classified as primary, secondary, or advanced (tertiary) treatment. Primary treatment consists of basic physical processes such as screening and sedimentation to remove floating and settleable solids. Secondary treatment involves biological and chemical processes that remove most of the organic matter. In advanced treatment, nutrients or special constituents are removed.

Wastewater treatment can also be classified as physical, chemical, and biological. Examples are: physical unit operations (screening, mixing, flocculation, sedimentation, flotation, filtration, gas transfer); chemical unit processes (precipitation, adsorption, disinfection); and biological unit processes (various biological processes, such as activated-sludge, trickling filter, stabilization pond). Major contaminants removed by wastewater treatment systems are: suspended solids, biodegradable organics, volatile organics, pathogens, nutrients, refractory organics, heavy metals, and dissolved organic solids. Industrial wastes may contain elements that must be removed by pretreatment before the wastewater plant. Examples would be: acids, high temperatures, toxic chemicals, and oils and greases (Tchobanoglous, Burton, and Stensel, 2003).

As an example of a large wastewater treatment plant (WWTP), Los Angeles's Hyperion Plant was honored in 1998 as one of APWA's top ten public works projects of the century. The plant, which protects Santa Monica Bay, had a $1.4-billion upgrade completed in 1998 and reached full secondary treatment levels. After the upgrades, the plant continuously treated 350 mgd (1.3 mcm per day) and met all requirements. Achievements included: end of spills; 95% reduction in solids entering the bay; elimination of the bay's ecological dead zone near the mouth of sludge outfall; vast improvements in the bio-integrity of the bottom marine community; big increases in indicator species; and partnerships between the public, regulators, government, dischargers, consultants, and contractors (WaterWorld, 2001).

More recently, a large WWTP in Seattle was nearing completion. King County's Brightwater plant is a $1.8-billion project sited on a 114-acre (46 ha) plot some 32 miles northeast of Seattle. It will eventually reach a capacity of 170 mgd (0.64 mcm per day) for peak flows, and the site will include a community center and environmental education site, as well as the conversion of 70 acres (28 ha) of former industrial land to open space and hiking trails. The project includes some 13 miles (21 km) of deep-bore tunnel (ENR, 2011).

Most of the nation's wastewater treatment plants are small, less than one mgd. Smaller wastewater systems might involve package plants or on-site systems, mainly septic tanks. Package plants are available in the range up to 1.0 mgd (3,785 cubic meters per day), but most are in the range of 0.01–0.25 mgd (38–95 cubic meters per day). The most common types are extended aeration, contact stabilization, sequencing batch reactors, rotating biological contactor, and physical/chemical. While not trouble free, they can perform satisfactorily for small flows (Tchobanoglous, Burton, and Stensel, 2003).

Reclaimed Water Systems

Distribution of reclaimed water requires advanced wastewater treatment to bring the water to minimum levels of quality for nonpotable uses. This option for wastewater management is being used with increasing frequency as dual water systems are evolving. The increased use of water that has been treated to remove contaminants and made available for use again is mainly to offset shortages. The main uses of reclaimed water are for nonpotable applications such as landscape and agricultural irrigation, toilet flushing, industrial process water, power plant cooling, wetlands, and groundwater. Another purpose is to provide options for the handling of wastewater.

Okun's (2005) and Asano et al.'s (2007) reviews are good starting points to study the evolution of reclaimed-water systems. Also, a set of "Guidelines for Water Reuse" was initiated in the 1980s, and it contains numerous examples (USEPA and U.S. Agency for International Development, 2004). AWWA's (2009) manual on distribution of reclaimed water explains the purposes of dual systems as for distribution of nonpotable and potable water in parallel.

By the 1980s, it was clear that the public did not want direct potable reuse, but indirect reuse was happening, and wastewater could also be reclaimed for nonpotable uses. This led to a continuing increase in the mileage of transmission and distribution systems for reclaimed wastewater. It is, of course, still possible that reclaimed water will be used for potable purposes in the future.

The distinction between the current situation and the ideal of a future dual water system was explained in a WaterRF project about conventional and unconventional approaches to water service provision (Raucher et al., 2004). In addition to reviewing the current status of reclaimed water distribution, the researchers explained how dual systems might evolve in the future and how a set of institutional and regulatory considerations must be faced. These include: acceptance by the public, utilities, and regulators; ownership and distribution rights; public education; and risk management of cross-connections and other code issues. They also explained the need for cost-effectiveness studies and to probe the infrastructure changes needed to implement dual systems. Finally, the team in this study wrote: "[T]he team struggled to obtain good comparative information with which to determine how much more it cost to develop dual systems.… Additional empirical investigation is necessary of the costs and benefits of specific reuse applications and experiences."

Wastewater Statistics

Statistics on wastewater systems are more difficult to obtain than for water systems. However, in its Clean Watersheds Needs Survey (CWNS), USEPA (2010b) maintains a count of publicly owned treatment works (POTWs) and a count of sewer collection systems. The count of POTWs is steady at around 15,000 facilities, but the numbers depend on how they are presented. The CWNS is an assessment of the capital needs to meet the water quality goals of the Clean Water Act and is published every four years with data on: publicly owned wastewater collection and treatment facilities; stormwater and combined sewer overflows (CSOs) control facilities; nonpoint source (NPS) pollution control projects; and decentralized wastewater management.

The most recent edition of the CWNS from 2008 is the 15th survey and shows total wastewater and stormwater needs at $298 billion. This includes $192 billion for wastewater treatment plants, pipe repairs, and buying and installing new pipes; $64 billion for combined sewer overflow correction; and $42 billion for stormwater management. In addition to the $298 billion in wastewater and stormwater needs, needs for nonpoint source pollution prevention and decentralized wastewater (septic) systems are $23 billion and $24 billion, respectively.

The CWNS reports show that needs are increasing, but if the investment targets are met for wastewater treatment, the number of nondischarging facilities and facilities that provide secondary or advanced treatment is projected to increase from 14,625 to 15,451 by 2028. The population served by

those facilities will increase, and by 2028, some 15,618 facilities will serve a future population of 284.2 million people, or 79% of the U.S. population. By 2028 the population will be about 360 million, and some 75 million will remain unconnected to networks.

The CWNS is organized by the following categories, which provide a way to classify wastewater infrastructure:

- I: Secondary wastewater treatment
- II: Advanced wastewater treatment
- III-A: Infiltration/inflow (II) correction
- III-B: Sewer replacement/rehabilitation
- IV-A: New collector sewers and appurtenances
- IV-B: New interceptor sewers and appurtenances
- V: Combined sewer overflow (CSO) correction
- VI: Stormwater management programs
- VI-A: Stormwater conveyance infrastructure
- VI-B: Stormwater treatment systems
- VI-C: Green infrastructure
- VI-D: General stormwater management
- VII: Nonpoint source (NPS) control—VII-A to -M—NPS control: Agriculture (cropland), Agriculture (animals), Silviculture, Groundwater protection, Marinas, Resource extraction, Brownfields, Storage tanks, Sanitary landfills, Hydromodification, Other estuary management activities
- X: Recycled water distribution
- XII: Decentralized wastewater treatment systems

USEPA also reports treatment facilities by flow range. Table 2.5 illustrates the large numbers of plants with small capacities, compared to the smaller number of larger plants, such as the one mentioned previously in King County.

Wastewater collection may be separated from treatment operations and operated by separate management units. USEPA reported that in 2008, some 19,739 collection systems were in operation. The total of treatment facilities and collection systems is of the same order of magnitude as the number of municipalities and special districts providing wastewater service.

If stormwater systems are connected to sewer systems, the result is a combined sewer. In 2008, there were 767 of these combined sewer systems that reported investment needs to USEPA. Most are in nine states (Indiana, Ohio, Pennsylvania, Illinois, New York, West Virginia, Michigan, Maine, and New Jersey) (USEPA, 2010b).

TABLE 2.5

Number of Wastewater Treatment Facilities in 2008 by Flow Range

Flow Range, mgd (cubic meters per day)	No. of Facilities
0.000 to 0.100 (0 to 380)	5,703
0.101 to 1.000 (380 to 3,800)	5,863
1.001 to 10.000 (3,800 to 38,000)	2,690
10.001 to 100.000 (38,000 to 380,000)	480
100.001 and greater (380,000 and greater)	38
Other[a]	6

Source: U.S. Environmental Protection Agency. 2008. Clean Watersheds Needs Survey 2008: Report to Congress. EPA-832-R-10-002. http://water.epa.gov/scitech/datait/databases/cwns/upload/cwns2008rtc.pdf March 4, 2012.

[a] Flow data not available for these facilities

On-site systems are available for individual homes and clusters of homes. Components include septic tanks, grease interceptor tanks, Imhoff tanks, disposal fields, disposal beds and pits, intermittent sand filters, recirculating granular medium filters, shallow trench disposal fields filled with sand and dosed with pressure sewers, mound systems, complete recycle units, and graywater systems. Sludge from wastewater treatment plants requires further processing. Operations include pumping, grinding, degritting, thickening, stabilization, conditioning, disinfection, dewatering, drying, thermal reduction, and ultimate disposal (Tchobanoglous, Burton, and Stensel, 2003).

Management Structures

Wastewater customers are generally the same as for water supply, but some businesses (such as large complexes, food and beverage facilities, hospitals and medical facilities, schools, or performance venues) may have unique wastewater service needs. Industrial wastewater systems also are a large and complex category, including centralized and stand-alone systems. On-site systems and package plants are used frequently in rural areas.

Some wastewater systems serving the public are connected to networks, but others are like the Transient and Non-Transient Non-Community Water Systems in the water supply sector. These might serve factories, schools, campgrounds, stores, rest stops, gas stations, and other facilities with septic tanks or package units. Manufacturing and process industries connected to networks are normally subjected to pretreatment regulations. Some have their own discharge permits.

Like water supply, management of wastewater is mainly centered in city departments, including municipal utilities. Some special-purpose districts also offer wastewater collection and/or treatment, including those that provide regional wastewater treatment, such as Denver's Metro Wastewater Reclamation District. Few private wastewater companies exist in the United States, but some of the larger private water companies will also take on wastewater operations. New privatization efforts focus mainly on contract operations, where a number of firms have subsidiaries to offer this service.

Interest Groups

The largest wastewater interest group is the Water Environment Federation (WEF), which represents interests ranging from operators and wastewater managers, to design engineers, to government officials, to financiers and equipment manufacturers. The Association of State and Interstate Water Pollution Control Administrators (ASIWPCA) represents state water regulators and interstate management officials. The National Association of Clean Water Agencies (NACWA, formerly the Association of Metropolitan Sewerage Agencies) represents some of the largest wastewater agencies. The American Public Works Association (APWA) also represents wastewater agencies.

Trends and Issues in Wastewater Systems

Wastewater management issues for point sources focus on subjects covered in the Clean Water Act. Nonpoint source policy is also governed by the CWA, but it involves issues of land-use policy as well as utility and industrial wastewater issues. Policy issues that recur are

- *Reforming the Clean Water Act*: It provides a great deal of authority and its parts require continual evaluation.
- *Costs of wastewater treatment*: As wastewater plants built with federal subsidies age, greater capital costs will pass along to customers, and rates will inevitably rise.
- *Industrial pollution control*: In areas where costs affect industrial competitiveness, clean water policy will come under continuing scrutiny.
- *New sources of pollution*: Pharmaceuticals in wastewater and new toxic materials will continue to challenge wastewater managers.
- *Watershed management*: Point source control alone will not provide a full response to water quality issues. Issues such as the Total Maximum Daily Load (TMDL) program for diffuse sources of pollution, wet weather water quality, and stormwater regulation will continue to confront cities and utilities.

- *Wastewater workforce renewal*: Wastewater utilities face the same issues as water supply in maintaining a vibrant workforce.
- *Security issues in the wastewater industry*: Some of the security issues that concern water supply utilities also confront wastewater utilities.

Stormwater Infrastructure Systems

Configuration and Functions of Stormwater Systems

Stormwater services (Figure 2.13) require minor and major stormwater systems. The minor system is similar to a wastewater collection system in its use of gravity pipes to drain water from points of generation to points of disposal. It also involves gutters and various other conveyance forms and appurtenances, such as street grates, small ditches, culverts, and detention ponds. Major systems consist of large pipes and waterways of different types. In contrast to wastewater systems where the water comes from fixed locations of water use, stormwater is generated at diffuse points of land and building surfaces.

Given that stormwater systems involve distinct functions for minor drainage and major flood control, they are sometimes named "stormwater and flood control" or "urban drainage and flood control" systems. The minor system may also be called the "storm drainage system" or the "initial" or "convenience" system. As it is not practical to construct piped stormwater

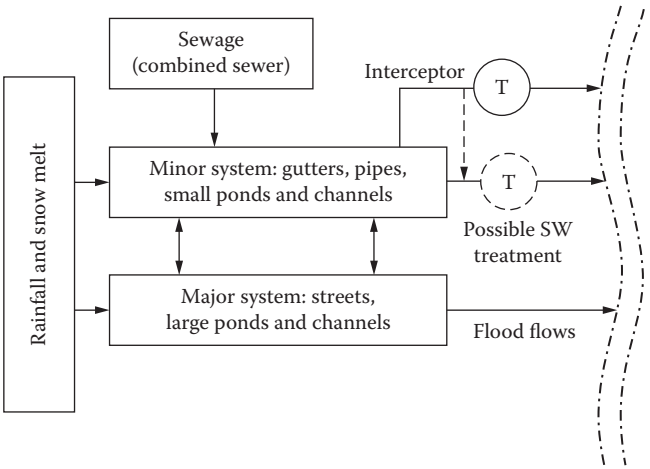

FIGURE 2.13
Stormwater system.

systems to handle the largest flows, the minor and major subsystems rely on different components.

Even though the minor system contains small facilities, it may require large pipes at downstream points. Figure 2.14 shows large pipe waiting for installation in Fort Collins, Colorado, and Figure 2.15 shows this pipe at its outfall near a river, which occurs adjacent to a water quality control basin. These large components were installed after a devastating urban flood demonstrated how unprepared the city was.

Like the emergency spillway on a dam, the major system drains larger floods and rare events and should be designed with risks in mind. You might not notice the system because it consists of familiar streets, large open channels, creeks, and rivers. It might not be used for years, but it must be there when needed; otherwise buildings will be damaged. Major systems may include flood hazard areas zoned to restrict building.

Stormwater systems handle excess water and function only during precipitation events. Stormwater varies from relatively clean runoff from a grassy field to contaminated runoff from industrial sites. The excess waters vary greatly in volume and rate of flow because storms vary. Whereas a local street system might have an 8 in. (200 mm) sanitary sewer, the storm sewer might be 24 in. (600 mm) in diameter just to drain a small area.

Standards for stormwater systems are mostly set by local governments and are not as uniform as those for water supply and wastewater. Common local standards revolve around design storm return period, which is the most influential factor in system cost.

FIGURE 2.14
Pipe awaiting installation.

FIGURE 2.15
Stormwater pipe near outfall.

For minor systems the design storm varies in the range of 2 to 25 years, with common recommendations being 2 years in residential areas and 5 to 25 years for commercial zones, where less disruption due to flooding can be tolerated. For example, a 5-year design might be implemented with a rule that storm drainage could be carried in a street gutter until the quantity just reached the top of a curb, and then an underground pipe would be required. Larger pipes would be required as you moved downstream in the watershed.

The major systems are generally planned for the 100-year event, under the influence of the Flood Insurance Act, although this standard is arbitrary. Gilbert White, who was a pioneer of U.S. flood policy, related to the author that this standard was implemented by government officials to provide a simple approach, and its effectiveness should be reviewed (see Chapter 11).

Combined sewer systems (CSS) are similar to minor stormwater systems but also contain connector, regulator, and treatment facilities, which deal with the sanitary sewer component. CSS normally deliver dry-weather flow to the treatment plant via interceptor sewers. If the capacity of the interceptor or the treatment plant is exceeded, overflows may occur.

Several professional associations have been active in research and education, but not in stormwater standard setting. The U.S. Federal Emergency Management Agency (FEMA) has been active in the national flood insurance program, and the U.S. Federal Highway Administration (FHWA) is active in stormwater research and practice because it is so important to highways.

Federal housing agencies also have influence in stormwater management, and USEPA has become active in stormwater quality regulation.

Stormwater Needs

Estimating stormwater needs is more difficult than for water supply or wastewater because of the multiple public works categories represented by the systems for drainage, flood control, and water quality. The National Council on Public Works Improvement sought to study the needs during the 1980s when they prepared national estimates of infrastructure needs, but they were not able to make credible estimates. USEPA includes stormwater quality needs as part of the CWNS, but the needs are for permitted facilities and do not represent all stormwater needs. Even the stormwater quality needs are underreported, according to USEPA.

An estimate of national stormwater needs for local drainage would be so dependent on local standards and subjective that it would not be very meaningful (Grigg, 1984). In a report in 1984, a figure of $169 billion was listed by the Associated General Contractors for drainage and minor flood control. There is really no way to know these needs with any precision, but most communities would say they have unmet stormwater system needs and will attend to them when the finances are available and they become a priority. Experience would seem to show that stormwater needs for local drainage would be on the same order of magnitude as for wastewater collection systems, but this might be increased by needs in areas where inadequate drainage was installed during land development.

Stormwater Planning

A great deal of work has been done to develop principles for planning stormwater systems (American Society of Civil Engineers and Water Environment Federation, 1993). Some of the main concepts are

- Drainage is regional and does not respect boundaries between jurisdictions or properties. This means that intergovernmental cooperation is especially important. It also means that stormwater systems should be designed beginning at the outlet and working upstream.
- Storm drainage is a subsystem of the urban water system. This principle supports the need for an integrated approach to urban water management.
- Every urban area has two drainage systems. This was explained previously as including the minor and major systems.
- Runoff routing is a space allocation problem. This means that the excess water must go somewhere, so storage and conveyance should

both be used, and stormwater problems should not be transferred from one place to another.

- Urban drainage should be multipurpose and multimeans. This principle underscores the fact that stormwater systems perform multiple functions and should be coordinated with other agencies. One of their functions is to protect natural drainage systems.
- After development, stormwater flows should remain at predevelopment conditions, and pollutant loadings should be reduced.
- Stormwater systems should receive regular maintenance.

Planning for stormwater systems requires monitoring data—topographic, surveys, soils, and boundary data; hydrologic and hydraulic data—as well as regulatory and financial considerations. Options include nonstructural and structural systems. Structural systems can include natural and built systems, which can include major drainageways, streets, storm sewers, inlets, intersections, flow control devices, trash racks, detention, and water quality mitigation structures. Evaluation of stormwater systems recognizes that they provide drainage, flood control, and water quality benefits.

Drainage of minor stormwaters and control of larger flood flows comprises the water-quantity side of stormwater. These services are distinguished from one another by the benefits provided: drainage provides convenience, cleansing, and safety from minor storm flows, and flood control provides damage prevention and life safety.

Water quality control is provided by stormwater systems in a number of ways. Separate systems, which include open-channel and closed-conduit components, can include facilities such as detention ponds and settling tanks to control contamination. Stormwater programs can also provide benefits from erosion and sedimentation control and beautification of urban stream environments. Combined sewer systems provide drainage services and also handle dry-weather sewage flows.

Thus, the benefits of stormwater systems include: reduced flood damage and risk to life; land value enhancement; reduced traffic delays and business and cleanup losses; reduced relief costs; increased recreation opportunities; less inconvenience; greater security; reduced health hazards; and improved aesthetics. Some significant stormwater benefits are intangible and cannot be quantified. Also, benefits that can be quantified, mostly prevention of flood damages, are not very visible, except right after flood events. As a result, decisions are often not based on straightforward economic or financial analysis.

Stormwater systems are normally planned through "risk-based design." When risks are high, there may be a need for design levels to anticipate rare events, and the concept of the "probable maximum flood" (PMP), caused by the "probable maximum precipitation," has been accepted for this level.

Management Structure

Stormwater management is mostly by local governments, usually through a drainage section in the public works department or similar organizational location. Some communities may locate drainage in the streets department. County governments also are involved with drainage and flood control services as a result of suburbanization, zoning, and roles in managing county roads.

Some local governments have created stormwater "utilities," seeking to convert stormwater into an enterprise, rather than a tax-supported service, and overcome the neglect that has plagued some stormwater systems. A stormwater utility operates in much the same way as a water or wastewater utility. The Water Environment Federation (1994) published a report to document case studies of stormwater utilities that solved the problems associated with user-fee funding. The report explains key elements of rate setting, management, and program planning.

Multijurisdictional stormwater management, such as by the Urban Drainage and Flood Control District (UDFCD) of Denver, has proved useful in jurisdictions with area-wide problems. The UDFCD has planning, development, and O&M programs, and has built and operated a number of regional systems, as well as helped in standard setting, technical guidance, and financial assistance for planning and construction.

State government roles have been limited to standard setting and technical assistance. A few state governments, notably Pennsylvania and Maryland, have passed stormwater legislation.

Until the stormwater permit program was developed by USEPA, the federal government did not pay much attention to stormwater. Flood policy and programs have been of greater concern to it, mainly because of the interstate nature of large floods and the National Flood Insurance Program (NFIP). A few exceptions were the U.S. Housing and Development Department (USHUD) grants of the 1950s and 1960s and some limited federal research about stormwater.

Regulatory measures for stormwater have increased in recent years. Whereas a few decades ago, a stormwater system was considered part of the street system, to be maintained and cleaned, but otherwise left alone, stormwater now attracts more attention.

Some states require local governments to prepare stormwater plans. Pennsylvania, for example, requires counties to develop plans for designated watersheds. Maryland and North Carolina have regulatory programs for erosion control. Pennsylvania's legislation includes the following elements (StormwaterPA, 2011):

1. Survey of existing runoff characteristics
2. Survey of existing obstructions
3. Assessment of projected and alternative land development patterns and the potential impact of runoff quantity and quality

4. Analysis of present and projected development in flood hazard areas and its sensitivity to damages from future flooding
5. Survey of existing damage problems and proposed solutions
6. Review of existing and proposed stormwater collection systems and their impacts
7. Assessment of alternative runoff control techniques
8. Identification of existing and proposed flood control projects
9. Designation of areas to be served by stormwater facilities within 10 years, and who will construct and operate the facilities
10. Identification of the floodplains within the watersheds
11. Development of criteria and standards
12. Establishment of priorities for implementation of action within each plan
13. Setting forth provisions for periodically reviewing and updating the plan

New Jersey also requires plans, but these are to be prepared by municipalities rather than counties. However, counties are in a review role.

Unlike for water and wastewater, no single interest group dominates stormwater. ASCE has given attention to research, mainly through its Urban Water Resources Research Council. The American Public Works Association also undertook investigations, and their report "Urban Stormwater Management" is a useful older reference. Flood management agencies with common interests formed the National Association of Flood and Stormwater Management Agencies (NAFSMA).

Trends and Issues in Stormwater Systems

Stormwater management offers different challenges than water supply and wastewater. Organizing a comprehensive approach requires attention to minor and major systems and to water quality. This involves land-use issues such as best management practices and zoning. Determining how to pay for systems is a challenge, since the "user pays" principle does not apply directly. Setting up master plans and connecting stormwater to watershed planning are difficult, and stormwater quality has led to regulatory issues under the Clean Water Act that continue to unfold in the industry (see Chapter 11).

In some communities, citizens may think the city spends too much on stormwater. This can arise if these citizens do not experience flooding and wonder why they must pay to protect others.

Another issue that is common in stormwater and flood programs is the objection of some citizens to floodplain management. They may be on the side of wanting to stop all floodplain regulation or on the opposite end, to remove all development from the floodplain.

Future Water Management Issues

The future seems certain to bring much change to water systems and services. Examining just a few of the "futures" articles shows many important trends (Grigg, 2011). Pressure on water and natural systems will intensify as global growth ratchets upward, including both population and rising standards of living. Although water systems of developed countries are mostly fixed, access to new water supplies there and in developing nations will continue to tighten, and water supplies will be more expensive. There will be tighter controls on municipal and industrial discharges, and wastewater systems will use more monitoring and reporting and have greater information requirements. As industrialization becomes more diversified and complex, new water quality challenges will continue to occur. So far, they have been manageable in the United States, but contaminants of emerging concern are worrisome, and many chemicals are found in surface and groundwater supplies.

Environmental consciousness continues to evolve and is spreading from developed countries to the emerging nations that enjoy freedom of the press and the right to express opinions. The emphasis on green infrastructure will increase. While arguments about climate change continue, the water industry has mostly accepted it but will not make large investments that are based on uncertain forecasts. The need for energy supplies for a growing world will add to the pressure on water systems, as explained through the water-energy nexus.

Several forces combine to cause the cost of water to continue to rise, and it seems that it will rise faster than inflation for a long time to come. Population growth in the United States will increase the demand for water—the result of more development of land and urban spaces, urban farming, and golf course expansion—but overall water use will remain flat due to conservation. The issue of water infrastructure is perhaps the most difficult to face, both because of the high cost and the difficulty in providing it in the face of obstacles such as environmental opposition, densely populated cities, and disorganized governance systems.

Technology will be an important driver for the water supply industry, led by information technologies for data collection and management, meter reading, and control systems. Security concerns are driven by the fact that water is interdependent with other networked infrastructure and service sectors.

Given rising populations and standards of living as well as the current extent of hunger in the world, the use of water for agriculture must grow, even as traditional irrigation systems fall from favor.

Organizational change in the water industry has been dramatic, and it continues. One result has been the unbundling of what were integrated water services into components. Outsourcing and privatization will increase, and industry consolidation will continue.

No solutions are in sight for the tough political issues regarding regional competition for water, such as in Georgia, where Atlanta has been trying to secure its future water supply for more than 20 years. Similar scenarios play out in other parts of the United States, where scarcity may exacerbate future conflicts, such as in the Colorado River Basin. China is trying to solve similar problems by mandating projects such as the south-to-north water transfer scheme, but such solutions are unlikely in the United States.

The media coverage of the "world water crisis" will continue, as it has for nearly four decades. This can translate into business growth in some areas—such as building infrastructure—but can thwart business ventures in other areas, such as investing in water rights. However, the water industry has many political and social aspects that can override business principles.

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3

Asset Management for Urban Water Systems

As cities developed over the past decades, their water assets were often out of sight and out of mind, known only to a few utility workers who were involved in construction or maintenance. The systems expanded and their infrastructures became mixtures of the new and the old. Then, management became more challenging as regulations tightened, workers retired, and new managers inherited vast underground systems of unknown condition and attributes. Now, the replacement value of water, wastewater, and stormwater infrastructure in the United States is in the range of $2 trillion, and a large backlog of investment needs must be met if required service levels are to be maintained. Further details of the investment needs are presented in Chapter 2.

The systems are capital intensive and require effective management tools to care for their infrastructure on a life-cycle basis. Managing these legacy systems can be a challenge, but computer-based tools and methods have created the potential to manage them effectively by applying data-centered management to tasks such as condition assessment, maintenance scheduling, and replacement planning. The tools fit into a management framework known as asset management. This is different from managing assets in the form of money and investments, and it relates to fixed assets. It might even be called *fixed-asset management* to be perfectly clear, but that term seems awkward.

An asset management program creates a coordinated approach to obtain the best return from investments in the infrastructure required for water services. The term *asset management* is synonymous with terms such as *infrastructure management*, *capital management*, and *life-cycle management*, and it is widely used to explain how the tools for life-cycle management can be coordinated.

This chapter begins by explaining the theories of asset management, and it presents guidelines for organizing and guiding an organization-wide asset management program. Because asset management is a cross-cutting responsibility in organizations, the chapter is written for engineers and managers with responsibility for it, regardless of their titles. A utility may or may not assign the title of director of asset management to someone, and responsibilities for it are normally dispersed throughout organizations.

A large international body of knowledge about asset management has been assembled in the last decade. For example, the Association of Local Government Engineering New Zealand, Inc., and the Institute of Public

Works Engineering of Australia have published an *International Infrastructure Management Manual* (2006). It has been well received, and a new edition appeared in 2011. The manual applies to all infrastructure systems, and this chapter explains how the universal concepts that it presents apply to water, wastewater, and stormwater systems.

Concept of Asset Management

As the concept of asset management has gained traction, a number of government agencies and industry associations have developed publications about it. The U.S. Environmental Protection Agency (USEPA, 2011) promotes asset management, and its guidelines and resources are explained in this chapter. The water supply and wastewater industries themselves have also outlined aspects of asset management, and several of their projects and programs are explained in this chapter (Water Environment Research Foundation, 2011; Kirmeyer et al., 2008).

A key to understanding asset management is to use common terminology and to clarify that the differences between the concepts of asset management, infrastructure management, and life-cycle management are only slight. Mainly, terms like these are used by different disciplines and agencies according to their own preferences. For example, an engineer, budget officer, and accountant might use different phrases, but their goals would be mostly the same. In any event, advances in information technology (IT) and organizational development are breaking down differences in vocabulary. Rather than something entirely new, asset management is an assembly of existing management methods for capital assets, with an overlay of new computer-based tools.

So the main thing that is new about asset management is how, as a concept, it draws together existing management methods. Another new development is the emphasis on using fixed assets better, which results from the buildup of investment needs and lack of funds for new investment. The explanations of how the methods fit together into the asset management framework is also somewhat new, having emerged in about the last decade or so. Finally, and moving fastest, have been the innovations in applications of databases and geographic information systems (GIS) to manage fixed assets of all kinds. The new methods are used within asset management systems for capital improvement planning and programming, inventory and condition assessment, renewal planning, and related capital and maintenance management tasks.

While there is no standard way to organize the tasks to create an asset management system, the concepts are widely understood. As is made clear by the *International Infrastructure Management Manual*, asset management for

infrastructure includes everything that is done to derive the most value from a physical or fixed asset across its life cycle.

When the first edition of this book was prepared during 2001, definitions of asset management were just emerging. The first edition of the *International Infrastructure Management Manual* had not yet appeared, although AWWA had published *Water Utility Infrastructure Management*, a book with several chapters about asset management, including Australia's new concepts that emerged in the *International Infrastructure Management Manual* (Hughes, 2002).

The initial impetus for the development of asset management methods came from firms seeking new markets for products and services. For example, Harlow and Armstrong (2001) wrote that asset management is "a structured program to optimize the life-cycle value of your physical assets" and that for infrastructure, it "may be known as infrastructure management." Brown and Caldwell (2001) wrote that asset management "is a structured program to minimize the costs of asset ownership while maintaining required service levels and sustaining infrastructure." They went on to explain that it focused on: minimizing costs of asset ownership with a life-cycle management approach; maintaining required service levels to increase reliability by giving close attention to asset condition; and sustaining infrastructure through to maintenance or short-term activities and refurbishment and replacement programs for the long term. These explanations remain valid 10 years later and are concepts for firming up life-cycle management.

For a wastewater inventory, Brown and Caldwell (2001) developed an Asset Information and Management System that converts isolated knowledge assets into enterprise-wide solutions. They applied it to create the Orange County (California) Sanitation District's Facility Atlas, which resulted from a 1994 needs assessment. The assessment revealed difficulty in compiling information from 50 years of operation and some 300 construction projects at two treatment plants and 650 miles of trunk sewers. The Facility Atlas is an electronic map of facilities that combines GIS, databases, and a document management system. In the system, facility objects are identified as process piping, equipment, surface features, and structures. Facility objects can be studied by using the database to get information on attributes such as construction material and project contract data.

Software firms viewed the systems more in terms of how information would be handled through manipulation of databases. For example, CartéGraph Systems (Everhart, 2000) wrote that "asset management…is a combination of tools and procedures to enhance the inventory, management and maintenance responsibilities of a public works organization" and that "public works asset management can most commonly be described as the daily practice of collecting, maintaining and analyzing this asset data." This emphasis continues, and the *International Infrastructure Management Manual* has a chapter on data management and explanations of the IT architecture of infrastructure organizations.

Australia and New Zealand were leaders in developing asset management systems, and Champion (2001) has described their new manual and new capital accounting standard AAS27 (similar to GASB 34, a statement of the Government Accounting Standards Board, which is described later in this chapter). He wrote that asset management has the goal to "meet a required level of service in the most cost-effective way through the management of assets to provide for present and future customers." He listed its elements as: a life-cycle approach; cost-effective, long-term management strategies; a defined level of service and performance monitoring; managing risk of asset failures; sustainable use of physical resources; and continuous improvement in asset management practices. Those elements have remained constant.

U.S. utilities started to embrace asset management, and Paralez and Muto (2002) quoted the Seattle Public Utilities definition: Asset management is a

> way of doing business that maximizes the public's return on their investment in utility infrastructure by implementing utility-wide strategies that emphasize reliability in the assets and processes so that the desired levels of service are provided to our customers in the most cost effective manner.

These definitions remain valid and explain how asset management (a) came to describe existing management techniques aimed at optimizing the return from investment in physical capital and (b) show that the asset management method uses information technology to integrate and link a number of existing techniques.

Although definitions and concepts for asset management were mostly in place a decade ago, new methods, tools, and concepts continue to emerge. A good place to catalog those relating to water systems has been created by the Water Environment Research Foundation (WERF, 2011), which has sponsored a software platform entitled "Water and Wastewater Sustainable Infrastructure Management Program Learning Environment" or the SIMPLE platform. Access to the tools is limited to subscribers to WERF and the Water Research Foundation, but their concepts and definitions have broad application.

The SIMPLE definition of asset management as derived from the IIMM, is a systematic approach to the procurement, maintenance, operation, rehabilitation, and disposal of one or more assets that draws from the earlier work behind the *International Infrastructure Management Manual*. It integrates the utilization of assets and their performance with the business requirements of asset owners or users. Asset management is all about the continuous alignment of asset performance to meet service delivery outputs to deliver the desired outcomes. The definition is attributed to an Australian "ASSETS" Project Development Team, and the information is consistent with the *International Infrastructure Management Manual*.

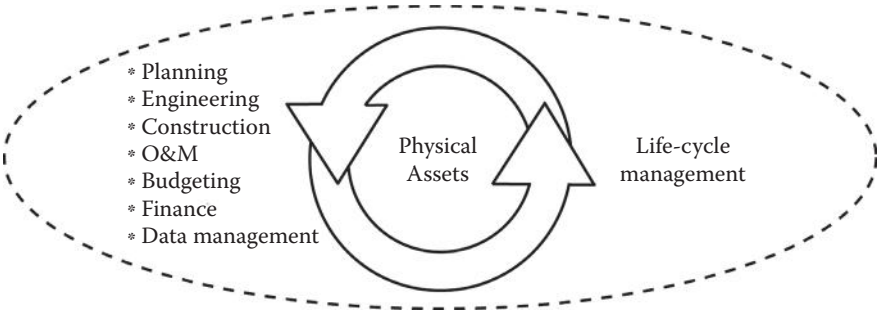

FIGURE 3.1
Data-centered management of physical assets.

SIMPLE goes on to explain that asset management is

> A management paradigm and a body of management practices that is applied to the entire portfolio of infrastructure assets at all levels of the organization which seeks to minimize the total cost of acquiring, operating, maintaining and renewing the organization's assets within an environment of limited resources while continuously delivering the service levels customers desire and regulators require at an acceptable level of business risk to the organization.

The definitions tend to be long and to incorporate the nuances and details of asset management. Recognizing this, in the first edition of this book, I offered a short definition, which still seems valid and useful: "Asset management for infrastructure is an information-based process used for life-cycle facility management across organizations." Its features include: viewing infrastructure components and systems as assets; life-cycle management; management across organizations or enterprise-wide use of asset management; and use of information-based processes and tools. You could wrap these concepts into this short phrase: IT-based enterprise asset management.

Putting the concepts together leads to the illustration in Figure 3.1, which shows data-centered life-cycle management of physical assets with the activities shown.

Organizing Asset Management Programs

Although the principles and guidelines of asset management are clear, the programs can be organized in different ways. Drawing from the definitions and explanations, the following attributes show that an integrated asset management program should:

- Optimize life-cycle value of physical assets
- Maintain required service levels
- Manage asset condition
- Monitor performance
- Manage risk of asset failures
- Seek continuous improvement in use of assets

How should an organization configure its asset management activities to achieve these goals? While the configuration will depend on the organization, the broad outlines will be similar and can be described by the processes and functional areas shown in Figure 3.2. The figure shows an organizational form with the activities allocated to sections for planning, engineering, finance, and information technology. Sometimes planning is done within engineering, and sometimes it might be done in a separate department. In some cases the GIS might be managed within engineering, and in other cases it might be an organization-wide program. So, there are different ways to organize, but the core functions remain the same.

In any case, the heart of the system will be the information base on which it depends, including the inventory, the condition assessment, and the financial records. That is the heart of the data-centered concept shown in Figure 3.1. Chapter 10 explains concepts of the databases in more detail. The main database is sometimes called the asset register, which uses inventory

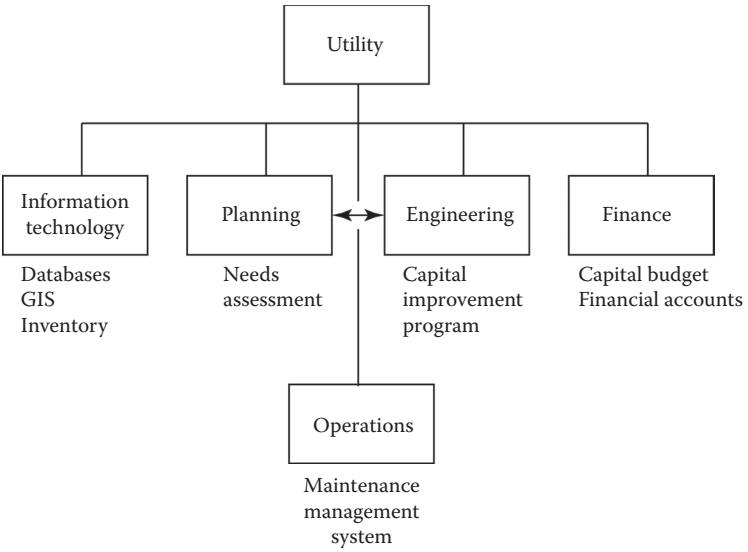

FIGURE 3.2
Asset management tasks across the utility organization.

TABLE 3.1

Linking of Functional Management Areas with Asset Management Activities

Functional Management Area	Asset Management Activity
Budget and finance	Capital budget and accounts
Planning	Needs assessment
Engineering and construction	Capital improvement program (CIP)
O&M	Maintenance management system (MMS)
Information systems	GIS, databases, inventory

information as the basis for scheduling maintenance and tracking condition, which determines the serviceability of the asset. The asset register is needed to rate condition and performance from best to worst to set priorities for replacement in the capital improvement program.

If inventory and condition assessment are functions of maintenance management (see Chapter 9), then asset management is a partnership between the financial, maintenance, information, planning, and engineering sections. Accounting and budgeting, maintenance management, and information management are ongoing activities, and planning and engineering deal with change in infrastructure renewal, replacement, and construction. Implementation of a software package might integrate these activities, as explained in Chapter 10.

In addition to the functional areas shown in Table 3.1, asset management should integrate efforts to manage capital on an organization-wide basis. Asset management links activities of organizations to minimize costs of ownership, maintain service levels, and sustain infrastructure. A data-centered asset-management system should link functional areas of the organization to work on asset management goals through planning, engineering and construction, budget and finance, operations and maintenance (O&M), and information systems. This is shown by the parallel lists in Table 3.1. On the left you see the regular functional departments of the utility. On the right are their main activities that support asset management. By coordinating the activities on the right, the organization has an asset management program.

Guidance from the International Infrastructure Management Manual

Guidance for assembling the asset management program is available from a number of sources, and the *International Infrastructure Management Manual* provides a comprehensive explanation of the overall process (Association of Local Government Engineering New Zealand, Inc., and Institute of Public Works Engineering of Australia, 2006). The manual uses the term *holistic asset management* to distinguish overall organizational activities from life-cycle asset management, which requires consideration of costs along the life cycle when decisions are made. The scope of activities extends from policy to

daily operation of facilities, and these include: planning strategies, creation/acquisition of assets, financial management, operations and maintenance, condition and performance monitoring, rehabilitation and replacement, rationalization (meaning to adjust inventory and operation to needs and resources), disposal, and audit and performance review.

The core system for asset management includes: risk and identification of key assets; asset registers with low level of detail of components; asset condition and performance data, hard for critical assets and less focused for noncritical assets; optimized decision making and simple benefit-cost analysis; and level-of-service analysis based on historical information. Advanced asset management would take the analysis to greater levels of detail of assets and use more sophisticated decision tools.

A written asset management plan should be part of a suite of plans to manage an organization but it should not be the governing plan. The manual includes a diagram that shows a nested approach to organizational planning similar to the concept in Figure 3.3, where the strategic plan drives more detailed plans, and the asset management plan is one of the sector or tactical plans used by the organization.

Drawing from concepts in the *International Infrastructure Management Manual*, a suggested outline for an asset management plan would include topics such as: services, customers, and standards; assets; demand planning; how services are managed; operational programs; management and

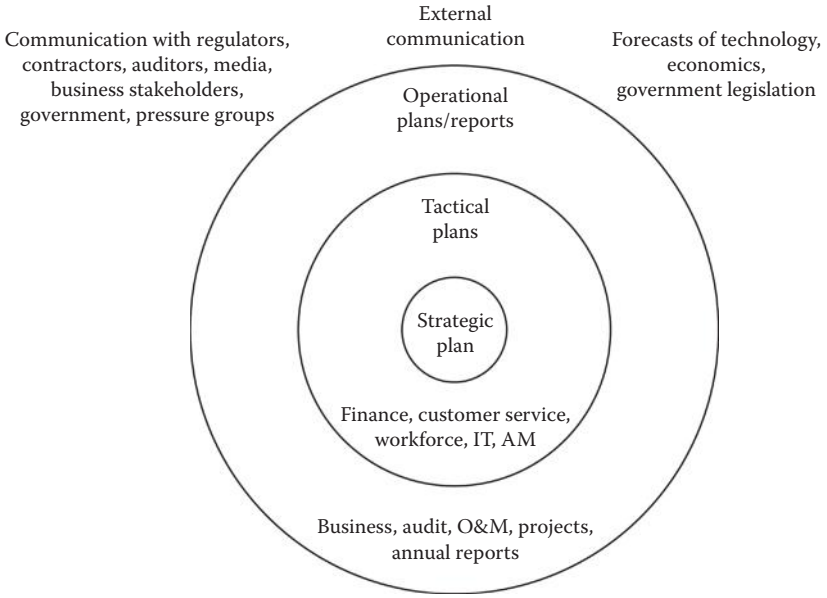

FIGURE 3.3
Asset management plan in the organizational planning system.

support processes; financial issues; and performance measurement. This range of topics seems to go beyond a narrow approach to asset management and extends into how well the assets are used, as well as how to care for them.

Asset Management Functions

Going back to Figure 3.2, which showed the organizational functions, the different parts of the asset management plan can be described. To facilitate the discussion, a position of asset management coordinator might be hypothesized to work among the sections of the organization. Normally, a position such as this would be assigned to planning or engineering rather than as a separate position in the organization. To see how the functions should work together, envision how a coordination mechanism like this can help with the shared tasks of asset management and in preparing the asset management plan and related plans, such as the CIP.

The order of discussion is coordination, planning, engineering and construction, O&M, financial management, risk management, and IT, but this does not imply a special priority, because all functions are important.

Coordination of Asset Management Functions

Success in asset management can be measured by the extent to which greater performance at lower cost can be derived from the organization's infrastructure. The performance depends on reliable delivery of services in a cost-effective way without experiencing adverse consequences from unexpected failures.

The first requirement to achieve good performance might be to prepare the asset management plan itself. In the last section the plan was shown to include parts to describe various organizational issues, and the asset management coordinator must go to the respective departments to find out what should be planned. This might involve coordination such as shown in Table 3.2.

Once the plan is prepared, the asset management coordinator should be involved with measuring outcomes and updating and improving the plan. Ideally, an annual report might be rendered that included a statement such as this hypothetical one:

> The organization's physical assets are valued at $xxx million, and during the past year they delivered improved service over the previous year that was indicated by (evidence of better service and fewer failures). Investments in renewal were $xxx, and improved condition assessment and repair methods have extended the life cycles of existing assets by xx%, representing a savings of $xxx for the city's utility and public works customers.

TABLE 3.2

Coordination of Asset Management Plan

Plan Section	Department Responsible
Services, customers, and standards	Planning
Assets	Engineering
Demand planning	Planning
How services are managed	Operations
Operational programs	Operations
Management and support processes	Administration
Financial issues	Finance
Performance measurement	Finance and budget

This hypothetical report is only partially complete and is missing data, but it illustrates how the organization is seeking to get more from its investments in assets by raising the management bar.

In addition to measuring asset performance and updating the plan, the coordinator might be assigned a role in continuous improvement. That is, should any part of the asset management program need strengthening, the coordinator can be an advocate and coach to help bring the improvement about.

Planning Section

While the list in Table 3.2 shows planning with definite functions that are focused on services, customers, standards, and demand planning, the fact is that planning is an organization-wide activity that is imbedded in other functions as well. For example, Chapter 4 explains planning in the context of the capital improvement program (CIP), which has interfaces with the engineering and financial departments. The asset management system should yield the facility information required for all phases of planning, from needs assessments through the stages from master planning to detailed facility plans. The planning section might be included within the engineering department or elsewhere, but it will be a key user of asset management information and might oversee some information management systems, such as the GIS.

Engineering and Construction

Chapter 5 explains common engineering functions, and several of these are providers of asset management information such as studies, investigations, and reports; surveys, maps, and the geo-database; capital improvement program records; consultant and contractor data; design drawings; cost data and estimates; construction contracts; construction and inspection reports; as-built drawings; and standards. Ideally, these information products should

be accessible to the asset management system. For example, as-built drawings from the engineering section could be accessed online by maintenance forces, and planners could pull up studies and investigations to provide data for needs estimates. In this sense, the asset management system could integrate the planning-engineering-maintenance cycles of infrastructure as well as the planning-financing-renewing cycles.

The engineering section has the key role in new construction management, and as new facilities are added, they should be added to the database and, when corrective actions are necessary, the standards and methods of new construction should be altered to achieve better system integrity. As an example, if a certain type of pipe material has proved less durable than others under the conditions in the area, the design part of the construction process should include requirements to either solve the problem or require a different material. Rehabilitation and replacement scheduling is also handled within engineering, and methods for handling them are explained in Chapter 9.

Operations and Maintenance (O&M)

To emphasize the importance of asset management, some argue that O&M should mean operations and *management*, instead of operations and maintenance. This argument is a recognition that the overall goal of operations is to obtain the best performance from all physical, human, and financial resources, while the goal of maintenance management is to care for assets to keep them in good condition to ensure maximum performance and longevity and the highest yield from investments. Asset management complements traditional O&M by reinforcing the life-cycle approach to facility management.

Effective operations can prolong the lives of assets. There is a link to workforce planning because incentives for operators are required. Some utilities have found that contract operations work better for asset management (Burrowes and Favre, 2001). Guidelines for operations management are explained in Chapter 7.

Maintenance management systems (MMS) are explained in Chapter 9. They provide a framework for preventive and corrective maintenance and for scheduling and recording the results of completed work. Maintenance management relies on inventories and condition assessments, which are core activities of asset management. Ideally, these are updated by the maintenance forces that provide the data for use by other sections, such as planning and finance. The data should be provided to the asset register, which will include operational procedures and maintenance requirements (see Chapter 10).

The ability of an asset to perform its mission depends on its condition, and condition assessment is a key part of the asset management program. How condition assessment is performed involves different approaches, which are explained in Chapter 9.

Financial Management

As shown in Figure 3.2, the financial section maintains the capital budget and the accounts, and the asset management system should be linked to them through the asset register. In an ideal world, the plans, programs, budgets, and current value of assets would be linked in a continuum through this database. In a practical sense, utilities are still working across the barriers that divide these different data elements.

As Chapter 6 describes, the focus in infrastructure financial management has been on accounting and reporting of operations, not on tracking and managing capital assets. In fact, accounting guidelines do not always provide effective means for reporting of infrastructure assets. This changed for general government assets during the late 1990s with a statement from the Government Accounting Standards Board (GASB), which sets standards for government reporting of financial accounts, including requirements for asset reporting. There were already requirements for reporting infrastructure assets if the organization is an enterprise.

The statement about fixed assets (GASB 34) is described in more detail in Chapter 6. Under GASB 34, financial reports must include the costs of asset ownership. In the past, this was not always required under the assumption that once public funds were sunk into physical assets, there was no reason to account for them. Once the assets were worn out, they would simply be replaced.

Risk Management

Risk management is an important part of an asset management program, but it might be embedded in other tasks. The key contribution of risk management is to identify the places where anything might go wrong and have unacceptable consequences. For loss of assets, the focus of risk management is on loss of key facilities or equipment during natural or human-made events. Risk management is discussed in Chapter 6 (financial risk), Chapter 8 (disasters), and Chapter 9 (failures). Of course, these are linked because the disasters can lead to failures that exacerbate financial problems.

Information Systems and Data Management

If you think of asset management systems as ways to apply knowledge to improved management of physical facilities, the need for effective information systems is apparent. Chapter 10 describes them more fully.

The close relationships between organizational form, function, and use of management information are still evolving. Before computers, organizations had more layers so that information could be passed down the chain to workers, but the information technology (IT) revolution has cut out middle managers who populated these layers. Now, information passes over networks and is more widely available, so organizations are flatter.

Organizations can function with fewer middle managers, but some management jobs have been replaced by IT jobs. The challenge with information systems is to use data to improve decisions and lead to better outcomes as opposed to creating more data that are not used effectively. The ideal is that data management systems enable workers to share information among functional departments. In a practical sense, obtaining enterprise-wide databases and GIS systems requires managers and workers to share information and authority, and this might generate resistance. Nevertheless, information technology drives change in organizations and offers advances in work processes that include mapping, inventory and facility information, maintenance scheduling, and work management systems, among others.

Asset Management for Water Systems

Everything written up to here about asset management applies to any fixed asset or infrastructure system. The methods could be used by a private company or a public agency, or they could even be used to manage facilities for a military unit. To focus on how they can be applied for water systems, it is necessary to be more specific.

To explain in clear terms what asset management means for a water department, the Fort Collins utility director wrote in the local newspaper that it includes a catalog of when replacements and repairs will be needed. This involves a record of the condition of pipes, valves, wires, and cables (they also manage the electric system), which is prepared at each maintenance project. Another feature is the locations and details of water system components to keep diagrams, maps, and drawings updated to supplement files and historical documents. The application of these features is to identify replacement and maintenance expenses in advance, set priorities, prevent failures, and avoid sharp rate increases (Janonis, 2011).

This is a good overview of the asset management system in general terms, but more specifics are needed to plan an actual system. Actually, only a few core activities are involved. USEPA (2008) summarized them in a "best practices guide," which was presented in a basic form for use by small systems but uses concepts that apply to systems of all sizes.

The USEPA best practices guide provides steps to organize your asset management program from the ground up. As seen in Figure 3.4, it begins with a question about the current state of the assets and proceeds through a series of questions that end up with the long-term funding plan. These will lack the words *water* or *wastewater* or *stormwater*, and they remain generic activities.

The process begins with very basic questions that include: What do I own? Where is it? What is its condition? What is its useful life? What is its value? While these are basic questions, they deal with core concepts of life-cycle

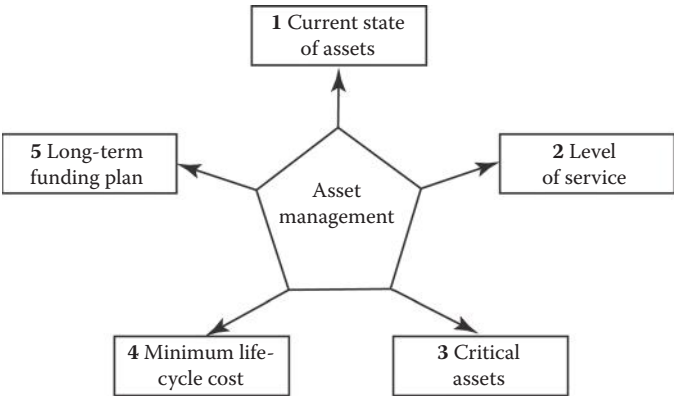

FIGURE 3.4
Asset management steps from a USEPA (2008) best practices guide.

management that include inventory, location, condition, planning horizon, and replacement value.

Best practices required to answer these questions include: preparing an asset inventory and system map; developing a condition assessment and rating system; assessing remaining useful life by consulting projected-useful-life tables or decay curves; and determining asset values and replacement costs.

Asset management is not an automatic thing without flexibility; rather, it requires you to determine the sustainable level of service you can and should provide and can afford. You cannot determine this in a vacuum; it depends on customer demand, governance, and regulatory requirements. To evaluate this level, you ask questions such as: What levels of service do my stakeholders and customers demand? What do the regulators require? What is my actual performance? What are the physical capabilities of my assets?

Answering these questions requires best practices that include: analyzing current and anticipated customer demand and satisfaction with the system; understanding current and anticipated regulatory requirements; writing and communicating to the public a level-of-service agreement that describes your system's performance targets; and using standards to track system performance over time. The level-of-service agreement will be the utility's action to inform customers about its services and to be transparent about the costs and benefits of providing them.

Asset management deals with the risk of failure of infrastructure assets and requires the utility to manage the consequences of failure. The asset management program requires the identification of critical assets with high risks and major consequences of failure. Assets should be ranked by their level of criticality by asking questions such as: How can assets fail? How do they fail? What are the likelihoods (probabilities) and consequences of asset failure? What does it cost to repair the asset? What are the economic, social, and environmental costs of failure?

The best practices for this phase of asset management include: listing assets by criticality to system operations; conducting failure analyses; determining the probability of failure and listing assets by failure type; analyzing risk and consequences; and reviewing and updating any vulnerability assessment available.

Best practices for asset management focus on budgeting for O&M and capital investments. Considerations include developing alternative strategies for managing O&M, personnel, and capital budget accounts; evaluating the costs of rehabilitation, repair, and replacement for critical assets; moving from reactive maintenance to predictive maintenance; knowing the costs and benefits of rehabilitation versus replacement; evaluating life-cycle costs; deploying resources based on asset conditions; and analyzing the causes of asset failure to develop specific response plans.

Financial decisions are required for asset management that lead to a sound long-term funding strategy that recognizes the costs and revenues of the water systems. The relevant questions are concerned with effective financial planning (also see Chapter 6) and include: Do we have enough funding to maintain our assets for our required level of service? Is our rate structure sustainable for our system's long-term needs? How should we revise the rate structure? Should we fund a dedicated reserve from current revenues? How should we finance asset rehabilitation, repair, and replacement?

Implementation of Asset Management for Water Systems

Applying this information to water assets, we can create a list of program elements, each of which are covered in the chapters of this book. The specifics of an asset management system for water, wastewater, and stormwater would then be found in how you apply these generic management activities to the specific cases of assets such as buried water pipes or treatment plants or any other infrastructure component that is unique to a water system.

The following list shows the chapters where these elements of the water asset management system will be found:

- Optimizing the life-cycle value of physical assets (Chapter 5)
- Promoting continuous improvement in assets (Chapter 5)
- Establishing a capital improvement program (Chapter 4)
- Developing a financial plan (Chapter 6)
- Assessing asset condition (Chapters 7 and 9)
- Monitoring performance and service levels (Chapter 7)
- Managing the risk of asset failures (Chapter 8)
- Instituting a data management system (inventory, location, attributes) (Chapter 10)
- Developing O&M strategies (Chapters 7 and 9)

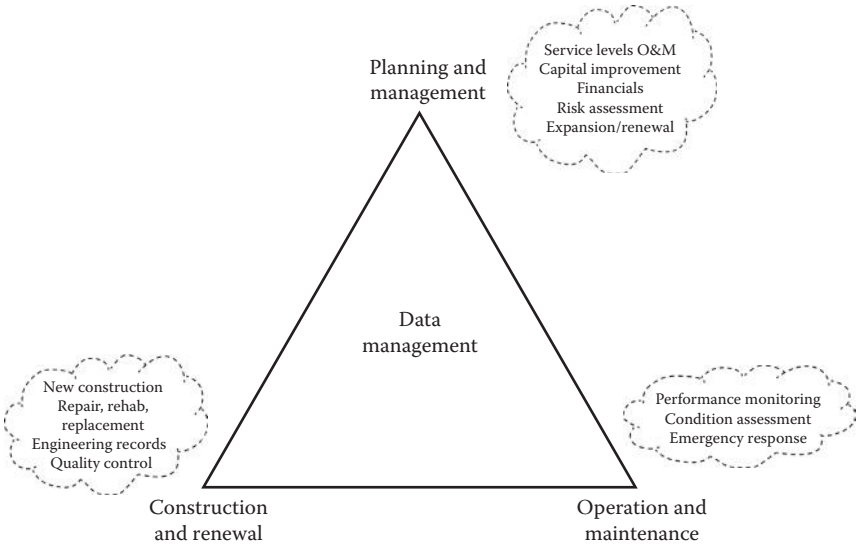

FIGURE 3.5
Asset management triangle.

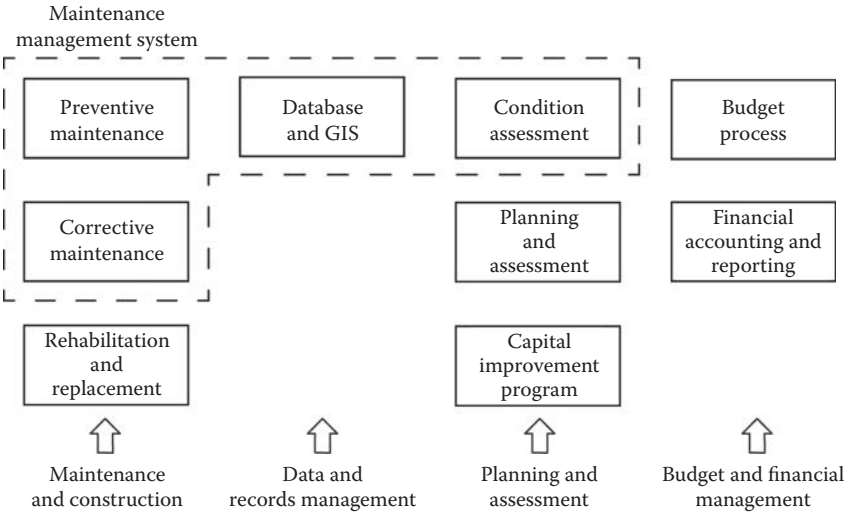

FIGURE 3.6
Functional view of asset management system.

To complete the picture of asset management, Figure 3.5 shows an asset management triangle to illustrate the main asset management activities as they relate to the core functions of planning and management, construction and renewal, and O&M. Key subsidiary asset-related activities are shown alongside each of the core functions.

Figure 3.6 completes the picture from another angle: how the functions are allocated among the departments of the utility. This figure shows the maintenance management system as it links to construction and maintenance, the database, the planning and budgeting system, and the financial management function. Taken together, these activities form a complete asset management system that requires a coordinated approach to consider the needs of infrastructure integrity.

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4

Capital Improvement Planning and Programming

Adequate funding is essential for life-cycle management of infrastructure, but it is difficult to obtain because, as utility and public works managers know, infrastructure investments are not as politically attractive as some tax- or fee-supported public programs. During lean financial times, it is hard to get funding for almost any public program. Sometimes it even takes a crisis to get the funds needed. This means that infrastructure upgrades get deferred and the backlog of investment needs grows.

The problem of funding is widely recognized in the infrastructure management community, and USEPA's (2008) asset management guidelines stress the importance of sound financial decisions and effective long-term funding strategies. It is considered a best practice to assess whether adequate funding is available to maintain the assets for the required level of service.

For most organizations, the starting point to address the funding issue is to request support through the capital improvement planning and budgeting process. Capital improvement planning is where engineering and finance meet, through the capital budget. Capital improvement planning is a well-known process for public or private organizations, and theories for how to do it are developed within the discipline of capital budgeting, which generally addresses the need to get the best returns from financial capital.

This chapter explains the mechanics of the capital improvement planning and programming process. Chapter 6 explains how these are translated into the capital budget, which is the vehicle through which funds are actually appropriated.

Planning–Programming–Budgeting Systems

The processes of planning, programming, and budgeting are somewhat different, but they are linked conceptually in a general process known as the planning–programming–budgeting system (PPBS). This general concept

has many variations and different names, but the main point is to have an organized way to plan, program, and budget so as to set priorities and get funding for important programs. The PPBS enables life-cycle management of infrastructure by providing a mechanism to assess needs, plan projects, and program the funds for future budget years. It adds objectivity and logic to a process that can seem chaotic and political.

The planning part of the PPBS can be carried out in different ways, but the capital improvement program (CIP) takes on a definite structure as it integrates the capital needs and plans of all sections of the organization. The capital budget is the most formal part of the system, in that it becomes part of the official budget of the organization.

While the PPBS can be used for both capital and operating programs, this chapter focuses on the capital planning process. PPBS for operating programs would focus on personnel and ongoing expenses rather than capital facilities. It can be used, for example, to plan budgets for operations and maintenance (O&M) of assets. The PPBS is more useful for the capital budget, however, because the levels of operating funds normally do not change as rapidly as capital programs.

Several departments participate in the capital improvement program, especially planning, engineering, and finance. These tend to be the same ones that participate in asset management, and while the CIP might be managed by a single office, close coordination is required among the departments. Recognizing this, it might be appropriate for the CIP coordinator to be part of the same group as the asset management coordinator, at least for the assets being planned. Later, the capital improvement planners pass the baton to the budget staff for the financial processes, and budget staff are more likely to be part of the financial office (see Chapter 6).

The CIP process is straightforward, but it can be a challenge to set priorities among competing projects and funding needs. A rational evaluation process can be developed to use tools such as benefit-cost analysis (BCA) and multicriteria decision analysis (MCDA), which are explained later in this chapter.

The PPBS process emerged during the 1960s to provide a systematic and orderly approach to replace piecemeal planning and budgeting processes. Under PPBS theory, an optimum use of resources will result from using tools of systems analysis for planning, which is followed by programming and then by budgeting for programs and projects. This should rationalize government operations and make them more transparent and objective. However, while the framework of the system is rational, the inherent political nature of the budget process still affects capital planning to a large extent.

Conceptually, the PPBS is straightforward and includes long- and short-range planning, preparation of the capital program, and then publication of the annual capital budget. These processes are shown in Figure 4.1.

Although the CIP focuses on planning, programming, and budgeting, it deals with all phases of the capital life cycle, as shown in Figure 4.2. That is, early-stage planning—such as comprehensive or master plans—must be translated into specific plans for design and construction and then for operations and maintenance (O&M). The need for repair, rehabilitation, and replacement may reinitiate the planning cycle to complete the life-cycle approach to capital management. The CIP thus can include facilities for growth, obsolescence, condition improvement, regulatory controls, or increase in reliability or service (Water Research Foundation, CH2M Hill, and AWWA, 2002).

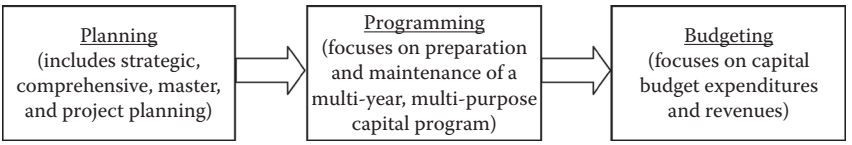

FIGURE 4.1
The planning–programming–budgeting system.

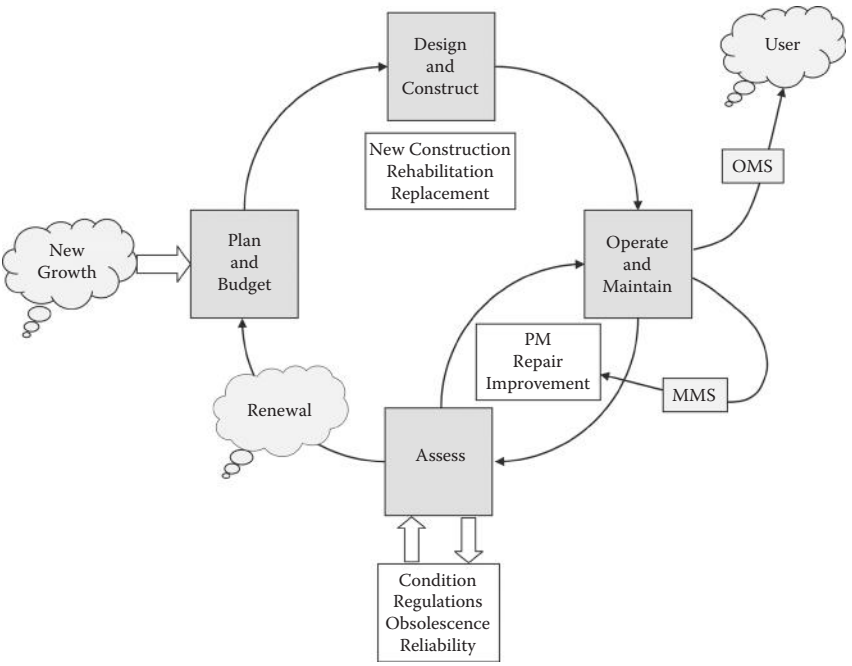

FIGURE 4.2
The infrastructure life cycle.

Planning Process: Multistage, Rational, and Political

The planning process for a project involves multiple phases, from development of policies and concepts to final planning of the details of the work. These are the rational steps of planning, where you set goals, compare alternatives, and obtain decisions. In between, the public and policy makers are engaged in finding solutions amidst many political and community issues. In this sense, planning is political, as it involves the process of government in working out community issues.

For any capital project, early planning precedes engineering design by studying the need for facility construction. Whereas it should be a continuous process, it is normal that firm planning may not occur until a specific event requires it, such as growth, obsolescence, regulatory controls, or a failure, when priority goes up and the governing board asks staff to prepare plans to address a particular issue. This can illustrate the "crisis" aspect of public works finance, but it also means that you want to spend your planning resources when the priorities start to line up.

In any public plan or program, there is an underlying planning process that is adapted to specific situations. As shown in Figure 4.3, the process includes rational problem-solving steps such as goal setting as well as a stakeholder engagement or political process, where the wishes of stakeholders are considered. Usually, these steps involve different stages of planning, from early to advanced planning. Stakeholder engagement may involve other employees of the utility and related organizations, but it can extend to members of interest groups and appointed or elected officials, who may bring political considerations to the table.

In rational problem solving, the standard procedure is to recognize the problem, set goals, find options, evaluate them, choose a course of action, and implement it. These steps involve data collection, studies, approvals, presentations, and many other tasks. Rational planning steps like this create a good outline for an engineering report, which is usually needed before the political process can engage with stakeholder issues.

In the rational planning process, the political issues enter at each step and raise questions such as: Whose problem is it? Who are the stakeholders? What is their stake and influence? What are the seen and unseen obstacles?

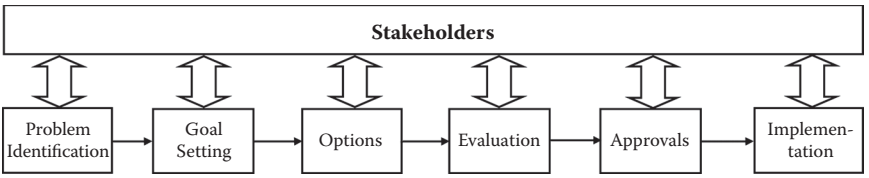

FIGURE 4.3
Steps in a rational planning process with stakeholder involvement.

How do we navigate the minefield of public opinion to win approval? What coalitions can be gathered to increase chances?

Recognizing the problem to be addressed (such as failing infrastructure) and then determining the need for investment actions for water systems involves detecting the need (a) for changes in capital facilities due to growth, obsolescence, condition, and regulatory controls or (b) to increase reliability or service. Setting goals then requires the balancing of supply and demand for the systems while considering realistic scenarios for fund availability, growth, regulations, and other system drivers. These steps were included in the asset management planning process that was explained in Chapter 3.

Finding options to solve problems is a creative process requiring information, knowledge, and experience with the systems. Options may also involve regional stakeholders who might partner with your system. For example, if a water system needed a new laboratory, perhaps it could cooperate with a nearby utility and share a lab.

Evaluating the options requires assessment of feasibility from technical, financial, social, political, legal, environmental, and managerial points of view. These viewpoints can be wrapped into a triple bottom line (TBL) framework for their economic, social, and environmental aspects, but the financial, political, legal, and managerial issues fall outside of this into a general institutional analysis category.

Utility managers face institutional problems, but these are hard to explain, and there is no comprehensive methodology for analyzing them. The term *institution* includes more than agencies and organizations, and extends to laws, customs, and management behaviors. An institutional analysis should offer a systematic way to answer questions that include: What are the laws and controls? What are the incentives? Who has control and what are the roles of those in control? What is the management culture? A methodology to do this was explained by Grigg (2005), along with a case study of institutional problems with water quality in distribution systems. This identified issues and gaps that inhibit solutions to institutional problems, including fragmented authority; inadequate legal controls stemming from poor technical understanding; and faulty incentive structures and management cultures as well as unclear roles and responsibilities, made worse by difficulties in enabling the players to undertake their responsibilities. It was evident from the case study that progress on the technical and management issues is not possible unless institutional problems are addressed first.

Evaluation is the stage where analytical tools such as models, benefit-cost analysis, public involvement, sensitivity analysis, and other tools are used. To illustrate, Chapter 9 includes a discussion of a model to prioritize investments in rehabilitation or replacement of pipes. Project options must be screened systematically, and the procedure used to eliminate options must be documented. To do this, the objectives of the project must be clearly identified, and measurable criteria to compare the options must be formulated. Multicriteria decision-analysis tools are useful for this process. It is

not necessary to have a detailed analysis for each criterion, as long as the procedure uses the same level of accuracy for all options. For example, the estimated construction cost of project options should lead to a smaller set of options to be considered in greater detail.

Choosing a course of action requires identification and involvement of decision makers. That is, in the planning process, knowing who will make the decisions and how they may act is as important as the analytical steps themselves. Implementing the plan may involve steps going beyond early stages of planning. New obstacles and possibilities sometime occur in implementation, opening the way to apply adaptive management, or to adapt to the new situation or information.

These steps take place during sequential stages of planning, ranging from the earliest to the final stages. Early or conceptual planning is where the need for a project is identified and the first set of options is developed and screened. Many discussions may take place in planning before the formal process begins, including in-house discussions by the owner's team. As ASCE's (2000) manual on *Quality in the Constructed Project* points out, the relationship between the owner and design professional separates early planning from the point where the design professional begins a design-related plan.

Early planning is a reconnaissance phase to identify projects that meet planning and development goals. It leads to further studies rather than definite plans. In more formal planning, definite feasibility is studied. In this phase, complex and expensive documents may be prepared. This phase leads to design, where plans, specifications, and operating agreements are prepared.

From Integrated Plans to Capital Improvement Programs

As the previous section explained, planning has many facets, and infrastructure plans flow from general, integrated plans to more specific capital plans for categories and sectors. Thus, an important aspect of the CIP process is the link between a capital project and the integrated plan, whether the systems involved are water, wastewater, stormwater, or other infrastructure categories.

An integrated plan considers links of infrastructure with planning objectives such as urban development and land use. Integrated plans are called comprehensive plans, policy plans, or other similar names. They often use slogans such as "Plan Fort Collins," which is the current comprehensive plan in my community. We have used other slogans, such as "Designing Tomorrow Today" (1970s), and other communities might use slogans such as "Vision for Metropolis," for example. Generally, these broad plans outline goals and strategies for urban areas and assess what must be done to achieve these. Sometimes these framework or scoping plans include regulatory implications by setting goals for urban design.

Integrated plans such as these must be disaggregated to show what is needed for specific facility plans, such as for water, wastewater, and stormwater systems. These facility or infrastructure plans must be translated into specific plans and programs, which requires a shift from the planning world to the engineering and financial worlds. In other words, integrated plans often do not carry firm commitments, but once you enter the engineering and financial worlds, the likelihood of implementation rises.

Capital Improvement Programs

Shifting from planning to programming involves an increase in commitment because planning can veer more easily from one project to another than capital programs can, and once a project gets on the program schedule, it takes on more legitimacy. Think of any plan as a document or a report about the feasibility of a concept. There can be many plans before commitment is made, and some refer to plans as "shelf art," because there can be so many of them on the shelf.

However, once a project is listed in a capital program, it implies that at least some commitment has been made to move ahead with it, regardless of how long it takes. Thus, the CIP is normally only published after tentative decisions have been made to undertake projects in future years. These decisions may include a vote by a governing board or city council.

Being on the CIP does not guarantee that a project will be implemented, because unexpected events can occur and funding can be allocated away from the project purposes. Economic shifts, new laws, voter swings, and financial problems can intervene in the best-laid plans and programs. Budget allocations for the project form the crucial test. Getting a planned facility onto a capital improvement program is one step in the bureaucratic struggle over budget politics. In the budget process, if you get your project on an official or approved list, you may stand a better chance of being funded than if you are not on the list. Thus, departments strive to get their projects on the approved capital programs list of an organization.

How serious a capital improvement program is depends on the organization. Capital programs can range from serious businesslike programs to wish lists. Their detail and commitment vary by level in an organization. For example, there can be an organization-wide program, and individual departments can also have programs. The important question is where the budget authority resides. Thus, if an organization has a capital program approved by the same authority that approves the budget, then having a project in the program is a big step toward funding. In the final analysis, the capital improvement program is a list of projects that an entity *intends* to implement under favorable circumstances. The uncertainty is about the intent and ultimate capability to follow through with the intent.

Water Supply Capital Planning

The *Capital Planning Strategy Manual* (Water Research Foundation, CH2M Hill, and AWWA, 2002) specifies reasons for capital programs in water utilities to address the following concerns:

- *Growth*: providing water supply to new areas
- *Obsolescence*: replacing old, undersized pipes
- *Condition*: renewing areas where pipes have deteriorated
- *Regulatory controls*: upgrading to meet stricter water supply rules
- *Increase in reliability or service*: spending to increase security

As an input to growth, water supply receives high priority in capital planning and budgeting. In an ideal case, new systems can be completely financed by growth fees and developer contributions as growth pays its own way. However, on a practical basis, the picture is more complex because the utility must share and participate in projects to ensure safety, coordination, and orderly growth.

Planning for water supply is driven by demand, location of demands, and required quality of supplies. As discussed in Chapter 2, estimates used to plan systems are normally based on per capita consumption, peak demands, and fire flows. The planning process for water supply is the same as for other facilities, but the water industry has worked more with the concept of Integrated Resource Planning (IRP).

Based on the experience of electric utilities and some water utilities, the WaterRF sponsored research on IRP in water utility planning (Wade Miller Associates, West Virginia University, and Tellus Institute, 1997). They offer a 20-step process to overcome budget constraints, environmental issues, multiple laws and agency jurisdictions, scarce resources, and special interests. IRP focuses on regional cooperation and involvement of interest groups to resolve differing views. The report shows how to consider avoided cost, externalities, and cost-benefit equations and presents case studies of six water utilities.

The 20 steps include: identify stakeholders, review stakeholder issues, identify supply issues, assess water quality and quantity issues, develop alternatives, analyze alternatives, compare alternatives, rank alternatives, select preferred alternatives, implement and, if necessary, modify alternatives. The process is consistent with the combined rational-political analysis described earlier in this chapter.

AWWA (1998) has a manual of water supply practices (M29)—*Water Utility Capital Financing*—that includes planning for capital improvements. The manual explains strategic planning for capital requirements and financing mechanisms, mainly the bond market. For planning, the manual describes an integrated, iterative process with stakeholder interaction. Basically, the

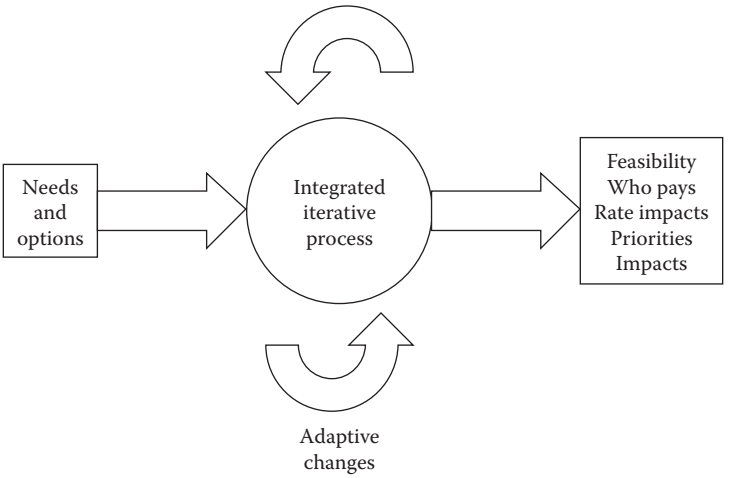

FIGURE 4.4
Financial planning as part of a capital improvement process.

process shows how financial planning is considered in the overall planning process (Figure 4.4).

Financial planning requires stakeholder interaction and leads to: safety, reliability, and efficiency; annual cost minimization; optimal use of financial resources; and minimized annual impacts. These are good objectives, but we must also keep in mind that in addition to these engineering and economic considerations, the overall process involves many other factors, especially those relating to citizen needs and politics.

Wastewater System Planning

Capital planning for wastewater facilities follows the same general process as for water supply, but the reasons and specific approaches differ due to the nature of the service. Wastewater system planning for collection, treatment, and disposal starts where water supply leaves off and is driven by service demands and regulatory controls. Collection systems are planned to handle inputs to the system and align with streets and land-use patterns. Treatment plants are planned to meet regulations and offer many options, such as regional cooperation to pool efforts and achieve economies of scale in treatment. Disposal systems are needed alongside the treatment plants, and these are planned to discharge liquid effluents and dispose of sludge residuals.

Whereas water supply can sometimes offer positive aesthetics, such as providing a new lake and multipurpose facility, wastewater planning deals with external effects that include negatives such as odor and image problems. Also, wastewater treatment and disposal systems are located downstream of cities rather than upstream and are often of concern to their neighbors.

Recent trends are to combine wastewater plants with other land-use objectives, such as regional parks, trails, and reclamation of former industrial sites. An example of that was provided in Chapter 2, which explained the new plant near Seattle.

The same reasons for capital improvements apply to wastewater facilities as for water supply. Examples include

- *Growth*: extension of gravity service to new areas
- *Obsolescence*: replacement of outdated pipes or equipment
- *Condition*: correcting infiltration or inflow problems
- *Regulatory controls*: upgrading a combined sewer overflow facility
- *Increase in reliability or service*: solving backup or capacity problems

The availability of grant funds through the Clean Water Act (CWA) drove wastewater planning for years through the Section 201 planning process. Later, the availability of revolving fund loans continued the push toward regional coordination of plans. Section 208 of the Clean Water Act also required area-wide planning, but did not lead as directly to capital improvements because it focused on nonpoint sources. Many of these plans were developed when grant funds were available, but funds for this program are no longer available. The 1987 CWA amendments established a Section 319 nonpoint source program to assist with state and local efforts. These can receive grant money for technical and financial assistance, education, training, technology transfer, demonstration projects, and monitoring.

Stormwater System Planning

Planning for stormwater is somewhat different than for water or wastewater because the systems are tied more closely to land use and may involve more purposes in a multipurpose approach. For example, in a new development, the stormwater system may involve aesthetic enhancements such as underground piping to drain streets, green strips as parkways and recreation areas, and ponds to detain runoff and improve water quality.

Drivers for capital facilities for stormwater include urbanization, flood problems, and nonpoint pollution. Stormwater facility demand may be driven more by local standards than is the case for water and wastewater. Using the same format as for water and wastewater, examples of planning for stormwater include

- *Growth*: provision of stormwater services to newly developed areas
- *Obsolescence*: replacement of older, undersized systems that are overloaded
- *Condition*: replacement of deteriorated stormwater systems

- *Regulatory controls*: expenditures to meet new mandates for risk or pollution
- *Increase in reliability or service*: upgrading systems for bigger storms

Evaluation Techniques and Priority Setting

The tool to use to evaluate choices among alternative water, wastewater, and stormwater investments is decision analysis, which provides a systematic way to evaluate the pros and cons of different decisions. When applied to public sector issues such as infrastructure, decision analysis considers economic, social, and environmental goals as well as financial rates of return. For example, decisions about pipe renewal are risk-based decisions and require you to weigh the risk of failure against the resources required to renew a pipe.

The fields of decision analysis and risk assessment converge to create methods for risk-based decision analysis. While you consider risk in most decisions about water, wastewater, and stormwater investments, it is more important in some decisions than others. For example, if you purchase equipment, you want to know the reliability of competing models. However, a program decision may hinge more on positive benefits rather than on risk of something going wrong. For example, if a community is considering a new police station, it is thinking about how it will improve police services and not so much about risk. Pipe renewal programs are different because the primary goal is to avoid a failure, so risk of failure becomes the dominant consideration.

Given that multiple goals and risks are to be considered in decisions, multicriteria decision analysis (MCDA) can be used to enable you to trade off among multiple goals. MCDA also involves a concept from public sector economics called *utility theory*. Public sector economics deals inherently with multiple objectives anyway. It is a branch of economics that addresses public issues and considers maximization of public resources by seeking the best values of public objectives in a community. Utility theory is a similar concept that applies for situations such as where money is not the main issue. There is a subfield of economics and political science called *public choice theory* to show how these should work in different situations.

MCDA is ideal for problems involving utility theory because it offers a way to assemble different measures of monetary and nonmonetary utility in one place. It indicates how different strategies, programs, or projects lead to achievement in categories of goals, and this requires data to measure outcomes. No one should assume that an MCDA analysis locks in just one preferred solution. People have different opinions about what the preferences

and scores should be, and MCDA results are considered to be advisory. After considering them, decision makers must look at sensitivities in the assumptions and consider trade-offs.

While decision analysis is organized through the planning process, it occurs in a political framework that wraps the basic steps of planning in an environment where stakeholders compete to advance their agendas. When policy makers decide to spend money on pipe renewal, they operate in their political environment in the sense that they must respond to stakeholder views.

A basic MCDA display shows how alternatives score in the economic, social, and environmental goal categories, as shown in Table 4.1. In the table, you provide a net score for each project in each category. To do this, you must be able to evaluate the projects to determine the scores, and you must have a scoring system that works across economic, social, and environmental categories. This requires benefit-cost tools, environmental impact analysis, and social impact analysis. Benefits and costs can be quantified more often with monetary values, but the estimates are often uncertain and inexact. Environmental and social impacts are harder to quantify and often rely on descriptive information and nonmonetary quantification. You can also display the incidences of the impacts on different stakeholder groups.

In planning for infrastructure renewal, the types of criteria to apply and those that might be included in an MCDA for a project plan are

- *Economic*: Does it pass a benefit-cost test, and does it have an acceptable rate of return?
- *Social*: To what extent are people impacted negatively?
- *Environmental*: Does the plan introduce negative environmental consequences?
- *Risk and vulnerability*: Does the plan reduce risk and vulnerability?

TABLE 4.1

Template for a Basic MCDA Display

	Economic Impacts		**Social Impacts**		**Environmental Impacts**	
	(+)	**(–)**	**(+)**	**(–)**	**(+)**	**(–)**
Proposed action 1						
• Group 1 impacts						
• Group 2 impacts						
Group *n* impacts						
Proposed action 2						
(add options)						
Proposed action *n*						

- *Technological*: Will the plan work and does it meet goals effectively?
- *Institutional*: Can the owner implement the plan in the long term; does it pass a test of legal feasibility; and is the plan politically feasible?

These criteria may seem daunting, but they are all applicable, and a good plan will consider all of them and even more. The criteria involve both quantitative measures and nonquantitative measures. It would be convenient if plans could be reduced to just numbers, but public decisions involve many issues that are not amenable to numerical comparisons.

How to Develop a Capital Improvement Program

After integrated planning, the CIP process includes the partition of programs into sectors. Decisions about the funding of competing priority projects in the sectors are made to combine the needs of different programs into the overall CIP. Each sector isolates a set of projects for planning and divides them into subprojects or stages. The projects are programmed for future years of construction and implementation. Although the CIP is published from time to time in planning documents, it should be maintained and updated annually.

The *Capital Planning Strategy Manual* explained seven basic steps of the CIP process:

1. Define mission
2. Frame problem
3. Establish data management protocol
4. Identify and screen
5. Prioritize
6. Finalize plans and gain approval
7. Implement

The manual also explains the ways to prioritize pipes: by voting, by using a matrix, or by using an application of more sophisticated decision analysis, which uses multiattribute utility analysis. This latter tool, multiattribute utility analysis, is another term for multicriteria decision analysis (MCDA), which can be applied in a spreadsheet prioritization tool (Water Research Foundation, CH2M Hill, and AWWA, 2002).

In summary, the steps in CIP preparation as they relate to infrastructure management can be presented as shown by the sequential set of steps presented in Table 4.2.

TABLE 4.2

Steps in CIP Preparation

Planning Stage	Activities
Integrated planning	Analysis of population, economics, environment, stakeholders, technologies, and multiple sector plans to determine overall need for infrastructure
Dividing up responsibilities for sectors	Organizational analysis of intergovernmental roles and responsibilities to determine lead agencies for infrastructure sector plans
Sectoral planning for a function	Isolating the conditions for a particular sector plan, such as water supply or wastewater
Deriving broad outlines of capital improvements	Scheduling and planning the capital process, what the CIP includes, who is involved, and how it is presented
Isolating a set of projects or systems for further planning	Selection of target systems to be isolated, based on urgency, political support, and ability to finance
Dividing the projects into subprojects or stages	Application of engineering and finance to assemble CIP packages
Preliminary planning for subprojects	Development of engineering plans to rough out designs, get costs, and review and coordinate plans
Programming of subprojects	Engineering assessment of time to design and build, time to gain approval, and time when systems will be needed
Determining methods to finance the capital budget	Assessment of methods such as bonds, loans, user charges, and sale to owners
Gaining approval for elements of CIP	An often difficult process that involves the public and decision makers, and sometimes elections
Publication of CIP and inclusion in capital budget	Shift of responsibility to budget and financial staff and executive officers

Example of a CIP

Many examples of capital improvement programs can be obtained simply by a search on the Internet. For example, the City of Raleigh, North Carolina, Stormwater Utility Capital Improvement Program (2011) has a website to explain to the public how it chooses projects. Raleigh's explanations align with the steps presented previously and are outlined here briefly to demonstrate the approach.

The first questions are: What are Stormwater Capital Improvement Program projects, and what is the purpose of these projects? Raleigh explained that the projects are mainly for drainage system improvements, but watershed planning studies and flood mitigation projects are also in the CIP. The projects are to reduce flooding on streets and in homes and businesses, to improve water quality, and to complete studies to identify future problems.

The next question is: How is this going to benefit the city? The explanation is that the projects will help reduce the costs of flood damages and future projects. Reducing street flooding also helps with traffic and evacuation during disasters. Also, the CWA requires water quality improvements.

Then the question is: Why are CIP projects classified by categories? The benefits are explained such that lake preservation and storm drainage system improvements prevent damages due to failure during floods, reduce flooding, and improve water quality using either public or private lakes. Storm drainage system projects are normally associated with streets. Stream enhancement and green projects reduce water quality impacts by reducing sediment and other pollutants and are normally associated with city property such as parks or fire stations. A category called *storm drainage and water quality petition projects* involves private property and reduces flooding, repairs eroded streams, and improves water quality. These are basic explanations, but they can help the public and policy makers to understand.

Raleigh has completed 125 projects at a cost of $31 million since 2004. Projects are selected based on the following general priorities: involving city streets or private property; public safety, including city streets or lake failure; mandated by a regulatory agency; flooding of homes or businesses; water quality improvement; and stream bank erosion. The backlog is, of course, huge. It is $123 million over 10 years beginning in 2012 and another 85 projects at over $60 million currently under design. The city hopes to reduce the backlog by implementing $100 million in projects by 2021. With a population of about 400,000 and growing, this amounts to $25 per capita per year or about $2 per month per capita. It would add about $6 per month to a residential bill for three-person families.

Raleigh's CIP states its goals, which include: 10-year protection for all streets and flooding in the finished floor areas of all homes and businesses in the next 25 years and removal of at least 50% of the streams from the list of impaired streams in the next 25 years. Raleigh has stormwater utility fees, and it reports that since 2004, about half of the fees or some $45 million have been used for the CIP.

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5

Engineering and Construction for the Infrastructure Life Cycle

The effective performance of water systems depends on the integrity of the infrastructure, for which the engineering and construction functions have major roles. This chapter is about how design and construction determine infrastructure integrity during the initial installation and how engineering has additional responsibilities along the life cycle. The process of engineering design includes planning phases as well as design documents, so it is engaged from the beginning throughout the infrastructure life cycle.

Much of water, wastewater, and stormwater work is utility construction, but it also involves heavy construction, such as dams and roads, as well as facilities construction for treatment plants and supporting structures.

Engineering functions are normally managed within utility or municipal departments, and they may apply to streets and other facilities as well as to water, wastewater, and stormwater systems. Roles such as the city engineer or infrastructure project manager may cut across types of systems. In any case, engineering functions such as setting quality standards and maintaining records are generic, but they apply in different ways to the categories of infrastructure systems.

Assuring the integrity of infrastructure depends on the quality of original installation, which in turn depends on the effectiveness of design and construction and on the materials and equipment that are used. Later, operations and maintenance are important, and periodic repair, rehabilitation, or replacement is also required.

The main participants in the design and construction processes are the utility or city engineer, the public works director, the design professional, the regulator, the constructor, and the vendor of materials and equipment. Figure 5.1 illustrates these groups, as it shows a pipeline under construction, where the design, the materials, the construction management, and the installation are evident. This chapter focuses on how the participants in design and construction work together to create high-quality infrastructure systems, and how the engineering department oversees infrastructure integrity throughout its life cycle. The focus here is on management issues, rather than the technical details of the systems.

FIGURE 5.1
Pipe under construction. (From American Water Works Association. Copyright 2001. All rights reserved.)

Stages of Design and Construction

After a project is initiated, the design and construction processes occur quickly, compared to the full infrastructure life cycle. A project might have been on a capital program and waited in the wings for a number of years, and then be moved to the front burner quickly to initiate serious design and construction. For example, during government stimulus programs, agencies will seek "shovel-ready" projects to initiate quickly. However, once a project is approved, the brief design-construction process will normally be followed by many years of operation and maintenance. The planning-design-construction period is therefore a brief window of opportunity to produce a long-term high-value project.

Factors other than initial cost determine infrastructure life-cycle costs. During the design and construction stages, infrastructure integrity is affected by many hands, ranging from drafters of plans, to manufacturers, to the installers who place the finishing touches on the systems. This is not a seamless process with integrated control over quality; rather, it is a chain

TABLE 5.1

Stages of Planning, Design, and Construction

Conceptual planning	The need for the project is identified and a first set of options is developed and screened. As a project nears approval, planning becomes more detailed. Conceptual planning might last for a long time, and some projects never enter the definite planning phase.
Engineering planning and preliminary design	Selected options are assessed in detail. This may include field investigations that are too costly for the conceptual phase. Field investigations may reveal information that alters the feasibility of options. An outcome of this phase is rating of options from the standpoints of engineering, financial, economic, and environmental feasibility. The preferred option and its scope are determined.
Final design	Design details are finalized and appropriate drawings are prepared. This phase includes specification of materials, sizing of members, and component details. Many decisions require experience and consultation. Results of design are detailed engineering documents and drawings to initiate construction.
Construction	The project is constructed. Depending on the project delivery method used, the phase may involve different elements, including design-construction coordination.

of events with the possibility of slippage in final quality along the way. As a result, quality assurance is important along this chain of events from concept to completion of the systems, as well as on maintenance and renewal that occur later in the life cycle.

The phases of planning-design-construction are not fixed in sequence or length. Planning can involve long periods of concept development before it starts to deal with design details. Design can be handled differently, depending on the project delivery method chosen. The stages of planning, design, and construction can occur in different ways, as summarized by the general phases shown in Table 5.1.

In these phases, the design professional requires a clear scope of work, an adequate budget, timely decisions by the owner, and a contract to work at a fair fee. The constructor requires clear plans and specifications with enough detail to prepare an effective bid and timely and fair decisions on contract administration. Projects require compliance with regulatory rules relating to public safety and health, environmental considerations, protection of public property and utilities, and conformance with all applicable laws and regulations.

Achieving Quality and Value in Infrastructure Projects

In water, wastewater, and stormwater systems, both quality and value are needed. Public health and safety require quality so that projects perform

well in multiple ways, and effective results are required for responsible use of public funding. The bottom line is measured in financial ways and in intangible ways, such as better health, safety, convenience, and livability.

A project-oriented definition of construction quality is used in the manual on *Quality in the Constructed Project*, prepared by the American Society of Civil Engineers (ASCE, 2000), which was developed in response to failures in the design and construction process. ASCE's definition is that quality is "fulfillment of project responsibilities in the delivery of products and services in a manner that meets or exceeds the stated requirements and expectations of the owner, design professional, and constructor."

Referring to the requirements of the owner, ASCE explained: "Actual requirements for a particular project…should be detailed and refer to...function, operation, schedule, technical matters, safety, quality, esthetics, fiscal, and administrative or management considerations."

Project value results from the expectations being met or exceeded in a cost-effective manner. In a private sector investment, the main goal is to achieve the highest rate of financial return, but in a public sector investment, the total returns are harder to measure, and cost-effectiveness analysis is used widely. This involves setting the goals of the project and finding the lowest-cost way to achieve them. Given the multiple goals of water, wastewater, and stormwater projects, cost analysis can show which projects meet or exceed requirements at lowest total cost.

ASCE's manual, *Quality in the Constructed Project*, is a compendium of principles for owners, designers, and constructors to follow in achieving quality in project construction. The manual was initiated after two walkways in the Kansas City Regency Hotel failed in 1981, causing heavy damage and loss of life. The construction industry was dismayed that this could have happened and decided to undertake a project to improve quality in construction to prevent such problems. To prepare the manual, ASCE organized a construction-industry steering committee with representatives from designers, constructors, owners, and suppliers. The manual has undergone extensive review since the original version in 1987.

The project quality attributes (delivery of products and services to meet or exceed the requirements of the owner, design professional, and constructor) imply that the resulting product demonstrates functional adequacy, is completed on time and within budget, has acceptable life-cycle costs, and can be operated and maintained as designed. For water, wastewater, and stormwater infrastructure, these attributes translate into: systems performing reliably and meeting performance and regulatory goals; the design and construction processes producing final facilities on planned schedule and budget; all life-cycle costs, from construction through final demolition, being minimized and/or controlled effectively; and systems working well for operators and maintenance being effective.

The organization of ASCE's manual comprises a list of best practices in design and construction. Topics covered that relate to water, wastewater, and stormwater include

- Project management; organization of the design team; selection of engineer and constructor; methods of project delivery, including design-bid-build and design-build; regulatory compliance; communication; risk and liability; and conflict and mediation
- Design process for water, wastewater, and stormwater infrastructure; design by consultants or in-house; equipment and materials; and design review
- Construction contracts and documents; shop drawings; contract documentation and submittals; contract administration; and inspection and quality assurance
- Owner roles, including engineering functions for the utility; codes and standards; postconstruction drawings, records, and assessment
- Design and construction guides for systems
- Networking and educational resources, including construction-industry associations.

Contractors say that quality comes from consistency and documentation. These and other procedures can be guided by quality benchmarks, such as those provided by the International Organization for Standardization (ISO, 2011), a nongovernmental organization based in Geneva, Switzerland. ISO is a federation of the standards organizations of 162 countries and promotes standardization of requirements to facilitate trade and economic cooperation. ISO has a family of standards (series 9000) to focus on good quality-management practices. Some of the principles of quality management that it promotes are: customer focus, leadership, involvement of people, process approach, system approach to management, continual improvement, factual approach to decision making, and mutually beneficial supplier relationships.

ISO 9001 sets standardized requirements for a quality-management system, regardless of the user organization, its size, or private or public sector status. This standard includes design services, and contractors might use it and/or seek certification under it. It has elements that include management responsibility, quality systems, contract review, design control, document and data control, and purchasing (Krizan, 1999). The latest revision of this standard is ISO 9001:2008.

Quality in design and construction depends on more than technical details. For example, according to ASCE (2003), insurance studies show that most legal actions by owners are not based on the projects themselves, but on situations such as surprises, frustration over problems not addressed, lack of

positive personal relationships, or not being informed about problems. Thus, in construction management, good communication and coordination help hold down conflict and improve quality.

Project Roles

The quality of projects requires clear delineation of the roles of the owner, design professional, and constructor. For water, wastewater, and stormwater infrastructure, the owner will most likely be a public entity. Another scenario is that the owner through the construction phase is a developer, but that is usually followed by a transfer of ownership and responsibility to a public entity or a regulated private entity.

In the project, the owner might carry out some planning before engaging a design professional. How this relationship between the owner and the design professional evolves delineates the early phases of the planning-design-construction processes. Involvement of the design professional is flexible, as outlined in ASCE's (2003) manual for engineering services.

The main roles in design and construction are shown in Table 5.2. In addition to the roles shown, the owner, design professional, and constructor are involved in review and advisory roles (ASCE, 2000).

TABLE 5.2

Main Roles in Design and Construction

• Owner	• Assemble team
	• Establish requirements
	• Arrange financing
	• Plan coordination and communication
	• Select design professional
	• Select preferred alternatives
	• Obtain approvals
	• Select constructor
	• Administer contracts
	• Make payments
	• Plan and staff start-up
• Design professional	• Assemble and manage qualified team
	• Perform design studies
	• Evaluate impacts
	• Technical review of contract submittals
	• Administer QA/QC for design
• Constructor	• Organize for construction
	• Initiate job safety
	• Present required contract submittals
	• Construct project
	• Administer QA/QC for construction

Engineering design will usually involve teams of professionals. The work of each group must be integrated into overall design, requiring coordination and cooperation to meet project specifications on time and on budget. Each member of the team must accept responsibility; strive for economy, efficiency, and quality; cooperate and coordinate; and adhere to budget, schedule, and program.

Project Delivery Methods

The design–bid–build process has been the traditional method of managing projects, but new forms and relationships are being developed to increase innovation and lower costs. Examples include design–build, turnkey, construction management, owner-construction, and build–operate–transfer (BOT) projects.

In the design–bid–build process, the participants and processes are divided by walls. In a typical form of it, the owner develops a request for proposal (RFP) without talking to the other participants; the designer is selected through a formal process run by the owner; and the design is prepared more or less in isolation. In some cases, the designer might consult constructors about the feasibility of the methods. After the design is completed, the bid documents are released for constructors to use to prepare bids. Then, a competitive bidding process is undertaken. During the construction process, the designer, owner, and constructor remain more or less at arm's length. There might be some collaboration, but definite walls separate the participants during construction.

This stereotype of a process seems rigid, and in most cases, some cooperation occurs in design–bid–build projects. However, newer project delivery methods are being developed, with design–build and its variants comprising the best known and most common. The Design–Build Institute of America has been formed to promote and explain this project delivery method. When the first edition of this book was completed in 2002, design–build was relatively new for utility projects, but many have since been completed. The Design–Build Institute (2011) has a database for projects, which can be searched for water, wastewater, and stormwater projects.

Amidst the need for improved productivity in building, construction management itself has emerged as a project delivery method, but it is really a set of professional management services, not a pure project delivery method. The Construction Management Association of America (2011) provides information on the disciplines and methods that it provides. The idea is to utilize a number of tools, such as collaboration, effective contracting, project inspection, dispute resolution, and other construction management methods to deliver a quality project that optimizes the outcomes for all participants.

New project delivery methods mean new and emerging roles for participants and a changing construction business climate. *ENR* magazine tracks these with studies of business trends and offers many instructive case studies as well as industry statistics. In its statistics, categories of owners include industry groups and utility sectors, such as water and wastewater. Design firms are classified by market, such as by water, sewer, and wastes. A trend toward more firms becoming engineer–constructors is evident, with design firms getting deeper into construction and constructors taking on more design. Design–build and construction management firms are developing new project delivery methods, and this category of service continues to evolve.

Some design firms are also categorized as environmental, with markets in water treatment/supply and wastewater/stormwater treatment. Water, wastewater, and stormwater construction is a relatively small part of overall construction volume, and the largest sector is normally building construction (although the housing bust lowered that volume considerably). Water, wastewater, and stormwater infrastructure construction can also be included in other categories. Specialty contractors are classified by specialty and market, such as utility contracting and water, sewer, and wastes.

With regard to most water, wastewater, and stormwater infrastructure construction, the City of Fort Collins Utilities (2009) has implemented a flexible system. In a recent request for proposal, the city informed potential consulting engineers:

> Filling traditional adversarial roles between the Owner, Engineer and Contractor is not an acceptable way of doing business for the City of Fort Collins Utilities. The project(s) require working in an atmosphere of trust with all parties working toward the same goals utilizing the City of Fort Collins's Alternative Product Delivery System (APDS) process (working with the owner, a selected engineer and contractor through the design and construction phases of a project).

The city is happy with this APDS system and uses it regularly for utility construction. Some of the elements of its requirements for design include: drawings in AutoCAD; as-constructed drawings provided on CDs, with stamped, original mylars to become the property of the city; contract documents and specifications using the utility's standard technical specifications in CSI (Construction Specifications Institute) format and the city's modified EJCDC (Engineers Joint Contract Documents Committee) general conditions and standard documents; identification of easements or properties required for construction and preparation of all legal exhibits needed; identification and location of known existing utilities and structures; preparation of all applications for permits; construction administration, submittal review, and field inspection of projects by qualified personnel; and fulfillment of all surveying and geotechnical services required.

Planning for Water, Wastewater, and Stormwater Projects

Planning for water, wastewater, and stormwater projects occurs either for expansion into new developing areas or for upgrades and retrofits in existing areas. As parts of integrated infrastructure systems, the projects must conform to policy plans for their utility sectors as well as to comprehensive and master plans for the areas they serve.

Project planning includes the steps from concept to completion, depending on the detail needed. For most water, wastewater, and stormwater projects, engineering planning comes after the land use and civil infrastructure concepts are fixed, and the time devoted to conceptual planning is limited. Utilities will be considered in the conceptual design phase to determine the most feasible ways to provide services. In some water-short areas, utility planning for water supply may be a major issue for the conceptual planning phase.

Sometimes there is a fuzzy line between planning and design, but in any case the planning function is important in project quality. Chapter 4 explained that the planning process involves recognizing the problem, setting goals, finding options, evaluating them, and choosing a course of action and implementing it, and that these steps involve data collection, studies, approvals, presentations, and other tasks. Once the initiation of a project becomes nearer, these conceptual steps take on more urgency and require more detail. This can take the form of an engineering plan or preliminary design. Whatever it is called, the outcome is a report with enough detail and evaluation to enable review, approval, and then moving on to the preparation of engineering designs and construction drawings.

While there is no rigid format for an engineering report, a water, wastewater, or stormwater project will involve a series of necessary studies and determinations. Taking a wastewater project as an example, these could take on steps such as those shown in Table 5.3.

Project Design

Design is a creative process requiring knowledge, experience, and insight. The process begins with selection of the best combinations of components and operations to solve the problem at hand. These must be described and explained in detail on design drawings and explanatory documents, and outcomes must be communicated to the owner, constructors, reviewers, regulators, suppliers, and other participants in the construction process.

The components to solve the problem at hand depend on the systems and subsystems, which were described in Chapter 2. Briefly:

TABLE 5.3

Outline for an Engineering Report for a Water, Wastewater, or Stormwater Project

Planning Step	Wastewater Project Example
Recognize the problem	Outline an *n*-year projected deficiency in wastewater collection and treatment that requires a new project.
Set goals	Wastewater goals are mostly set by levels of service and regulatory requirements, but added features may be considered, such as enhancing land-use features around a facility.
Find options	In this step, configurations of project elements are studied to find alternative ways to achieve goals. For example, a wastewater project may involve different routes and sizes of lines, different treatment plant sizes, and different locations.
Evaluate options	Evaluation involves financial, legal, economic, social, political, and environmental criteria. Unless these triple-bottom-line criteria are considered, chances for approval are less.
Choose a course of action	This decision-making step may involve stakeholders, including regulators, governing boards, and in some cases a vote of the public.
Implement the project	Implementation can involve long periods of studies, contract work, financing, further approvals, construction, start-up, and adjustment.

- Water supply systems are designed to provide the quantity and quality of water needed for domestic, industrial, and other uses and to use source of supply, treatment, and distribution system components.
- Wastewater systems are provided to collect, transmit, treat, and dispose of used waters.
- Stormwater systems provide for convenience (minor or initial) drainage, major drainage in urban areas, and for parts of wet-weather water quality control, using collection, transmission, and sometimes treatment systems.

Guidelines for design of these systems are discussed briefly later in the chapter.

Engineering design work may be done in-house or by outsourcing. With in-house work, the owner's organization can maintain control over details and might reduce apparent costs. Advantages of using consultants include the wide selection of skills available, and using them only when needed. During the current downturn, the word we hear is that use of consultants is especially beneficial because public agencies lack the funds for full-time staff. Figure 5.2 shows an engineer designing pipe rehabilitation projects. The photo was taken at a large utility in 2002, and the technology of the time is evident, but the only difference today, 10 years later, would be new computer monitors, as the same procedures and information systems are in use (see Chapter 10).

FIGURE 5.2
Engineer designing pipe rehabilitation projects.

On the basis of quality, there is no consensus about whether in-house development or outsourcing of design work is best. Naturally, both public sector employees and consultants are proud of their accomplishments, and each situation must be handled individually. Some utilities favor in-house work. At the 2002 AWWA Infrastructure Conference, Chicago officials reported that they do about two thirds of pipeline construction with in-house forces, giving them the capability to move more quickly without the need for a contracting phase. At the same meeting, a group of U.K. engineers reported that they get more flexibility and efficiency from contractor forces. Much of the difference in approach would seem to be attributable to differences in public and private approaches as well as the number of rules that constrain renewal projects, including union rules.

If design is outsourced, it will normally be to a consulting engineering firm. In the United States, these are organized through state councils and the American Council of Engineering Companies (2011), which was formerly the American Consulting Engineers Council or ACEC and has headquarters in Washington, D.C. In 2001, when the first edition of this book was prepared, ACEC reported 5,800 member firms. In 2011, they indicated over 5,000 firms, indicating relatively stable membership. Consulting firms come and go, especially small ones, but when all firms are included, the national total will normally range between 10,000 and 20,000, according to the economic surveys of the Bureau of Census (Grigg, 2010).

The engineering design cost of a project might be 10% to 15% of the construction cost, depending on circumstances, and it might seem like a major expense, which it is. However, considering that water, wastewater, and

stormwater facilities can last a long time, engineering may be a much lower proportion of life-cycle cost than it is of initial cost. If good engineering produces longer life, lower maintenance, and more effective operation, the payoff from quality engineering is high.

To illustrate, say you have two options for the engineering design fees for a facility with a $1,000,000 construction cost. The design work for Option A costs 10% of construction cost ($100,000) and for Option B it costs 15% ($150,000). Assume that the result of Option A is a facility that requires $150,000 per year in maintenance costs, but Option B engineering can produce a facility that requires 25% less annual O&M cost, or $112,500. Also, the Option B facility will last longer at 40 years rather than 30 years. Calculating the life-cycle costs of Options A and B shows a savings of $43,000 in annual costs, mostly from the reduced O&M. The present value of the savings is $362,000, which yields a benefit-cost ratio of 7.2 for the added design cost of $50,000. The calculations were made for a 7% interest rate, but the benefit-cost ratio of over 7 remains about the same if the interest rate is lowered to 4%.

Of course, the indication of a high return from better engineering depends on the assumptions about the numbers, but the approach seems logical, assuming that the better design does yield a superior product. In any case, the lifetimes of pipelines, the most expensive components of water, wastewater, and stormwater systems, should be much longer. As Chapter 9 explains, some of them should last 100 years or more, with minimum repair, rehabilitation, or replacement (3Rs). Repair, rehabilitation, and replacement of these components also require attention to design and construction problems, in a similar way as original construction. Chapter 9 provides more insight about the economics of these 3Rs.

Management of Engineering Services

In its manual of practice about consulting engineering, the American Society of Civil Engineers (2003) includes the following topics, which indicate the range of work done by consultants:

- Practice of engineering (professional responsibility, client–engineer relationships, and selection of a consulting engineer)
- Classification of engineering services (feasibility investigations, appraisals and valuations, preliminary design, and operation)
- Guidance on the selection of an engineer and the selection procedures available
- Methods of charging for engineering services (hourly billing rate or fixed price)

- Total project cost (legal and administrative costs, and contingency allowance)
- Contracts for engineering services (contracts with associate professionals, limitation of risk, and partnering)
- Other services (field investigations and data collection, environmental impact assessment, preparing reports and impact statements, design services, preparing specifications, securing bids, observing construction, testing and evaluations, and making appraisals)

Selection, contracting, management, and compensation of consultants are responsibilities of the owner, normally an infrastructure management organization. The selection and contracting arrangements have varied over the years, and some important issues are involved. Some 40 years ago when I entered the consulting field, the ideal selection method to our firm was to obtain an opportunity to submit a proposal, either on a competitive or sole-source basis. Selection would be only on the basis of qualifications, but not on price. Once selected, the consulting firm would provide a fee schedule to the owner, who could accept it, reject it, or negotiate.

Over the years, lawmakers and regulators have claimed that procedures such as this comprise restraint of trade, and they have imposed requirements, especially for publicly funded projects.

Today, the selection of consultants is usually through what is known as *competitive negotiation*, a process that has superseded the earlier practice of selecting firms without a structured decision process. This procedure, advocated by ACEC and in compliance with the restraint-of-trade requirements of the federal government, provides an alternative to the lowest-bid process, which is not seen to lead to the highest quality work or the best arrangement for either client or engineer.

This process has found its way into some state laws, such as in Florida's Consultants' Competitive Negotiation Act (American Council of Engineering Companies of Florida, 2011). The law governs selection of architects, professional engineers, landscape architects, and registered surveyors and mappers. It covers public announcement and qualification procedures, competitive selection, and competitive negotiation. It prohibits contingent or "finder" fees, and it also specifies separate procedures for design-build contracts.

To select the design professional, ASCE recommends a qualifications-based selection (QBS) process, where the design professional submits statements of interest and qualifications. After the owner selects a design professional on the basis of qualifications, negotiations include compensation. ASCE believes that the best agreement results from establishing a fee after scoping discussions. QBS is not completely different than competitive negotiation, but the difference is in the required competition for the initial selection.

Regardless of the selection method, when a request for proposals is used in the selection of consultants, the client uses the process to provide a clear statement to the engineer and all others involved of the scope and objectives of the project. The preparation of proposals by consultants is a creative process, and the engineer expresses ideas about the solution of the client's problem as well as presenting credentials.

In competitive negotiation, the client asks engineering firms to submit qualifications and performance records. Factors to consider in developing a short list are: technical qualifications, experience in similar projects, reputation, timeliness, mobility and workload, and financial references. Firms making the short list make presentations explaining their concepts of the work to be done. The client ranks the firms and begins a negotiation with the top one. The negotiation involves the scope of work and other contract provisions and, finally, the compensation. If the negotiations are successful, the contract is drawn. If not, the next firm on the list can be asked to begin negotiations.

The management of consultant activities begins with the preparation of the contract that specifies the scope of work and all items that are required for delivery. Also, regular reports are required from the consultant. Frequent meetings are required to maintain coordination. The consultant should be viewed as an extension of the client's staff in one sense, and as an independent contractor needing direction in another sense.

A competent design engineer is worth a lot because of the value good designs bring to the construction process and to the life cycle of the facility being designed. This competency extends to diagnosis of problems, designing solutions, selecting components and methods, and describing these on drawings and in specifications.

Problem diagnosis requires extensive knowledge of the regulatory and service environments for water supply, wastewater, and stormwater. Designing solutions requires knowledge and experience of successful design approaches, perhaps learned from actual systems and their operators, rather than from textbooks, which are useful but necessarily general.

Selecting components and methods requires experience, knowledge, and familiarity with the industry. The designer must attend trade shows and conventions, visit successful plants and manufacturers, and generally maintain a high level of knowledge of trends in industry technologies. Regulators may also be a source of useful knowledge about successful components and methods.

Describing solutions, components, and methods on drawings and in specifications is a continuing challenge to designers. Educators hear a constant refrain from industry to teach students more computer-aided design (CAD) methods (also CADD for computer-aided design and drafting) so the students will be competent in them when they graduate. This is a difficult assignment because:

Learning to prepare drawings requires much more than learning a computer program.

The computer programs are complex and require considerable time to learn well.

CAD technologies are continually changing.

In my university, we teach basic CAD skills to students so that employers are satisfied with their initial abilities. However, the general issue of teaching CAD masks a developing dilemma within the design industry—how to prepare the most effective construction drawings. The problem was outlined in a feature story in *ENR*, where contractors said that the quality of drawings had diminished over the years, and that drawings were uncoordinated and lacked detail and dimensions (Post, 2000). Designers countered that contractors view drawings as ways to request extras by alleging missing data, and that the requirements for drawings increase at a time when budgets are cut and owners make more demands for quick completion of design projects.

Issues such as this must be addressed no matter what technique is used to put drawings on paper. One issue is the increasing complexity of facilities and the capability to illustrate designs by drawings. Years ago, facilities were simpler and there were no civil, structural, mechanical, electrical, and plumbing drawings; the contractor figured these out from floor plans, elevations, and building sections.

Behind the problem is the alleged poor quality of electronic drawings. These often present problems to contractors, who allege that designers sometimes do not understand their designs and produce "pretty, unchecked CAD drawings." Of course, there are many advantages to CAD, such as enabling use of standard details. Disputes revolve around incomplete documents and contribute to the litigious nature of the design and construction business. Legal, governmental, and financial drivers divert designers from their core task of preparing drawings.

There is a need to rethink the design process, including design, bid, build, and other delivery methods. Quality construction, as outlined elsewhere, requires review and checking. If designers should design and builders should build, is it acceptable for engineers to pass work down the stream to the contractor and the detailers and estimators working for him or her?

One possibility is a trend toward negotiated design-build systems, where the general contractor or construction manager is selected at the same time as the design professional. The negotiated price delivery system enables preconstruction design review meetings and constructibility reviews, which may include subcontractors and suppliers.

Electronic drawings and project Web pages are helpful, and many wonder if we are moving toward a computer-facilitated construction industry. If we are, current problems such as the dilemma over drawings will have to be solved.

TABLE 5.4

Best Practices for Design Review

Owner's role	Be a smart buyer with an adequate in-house staff
	Develop a scope of work that fully defines the owner's needs
	Avoid the temptation to micromanage design reviews
Teamwork and collaboration	Use team building and partnering to build good working relationships
	Involve all interested parties in design reviews from the inception of planning and design
	Use the same architectural and engineering (A/E) firm throughout the facility-acquisition process to maximize continuity
	Use senior, experienced personnel to evaluate the design process and guide the review
	Avoid changing participants during the review process
	Participate in a design awards process to recognize and reward excellence
Advance planning	Focus attention on review early in the process to maximize improvement
	Do not start plans and specifications until preliminary engineering is complete
Process	Tailor design review to project specifics
	Maintain momentum and keep facility acquisition on schedule
	Attend to interfaces between civil, structural, electrical, and mechanical facets
	Exploit technology, especially information technology
	Conduct a post-occupancy review to identify lessons learned
Benchmarking	Assess benefits of design review
	Document unusually good and bad performance

Peer review can add value to the design process and, according to ASCE (2000), is the "highest level of action to improve quality in design of constructed projects." After designs are completed, design-review tools such as "value engineering" can be used to check if the design is optimum for the cost. Best practices have been identified for design review, as shown in Table 5.4 (Spillinger, 1999).

Value engineering is one of several cost-reduction methods and does its job by analyzing functions and asking whether methods, processes, and materials that have been in use for years could not be replaced by more economical elements. It asks the following questions: What is it? What does it do? What must it do? What does it cost? What other material or method could do the same job? What would the substitute method cost?

Construction Phase

The goal of the construction phase is to build the project as close as possible to the final design, including cost and all other constraints. A constructed project will involve many design parameters, including location, specifications, methods, and other details. As shown in Figure 5.3, these include the owner's requirements, cost and funding available, social and environmental constraints, regulatory considerations, and local site conditions.

If the project is not constructible, then the design will have to be modified. Should this occur, information should be fed back into the design process so that future problems are eliminated. Even if the design is constructible, changes may occur during the construction phase. A common cause is unavailability of the specified construction materials. Another common cause is discovery of an unanticipated field condition. All construction changes must be evaluated to ensure that the design integrity of the project is not compromised.

The construction involves complex operations that must be designed to fit the infrastructure situation involved. The construction process involves bidding, review, award, organization, construction, inspection, and acceptance. A formal process for these steps has been developed over many years as a

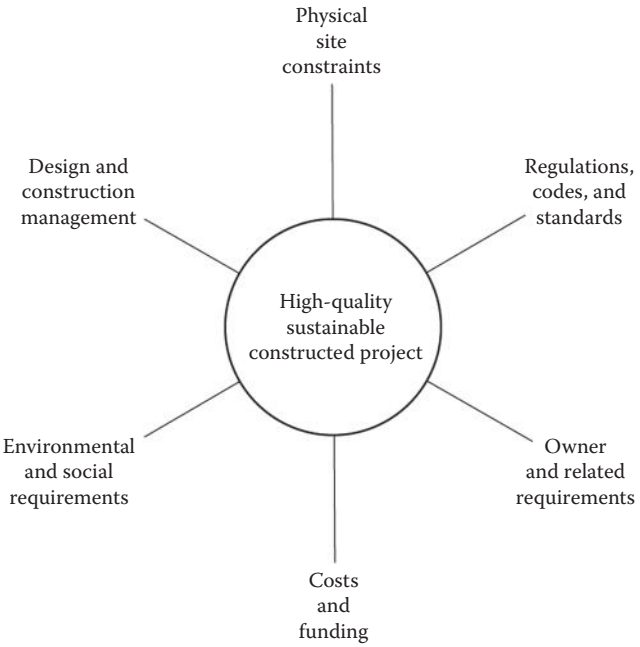

FIGURE 5.3
Elements of high-quality constructed project.

requirement to control costs, the quality of construction, and the quality of the final product. The construction phase begins with the preparation of the contract documents. Quality control and quality assurance continue throughout the process, culminating with the final inspection and acceptance.

Construction documents are described by publications of the Engineer's Joint Contract Documents Committee (EJCDC). ASCE (2011) has published sample forms and documents from this committee that include documents for construction, the owner and engineer, design/build, engineer and subconsultant, environmental remediation, funding agencies, joint venture, peer review, and procurement. These include many specific forms, such as agreements between parties, standard general conditions, application for payment, bid bonds, and standard form of agreement between owner and engineer.

A number of tools are available to help the project manager, although no cookbook method can anticipate every eventuality. A project management system utilizes an integrated approach to successfully control and direct a project. A project is a definable concept that employs planning, design, finance, construction, and control to achieve an end. Management is the activity that directs operations to complete the project on time, within budget, and at an acceptable level of quality. An information network integrates functional requirements through levels of management to direct and guide the project to an efficient end (Colorado State University, 1984).

Project management tools that can be used to improve overall effectiveness include: a good definition of project scope; clear roles and responsibilities; effective documents for design and finance procedures; valid estimates; activity-based schedules; cost-control systems; QA/QC (quality assurance/quality control) systems; information-handling systems; change-order handling systems; and project management manuals.

Figure 5.4 illustrates tasks of the construction management process. The project manager (on the right) is on the job site and explaining to a student group how the work is organized. He is on site continually, making adjustments with the engineer and constructor as needed for this large stormwater project.

Some public entities have project management manuals or guidelines in other forms. Other manuals and texts present general guidance about phases of project management—as, for example, Levy (2002), who presented the main elements of project management—that practically comprise a list that could be used for a curriculum in construction management:

- Planning, approvals and permits, financing, and organization of project team
- Selection of design professional and design process
- Selection of constructor
- Start of the construction process (types of contracts, role of construction manager during design and construction stages, partnering, bonds)

FIGURE 5.4
Project management for stormwater pipeline installation.

- Communication systems
- Risk and liability control
- Structure of construction contracts
- Estimating
- Project organization (office organization, job files, specifications, estimates, shop drawings, inspections and testing, scheduling, field organization)
- Subcontracting and purchase orders
- Cost-control procedures
- Change orders and liquidated damages
- Project documentation
- Claims, disputes, arbitration, and mediation
- Project delivery methods (design–bid–build, design–build construction management, owner–construction, and build–operate–transfer)
- OSHA and safety in construction
- Acceptance of project
- Implementation and startup of facilities
- Project closeout

The owner of a water, wastewater, and stormwater system will normally be a public agency or private utility and have an engineering staff. A small entity might contract with an engineer to be the owner's representative to work with the design professional and constructor. In any case, the owner's engineer has a number of important responsibilities.

Engineering functions relating to design and construction go beyond the design contract and process to include a number of ongoing responsibilities. In a text about public works management, Martin (1986) listed processes that fall into the category of engineering and contract management. From these processes and with other information, Table 5.5 was compiled to show in-house engineering responsibilities.

Codes and standards regulate the quality of materials and procedures. A code is a system of laws, rules, or regulations, for example a building code or a code of regulations. Standards are criteria, or measures for comparison of qualitative or quantitative values. A benchmark is very similar, a standard to measure against for comparison. Specifications are statements prescribing materials, dimensions, or workmanship for something to be built or installed.

Model designs are systems of components that have been shown to work and are worth emulating. Some water and sewer designs are repetitive, and it is not always necessary or desirable to develop a unique design for each project. For example, a book of model culvert designs would show placement and details that could be used in design. State departments of transportation develop design manuals that include suggested procedures to determine the size and

TABLE 5.5

In-House Engineering Responsibilities

Function	Responsibility
Surveys	Usually outsourced but could be in-house
Studies and investigations	Usually outsourced but could be in-house
Capital improvement program	Usually in-house
Planning	Some in-house, some might be outsourced
Design and cost estimating	Usually outsourced but could be in-house
Construction contracting	Mainly in-house but could be outsourced
Construction inspection and supervision	Usually outsourced but could be in-house
Preparation of construction and reports	Usually outsourced but could be in-house
Critical path method and PERT charts	Mainly in-house but could be outsourced
Maintenance, repair, and reconstruction	Mainly in-house but could be outsourced
Interfacing with developers, consultants, and other private sector participants	Mainly in-house but some could be outsourced
Retention and use of consultants	Usually in-house
Setting standards for infrastructure	In-house
Maintenance of maps, records, drawings	In-house

shape of highway culverts. This procedure will list the steps in the process, including recommendations on the use of specific models and design codes.

The experience of the profession should be used in this way to document accepted solutions to standard problems. These accepted solutions should have been validated in the field and usually consider risk through factors of safety.

The engineer should consider risk and uncertainty during the design process, and while design and analysis normally use standard procedures and codes, the engineer should understand how these consider risk. In engineering projects, risk is the probability that a project will not meet its demands over a specified time period, and a factor of safety is the ratio of the capacity to the demand for a project. Design codes usually embody factors of safety to account for variable aspects of the project.

During the design process, the engineers attempt to identify the possible sources of failure and to quantify the probability associated with those sources. The designer wishes to provide the capacity in the project to meet the project requirements within a specified probability of failure. This is covered in Chapter 8 under vulnerability analysis.

Managing standards is an important activity in all industries. Standards, guidelines, and codes are managed by professional organizations. Figure 5.5 shows a sales display of such material by the American Water Works Association.

Many standards are involved in water, wastewater, and stormwater systems because of performance, safety, public health, and environmental aspects. On a national basis, two main standards organizations are the

FIGURE 5.5
Publications display at convention of American Water Works Association.

American National Standards Institute (ANSI) and the American Society for Testing and Materials (ASTM). The American National Standards Institute has over 13,000 standards from a number of industries (see www.ansi.org).

The National Institute of Standards and Technology (NIST) is a federal agency concerned with standards setting. Internationally, the International Organization for Standardization (ISO) coordinates standards and the International Building Code Council coordinates building codes.

ASCE publishes engineering standards, some of which relate to the water industry. For the water industry, AWWA publishes many standards, to be discussed in the next section. Also, the NSF Foundation (formerly National Sanitation Foundation) has standards on bottled water, water treatment, wastewater treatment, and plumbing and faucets.

AWWA (2011) has published consensus standards since 1908. Today, AWWA standards cover 116 products and procedures. They provide minimum requirements for drinking water systems and are widely used, including in other countries. While compliance for AWWA is voluntary, some standards are mandated by utilities and regulatory agencies. AWWA standards are not specifications, certifications, or approvals of any product. A standard does not provide all information necessary for a design and may not cover all parts of a project. AWWA does not test products, and no products are "AWWA approved." For that reason, there have been experiments with creating instrument testing and approval services for water and wastewater.

Volunteer committees develop AWWA standards, and consensus is reached by representatives of all segments of the drinking water community. The AWWA Standards Council and Executive Committee ratify standards. Categories of AWWA standards are

- Groundwater and wells
- Treatment
- Filtration
- Filtering material
- Softening
- Disinfection chemicals
- Coagulation
- Scale and corrosion control
- Pipe and accessories
- Ductile-iron pipe and fittings
- Steel pipe
- Concrete pipe
- Asbestos-cement pipe
- Valves and hydrants
- Pipe installation

- Disinfection of facilities
- Meters
- Service lines
- Plastic pipe
- Plant equipment

WEF is not as active as AWWA in standard setting, but publishes some water testing standards, which are registered with ASTM. These are published in ASTM standards on environmental sampling. Like AWWA, ASCE has a rigorous process for reviewing standards and is active in standard setting related to water, wastewater, and stormwater systems. ASCE will cooperate with AWWA and WEF for water and wastewater standards, and it might take the lead on standards related to stormwater and flooding.

In addition to national and international standards, local codes specify details of water, wastewater, and stormwater as well as plumbing installations. For example, local building codes, subdivision and stormwater regulations, and state-level rules, such as in an agency like the Texas Department of Health, may specify rules for design and construction.

Design Guides for Water, Wastewater, and Stormwater Systems

Many civil engineers design water, wastewater, and stormwater facilities, but some components or situations may require experts and state-of-the-art knowledge. General-purpose facilities such as pipelines and pumping stations are more likely to be designed by nonspecialist civil engineers, and many miles of water pipe, sewer line, and storm sewers are similar to each other and follow fairly standard installations. Also, many water, wastewater, and stormwater components require site work and buildings requiring the same design inputs as other types of facilities.

On the other hand, treatment systems may require specialists who are trained and experienced in how different components perform with local source waters or wastewater generated in a particular city. This need for specialists has contributed to the emergence of the environmental engineering specialty, which crosses several disciplines of engineering, especially civil and chemical engineering.

Design information for water, wastewater, and stormwater facilities comes from a variety of sources. AWWA's manuals present useful design information for water supply facilities. WEF provides handbooks and manuals for wastewater and stormwater, and ASCE provides general design information as well as a comprehensive manual on stormwater.

Designing water, wastewater, and stormwater systems involves many similar considerations. Planning involves setting of goals, defining regulations and criteria, collecting basic data, analyzing basins and topographic situations, formulating options, and screening options to find the preferred ones. In preliminary design, you evaluate alternatives and recommend final design. In final design, the grades, geometry, elevations, and dimensions are selected, and systems are designed hydraulically.

Design conditions include hydraulic, earth, groundwater, and superimposed loads. Structural design will include stability analysis, structural members, bedding, and safety factors. Components that require design include facilities of different kinds and hydraulic components of the systems themselves. Chapter 2 discusses each facility type separately.

Data required in the design process include surveys and investigations, topographic mapping, aerial photographs, maps of vegetation and soils, property surveys, other survey data, and property maps. Field investigations will include basin boundaries; land uses; flow and channel characteristics; sites for facilities; physical features that affect location of facilities; rights-of-way and easements; and meteorologic, hydrologic, and hydraulic data. Regulatory data also must be collected to determine rules and codes to follow.

Design of water supply source facilities depends on whether surface or groundwater is used, and may include dams, wells, and support facilities. The greatest hurdles in recent years have been obtaining approvals and permits. Designing source facilities requires integrated knowledge, and all of the needed information is not likely to be found in one source. There are, of course, numerous excellent sources on issues related to water supply, but to design a supply requires knowledge of surface water, groundwater, dams, pipelines, etc. Water supply is difficult to gain approvals for, and water supply development faces a number of constraints (Graham et al., 1999).

Designing treatment plants is highly specialized and depends on source waters. Several texts are available. AWWA's (1999) handbook provides a good overview, and specialized research reports are probably the best source for unique problems of waters with special requirements.

Pipeline materials offer numerous possibilities and choices for design, as discussed in Chapter 2. Distribution systems design also involves pumps, valves, and other components. Mays's (2000) handbook presents information such as pipeline preliminary design (alignment, rights-of-way, and underground conflicts), materials, and water quality related to construction (disinfection, flushing, and cross-connection control). Design conditions for distribution systems include hydraulic, earth, groundwater, and superimposed loads; stability analysis; structural members and bedding; and safety factors. The designer might also want to consult AWWA and other manuals for guidance in design. See Chapter 2 for a listing of some manuals.

A good reference for wastewater collection is the manual by WEF and ASCE (1982), and Chapter 2 has more information. The engineering steps

required to design sewers may include special topics such as tunnel construction, trench construction, or trenchless technologies. Special construction challenges include crossings of railroads, main traffic arteries, and streams and rivers. Outfall structures must be built, including ocean outfalls in some cases.

Similar to water treatment, wastewater treatment involves numerous specialized design features. The text sponsored by Metcalf & Eddy, Inc., is a good example of comprehensive treatment of design topics (Tchobanoglous, Burton, and Stensel, 2003). ASCE (1992) Manual 77 (developed with WEF) covers topics related to design and construction of stormwater systems.

Many issues remain to be worked out in design and construction of quality water, wastewater, and stormwater systems, and the technologies should be appropriate for the economic and political setting where systems are built. For example, Figure 5.6 shows canal construction in a developing country. In many countries, technology and income levels require different approaches to design and construction than are practiced in countries with greater per capita resources.

For future information, water industry associations offer a great deal of guidance for design and construction of water, wastewater, and stormwater systems. AWWA, WEF, and ASCE will continue to develop design and construction manuals, and their research foundations will sponsor future projects, as will USEPA. Also, suppliers to the industry participate. For

FIGURE 5.6
Canal construction using hand labor. (Courtesy of World Bank.)

construction issues, the National Utility Contractors' Association (NUCA, 2011) has about 2,000 members engaged in construction of pipes for storm and sanitary sewers and drainage, water lines, cables, ducts, conduits, and other utility work. NUCA is also engaged in related projects such as sanitation, sewage disposal, and irrigation. NUCA represents the policy interests of contractors with regard to state and local codes and federal programs. The National Association of Sewer Service Companies (NASSCO) also provides technical assistance for infrastructure renewal technologies. A number of other suppliers provide assistance, such as the Ductile Iron Pipe Research Association (DIPRA) and the Plastics Pipe Institute (PPI).

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6

Financial Management for Urban Water Systems

By the end of the 20th century, a clear picture had emerged of high levels of deferred investment in renewal of water and wastewater infrastructures, and it appears that this problem may get worse before it gets better. Fortunately, the asset management tools explained in Chapter 3 and the capital planning methods of Chapter 4 explain how to request funding and manage assets, but the real question is: Where will the money come from?

Many ideas have been developed for finding the money. USEPA's (2008) suggestions for possible strategies include rate structure revisions; funding a dedicated reserve from current revenues; and financing asset rehabilitation, repair, and replacement through borrowing or other financial assistance. Financing methods such as these are explained in this chapter, which also summarizes the knowledge needed to manage the finances of water systems.

With the United States in recession and governments seeking to cut spending, it will be difficult to increase the rate of investment unless businesslike approaches to enterprise management are taken. The financial crisis had roots in the housing sector, which drives demand for new water systems and investment for renewal of existing systems. While it might seem that the financial outlook for urban water infrastructure has worsened, prudent policies can turn the situation around, but they will require effective financial management to provide the needed reforms.

This chapter covers financial principles and information required to manage infrastructure. The manager needs this information to prepare budgets and business cases to justify them, to read and understand financial statements, to float bond issues and stay away from the trouble caused by excessive debt, to prepare financial reports, to use cost accounting to manage programs, and to explain tax and rate proposals to the public and policy makers.

The financial management principles covered in this chapter are needed to implement reforms to respond to: the difficulty in raising capital for new or renewed infrastructure investments, the need for rate increases to provide the continuing funding for operations and maintenance, and the need for adjustment of standards and expectations so that we can afford the systems on a sustainable basis. The focus in this chapter is on financial management for line managers and executives, who must use financial tools to follow the money as they manage infrastructure. It goes without saying that an adequate funding base for operations, maintenance, and renewal of water

systems is important to utilities, and this requires involvement of all managers and the financial staff.

The material in this chapter has been tested in presentations to professionals and the public as well as to graduate engineering students. It has technical content for utility managers but also is addressed to nontechnical managers. In addition to guidance for financial management, the chapter explains the financial statistics of water, wastewater, and stormwater systems and why the deferred investment in infrastructure occurs. The chapter is not meant to be a financial guide so much as it is an introduction to water, wastewater, and stormwater finance, with a focus on infrastructure issues. The guide by Raftelis (2005), along with appropriate AWWA manuals, provides more detailed step-by-step approaches.

Water systems finance can be a dry subject, especially when it is presented abstractly. To get around this problem, this chapter presents examples from the actual financial plans and records of the Fort Collins, Colorado, water utility. The financial plans and documents can be downloaded in their full forms from the Internet, and they make excellent instructional materials to illustrate how the finances of infrastructure work. A summary of these plans and records is included as an appendix to this chapter, and examples drawn from it are worked into the discussion along the way.

Financial Knowledge for Water Systems Management

Most utility management activity takes place in a public sector environment where rules of governmental accounting apply. For example, government-owned utilities prepare their financial statements in compliance with standards promulgated by the Government Accounting Standards Board (GASB). However, some water companies operate as regulated privately owned utilities, where private sector accounting rules and rules of state public utility commissions apply. Many of these companies operate across the United States, and management of water utilities crosses into both the public and private worlds of accounting and finance.

Picture the engineer or rising manager who seeks an understanding of the financial side of managing water, wastewater, and stormwater systems. This might be the case for an engineer or operator who rises from the technical ranks into management. What elements of knowledge would be required in a course for this rising manager? The knowledge elements would correspond in a practical way with the organization of financial knowledge for other management scenarios, but they would focus specifically on the water systems and services being managed.

There are actually quite a few of these knowledge elements, which would include budgeting and financial planning, accounting and reporting, revenue

generation, taxation, cost control, capital markets, financial regulation, and knowledge about public finance responsibilities. The rising manager would need to know why these knowledge elements are important and how they apply in specific ways to job responsibilities.

The water, wastewater, and stormwater manager works with financial staff and other managers to obtain funding through the budget process and then to manage funds through control and reporting systems. Line managers oversee the preparation of budgets and manage revenues and costs. They must also plan the use of operating and capital finances, anticipate and develop proposals for rate increases, and seek capital for their systems by planning bond issues. Finance offices support this work of line managers with budgeting, accounting, auditing, assessments, purchasing, and treasury work done by specialists.

Where the finance office is located depends on the organizational chart. In Fort Collins, a finance staff operates within the Utilities Department and is named Utilities Finance & Budget. Located separately is the City Financial Services Department, which prepares the overall budget and financial reports. Financial Services had 39.85 full-time equivalent (FTE) employees for 2011, and Utility Services showed 91.3 FTE employees for customer services and administration, but this covers many more categories than financial management.

Each year the utility must issue a comprehensive annual financial report (CAFR) that outlines and discloses results of financial operations. The CAFR for Fort Collins was used to outline some of the financial results for the water utilities that are explained in this chapter (see the appendix to the chapter).

Managers budget for and supervise finances separately for operations and maintenance, which requires recurring expenses and the long-term funding of capital programs. For operations and maintenance (O&M), the issue is keeping costs under control, and in capital management, the issue is raising and managing funds for new or renewed systems.

Today, competitive pressures require line managers and financial managers to work together to use information to improve management in all areas. Bridging the dividing line between management and finance work can improve overall management of infrastructure systems by sharing data and making it more useful. The days when the financial section mainly kept the books but otherwise kept out of the way are over.

Deferred Investment in Water, Wastewater, and Stormwater Systems

Specific investment needs in local areas are mirror images of those that form the national picture of a large backlog of deferred investments in renewal

of water, wastewater, and stormwater systems. The challenge facing utility managers is to find sustainable solutions to these problems as they occur in their local systems.

On a national basis, legislators and officials require information about overall needs to make decisions about policies and appropriations, and the starting point is the inventory and condition assessment of the systems. In response, during the last decade a number of government and nongovernmental reports have addressed the national investment needs for water, wastewater, and stormwater systems.

According to USEPA's (2010) Community Water Systems Survey, the inventory of water mains in the United States is about 2 million miles of mixed materials and condition. Some utilities have pipelines that are more than 100 years old, and patterns of growth indicate that there is currently a large national inventory of pipeline at around 50–60 years of age. The buildup of replacement needs can be illustrated by a "Nessie Curve," which is a graph of investment needs by year and resembles the spine of the Loch Ness monster (Cromwell, Nestel, and Albani, 2001). Figure 2.10 displayed this curve, which was based on the trends in AWWA's (2001) *Dawn of the Replacement Era* report.

Chapter 2 includes data on the asset value or replacement cost of the national water supply pipeline inventory, which was estimated to be in the range of $1 trillion. It explained that based on current utility investment levels, water-main replacement cycles are close to 200 years, or around 0.5% annually on the basis of mileage. However, USEPA's (2009) needs estimates, which identify funding to overcome past deferred renewal, show that the nation should rehabilitate or replace about 30% of the asset value of its water supply infrastructure systems within the next 20 years. This would require a replacement rate of about 3% per year to catch up, far higher than the current rate of 0.5% per year.

Most funds must come from local ratepayers, and while it would relieve these local citizens if federal funds could subsidize these investments, current policy is for loans rather than subsidies. These are offered through the Drinking Water State Revolving Fund (DWSRF), which is a loan program that requires repayment on a revolving basis. It had an appropriation of some $830 million in FY 2009 and $1.4 billion for FY 2010. Since its inception in 1997, federal and state contributions have increased the DWSRF to about $14 billion in total capitalization and lending capacity (USEPA, 2011a). This helpful financing mechanism eases access to capital for water supply utilities.

Current spending shows that in in 2006, water systems incurred about $54 billion per year in total expenses and invested more than $13 billion annually in capital improvements. Of these capital improvements, 53% went to expansion, 37% went to repair and replacement, and 10% went to compliance. Major capital spending for transmission and distribution was about 50% of the total capital spending, so the indication is that capital spending

for renewal of water mains was about half of the 37% of the $13 billion, or about $2.4 billion per year.

In round numbers, the annual investment needed to stay even (based on 100-year pipeline life) is about $6.5 billion. This would increase to $10 billion to catch up with past deferred renewal. The current annual investment (based on the CWSS) is about $2.4 billion, so the added backlog every year (based on 100-year life) is about $4.1 billion. This estimate of added backlog compares well to the $5 billion per year capital gap estimate in USEPA's (2002) gap analysis of needed water and wastewater funding.

The conclusion from these approximate figures is that to finance the $4.1-billion shortfall would require an increase in annual water utility expenditures of about 8%, and if this is financed by increased user charges, they would amount to around $0.33 per thousand gallons, based on an assumed national average of 120 gallons per capita per day ($0.087 per cubic meter, based on 450 liters per day). These are affordable numbers, but utilities report strong resistance to any increases in rates for renewal or other needs from customers, and they indicate that it is important for leaders and customers to appreciate the need for the capital spending. Also, if rate increases cut water consumption, the net result might well be fewer funds for renewal.

Raftelis (2005) reported the results of studies showing that combined total water and wastewater bills amounting to 3%–5% of household income are the limits of affordability, and these vary by level of income. Commercial charges are passed on as costs of doing business and affect the competitiveness of businesses. Keeping rates low is important to all customers, but when the broader needs of infrastructure and the environment are considered, higher rates may be required to maintain existing service levels.

A similar analysis can be made of deferred investments in wastewater, although USEPA statistics for it are not as extensive as they are for drinking water. No studies of stormwater needs are available on a national basis, but in many local areas the need for stormwater upgrades is evident, and systems that were constructed decades ago are aging and will eventually need renewal.

Fort Collins does not report its deferred investment levels, and the city believes that it is mostly keeping up with needs. It does not report main breaks in utility documents, so it is difficult to determine trends in system conditions. On the basis of media reports and observed problems, the city does not seem to have the kind of spectacular failures that have been reported in some older and larger cities. However, as the information in the appendix to the chapter indicates, Fort Collins is investing little in water main renewal and may be delaying the time for reckoning to another day.

Financial Tools in Utility Management

Implementing best financial management practices is a good starting point for water organizations. The manager will need information from accounting, engineering, and financial planning and forecasting. Best management practices cover topics such as funding commitments, revenues, use of information, and budgeting (see Chapter 1). For example, the organization should seek sufficient funding to fully fund operating and maintenance costs annually. This prevents it from falling behind and getting into financial trouble, almost like running up a credit card bill.

Another best practice is to seek alternative methods for financing so as to spread the risk. Next, targeted and approved funding is needed for the capital improvement plan, which ought to include debt financing based on revenue bonds. In addition, a pricing system and developer contributions are used to finance capital investments, and local funds are leveraged with state and federal dollars.

In the budgeting process, operating and capital budgets should be linked. As an example, if you implement a capital project but fail to include operating and life-cycle costs, you are not considering the full picture. Agency requests should be supported by solid information. Estimates of costs and debt should be accurate, and long-term maintenance costs and life-cycle costing should be used to inform decision makers.

Field of Public Finance

Many of today's engineers lack formal training in financial management, but the field of infrastructure finance owes much of its development to the engineering profession. Prior to about 1900, finance was not the organized discipline that it is today. Engineers developed project finance, which became engineering economics, and the field of finance split off from it in about 1900 as business education became popular.

Government-owned water programs operate under the rules of public finance, which is the field that controls management of public funds for any government purpose, such as infrastructure or regulating the environment. The budget, finance, and accounting sections of a public organization provide the basic building blocks for financial management. They maintain the records and prepare the reports on which decisions are made. The internal or external auditors coordinate with the accounting office to make independent assessments of financial condition.

In public sector infrastructure organizations, the main goal is to provide mandated services on a cost-effective basis. To enable and control this,

public finance has its own standards, associations, and reference materials. The Government Accounting Standards Board (GASB) is important for this because it issues a guidance statement to go along with the generally accepted accounting practices (GAAP) that apply to all organizations.

How accounts are handled depends on whether a water service is offered by a general government department or a utility. In a government department, funding is often applied to mixed purposes, and revenues may not always go toward the program where they are generated. In a utility, the services usually focus on specific missions, such as providing the water supply or a stormwater service, and utilities can be organized as the management units for these purposes. Normally they will be enterprises and are organized to deliver a service and fund themselves from revenues.

Government-owned utilities follow the enterprise principle and are self-supporting from user charges. They normally do not receive regular subsidies from general revenues or intergovernmental transfers, although they may receive some funds from sources other than user fees. When a service is self-supporting, revenues and financial control are under the control of the manager rather than the political process. There are exceptions, and Chapter 2 presents a case where a subsidy was used in a construction grants program for wastewater.

The field of public finance involves a key set of government and other regulatory authorities. The following list identifies the key organizations that issue rules or important reports:

CBO: Congressional Budget Office performs analysis of budget for the legislative branch.

FASB: Financial Accounting Standards Board sets accounting standards for all types of organizations.

FASAB: Federal Accounting Standards Advisory Board performs similar functions to GASB, but for federal agencies.

GAO: U.S. Government Accountability Office (formerly General Accounting Office) is part of the Office of the Comptroller General of the United States.

GASB: Government Accounting Standards Board sets accounting standards for state and local government organizations.

GPRA: Government Performance and Results Act.

OMB: U.S. Office of Management and Budget controls the federal budget. State and local governments have budget offices with comparable roles.

Treasury: U.S. Department of Treasury handles borrowing for the federal government.

In addition to the work of these organizations, performance reporting at the federal level is required through the Government Performance Results Act of 1993 (GPRA), which introduced new controls and reporting requirements on how government funds are spent.

Regulated utilities follow the rules of commercial accounting, but they must also comply with regulatory commission rules. While there are quite a few regulated water supply utilities, there are fewer private sewer systems and stormwater systems. Despite this, a number of private or quasi-private entities operate utility-like operations. For example, a large industrial site or recreation complex will operate its own water, wastewater, and stormwater facilities.

Financial Planning

The core functions of financial management are to ensure that revenues and costs are in balance and that the organization is accountable financially. These are broad responsibilities, and for public organizations and utilities, the starting point is financial planning, which has the following steps, according to the Government Finance Research Center (1981):

- Revenue analysis to determine sources that are feasible
- Cost analysis to consider all costs of construction, operation and maintenance, and regulatory programs, as well as allocation to users (cost allocation)
- Institutional analysis to determine the ability of existing or planned institutions to manage the program
- Ability-to-pay analysis to determine the capability of the community and its citizens to bear the cost of the service
- Secondary-impacts analysis to study economic, social, and environmental issues
- Sensitivity analysis to examine changes in outcomes that result from changes in the assumptions

These generic steps, which were originally prepared to advise on wastewater program finance, apply to any public enterprise. They comprise a good outline for a financial study of any proposed project or program that requires revenues to be sustained. The guide by Raftelis (2005) also presents steps in financial planning.

Budget Processes

The process by which budgets are set determines the availability of funding for infrastructure management. Budgets are powerful planning and management tools for organizations and do more than just track expenditures. As an adopted plan for expenditures and revenues of the programs and divisions of an organization, the budget is used for policy, operations, financial control, and communications. It shows how money will be allocated to personnel, equipment, contracts, and other expenditures of programs, and it specifies sources of revenue, whether from debt, user charges, or other sources.

Utilities normally have separate budgets for capital and operations. In the operating budget, the ongoing expenses and revenues are projected, approved, and reported. Capital budgeting considers longer time spans for capital items such as facilities and equipment. Construction projects, equipment, and acquisition of real property are financed through capital budgets.

Chapter 4 explains preparations for the capital budget through a process of planning, which begins at the general level and drills down to the specifics. Figure 6.1 shows the relationship between the comprehensive plan, the capital improvement program, and the capital budget. Note that the sequence of comprehensive plan, capital program (by sector), and capital budget (also by sector) provides a way to rationalize expenditures according to needs and priorities.

The operating and capital budgets are planned through the budget process, which has many variations. They are planned on multiyear cycles, where the capital budget is linked to comprehensive planning and needs assessment processes, and the operating budget is linked to plans for services, organizational development, and programs. The budget schedule determines the sequence of activities in the cycle, as shown by Figure 6.2.

Note how, at any time, the manager may be involved with several budget years: one for planning, one for approval, one for operating in the current year, and sometimes even being audited for the previous year. In the planning year, the organization submitted estimates of funds needed for a multiyear period. In the budget preparation year, detailed planning leads to approval by the governing board of the next year's budget. In the year that the budget is spent, funds are those approved during the previous fiscal year.

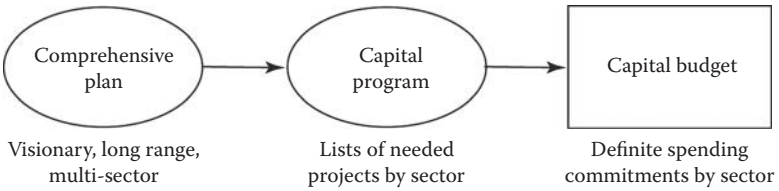

FIGURE 6.1
Hierarchy of plans, programs, and capital budget.

	Preplanning year	Budget approval year	Budget year	Budget audit phases
Federal cycle	Agency plans OMB analysis	President's message Congressional action	Agency spending Supplementals	Financial and performance audits
Local cycle	Preliminary department and program plans	Chief executive message Council actions	Department spending	Books close Audits

FIGURE 6.2
Budget schedule and process.

Public budget processes differ by government levels, and the federal process is more complex than those at state and local levels. At the national level, many interest groups and programs compete for funding, and decisions about the federal budget have far-reaching impacts on national economic health. The federal government has been in deficit spending for a number of years, and this tends to hold down the prospects for any subsidies to water and wastewater programs.

State and local governments and utilities have different budget cycles, but their processes are the same. The agencies prepare provisional budgets, which are reviewed by a budget office. Recommendations go to the chief executive, who submits the budget request to the approving body. In state government, approval is normally with the legislature, and in local government it is with a city council or board of directors.

In their attempts to use budgets to control programs and spending, public organizations are turning to variations of what can be called performance budgeting, or to link budget appropriations to past performance and alignment with public expectations and desires. For example, Fort Collins uses a Budgeting for Outcomes (BFO) process, which is explained in the appendix to this chapter.

Capital budget expenses are to build new systems or renew old ones. New systems may be required for growth, improvement, or regulatory requirements. Old systems might require major repairs, rehabilitation, refurbishment, or replacement. Capital budgets for these expenses should be linked to operating budgets and to capital planning and programming. Capital budgeting is "the way organizations decide to buy, construct, renovate, maintain, control, and dispose of capital assets" (U.S. Government Accountability Office, 1982). This refers to all types of organizations, as capital budgeting is required for many private companies as well as infrastructure organizations.

The capital budget should be prepared with the long-term cost of capital and risk management in mind. For example, a sewer collection system might be 50 years old and contain pipes that are too small and/or worn out. The decision might be to replace part of the system with newer, larger sewers

and to rehabilitate other parts. Funds for this would come from the capital budget. Another case might involve a water supply transmission main that is vulnerable to failure due to a flood. The utility might decide to install a parallel main over another route to increase reliability and reduce risk.

In linking the capital budget to the operations budget, the organization should consider what is required to sustain infrastructure and to use it effectively. Naturally, an effective workforce is required and, for example, in a stormwater organization, a section manager may supervise engineering and maintenance branches together. Employees might include an engineer, a floodplain specialist, a data manager, and maintenance workers. Salaries and benefits would be paid by the operating budget, but the group would also have a capital budget. The group will normally also have office and maintenance equipment, including vehicles, and the ongoing expenses would be paid by the operating budget. The equipment would be handled through the capital budget.

Public sector budgeting involves political maneuvering because so much money is involved. This is more evident at the higher levels of government, especially at the national level, where interest groups vie for favorable treatment in the federal budget, but even at the local level, budget politics are at work because interest groups and individuals have different views of how resources should be spent.

Budget politics is a topic for discussion among a set of political scientists (Wildavsky, 1984). Competition for funds can be internal and external and affects managers at all levels and is a form of bureaucratic competition. Infrastructure budgets involve a great deal of money and are especially susceptible to budget politics. Issues include agency roles and expectations, deciding how much to ask for, deciding how much to spend, department versus bureau politics, role of the budget office, deciding how much to recommend, appropriations committees, deciding how much to give, and client groups.

External lobbying for budget occurs due to the "iron triangle" phenomenon, which is discussed in more detail in Chapter 12 (see Figure 12.3). Interest groups seek budget appropriations to benefit from programs or increase their influence. They may even have paid lobbyists working to increase their budgets. Client groups at the federal level range from the elderly, who have a great interest in Social Security, to environmentalists who will lobby for more money to build wastewater plants. At the local level, developers watch the budget process to determine how much they will be expected to pay in infrastructure fees.

The internal politics have to do with gaining power and influence. Employees and managers may seek status and power within a public organization by growing their budgets. Deciding how much the unit will request is one tactic in budget politics. At lower levels, managers may ask for what they need and perhaps more, knowing they will be cut. Deciding how much to spend is the role of the executive leadership in the agency, which must

pare down competing requests. In infrastructure organizations, it is always easy at budget time to defer capital items that have long-term implications but few short-term consequences.

The budget office has a tough job in dealing with line managers at all levels of government. The budget officers must support the goals of top management, and these may not be the same as those of line managers. The budget office will decide how much to recommend to the approval authority. This will be different in a local situation than in the complex world of federal government politics.

At the state and federal levels, the perspectives of appropriations committees will be important. This is normally not a factor at the local level, unless the governing board has a budget committee to deal with. In the case of the Fort Collins BFO process, the area committees act like proxies for budget appropriation committees.

The policy organization decides on appropriations, as in the case of the annual appropriation ordinance of Fort Collins. It faces constraints in the form of available revenues and debt levels. The federal government is the only level that is normally allowed to go into debt, with the exception of government enterprises like utilities.

Budget methods continue to evolve, and Fort Collins's BFO is more than just a budget process and extends to a change in the philosophy of how government is run. Other budget techniques that have evolved over the years also seek to reform government processes.

Accounting and Reporting Infrastructure Condition and Needs

After planning and budgeting for infrastructure investments take place, the needs and expenditures are tracked through the financial accounting system. Accounting is the language of business, which requires records of the transactions of an organization and reports of revenues, expenses, and the balance among assets and liabilities. If a rising manager was going to take one course in finance, it should probably be basic accounting.

Basic Principles of Accounting

A professional receiving training in accounting from a business school can gain experience and become registered as a certified public accountant (CPA). Many other employees have on-the-job training or some qualifications to be involved in preparing accounts and analyzing financial information.

The accounting process uses information to create financial records of businesses, government, and nonprofit organizations. While methods differ, most accounting principles apply to all types of organizations. Infrastructure

management involves mostly government accounting, although many types of organizations must manage capital expenses (Razek, Hosch, and Ives, 2008).

In accounting, the basic transactions are recorded in journals and ledgers. Accounting statements such as the income statement and the balance sheet track the flows and levels of funds over time. Double-entry accounting tracks debits and credits as they affect assets, liabilities, and equity. Bookkeeping shows how transactions become debits or credits to different accounts. Accounting can be done by the accrual basis, meaning that transactions are posted when they occur, or by the cash basis, which tracks when cash changes hands. In the course of a given time period, such as a year, changes in revenues and expenses are recorded and appear on the income statement or operating statement.

Information about assets and liabilities is presented on the balance sheet or statement of financial position. The difference between assets and liabilities is equity or capital, and this provides the basic accounting equation: assets = liabilities + equity. An asset can and should be amortized and depreciated over a period of time.

As a municipal government, Fort Collins follows the same principles of financial accounting as other U.S. local governments. Accounting rules are not set in stone by a government agency but are instead regulated by the accounting profession itself. They begin with a core of the Generally Accepted Accounting Practices (GAAP). These are managed by the accounting profession through the Financial Accounting Standards Board (FASB). The Government Accounting Standards Board (GASB) was established in 1984 as a companion to FASB, and both are overseen by the Financial Accounting Foundation (FAF). Members of the FAF and of FASB are appointed by the American Institute of Certified Public Accountants and other financial organizations (Blossom et al., 2007). Prior to GASB, a National Council on Government Accounting (NCGA) set guidelines as a committee of the Government Finance Officers Association (GFOA), which was formerly known as the Municipal Finance Officers Association. Now, GFOA acts in an advisory capacity to the GASB. In a nutshell, government accounting complies with the GAAP and follows an overlay of special rules established by the GASB.

Another category of accounting applies to nongovernmental utilities that are regulated by state public utility commissions. Financial reporting by the regulated utilities that are also publicly held (such as large private water companies) are also regulated by the U.S. Securities and Exchange Commission (SEC). The National Association of Regulatory Utility Commissioners (NARUC, 2011) has a uniform system of accounts and specifies categories for water and wastewater.

The United States has a number of regulated privately owned water supply utilities, but fewer privately owned wastewater utilities. Large water companies may seek to buy wastewater utilities to add to their portfolios, however.

Stormwater utilities are wholly managed within government, although many private installations, such as industries and large farms, must also provide stormwater service.

Although they do not prepare official financial statements, line managers work with management accounting, which means to use and interpret financial information for management and control of the organization. The infrastructure manager requires financial accounts to track planning and control of the funding for operations. The operations budget is accounted for by keeping up with ongoing labor, supplies, and energy costs. The capital budget involves investments for construction, equipment acquisition, and property.

Management accounting refers to accounts produced for the internal use of managers (Storey, 2007). Whereas financial accounting emphasizes flows of money, management accounting should produce timely and useful statements so managers can make decisions about expenses and actions. However, management accounting does not normally produce much information on fixed assets because the information is not used much by managers. Rather, the situation is more like Peterson (1994) described: "Put it in, use, if it breaks repair it; if it breaks too many times, discard it and replace it." Fortunately, although asset accounting has not stimulated the interest of accountants and managers, new attention to fixed assets has begun to replace this old attitude.

Government Accounting Principles

Principles of government accounting have been developed and published by GASB (Blossom et al., 2007). These are updated periodically, and the main ones that relate to infrastructure systems are summarized here. An understanding of these principles will take you a long way toward understanding how financial management is done within utilities. Some of these principles are

1. A government accounting system must fully disclose operations of the government unit and comply with GAAP and legal and contractual provisions.
2. Government accounting systems should be organized around "funds" that are segregated to focus on special program operations.
3. Types of funds include the General Fund; Special Revenue Funds; Capital Projects Funds; Debt Service Funds; Enterprise Funds; and Internal Service Funds.
4. The number of funds should be minimized to eliminate undue complexity.
5. Accounts should distinguish between fixed assets and long-term liabilities in proprietary funds (enterprise funds) versus other funds.

6. Fixed assets should be accounted for at cost (historical cost).
7. Depreciation of fixed assets "should not be recorded in the accounts of governmental funds. Depreciation may be recorded in cost accounting systems or calculated for cost funding analyses, and accumulated depreciation may be recorded in the general fixed asset account group." (See later discussion of GASB 34 about this.)
8. The modified accrual or accrual basis of accounting should be used. This means that expenses and revenues are credited when they occur, rather than when the cash is received or disbursed, and that the financial reports will reflect a picture of the actual financial health at all times.
9. An annual budget should be used by every government unit.
10. Interfund transfers and proceeds of long-term debt should be recorded separately from fund revenues and expenses.
11. Common terminology should be used in budgets, accounts, and financial reports.
12. Financial reports should be prepared to facilitate management control, legislative oversight, and external reporting.

Fund accounting for public sector activities under GASB principles is important to show accountability rather than profit and loss. Funds are self-balancing accounts to report expenditures by designated purposes and are designated by account numbers. The National Council on Government Accounting suggests the following categories of funds, all of which you can view in the Fort Collins financial documents:

General Fund: Used to account for most of a municipality's operations such as general administration and police

Special Revenue Funds: Used for specific purposes such as a tax levy for parks

Capital Project Funds: Used to finance capital projects from a variety of revenue sources

Debt Service Funds: Used to collect funds to repay debt

Permanent Funds: Used for special purposes on long-term basis

Enterprise Funds: Used for separate enterprises to provide services to external parties, such as utility services

Internal Service Funds: Used to account for intergovernmental transactions of services and payments

The first five are governmental funds, and the next two (enterprise and internal service) are proprietary funds. Other types of funds can handle issues such as special assessments, investment trusts, and other fiduciary purposes.

Accounting for Fixed Assets

Infrastructure management deals more with fixed assets than with current assets, such as cash and accounts receivable. Fixed assets generally are tangible, have a life longer than one year, and are of significant value. They include property, plant, and equipment, and are sometimes called plant assets (Williams, 2007). The term *plant* might be confusing, but it originates from the fixed assets in manufacturing accounts. Property, plant, and equipment are usually separated in accounts. Fixed assets normally do not receive as much attention from accountants as current assets, which have more dynamic financial turnovers and greater effects on annual statements. In the case of private businesses, the annual results have profit and tax implications.

No comprehensive document has been published to bring the concepts of accounting for property, plant, and equipment together (Peterson, 1994). Accounting boards offer courses on capitalization of assets, but they cover tax implications or valuation, and do not discuss how to set asset policies and apply them within an organization.

Fixed assets are depreciated by accountants, but depreciation relates to tax obligations more than it does to condition of assets. In fact, in general government accounting for infrastructure, depreciation of fixed assets used to be optional. Now, with GASB 34, accounting for them is required. Depreciation accounting was already in used for the enterprise organizations that many cities use for their water, wastewater, and stormwater services.

In the past, GASB had a separate category for infrastructure fixed assets, which were defined as "immovable and of value only to the government unit." It authorized the nonreporting of these assets for other than enterprises and specified that if they were accounted, they should be in a general fixed-asset account group, which is an auxiliary record to be maintained at historical cost. Now, with GASB 34, government entities must report their capital assets in their annual balance sheet and income statements, even if they are not enterprises. GASB 34 was adopted in 1999 to identify the costs of acquiring, owning, operating, and maintaining infrastructure. It seeks to give governments the choice to adopt traditional methods of calculating depreciation based on historical costs or to adopt an asset-management system. Chapter 3 on asset management covers the procedures in more detail.

Accounting for fixed assets in the framework of management accounting is where the world of inventory begins. There is still a wide gap between compliance with rules, such as GASB 34 or depreciation accounting within utility enterprises, and the needs of managers to identify investment needs and budget the funds for infrastructure renewal.

In the case of regulated utilities, the cost of assets is part of the rate base, and attracts attention from regulatory commissions. Large sums of money can be involved in assessing the value of a system and the needs for investment, so fixed-asset accounting, including the condition of assets, is very important.

Fixed-asset accounting is important to doing an effective job in capital management. Peterson (1994) asked: "Do you have in place a process that monitors the current condition, evaluates the future need for replacement, and brings to your attention needs to modify that plan?" He also wrote: "There is a need to emphasize that assets must be managed, not just purchased, used up, and replaced." The objective is to provide not only accounting for assets, but to include that accounting in a process that will allow management to get the most out of the company's investment. It has become obvious that there is a need to change the manner in which management approaches long-term tangible assets. The many production facilities built in the United States are wearing out. Government infrastructures of roads, sewers, sidewalks, and utilities are all suffering from the concept of "put it in place and forget about it."

Financial Statements

GASB requires financial statements to be published in the comprehensive annual financial report, which contains three parts: introductory, financial, and statistical. The most common financial statements are the balance sheet, the statement of revenues, expenses and changes in retained earnings (income statement), and the statement of change in financial position. The introductory and statistical sections of the CAFR are more flexible than the financial statements.

The statement of revenues, expenses, and changes in retained earnings is like the annual water budget, where the report is of inflows, outflows, and change in storage. The balance sheet is like the report of how much water is in the reservoir at the end of the year, along with how much is owed to users and how much is expected from others.

Audits

No matter how careful management is, it cannot be fully objective, and an outside audit provides objectivity as a control function for the finances of an organization. Auditing is an important tool for management, since it also provides management consulting services to suggest how things can be done better.

The performance of an organization, including how well it uses its capital, can also be audited. To extend the concept of the financial audit into performance evaluation, the U.S. Government Accountability Office (1982) used the term *performance audit* to include financial, economic, and programmatic performance. Its explanations were as follows:

- Financial and compliance—determines (a) whether financial operations are properly conducted, (b) whether the financial reports of an audited entity are presented fairly, and whether the entity has complied with applicable laws and regulations.

- Economic and efficiency—determines whether the entity is managing or utilizing its resources (personnel, property, space, and so forth) in an economical and efficient manner and the causes of any inefficient or uneconomical practices, including inadequacies in management information systems, administrative procedures, or organizational structures.
- Program results—determines whether the desired results or benefits are being achieved, whether the objectives established by the legislature or other authorizing body are being met, and whether the agency has considered alternatives which might yield desired results at a lower cost.

Triple Bottom-Line Accounting

Infrastructure organizations can utilize "triple bottom line" (TBL) reporting to display achievements in the economic, environmental, and social categories. This can include financial data, but it would address more issues such as economic development and environmental and social positives and negatives. A TBL report can build on a regular CAFR with additional social, economic, and environmental results, or it can be a focused report with only economic, social, and environmental results. In that form, it would be like what is called a "popular report" in financial reporting. TBL reporting received its name from the sustainability movement, but infrastructure managers have reported economic, social, and environmental impacts in the past. These were often considered as planning reports, whereas a TBL report can be considered as a business report.

Revenue Generation

Although there are many financial issues, the bottom line in infrastructure management is to have enough revenue to manage the systems. Revenue generation is, of course, an important issue for all utilities, but water services have special issues because of their public and private aspects. The basis for charging for urban water services stems from the wet water and other services (such as storm drainage) delivered, which include components for private and public goods. This means that you can buy and pay for some of the water and related services as if they were offered by the private market. Other water and services provide benefits to society at large, and are public goods.

For example, water supply utilities deliver water for multiple purposes and can be considered as selling a commodity. They also provide water for fire protection and for various other public purposes, such as for fountains in community parks, and this is public-purpose water, not a commodity. The

private service delivered by a wastewater utility is to remove the unwanted used water while also providing public area-wide services to maintain a clean environment. Stormwater service is provided to protect and improve private property by removing excess water while also serving the public by keeping streets safe and the environment cleaner.

For a general revenue model, the main source of revenues for operations of urban water systems is from user fees and charges and, when appropriate, from public taxes. If it is an enterprise, it should be self-supporting from fees and charges. Capital revenues sometimes involve debt financing through borrowing, but borrowed funds are repaid from fees and taxes.

The Fort Collins financial model can be used to illustrate how revenue works. During the 1990s, when I served on the city's Water Board, the utility manager (Michael B. Smith) developed a diagram to explain to citizens and professionals how the finances worked. He developed the concept for the diagram shown in Figure 6.3, which illustrates typical revenue categories for a water and wastewater utility. The financing streams divide into system expansion (capital) and operations. Funds for expansion are mainly from developers or builders, and for operations they are mainly from customer charges, although the customer ultimately pays for expansion in the purchase price of property.

The developer or builder finances system expansion through plant investment fees (PIFs) and cash in lieu of water rights. The PIFs pay for the infrastructure, and the cash in lieu of water rights pays for water rights for new residents. Although water rights are a unique feature of western water systems, eastern water utilities incur water development charges that add to the cost of infrastructure.

In addition to operation and maintenance and administrative costs, customer water rates pay for facility replacement. In Figure 6.3, replacement is shown with operations charges, which are separate from expansion charges. Adding replacement to expansion creates the total capital category, and the separation illustrates a policy question of the extent to which renewal of infrastructure is to be considered within operational categories and/or capital categories.

The diagram shows the flow of funds from fees to debt service to illustrate how the customer pays for capital charges. Debt is used to finance capital costs and fees are used to retire debt. When a developer pays a PIF, the customer repays it in the price of the property, so in the end, the customer pays for everything.

As a self-supporting enterprise, the utility receives no tax subsidies, at least in the case of Fort Collins. Some infrastructure enterprises do receive some tax subsidies, and some public works services are financed by general taxes and not by utility fees. Fort Collins does a PILOT (payment in lieu of taxes) to the General Fund and an administrative charge that compensates it for services such as supervision and accounting.

In the past, property taxes were used for operating budgets more often, especially in sewer and stormwater services. Now, however, with the

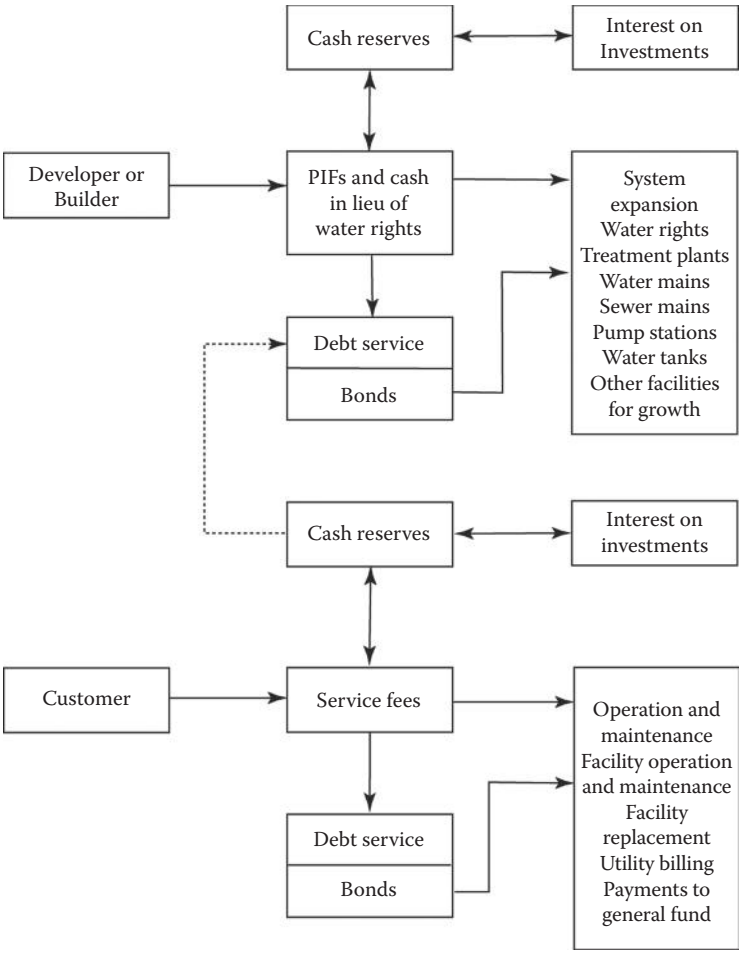

FIGURE 6.3
Utility financial flows. (Courtesy of the City of Fort Collins, Colorado.)

emphasis on enterprise budgets, the trend is toward greater reliance on user charges and the user-pays principle.

The theory of user charges is that people pay for what they use. There should be a close connection between service rendered and the charge imposed. Revenues should come from appropriate sources, and the operating and capital budgets are normally financed in different ways. Services should be charged according to benefits users receive, and user charges should be the basis for allocation of services. Charging schemes should be fair and reflect benefits received by users so that social equity results.

Operating funds should come from current revenues and avoid subsidies if possible. They normally come from fees and user charges, taxes, grants

and intergovernmental transfers, and interest income. The fees ought to reflect the cost of service, and the percentage of cost recovery through fees might vary with the type of facilities, the extent of benefit to fee payers, the level of service, and the ease of collection of fees.

Theoretically, fiscal discipline results if charges incentivize the customer to ration use of the service so that economic efficiency and equity are the result. Efficiency means no waste because the user gets the service paid for and use of the public service is rationed effectively. Electricity and phone service charges are familiar ones that demonstrate this principle. However, in some cases, water, wastewater, and stormwater charges are not high enough to attract much attention. This situation is changing and is not the case, anyway, in Fort Collins, where water and sewer charges are high enough to attract people's attention. You can see the direct link between the amount of water you use and your monthly bill, but sewer charges are based on the winter quarter average or indoor use and are not as sensitive to lifestyle as outdoor water use is. Stormwater charges are not linked to behavior but are set at lot size. So, the only decision you make that influences them is the selection of your property in the first place.

Some public utility services can be metered, such as use of water, electricity, gas, transit service, and use of airports, but others are hard to measure and public purposes dominate. Examples of these are environmental water quality management, air pollution control, and nontoll highway usage control.

Sometimes user fees are opposed because services bring social benefits that cannot be measured and charged for. A surprising example was 1990s opposition to water meters in Fort Collins. Some proponents of water rationing opposed water meters because they thought that the meters might enable discrimination against lower-income people. The utility explained that it was the rate schedule that could discriminate, not the meters, but the opposition occurred anyway.

Principles for user charges can be summarized as follows:

- They should be levied on beneficiaries of services.
- Prices or fees should be set at the incremental cost of providing the service, not the average cost.
- Peak-load pricing should be used to manage demand.
- Special provisions should ensure access to services for low-income residents where burdens result from marginal-cost pricing.
- User fees should be responsive to inflation and to economic growth.
- While rate setting differs across sectors of infrastructure and public services, a common set of principles for rates can be presented (Vaughn, 1983).

Some groups oppose rates as instruments to charge for public services. Their arguments focus on the obligation of government to provide services more uniformly and not only on the basis of a charge. These arguments include (Vaughn, 1983):

Social benefits: Services bring social benefits that cannot be measured and charged for.

Income distribution: Tax payments for services redistribute income to those who cannot afford vital services.

Economic development: Public facilities and services attract economic development and tax revenues to help finance services.

Earmarking: Dedicating tax revenues to services (a form of user charges) reduces budget flexibility and reallocation during times of changing priorities.

Coordination: Managing individual services with dedicated user charges inhibits coordination of public services.

Some services have direct benefits for individuals, and others serve distributed public purposes and may merit tax subsidies to spread charges across taxpayers. User charges dominate utility finances, but property, income, and sales tax revenues remain a source of finance for some infrastructure systems, particularly where it is difficult to identify beneficiaries. Tax payments provide for redistribution of benefits to those who cannot afford the services. Property taxes are ad valorem taxes that are usually applied at the local level; income taxes are used at the state level; and sales taxes are often found at both the local and state levels. It would be usual to find tax revenues supporting a water utility, but wastewater and stormwater utilities and programs are more likely to rely on them. A service may be individual, such as basic water service, but be required for public purposes such as for human rights and community sanitation. Sewerage service serves individuals and benefits communities. Residential telephone service benefits individuals but also knits communities together in functions such as emergency response.

User charges increased in popularity after taxpayer revolts that led to initiatives such as the 1978 Proposition 13 in California and Colorado's 1992 Taxpayer Bill of Rights (TABOR). Strong efforts to limit state and local tax collections continue. TABOR placed constitutional limits on state and local tax receipts, and this has placed very tight restrictions on funding for infrastructure as well as other government programs.

User charges can be viewed as a technique to get around tax limits or resistance to taxes. For example, in the 1980s, Fort Collins created a stormwater utility, which enables the city to collect both operating and capital fees on a monthly basis. The funds are used to improve systems on a basin-by-basin basis.

Rate Setting

Water Supply Rates

Water rates are normally based on principles such as those explained in the American Water Works Association's (2000) basic manual on rate setting. AWWA's Manual M1 is entitled *Principles of Water Rates, Fees, and Charges*, and is now in its fifth edition. It explains how the rate-setting process for water supply begins with determination of revenue requirements, the determination of the cost of service by customer classes, and the design of the rate structure. AWWA specifies two approaches to determine cost of service by classifying the costs differently: the commodity-demand method and the base–extra capacity method.

Many utilities are developing alternative rate structures to promote water conservation. These typically have increasing block-rate structures. The traditional method to compute rates was by cost of service, which reflects the marginal cost of operations. The economic theory behind cost of service is that efficiency in allocation of resources occurs when rates are set at the marginal cost of providing the service, which is the cost to add a new unit of capacity. Take the case, for example, where you provide 10 million gallons per day of treated water and add 2 million gallons per day of capacity at a cost of $3 million per year. The marginal cost of the added capacity is $4.11 per thousand gallons delivered. The average cost to deliver the current 10 mgd capacity might be less per thousand gallons, but marginal cost pricing would require the new capacity to be charged at its full cost. In a strict sense, this might create an inequitable situation where you distinguish between old customers who qualify for the old rate and new customers who pay the higher rate. The way around this is to charge the plant investment fee to pay for the new capital cost, under the assumption that the operating costs are about the same for old and new facilities.

In reality, the cost to develop a supply may not include all of the externalities, such as social equity and environmental quality, and a rate-setting body, such as a city government, may decide to set rates differently to recognize those. This is the basis, for example, for the "conservation rate" used in some water utilities.

The water rate in Fort Collins is based on the conservation rate, which is tiered. Then, on the sample bill shown in Table 6.1, the base charge of $13.60 is in place regardless of use. The first block of water use goes at a rate of $2.11/TG ($0.557/CM). (TG = thousand gallons; CM = cubic meters.) The next block goes at $2.42/TG ($0.639/CM), and the rest at $2.78/TG ($0.734/CM). The idea is that the increasing block rate will encourage people to conserve. Note in the bill that the average cost is higher than any of the block rates because it includes the base charge.

This is a summer month in Fort Collins, and for the two-person household shown during a 30-day month, the water usage was 307 gpcd (1.2 CM), which seems quite large except that it involved lawn irrigation. If the in-house use was 100 gpcd (0.38 CM), and if lawn area was 5,000 square feet (464 square

TABLE 6.1

Sample Water Bill from Fort Collins, Colorado

	Usage, Gallons (cubic meters)	Unit Charge, $/TG ($/CM)	Charge, $
Base charge			13.60
Block 1	7,000 (26.5)	2.11 (.557)	14.77
Block 2	6,000 (22.7)	2.42 (.639)	14.52
Block 3	5,400 (20.4)	2.78 (.734)	15.01
	18,400 (69.7)		57.90
Average $/1000 gal ($/CM)			3.15 (.832)

meters), the applied water during the month was about two inches, which is actually on the low side, depending on the weather.

Current actual water use in Fort Collins is in the 160-gpcd (0.61 CM) range, and a city committee is studying a target range to plan future water supplies. The estimating parameters are for in-house water use in the range of 100 gpcd (0.38 CM) and outdoor use to sustain reasonable green areas for public and private lands in the city.

Another emerging approach is the "water budget" rate structure being used by the City of Boulder, Colorado (2011). The user is entitled to a basic amount of water for indoor use (7000 gallons per month for a family of four) and pays a step increase rate according to remaining outdoor use and lot size. The extra charge for water is much steeper than Fort Collins's highest rate. Boulder's rates in 2011 per thousand gallons are shown in Table 6.2.

Wastewater Rates

Wastewater rates are set by different procedures than water supply, but utilities still try to link them to water use and thereby to demand for wastewater treatment. Prior to the 1970s, most wastewater charges were based on property taxes or were simply a part of a bundle of city services, but after the

TABLE 6.2

Rates Based on Water Budget in Boulder, Colorado

Block	Use, % of Water Budget	Rate, $/tg ($/cm)	Ratio to Base Rate
1	0–60	$2.18 ($0.58)	¾
2	61–100	$2.90 ($0.77)	1
3	101–150	$5.80 ($1.53)	2
4	151–200	$8.70 ($2.30)	3
5	More than 200	$14.50 ($3.83)	5

Construction Grants program, USEPA required user-charge systems as a prerequisite to obtaining funding. Now, wastewater is mostly operated as a utility where rates are set according to discharge to follow the user-pays principle.

For example, in Fort Collins, wastewater charges are based on the winter-quarter average water usage (January–March). To compute the charge, you use the average water use quantity for the winter quarter and apply the wastewater charge per thousand gallons. For residential use, the base charge is $14.79 and the volume charge is $2.87 per thousand gallons ($0.76/CM). If the average winter-quarter use for a three-person household was 100 gpcd (0.38 CM per person), then for January the use would be 9,300 gallons (35.2 CM) and the monthly charge would be $41.48. You can save money by cutting your in-house water use during the winter quarter, but it is difficult to save to the extent that you can with your outdoor water use.

Stormwater Rates

Stormwater is the newest water service that incorporates user charges. These started with the city's utility concept to enable it to collect operating and capital fees. This concept of charging for stormwater service as a utility rather than just financing it from general taxes goes back to the 1980s (Cyre, 1982). It was in that era that Fort Collins developed a stormwater utility, and charges were initially divided into development charges and monthly fees. The Plant Investment Fee (PIF), which was initially the Basin Fee, covered the infrastructure cost and was applied for any new impervious surface of more than 350 square feet (32.5 square meters). An operating fee was also charged.

The current stormwater (2011) PIF is $6,313 per gross acre (.404 hectare) for all areas of the city, based on this formula:

$$\text{PIF} = (\text{Gross acres of development}) \times (\$6{,}313/\text{base rate per acre}) \times (\text{Runoff coefficient})$$

where:

Gross area in acres of each parcel of land includes open space and rights-of-way.

The base rate is $6,313 per acre.

Runoff coefficient is determined by the percentage of impervious area in the development.

The runoff coefficients used are normally 0.5 for residential and 0.8 for commercial.

In the beginning, stormwater fees were about $2 per month per house, split about evenly between operating and capital charges. Now, Fort Collins has gone to a simpler formula, and the monthly rates are based on lot size (lot area plus share of open space in a development); a base rate of $0.0041454

in the city; and a rate factor, which is based on impervious area. For a 10,000-square-foot (929 square meters) lot with a rate factor of 0.25 for a very light impervious area, the monthly charge would be $10.36. However, an average lot might be 8,000 square feet (743 square meters) with an impervious percentage of 0.4 counting the roof, garage, driveway and patio, so the charge would be $13.27.

In Fort Collins, citizen resistance has capped the stormwater rates for the time being, and the rates have not increased for several years, while water and wastewater rates have increased. The citizen opposition has varied mixed reasons. The development community thinks the charges are too high. Progressive government people think the charges are too high also, but for different reasons. Some people thought that the floodplain management component was raising the value of land by using stormwater fees.

The opposition to stormwater utilities is felt around the country. Some antitax advocates call stormwater fees a "rain tax." Kaspersen (2011) wrote that there is fierce resistance to stormwater fees in many communities. A South Carolina county rejected a $12 per year fee, and one councilman complained about unfunded mandates from the federal government, while others felt the fee was not equitable. Colorado Springs, Colorado, established a stormwater enterprise in 2005 but discontinued it in 2009. The city has an ongoing dispute about collecting past-due bills.

Capital Financing

Given the capital-intensive nature of water, wastewater, and stormwater systems, capital funds are always an issue. AWWA's (1998) capital financing manual discusses the capital financing strategies for water utilities, and its principles also apply mostly to wastewater utilities. Stormwater finance is similar to wastewater, but as discussed previously, it has differences due to the nature of the services.

Raftelis (2005) included a chapter on capital planning and one each on public sector and private sector financing. Which source to use for capital depends on factors such as: government- or investor-owned utility; short- or long-term needs; current inflation rate and economic condition; credit rating; availability of alternative sources; and public support for funding mechanisms. Internal sources of capital are mainly user charges and other contributions, such as plant investment fees. External sources include debt and loans for publicly owned utilities, and stock issues can be added to these for investor-owned utilities.

Using current revenues or "pay as you go" financing is the most direct way to finance capital due to the administrative ease involved and lack of carrying charges. Pay-as-you-go financing can reduce interest, and is convenient for low-cost, short-term projects. It is easily understood by the public and politically acceptable. Current revenues are used by many utilities, but they may only comprise a portion of capital spending.

Ways to generate internal funds for capital are to use savings or revenue enhancements and to increase the accounting of depreciation as a cost. Savings would feature cost cutting while maintaining income constant and directing funds into a capital reserve account. Revenue enhancements involve new or expanded sources, such as billing for water that was formerly lost or unbilled, and finding new sources of revenue, such as system development charges and other developer contributions. Including realistic depreciation is a valid way to increase revenue and divert funds to the capital reserve account. However, capital reserve accounts make tempting targets when other priorities hit or a crisis occurs.

When using pay-as-you-go financing, an equity issue may arise. Current revenues come from today's rate payers, and if the funds are used to serve future customers, today's users may pay for facilities that will be used by others. Debt financing, or "pay as you use" financing may be more appropriate in these cases.

System development charges are normally based on developer contributions, and are a way to have growth pay for capital needs. They isolate the cost to serve a particular segment of a system and charge for it. They allow new users to "buy into" an existing system by paying a fair share. System development charges are also known as plant investment fees, impact fees, or developer contributions. They are used most frequently in medium- to large-size areas, areas with growth, and areas with scarce water supply. They assign the cost of capacity growth to those causing the growth rather than existing customers.

Facilities most often financed with system development charges include backbone facilities such as source of supply, transmission, treatment, high-service pumping, and major transmission mains. Distribution mains might also be covered, depending on state statutes and local rules. Opposition from builders may arise, but builders also might like the program because expansion can occur when it could not otherwise occur.

Consider a community water supply system that requires added capacity for new developments. The fair cost of serving the new development is a fee for the added customers to purchase their shares of the existing system, which was built by others. The fee is normally paid by the developer and passed on to the homeowner in the purchase of property.

For example, Fort Collins follows a growth-pays-its-way philosophy to justify system development charges. In addition to the water plant investment fee, it charges fees for water rights acquisition, sewer plant investment, storm drainage, street oversizing, off-site street improvements, electric power, and parkland.

Debt financing is known as pay-as-you-use financing because funds are borrowed to construct facilities to be used in the future, while and after the debt is repaid. If the repayment period is the same as the life of the facility, then the facility is paid for just as it needs replacing. Of course, the usual

situation is that the facility lasts longer than the debt period, but it may need renewal during its lifetime, thus requiring additional capital investment.

Several sources of debt financing are available to utilities. For long-term debt, general obligation bonds, revenue bonds, and government loans are common sources. For short-term debt, bank loans, anticipation notes (for bonds, taxes, grants, and revenue), commercial paper, tax-exempt commercial paper, and floating-rate demand notes can be used.

Revenue-secured debt is popular for capital financing, while general obligation bonds are the second most popular form of capital financing. Not all agree that revenue bonds are the best for all infrastructure. Touche Ross & Company (1985) surveyed infrastructure organizations, and their conclusion was that general obligation bonds and federal grants were best to finance facilities, with revenue bonds and special assessments next. Less than 30% favored privatization, tax-increment financing, infrastructure banks, or other financing means. These surveys tend to have different results over time, of course.

The East seems to favor general obligation bonds and federal grants, and the West favors revenue bonds. Having worked in both regions, my sense is that the West has been quicker to adopt newer forms of financing and management, probably because as a rapidly growing region it must invent ways to face emerging issues. Some areas of the East, such as Georgia and Florida, have similar growth issues, of course. While the guarantee of general obligation bonds is the faith and credit of the organization, the bonds are often paid off with revenue anyway. An organization requires taxing power to issue these bonds, and it makes sense to issue them when the project has community-wide benefits.

Revenue bonds are used when the revenues of a self-supporting project can be used to pay the bonds off. Revenue bonds can be issued by more entities than general obligation bonds, and are usually viewed as riskier, with higher interest rates. Infrastructure services such as water, power, buildings, solid waste, parking garages, airports, and other facilities that can be used for a fee are candidates for revenue bond financing.

Since revenue bonds are paid by dedicated revenues, user charges are required. Repayment schemes consider that citizens have fair access to needed services. If charges are too high, or not well distributed, the community's ability to compete may be impaired. The repayment of the debt will require funds to be allocated from revenues, usually from the operating budget, to retire the bonds.

Preparing for a bond issue is complex and expensive. This is one of the disadvantages of going into the bond market. The approach to debt financing is to determine how much money is needed and when, and to find the best deal with professional advice. Many firms vie to provide this advice. Several parties have roles in bonding arrangements. When bonds are sold, they are issued by the issuer, who goes through the trustee to sell them to the bondholders. Revenues flow from users to the issuer and eventually to

the bondholders. In debt financing, statutory limits apply, with usual limits of about 10% of assessed value.

Development banks provide special loans for infrastructure. They are usually sponsored by state and national governments or internationally. A development bank makes loans to assist in economic development, and infrastructure projects are one of the most common loans. They normally have regular loans and subsidized loans. A regular loan is repaid at market interest rates, and a subsidized loan is repaid at less than market rates, perhaps even no interest. Since the development bank may not make money, depending on the subsidy, it is necessary to make up funds from supporting governments. The bank may also borrow from the bond market and repay according to the practices of bond financing.

In the United States, infrastructure banks have been organized in a number of states. They operate as development banks, but their loans are focused on infrastructure. From time to time, a national infrastructure fund or bank is proposed, but none have been approved so far.

State revolving loans used to finance water and wastewater facilities operate much like development banks. USEPA (2011a, 2011b) administers these funds for drinking water and wastewater at the national level. The Clean Water State Revolving Fund (CWSRF) program was initiated with the 1987 amendments to the CWA. Title VI of the revised CWA replaced the Construction Grants program with the CWSRF, which applies to nonpoint source, watershed protection or restoration, and estuary management projects, as well as wastewater treatment. The CWSRF calls for each state and Puerto Rico to maintain revolving loan programs, and many of them provide matching funds. Total funds available since the program's inception are now over $77 billion. CWSRF programs operate like infrastructure banks that are capitalized with federal and state contributions, and the funds are loaned to communities, with repayments recycled back into the program. The newer Drinking Water State Revolving Fund (DWSRF) operates in a similar way. It stems from the 1996 amendments to the Safe Drinking Water Act, which established the fund to finance drinking water system improvements and provide funds to small and disadvantaged communities and to programs that encourage pollution prevention for safe drinking water. Funding for FY 2010 was $1.387 billion. From its inception through 2009, the program had provided over $16 billion in assistance.

States can choose financing methods from a menu of loans, refinancing, purchasing, or guaranteeing local debt and purchasing bond insurance. States set loan terms at interest rates from zero percent to the market rate and repayment periods up to 20 years. Loan terms can be customized for small and disadvantaged communities. Most of the loans go to smaller communities, and in 2009, 23% of the funding went to communities of less than 10,000 in population.

Grants can also be used to finance infrastructure system construction. There have never been large national grants for water supply, but the

wastewater Construction Grants Program financed some $40 billion in treatment facilities over 10 to 15 years.

Intergovernmental revenue, as grants are sometimes called, is an important part of the financing of local infrastructure. In the recent past, grants from the federal and state governments were reported to be important parts of the financing picture for cities, but with the current bleak financing picture, this may not continue in the future.

Another way to gain access to capital is to lease it. The private sector seeks ways to gain reliable and attractive returns on investments, so a utility could offer a private investor the opportunity to finance a facility in return for lease payments. Deals such as lease purchase, build-own-transfer, and sale-leaseback arrangements have all been used.

Repaying debt relies heavily on rate income. Typically, bondholders will want good coverage of operating revenues over operating expenses, including debt service, and they will want safe revenue-to-debt service ratios. The proportion of debt service to operating revenue depends on how much the utility (and the rate payers) are willing to raise rates to support more debt. Some communities want little debt and want to pay as they go, while other communities are willing to issue more debt, even up to allocating 50% of revenue to debt service, which is very high.

Tax Revenues

Tax revenues are not used much to finance enterprise operation of water systems, but they are used sometimes for wastewater and often to support stormwater programs. The main two taxes are the property tax and the sales tax. Of course, the income tax is the main federal revenue source, and part of it is returned for use in environmental programs through programs such as the CWSRF. Property taxes are levied against residential, commercial, industrial, agricultural, and vacant land properties, as well as on natural resources, mines, and oil and gas. They are ad valorem taxes, meaning they are calculated according to the value of the property. Sales taxes are levies on economic activity and sales. They rise and fall with the economy and may create shortfalls when governments come to rely on them.

One trend in taxation that has affected utilities is tax-limitation initiatives. These started in California in the 1970s with a measure called Proposition 13, which was to roll back tax levels and limit the growth of government. Colorado passed a similar initiative called the Taxpayer Bill of Rights (TABOR) in 1992. Utility programs moved to define themselves legally as enterprises so as to escape some of the controls of this law. While the goals of these initiatives seem directed toward control of government spending, they have seemed to spawn moves toward exploiting loopholes and to create extra work for managers. They also tend to move charges away from general taxes and toward fees, which might be a good thing. Still, water, wastewater,

and stormwater programs provide some general benefits to the public, for which tax revenues seem more appropriate than fees.

Privatization and Public–Private Partnerships

Discussion of privatization of water systems became a popular topic during the 1980s, and since then many experiments have been launched. The arguments for privatization center on using private sector efficiency to overcome public sector problems. Most utility services can be offered by either the private sector or by government, but it seems that privatization for water supply is more widespread than for wastewater, and stormwater programs do not lend themselves to it.

The most visible water privatization was the British sell-off of state-owned enterprises during the 1980s, which led to today's collection of large British water companies. In the United States, a number of local experiments with privatization of water, wastewater, and other public services have been carried out. The scorecard of success is mixed on these.

Many developing countries have networks of state enterprises to provide water services, but most seem to lack good track records. Therefore, they seem to be attractive targets for privatization. Some successes have been recorded, but some public protests against privatization turned violent. People are interested in their social safety nets and often fear privatization.

As a result of several decades of studying privatization initiatives, it seems that the arguments for and against them are now clear. On the basis of ideology, some argue that water is an economic good and ought to be managed by the private sector. Others say that water is mostly a public good and ought to be managed by government so as to resist the excesses of the private sector. Perhaps more compelling is the efficiency argument. Some argue that the private sector is more competent than the public sector and can achieve cost savings in construction, procurement, and management. Others dispute this and say that the public sector is efficient and that cost savings in privatization are fictional. The arguments go further. Some say that the government is not reliable and people do not always trust it, whereas others argue that privatization leads to loss of political control, jobs, and the public benefits of water programs. Another argument is that private firms will guarantee performance, but others say that effective management by government minimizes risk. Finally, there are financial arguments about the private sector's greater access to investment capital and avoidance of government debt.

The jury remains out on privatization, and we should also keep in mind that it can be done incrementally and in pieces. For example, something as simple as contracting out maintenance tasks represents a degree of privatization. Sale of a whole system with all of its assets may be a big leap, but many advantages can accrue without such drastic steps.

Further Guidance for Water, Wastewater, and Stormwater Finance

For water supply finance, AWWA has published manuals and guides on water utility accounting, capital financing, and rate setting. These are listed by AWWA's (2011) website for the bookstore, which is updated regularly. AWWA Manuals M1, M29, and M54 may be particularly helpful. Rate setting in the wastewater field involves a number of complex issues, and the Water Environment Federation (2004) has published a guide for finance of wastewater systems. Raftelis (2005) has published a comprehensive guide on the principles of water and wastewater finance and pricing.

Stormwater finance is newer and not so well organized, but a number of papers and reports are available. USEPA sponsored a website with a collection of materials at the Center for Urban Policy and the Environment (2011). The University of North Carolina's Environmental Finance Center (2011) also has an ongoing program related to stormwater finance. For detailed financial statistics, several associations have published results of surveys. The AWWA (1996) Waterstats program remains the most comprehensive, even if it is dated. USEPA's (2010) Community Water Systems Survey has also become a good source of water industry statistics.

Appendix: Fort Collins Financial Data

Information Sources

The City of Fort Collins maintains its financial reports on the Internet, and they are easily accessible by the public. The reports and other information that seem most helpful in explaining the finances of water, wastewater, and stormwater programs are

- Budget document (City of Fort Collins, 2011a)
- Comprehensive Annual Financial Report (CAFR, City of Fort Collins, 2011b)
- Rates for services (City of Fort Collins, 2011c)
- Plant investment and development fees (City of Fort Collins, 2011d)

The following information is derived from these sources and comprises examples of the financial issues discussed in this chapter.

Budget Document

Financial statements for the water, wastewater, and stormwater utilities are located in the budget document and in the CAFR. The budget document contains an initial explanation of the utility funds (City of Fort Collins, 2011a):

> Utility Funds. The City's Enterprise Funds are those funds that provide services based on fees. These services include Electric, Water, Wastewater, and Stormwater. Following is a summary of revenue expectations for the City's Utility Funds:
>
> - Electric. This budget includes an electric rate increase of 6.5% in 2011 due to increases in the cost of generating power from Platte River Power Authority and for programs to meet energy policy goals. A 6.23% increase is planned for 2012 due to increases from Platte River Power Authority and for capital improvements.
> - Wastewater. This budget includes a wastewater rate increase of 9% in 2011 and 8% in 2012. These rate increases are needed to continue to pay for significant debt service related to the new Mulberry plant and for increases in utility operations.
> - Water. There is a 3% increase included in the 2011 budget. This rate increase will help cover ongoing operational costs for the Water Utility. At this time, there is no rate increase projected for 2012.
> - Stormwater. Stormwater rates will remain unchanged in both 2011 and 2012.

Even though water, wastewater, and stormwater are enterprise funds, the budgets still must be approved through an appropriation ordinance. The following are sums appropriated for 2012:

Stormwater:

Operating: $10,709,394

Capital Total: $1,018,333

Total Stormwater: $11,727,727

Water:

Operating: $26,202,294

Capital Total: $5,193,333

Total Water: $31,395,627

Wastewater:

Operating: $18,277,139

Capital Total: $2,958,334

Total Wastewater: $21,235,473

These total $64.3 million. By comparison, the total electric power budget is $111 million, of which $110 million is operating funding. Fort Collins seems to be spending very little on capital improvements in any of its utilities. The total utility or enterprise funding is $178 million, whereas the general fund is $103 million.

Some utility-related financial items are in other budget funds. For example, Utility Customer Service and Administration at $15.2 million is included in the Internal Service Fund. The utility will be charged fees to offset this cost.

The budget document shows information about the city workforce and operations. For example, the number of utility employees approved for 2011 are

Customer Service & Administration	91.3
Light and Power	98.5
Stormwater	25.53
Wastewater	60.76
Water	73.21

As was explained earlier in this chapter, the Fort Collins budget process is based on a process known as BFO, or budgeting for outcomes. This spreads the budget requests out over the following seven outcome areas, but as a practical matter, water, wastewater, and stormwater programs fit narrowly into a couple of the categories.

- Culture, Parks and Recreation
- Economic Health
- Environmental Health
- High-Performing Government
- Neighborhood Livability
- Safe Community
- Transportation

The Environmental Health area "also includes the offers for core water and wastewater programs, and services, including the water and wastewater system distribution, treatment and infrastructure replacement. In addition, the Environmental Health Result Area funds Utilities engineering services, environmental regulation management and water conservation programs" (City of Fort Collins, 2011a).

The High-Performing Government area includes internal services, so it shows $15.2 million for utilities in 2012.

The Safe Community area includes "core Utilities Light and Power operations and Stormwater operations. Purchased electric power is the biggest element of the Light and Power program, along with general operations and capital projects such as the Southwest Annexation Electric System. Major Stormwater programs include operations, capital construction/engineering, and master planning."

Fund statements are presented for the water, wastewater, and stormwater program areas. To illustrate, the water fund statement is shown here as

Table 6A.1. It shows projects, revenues, expenditures, and changes in the fund balance for five budget years. It is not clear why depreciation was zero for two of the years, unless there was a change in accounting methods.

The city's debt position is displayed in the budget document as shown in Table 6A.2. It is accompanied by this statement:

> The City prefers to use securities supported by specific revenue sources, rather than rely on the pledge of general obligation (property tax supported) debt. In part, this is due to a state constitutional limitation on the amount of general obligation debt. Total general obligation debt may not exceed 10 percent of the assessed valuation of the property. An important exclusion from this calculation is debt issued for water rights and water treatment facilities. The City does not have any outstanding general obligation debt subject to the state constitution debt limit. The debt for water rights and treatment facilities does not count in the City's debt burden for purposes of the limitation. This means that the City has conserved its general obligation issuance capacity for future projects to be approved by the voters.

The city's bonds are rated as follows:

	Moody's	**Standard & Poor's**
Water revenue	No rating	AA+
Sewer revenue	Aa2	AA+
Storm drainage revenue	Aa2	AA+

Comprehensive Annual Financial Report

The Comprehensive Annual Financial Report (CAFR) follows the rules of government accounting, which are based on FASB and GASB guidelines. In the Management Discussion and Analysis (MD&A) section, the following items relate to the water utilities. The MD&A section is a required part of corporate and government annual reports.

> There were $3,900,000 in Wastewater Utility Sewer Revenue Refunding Bonds issued since long term interest rates were favorable. The net effective interest rate on these 10 year bonds is 2.99%. The proceeds were used to retire the remaining 2000 Wastewater Utility Sewer Revenue Bonds. The present value savings accomplished through this refunding is $331,980.
> Business-type activities in the utility funds increased the City's net assets by $17.8 million, accounting for 55.8% of the City's $31.9 million increase in net assets. Major variations are due to the following: Charges for services in the utilities business activities increased $14.2 million (10.1%) from 2009 to 2010. The light and power fund operating revenues increased 11.8%. This is due to a 7.4% rate retail increase in January 2010 as well as increased sales, in the residential sector. Water operating revenues increased 11% compared to 2009. Demand for water

TABLE 6A.1

Comparative Budget Statement

	ACTUAL 2008	ACTUAL 2009	BUDGET 2010	BUDGET 2011	BUDGET 2012
Beginning Fund Balance	**$227,142,270**	**$237,651,366**	**$240,702,357**	**$243,008,289**	**$245,157,189**
Revenues					
Water	24,283,914	21,752,118	26,448,689	25,008,022	25,123,487
Interest Revenue	2,790,750	1,553,797	1,195,035	1,473,191	1,636,879
Security Lending	124,606	19,675	0	0	0
Rents	69,468	23,266	50,000	50,000	50,000
Contributions & Donations	5,367,029	2,115,681	1,839,816	1,091,649	917,287
Sale of Property	16,585	10,219	0	0	0
Non Operating	103,949	92,141	80,277	78,043	75,783
Other Miscellaneous	139,480	134,248	60,000	81,500	83,045
Total Revenues	**$32,895,782**	**$25,701,145**	**$29,673,817**	**$27,782,405**	**$27,886,481**
Other Financing Sources					
Transfers from Funds	$0	$0	$90,856	$92,292	$0
Total Other Financing Sources	**$0**	**$0**	**$90,856**	**$92,292**	**$0**
Total Revenues & Other Financing Sources	**$32,895,782**	**$25,701,145**	**$29,764,673**	**$27,874,697**	**$27,886,481**
Expenditures					
Minor Capital	594,378	713,005	2,332,539	1,987,412	2,031,853
Payments and Transfers	11,172,217	11,171,631	8,446,234	7,946,733	7,994,498
Transmission & Distribution	2,316,977	2,255,027	2,578,911	2,516,845	2,604,635
Water Meter Operations	522,268	543,655	708,044	690,650	709,786
Water Production	4,355,886	4,772,714	5,974,088	6,023,153	6,195,041
Water Quality	874,180	941,200	978,428	983,452	1,010,211
Water Resources	1,386,216	1,493,842	1,942,418	1,932,930	1,973,103
Capital Projects	3,401,817	3,378,133	7,805,938	4,603,333	5,193,333
Total Expenditures	**$24,623,939**	**$25,269,208**	**$30,766,600**	**$26,684,508**	**$27,712,460**
Other Financing Uses					
Debt Financing	6,424,615	5,854,267	4,421,935	3,686,416	3,683,167
Transfers Out	183,940	189,458	0	0	0

TABLE 6A.1 (*Continued*)

Comparative Budget Statement

	ACTUAL 2008	ACTUAL 2009	BUDGET 2010	BUDGET 2011	BUDGET 2012
Total Other Financing Uses	**$6,608,555**	**$6,043,725**	**$4,421,935**	**$3,686,416**	**$3,683,167**
Total Expenditures & Other Financing Uses	**$31,232,494**	**$31,312,934**	**$35,188,535**	**$30,370,924**	**$31,395,627**
Depreciation	0	0	5,134,941	5,147,326	5,174,212
Capital Expenses	(8,845,808)	(8,662,780)	(12,864,736)	(9,792,453)	(10,538,211)
Net Debt Proceeds	0	0	0	0	0
Net Adjustments to GAAP	**(8,845,808)**	**(8,662,780)**	**(7,729,795)**	**(4,645,127)**	**(5,363,999)**
Net Change in Fund Balance	**$10,509,096**	**$3,050,991**	**$2,305,933**	**$2,148,900**	**$1,854,853**
Ending Fund Balance	**$237,651,366**	**$240,702,357**	**$243,008,289**	**$245,157,189**	**$247,012,042**

Note: Ending fund balance includes nonliquid assets.

> increased 8.0% and there was a 3.0% rate increase implemented January 2010. Wastewater operating revenues increased 8.0% from 2009 after implementing a 10.0% rate increase. Storm drainage rates remained unchanged in 2010 and the fund's revenues increased 1.5%. Investment earnings decreased $2.1 million primarily due to the lower average interest rates. The increases in net assets in the utilities are being accumulated for significant future capital purchases.

About capital assets and debt administration, the CAFR reports:

> The City's investment in capital assets for its governmental and business-type activities as of December 31, 2010 amounted to $1,208.9 million (net of accumulated depreciation). This was an increase of $37.7 million (3.2%). This investment in capital assets includes land, water rights, buildings and improvements, machinery, equipment, and light & power, water, wastewater and storm drainage infrastructure as well as street system infrastructure.

Related to the application of GASB Statement 34 (see Chapter 3), the CAFR states:

> The City has elected to use the modified approach for infrastructure reporting of its street system infrastructure. The City completes assessments of its entire street system on a 3 year cycle. The most recent 3 year assessment was completed as of December 31, 2009. It resulted in

TABLE 6A.2

City of Fort Collins, Colorado, Debt Outstanding at Year End: Actual 2010 and Projected 2011 and 2012

	Actual 2010	Projected 2011	Projected 2012
Government Debt			
Downtown Development Authority Tax Increment	$15,996,000	$12,500,000	$11,800,000
Highway Users Tax Revenue	$670,000	$340,000	…
COPS/ALPS	$49,687,352	$46,415,245	$42,981,223
Capital Leases	$799,747	$288,421	$71,268
Total-Government	$67,153,099	$59,543,666	$54,852,491
Enterprise Fund Debt			
Light and Power Revenue Bonds	$16,085,000	$14,670,000	$13,215,000
Water Revenue Bonds*	$23,288,228	$20,533,347	$17,679,148
Sewer Revenue Bonds	$39,105,553	$36,123,842	$33,025,168
Storm Drainage Revenue Bonds	$31,405,000	$23,622,500	$25,727,500
COPS/ALPS—Golf portion	$3,227,648	$2,963,755	$2,688,777
Capital Leases	$442,124	$173,771	$31,630
Total-Enterprise	$113,553,553	$103,087,215	$92,367,223
Grand Total Debt and Other Obligations	$180,706,652	$162,630,881	$147,219,714

* Includes Subordinate Water Revenue bond dated 12/01/03 issued January 2004.

> a Pavement Condition Index (PCI) rating of 71. It met the City's policy of achieving a good (Level of Service B) rating. For 2010, the City spent $7.3 million on its street maintenance program as compared to $13.4 million, the asset management system estimate needed to maintain streets at Level of Service B.

This shows the application of GASB 34 to streets but not to utilities, which operate as enterprises.

As to the financial statements, the CAFR states:

> The government-wide financial statements are reported using the economic resources measurement focus and the accrual basis of accounting, as are the proprietary funds and the pension trust funds.
>
> The City reports the following major proprietary funds: The Water fund is used to account for the operation of the City's water utility. The Wastewater fund is used to account for the operation of the City's wastewater utility. The Storm Drainage fund is used to account for the operations of the City's storm water utility.

To see the full picture, it is also necessary to note the use of the internal service funds. The CAFR states:

> Internal Service funds are used to account for the City's fleet maintenance services, phone equipment and services, self-insurance of employee health care and other employee benefits, and a risk management insurance program. There is also an internal service fund to account for the customer and administrative services provided exclusively to the City's utility enterprise funds.

The utilities operate as proprietary funds.

> Proprietary funds are budgeted on a basis that includes capital items such as amounts for capital outlay and principal reduction of debt. Such budgets exclude depreciation. Proprietary Funds recognize gain on inter-fund sales of capital assets for budgetary purposes only. Capital project budgets for certain enterprise funds are nonlapsing.

About the budget, the CAFR states:

> The legal level of budgetary control is at the individual fund level, except for capital projects and federal and state grants for which the legal level of control is at the project or grant level. For budgetary purposes, operating transfers are considered expenditures.

The pledged revenues for utility systems are listed in the CAFR. These illustrate typical revenue bond issues, and some relating to water, wastewater, and stormwater are shown in Table 6A.3.

The bonds have varying interest rates. The data for the Water Fund in Table 6A.4 show bond issues, interest rate ranges, date of maturity, original balance, and current balance.

The city refunds bonds from time to time to save on interest costs. The CAFR reported that:

> On April 6, 2010, the City issued $3,900,000 of Series 2010A Sewer Revenue Refunding bonds with an average interest rate of 2.99 percent, to refund $3,820,000 relating to outstanding Series 2000 Sewer bonds, with an interest rate ranging from 5.00 percent to 5.50 percent. The net proceeds of $3,853,583 along with $161,819 of additional City funds were used to purchase the new 2010 bonds (after payment of $46,417 in underwriting fees, insurance, and other issuance costs)…. The refunding resulted in a difference between the reacquisition price and the net carrying amount of the old debt of $193,901. This difference, reported in the accompanying financial statements as a deduction from bonds payable, is being amortized over the life of the bonds.

In terms of risk management, the CAFR discloses how the city insures its operations:

TABLE 6A.3

Pledged Revenues Relating to Water, Wastewater, and Stormwater

Issue Date	Description of Revenue Pledged	Revenue Pledged	Purpose of Debt Commitment
1997	Water revenue bonds	$5,007,987	Water capital projects through 2017
1999	Water revenue bonds	$3,120,220	Water capital projects through 2019
2003	Subordinate water revenue bonds	$2,833,217	Water capital projects through 2030
2008	Water revenue refunding bonds	$11,547,597	Water capital projects through 2018
2009	Water revenue refunding bonds	$5,594,726	Water capital projects through 2013
2001	Storm drainage revenue bonds	$8,589,903	Storm drainage improvements through 2021
2002	Storm drainage revenue refunding bonds	$11,580,435	Storm drainage improvements through 2022
2007	Storm drainage revenue refunding bonds	$17,059,651	Storm drainage improvements through 2019
2007	Storm drainage revenue refunding bonds	$3,177,535	Storm drainage improvements through 2017
1992	Sewer revenue bonds	$5,493,644	Sewer capital projects through 2014
2009	Sewer revenue bonds	$44,662,669	Sewer capital projects through 2028
2010	Sewer revenue bonds	$4,353,299	Sewer capital projects through 2020

TABLE 6A.4

Water Fund Bond Issues

Issue Date	Type of Issue	Interest Rate Range	Maturity Date	Original Amount	Current Amount
1997	Water revenue bond	3.80%–5.30%	2017	$10,125,300	$4,089,698
1999	Water revenue bond	3.28%–5.25%	2019	$4,998,395	$2,474,722
2003	Subordinate water revenue bonds	5.03%	2030	$2,476,446	$1,953,809
2008	Water revenue bond	3.46%	2018	$9,645,000	$9,560,000
2009	Water revenue bond	2.25%–4.00%	2013	$7,815,000	$5,210,000

The City self-insures a portion of its comprehensive automobile liability, general liability, police liability, and public official liability exposures as well as damage or destruction of property…. The City purchases property insurance that has a $50,000 deductible for most causes of loss including earthquake and flood. Special flood hazard areas of 100 year flooding, as defined by FEMA have a deductible of 5% of the total insurable value at each location, subject to a minimum of $500,000 at any one occurrence…. In 2010, the City purchased liability insurance through a

> risk retention group called States. This policy has a $500,000 deductible for all types of liability claims. Coverage limits are as follows: General, Auto, Law Enforcement & Wrongful Acts Liability—$3 million/occurrence, $6 million aggregate.

This would indicate that liabilities of the water utilities would be mostly covered through self-insurance, but if losses were greater than $500,000, the risk retention policy would apply. Water-main breaks, errors by utility crews, and similar issues might fall into this category.

The CAFR contains further information about GASB 34 under "Required Supplementary Information." It states that:

> In accordance with GASB Statement No. 34, the City is required to account for and report infrastructure capital assets. The City has several major infrastructure systems including the street system and various systems that distribute utility services. Each major infrastructure system can be divided into subsystems. For example, the street system can be divided into concrete and asphalt pavements, concrete curb and gutters, sidewalks, medians, streetlights, traffic control devices (signs, signals and pavement markings), landscaping and land. Subsystem detail is not presented in these basic financial statements; however, the City maintains detailed information on these subsystems. The City has elected to use the "Modified Approach" as defined by GASB Statement No. 34 for infrastructure reporting for its Streets Pavement System.

(There follows a detailed explanation of the condition assessment and asset management program for streets.)

Financial statements for the funds are included in the CAFR. They look similar to the statements in the budget document, which can be considered as planning or pro forma statements. The CAFR includes Table 6A.5, a statement for the wastewater fund.

Additional information is necessary to reconcile the accounts to a GAAP basis, as shown in Table 6A.6.

The statement of net assets for the funds shows information about assets and liabilities, similar to a regular balance sheet, as seen in Table 6A.7.

Pledged revenue coverage for the storm drainage bonds is illustrated in Table 6A.8.

Information is provided about SEC Rule 15c2-12, which is about information to be released relating to customer base, rate structure, and enforcement. The following is information on the sewer charges, and similar information is available for water and stormwater. Rate information is also on the city's website.

The sewer (wastewater) system serves a customer base that has grown as follows in the years 2001 to 2010:

TABLE 6A.5

Wastewater Fund: Schedule of Revenues, Expenses, and Changes in Net Assets—Actual and Budget (Non-GAAP Budgetary Basis) for the Year Ended December 31, 2010

	Actual	Budget	Variance
Revenues			
Charges for services	$19,136,611	$17,622,768	$1,513,843
Oilier nonoperating income	143,390	62,830	80,560
Earnings on investments	412,086	449,820	(37,734)
Interest on security lending income	3,301	…	3,301
Transfers	75,815	75,815	…
Gain on sale of capital assets	32,941	…	32,941
Contributed capital	2,441,543	2,657,661	(216,118)
Proceeds from issuance of long term debt	4,015,402	4,100,000	(84,598)
Total Revenues	26,261,089	24,968,894	1,292,195
Expenses			
Programs (fund level of budgetary control)			
Customer and administrative services	2,200,049	2,640,059	440,010
Trunk and collection	1,663,565	1,911,416	247,851
Payments and transfers	10,491,018	11,997,026	1,506,008
Water reclamation	4,606,143	5,246,540	640,397
Security lending interest expense	2,162	…	(2,162)
Security lending agent fees	287	…	(287)
Water engineering	90,100	97,773	7,673
Pollution control	1,082,511	1,203,171	120,660
Total Programs	20,135,835	23,095,985	2,960,150
Projects (project level of budgetary control)			
Collection System Replacement	6,067,841	10,568,321	4,500,480
Harmony Lift Station	62,644	49,529	(13,115)
Service Center Improvements	2,066,667	2,619,748	553,081
Treatment Plant Expansion	35,712,680	36,316,643	603,963
Sludge Disposal Improvements	5,478,805	6,319,446	840,641
Collection System Study	607,860	750,000	142,140
Water Reclamation Replacement Program	3,582,644	6,424,000	2,841,356
Mulberry Water Reclamation Improvement	28,023,886	37,329,146	9,305,261
Flow Monitoring Stations	769,675	840,000	70,325
Total Projects	82,372,702	101,216,833	18,844,132
Total Expenses	102,508,537	124,312,818	21,804,282
Excess (deficiency) of revenues over (under) expenses before reconciling items	$(76,247,448)	$(99,343,924)	$23,096,476

TABLE 6A.6

Reconciliation to GAAP Basis

Capital outlay—programs	309,628
Current year's project expenses	13,103,651
Prior years' project expenses	69,269,047
Principal reduction—long-term debt	7,393,179
Proceeds from issuance of bonds	(4,015,402)
Depreciation	(3,300,653)
Bond amortization	(146,856)
Total reconciling items	82,612,594
Change in net assets	6,365,146
Net assets—January 1	126,499,546
Net assets—December 31	$132,864,692

Years (on December 31)	Wastewater Customers
2001	32,564
2002	32,905
2003	32,865
2004	32,637
2005	32,757
2006	32,038
2007	32,992
2008	32,847
2009	32,134
2010	32,226

Further information is provided about the customers and rate structure:

> Approximately 94% of the wastewater customers are residential, with the remaining 6% being industrial and commercial customers. Currently, only two customers represent more than 3% of wastewater system revenues. In 2010, amounts paid by an industrial customer comprised 9.3% of wastewater revenues ($1,649,777) with a total flow representing 0.0% of total system usage; and amounts paid by the university comprised 5.2% of wastewater system revenues ($973,966), with a total usage representing 2.82% of total system usage.

Rate Structure

User Charges

Table 6A.9 shows the city's monthly wastewater user charges in effect on January 1, 2011. Historically, user-charge increases were 6.0% per year for all customer classes in 1992, 1993, 1994, and 1995; 3.0% in 1996; 0% in 1997; 2.0% in 1998, 1999, 2000, 2001, 2002, and 2003; 5% in 2004, 2005, 2006, and 2007; 12% in 2008; 11% in 2009; and 10% in 2010. An increase of 9% has been projected

TABLE 6A.7

Proprietary Funds Statement of Net Assets, December 31, 2010

	Light And Power	Water	Wastewater	Storm Drainage
Assets				
Current Assets				
Cash and cash equivalents	$5,432,347	$7,230,625	$3,546,922	$1,428,178
Investments	32,431,260	63,430,323	23,364,484	12,528,809
Securities lending collateral	1,715,989	2,298,265	1,127,365	454,392
Receivables				
Accounts, net	12,001,589	2,151,105	2,471,636	1,828,907
Note receivable	72,202	…	…	…
Interest	231,665	310,086	152,148	61,301
Prepaid item	…	…	…	…
Due from other governments	936,602	…	…	…
Inventories of materials and supplies	4,371,272	…	…	…
Total Current Assets	57,192,926	75,420,404	30,662,555	16,301,587
Non-Current Assets				
Advance to other funds	…	…	…	30,000
Restricted Assets—cash & cash equivalents	…	292,490	381,741	356,117
Restricted Assets—investments	14,889,304	…	7,752,244	…
Land, water rights, other	1,878,377	48,203,256	3,217,675	7,647,132
Buildings, improvements, and equipment	215,833,791	229,330,069	159,035,002	101,554,864
Accumulated depreciation	(119,682,534)	(97,339,433)	(65,592,478)	(24,751,556)
Construction in progress	18,296,533	16,740,911	40,077,180	15,712,238
Note receivable	326,760	…	…	…
Unamortized bond issuance costs	183,300	129,410	323,121	170,621
Total Non-Current Assets	131,725,531	197,356,703	145,194,485	100,719,416
Total Assets	188,918,457	272,777,107	175,857,040	117,021,003

TABLE 6A.7 (*Continued*)

Proprietary Funds Statement of Net Assets, December 31, 2010

	Light And Power	Water	Wastewater	Storm Drainage
Liabilities				
Current Liabilities				
Accounts payable	7,998,436	826,642	1,501,800	705,188
Interest payable	51,859	89,113	150,707	125,270
Wages payable	188,985	121,774	95,935	43,764
Compensated absences	580,526	397,953	332,641	145,021
Bonds payable	1,475,804	2,771,980	2,901,515	2,757,708
Claims payable	…	…	…	…
Capital lease obligations	…	…	…	…
Deferred revenue	44,643	…	…	…
Obligations under securities lending	1,715,989	2,298,265	1,127,365	454,392
Total Current Liabilities	12,056,242	6,505,727	6,109,963	4,231,343
Non-Current Liabilities				
Postemployment health-care benefits	257,642	162,732	215,277	…
Bonds payable	15,217,275	20,450,070	36,667,108	28,447,136
Claims payable	…	…	…	…
Capital lease obligations	…	…	…	…
Total Non-Current Liabilities	15,474,917	20,612,802	36,882,385	28,447,136
Total Liabilities	27,531,159	27,118,529	42,992,348	32,678,479
Net Assets				
Invested in capital assets, net of related debt	114,522,392	173,712,754	104,921,001	68,957,833
Restricted: debt service	…	292,490	381,741	356,117
Unrestricted	46,864,906	71,653,334	27,561,950	15,028,574
Total Net Assets	$161,387,298	$245,658,578	$132,864,692	$84,342,524

TABLE 6A.8

Storm Drainage Revenue Bonds

	Gross Revenues	Expenses	Net Revenue Available For Debt Service	Debt Service Requirements			Coverage
				Principal	Interest	Total	
2001	$8,289	$2,257	$6,032	$1,410	$1,645	$3,055	1.97
2002	11,583	2,621	8,962	1,655	2,337	3,992	2.25
2003	12,910	2,574	10,336	2,163	2,284	4,447	2.32
2004	13,762	3,782	9,980	2,248	2,194	4,442	2.25
2005	14,848	3,741	11,107	2,325	2,114	4,439	2.50
2006	15,396	3,779	11,618	2,405	2,030	4,435	2.62
2007	16,698	4,615	12,084	2,150	1,643	3,793	3.19
2008	15,139	4,865	10,274	2,610	2,483	5,093	2.02
2009	14,219	5,838	8,381	2,568	2,346	4,914	1.71
2010	14,613	5,052	9,560	2,683	1,606	4,289	2.23

TABLE 6A.9

Monthly User Charges for Wastewater

Residential Metered		
Single family	$13.95	plus $2.712 per 1,000 gallons of WQA
Duplex	$18.07	plus $2.712 per 1,000 gallons of WQA
Multifamily (per living unit)	$2.13	plus $2.712 per 1,000 gallons of WQA
Commercial Metered		
¾″ metered	$7.83	plus $2.712 per 1,000 gallons
1″ metered	$18.07	plus $2.712 per 1,000 gallons
1½″ metered	$36.37	plus $2.712 per 1,000 gallons
2″ metered	$62.23	plus $2.712 per 1,000 gallons
3″ metered	$99.43	plus $2.712 per 1,000 gallons
4″ metered	$157.03	plus $2.712 per 1,000 gallons
6″ metered	$688.35	plus $2.712 per 1,000 gallons
8″ metered	$794.80	plus $2.712 per 1,000 gallons

Notes: Monthly user charges exclude payments in lieu of taxes, which are included as an additional 6% charge in the wastewater bill and remitted to the general fund. For residential metered, WQA is the average monthly amount of water billed during January, February, and March. For commercial metered, the usage charge of $2.712 is multiplied by each increment of 1,000 gallons either (a) actually consumed or (b) based on WQA, if customer is eligible.

for 2011. The minimum winter-quarter average consumption (WQA) is 3,000 gallons for single-family customers (4,000 gallons for duplexes).

Special situations that have arisen and may affect revenues are explained by this note:

> Beginning in 2011 the City's largest customer will no longer be utilizing the City's wastewater system. This will result in an annual loss of approximately $1.7 million in operating revenue. This customer comprised approximately 10% of the wastewater fund operating revenue in 2009 and 8.7% in 2010. Large commercial customers who have facility or manufacturing processes that result in a significant difference between the volume of water delivered and the volume of wastewater discharged will start metering their flows beginning in 2011. It is difficult to predict, but projections for this potential loss are $.5 million in 2011 and up to $1.7 million by 2014, when it is expected all metering has been implemented.

Plant Investment Fees for Wastewater

> The plant investment fee is collected to pay for new development-related capital expansion costs of the City's wastewater treatment plants, collection system and sludge disposal facilities. This fee is paid at the time a building permit is issued. Set forth in the following table [see Table 6A.10] is the current plant investment fee schedule which becomes effective on January 1, 2011. Revenue generated by the plant investment fee generally is restricted for the purpose of capital improvements and expansion of the wastewater treatment plant.

Other Fees and Charges

> The City also charges additional fees and charges related to the provision of sewer service, including wastewater strength surcharges, industrial wastewater discharge permit application and administration fees, wastewater monitoring and sampling charges, laboratory analysis and support service charges, a private sewage disposal system permit and inspection fee, and a building sewer permit and inspection fee.

Enforcement

> The City's collections of wastewater charges historically have been in excess of 99%. Unpaid charges constitute a perpetual lien on the property to which service was delivered. Customers with delinquent active accounts are sent courtesy notices after 38 days.
>
> Wastewater service is not discontinued due to delinquency because of public health regulations. However, the City may discontinue water and electric service on delinquent accounts. Sometimes liens are filed while the delinquent customer is still an active account. Customers who have moved from the address where service was supplied and left the account owing to the City are typically assigned to collection agencies.

TABLE 6A.10

Plant Investment Fees

Residential	
Single-family residence	$3,550
Duplex and Multifamily residence (per living unit)	$2,490
Nonresidential (based on water connection size)	
¾″	$7,100
1″	$17,880
1½″	$31,490
2″	$55,290
3″	$150,130
4″	Calculated on an individual basis, but not less than the 3″ charge

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7

High-Performance Operation of Water Systems

After a water, wastewater, or stormwater facility is constructed, it enters the operational phase of its life cycle. If the facility has been constructed well and is maintained effectively, this phase can be long and productive, delivering many valuable services to customers. If construction is poor and maintenance is neglected, the opposite will be true. This period in the life cycle is often called the O&M (operations and maintenance) phase, but the name *operations* is another common term. Whatever the name, the focus will be on operations and maintenance as well as all-around security for the system and its associated equipment, materials, and personnel. While the concept of operations is simple, it becomes a challenge when applied to complex systems with many components.

The root of the word *operation* is "to operate," which means to cause something to function. Thus, operation of an infrastructure system involves everything you do to cause it to function to achieve its purpose. The goal of operations is to use management actions to obtain the greatest performance from your system. Therefore, operations management is about how you choose the management actions and how you measure their results in terms of performance.

This chapter is about these aspects of operations management as well as goal setting, monitoring, decision making, and performance assessment. Also included is the concept of quality improvement. The next three chapters explain the related subjects of maintenance, information technology (IT), and security. These four chapters together explain the major requirements to manage water systems during the O&M phase of the life cycle.

Given these many tasks, the effectiveness of operations depends on the workforce, which uses a great deal of technology, especially information technology. The symbiotic relationships between the workforce, technology, and O&M tasks are shown in Figure 7.1. The concept is that maintenance supports operations management, and both are carried out by the workforce with technologies for information management, construction, and repair work.

The operations of water, wastewater, and stormwater systems are discussed after a brief introduction to operations management as a discipline. The last part of the chapter explains current operational challenges faced by the water sector.

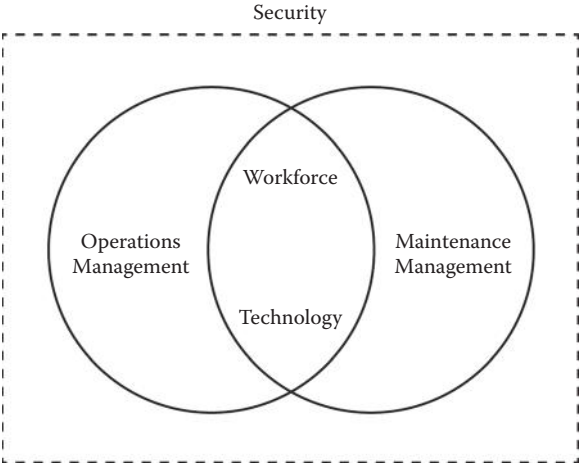

FIGURE 7.1
Operations, maintenance, and the workforce.

Operations Management as a Discipline

Operations management is a broad concept that involves the functions required to cause a system to achieve its mission effectively and reliably. In operations of facilities such as water, wastewater, and stormwater systems, the infrastructure is the main focus. Operation of a facility such as a water treatment plant or a pumping station involves data collection and actions to manage the output of the system. The concept is shown in Figure 7.2, which illustrates, for example, how data on current water demand are used in a treatment plant to inform the plant about the rate of flow needed. Decisions are made about the valve settings and pumps that control the system. Within the plant, differential settings and pumping rates among the component pumps and valves may be needed to achieve the desired flow rates. The models and "what if" queries might forecast demands on the system for the next few hours.

Another useful concept for an operations model is the military acronym C^3I, which stands for command, control, communications, and intelligence. During World War II, the concept of operations research was developed as a way to study the improvement of operations. Today, operations research is an important method to study and improve many types of operations by applying simulation and optimization models.

The goal of operations management of water systems is the same as for other physical facilities: to achieve high productivity in the use of resources. Productivity is measured by the value produced, such as clean water or wastewater service, and it compares output to input and involves effectiveness and efficiency. Effectiveness is producing something of value efficiently.

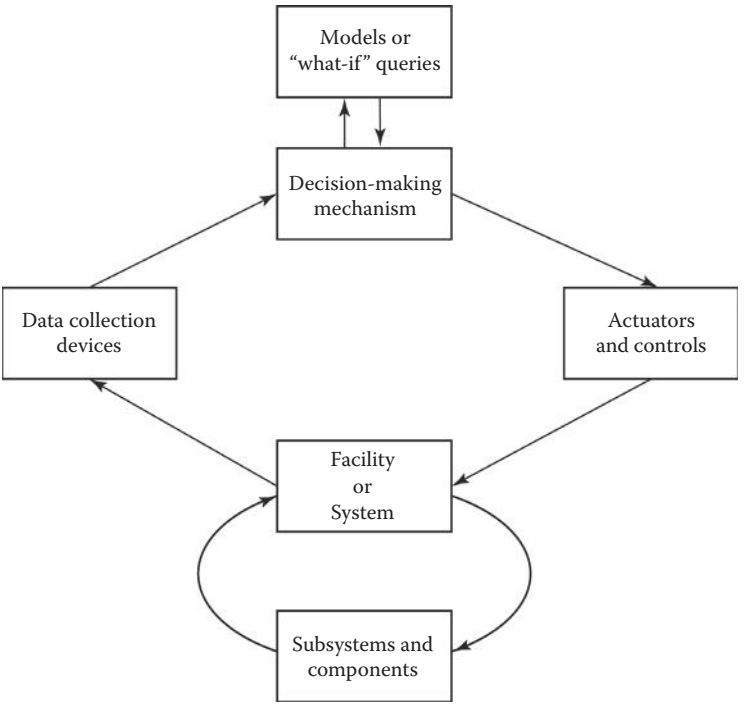

FIGURE 7.2
General model of facility operations.

In water services, value is providing customers with services they need, keeping costs low, and avoiding regulatory problems.

The roots of operations management as a discipline are in scientific management, as developed in the early 20th century to improve efficiency and effectiveness in construction and manufacturing. A pioneer was Frederick Taylor, who is credited with introducing many efficiency methods. Frank and Lillian Gilbreath were also pioneer industrial engineers, as featured in the movie *Cheaper by the Dozen*.

Scientific management and industrial engineering have developed many innovative tools, such as the assembly line and quality control programs. Early scientific management had a negative side, when some thought that it was a plot of owners and managers to exploit workers for profit. However, the labor movement and government regulations have largely offset these problems. As the focus shifted to humane treatment of workers, industrial psychology emerged as a discipline for creating a better and safer workplace. These tools and methods now drive change in water and wastewater utilities.

Today, water, wastewater, and stormwater utilities are operated like businesses and recognize the need for effective operations management. To illustrate, several national associations have teamed with the Kenan–Flagler

Business School at the University of North Carolina at Chapel Hill to institute a Water and Wastewater Utility Leadership Center (see Chapter 12). The associations include the National Association of Clean Water Agencies (NACWA), the Association of Metropolitan Water Agencies (AMWA), the American Water Works Association (AWWA), and the Water Environment Federation (WEF).

Elements of Operations Management

Operations are carried out with a set of principles, tools, and methods that include: a clear purpose; an effective organizational structure; effective communications and information systems; missions and objectives for the organization's units; job descriptions; plans and production targets for units; a work management system; methods for checking performance; and procedures for continuous improvement. Each of these is interpreted in special ways for operation of water systems.

The activities shown in Figure 7.3 illustrate the elements of operations management as they are applied at the organizational, unit, and worker levels. At the organization level, purpose, strategy, and plans are made for

FIGURE 7.3
Requirements of operations management by organization level.

the full set of programs carried out by the utility. At the unit level, goals and plans become more specific, such as, for example, the plans of a treatment plant unit. At the worker level, jobs are much more specific and aimed at duties that are required by an individual position. Operations support activities that apply to the entire organization and that also apply to the unit and individual levels are shown around the outside circle, and these include performance assessment, capacity building, work management, and continuous improvement.

To establish their organizational purposes, water, wastewater, and stormwater systems are usually based on local government statutory authority. For example, Chapter 26 of the City of Fort Collins (2011) City Code covers "Utilities" and the basic rules for the water, wastewater, and stormwater utilities. This chapter of the code presents many details of the operation and management of the utilities, such as this general provision:

> (a) The electric, stormwater, wastewater and water utilities shall be under the immediate administrative supervision and control of Utility Services which shall operate the properties of the various utilities in an efficient and economical manner; and (b) Utilities Services shall be headed by the General Manager of Utility Services pursuant to § 2-506 of this Code.

Codes such as this establish the authority and general purposes of utilities. For utility purposes, the code sets forth general aims such as these for the water utility:

> …to promote the public health, safety and welfare of the community by providing for protection against cross-connections, acquisition of sufficient water rights as the City grows and develops, adequate water quantity and pressure for customer use and firefighting, water conservation and the equitable distribution among all users of the costs of expansion, replacement, maintenance and operation of facilities for the safe and efficient delivery of water to City residents and other water users.

For wastewater, the code specifies that it is "necessary for the health, safety and welfare of the residents of the City to regulate the collection and treatment of wastewater to provide for maximum public benefit." Also, the objectives are to

> (1) Prevent the introduction of pollutants into the wastewater system which will interfere with the operation of the system or contaminate the resulting sludge; (2) Prevent the introduction of pollutants into the wastewater system which will pass through the system, inadequately treated, into receiving waters or the atmosphere or that would otherwise be incompatible with the system; (3) Improve the opportunity to recycle and reclaim wastewaters and sludges from the system; (4) Provide for equitable distribution among users of the cost of the wastewater system;

> and (5) Provide for and promote the general health, safety and welfare of the citizens residing within the City limits and downstream water users.

Stormwater utilities are not found in every city, but in Fort Collins, the city council found that

> [T]he necessity of providing an integrated, sustainable stormwater management program that reflects the community's values of protecting and restoring the City's watersheds, its tributaries and the Cache la Poudre River for mutual economic, social and environmental benefits, including, but not limited to, the following: (1) Economic: flood damage reduction, increased recreation and tourism along stream corridors, reduced business interruptions; (2) Social: public safety and welfare, reduced need for emergency response, recreation opportunities promoting community wellness; and (3) Environmental: preserve natural and beneficial functions of floodplains, enhance stormwater quality, preserve riparian habitat.

The organizational structure of most utilities today is as a self-supporting enterprise with divisions to handle its responsibilities. There are some exceptions, where the water service is handled as a government department with support from general tax revenues, but these are increasingly rare, except for stormwater services. Normally, the line divisions of utilities are focused on operations and maintenance, and staff offices handle planning, engineering, legal, IT, finance, human resources, billing, and customer service. The focus of operating the infrastructure will normally be with the operations section. Of course, many variations of this basic line and staff organizational structure are possible.

Effective communications and information systems are required for any organization to be successful. These are based on formal and informal communication systems, ranging from strategic to daily operational communications through data systems and the cyber system, which is needed for SCADA (supervisory control and data acquisition) and other controls.

Establishment of the missions and objectives for the organizational units involves planning activities from the strategic level through planning for annual work targets and operations. The annual operating plan is a common way to establish specific objectives for the coming year.

How the objectives are met is determined by the combined outputs of the workforce, which are targeted by establishing job descriptions and annual work plans for individuals and teams. Once a job description is set and plans are made, an operator is ready to perform the tasks of management, monitoring, making decisions, controlling, and improving. Preparing for these tasks requires adequate training and preparation through organizational capacity building. Plans and production targets result from the annual operating plan for the organization and the annual work plans for individual positions.

Coordinating the organizational work requires a mechanism for scheduling, coordination among tasks, and follow-through. As workforces downsize and information technology advances, these are increasingly becoming like enterprise management systems (see Chapter 10).

The output of a utility organization is measured by the level of service provided, which is measured by performance indicators. For example, for water or wastewater treatment, the output is the quality of the water, and operators might say "we make water" in recognition of the service they provide. In the case of stormwater, the output is protection from damage and disposing of excess water. At a basic level, productivity of any of these systems is a measure of how well a system meets its goals by compliance with regulations and goals. However, successful operations with performance measurement can deliver better results for the same cost and achieve greater customer satisfaction (see Chapter 12 for industry trends).

A system for continuous improvement is needed, such as in industries that have learned that quality is not only good for competitiveness, but essential to stay in business. Terms used for quality management include *quality assurance* and *total quality management*, or TQM. The processes of self-assessment, certification, and accreditation help water, wastewater, and stormwater organizations toward continuous improvement, which is discussed under quality control later in this chapter.

Water, Wastewater, and Stormwater System Operations

Management of water, wastewater, and stormwater systems requires attention to different levels of system operation. Figure 7.4 illustrates how, at the systems level, the utility operations manager will have responsibility. At the next level down, where a complete subsystem such as a treatment plant or distribution system is operated, a department manager or head operator will normally have overall responsibility, whereas operators will have charge of the components. This recognizes that differences will occur in organizations, such as a smaller system where an operator might be responsible for everything, or a larger system that might have complex hierarchies of operational responsibilities.

While water, wastewater, and stormwater systems involve similar components, they have different operational requirements, as specified by their purposes and regulatory controls (see Chapter 2). The focus of water supply is on delivery of safe and reliable water for multiple purposes, especially for drinking. Regulatory control is by the Safe Drinking Water Act (SDWA). Wastewater has the opposite purpose: to remove water that has been used, treat it, and return it safely to the environment. Regulatory control for wastewater is primarily by the Clean Water Act (CWA). Stormwater has a related

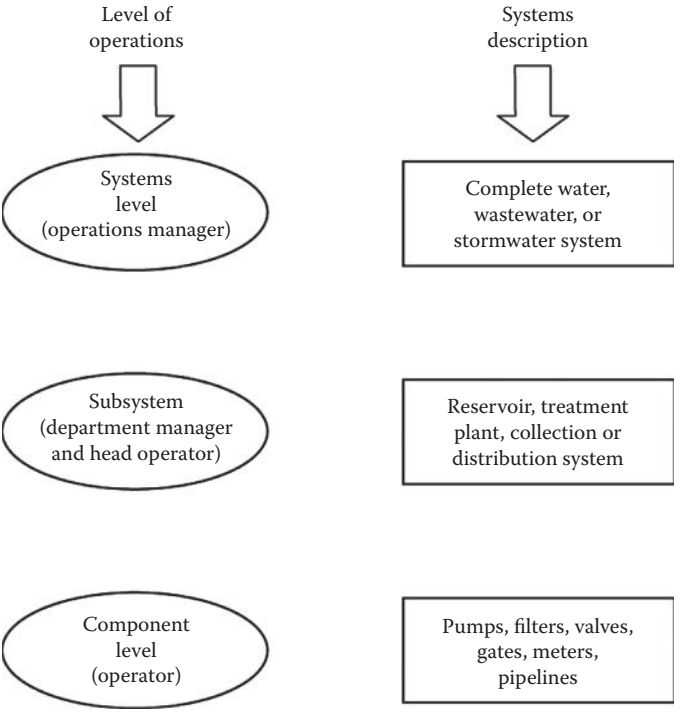

FIGURE 7.4
Levels of operations for water systems.

purpose, to remove excess waters from precipitation and to dispose of them safely to the environment.

Operation of systems involves active management, such as to turn pumps on and off, and they sometimes involve passive management, such as to monitor a stormwater drainage system. In the case of passive management, the concept of operation sometimes means to fix it when required, or to be vigilant in corrective maintenance. Consequently, the operation of a system involves a combination of active and passive management activities.

Five main functions of the equipment and infrastructure in water, wastewater, and stormwater systems are shown in Table 7.1 (Grigg, 2005). The list is not exhaustive, but a number of different components are shown, and the list shows that operations involve individual components and interactions within systems.

While much knowledge is transferable between the systems, operators usually specialize in water, wastewater, or stormwater systems. Operator classifications and licenses are established by state governments for water and wastewater separately. Licenses for stormwater system operation are not required, although complex systems require a high level of expertise. Duties of operators are explained later in this chapter.

TABLE 7.1

Five Main Functions of the Equipment and Infrastructure in Water, Wastewater, and Stormwater Systems

	Water Supply	Wastewater	Stormwater
Conveyance	Canals, pipes, tunnels	Pipes	Culverts, pipes
Storage	Dams, reservoirs, tanks	Tanks	Dams, ponds
Treatment	Treatment processes	Treatment processes	BMPs
Pumping	Pumps	Pumps	Pumps
Control and measurement	Meters, valves, SCADA	Meters, regulators, SCADA	Gauges, regulators, SCADA

Water Supply

An overview of water supply operations is available from AWWA's (2011a) series of texts about basic water supply operations. These cover water sources, treatment, transmission and distribution, and guidance on basic science and water quality. Water source operations involve decisions about withdrawing raw water from surface diversions, reservoirs, and wells. The systems range from wells with on-site disinfection and direct pumping directly into the distribution system to large, multipurpose systems of reservoirs supplying water to one or more treatment plants. Operation of a reservoir can involve many complex issues and often-conflicting goals.

More complex systems may involve coordinating with other users, managing quality of raw water supplies, and working with the public. In addition to hydrology, AWWA's text covers emergency and alternative water sources, use and conservation of water, quality of raw water, and water source protection.

Water treatment plants are configured to respond to the quality of raw water and the goals for finished water quality at each location. Treatment operators require a basic knowledge of chemistry and biology as well as hydraulics. They also are required to interpret instrumentation and to actuate controls for valves and pumping systems. AWWA's text begins with a discussion of treatment of water at the source, and then it turns to initial processes such as coagulation and flocculation and sedimentation basins and clarifiers. Filtration is a basic component in many plants, followed by disinfection and delivery to the distribution system. Some plants include fluoridation and special processes for iron and manganese control, lime softening, and ion exchange, among others. Membranes are used in special cases where required. Management of water treatment plant residuals is an important part of the overall plant operations.

Water transmission and distribution systems require active and passive management. This might vary from a gravity system that delivered water at the correct pressure without any pumping or valving to a system with many pressure zones that required constant monitoring and adjustment.

Operators of distribution and collection systems must know the objectives and constraints of operating their systems and make sure the systems work as intended. This may range from simple systems with few operating decisions to vast, complex systems with many operating components such as pumps and regulating stations. In distribution systems, the operator maintains adequate pressure and supplies for household, commercial, or fire flow. The system must be monitored for pressure and water quality. This requires pressure-sensing devices and problem detection using water audit methods (see Chapter 9). Water distribution system network models may be used to simulate conditions.

As you would expect, AWWA's guides explain pipe systems and piping, storage, pumping stations and pumps, and the hydraulics of overall water distribution systems. There are quite a few different components to manage, such as valves, fire hydrants, and water meters. Meanwhile, several processes are required to ensure the security of the systems, including backflow prevention and cross-connection control and overall system security and emergency response.

For distribution systems, Smith (2000) wrote that future operations will deal with raw water that goes through innovative treatment, including membranes, ozonation, granular activated carbon (GAC), and ultraviolet disinfection. However, unless distribution systems improve, the water may still have questionable taste, odor, color, residual disinfectant, microbial growth, sediment, and corrosivity. The real question will be what it is like at the tap. Distribution systems will need new materials, monitoring, controls, hydraulic efficiencies, and operating procedures. Dual systems may be coming, providing another dimension to distribution system operations.

Wastewater

Wastewater collection systems are similar to water distribution systems in the sense that they require active and passive management, but they mostly operate under gravity and require little pumping and decision making. Decisions in wastewater collection systems involve maintenance more than operations, and are the focus of the operator certification discussed later for collection systems. An exception to the passive nature of wastewater collection systems is operation of combined sewer systems. As these can cause overflows and violations of regulatory standards, more care must be given to their operation.

To the untrained eye, wastewater treatment plants might look similar to water treatment plants, but they involve different processes. Treatment of wastewater might begin with pretreatment that includes screening to remove large objects, grit, and grease. A primary treatment stage might include sedimentation tanks and clarifiers to allow for settlement of particles and for oil and grease to float so as to be skimmed off. The next stage of secondary treatment would focus on biological change to treat the organic content

from human and food wastes. Aerobic digestion using activated sludge or trickling filters is the most common treatment process for this purpose. Secondary treatment includes settling of the biological floc, which is sent to the sludge processing facility. Where tertiary treatment is used, it provides final treatment and may involve several processes, such as filtration, carbon adsorption, nutrient removal, and disinfection.

Biosolids or sludge treatment is also required for wastewater. It might involve anaerobic or aerobic digestion and composting, followed by thickening and then disposal. In some cases it can be hauled away for direct land application, but care must be given to disease-causing organisms and to heavy metals that can accumulate on the land.

Reclaimed Water Systems

Reclaimed water systems are becoming common to extend the use of water supplies and to provide new options for wastewater disposal. They involve a source of reclaimed water, which is usually the effluent from a tertiary treatment plant, and a distribution system for the reclaimed water. The main uses of reclaimed water are for irrigation and industrial cooling. Systems are evolving to serve industrial and commercial customers, although some also provide service to residential customers.

Stormwater Systems

In their simplest form, operation of stormwater facilities resembles wastewater collection systems and requires only passive management. This would be the case, for example, for a stormwater collection system operating to drain a system of urban streets and properties during an average storm event. In stormwater systems, treatment is usually not required, but the same types of facilities as wastewater are usually involved, including: channels, pipes, ponds, instruments, and sometimes pumping facilities. With increasing complexity of stormwater systems that include detention ponds for temporary storage and best manufacturing practices (BMPs) for treatment, more attention to operation will be required in the future.

SCADA Systems

Information technology will increasingly be used in water, sewer, and stormwater systems. Operators of supervisory control and data acquisition (SCADA) systems will be skilled in both computing and telemetry. This can range from the operator who enters data or monitors a central control room (but without much knowledge of the underlying system) to the sophisticated operator who participates in design of the SCADA system and uses that knowledge to work with other operators on a program of continuous improvement.

SCADA concepts and systems have evolved for a number of years and are used across multiple industries. For urban water systems, McPherson (1971) labeled early applications of them as "Metropolitan Water Intelligence Systems" before the term SCADA was invented. He thought automation of water distribution systems would proceed quickly, and also studied automatic control of combined sewer overflow, which seemed technically difficult due to control logic.

SCADA uses both databases and controls and may involve automation or may simply transmit and display information. The separate functions involved include instrumentation, data transmission, data display, decisions (by operator or computer), transmission of commands, and application of controls.

To "automate" means to convert to self-operation. A machine or system that is automated runs itself. The term *automation* traces back to the early days of computer development and perhaps earlier. Control theory is a field unto itself. It begins with the basic control loop, or the lowest level of control, such as a pump that is controlled by devices that respond to flow and/or pressure measurements. Other control loops include chemical feed, valve operation, or tank storage level. In the case of water and wastewater treatment, control loops are used for unit processes. The programmable logic controller (PLC) has been developed as a basic way to handle control loops and combinations of loops. The next level is combinations of control loops or unit control level. Loops are connected with a data highway and an operator station. Multiple controllers or local area networks can be linked to the data highway.

Automation does not have to be "closed loop." Supervisory control applies to situations where system conditions or states are telemetered to the control center. A second phase might be where the data is logged and stored automatically. A third might be where computer models provide information about operating the system, and this information could be used by the operator to make decisions. The final or ultimate stage would be where a computer model makes all the decisions and the system goes on closed-loop automatic control.

Some SCADA applications to water, wastewater, and stormwater systems are shown in Table 7.2. Discussions of SCADA can be confusing and illustrate the need for technical experts. Expertise to integrate IT technologies can help the utility prevent a system from being cobbled together and not working when one component fails. As an example of complexity, consider the SCADA for a plant of the Sanitary District of Decatur, Illinois. It included nine monitoring distributed-control units (DCUs) connected to two distributed-control operator consoles by two redundant fiber highways. They had a legacy proprietary system, which was replaced by a new off-the-shelf PLC–based SCADA with a human–machine interface (HMI) and a local area network (LAN) and a centralized server. The result was a HMI/SCADA system with alarm-management software to monitor alarms and to process variables and events. Notification was by phone, pager, radio, e-mail, fax, PA

TABLE 7.2

Some SCADA Applications to Water, Wastewater, and Stormwater Systems

Source of supply	Reservoir releases controlled by SCADA with decisions based on hydrologic information. Operations may involve water uses for supply, pollution control, flood control, recreation, hydropower, irrigation, fish and wildlife, and navigation. Water quality can be incorporated, as quality of raw water affects treatment decisions.
Treatment plants	Water and wastewater treatment plants use SCADA with plant instrumentation and automation. Treatment plants use programmable controllers and PCs to operate valves and pumps and generate reports. Instrumentation and control in wastewater plants can be difficult.
Distribution systems	Distribution systems use SCADA for energy and water savings through control, to control pressure, and to monitor losses.
Wastewater collection	In wastewater collection systems, pumping stations can be automated, or pressure systems can be monitored. Gravity systems can be monitored.
Stormwater	Flood warning systems, detention storage, weather forecasting, and combined sewer overflows can use SCADA.

system, and PC workstation popups. The district also has a computerized maintenance management system (CMMS) and a laboratory information management system (LIMS) (Cowger and Kuchy, 2001).

Performance Assessment, Optimization, and Quality Control

Water, wastewater, and stormwater systems are complex and multifaceted, and their operation requires both skill and detailed system knowledge. Much progress has been made in developing management systems to aid system operators.

Today, the performance of water, wastewater, and stormwater facilities must be assessed during normal and extreme conditions. Tools for this assessment include performance indicators, optimization strategies, and quality control programs.

Performance indicators and benchmarks enable utilities to measure their performance against both their goals and best-in-class performers. In a general sense, indicators can range across variables that include effectiveness, reliability, and cost, which are the three categories selected by the National Research Council (NRC, 1995) in a study of infrastructure performance. According to the NRC, each measure should be meaningful and useful to decision makers; as a set, measures should support a thorough assessment of performance; and the costs of measurement should be reasonable.

In a project for the Water Research Foundation, Deb, Hasit, and Grablutz (1995) identified performance indicators for water distribution systems that included 12 indicators for adequacy, dependability, and efficiency. The indicators reach to the level of details for: adequacy (pressure, flow, water quality, customer complaints, responsiveness to customer complaints, and customer satisfaction); dependability (service interruptions, water quality violations of extended duration, inoperable valves and hydrants, and main breaks); and efficiency (unaccounted-for water and pumping efficiency).

A broad research effort for water utilities was reported from the European Union in a book entitled *Performance Indicators for Water Supply Services* (Alegre et al., 2006). So many performance indicators are available that it can become confusing unless a few key ones are selected, and it is a challenge to select those that will apply everywhere.

The use of performance indicators (PIs) can help to develop optimization strategies for water processing facilities. In this context, optimization means to adjust operations until you get the highest productivity, however it is measured. For example, optimizing a treatment process might entail adjusting chemical feeds and pumping rates to obtain the best water quality over a range of different water quality indicators. In the case of distribution systems, a Water Research Foundation project studied optimization across water quality, hydraulics, and structural integrity (Friedman et al., 2010). The project goal was to develop a continuous improvement program based on optimization principles and to identify metrics to aid in measuring performance. The outcome was a recommendation for three optimization metrics:

- Chlorine residual to represent water quality integrity
- Pressure measurement to represent hydraulic integrity
- Main breaks to represent infrastructure integrity

Performance indicators and optimization offer power tools and concepts. However, the overall approach to improving operations is through quality control programs that have a focus on performance and require a comprehensive approach to improving output by correcting problems and adjusting variables to improve operations. As mentioned previously, these cover a range of methods, such as performance assessment, continuous improvement, and optimization.

As an example of why quality control is important, we can recall the 1993 Milwaukee cryptosporidium outbreak that caused numerous illnesses and deaths. The issue here was quality control of the output of the water treatment plant. Quality control of a wastewater plant is also monitored and reported to regulatory authorities, but failures in stormwater controls are mostly evident by flooding problems.

Quality control (QC) has many variants, such as the Deming Cycle (also sometimes called the Shewhart Cycle) (Arveson, 1998). Concepts such as these are

ways to present the most important elements of quality control, which can be very complex, in a straightforward way. For example, the Deming Cycle involves:

- *Plan*: Design or revise business process components to improve results
- *Do*: Implement the plan and measure its performance
- *Check*: Assess the measurements and report the results to decision makers
- *Act*: Decide on changes needed to improve the process

The U.S. Environmental Protection Agency (USEPA) has developed regulatory rules and advice to improve operations in water processing facilities, but the water industry itself has participated in development of quality control programs to aid in overall operations. An example is the voluntary QualServe program, which has been developed for water and wastewater by AWWA (2011b) and WEF. QualServe's goal is to help your utility achieve superior performance, maximum efficiency, and outstanding customer service. QualServe is owned and operated by AWWA and focuses on the processes that produce the outputs. It takes a broad look at a number of business process categories at water and wastewater utilities. The programs include self-assessment, peer review, benchmarking performance indicators, and a benchmarking data-sharing workshop.

Quality goals for water treatment and distribution were also developed through the Partnership for Safe Water (AWWA, 2011c). AWWA and several other water associations participate in the Partnership for Safe Water, which began as a program for optimizing the operations of surface-water treatment plants and has expanded into management of distribution systems. The distribution program is patterned after the treatment program and focuses on optimizing the distribution system. It involves commitment, data collection, use of assessment software, self-assessment, and peer review. The program can involve visits by outside peers.

For public works on a general basis, the American Public Works Association began a trial program during the 1990s for performance assessment, and it was clear that managers wanted a voluntary program that they could use for benchmarking and self-assessment. However, they were not so keen on certification and accreditation because these might lead to pressure for adoption and cost too much. As a result of experiences such as these, it appears that voluntary programs such as QualServe are the best way to help utilities improve performance and increase customer satisfaction on a continuing basis.

Utilities can develop their own customized comprehensive programs for water supply, such as the Comprehensive Water Quality Control Program developed by the Southern California Water Company (Cohen, 1999). The program is a comprehensive monitoring and response plan for source, treatment, storage, and distribution. The monitoring plans detail why, how, when, and where monitoring is to be conducted. The program also includes

operation guidelines for treatment plants as well as guidance for maintenance issues such as cross-connection control; dead-end flushing; and maintenance of valves, hydrants, wells, and reservoirs. Emergency response and customer complaint response are also included.

Other utilities have mounted impressive improvement programs for overall quality. For example, the Louisville Water Company (1995, 1999, 2011) undertook a concerted effort to transform itself to a total-quality organization. The Louisville Water Co. (LWC) is a private company owned by the city. A management team identified its core businesses as production and delivery, construction and maintenance of infrastructure, serving customers, and business resourcing. Their focus was on the full organization and workforce, and they created a broad definition of a total-quality culture with a focus on employee and team involvement. LWC (1999) defined systems-based management as "an organizational leadership method based on defining and understanding business processes, developing measurement data to know how well the processes are performing, and making decisions based on data to drive sustainable improvements to the processes." They considered that "systems-based management is the key element to attain the next level of quality (Louisville Water Company, 1999). The LWC program to transform itself into a quality organization shows the necessary elements for success and recognizes the importance of the quality of work life in advancing the organization. The 2010 annual report reported that, despite active infrastructure programs, the number of main breaks was up to 817, which translates to about 0.23 breaks per mile of pipe (0.14 breaks/km), a figure that is not far from the national average. This illustrates the continuing challenge to manage vast water supply infrastructure.

The need for improved operations was evident during the 1970s after the Construction Grants program began massive investments in wastewater treatment plants. In its study of the 1970s federal subsidies for wastewater, the U.S. General Accounting Office (1980) assessed a sample of 242 plants in 10 states. The results of the study showed that 87% were in violation of permits and that 31% were in serious violation. The problems identified by the study included design and equipment deficiencies, infiltration/inflow overloads, industrial waste overloads, inadequate budget, insufficient staff training, ineffective maintenance, and utilization of operators in other duties.

In a follow-up, after some 287 site visits and some diagnostic analysis, USEPA (1979) found a number of factors leading to poor plant performance. The principal recurring difficulties were operator error; inadequate process control testing procedures; infiltration/inflow problems; inadequate understanding of wastewater treatment; inadequate technical guidance and O&M manuals; inadequate sludge-wasting capability; inadequate process controls and flexibility of processes; and poor design of aerators.

As a result, EPA developed a Composite Correction Program with procedures to evaluate and correct performance. The program consists of a diagnostic approach, with provisions for prescribing and implementing

improvements. The program focused on weak points in the system by identifying performance-limiting factors. The composite correction method can also be used for water supply utilities. Hegg et al. (2000) described a small Washington utility that, when faced with a need to upgrade, hired a consultant to perform a composite correction review instead. The program focused on optimizing existing facilities with a comprehensive performance evaluation, followed by technical assistance. Unit processes were evaluated and performance-limiting factors identified. They found a lack of operating information, undocumented procedures, inadequate maintenance of some units, and a need to improve procedures. Staffing changes, automation, and shutdown capability were also needed. Comprehensive technical assistance included transfer of optimization skills to plant staff, demonstration of improved performance, and special studies. USEPA's (1998) method is described in its 1998 handbook.

In many cases, it is difficult to separate operations from maintenance. For example, USEPA developed a Capacity, Management, Operations, and Maintenance (CMOM) program to support the sanitary sewer overflow (SSO) rule. The goal is to provide best practices information without issuing too many regulations (Davis and Prelewicz, 2001).

The SSO rule was aimed at curbing unintentional discharges of raw sewage from municipal sanitary sewers that are caused by weather, improper operation and maintenance, and vandalism. These can contaminate waters, cause water quality problems, back up into basements, cause property damage, and threaten public health (USEPA, 2011).

Implementation of the SSO rule had three parts: a prohibition of unpermitted discharges from sewer systems; requirements for recordkeeping, reporting, and public notification; and the CMOM program. The CMOM program involves planning, assessment, training, and implementation of regulations. Its emphasis was on establishing authority over issues such as infiltration and inflow (I&I), design and construction standards, and new sewer testing; assessing system capacity to compare measured flows to design flows; identifying and prioritizing structural deficiencies; inventory and priority setting; and training staff.

As an example of implementation of CMOM, the Wastewater Collection Division (WCD) of the Fairfax County (Virginia) Department of Public Works and Environmental Services was concerned about SSOs and took action to respond to backups and other problems, customer needs, environmental quality, and financial claims (Fillmore et al., 2001). The organization chart of WCD shows branches for administration, gravity sewers, and pumping stations. The pumping station branch operates a pressure sewer network, pumping stations, flow meters, and stations where chemicals are added for odor and corrosion control. The gravity-sewers branch handles routine maintenance, CCTV (closed-circuit television) inspections, sanitary sewer repair and rehabilitation, and line location and marking. The county performed a self-audit to benchmark its performance, reduce I&I, extend service

lives, and reduce backups and overflows. Based on the self-audit, it made improvements, including a streamlining process, outsourcing, consolidation, and refocusing, despite downsizing.

WCD found that outsourcing rehabilitation worked better, to include slip-lining, chemical grouting, and easement clearing. However, they found that O&M works better in-house, and switched from reactive to proactive maintenance. WCD separated inspection from cleaning operations and increased the number of inspected miles. Cleaning now focuses on high-priority lines. It also procured new equipment and arranged for vendors to train crews.

Capacity assurance uses a computer model of the primary sewer network to project system capacity in 5-, 10-, and 15-year increments. Flow metering is used to verify the model. The I&I abatement program uses CCTV and rehabilitation with a cured-in-place pipe-relining process. Trenchless technologies are used to include cured-in-place pipe-relining, fold-and-form, robotic point repair. Manhole rehabilitation is by spin-cast and cast in situ processes. A sanitary sewer maintenance management system is now in place.

Performance indicators include backups and overflows per 1,000 miles and the number of pumping station failures that create overflows, bypasses, and backups. The overflow response plan found 177 critical segments that are now carefully monitored. Human resource management is a priority, with greater responsibility for employees, awards, a program to empower employees and encourage initiative, self-evaluations, and peer reviews.

Operations can also consider the overall environmental plan for a wastewater treatment plant. For example, in 2009 Virginia Polytechnic Institute and State University's Center for Organizational and Technological Advancement conducted a Baseline Environmental Review of the Fort Collins plant, called the Drake Water Reclamation Facility. This has been a well-run facility, which received EPA O&M awards in 1987 and 1993. I was on the city water board at the time and also served as an environmental consultant for the Baseline Review in 2009. The overall purpose of this program is to create an environmental management system for the plant that is in compliance with ISO 14001 standards for the wastewater utility. The Baseline Environmental Review establishes a foundation of environmental information and knowledge about environmental activities and issues related to operation of the facility. The city's staff members participated in further workshops at Virginia Tech and prepared the environmental operating plans.

Workforce Issues and Operators

Operations of water utilities involve multiple types of work, and it helps to focus on key roles. These represent jobs in the utilities and were explained in a book by Grigg and Zenzen (2009).

Engineers and technical managers are key occupations for planning and operation of water and wastewater systems, and they often work as supervisors and managers. Technical managers may or may not be engineers, and some are able to learn on the job, rising from positions as operators or from other original jobs.

Operators are on the front lines of the work, and engineers and technical managers are involved, as well as laboratory analysts and IT support staff. Managers have the ultimate responsibility, of course, especially those with the title "operations manager," or a variation of that title.

The number of categories of operators has been increasing, and their certification to work in water and wastewater utilities is explained by the Association of Boards of Certification (ABC, 2011), which publishes training criteria for the following categories:

- Water and wastewater treatment operators
- Backflow-prevention assembly testers
- Distribution and collection operators
- Industrial waste operators
- Water and wastewater laboratory analysts
- Very small water system operators
- Biosolids land appliers

A good place to read a narrative about the work of treatment operators is in the *Occupational Outlook Handbook* published by the Bureau of Labor Statistics (2007). The following is a brief extract from this handbook:

> Operators in both types of plants (water and wastewater) control equipment and processes that remove or destroy harmful materials, chemical compounds, and microorganisms from the water. They also control pumps, valves, and other equipment that moves the water or wastewater through the various treatment processes, after which they dispose of the removed waste materials.
>
> Operators read, interpret, and adjust meters and gauges to make sure that plant equipment and processes are working properly. Operators operate chemical-feeding devices, take samples of the water or wastewater, perform chemical and biological laboratory analyses, and adjust the amounts of chemicals, such as chlorine, in the water. They use a variety of instruments to sample and measure water quality and they utilize common hand and power tools to make repairs to valves, pumps, and other equipment.
>
> Water and wastewater treatment plant and system operators increasingly rely on computers to help monitor equipment, store the results of sampling, make process-control decisions, schedule and record maintenance activities, and produce reports. When equipment malfunc-

> tions, operators also may use computers to determine the cause of the malfunction and seek its solution.
>
> Occasionally, operators must work during emergencies. A heavy rainstorm, for example, may cause large amounts of wastewater to flow into sewers, exceeding a plant's treatment capacity. Emergencies also can be caused by conditions inside a plant, such as chlorine gas leaks or oxygen deficiencies. To handle these conditions, operators are trained to make an emergency management response and use special safety equipment and procedures to protect public health and the facility. During these periods, operators may work under extreme pressure to correct problems as quickly as possible. Because working conditions may be dangerous, operators must be extremely cautious.
>
> The specific duties of plant operators depend on the type and size of the plant. In smaller plants, one operator may control all of the machinery, perform tests, keep records, handle complaints, and perform repairs and maintenance. A few operators may handle both a water treatment and a wastewater treatment plant. In larger plants with many employees, operators may be more specialized and monitor only one process. The staff also may include chemists, engineers, laboratory technicians, mechanics, helpers, supervisors, and a superintendent.

The Safe Drinking Water Act Amendments of 1996 required USEPA to develop guidelines and standards for certification of operators of public water systems, including treatment and distribution systems (USEPA, 1999a, 1999b). State operator certification programs must include baseline standards that include legal authority to require certification of operators; classification of operators and a requirement to place direct supervision of water systems (including treatment and distribution systems) under the responsible charge of a certified operator; examinations for certification; enforcement capabilities; a process for recertification, including training requirements; funding of operator certification programs; stakeholder involvement in certification programs; and reviews of the operator certification program.

Requirements for operators of wastewater treatment plants and collection systems are not as tightly controlled by the federal government, but on a state-by-state basis they are comparable to those for drinking water systems. The main differences between water and wastewater certification are in the types of processes and rules. For example, water operators must evaluate characteristics of source water (drinking water), whereas wastewater operators evaluate incoming wastewater characteristics. Also, they comply with different sets of regulations.

For infrastructure management, distribution and collection operators hold key roles. Compared to treatment operators, distribution and collection operators are a hybrid grouping, and organization of their work is in transition. The focus is on the water supply side because of public health requirements. These operators perform both operations and maintenance, as explained by the position descriptions in the AWWA Water Utility Compensation Study

(RSM McGladrey, 2007). This study has categories for water treatment plant operators, water operations managers (responsible for distribution system flows), and water maintenance managers (responsible for construction and maintenance of the distribution system).

Operations requires skilled IT staff, but no certifications are required to work in utilities. RSM McGladrey (2007) listed categories for information services manager (including equipment selection, systems analysis, and programming and operations); SCADA manager; and programmers and analysts. In addition to normal organizational computer support, IT staff are required for the special needs of water and wastewater utilities such as SCADA, facility mapping, enterprise work management programs, technical databases, and specialty simulation models. Water and wastewater utilities also require laboratory work, where education backgrounds focus on chemistry or microbiology. ABC (2011) has guidance for both water and wastewater laboratory analysts.

To operate water, wastewater, and stormwater systems, staff often must be jacks-of-all-trades, or persons who are handy with many types of work. This is especially the case in smaller utilities. The trend toward "doing more with less" affects all utilities, especially in down economic times. Therefore, operators of water, sewer, and stormwater systems work with maintenance staff to perform all functions required to operate and maintain a wide range of systems and equipment. Given the many operating situations, a wide range of skills is required, and requirements change with automation and new processes.

Operation requirements can be outlined in terms of processes, decisions, and activities. This information might be used, for example, to plan a training program for operations staff. Table 7.3 shows some examples of operational requirements. Associations and community colleges offer training in the subjects outlined. To use this information for a training program, the levels of training needed can be organized from basic to advanced levels, as shown by the list of skill levels for operations in Table 7.4.

In the past, the plant operator was someone who was trained to operate equipment and facilities that someone had designed and built. The operator role was lower on the technical scale than the engineer's role. However, operations will become more complex, and the line between operators and engineers will blur. The realm of operations will include a role for operating engineers who work with operators to plan, design, and install control and monitoring equipment. They must be familiar with operating requirements and with the available technologies, and they have responsibility for implementing innovations to make systems work better. A large and complex organization may have a staff of operating engineers.

Some of the organizations involved in training for operations include the Association of Boards of Certification (ABC, 2011), which deals with drinking water, wastewater, labs, and distribution systems; the National

TABLE 7.3

Examples of Operational Requirements

	Source of Supply	Treatment Plants	Distribution and Collection Systems
Decisions made	Withdraw water Water quality	Unit operations Maintenance and repair	Pumping Maintenance Repair Schedule work
Problem solving	Drought response Water quality Use conflicts	Process upsets Equipment failure	Breaks and leaks backups
Monitoring	Water levels Watershed issues Water quality Safety Environment	System production Water quality Equipment condition	Flows Problems Water quality
System improvement	Increase yield Increase efficiency Repair Security	Increase efficiency Maintenance Security Reliability	Reliability Efficiency
System knowledge	Hydrology Groundwater Infrastructure Nonpoint pollution Reservoir chemistry Fish and wildlife	Equipment Processes Regulations	Pipes Pumps Appurtenances
Management tasks	Maintenance management Public relations	Maintenance management Public relations	Maintenance management Public relations
Knowledge, skills, abilities, experience	Math and science Computers Mechanical Management Environmental	Math and science Computers Repair Telemetry Operations	Hydraulics Water quality

Environmental Training Association; state governments; AWWA and WEF sections; and the National Rural Water Association.

ABC identifies the critical job tasks of operators and the skills required, and it shares information and works on certification laws, certification, and transfer of certification. It offers training materials in wastewater treatment, distribution, collection, water treatment lab, and wastewater lab. ABC also publishes *Model Act and Regulations*, with guidance for certification legislation and regulations. It covers terms, classification systems, models for certification boards, regulations and procedures, prohibited acts and penalties, reciprocity, funding authority, utility classifications, qualifications, exams, certificates, and revocation.

As an example of a state certification activity, Maryland's operator program was spurred in the late 1970s by an incident when an uncertified operator

TABLE 7.4

List of Skill Levels for Operations

Skill Category	Basic Levels	Advanced Levels
Math and science	Basic calculations, chemistry, physics, biology	Sophisticated knowledge to improve operations
System knowledge	Basic understanding for operation of components	Systemic knowledge of system components and performance
Information technology	Ability to utilize computers, telemetry systems, displays	Program and improve computers and telemetry systems and displays
Law	Familiar with regulatory controls in sphere of operations	Knows and works with laws, regulations, and regulatory agencies
Emergency operations	Familiar and trained with emergency operations procedures	Able to recognize threats, modify procedures, work with others in improving system readiness
Management	Basic competence in supervision, communications, records, reports	Higher level skills in supervision, communications, teamwork, reports, finance, public relations

spilled excessive fluoride into a public water supply and harmed dialysis patients (Barrett, 1998). At about the same time, EPA started funding state operator training centers, primarily for wastewater. The Maryland Center for Environmental Training was built at a community college, in the same period as another 40 state centers. The Maryland center expanded from wastewater programs to also offer training in drinking water and other environmental and safety areas. Maryland enacted a process-specific certification law for operators of water treatment plants and distribution systems. The law specifies four levels of water treatment and one for distribution systems. Examples of courses and training aids at the Maryland Center are shown in Table 7.5.

For operator resources, AWWA publishes *Opflow*; the WEF includes a special Operations Forum in each issue of *WE&T*; and both publish special operator training materials. California State University at Sacramento has operated a training center for a number of years, and Kerri (1998), who has developed operator training materials, explained how to plan and organize an operator training program. Instructional programs should be planned, organized, and assessed using proven educational methods.

APWA (2002) publishes a manual on safety programs for municipal or industry-based water or wastewater plants. It covers regulations of the Occupational, Health, and Safety Administration (OSHA), safety audits in wastewater plants, new lock-out/tag-out procedures, and ergonomic safeguards.

Since the first version of this book was published, stormwater training opportunities have increased substantially. I was involved in planning

TABLE 7.5

Courses and Training Aids at the Maryland Center

Law	Safe Drinking Water Act compliance
Maintenance	Program assessment
Emergency planning	Risk assessment and emergency plans
Management	Public relations and drinking water
Planning	Life-cycle planning
	Capital improvement planning
Finance	Five-year revenue and expenditure analysis
	Rate calculations
	Setting and implementing fair and effective rates
	Financing and debt management
Organization	Restructuring and consolidation
Water treatment	Introduction to water treatment
	Lead in public drinking water
	Chlorination technology, use, and safety
	O&M of chlorine systems
	Iron and manganese removal
	Water polymer technology
	Preparing plant for sanitary survey
Distribution systems	Water distribution
Source of supply	Well system O&M

stormwater short courses from the 1970s, and we found that courses in hydrology, hydraulics, modeling, detention storage, finance, regulations, and program management were required. Today, stormwater training has expanded to include USEPA's regulatory programs and related stormwater issues, such as best management practices.

Trends in Water, Wastewater, and Stormwater Operations

The infrastructures of water, wastewater, and stormwater systems are aging and subject to challenges from new regulations, underfunding, and workforce turnover. The operations staff must continue to derive good performance from the systems while responding to these challenging issues. As utilities face these challenges, we can look back to see how quickly things are changing and what may happen in the future.

The first edition of this book was prepared soon after the year 2000, and we knew by then that the Y2K (year 2000) computer problem would not happen. This was the great fear, which turned out to be exaggerated, that computer systems were programmed to calculate based on years that reached up to

1999, but could not handle 2000. Other lessons from operating experiences of that era can give us perspective on the future.

An AWWA (2000) roundtable discussed how operations would change, with a focus on solving financing problems for small systems and the possibility of consolidation. This seems to be occurring, as the latest Community Water Systems Survey (CWSS) showed a decrease in the number of systems. However, a prediction of a trend away from regulations to customer-driven treatment does not seem to be occurring. Operations do not seem more flexible but are still regulation-driven. The industry seems to be reconciled with the level of regulation, and we do not hear much discussion of rolling it back.

Trends toward increasing technology continue. More operator-friendly plants are available with smart control panels and automation. Laboratories are changing to become more standardized and managed to meet the regulatory needs of plants of all sizes. More on-line and kit monitoring systems are available, reducing the need for work at central labs. Operators must be multiskilled and sophisticated to work with monitoring and laboratory results.

New software is coming on line for all water, wastewater, and stormwater operations. For example, a package named OASIS (Operator Assisted Sewer Information System) is a database program for managing systems of wastewater collection, stormwater, or combined sewers. It has features for inventory, inspection, condition ratings, maintenance, and work orders (Utility Software, 2011).

New treatment technologies have become available, both for water and wastewater, and BMPs for stormwater continue to be developed. Emerging pathogens and chemicals are a concern because microorganisms mutate, and new compounds have entered the waste streams. Health effects continue as a big concern, with a focus on reproductive systems and cancer and other diseases.

As treatment plants changed from a few processes to sophisticated ones with complex physical, chemical, and biological operations, Lewis (2000) described a vision for the water supply treatment plant of 2050. It is worthwhile to see how, 10 years on, some of her projections are happening. Her model for treatment was of six stages, each capable of zero-, low-, intermediate-, or high-intensity processes, based on variable chemical types, dosages, and residence times. Stage 1 controls zebra mussels and nuisance organisms. Stage 2 removes coarse particulates with precoagulation, coagulation, settling, dissolved-air flotation, or rapid media filtration. Stage 3 removes coarse organic materials using low dosages of ozone, rapid filtration through coarse carbon, or aeration. Stage 4 provides disinfection with or without pH adjustment. Ozone, peroxide, chlorine, and ultraviolet (UV) light are all available for disinfection. Stage 5 removes organics, inorganics, and fine particulates with biological GAC, membranes of varying porosities, or ion exchange. Stage 6 provides any needed stabilization. All of these are available and seem to represent options to be implemented as needed in different plants.

Lewis envisioned limited public access to avoid security problems, but more ability of the public to take virtual tours of plants to check on their operations. Certainly, after 9/11 the access has been limited, but the virtual tours are not yet a reality, at least not in many places. She saw redundant intakes with real-time data and an intelligent plant system that used data to recommend treatment modes. This is occurring with more use of models and computer-assisted knowledge-management systems.

Lewis was on the mark in projecting a new meaning for multiple barriers, to include watershed and distribution system, as well as the treatment plant. She saw an emerging capability to automatically detect genus, species, and infectivity of microbes. This kind of biological monitoring seems still in the future. She foresaw a high reliability of operations, with the operator and chemist able to perform scheduled maintenance while the plant is automatically operated, most of the time. The maintenance management system would have been in place for many years and have so much data and work so well that breakdowns would be rare. These levels of O&M seem closer all the time.

Lewis concluded her article with a vision of the operating environment. She wrote that "flexibility of treatment processes and redundancy of equipment have served us well." Changes such as global climate change and urban development had changed runoff characteristics. Regulations were continually modified. However, "with the care of capable and highly skilled staff, the plant performs to whatever level of treatment is necessary to protect public health." These predictions seem to hold up well as we enter the year 2012.

The use of marginal waters has increased, and more reclaimed water systems are used now. It seems that water reclamation will continue to increase, both to help with wastewater requirements and to avoid the need to tap new sources. Water use efficiency has increased, causing changes in operational requirements. New problems, such as lack of enough flow to flush sewers, are reported.

If anything, the backlog of infrastructure funding required has increased. Older plants and pipelines will have to be retrofitted and last longer. Distribution system renewal will be a bigger concern than in the past. New noninvasive, nondestructive technologies for condition assessment continue to be developed. Ideally, future pipes will locate themselves, monitor for contaminants, and have structural integrity for 200 years. Collaborative research to develop equipment with shorter time to market will occur.

For water supply, the multiple barrier approach will take on more dimensions. Security will increase, and there will be integrity against intrusion. Reservoirs will be protected against intrusion and managed for water quality as well as quantity.

For contract operations, the jury remains out as to whether this approach is better than in-house operations. The answer seems to be, "it depends," just as it was a decade ago, when a survey showed that contract operations are in place at more than 1,200 water and wastewater plants in the United States.

Liner et al. (2000) reported on results of contract operations, which produced 15%–35% lower cost in a group of surveyed utilities. The survey studied variables to include regulatory compliance, asset condition, utility costs, staff and utility management, staff morale, and customer satisfaction. Large cities cited high costs and poor management as reasons to contract out operations, and small cities cited lack of qualified operators. Although the survey suggested that contract operations are superior overall, employee issues and working environments are factors, and more evaluation is needed.

Outright privatization remains controversial, although alternatives remain available (Greenough et al., 1999). Three levels for delivery of public works services include the traditional model, privatization, and managed competition. Each of these has advantages and disadvantages. Utilities using the traditional model are usually making improvements and adapting to change, while doing more with less. Privatization can involve turning services completely or partially over to the private sector, and involves decision factors such as risk, cost, frequency of use, legal environment, and expertise. Managed competition is a compromise approach that aims to maximize advantages and minimize disadvantages where either government services or privatization can be used, as appropriate.

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8

Risk Management and Disaster Preparedness

If you manage a water utility, you will recognize your risks and want to avoid problems like broken water mains and boil-water orders, at least as much as possible. That's only the beginning of the set of risks you face, which range from running out of water or money to the nightmare of a terrorist attack or even insider sabotage of your water supply. Things can go wrong with wastewater or stormwater systems as well. With wastewater, they range from lower-profile sewer backups to high-profile regulatory cases against a utility. With stormwater, a failure in your drainage system can cause property damage and even loss of life. For example, a 1997 flood through Fort Collins, Colorado, caused damage of over $100 million and resulted in four lives lost.

Much of this chapter is about risk management for water supply utilities that have the highest-profile risk among water systems. Wastewater security has received less attention, but after the September 11 terrorist attacks, wastewater utilities became aware of more risks, and security guidance has been developed by USEPA and the Water Environment Federation. Stormwater and flood systems are based on risk and hazards, and a failure occurs when the systems are not adequate. Stormwater systems also present risks in similar ways to water supply and wastewater because of their close associations with transportation facilities. Inadequate stormwater systems can cause failure in roads and other transportation systems through interdependencies.

Failure of infrastructure can be one of the most serious risks to a utility or city, especially when the consequences to life, property, and business continuity are high. Utilities must be on guard not to let the threat of disasters undermine public confidence in water services. It can be an uphill battle, because public confidence in the government's ability to safeguard water supplies has been and remains low, no doubt pulled down by overall low confidence in government institutions (*Business Week*, 2001; Jones, 2008).

Risk is a multifaceted concept and requires managers to think outside of the box, especially with new threats popping up. Threats can cause problems with finances, public health, disaster losses, and mistakes and accidents, among others. Because water, wastewater, and stormwater utilities cannot tolerate much risk, they must assess the likelihoods and consequences of threats to create plans to manage the risk. These require a great deal of data and preparation, as will be explained in this chapter.

The world of risk seems to expand continually for water managers. Risks facing water utilities are growing from infrastructure decay, natural disasters, accidents, and malevolent threats. Systems can also fail from collateral damage and interdependencies with other failed systems that cause cascading effects, especially electric power systems. Large events, such as Hurricane Katrina or massive failures of the power grid, can disrupt entire water systems. One of the major risks faced by system managers is loss of service due to natural or human-caused events. Imagine the loss of services that occurred due to the great earthquake and tsunami in Japan in 2011, for example. Details are not available yet, but if the past is a guide, there would be thousands of water main breaks, loss of wastewater conduits, flooding problems, and similar consequences.

Risk is a broad subject for water system managers, and the purposes of this chapter are to outline the main threats, relate them to the integrity of infrastructure systems, and explain how to reduce vulnerability to them. The chapter explains the background of the threats and the responses that utilities can make to prepare for and respond to them. Life-cycle management of infrastructure requires managers to deal with risks that go beyond engineering design and construction. They do this by adding security and risk management to the tasks of planning, design, construction, operation, and maintenance. Avoiding disasters and providing security is an everyday business for utilities.

How Risk Is Increasing

The buildup in risk can be seen from Figure 8.1, which illustrates that, prior to the mid-1800s, the main risks of water organizations were financial and

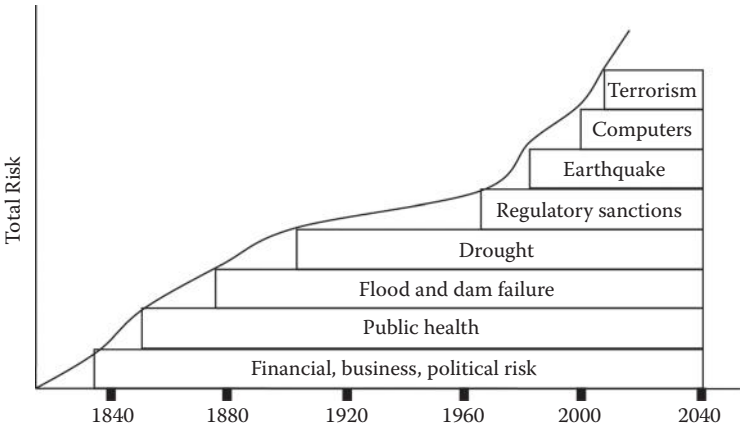

FIGURE 8.1
Buildup of risk to water utilities.

political. At that time, many water supply services were provided by private companies, and little wastewater or stormwater service was provided. Public health risks were known because sickness from waterborne diseases was common. Also, spectacular dam failures occurred in the 1800s, such as in Johnstown, Pennsylvania, in 1889, a failure that caused a giant flood with many deaths.

As cities developed further, drought also became a greater risk and then, with the environmental revolution, all of a sudden regulatory sanctions were a risk. The larger and more complex systems were more subject to earthquake, although the great Chicago fire of 1871 and the San Francisco earthquake and fire of 1906 had already demonstrated the vulnerability of water systems. Computers made systems more vulnerable, both to outright failure and to hacking, and now terrorism threatens water systems.

Examples of Failures

Water systems have experienced many failures due to natural disasters. Figure 8.2 illustrates earthquake damage from the San Francisco Bay area, and it is easy to see how many pipelines are damaged. Floods are especially tough on water facilities. Figure 8.3 shows an inundated water treatment plant in Grand Forks, North Dakota, and Figure 8.4 shows flood pumping in the small town of Elba, Alabama.

The most visible risks to water, wastewater, and stormwater systems involve public health and safety, which affect system design and management and require capital investments and/or decisions. Figure 8.5 shows a chemical storage area, illustrating one of the most serious safety concerns of water and wastewater utilities.

FIGURE 8.2
1989 Loma Prieta San Francisco Bay quake. (From Federal Emergency Management Agency, Mitigation Resources for Success CD.)

FIGURE 8.3
Flooded water treatment plant in Grand Forks, North Dakota. (From Federal Emergency Management Agency, Mitigation Resources for Success CD.)

FIGURE 8.4
Elba, Alabama, pumping plant to dewater from behind a levee. (From Federal Emergency Management Agency, Mitigation Resources for Success CD.)

FIGURE 8.5
Chemical storage area. (From American Water Works Association. Copyright 2001. All rights reserved.)

Risk Management Terminology

Because risk is such a broad field, varied terminologies are used in risk management by different groups. For example, what comprises risk to a banker will look different from the risk that a police officer confronts. The terms used include hazard assessment, disaster mitigation, risk assessment and reduction, vulnerability assessment, mitigation, emergency management, and contingency planning, among others. On close inspection, however, these fields mostly involve the same processes.

One guide to standard terminology within the water field is from the SIMPLE (Sustainable Infrastructure Management Program Learning Environment) website (see Chapter 3; this is the website managed by the Water Environment Research Foundation [2011]). It reports on definitions by others, but does not try to standardize the terms. For example, for risk, it lists four definitions from different sources. Three of these seem applicable to water, wastewater, and stormwater analysis:

- The chance of something happening that will have an impact on objectives
- The potential for realization of unwanted adverse consequences to human life, health, property, or the environment
- The possibility that an outcome is not achieved or is replaced by another outcome or that an unforeseen event occurs. This includes both uncertainty due to future events and the consequences of limited knowledge, information, or experience.

In the same way, SIMPLE presents definitions of risk management from several sources:

- A systematic way of identifying and analyzing potential risks and devising and implementing mitigation responses appropriate to their expected impact
- The systematic application of management policies, procedures, and practices to the tasks of identifying, analyzing, assessing, treating, and monitoring risk
- The culture, processes, and structures that are directed toward the effective management of potential opportunities and adverse effects
- A structured way of identifying potential risks, analyzing their consequences, and devising and implementing responses so as to ensure that proposal or project objectives are achieved. This includes management of ongoing risks associated with the ownership of assets.

In an attempt to standardize language, the International Organization for Standardization (ISO) has published terminology for the risk management field. Some of the ISO terms (marked by asterisks) are given in Table 8.1, along with other terms that are relevant to water, wastewater, and stormwater systems (ISO, 2001, 2002; Grigg, 2003).

The ISO definitions are concise and useful, but the risk field seems certain to continue with many different definitions. The ISO standard helps writers of standards address risk management issues coherently regardless of the industry sector. Whatever the terminology used, risk management is the overall way that an organization handles risk, and its elements are to consider hazards that can threaten systems, to assess risks and consequences, and to organize necessary actions, including mitigation, response, recovery, and communication of risk to constituent groups.

While the steps in risk management can be described in different ways, the main idea is to identify, manage, and respond to threats to an organization and seek to answer the following questions (Kolluru, 1996):

- What can go wrong and why (what are the hazards and threats, what disaster can occur)?
- How likely is it (what is the risk, chance, probability, likelihood)?
- How bad can it be (who or what would be affected, what is the vulnerability, what would be the consequences)?
- What can be done about it (what should be management actions: mitigation, response, or recovery)?

TABLE 8.1

Terminology for Risk Management

Term	Definition
Contingency planning	Planning to ensure continuity between the impact of a problem and return to normal functioning of an organization. Used by business planners and called *business continuity planning*.
Consequence	Outcome of an event (ISO)*.
Crisis management	Crisis management involves special measures to solve problems during a crucial or decisive point or situation, such as war or a kidnapping.
Disaster	An event that will cause widespread destruction and distress. The term is used in medical, search and rescue, relief, fire, and accident response.
Emergency management	The term is used for police, fire, and medical work, as well as by utilities. The Federal Emergency Management Agency (FEMA) uses this phrase in its name. *Emergency preparedness* is also used.
Event	Occurrence of a particular set of circumstances (ISO)*.
Hazard	A "potential source of harm" (ISO)* or a source of potential damage from a disaster. See also *threat*. A hazard does not lead to disaster unless it penetrates the defense.
Incident management	An event of a certain type. A widely used concept is the Incident Command System (ICS).
Likelihood	The chance or probability that an event causing consequences will occur.
Mitigation	Limitation of any negative consequence (ISO)*. In water supply, mitigation includes reliable and flexible supply systems, mutual aid, conservation, alternative treatment, and removing high-risk components.
Recovery	A phase of an emergency, indicating a period after response until systems return to normal or better.
Response	The phase following an emergency or disaster.
Risk	Combination of the probability of an event and its consequence (ISO)*. Residual risk is risk remaining after risk treatment (ISO)*. Risk identification is the process to find, list, and characterize elements of risk (ISO)*. Risk reduction comprises actions take to lessen the probability, negative consequences, or both, associated with a particular risk (ISO)*.
Risk analysis	Systematic use of information to identify sources and to estimate the risk (ISO)*.
Risk management	Coordinated activities to direct and control an organization with regard to risk (ISO)*.
Risk treatment	Process of selection and implementation of measures to modify risk (ISO)*.
Safety and security	Safety is freedom from unacceptable risk (ISO)*. *Safety* is a general term meaning to be secure from harm, danger, and evil. *Security* means freedom from danger, harm, or risk of loss.
Source	Item or activity having a potential for a consequence (ISO)*.
Terrorism	The unlawful use of force or violence against persons or property to intimidate or coerce a government, the civilian population, or any segment thereof, in furtherance of political or social objectives (FBI definition, quoted in Kozlow and Sullivan [2000]).
Threat	A potential source of damage. Similar to hazard.
Vulnerability analysis	Vulnerability analysis identifies all possible vulnerabilities, presents historical data about past disasters, assesses future probability and frequency of emergencies and disasters, analyzes impacts and effects, and validates data (U.S. Federal Emergency Management Agency, 2010).

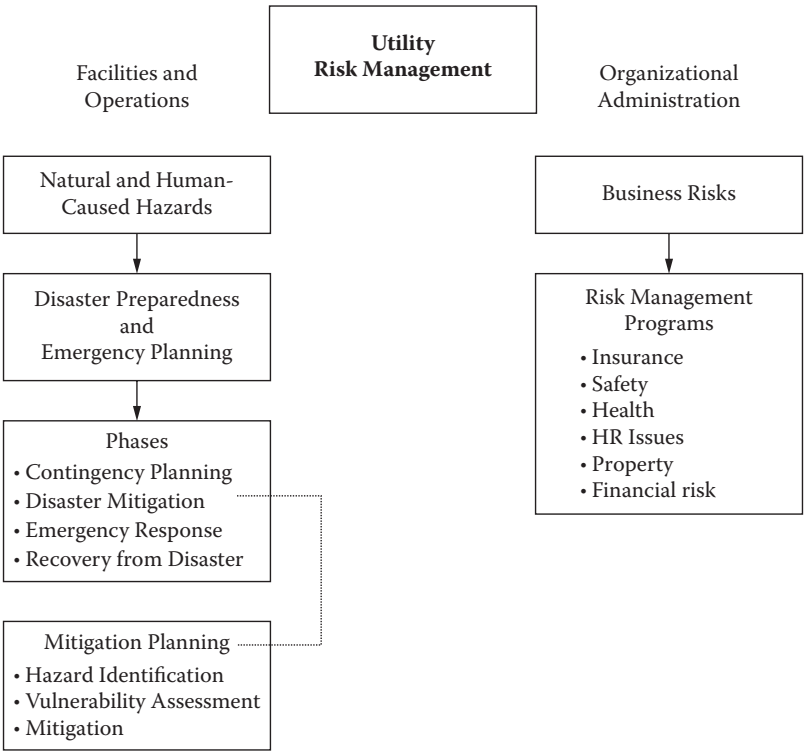

FIGURE 8.6
Utility risk management programs.

These can be grouped into two basic categories, risk assessment and risk reduction. Risk assessment asks what can go wrong and why, how likely it is, and how bad it can be. Risk reduction asks what can be done about it.

Risks in organizations can be classified in different ways, as shown in Figure 8.6, which divides utility risk management programs into those for natural and human-caused hazards and those for business risk. Risk from natural and human causes is focused on facilities and operations, while business risks are focused on administration. These are not clear-cut distinctions because, as you can imagine, a facility risk becomes a business risk quickly. Still, this classification of risk concerns helps to show the purviews of the asset-management side (facilities and operations) and the business side.

The facilities and operations sides of the organization are mainly involved with risks dealing with infrastructure. For example, the director of engineering might be most concerned with risk to structures, whereas the director of risk management might be more concerned with claims and insurance. Business risk is generally considered to include all contingencies that affect the finances or legal liabilities of the organization.

Natural and Human-Caused Threats to Water Systems

Threats to water systems occur from natural and human causes, and can also result from interdependencies with other infrastructures, such as the electric power or transportation systems. The threat sources are summarized in Table 8.2, which follows a listing by AWWA (2001) with additions.

Many earthquakes have occurred with threats and/or damage to water systems. One of the most famous U.S. quakes was the 1906 San Francisco event and its fire, which caused great disruption to public services in an era before modern water utilities or emergency management systems were in place. In 1971, a quake in Southern California damaged hydraulic structures and lakes forming part of the Los Angeles Aqueduct system. The Loma Prieto quake of 1994 caused great damage, including many breaks of water mains and residential services. As a result of this quake, the East Bay Municipal Utility District (EBMUD) initiated a seismic improvement program. The next year, an earthquake caused over 5,000 deaths in Kobe, Japan. Again, there were many breaks and great damage to pumps and treatment plants. The damage done by these quakes was dwarfed, however, by the great earthquake and tsunami in Japan in 2011. Data on damage is still being compiled, but it seems certain that the total damage will far exceed that of the previous quakes.

TABLE 8.2

Threats to Water Systems

Natural hazards
Earthquake
Flooding—river, flash, coastal, dam break
Wind—hurricanes, tornados
Waterborne disease—*Cryptosporidium, Giardia, E. coli, Legionella*
Drought and dust
Other severe weather—cold, heat, snow, ice, high winds, lightning
Fire—forest, brush, firestorm
Mudflow and landslide
Volcano and ashfall
Human-caused hazards
Hazardous material releases
Breaks, system failures, power or computer system failure
Major accidents—nuclear power, construction, transportation
Structure fires
Terrorism, vandalism, riots, strikes, sabotage, hoaxes, cyber attacks
Nuclear power plant accidents or nuclear explosions
War and civil unrest

The 2011 Japan event included much flood damage due to the tsunami, and other massive flooding, such as caused by Hurricane Katrina, has shown the damage potential of great floods. Katrina was the United States' most recent devastating hurricane and flood disaster, and it shut down all water systems in New Orleans. Response and recovery were slow and seemingly ineffective. New Orleans had attempted to prepare for flood disasters, but during Katrina, the water-supply and flood-control facilities suffered collateral damage from levee failures and could not cope with overwhelming conditions. River flooding causes high levels of property damage in the United States every year. The 1993 Midwestern flood contaminated water at 250 drinking water treatment plants in Missouri, Kansas, Illinois, and Iowa. Des Moines, Iowa, lost service from its treatment plant for a number of days. Hurricane Floyd in 1999 caused high flooding in North Carolina, New Jersey, Pennsylvania, Virginia, and New York. Although it was induced by a hurricane, much of this was river flooding. In 2005, Hurricane Irene raced up the East Coast and caused massive flooding, similar to Floyd.

In many ways, disease outbreaks seem like natural disasters as they occur as a result of earthquakes and floods. Actually, they are a different kind of event and can be considered as human caused, but they are more in the category of accidents than in the category of malevolent events. Rather than a threat, they might be considered a consequence. They can occur from natural or human causes. In any event, water supply and wastewater utilities are very concerned about disease outbreaks. The Milwaukee cryptosporidium outbreak of 1993 caused illness in 400,000 persons and a number of deaths. The water supply was from Lake Michigan, and before the outbreak there were severe spring storms. There may have been a rise in particulates passing through the plant, and studies were done to assess what may have happened to allow oocysts to pass through the plant (Craun et al., 1998). The May 2000 *E. coli* contamination incident in Walkerton, Ontario, led to seven deaths and over 2,000 were sick, half the population. Flood waters sweeping over cattle grazing lands and allegations of utility problems were implicated, along with lack of training (Grigg, 2003).

Human-caused threats occur in different ways, and their classification is not as clear as for natural hazards, especially those that involve malevolent intent. Failures and accidents are unintentional threats, and attacks and psychological threats are intentional threats that can come from insiders or outsiders. Table 8.3 shows one way to classify human-caused threats.

Although there have been no major attacks against water infrastructure facilities, the threat seems continually on the rise since 9/11. A book published in 2011 detailed the potential issues (Doro-on, 2011). It explains how, after the execution of Osama Bin Laden, intelligence reports showed plots against water supply and other infrastructure systems, including some dams. An initial focus is on water infrastructure terrorism, which might involve attacks on treatment plants, cyber terrorism, or bioterrorism. Targets might be terrorism against major infrastructure such

TABLE 8.3

Classification of Human-Caused Threats

- *Intentional attacks*: terrorism, vandalism, sabotage, arson, cyber attacks
- *Intentional psychological threats*: hoaxes, misinformation, incitement of panic
- *Accidents*: transportation, construction, industrial, nuclear power, hazardous material releases, fires
- *System failures*: breaks, system component failures, computer system failure

as aqueducts, dams, or aquifers. Although dams might be targets, the author thinks that terrorists could damage powerhouses but not dams, which are often built of massive concrete. Poisoning of the water supply might occur by chemical weapons. Targets might include hydrants, computer controls, or water tanks, as well as source waters. Chemicals might include pesticides with low lethality concentrations. An example was in Barstow, California, during 2010 when the governor declared a state of emergency over contamination with perchlorate, the toxic chemical used to make explosives and rocket fuel. Improvised explosive devices (IEDs) might be used to destroy water infrastructure like dams. The author calls for risk and vulnerability assessment models for critical infrastructure protection and strategic intelligence.

Cascading failures are those system failures that occur due to power loss, source contamination by chemical spill, pipeline loss due to another system's failure, or similar events. In other words, a cascading effect is caused when failure of one system propagates to another system that is interdependent with it (Rinaldi, Peerenboom, and Kelly, 2001). The National Infrastructure Protection Plan defines an interdependency as the "reliance of an asset, sector, or sectors on other assets to function properly, and their reliance on the original entity in return. This reliance is reciprocal and at a minimum, bi-directional" (U.S. Department of Homeland Security, 2011).

Water utility buildings, pipes, reservoirs, electrical systems, and other vulnerable components may suffer damage along with other parts of cities due to interdependence with other systems. A road system that fails in an earthquake may rupture underlying utilities, and repair crews may be delayed in reaching their damaged facilities and be unable to repair them until the roadway is restored. The World Trade Center attack destroyed all infrastructure connected with the structures. The New Orleans levee failure created flooding that destroyed the water utility's ability to provide service. Another example is a large-scale power failure that causes sudden shutdowns, which might siphon contaminants through leaks in distribution systems and cause illness. In Harbin, North China, in November 2005, river contamination from a chemical spill shut down source water and caused loss of water service to a large city. A second toxic spill occurred in China in the same month on the Bei River near Hong Kong (Dean, 2005).

Risk and Vulnerability Assessment

Anticipating these threats is the job of risk assessment, which is the systematic use of information to identify sources and to estimate the risk. Risks are usually defined as a function of the threat and the consequences of an event, but vulnerability of the facility or people being damaged affects the consequences. If the event is a pipe break, then the vulnerability of the pipe itself to damage is an element of risk.

More often than not, you are unable to compute either the likelihood of the event or the magnitude of the consequences, so a good way to illustrate the magnitude of risk is by a risk triangle, as shown in Figure 8.7 (Crichton, 1999). This is a useful way to explain risk and shows that if you place each variable at a corner of the triangle, then the triangle indicates the magnitude of risk. If any corner of the triangle moves, that is if threat, vulnerability, or consequences change, then risk gets larger or smaller.

The risk matrix is another useful way to show how to classify risks by probability of occurrence and the magnitude of consequences. In this case, the variable vulnerability is implicitly included in both the probability of an event and its consequences. A few hypothetical examples of events are shown on the matrix in Figure 8.8.

The science of measuring risks is well advanced for some threats but not for others. Risks to water, wastewater, and stormwater systems are normally difficult to quantify, although possibilities might be listed and mapped, as shown in Table 8.4. The risks shown are not independent of each other, but Table 8.4 indicates a way to view them for purposes of assessment and management.

Risk and vulnerability assessment (VA) are, for all practical purposes, the same process. VA identifies all possible vulnerabilities, presents historical

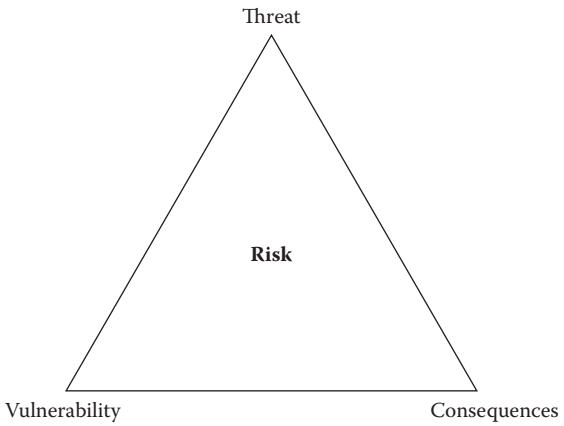

FIGURE 8.7
Risk triangle.

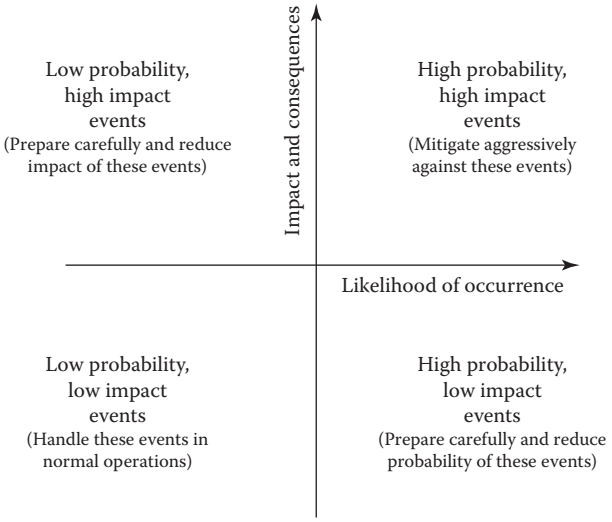

FIGURE 8.8
Risk matrix.

TABLE 8.4
Quantification of Risk

Risk Category	Measurement of Risk
Natural disaster	Natural disaster risk can be quantified for earthquake and floods, but some events, such as fire or lightning damage, are more difficult to quantify.
Human-caused disaster	This category of risk is highly visible but difficult to quantify.
Performance failure	If design is for a fixed event such as a flood, the risk can be quantified. If failure is caused by an unexpected event such as a mistake, it is difficult to quantify.
System or component failure	These might be quantified from data on service records, but in practice are difficult to quantify.
Construction or maintenance failure	These failures are difficult to quantify because they can occur in many ways. Claims for construction damages might be quantified from insurance data.
Health and safety	This category includes risk categories, such as deaths from water contamination, where empirical data may be available but risk is difficult to quantify.
Liability	In theory, many areas of liability could be mapped, but risk is difficult to quantify.
Financial	Financial risk such as adequacy of revenues can be modeled.
Employee problems and accidents	Employee risks are difficult to quantify, although data might be available through the insurance industry.

data about past disasters, assesses future probability and frequency of emergencies and disasters, analyzes impacts and effects, and validates data. Although the term *vulnerability* refers to susceptibility to being damaged, VA as a tool extends to determining the consequences of the hazards affecting the facility or operations of concern. After 9/11, Congress passed the Public Health Security and Bioterrorism Preparedness and Response Act of 2002 (Bioterrorism Act) to require and provide some funding for VAs in the larger water utilities (USEPA, 2011).

In vulnerability analysis the effects of the threats or hazards on water system components and water quality and quantity are determined. The entire system should be analyzed, as well as the components. AWWA (2001) wrote that vulnerability assessment in water utility emergency planning has four basic steps:

- Identify components of the water supply system
- Estimate potential effects of probable disasters
- Establish goals for performance and levels of service
- Identify critical components

These steps, although presented for water supply systems, also apply to wastewater and stormwater. Details on applying them include the following:

- Identification of system components requires an inventory with maps, condition inspections, and data for operations and maintenance scenarios, including emergency actions. This is a link between disaster and asset management.
- Quantifying magnitude of anticipated disasters determines the scale and magnitude of each potential disaster or contingency. Estimating the effects of anticipated disasters on each component of the system involves disaggregation of systems to assess the effects of each disaster type on each component. (For example, a storage reservoir might be vulnerable to a mudslide, whereas the treatment plant might fail during a power outage.)
- Estimating demand during and after a disaster is an extension of normal demand-estimating procedures. Determining the capability of a system to meet demands during emergencies requires modeling and analysis to match demands and supplies during the emergency.
- Identifying critical components that cause failure during emergencies is the result of the vulnerability analysis and pinpoints the components that need strengthening.

TABLE 8.5

Critical Support Systems and Lifelines

Subsystem	Examples of Components
Administration and operations	Personnel, buildings and computers, records, emergency plan
Source water	Watersheds and surface sources, reservoirs and dams, aquifers, wells and galleries
Transmission	Intake structures, aqueducts, pumping stations, pipelines and controls
Treatment	Structures, controls, equipment, chemicals
Storage	Tanks, valves, piping
Distribution	Pipelines, valves, pumps, materials
Electric power	Substations, transmission lines, transformers, generators
Transportation	Vehicles and construction equipment, maintenance facilities, supplies, parts and fuel, roadway infrastructure
Communications	Telephone, radio, telemetry, mass media outlets

AWWA's manual specifies the water system to include five subsystems and their components: source, transmission, treatment, storage, and distribution. These can be expanded into a list of critical support systems and lifelines, as shown in Table 8.5.

Wastewater and stormwater systems can also be disaggregated into their component parts, as explained in Chapter 2. Disaster and security studies will be concerned with different parts of the systems. For example, interrupting a source of water can be disastrous, whereas in a stormwater system, using the system to gain access to a critical facility by a saboteur might be the major issue.

Consequences of disasters and emergencies can be dire. Some listed by AWWA (2001) for water utilities are

- Personnel shortages
- Contamination of water supplies
- Contamination of air
- Well and pump damage
- Pipeline breaks and appurtenance damage
- Structure damage
- Equipment and material damage or loss
- Process tank or basin damage
- Electric power outage
- Communications disruption
- Transportation failure
- Hazard effects on system components

The different risks can be shown together in one place, but they represent a range of different types. In addition to health and safety, risks involve economic damage and other social effects. The range of risks that must be assumed by the utility is shown in Table 8.6, and our knowledge and awareness of these risks continues to increase with experience.

Mitigation Measures

Mitigation consists of disaster-proofing activities that eliminate or reduce the probability of disaster effects. AWWA says that they reduce vulnerability of components or systems. The general goal is to produce reliable

TABLE 8.6

Range of Risks

Risk Category	Water Supply	Wastewater	Stormwater
Health, safety, environment	Contamination, sickness, death	Contamination, damage to property, health risks, environmental damage	Children playing around flood facilities, pipes, ponds, etc.
Performance failure	Loss of fire flow	Overflow of untreated sewage and enforcement action	Inadequate protection from flooding
Construction or maintenance failure	Another utility damages pipe while digging	Trench cave-in	Pipe damaged during construction
System or component failure	Pipe break	Sewer backup due to clogging, leading to property damage	Flooding due to clogged facilities, leading to property damage
Liability	Pipe leak leads to cave-in and damage to property	Industrial waste contaminates aquifer	Redirected flood waters damage property
Financial	Rates are inadequate to pay costs for utility, leading to crisis	Inadequate rates to pay for improvements, leading to fine	Utility held responsible for damage, not able to pay judgment
Employee problems and accidents	Employee inhales chlorine	Employee injured in maintenance event	Employee sues for discrimination
Disaster, human caused	Pranksters contaminate water in tank	Construction project damages large sewer	Industry dumps toxic waste in drainage system
Disaster, natural	Earthquake causes breaks	Tornado damages treatment plant	Flood overwhelms facilities

TABLE 8.7

Risk Mitigation Measures

Management Measures	Engineering Measures
Planning for emergency response	*Source water and transmission*: providing alternative sources, protecting wellheads, retrofitting dams and aqueducts
Administrative systems in place	*Treatment*: isolation, bypass, fire resistance, flood proofing, alternative systems
Cooperative plans for water sharing and interconnections	*Distribution*: design, control, interconnections
Improvements in communication to include codes, backup systems	Remove high-risk components
Personnel: education, cross training, replacement, ensuring a safe workplace	Bury in solid soils/rock, use vegetative cover
Placement of redundant equipment and auxiliary generators	Replace rigid with flexible systems
Improved access	Use retaining walls
Preparing to conserve	Detect slow landslides, relocate away from landslides
Provision of alternative transport	Repair leaks in areas of unstable soils
Frequent inspections	

and flexible supply systems. Table 8.7 outlines mitigation measures listed by AWWA (2001) and the Pan American Health Organization (PAHO, 1998).

Design and construction offer opportunities to mitigate against disasters. For earthquakes, advances have been made in seismic upgrades, such as redesign of critical pipelines in fault zones. Water systems should be designed to maintain structural integrity of storage facilities, pipeline viability, and the continuity of control systems during disasters. For floods, design provisions for a treatment plant might include protection of the intake structure, protection against flotation, ice jams, internal flooding, and parasitic microorganisms such as giardia and cryptosporidium. Treatment plant design should also focus on chemical handling and spill containment as well as chlorine leaks. Electric fault protective devices also require attention.

Reliability as a key design goal means the extent to which a system performs its function without failure. Design for reliability focuses on the consequences of loss of the plant or bad water (Spitko, 1998). Reliability is driven by the regulatory consequences of a loss of part or all of a plant and the consequences of not meeting standards. A systems approach would make sure that failure of a component does not lead to failure of the system. Reliability depends on the treatment train, equipment, processes, standby equipment, redundancy, parallel systems, and flexibility.

The following are principles and ideas for reliable systems (Spitko, 1998):

- Ensure that failure of any one component does not cause operating failure or noncompliance
- Provide operational flexibility to handle problems with source water variability
- Have reserves and redundancies to keep operating if one unit is out of service
- Have one or more processes perform the same function, such as filters and sedimentation both to remove particulates
- Gain flexibility through redundancy, conservative sizing, or unit arrangements
- Ensure overall reliability through interconnections and different sources
- Avoid independent process trains; use interconnections instead
- Use gravity flow versus pumping
- Ensure component system reliability—electrical, controls, etc., many factors
- Consider disasters in design
- Use waterproofing
- Control access
- Have plant security
- Store chemicals on site to mitigate truck blockades
- Have on-site generation of chemicals, chlorine
- Have a HAZMAT program
- Have a safety program
- Do a vulnerability analysis
- Have multiple intake ports or well screens
- Use off-stream sources
- Have dual power sources and standby power
- Ensure reliability of chemical storage
- Verify the reliability of process design
- Facilitate the tasks of operations and maintenance (O&M)
- Ensure accuracy of shop drawings
- Install computerized maintenance systems
- Train your people

An example of a design feature that increases reliability is the use of flex pipe, which is illustrated in Figure 8.9. The flexibility feature enables the pipe to withstand movement around faults better than rigid pipe.

FIGURE 8.9
Installation of EBMUD flexpipe. (From Federal Emergency Management Agency, Mitigation Resources for Success CD.)

Security and Emergency Management

Dealing with risks involves the whole organization and includes the security and emergency management forces as well as the engineering forces. The term *security* connotes a control program to deal with human-caused threats, while emergency management is provided for all threats and events.

At the same time that risk has increased, so have awareness of security needs and response capabilities. During the 19th century, when water systems were emerging, infrastructure was not extensive, and security of water systems was not a high-profile issue. As cities and infrastructure systems became more complex, so did political issues. President McKinley was assassinated by an anarchist in 1901. During World War I, the United States faced an infrastructure crisis to prepare for mobilization, and in the interwar period, national security focused on mobilization preparedness, especially transportation and supply systems, as well as the defense industry. World War II taught lessons about preparing for national security through economic efforts guided by government industrial policy.

Although local infrastructure was not considered a security issue during WWII, there were some sabotage threats. National security was evolving to include homeland security. After World War II, the cushions of time and distance that protected the United States diminished. During the 1950s, it was the

threat of nuclear war that consumed us, and under the Federal Civil Defense Act of 1950, the Defense Civil Preparedness Agency was born. In 1979, FEMA was created, and it merged responsibility for emergencies and disasters (natural, technological, and human made as well as war or nuclear attack). In its first years, emergency management at the national level was focused more on national security than on natural or human-made emergencies or disasters.

After about 1989, the world changed with geopolitics and large-scale natural disasters. Hurricanes, earthquakes, and flooding shifted emphasis from civil defense and attack preparedness toward natural disasters. Then, terrorism became a larger factor in national security. The United States had learned lessons about guerrilla warfare in Vietnam, but it did not involve radical terrorism, such as that which emerged from value-driven causes.

By the 1990s, concern about terrorism had increased, especially with the first World Trade Center bombing. In 1996, the Presidential Commission on Critical Infrastructure was formed under Executive Order EO 13010, which cited:

> Certain national infrastructures are so vital that their incapacity or destruction would have a debilitating impact on the defense or economic security of the United States. These critical infrastructures include telecommunications, electrical power systems, gas and oil storage and transportation, banking and finance, transportation, water supply systems, emergency services (including medical, police, fire, and rescue), and continuity of government. Threats to these critical infrastructures fall into two categories: physical threats to tangible property ("physical threats"), and threats of electronic, radio-frequency, or computer-based attacks on the information or communications components that control critical infrastructures ("cyber threats"). Because many of these critical infrastructures are owned and operated by the private sector, it is essential that the government and private sector work together to develop a strategy for protecting them and assuring their continued operation. (Office of the President, 1996)

Now, the U.S. Department of Homeland Security (2011) has been formed, and it is the custodian of the National Infrastructure Protection Plan (NIPP) and its sector plans, including one for water supply. The most recent version of the NIPP is 2009 at this time, and its goal is to provide the unifying structure to integrate efforts for protection and resiliency of the nation's critical infrastructure and key resources (CIKR). This is supposed to help build a safe, secure, and resilient nation by thwarting terrorism. The 2009 NIPP broadens the plan to include a focus on an all-hazards environment.

The 17 sector-specific plans include several that involve water, wastewater, and stormwater infrastructure: dams, emergency services, health care and public health, nuclear, transportation, and water. The reason that water is a factor in these (and others to a lesser extent) is that so many economic and social systems are dependent on reliable water infrastructure.

Presidential Decision Directive 63 in May 1998 established the National Infrastructure Protection Center (NIPC) inside the Federal Bureau of Investigation (FBI). The NIPC at FBI headquarters deals with threat assessment, warning, vulnerability, criminal and national security investigation, and response. Its mission is to detect, deter, assess, warn (users), respond to, and investigate unlawful acts that threaten or target our eight critical infrastructures (telecommunications, electric power, gas and oil storage and delivery, banking and finance, transportation, water supply, emergency services, and government operations).

Under NIPC, the InfraGard initiative set up a public–private information-sharing mechanism that funnels threat warnings to sectors, including the water supply sector. NIPC has since been transferred to DHS, but the FBI has retained control of InfraGard and its partnership with the private sector. InfraGard was initially focused on cyber infrastructure protection, but after 9/11, it was expanded to include physical infrastructure. All 56 field offices of the FBI have opened an InfraGard (2011) chapter with company members across the nation. InfraGard provides member services to include an intrusion alert network using encrypted e-mail, a secure website about suspicious activity, local chapter activities, and a help desk.

Threats are reported through an Information Sharing and Analysis Center (ISAC) for the water supply sector. The WaterISAC (2011) is a secure Web-based interface for water utilities to share security information.

USEPA has organized a Water Protection Task Force to help federal, state, and local partners expand their tools to safeguard drinking water from terrorist attack. EPA has said that the threat of harm from an attack on our water supply is small, and the goal is to provide access to the best scientific information and technical expertise. EPA already has a notification system to share information among drinking water providers, the law enforcement community (local, state, and federal), and emergency response officials, developed with the Association of Metropolitan Water Agencies (AMWA) and the FBI.

Sandia National Laboratory has been assigned a role in developing a vulnerability assessment methodology for water utilities. Detect, delay, and respond are the keywords of the planned approach, according to Sandia. Sandia's Security Risk Assessment Methodology for Water Utilities (RAM-W) methodology has been published in a RAM-W process.

Emergency management and disaster preparedness anticipate diverse situations that threaten security. They involve police or military skills, but critical infrastructure systems such as water supply require special expertise. Emergency management is allied with civil defense, and during the 1970s the United States organized the Federal Emergency Management Agency (FEMA, 2011), whose mission statement is: "to reduce loss of life and property and protect our nation's critical infrastructure from all types of hazards through a comprehensive, risk-based emergency management program of mitigation, preparedness, response and recovery." Although emergency

FIGURE 8.10
Meeting of emergency managers. (From Federal Emergency Management Agency, Mitigation Resources for Success CD.)

management involves both the government and the private sector, in the case of water, wastewater, and stormwater, the utility must take primary responsibility. Emergency management involves close coordination among different parties. Figure 8.10 shows a meeting of emergency managers and illustrates how problems are worked out during an emergency.

The Utility Emergency Plan is a valuable tool to plan, coordinate, and transfer roles during emergencies. It can range from a one-time exercise that goes on a shelf to being a dynamic, living plan that guides preparation and change as the utility continues to learn and become more resilient.

The basic outlines of emergency plans can be drawn from Manual M19 by AWWA (2001), which is entitled *Emergency Planning for Water Utilities*. The manual explains hazards, vulnerability analysis, elements of a plan, and corollary issues such as how to train. Plans should be adapted to respond to the unique requirements of each utility. Some regions are more prone to earthquakes, others to flooding. Some utilities might seem more vulnerable to certain accidents or attacks than others.

If an emergency plan is available but personnel are not trained with it, the plan may not work when needed. Staff and networks change, so constant adjustment is required. The utility should build on existing information, ideas, and real life experiences. It is essential to practice with exercises because experience shows that staff must be ready for their first response via training.

More information has become available, for example, a project by the Water Research Foundation (WaterRF) on "Emergency Response and Recovery Planning for Water Systems: A Kit of Tools." The report addresses disaster response, recovery, and business-continuity planning for water utilities, including domestic terrorism. Project objectives focus on review of existing guidance and the current state-of-emergency response planning,

as well as on identification of gaps and best practices. The WaterRF had another project (#3046) being undertaken in partnership with the Water Environment Research Federation on "Emergency Communications with Local Government and Communities." It will provide statements for water and wastewater officials to communicate with the public following disasters as well as during disaster warning alerts. This project will also provide an action plan to increase public awareness of health risks and responses.

Since 9/11, the threat of terrorism has loomed large, and utilities have focused on security. Title IV of the Bioterrorism Act of 2002 amends the Safe Drinking Water Act and is entitled "Drinking Water Security and Safety." It requires all community water systems serving more than 3,300 persons to conduct vulnerability assessments and to certify to USEPA that they had been conducted. The act also requires the utilities to include responses to terrorism in emergency response plans.

Security enhancements that were mentioned in the act include detection equipment; fencing, gating, lighting, and security cameras; tamper-proofing of manhole covers, fire hydrants, and valve boxes; rekeying of doors and locks; electronic, computer, or other automated systems and remote security systems; training; storage or handling of chemicals; and security screening of employees or support services.

AWWA (2011), WEF, and ASCE created a Water Infrastructure Standards Enhancement (WISE) Committee to plan for implementation of security measures, with AWWA taking the lead on water supply, WEF on wastewater, and ASCE on contaminant monitoring (Hanson, 2005). WISE has developed voluntary guidance documents, training materials, and standards to aid utilities in their security programs.

Lessons Learned

Water utilities have gained a lot of experience through many events of the past decades, and they are focused on preparing for disasters and responding to emergencies. Lessons learned can be invaluable in preparing for the future. Whereas some emergency forces have the mission to save, rescue, and care for people and property, water utilities must respond to emergencies to keep their own systems running to deliver reliable and safe water. They save, rescue, and care for their infrastructure, their equipment, their workforces, and their procedures, and they must ensure business continuity under all conditions. Disaster preparedness and emergency response are required for business continuity despite threats and harmful events, and principles for these have been summarized by Grigg (2003).

If any single term subsumes the tasks of water utilities in protecting against threats, it is *risk management*. In it, utilities must plan for a range of threats

with a comprehensive approach to consider both natural and human-caused threats. Utility experiences show that most disasters have been caused by earthquake, flood, and wind-induced flooding, but less is known about human-caused threats. The basic protection against them is the security system, along with management and engineering measures.

Risk management comprises a set of coordinated activities to direct and control an organization with regard to risk. It involves a range of programs and concepts that describe preparation and response and that include safety, security, and emergency management programs. Activities range across disaster preparedness, contingency planning, business continuity, emergency response, crisis management, and incident management. Each of these is a different phase, a different way to organize tasks, or simply a different name for the same activities within disaster preparedness and emergency management. Emergency management comprises preparedness, mitigation, response, and recovery (or reconstitution). In the response phase, the Incident Command System (ICS) is widely used, and the Department of Homeland Security has created a National Incident Management System (NIMS).

Emergencies are the primary missions of first responders, but water utilities must also deal with them along with their many other operational responsibilities. Utilities must be ready to respond, but they have to prepare in other ways too. If water utilities are to remain vigilant and have comprehensive measures to protect against threats, they require organizational commitment and leadership. Without these, complacency will set in, and the utility may be caught unprepared when an emergency occurs. Utilities report from their experiences in preparing for and surviving disasters, including natural disasters and anticipated security threats, that they need a top-down and bottom-up approach that fits within their overall risk management program. While utilities may have safety, security, and emergency response programs, they must integrate them through organization-wide efforts led by top utility managers, who can fight complacency.

Organizational commitment and leadership require a champion at the top to fight complacency and guarantee commitment. Managers must realize the need and create a plan; employees must cooperate; and partners must be involved. A utility may have an emergency plan, but the plan can be useless unless the organization is prepared well. Organization-wide efforts should include: a focus on planning and coordinating; a living emergency plan to provide cross-cutting coordination during emergencies; plans to adapt to rapidly unfolding unstructured-decision scenarios; training for emergency planning; plans for intra- and interorganizational coordination; use of drills and exercises to transfer lessons learned; matrix management to create lines of authority for emergencies; use of an Incident Command System; and study of varied scenarios, including those involving interdependencies between systems and components.

Because disaster preparedness and emergency management are organization-wide activities, they require a set of best practices that go beyond the responsibilities of individual utility departments. Some of these best practices are (Grigg, 2003): maintain an emergency plan with an all-hazard approach; prepare for complexity, as disasters can only be overcome with serious preparation; maintain a clear line of command with planning and preparation, including drills; mobilize the organization with ongoing attention to plans and exercises; mitigate consequences with facility redundancy and backup power systems; use prepositioned repair systems; develop good communication relationships both internally and with external organizations that might provide mutual aid; coordinate and cooperate with committees, staff meetings, clarification of roles, cross-communication, and project-oriented units; conduct drills and tabletop exercises; and assess preparedness. Emergency preparedness must also be funded, and records should be maintained during emergencies as well, especially during flood and fire.

Water utilities are better prepared than in the past, but the challenges from intrinsic threats, natural disasters, and external threats loom large. At the end of the day, disaster preparedness and emergency response in water utilities will depend as much on how well managed and led the organizations are as they will on procedures, drills, and emergency plans. Water utilities have many other issues on their plates, and they must be ready for any contingency so that they can continue to operate and provide safe and reliable water. Disaster preparedness and emergency management depend more on people than anything else. If water utilities are well staffed and led, and if key personnel know their jobs, they can prepare for and respond effectively to contingencies. Institutional memory is very important, as history shows us that disasters will continue to occur in the future. Adaptable and well-led organizations that learn and use good management practices will survive and continue performing their core mission of providing reliable and safe water.

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9

Maintenance and Renewal of Water Infrastructure

After installation of water systems infrastructure and equipment, effective maintenance is required to sustain their condition and performance. When the systems deteriorate or fail, major repair, rehabilitation, and replacement may be required. Taken together, these maintenance and renewal requirements create a need for organized management programs, which are the subject of this chapter. One of the organized programs is the maintenance management system, and the other is the program for planning of renewal of the systems. Renewal can be by repair, rehabilitation, or replacement, and is sometimes designated as the RRR program or 3R program.

This chapter explains how management systems for maintenance and renewal can be applied to infrastructure systems and components to optimize their life-cycle costs. The maintenance management system is well known as a keystone of utility management systems, and the renewal management system is supported by the capital programming and budgeting processes discussed in Chapter 4. Maintenance and renewal management are part of the overall asset management systems explained in Chapter 3.

Effective maintenance and renewal can be expensive and difficult to manage, but without them, assets may deteriorate quickly, fail to function, and cost more. Therefore, management systems for maintenance and renewal are essential parts of overall asset management strategies, and the life-cycle performance of utility assets depends on their success.

Maintenance and renewal are related, but they are different tasks. Maintenance is a continuous activity that occurs during the operations and maintenance (O&M) phase, while renewal occurs periodically as required. An everyday example can be seen from roads, which might be maintained regularly by filling in potholes and restriping, among other tasks. Then, they might require renewal by a new seal coat or replacement of the pavement from time to time.

The maintenance and renewal concepts over a facility life cycle are shown in Figure 9.1, which illustrates an ongoing O&M phase and a renewal phase that occurs in the capital cycle and happens periodically. When renewal involves major rehabilitation or replacement, it is like new construction and might require planning in the capital cycle. However, renewal sometimes involves some degree of major repair, and this might be funded from the operations budget and thus be part of O&M.

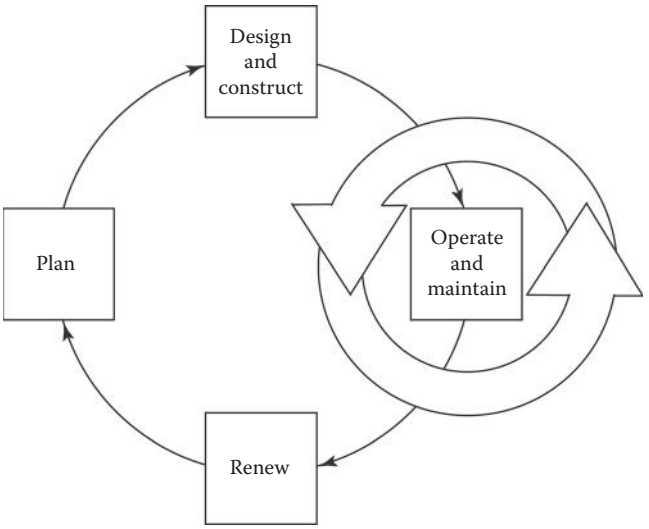

FIGURE 9.1
Maintenance and renewal in the facility life cycle.

The chapter begins with explanations of the functions included in management systems for maintenance and renewal. Then it discusses unique features of water, wastewater, and stormwater systems maintenance. It explains concepts of condition assessment and relates them to the system for planning of facility renewal. The final part of the chapter is a look ahead toward the future of maintenance and renewal management.

Maintenance Management Systems

Maintenance management systems (MMS) are not unique to the water industry: They are required to support any business or public service operation that requires significant infrastructure or equipment. MMS is an organized way to schedule, perform, and assess maintenance activities. It offers a framework to manage essential activities through a systems approach to preventive and corrective maintenance activities. Different versions of the MMS are specific to industries such as aviation, railroads, or road transportation, and many people are involved in maintenance work, from the mechanic in the small-engine repair shop to the sailors taking care of a giant aircraft carrier.

In facilities management, which is a broad concept that is normally used for buildings and structures, the trend is to use the computerized MMS (CMMS). Another popular term in use for a CMMS is maintenance

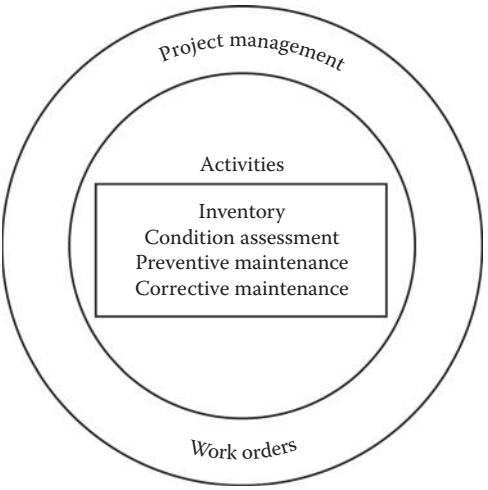

FIGURE 9.2
Work tasks of a maintenance management system.

management information system (MMIS). All of these acronyms point to the same set of tasks, but they may be assembled in different ways.

One view of a CMMS is as a sophisticated "to do list" with three parts: a preventive maintenance (PM) schedule, work order tracking, and project management (Thomas, 2001). This shows what is done (preventive maintenance) and how it is coordinated and controlled (work orders and project management). You can add inventory, condition assessment, and corrective maintenance to create a complete MMS, as seen in Figure 9.2.

The activities can be organized in different ways. As explained in Chapter 3, some of the activities might apply to other work systems, such as (a) the inventory task belonging to the data management system and (b) condition assessment and some corrective maintenance belonging to the capital renewal system. The fact that work tasks apply to different management systems illustrates the need for sharing of information across the organization. Inventory will be discussed in Chapter 10, which covers data management systems. Condition assessment is discussed later in this chapter.

Maintenance and Facility Management

The field of facility management (FM) offers guidance for work in water, wastewater, and stormwater systems. Facility management is the "practice of coordinating the physical workplace with the people and work of the organization." This definition from the International Facility Management Association (IFMA, 2011) encompasses broad organizational management, but sees maintenance as a core activity. IFMA has organized FM activities into functional areas, all of which require attention from O&M staff: long-range and annual

facility planning; facility financial forecasting; real estate acquisition and/or disposal; work specifications, installation, and space management; architectural and engineering planning and design; new construction and/or renovation; maintenance and operations management; and telecommunications integration, security, and general administrative services. Originally, the focus of FM was on operations and maintenance, but now other considerations such as safety, workplace environment, building air quality, security, and Americans with Disabilities Act issues are included, and IFMA has a certification program for facility managers to encompass these activities. IFMA publishes a number of guides for facility maintenance, which can be useful for organization of utility maintenance management programs.

Benefits of Maintenance Programs

While the need for effective maintenance is obvious to public works professionals, its benefits can impress even a hardened financial officer or uninformed citizen, provided they are explained well. Unfortunately, maintenance benefits are often not explained effectively to managers and boards, and maintenance budgets are easy to cut. Therefore, in times of financial shortfalls, it is especially important to make the case for the benefits of maintenance.

For example, consider a hypothetical city of 100,000 with water, wastewater, and stormwater systems having a replacement value of $10,000 per capita or $1.0 billion total. This includes facilities for all three services, including source of supply, treatment plants, distribution and collection, and stormwater systems. We would expect water supply to have the greatest replacement value (maybe 40%–50%), followed by wastewater (maybe 30%–40%), and the remainder would be stormwater (perhaps at 10%–20%), although the breakdown would vary with jurisdiction.

The total annual water, wastewater, and stormwater budget for a utility of this size might be on the order of $60 million. This is approximately equal to the water-related budget for the city of Fort Collins, Colorado, which shows projected 2012 expenditures of $31 million for water, $21 million for wastewater, and $12 million for stormwater. Fort Collins has a current population of about 145,000, but part of the city is served for water and wastewater by a special district.

To see what maintenance can do, say you can use maintenance to extend the service lives of the infrastructure from 30 to 50 years. At an interest rate of 7% for the utility's borrowed funds, you would get an annual benefit of about $8 million. The cost to perform this maintenance is not known, but if it added 10% to the budget, or $6 million, then the benefit–cost ratio of the maintenance program would be 1.3. In addition to this benefit, disruption would be lower, quality of service would be higher, and the image of the utility and city would be higher. The maintenance benefit would increase if the cost of money were lower. For example, at a 4% interest rate, the annual benefit is over $11 million.

Note that the service lives of most components are probably longer than we think. Recent research shows that some distribution pipelines have life spans of 100–150 years. It appears that Australian utilities are more willing to repair and take some leaks and breaks, while North American utilities would prefer to replace pipes earlier (Cromwell, Nestel, and Albani, 2001). On the other hand, pumps and other equipment have much shorter lifetimes.

This example may not be realistic, but it introduces the subject of how maintenance can be analyzed with economic tools. Utilities should question the amount of money spent on maintenance, and it is important to know its financial benefits as well as the need for reliability, security, and customer service.

Preventive and Corrective Maintenance

Maintenance work divides into preventive and corrective categories, meaning work done to prevent a future problem and work done to correct a problem. Preventive maintenance (PM) or the ongoing program of care given to equipment or components requires consistent and timely completion of scheduled tasks prescribed by documented procedures. Information sources for PM are O&M manuals, product information, and experience of workers. PM records will normally include equipment data, the PM record, the repair history, and a spare parts stock card (Jordan, 2010).

Corrective maintenance means to repair equipment or components that have failed or deteriorated. It can range from minor to major repair, and requires a decision as to whether the deficiency is minor or if it is major enough to require funding requests through capital budgeting. If the problem is major, the repair should incorporate information about new standards and forecasts of growth.

Decision Making for Maintenance Levels

Maintenance strategies can be proactive or reactive, but in any case can be based on economic and reliability analysis. For example, the East Bay Municipal Utility District in Oakland, California, has utilized reliability-centered maintenance, which offers flexible approaches that range from proactive maintenance to a run-to-failure policy for some equipment. This may lower cost, and it places a focus on critical equipment and components, which are defined by water quality violations, productivity, regulations, and safety. Higher maintenance cost is a big factor in rates. Reliability-centered maintenance is data intensive and uses a multidisciplinary team, including maintenance, mechanical, electrical, and instrument engineers and operational personnel.

Maintenance of Water, Wastewater, and Stormwater Systems

For water, wastewater, and stormwater systems, the operations section will normally be responsible for overall maintenance to support operational goals such as compliance with regulations. The details of maintenance must then be organized by system component and by the work schedule.

There are many components, and maintenance management for water, wastewater, and stormwater systems covers buildings and grounds, equipment including the fleet, and the infrastructure of the water systems themselves. Procedures for maintenance of buildings and grounds are not discussed here, but the facilities management literature offers guidance for them. Fleet maintenance is not covered either, but sources such as the American Public Works Association, which focuses on fleet management, provide guidance. The focus here is on the specialized maintenance required for the water facilities themselves.

Maintenance of water facilities covers an extensive group of systems and components. Systems include source of supply, treatment trains, and distribution and collection systems. Source of supply facilities can include reservoirs, well fields, and other raw-water facilities. Water and wastewater treatment plants are like factories, with diverse equipment and controls to manage. They require maintenance of buildings and grounds as well as specialized process trains. Failure in maintenance of treatment facilities systems can bring regulatory sanctions and even public health problems.

Much of the focus in maintenance of water and wastewater is on the underground networks of distribution and collection systems, which comprise about two-thirds of system capital assets. Pipe repair is a factor in controlling service disruption and cost. In addition to pipelines, distribution and collection systems involve additional components such as hydrants, valves, regulators, and pumping stations. Stormwater systems include conveyance and storage facilities that may be integrated with parks and open space and create an interface with buildings and grounds for purposes of maintenance.

Looking past these many systems and subsystems, an even greater number of individual components require maintenance. Examples from the water supply field include pipes, valves, pumps, hydrants, tanks, meters, generators, booster chlorination stations, and backflow-prevention devices.

While water and wastewater systems are similar, their equipment and components vary in maintenance requirements. For example, water distribution pipes, wastewater sewers, and storm sewers use different materials and design procedures. A treated-water pump will be different from a flood-control pumping system. A wastewater treatment plant uses different processes than a water treatment plant.

Guidelines for maintenance programs for water, wastewater, and stormwater systems begin with basic references, such as the *Facility Management*

Handbook (Cotts, Roper, and Payant, 2009). This reference will guide you in a general way for your overall program.

Specialized guides for water and wastewater systems include basic texts from AWWA on water utility maintenance, which provides concepts and processes that are transferable to wastewater and stormwater systems. AWWA also publishes specific guides on maintenance for system components, such as pumps and storage tanks, each of which requires specialized procedures. A good way to peruse these is to consult the AWWA publications catalog at the association website.

Some AWWA publications, such as Jordan's (2010) *Maintenance Management for Water Utilities*, also apply to most wastewater issues. Given its heavy involvement in wastewater, USEPA has developed many publications on wastewater O&M. USEPA has relatively fewer publications about water supply, mainly because that industry has been operating for longer than wastewater and has developed its own standards and publications. The Water Environment Federation (WEF) also has some publications on maintenance and operations of wastewater facilities, but its publications outlet is smaller than AWWA's.

Distribution system maintenance involves processes such as flushing and valve exercising. Flushing at hydrants removes sediments, stale water, slime, and other unwanted constituents. Chlorine additives may be used to kill bacteriological growth. Cleaning may remove deposits in the pipe. Methods of cleaning include mechanical, air purging, swabbing, and use of "pigs" (pipeline inspection gauges) that are inserted into the pipelines to scrape and push the deposits and scales out.

In older systems, many valves may not have been exercised for years. In fact, some may not even be listed on records. Some tips on developing preventive maintenance programs for valves are given by Skorcz (1983). AWWA has published several separate manuals on valve operation and maintenance. The Office of Water Programs at California State University at Sacramento publishes a series of practical operator training manuals, and one by Kerri (2005) applies specifically to distribution systems.

Corrosion is an important issue for distribution systems, and it might even impact health, since metals leached from pipes such as lead can be harmful. Corrosion also causes financial damage such as staining clothes in washers. Deposits can form from tuberculation, or formation of tubercles on pipe walls from corrosion. These roughen pipe walls decrease the "C" factor, and increase the energy required to pump water. Eventually flow can cease altogether. Pipe replacement may be required to cure the problem.

On internal corrosion, AWWA's policy states that "water should not be corrosive or encrusting to, or leave deposits on, water-conveying structures through which it passes, or in which it may be retained, including pipes, tanks, water heaters, and plumbing fixtures" (W. Smith, 1989).

Postprecipitation deposits that clog pipes occur from calcium carbonate, iron, lead, zinc, aluminum, magnesium, manganese, polyelectrolytes, and

microbial growth. The iron postprecipitation phenomenon is direct corrosion. Zinc and lead reactions are similar to iron but form a more compact precipitate and tough coating. Remedial action requires analysis of reasons for precipitation, followed by adjustment of treatment processes.

External corrosion of water pipes is electrochemical, with electrons and ions moving between anodes and cathodes, thereby eroding metal from components. The types of corrosion are uniform and localized, and these includes galvanic, crevice, and pitting corrosion and erosion. Corrosion reactions for iron pipe, galvanized pipe, lead pipe, and copper pipe are different in nature. The corrosion potential in treatment plants varies. Cathodic protection can help prevent metal pipe corrosion.

Figure 9.3 shows the corrosion of an excavated water pipe that was installed with a torn external wrapping. It is important to maintain the integrity of the wrapping during installation to avoid problems such as this.

The SDWA requires that utilities determine the corrosivity of water and soil as well as materials in the distribution and home plumbing lines. This monitoring requirement calls for the design of a program to examine water quality and pipe-material determinants of corrosion. Implementation of a corrosion control program can have a positive benefit-cost ratio, so water utility managers may consider corrosion control programs going beyond regulations.

Maintenance and operations of water supply systems also involve monitoring to find cross-connections. AWWA listed situations to watch: unapproved supplementary supplies, industrial or fire-protection water, premises that handle sewage or industrial process water, circumstances where there is a special possibility of backflow of sewage or contaminated water, and water supply lines that end at piers. Provisions to guard against these are:

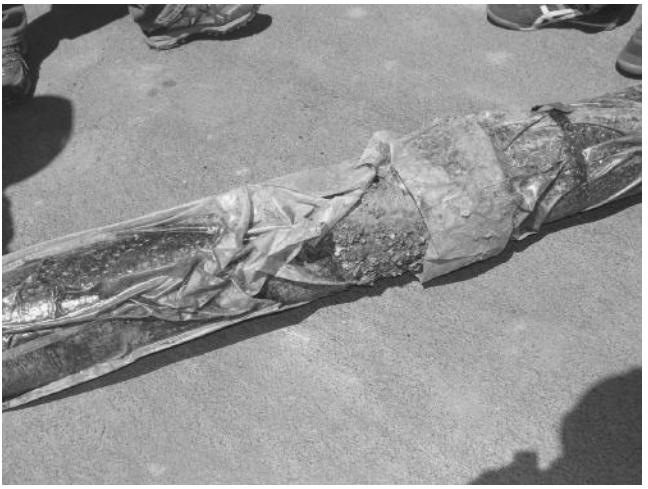

FIGURE 9.3
Excavated water line showing a torn wrap and external corrosion.

plumbing changes, relief valves, backflow protection on all supply lines in addition to the primary ones controlled on a property, inspection of backflow protective devices, and discontinuing service in some cases (Mays, 2010).

Also, the management of distribution systems may extend to providing guidance for maintenance of home plumbing systems, where the variety of situations is great and the range of materials is wide. These systems are the responsibility of the property owner, and utilities do not have legal responsibility for them, but they may choose to offer services such as sampling, interviewing homeowners and local plumbers, and making visual inspection of discarded water heaters and other equipment to identify issues that arise.

Maintenance of collection systems affects the operation of the wastewater treatment facility, since flows into the facility are affected. Common maintenance problems associated with sewer systems include infiltration of groundwater, inflow of stormwater, clogging, and breaks and damage from unauthorized and improper waste material (Foster, 1976). The corrective measures include replacement of damaged pipe with infiltration-resistant pipe, better installation of pipe, sewer cleaning, analysis of infiltration and inflow through flow-measurement techniques, inspection and testing of sewers, grouting, and implementation of a safety program.

The Clean Water Act of 1972 and its implementing regulations specified that new plants constructed through the construction grants program had to be preceded by sewer system evaluation and rehabilitation programs, complete with infiltration and inflow (I&I) analysis. This led to the use of new techniques such as video inspection to find problem areas.

EPA found that original I&I requirements were too burdensome and issued regulations for simplified investigations. A subsequent evaluation showed that expectations of the I&I program were not being fulfilled, that most municipalities did not implement long-term sewer system maintenance programs, and that maintenance budgets were often cut. They observed that operating budgets barely had enough funds for emergencies, much less maintenance. Guidance for collection system maintenance is included in USEPA's Capacity, Management, Operations, and Maintenance (CMOM) program, which is explained in Chapter 7.

Given the importance of sewer system maintenance and rehabilitation, ASCE and WEF (2009) completed a manual of practice on the topic, which is now in its third edition. It covers maintenance, repair, rehabilitation, and replacement of existing sewers. Topics include sewer evaluation and monitoring, rehabilitation methods and materials, and quality assurance.

USEPA has issued several reports on sewer system evaluation and rehabilitation, including a training manual prepared by California State University at Sacramento (1983). Topics covered are: nature of the system, the operator's responsibility, organization for O&M, pipeline cleaning and maintenance, repair procedures, administration, and safety.

As an example of an advanced CMMS, Los Angeles County Public Works developed a centralized database for inventory, tracking, and maintenance

of roads, waterworks, sewer maintenance, and flood control. Inventories are of more than 600,000 facility records. The CMMS uses Oracle-based Maximo software and is used at over 40 locations with more than 500 registered users. Communication is via a wide area network with a central server in department headquarters on a large server. The department's Information Technology Division provides communications, programming, and data processing support. In 1999, the department placed the system under the Central Work Controls Group, which acts as the owner for the software. Its missions are to ensure that maintenance divisions use the software; have adequate training; use published standards for data entry; assist in adding new facilities to the system; solve problems; and implement new features and reports. The plans are for future interfaces to financial systems, waterworks billing, a pavement management system, a bridge management system (state mandated), a geographic information system (GIS), and mobile data terminals (D. Smith, 2001).

As an example of sewer maintenance challenges, work by the Metropolitan St. Louis Sewer District during the 1980s on their combined sewer program was reported in the first edition of this book (Koeper, Koble, and Coll, 1982). The district had about 1,100 miles (683 km) of sewer serving a population of 450,000. Some of the sewers were 125 years old. In 1981, they had 370 failures with repair costs ranging from $5,000 to $500,000. They focused on high-risk areas by compiling maps with risk factors to enable inspections with potential payoffs. They used up-to-date detection technologies such as inspections, ground-penetrating radar, gravimeters, and infrared photography, and they planned to enter the data onto computerized system maps. Rehabilitation methods to be considered include shotcreting, the process of spraying concrete onto a surface; seal grouting, including chemical grouting; compaction grouting; sliplining; steel plate lining; and in situ forming. Programs such as this take a long time and often require more work and investment than anticipated. During 2011, the district entered into a consent decree settlement that requires it to improve its sewer systems and treatment plants, at an estimated cost of $4.7 billion over 23 years, to eliminate overflows of sewage and to reduce pollution levels in urban rivers and streams. Parties to the decree are the U.S. Department of Justice and the U.S. Environmental Protection Agency. The new infrastructure will include three large storage tunnels ranging from approximately 2 miles to 9 miles in length and new capacity at two treatment plants (USEPA, 2011).

Maintenance of stormwater facilities differs somewhat from sewers because many stormwater systems were managed jointly with street systems. However, more complex systems involving parks and open space have changed the requirements. Stormwater organizations such as the Urban Drainage and Flood Control District in Denver have responded with maintenance programs for major drainageways and facilities (Hunter and Tucker, 1982). Examples of routine work include vegetation mowing, trash and debris cleanup, weed control, and revegetation. Examples of restoration

work include detention pond mucking, trash rack cleaning, rebuilding steep rundowns, tree thinning and clearing operations, extending trickle channels, repairing local erosion problems, and doing local channel grading and shaping. Examples of rehabilitative work include rebuilding or replacing drop structures; installing trickle channels; reshaping channels; installing riprap, protective rock, to correct or prevent erosion; establishing maintenance access into drainageways; and providing protection for existing box culverts, retaining walls, or road crossings.

Maintenance of underground stormwater pipes has received comparatively little attention, compared to water and wastewater. When a flood backup occurs, stormwater maintenance crews will fix it, but data such as historical breaks, regulatory sanctions, and performance measure are mostly missing from stormwater programs, mainly due to absence of regulatory oversight.

Other stormwater organizations, including county governments, have manuals for general maintenance. These address inspection and monitoring, record keeping, economic studies, sedimentation control, aquatic vegetation control, mosquito control, pollution and erosion control, structural maintenance, safety measures, and multiple-use management.

The importance of maintenance of stormwater systems made the front page of the *Denver Post* in July 2011, when a rash of minor storms caused havoc among city streets, waterways, and at Denver International Airport. The Denver Public Works Department had to dispatch special crews to open clogged storm drains, and they issued notices to residents to help control litter, trash, and debris from multiple sources. Some of the newer storm drainage facilities have filters and screens to catch debris and limbs that clog drainageways, but some lack them and must be cleaned regularly. Denver reported vacuum trucks and some 25 two-man crews out cleaning the system. The city reported 750 miles (466 km) of stormwater pipes and some 25,000 inlets (Gibbons, 2011).

Traditional maintenance practices of equipment and facilities are well established, and the need for them is widely recognized. Given the long lives of most water, wastewater, and stormwater assets, the cumulative cost of this maintenance can be very high, and utilities are looking for ways to optimize their investments.

The WaterRF (2009) conducted a project to develop Best Management Practices for Maintenance of Water Distribution Assets, and the report should be available by the end of 2011. The need for this project was the highest ranked idea at a workshop to develop an Asset Management Research Needs Roadmap that was held in December 2006 and attended by approximately 40–50 water utility professionals, including your author. The group recognized that different approaches to maintenance are being taken and that reliability-centered maintenance is of interest to utilities (Fynn et al., 2006).

The research planners performed a literature search to assess past work to identify best management practices (BMPs) for water system maintenance

and found that Deb et al. (2000) had prepared a guide for distribution system O&M.

Friedman and Holt (2003) studied the specific velocities needed for flushing, and Hasit et al. (2004) outlined the benefits of distribution system flushing. In another study about maintenance of valves, Rosenthal, Mesman, and de Koning (2002) developed key criteria for both operation and maintenance.

Condition Assessment of Infrastructure and Equipment

Assessing the condition of infrastructure is important to know the actual situations with your systems and equipment. The condition of a facility means how its status compares to "like new" status and whether it is ready to do its job. You might say, for example, "My car is old but in good condition." This would be a general statement that embodied paint job, interior, engine, running gear, and other systems. You could rate your car as being in "poor" or "average" or "like new" condition, and all of the terms would be familiar, even if you have a conflict of interest in rating your own car. The concept of condition of an infrastructure facility is the same. It provides a measure of the facility condition compared to a replacement. While research about condition assessment has been completed, it is still difficult, particularly for buried water supply mains.

While preventive maintenance is scheduled regularly and in many cases does not depend on condition assessment, corrective maintenance and needs assessments require more effort to determine facility condition. With some approaches to maintenance such as reliability-centered maintenance, knowledge of condition is required for critical facilities. Some industries use "on condition" maintenance, where preventive maintenance is scheduled according to facility condition (Hudson, Haas, and Uddin, 1997). A project by Marlow et al. (2007) developed strategies and protocols for condition assessment of both water and wastewater assets.

The condition of a facility is a multiattribute variable. Some of the attributes include physical condition, safety, structural integrity, capacity, quality of service, and age. Inspection items will differ by system. For example, for water supply, they may include: water quality sampling to signal if the system is working satisfactorily; pressure and flow checks at hydrants to determine if flow characteristics are satisfactory; inspections to detect damage, unauthorized connections, leaks, vandalism, and other unacceptable threats; and leak detection to discover small or large system leaks.

A utility that is developing an overall program of condition assessment might include the following attributes of components: physical condition, age, capacity, performance, threats to capacity or vulnerability, likelihood of failure, safety attributes, and the cost of deferred maintenance or repair.

Based on these, it should be possible to make schedules for repair, replacement, and rehabilitation.

Knowledge of these attributes might be obtained from data records, from maintenance histories, and from recent failures. Or, condition assessment might involve sensor and analysis techniques, such as location of buried pipelines, leak detection, and nondestructive testing (NDT). Some of the NDT methods include noninvasive, nondestructive techniques (ultrasonic, acoustic emission, remote-field eddy current, magnetic flux leakage); coupon tests; and leak location studies (acoustic, infrared thermographic, chemical, mechanical).

Newer methods to assess condition are coming on line. They include smart pipes with built-in reporting of leaks, structural stresses, corrosion, water quality, pressure, and flow; improved pigging and in-pipe assessment technologies to evaluate variables such as tuberculation and sedimentation; new capability to evaluate joints, valve interiors, and other nonpipe components; and tools to precisely locate problems and make repairs, including trenchless technologies and robotics (L. Smith et al., 2000). While newer methods are becoming available, they may be expensive and may not always be applicable to specific situations. The best way to begin is to use existing records and knowledge, and then build on them with proactive inspection approaches.

For example, in a distribution system, the knowledge that might be available from operational data might include: water audit, flow measurement to test roughness, hydrostatic tests to test for leakage, zero-consumption measurement, network analysis models, and a program to monitor water quality in the distribution system. By interpreting this information, you could glean much knowledge about system condition.

A water audit is a starting point to learn about leaks and losses. It checks master meters for accuracy, tests industrial meters, checks for unauthorized use of water, and locates underground leaks through surveys. An audit results in a balance sheet of accounted-for and unaccounted-for water. Leaks, breaks, and unaccounted-for water cause loss in revenue, higher operational costs, and need for greater system capacity. Leak detection and repair can yield important benefits. The state of California found that water audit and leak detection could even benefit communities with low values of unaccounted-for water (Boyle, 1982). The leak-detection program offers an opportunity to improve the database while solving leak and breakage problems and to organize data for main replacement decisions.

While many utilities still use older methods for water accounting, AWWA (2009) has a new manual of practice to guide utilities in water auditing. The manual was developed in cooperation with the International Water Association to provide accountability of real losses (leaks) and apparent losses (such as billing and meter errors) to help utilities with management and revenue recovery. Some of the topics are water auditing to measure consumption and loss, control of apparent losses in metering and billing

operations, and leakage and pressure management programs to control losses costs. The procedure has been thought out carefully, and is still in the implementation stage among utilities. The Texas Water Development Board (2011) has published extensive guidance on how to use this method.

A number of guides are available for analyzing the condition of wastewater collection systems. After the Clean Water Act, procedures for sewer system evaluation surveys (SSES) were developed to gather information on capital needs. SSES are expensive, so they must be prioritized. Manuals for the procedures are available, such as USEPA's (1991) *Handbook for Sewer System Infrastructure Analysis and Rehabilitation*. Methods for inspection and condition assessment of collection systems include closed-circuit television (CCTV), cameras, visual inspection, and lamping. CCTV inspections are useful in diameters of 4 to 48 in., and raft-mounted cameras might be used in larger pipes. In a visual inspection, safety rules are paramount, of course. Innovations for sewer condition assessment include light-lines, sonar, sonic caliper, and lasers.

In wastewater systems, condition indicators include structural defect parameters (installation history, material, age, soil type, groundwater, loads, exfiltration, inspection history); corrosion and erosion parameters (material, wastewater temperature and velocity, pollutants, pipe type and structure, inspection history, soil, stray currents, coatings, cathodic protection, debris); and operational parameters (roots, trees, surcharging).

It would be helpful if a composite condition index could be created for water facilities in the same way that the pavement condition index is used for maintenance planning. If such a composite condition index could be compiled, it might resemble the pavement-condition curve that shows decline in condition with age, but the situation will normally not be so simple. Many variables determine the condition of a water or sewer pipe, including the initial quality of construction. Figure 9.4 shows how this can affect the assumed condition-versus-time relationship for an asset. Hudson, Haas, and Uddin (1997) discuss methods of compiling composite condition indices.

Condition assessment requires multiattribute measurement, and condition cannot normally be reduced to a single score, although infrastructure "report cards" do that to emphasize the need for infrastructure investments. However, single condition indices are not feasible for water distribution infrastructure. The challenge of assessing the condition of hidden infrastructure assets is formidable.

Methods for the field of facility condition assessment are relatively new, and some remain under development and controversial. For example, some utilities in implementing their asset management systems seem to feel that trying to assess the condition of hidden assets is not important—that the emphasis should be on the financial bottom line and on simply repairing breaks when they occur.

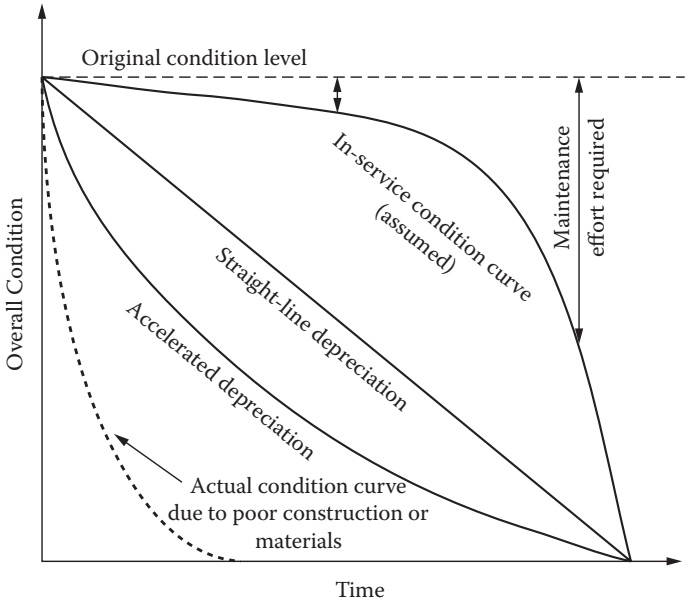

FIGURE 9.4
A facility condition curve compared to depreciation schedules.

Planning and Managing the Renewal of Infrastructure

Renewal of infrastructure or equipment can be by major repair, rehabilitation, or replacement (3Rs). Timely and effective action is essential to sustain effective operations and manage risk. Even when maintenance and repair programs work well, expenses can grow to the extent that replacement of outmoded or worn out systems is the best policy.

How renewal supports life-cycle management was explained in Chapters 3 and 4, and the goal is to plan for and manage the decline in condition level of an asset by taking required and timely corrective actions. Figure 9.4 showed why and when the 3Rs are required. The condition level was depicted by the horizontal line of constant "like new condition." This would be the case if the original installation was of high quality (see Chapter 5) and there was no decline. However, gradual deterioration in condition occurs in all facilities, as shown by the in-service condition curve. The gradual decline is followed by a sharp decline, such as the case of road pavement, which wears somewhat evenly until it passes a critical point, where the sharp decline begins. This might be the shape of a condition curve for a water system asset as well, but each situation is different. With a condition curve of this shape, it is easy to see that renewing the asset from time to time before the sharp decline starts is the best policy.

A number of traditional and emerging technologies are available for water and sewer main renewal. For the most part, stormwater pipelines will be replaced when they fail, and often they are upgraded to retrofit old areas that lack adequate systems.

At a technology-transfer conference Grigg and Heitzman (2004) explained that renewal in water distribution systems is more complex than in wastewater systems due to their more extensive hardware (valves, hydrants, meters). There is a wide variation in the use of methods among utilities, and some utilities only replace, rather than rehabilitate, pipelines. Pipe break and leak repairs can use clamps for circumferential or corrosion pipe failures, and various other repair methods can be used, such as replacement sections for split pipe failures, recaulking or installing repair clamps for lead or rubber joint leaks, replacing mechanical joint bolts for corrosion, service line repairs, and repairs to valves and hydrants.

Some work will be done by open cut, and some can be done with trenchless methods, where methods are becoming more extensive and common. Pipe cleaning (using hydraulic, mechanical, and chemical methods) has been done since the 1930s, and in situ cleaning and cement mortar lining has been done since the 1940s. Internal joint seals have been available since the 1980s, and epoxy lining became available in the 1990s.

The New England Water Works Association (2011) has a video on responding to water main breaks that shows an approach based on people, communications, materials, safety, and risk reduction. The people issues include decision making, operator skills, cross-training, and other employee issues. Communications assures a fast response and includes techniques such as use of a phone tree to get the word out. Emergency response and contingency planning techniques are emphasized, and materials and equipment must be on hand and ready to go. Cooperation might promote preset loan and sharing arrangements through mutual aid. Safety is paramount and includes roads, confined spaces, trenches, and other concerns. Risk reduction includes record keeping, PM and operations, stockpiling materials, and contingency planning.

A listing of technologies available includes (L. Smith et al., 2000):

- Pipe cleaning
- Lining by nonstructural or semistructural means (epoxy coating, cement mortar coating, close-fit pipe, woven hose, cured-in-place pipe, spirally wound pipe)
- Lining by structural means (continuous pipe, segmented pipe)
- Trenchless replacement (pipe bursting, pipe replacement, microtunneling)

Two of the trenchless technologies are illustrated in Figures 9.5 and 9.6, which show, respectively, a pipe-bursting demonstration on the surface (for

FIGURE 9.5
Demonstration of pipe bursting.

FIGURE 9.6
Pipeline sliplining project in a high-density urban environment. (Courtesy of Los Angeles Department of Water and Power.)

demonstration purposes only) and a sliplining project in Los Angeles. The trenchless method was selected for the sliplining project because of the high-density urban environment.

Rehabilitation of wastewater conveyance systems has generally been wrapped in with the topic of O&M, as in the manual prepared by the New England Interstate Water Pollution Control Commission (2003). The goal of rehabilitation, to maintain viability or integrity, is explained as requiring structural integrity, limiting the loss of capacity by reducing infiltration and inflow, limiting the potential for groundwater contamination that occurs through exfiltration, and limiting the potential for backups and overflows.

Rehabilitation methods include nonstructural repairs by the sealing of leaking joints through in situ methods to test and grout or seal leaking joints. Structural repairs normally involve either replacement or lining of the sewer and can be done by trenching or trenchless technologies. The latter include slip lining, cured-in-place pipe (CIPP) technologies, and fold-and-form technologies. Pipe bursting might be used to create a tunnel through which a replacement pipe is pulled.

Trenchless methods are often used for wastewater system upgrades, and they are especially useful in urban areas. They have many benefits, such as faster installation, less need for service continuation during construction, reduced surface disturbance, lower traffic disruption, and friendlier construction in general. The cost may be higher than conventional trenching, and control of alignment might be less.

Pipe bursting can actually increase hydraulic capacity, but some relining methods will decrease hydraulic capacity by reducing the diameter.

Planning for infrastructure renewal is a significant issue in utilities. Given the vast sums required, it makes sense to renew these systems in a timely manner. In fact, most growth of U.S. water systems has occurred over about the last 100 years, and it is apparent that utilities will face crescendos of deferred maintenance as their systems age.

Ideally, utilities will have effective decision-support systems for prioritization of renewal decisions. These require criteria to prioritize renewal actions, even when little historical maintenance information is known. For example, a point scoring system might apply different criteria to establish a set of priorities. However, the economic stakes are high, and utilities need good data to justify capital expenditures.

Asset management and capital improvement systems provide a structure for renewal planning (see Chapters 3 and 4), and utilities can use them to prioritize their capital expenditures. Use of information technology is essential (see Chapter 10), and software is needed for functions that include the inventory, MMIS, GIS, and the design software. The inventory is linked to maps and to the MMIS, and it should contain files such as valve cards, drawings, water segment attributes, and equipment location. The MMIS is linked to work programs and contains database information from work orders, contracts, and repairs. The GIS allows manipulation of spatial data, including

many of the attributes in the inventory. The design software is used to prepare design drawings and allows importation of information from the other packages.

The ultimate purpose of renewal actions is to sustain effective operational performance of systems and prevent failures. Failure modes vary across the water, wastewater, and stormwater systems. For example, the causes of failures in treatment plants are different from those in water or sewer pipelines. Water supply pipeline failures are more dramatic than sewer failures.

Causes of pipeline failures include poor installation; service loads; routine service conditions; accidents; soil displacements; temperature extremes; or degradation of metal, concrete, or plastic pipe (L. Smith et al., 2000). Diagnosis is required to predict failure so that pipeline renewal can precede disasters and enable capital planning. A bottom-up approach to this would apply science to build the evidence leading to prediction of failure, and a top-down approach would be more reactive to manage breaks and failures as they occur.

Research on why pipes fail shows that, paradoxically, the oldest pipes do not necessarily fail more often. Failure rates seem to depend more on construction effectiveness, corrosion, and traffic load than on age alone. Water temperature is an important factor in many areas, with many more breaks occurring as cold weather sets in.

For cases where no break is acceptable—such as critical areas, high damage costs, public safety, and public health—utilities must ensure that renewal occurs before failure.

Predicting main life using operational records is a goal of utilities. A main-break history database is important to help anticipate future failures. GIS systems with break history shown by dots on a map may be an effective starting point to anticipate failures in some cases.

Materials

Research is needed to understand pipe materials better. For example, European utilities may do a better job than the United States in preparing ductile iron. They use an alloy coating, epoxy, and polyethylene bags, whereas the United States only uses the PE bags. Thus, a scratch on the pipe can initiate corrosion. A simple, valid test for new ductile iron pipe (DIP) is needed.

There is a good bit of interest in plastic pipe. Utilities would like to know the limits or recommended guidelines for connections to PVC pipe. For example, they would like to know what effect a same-size tap has on the integrity of the pipe or what minimum spacing should be maintained between service connections. They would also like to know the available types of fittings

and connections to PVC pipe and which ones work best. Plastic pipe has advantages, but connections involve a number of questions. Another issue is traceability, and yet another is permeability near leaking petroleum tanks. Some reports say that use of PVC is increasing rapidly in the United States.

Future Issues and Needed Research

A number of recent reports focus on new directions and research needs. For example, L. Smith et al. (2000) list a number of research needs, and Ellison's (2001) study of distribution systems offers additional ones based on his survey. These research needs and future trends focus on new uses of information technology, instruments, operating systems, assessment tools, and renewal techniques. EPA is working on smart systems for pipes. EPA concerns include health effects and verification of environmental technologies. Trenchless technologies for water and sewer pipe rehabilitation offer great promise. Benchmarking for managers offers a new way to compare performance. A tool by Arbour and Kerri (1998) uses a benchmark to focus on system characteristics, level of O&M, and system condition.

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10

Information Technology for Water Infrastructure

Information technology (IT) offers powerful tools for the management of water, wastewater, and stormwater infrastructure systems. In the past, data on water infrastructure was maintained separately within different departments, but now there are fewer staff with less institutional knowledge, and the data are being shared through centralized databases.

Change will continue, and utilities must make careful choices about which new tools to adopt. In addition to providing new tools and methods, IT has been responsible for downsizing organizations and for much of the trend to "do more with less" that affects utility workforces. Utilities are adjusting to a broad range of IT applications, and they are gaining experience about how IT can help manage systems.

Ten years ago, e-commerce was changing old business forms rapidly, and since then the changes have been accelerating. As this is being written, we have new tablet computers, smart phones from different vendors, and big changes in every business that depends on information. The changes are also evident in the water field, which involves public utility-type businesses, which operate under the control of regulations, not a free market.

The advantages of IT can be overpromised. While the cost and power of computing and the availability of software change rapidly, the complexity of management and problem solving still seems to increase. This combination of more complex problems and technologies and smaller workforces creates one of the business pressures felt by utilities as they seek to sustain their levels of service with limited financial resources.

Information can be used to improve productivity in management and administrative work or in production work. All levels in organizations involve information processing and decision making, but operator work focuses on materials and machine or manual operations, and management levels focus on administrative work, cross-sector coordination, and communication with more people. Whatever the level, the value of IT is in helping in decisions or performing operational tasks. Examples are the maintenance management system to help with decisions on maintenance, the SCADA (supervisory control and data acquisition) system to send commands for control operations, and a financial-risk model to help with strategic decisions.

The types of IT platforms are changing. A decade ago, PCs, laptops, and mainframes and servers were in widespread use for system management,

and discussion of handhelds or personal digital assistants for field work was starting. SCADA systems were advancing, and software was becoming more sophisticated. Now, the same types of equipment are in place, but there has been a revolution in small devices, including the migration of computing power to cell phones and the use of a broad range of laptop-type devices, such as tablets and computing pads. The use of the Internet has exploded, with both wired and wireless applications. Lest we get too excited about all of this, the need for cyber security has also multiplied, and it takes a great deal of organizational effort to control IT systems so as to avoid breaches or outright disasters.

We stand at the threshold of a bold new age in computing, but we must learn to harness its power and control the possible negative effects. To see the new possibilities, follow a reporter at the 2011 AWWA Conference, where he wrote about intelligent software for metering billing, operations, and overall utility management (Laughlin, 2011). Management applications included leak detection, customer tools for monitoring water usage, information on finances, and maintenance scheduling. Use of these applications is aided by streamlined reporting tools, user-defined alerts, and charting and mapping tools. The flood of data can be managed by integrating information systems and managing data on one central, secure database. Although most utilities manage their own data, subscription services are also available.

This chapter describes how evolving hardware and software tools are used to manage water systems and how future uses might occur. It builds on established technologies, such as databases and supervisory control systems, and extends to emerging topics such as handheld devices and new management methods such as automatic meter reading (AMR) and global positioning systems (GPS). Other new topics include possibilities to use the Internet, advanced metering infrastructure (AMI), customer information systems, and knowledge-management systems. While this might seem like alphabet soup, it is important to learn and embrace these emerging technologies (Hughes, 2006). Of course, cyber security is an important issue due to the vulnerability and importance of the infrastructure systems.

IT across Organizations

By definition, IT systems focus on how the information is organized in the utility or its information architecture, which involves many sources of data. Information can be classified by organizational units or work processes. If organized by unit, it relates to which units share or manage the information. Management information by unit can be intrasystem (as within one water utility), intersystem (as between two cooperating utilities), and interservice (shared among electric utilities, roads departments, and other services).

Ten years ago, IT departments were emerging. Now it is clear that special units are needed to manage and provide security, and the IT department has now become a core part of organizations. In some businesses, a title of chief information officer (CIO) has been created. The Anchorage, Alaska, Water/Wastewater Utility reported positive results from organizing an IT Division and plan back in 1992 (Lauer and Premo, 2000). It allocated capital improvement funding to promote IT and reported big increases in efficiency and a high return on investment. They focused on six strategies: improving the enterprise-wide computing environment; reducing paperwork through e-mail, intranet, GIS, and Internet; integrating data and removing islands of automation; improving business processes and work flow to enhance organizational effectiveness; replacing obsolete equipment; and expanding IT infrastructure to increase bandwidth and improve reliability. These plans have held up, and in today's IT world they might look about the same, thus showing stability in the evolution of IT and its organization in utilities.

Information flow also considers links with other organizations that might have a stake in a decision or action. An example would be weather and demand data, such as when hot weather places severe demands on water systems (such as Chicago's use of inner-city fire hydrants to spray water to cool the population and relieve social tensions) at the same time that electricity supplies would be strained due to air-conditioning demand, creating a time of heightened risk of system failure and security concerns.

Speed of access to information can be called its velocity. In infrastructure management, the highest velocity required is for emergencies, where delays can be catastrophic. Even in normal operations, delays can cause serious problems. Design and construction require lower but more deliberate velocities, and delays can have severe economic and safety consequences. Planning is the slowest, but it is important to have comprehensive and valid information available.

Every organizational unit requires IT systems and data, and IT affects utilities on both the cost side and the service side. On the cost side, they involve downsizing and more use of IT tools. On the service side, customer relations involve more disclosure through IT systems, especially the Internet. IT is affecting organizational forms in utilities because information can be shared in different ways. It is inefficient for each group to gather and maintain its own data, and they should cooperate to harness the power of data and save on redundancies. Table 10.1 provides an overview of how IT is applied in different units of utilities.

Information can also be organized by issue or business process (capacity expansion, risk management, operations, design and construction, finance, maintenance, etc.). This focuses the information on the specific problem to which it will be applied.

As IT applications spread, a map of the tools and systems show us where infrastructure-related tools are emerging. Table 10.2 focuses on software and applications, but a utility must also manage personnel, finances, and

TABLE 10.1

Application of IT in Different Units of Utilities

Unit	Application of IT
Planning	Modeling and databases for projections; GIS for spatial planning; IT-based displays for presentations
Design and construction	Webcam construction monitoring, electronic construction documents
Operations	SCADA, meter reading, communications
Maintenance	CMMS, condition assessment
Finance	Asset and financial information
Organization-wide	Inventory, asset management, emergency management

TABLE 10.2

Utility Applications in Various IT Categories

Utility Applications	IT Category [a]
Infrastructure databases	Databases
Device controls, data transmission	Telecommunications, SCADA
Mapping, document management, design	GIS, BIM, CAD software
Work management, CMMS	Work management software
Models, advisory systems	Decision support systems

[a] Abbreviations: BIM, building information management; CAD, computer-aided design or drafting; CMMS, computerized maintenance management systems; DSS, decision support systems; GIS, geographic information systems; SCADA, supervisory control and data acquisition.

other administrative systems. The software categories require their own hardware platforms. For example, databases are for the most part kept on servers using a variety of database management software packages. SCADA systems include programmable logic controllers (PLC), smart actuators, and Ethernets.

Some IT applications were introduced earlier in the book, including asset management systems (Chapter 3), planning and programming models (Chapter 4), computer-aided planning and design and construction management (Chapter 5), system accounting systems (Chapter 6), SCADA (Chapter 7), emergency management (Chapter 8), and computerized maintenance management systems (CMMS) (Chapter 9).

Enterprise software systems are used by the organization as opposed to individuals, and they are in widespread use in utilities. Some applications are shown in Table 10.3, which is organized by department. A strategic IT plan can establish strategic vision and goals; assess the current IT state (includes business process workshops); recommend IT projects and develop a business case; and develop a phased implementation plan (Wood and Dell, 2006).

TABLE 10.3

Applications of Enterprise Software Systems

Customer service	Application for service via Internet, automated permits system
Engineering	GIS for infrastructure, recording as-built drawings in field on CDs
O&M	Work-management system, monitoring via Internet, mobile computing
Human resources	Utility policies and procedures on Intranet, utility-wide communications via Intranet, database to track training
Finance	Financials with Intranet presentation, asset management system
Treatment	Laboratory information management system, consolidated reporting with Intranet presentation, SCADA

IT Applications

The emergence of new IT approaches occurs like a stair step where a new technology changes our work, and then another one changes it again. Ten years ago, Rosen (2000) explained how these were evolving for water supply utilities that use handheld devices for data logging and related tasks; decision-support systems to help operators with daily tasks and to automate routine decisions; sensors to automate data collection; GIS for mapping and related uses; sampling drones to take over routine monitoring; wireless applications for communication among devices; and automatic meter reading, consumption monitoring, and billing. Today, these technologies are further along, and the mobile computing has definitely taken hold. It can even lead to better coordination, as in the case of risk management, where there can be more feedback from public health systems and hospitals to alert water utilities of possible negative changes in system conditions.

Rosen (2000) thought that the information available would give utilities an edge and change the regulatory environment from command and control to one where utilities can decide on actions themselves in the best interests of their customers and businesses. While there is little evidence that this has happened, there is a growing sense that the limits of the regulatory system have been reached, and utilities must be ever more vigilant themselves.

IT products fall into groups that can be employed in different ways by utilities. Of course, the use of software for administrative work by utilities is similar to that of other organizations, and there have been many changes in the use of word processors, spreadsheets, databases, graphics, and communications packages for document management and office automation, computing, decision making, and communications. Mobile computing and the use of phones as computing devices is increasing rapidly.

A database application in a utility might be an asset inventory, whereas the same software in a retail chain might be used to track inventory or customer characteristics. Data management in organizations is recognized as a powerful capability that gives companies a competitive edge. While utilities do

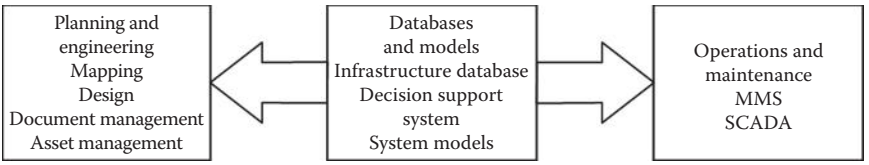

FIGURE 10.1
Information support for infrastructure management tasks.

not normally compete with each other for market share, they can ride on the coattails of advancing data-management technologies developed for private industry.

Figure 10.1 shows a model for how infrastructure-related IT support can be provided. You see the databases and models at the central location, with information support provided to engineering and planning on one side and to O&M on the other side. Other configurations are possible: This is just a generic approach.

Databases, Models, and Decision Support

The infrastructure database is the heart of a utility's capability to manage its far-flung inventory, especially the buried assets. Databases are used for multiple purposes, such as maintaining system inventories, keeping records of system condition, tracking stocks of spare parts, studying customer demographics and historical demands, and studying weather and extreme conditions. Databases can even be used to track and report security threats and incidents (see Chapter 8).

Databases are works in progress because utilities have legacy systems of infrastructure, and older distribution and collection system maps are evolving into digital information systems that are managed within database software or GIS systems. Some utilities have well-developed databases with comprehensive, accurate, and accessible information about assets. Others still have paper maps waiting to be digitized sometime in the future. In the worst cases, even paper maps may be sketchy or missing.

In the past, infrastructure data were organized around working units and kept in the file drawers of managers and the engineering office. Now, it is not acceptable for only a few people to have access to data on the infrastructure system. Not only does it hinder operations, it does not prepare the next generation to manage the system.

As utilities sought to modernize, some developed excellent inventories even before computers were available. For example, Batts (1984) described a system that is over 100 years old in Kalamazoo, Michigan, for mapping

distribution system records. The manual version of this system began with a wall map of the entire system, which was also available at a reduced size of 6 × 8 ft. Working maps at a scale of 1 in. = 50 ft showed details of each area and were available at legal size to be bound into books. This was a manual version of today's GIS capabilities. The maps showed material and size of main, work-order numbers and dates of installation, distances from property lines, fire hydrant data, valves, service lines larger than 1¼ in. in diameter, and all location data. Maps were updated annually. Data on system components were maintained on asset files and ledger cards showing initial installation information. Service line information was recorded in the field when connections were made, and main-break records were kept.

There is a lot of good theory about how to organize databases, and it would be good if utilities could organize them from scratch by identifying data classes and grouping the data into logical clusters, but the organizational units are changing at the same time as the IT platforms are. For this reason, data management in utilities is a dynamic situation.

The decisions of any unit can be linked to information flows and databases. Databases result from business system planning, which begins by defining the business and its business processes, independent of position on the organizational chart. Clusters of data systems, called *data classes*, should be mutually exclusive and independent of the organizational structure. Information architecture is the matrix relating business processes to data classes and relates decision points to information.

Data classes that are found in utilities include: the system inventory and condition databases (Chapter 9); the hydrologic and water use databases (Chapters 4 and 7); control-system databases for managing treatment plants and preparing regulatory reports (Chapter 7); engineering analysis and design databases (Chapter 5); and the financial database (Chapter 6).

The infrastructure inventory can be used by several utility functions. Because of its utility-wide importance, it should not be restricted to use by maintenance forces, but should also be available for needs assessment, asset management, and property accounting. The word *inventory* means a list or record of things in stock, the process of making a record, or the individual items in a record. In an infrastructure inventory, components are listed and described, but it is more like a property inventory than an inventory of goods.

The field of financial accounting provides a framework for inventory, and methods differ for real property, fixed assets, and equipment. Classification systems can break these categories into specific items or inventory objects, but no method has brought all concepts of accounting for property, plant, and equipment together. To account for the assets, they must be classified. One classifier is tangible (fixed assets) or intangible. On balance sheets, assets are classified as current and noncurrent, which include property, plant, and equipment, sometimes called fixed assets or plant assets. So, the assets we are interested in are intangible and noncurrent, and often called fixed assets.

The distinction between property, plant, and equipment is also used, with the word *plant* originating from manufacturing accounts.

So, accounting for fixed assets is where the world of inventory begins, as discussed in Chapter 6. The accounting function has different specialties, and management accounting refers to accounts produced for the internal use of managers. This is the approach intended for uses such as infrastructure systems management, which requires timely statements so managers can make decisions about expenses and actions. Management accounting does not normally produce much information on fixed assets because the information has not been used much by managers, at least not so far. Rather, the situation is more like Peterson (1984), from the telephone industry, described: For asset management, we "put it in, use it, if it breaks, repair it; if it breaks too many times, discard it and replace it." Fortunately, new attention to fixed-asset accounting has begun to replace this old attitude.

Most infrastructure management is under government accounting and follows rules of the Government Accounting Standards Board (GASB), which has created a category for infrastructure fixed assets. For utilities that are enterprises, as opposed to general government, depreciation is accounted for under GASB rules. For general government, GASB previously authorized the nonreporting of public fixed assets (infrastructure) that are immovable and have value only to the government unit, as opposed to enterprises. However, this changed with GASB 34 (see Chapter 3).

In the case of regulated utilities in private ownership, asset costs will be part of the rate base and will attract a lot of attention from regulatory commissions. The National Association of Regulatory Utility Commissioners (NARUC, 2011) specifies a uniform system of accounts for categories of utilities, and this provides an initial concept for the inventory of fixed assets. The categories are Classes A, B, and C for water and wastewater, separately, as distinguished by annual operating revenues.

Since the inventory involves real property, fixed assets, and equipment, a master inventory for an organization is needed to bring them together. The only place this happens is in the accounting function. Accounts are good for real property, less so for equipment, and even less so for fixed assets such as buried pipes. This is why Peterson (1984) wrote, "Managers have found it necessary to provide separate records for property, plant, and equipment, and created records for insurance, security, utilization, and maintenance." In other words, you might end up with a number of separate records, each one duplicating the same information.

In today's digital world, the manager can theoretically have all inventory information in one place. Ideally, the main place to centralize data would be in the financial accounts. Then, if management units could each have their own subaccounts for inventory, all data could be coordinated. So, with the advent of computerized management systems, we would be able to integrate information for financial and management uses. This does not seem to be practical yet, and financial accountants can get system information from the

centralized infrastructure database or they may simply depreciate historical procurement information without regard to the real condition of the system.

One problem is that fixed assets have not received as much attention from accountants as current assets, which have more dynamic financial turnovers and greater effects on tax and profit reports. Accounting for fixed assets shows that assets must actually be managed, not just purchased, used up, and replaced. The objective is to provide not only accounting for assets, but to use accounting to help managers get the most out of the company's investment. Peterson (1984) asked: "Do you have in place a process that monitors the current condition, evaluates the future need for replacement, and brings to your attention needs to modify that plan?"

Accounting concepts for capitalization of private sector assets cover tax implications or valuation, but they do not determine how to set asset policies and apply them within an organization. Fixed assets are depreciated by accountants, but depreciation relates to tax obligations more than it does to the condition of assets. If infrastructure managers reform their accounts for long-term tangible assets, the fact that facilities are wearing out will be known, and we can reverse the mentality of "put it in place and forget about it."

An inventory can be as simple as, for example, a set of drawings indicating where sewer pipes are located in a section of a city, along with their attributes. These drawings, with annotations, could be used by maintenance forces to locate and service pipes. On a more sophisticated level, the drawings could indicate other nearby facilities, such as water and electricity lines, and also be used to coordinate services. The widespread adoption of GIS systems is making this a reality in many places, enabling coordination of data for different sections of the organization whose work involves shared data, processes, facilities, and staff.

Guidance for data elements leads to property record systems, which include more data than might be needed for management purposes. Examples of data in these systems include: historical cost and how it was established, date of acquisition, location, custodian, property tax information, vendor or donor, restrictions on use, depreciation method, estimated remaining life, and future usefulness. Management versions of these records require spatial data, either on a map or GIS, as well as appropriate descriptive data, either in text entries or a database.

According to Peterson (1984), reports that can be generated from the property record system include forecasts of maintenance, asset replacement value, management reports of maintenance issues, production rate, location of equipment, and responsibility for property. Thus, reports should be available via the accounting system, although in reality many such reports might be generated directly from a maintenance database.

Computers are useful to manage databases, and a number of commercial software packages are available. Relational databases offer new ways to organize data to facilitate decisions and actions. Communication systems offer ways to link inventory data to other management actions. For example,

a system component such as an overflow weir in a combined sewer system can be linked by a wire or wireless system to a central computer system, which shows its location and current status, enabling maintenance decisions to be coordinated with operations.

A generic inventory system should work for water, sewer, and stormwater systems. Although components differ, their general categories are similar, as shown by the available classification systems. There are several ways to identify a utility's assets. For water supply, one method outlined by the National Association of Regulatory Utility Commissioners (NARUC, 2011) gives a listing by real property, fixed assets, and equipment (see Table 10.4). Inventories for water, wastewater, and stormwater are comparable (see Table 10.5).

The inventory concept has been taken further in a report for the Water Research Foundation about key asset data (Oxenford et al., 2011). This report was prepared in recognition that water and wastewater utilities require accurate and timely information about their assets and that information about them comes from diverse sources, requiring effective acquisition, storage, and management of asset data. The project created a list of terms and definitions and a classification system for key water and wastewater assets, including aboveground and buried assets. Performance indicators were also developed.

Inventory technologies are improving, including sensors, computers, communications, and management methods. Technologies for locating pipe include metal detectors, ferromagnetic locators, radio transmission locators, nonmetallic locators, and ground-penetrating radar. To aid in locating components, the WaterRF sponsored a project entitled "New Techniques for Precisely Locating Buried Infrastructure" by Roy F. Weston, Inc. (2001). Its purpose was to "identify and comparatively evaluate methods and emerging technologies for accurately locating metallic and nonmetallic buried assets

TABLE 10.4

Identification of Utility Assets Using Real Property, Fixed Assets, and Equipment

Real Property	Fixed Systems or Assets	Equipment
Land	Reservoirs	Power generation equipment
Structures and improvements	Intakes	Pumping equipment
	Wells and springs	Water treatment equipment
	Infiltration galleries and tunnels	Office equipment
	Supply mains	Transportation equipment
	Distribution reservoirs and standpipes	Equipment storage
	Transmission and distribution mains	Tools, shop and garage equipment
	Services	Laboratory equipment
	Meters	Power-operated equipment
	Hydrants	Communication equipment

TABLE 10.5

Identification of Utility Assets Using Inventories for Water, Wastewater, and Stormwater

Item for Water System (From Naruc List)	Comparable Item for Sewer System	Comparable Item for Stormwater System
Land[a]	Land	Land
Structures and improvements[a]	Structures and improvements	Structures and improvements
Reservoirs	Equalization ponds and large aeration basins	Detention ponds and flood control reservoirs
Intakes	Discharge and overflow points	Discharge structures
Wells and springs		
Infiltration galleries and tunnels	Wastewater tunnels	Stormwater tunnels
Supply mains	Main and outfall sewers	Large storm sewers
Power generation equipment[a]	Power generation equipment	Power generation equipment
Pumping equipment[a]	Pumping equipment	Pumping equipment
Water treatment equipment[a]	Wastewater treatment equipment	Stormwater treatment equipment
Distribution reservoirs and standpipes		Small detention ponds and tanks
Transmission and distribution mains	Collection sewers	Storm sewers
Services	House sewers	Building drains
Meters	Measuring equipment	Gauging points
Hydrants		
Office equipment[a]	Office equipment	Office equipment
Transportation equipment[a]	Transportation equipment	Transportation equipment
Equipment storage[a]	Equipment storage	Equipment storage
Tools, shop and garage equipment[a]	Tools, shop and garage equipment	Tools, shop and garage equipment
Laboratory equipment[a]	Laboratory equipment	Laboratory equipment
Power-operated equipment[a]	Power-operated equipment	Power-operated equipment
Communication equipment[a]	Communication equipment	Communication equipment
	Manholes	Manholes
	Sludge drying beds	Grates and drainage intakes
		Open channel segments

[a] Indicates categories that are generically the same. Components within categories may differ. For example, a wastewater pump will normally be of a different type than a water supply pump. For stormwater, curbs and gutters would be considered part of streets rather than stormwater systems.

TABLE 10.6

Data Elements for Typical System Inventories

Type of Data or Display	Treatment Plant Equipment	Distribution Pipes
Location and spatial data	Drawings or plant diagrams showing location of equipment	Maps or GIS
Specifications and descriptive data	Original specifications for installation, manufacturer's literature, O&M manuals	As-built drawings, manufacturer's literature
Displays	PLC outputs, SCADA systems	Map books, GIS screens and printouts

in a wide range of environments (i.e., in cities, under roads, with different soils)." Databases for the inventory include the location and status of system components, and they require records of pipes, valves, manholes, and other appurtenances. Table 10.6 shows data elements for typical system inventories.

As part of a project for the Water Research Foundation, I and my team studied how utilities currently manage pipeline data for their risk studies of main breaks. While our studies focused on water mains, much of the results also apply to wastewater. They are less applicable to stormwater because those systems come under less scrutiny. We contacted a number of utilities and found that the formats in use include GIS, in-house digital data sets, and commercial asset management or maintenance management databases. Of course, some utilities do not have computer-based data sets, but rely on older map-based systems and lists.

It takes a large amount of data to do pipe renewal planning, and most utilities have a repository of data in the form of as-built drawings, maps, maintenance records, and other data elements. These separate records are part of a utility's overall data-management system, which will have data classes and sectors.

The earliest records were kept on paper in engineering and management offices. As database theory evolved, firms sprang up to support business operations with new data products and services. An early example was a system named Metrocom and developed for Houston, Texas. It required over 300 work years to develop and had a map of some 600 square miles of the city, with 554,000 parcels of property and location information on water, sanitary and storm sewers, and roads and bridges (Hanihan and Rivera, 1984). At the same time, a firm was marketing a system with limited graphics capabilities called an Infrastructure Management System (IMS) with Census Bureau maps and information added by users.

In these years, utilities still believed that their O&M expenditures were adequate to maintain reliability. A survey by CH2M Hill at AWWA's 1985 Distribution System Symposium showed that actions differed among small, medium, and large utilities. The reported actions can be deceiving, but 63%–100% of utilities (small to large) reported that they had methods to determine

pipeline replacement needs (including reports of main breaks). Most also reported that they had computer models of system hydraulics (48%–90%) (O'Day et al., 1986). Our experience suggests that those percentages are optimistic, as many utilities are still developing their data-management practices some 25 years later. However, a lot of progress has been made. During the 1990s software firms developed products for maintenance and work management, and databases were attached to them.

A leading example of database development is the Washington Suburban Sanitary Commission (WSSC), which compiled information on the condition of its system during this era and includes it in internal reports. WSSC's practices illustrate a comprehensive approach to using system data to track the condition of water mains, compile databases, and use the information to plan renewal projects. As reported by Woodcock (2003), WSSC had computer-based applications for the Maintenance Management Information System (MMIS), Webmap, GIS, and AutoCad. The MMIS is linked to work programs and contains database information from work orders, contracts, and repairs. It was programmed in the 1980s, and WSSC planned conversion to a new platform. Webmap was based on Autodesk, used conventional maps, and is linked to the MMIS and document files such as valve cards, drawings, water-segment attributes, and equipment location. The GIS, based on the ArcView platform, allows manipulation of spatial data, including many of the features of Webmap. The AutoCad package was used to prepare design drawings and allows importation of information from the other packages. Recent information is that WSSC is modernizing these legacy systems and working with MMIS, a GIS, and a financial data system for asset management.

Our observations are that utilities of different sizes are still adapting their technologies and methods according to their needs, their resources, and their opportunities. GIS systems have emerged as the leading contender for the database management system of the future, but alternative mapping and data-management technologies continue to compete with it.

For example, the ArcGIS Water Utilities Data Model provides a GIS system based on a collection of objects, feature classes, and attributes defined for water distribution networks. It can be tailored for integration with other data-management systems. ESRI (2011) explains that GIS provides a common platform to access all business data, network information, work orders, customer information, or report information. Visualization and mapping are supposed to give a connected view of the network in relation to customers and other infrastructure. With the data model, GIS keeps up with compliance, inspection data, and condition ratings. ESRI provides a number of free templates for various applications related to water supply and other urban public works systems.

Utilities can develop their own GIS systems or they can purchase or contract with a vendor. Halfawy, Newton, and Vanier (2006) evaluated Synergen, CityWorks, MIMS, Hansen, RIVA, Infrastructure 2000, and Harfan. They concluded that the systems were not as far along as systems for construction

management, and that methods and tools for long-term renewal planning of infrastructure assets were particularly needed. Since this review, vendors seem to have migrated toward GIS. For example, CityWorks (2011) software works with ESRI's ArcGIS and is certified by the National Association of GIS-Centric Solutions. It is aimed at asset management and other infrastructure applications.

Other vendors have stuck closer to database technologies. Synergen, Inc., was acquired by SPL WorldGroup, Inc., in 2004, which was acquired by Oracle in 2006. It provides enterprise asset management and computerized maintenance management system (CMMS) packages. Their products focus on work management, asset maintenance, scheduling, inventory control, and related business processes. Oracle (2011) offers a range of related products that are based on database technologies.

In leading-edge utilities, you may find a functional GIS that is adequately serving the needs of asset managers, but condition information might be lagging. In the smallest utilities, you will mostly likely have no asset data-management system other than the legacy paper records that exist. Transitional systems exist in many utilities, but their status will depend on a number of factors. For example, in the WSSC system, the utility had developed advanced methods, but the technology available has outstripped the original platforms. In another utility we visited, a legacy data system was in operation as a patchwork of older systems that were developed by consultants and maintained and improved by utility staff over the years. A GIS has been developed in another part of the city government, and now the utility asset managers are trying to determine the best way forward, given the patchwork of legacy systems.

The future seems most likely to be one of continuing adaptation, both to new technologies and to demands for decision information. Many factors will determine the pace of change and the way that data-management systems for infrastructure evolve.

To assess the level of IT applications in asset data management, we circulated a short questionnaire to a selected group of utilities. The questions asked whether the utility had an inventory of pipe assets, how it organized data on water-main failures and how it used the information to plan future pipe renewal. Although many utilities were contacted, only a few responded. These included very large cities, medium cities, and small towns.

Most of the small towns are struggling to move their data from paper to digital formats. The larger cities used more sophisticated IT methods to manage their pipe inventories and operations. Some larger utilities can use their data to run system hydraulic models and/or use pipe-break information to plan for renewal. Many of the medium-to-large utilities are using GIS, and some use a separate in-house database to store pipe conditions and repair histories of pipes.

Models and Decision Support

Utility work involves many decisions that can take different forms. When decisions are structured, databases and automatic control are easier to apply. Operating decisions, as opposed to management decisions, are more definable, on shorter time spans, more repetitive, simpler, less risky, less uncertain, and based more on knowledge of operational data. When decisions are unstructured, they are more difficult and subjective. Examples of these include political decisions, such as those made by governing boards. "Miller on Managing," described in Chapter 12, addresses some of these.

IT products are part of decision support systems (DSS), which feature databases, models, and dialog systems. They help the decision maker process information for a decision. The manager applies logic, rules, procedures, and data to create a decision or recommendation. Computations and communications can be automated via IT. Expert systems may be part of a DSS. Chapter 9 describes one that could be used to advise utilities on priorities for sewer inspections.

A typical computer-based decision support system will be structured as shown in Figure 10.2. The DSS can be applied to situations involving planning, design, or operations. Two situations are shown in Table 10.7. In the first, the common operational example of pressure management in a distribution system is illustrated, and in the second, a capital planning problem for the distribution system is shown.

In the pressure-management situation, the operations manager must monitor the system to detect the actual versus target pressures and make adjustments to maintain the system in balance. To do this, a calibrated hydraulic model with feedback from pressure measurements and graphically illustrated by a SCADA system would be ideal. In the planning case, data on pipelines are needed so that risk models can be run to identify the most likely candidate pipelines to cause trouble, and thereby place them on a list for renewal actions.

Models

Many models are in use for water, wastewater, and stormwater system planning and operations. A model is a mathematical tool where the state of a system is simulated or predicted, usually for a particular time. One example is a water supply reservoir, where at any time a flow rate enters, another flow rate leaves, and the result is the amount of water in the reservoir at any time, which is also a function of losses. Another model could track growth in water demands by population increases, and could be linked with the utility's finances by water sales and expenditures on capital and water supplies. At Colorado State we used a systems dynamics technique to develop a model of this type in the 1970s to simulate the water supply, demand, infrastructure,

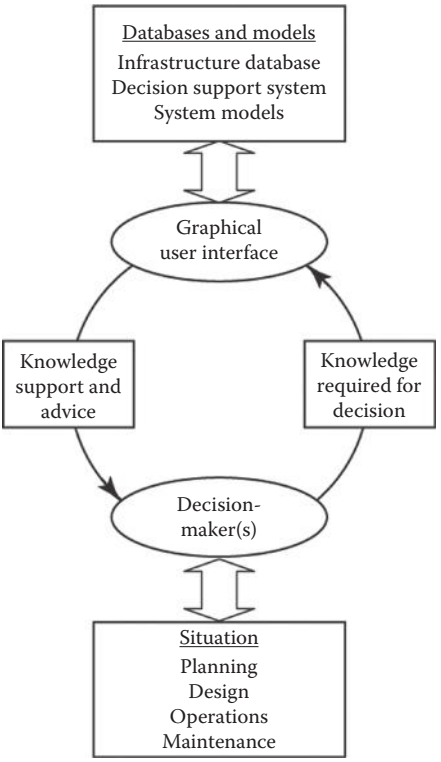

FIGURE 10.2
Decision support system.

TABLE 10.7
Decision Support System

Situation	Pressure management	Capital planning for pipeline renewal
Decision	System adjustment	Selection of pipelines and method for renewal
Knowledge required	Comparison of actual to target pressures	Risk of main breaks and consequences
Database	System hydraulic characteristics	Pipeline asset database
Model	System hydraulic model	Pipeline risk rating models

and financial aspects of the Fort Collins, Colorado, water system. Today, such models can be developed using spreadsheets.

This type of model can be called a simulation model or a process model. Another type is the optimization model, but it refers to techniques to find the highest or lowest value in a mathematical relationship and is used in combination with simulation models.

TABLE 10.8

Simulation Models

Water Supply	Wastewater	Stormwater
Basin or well yield	Generation of waste by quantity and constituent	Watershed runoff
Storage in reservoirs and tanks	Flow prediction and routing	Flow prediction and routing
WTP operations	WWTP operations	System storage and changes
Distribution system models, water quantity and quality	Stream and reservoir water quality	Routing of flows to points in system
Demand forecasting	Nonpoint source discharges	Stormwater quality changes

Models can be used by water, wastewater, and stormwater utilities in many ways, and perhaps the best way to illustrate is by examples, as shown in Table 10.8, which is arranged from upstream to downstream applications.

Each of these model categories has undergone research, and commercial products are available. While they offer potential to improve management, models are not a replacement for monitoring, engineering analysis, and good judgment. Modelers see many applications and may get ahead of the state of practice and the capability of users to assimilate new advances. This is a good thing because they are pushing the envelope of innovation in management.

There is a movement toward open-source models, where developers can start with a generic code and develop custom applications. How these are managed varies, but an example might be the Stormwater Management Model (SWMM), which was originally developed by USEPA in the 1970s and remains in wide use today. I am in touch with other modelers, and note their significant interest in cooperating with others to create user groups toward the goal of improving the status and use of model groups. These open-source model efforts might be attractive to utilities for some applications, but proprietary models will still form an important part of the IT available for infrastructure management applications.

Engineering and Planning Support

The suite of tools used in planning and engineering applications is broad and getting broader. Perhaps the broadest category is asset management, and tools for mapping, design, and document management are improving continually.

Chapter 3 is devoted to asset management tools, which were explained as an information-based process used for life-cycle facility management across organizations. In that sense, it is an enterprise system that is meant to embrace the full needs of the organization to manage its infrastructure assets. Its features were explained to require the use of information-based processes and tools for the various components of asset management, which include everything from system planning and finance to maintenance management.

Mapping, design, and document management go together in the sense that they comprise traditional and well-developed functions of the engineering office. Engineering visualization for design and construction and the practice of mapping for site work have changed dramatically with the new tools available today. The tools include geographic information systems (GIS), building information management (BIM), computer-aided design and drawing (CADD), and others.

GIS

Perhaps more than any other IT platform, GIS has gained traction among utilities and other infrastructure organizations because its powerful capabilities can organize infrastructure-related spatial information. Applications have improved continually and will continue to evolve. Although GIS is still an emerging technology, it has revolutionized planning and management in the industries where maps were used. GIS is defined by its link to map making and usage, where a GIS includes a computer link between its map information and database, and offers the capability to capture, store, manage, retrieve, analyze, and display spatial information (Clarke, 2010).

Many GIS applications and products are on display at meetings of the water, wastewater, and stormwater industries. Large meetings of GIS professionals also occur, and one where many utility applications are discussed is the annual user conference of ESRI, which attracts thousands of participants. From these meetings and the development work of ESRI you can get a feel for how GIS can become a multifunctional platform for water, wastewater, and stormwater infrastructure management. For example, Crothers, Miller, and Oppmann (2011) demonstrated how GIS can be used for solutions ranging from internal asset management to external stakeholder engagement. They have templates for a local government data model, operational awareness, and capital improvement planning, among others.

The Urban and Regional Information Systems Association (URISA), the Geospatial Information and Technology Association (GITA, 2011), and the American Congress of Surveying and Mapping (ACSM) also provide networking and training opportunities for the geospatial community. For example, a URISA congress will feature mapping applications of interest to the water industry. The 2010 GITA conference included sessions about GIS but also other spatial tools, such as one used by the Tampa Water Department to visualize its SCADA system for operational control. The focus was on analysis of system behavior with time to detect hidden trends and avoid future failures. Tampa used GIS in an application that manipulated time-based data and displayed it in a video format to show deviations or predict future scenarios in daily operation.

In infrastructure management, a valuable application will be the system inventory, with GIS providing the mapping capability and, in many cases, a home for the database. This will have many applications from locating

addresses to finding broken pipes and maintenance problems. Watershed maps are also needed by water, wastewater, and stormwater utilities for other reasons. GIS integrates spatial information of this kind to enable utilities to cooperate across functional differences to share information and resources.

While it may seem that GIS can do it all, the jury is still out on how it will play out in the future for utility applications. GIS has powerful spatial capabilities and can serve as the host for other data platforms, including commercial off-the-shelf (COTS) software. However, GIS is complex and can be expensive to organize and maintain, so with the many smaller utilities, other approaches might work. For example, a digitized system of any accurate base maps and records might be enough to form the IT core for the simplest situations. These might be created from a commercial application such as a Google map, which is carefully prepared and maintained.

It seems that the popularity of GIS will hold up. The earliest extensive utility applications were initiated in the 1980s and 1990s, so elements of the technology as applied to utilities date back well over 20 years. It would seem a good move to make a commitment to GIS, with the understanding that any investment in locating and mapping facilities can be ported to other applications as needed.

It can be difficult to choose the GIS application for water, wastewater, and stormwater systems, and competing packages continue to be developed. Ten years ago we reported that eight products with recognized brand names were dominant. The changes since then have been rapid, and it would be complex and problematic to summarize the products available. This has implications for the utility choosing a platform, because you want to make sure your investment pays off and can be sustained for the long term. Another issue is that coordination of GIS and mapping within organizations can be difficult because the demands by different units for map information vary widely, and it is a challenge to create a system where "one size fits all."

A practical suggestion for converting a 1990s CADD-based system to GIS for mobile applications was made by Lewis (2011) of WachsWater Services. The GIS yields 1 in. = 200 ft maps that are reduced and bound to carry in trucks. Lewis began with some historical background, such as that mapping systems were drawn manually in the beginning. The utility would enlarge USGS or property maps to create base maps for the pipelines. The drafter would use all available information to create the utility's mapping system. Although the maps had various sources of errors, they were still useful for approximate locations.

As the land uses changed, the mapping and its accuracy continued to evolve, and new errors crept in. When CADD systems arrived, the manual systems were digitized. The conversion created new errors due to additional handling and approximations. The CADD maps were useful and cost effective, as you can imagine. The GIS could be built from the legacy maps or the utility could start over by locating everything again and going to source

documents to get original information. The mapping would be more accurate than the original base maps, in any case.

If the maps were converted from CADD to GIS directly, a number of conversion decisions about standards would have to be made. If the problems can be solved, the utility can have a map system up and running quickly. However, when most water GIS were created, few of today's accuracy issues were faced. Lewis thinks the future workforce will have difficulty unless corrective actions are taken. To go mobile, he suggested five data considerations: an acceptable level of spatial accuracy; adequate and accurate levels of detail; presenting enough data; keeping data current; and proper data integration.

Design Platforms

Design platforms for infrastructure management might or might not involve GIS systems. Ten years ago, AutoCad by AutoDesk was described as a generic CAD system for design and drafting, and its capabilities have increased continually. The list of competitors also continues to grow, and Bentley Systems's Microstation and related design software packages are also prominent. To educators, it is difficult to know how to present the many possibilities for design graphics because students must know fundamental concepts as well as how to manipulate software. The only conclusion to reach is that the world of design and drafting will continue to evolve as more and more capabilities are added.

BIM

For design of buildings, the concept of Building Information Modeling (BIM) has become popular in the last decade. BIM uses geometric objectives to create images of a building's systems in three-dimensional (3-D) space, and is an umbrella technology for a number of software approaches. As GIS technologies advance, the connection between them and BIM technologies may offer a way to have a fully integrated 3-D database of all facilities in your city.

Document Management

Document management is another important IT application for infrastructure management. The issue is how to store, access, and manage the vast store of documents that stands behind a legacy and growing system of infrastructure. Clearly, you need to maintain as-built drawings, modifications, specifications, and records of many kinds. Computer-based documents in various forms can be used, and these can be linked to software packages that include GIS, databases, or other mapping systems. Innovators are creating new types of information-access systems such as a Google map with notes on it that lead you to the documents you need by a few clicks.

Design and e-Construction

IT is changing the face of design and construction through innovations such as digital drawings and electronic construction documents. Another application is Web construction site monitoring. For example, you can use a construction project website to have a project directory, project calendar, request for information log, photos, discussions, meeting agendas and minutes, monthly reports, schedules, weather, specifications, partnering information, operations and maintenance data such as safety data sheets, punchlists, training calendar and manuals, and O&M manuals.

O&M Support

To infrastructure managers, work-management software focuses on the maintenance management systems. Chapter 9 discusses these, as they provide information for maintenance and repair needs and for budgeting. In the MMS, advisory functions are computerized to include the inventory, scheduling system, and record keeping. A number of viable commercial software packages are available for maintenance management. These are merging into enterprise systems, which are discussed later in the chapter.

SCADA

Supervisory Control and Data Acquisition (SCADA) system is the term that frames the use of IT in operations. These were discussed in Chapter 7. In addition to IT applications for computing, SCADA relies on telecommunication systems, which are increasingly integrated with computing systems.

Telecommunications

Telecommunications has changed dramatically from landline telephone and radio applications to today's myriad systems for transmitting information. Communication systems include radio, broadcast and cable television, Internet, wireless, and emergency communication systems. Utilities use these for many purposes, including command, control, and coordination during normal times and emergencies.

The technologies that are having the greatest impact on water systems are new data transmission methods and use of the Internet. Use of data transmission systems has increased along with the use of data for automated tasks. Data transmission means the transfer of data over any type of system, whether wired or wireless. Wireless data transmission can range from localized Wi-Fi systems to longer-range transmission using microwave. Wi-Fi is a trade name that generally means wireless local area networks. Analog data transmission has been around a long time, but is being supplanted by digital communications or the transfer of discrete packages of information.

The Internet has changed the way we do business dramatically. Posting system information on the Internet enables utilities to share data with their customers and with each other. Internet connections can be either open or secure, depending on the applications. In regional water supply management, for example, utilities can post system state information and decide among themselves how to share water supplies. In a stormwater application, operators can access real-time storm and flood information. Mechanisms for coordination are especially important because of interdependencies among utilities and the need to control far-flung operations.

One-Call is a communications area where IT has made contributions. One-Call Systems International (OCSI) is the current version of a program that has existed since the 1960s. It promotes facility damage prevention and infrastructure protection through education, guidance, and assistance. It became a committee of the American Public Works Association (2011) and has now joined the Common Ground Alliance. OCSI has alliances with other organizations to promote infrastructure protection and prevention of damage to buried facilities.

Reverse 911 is a tool of emergency managers, rather than utility managers. According to Cassidian (2011), an EADS North America company, the Reverse 911 (REVERSE 911®) system uses a combination of database and GIS technologies. In 2000, its CEO told a national "All Hazard Warning Roundtable" hosted by the National Telecommunications & Information Administration that standards were needed for alerting emergency message recipients. The roundtable was discussing new telecommunications and information technologies, which can be used to deliver warnings to citizens at risk in emergencies. The wisdom of this warning has been demonstrated a number of times since then, as disasters require robust communications that reach many parties quickly.

Enterprise Systems

Enterprise software systems are being used by many businesses to support work processes across an organization or a department. In utilities, much of the work is focused on O&M, so enterprise systems can be used to view system-wide operations or to plan maintenance and service work.

A key concept for enterprise systems is that the same information can be used for different purposes, to include operations, emergencies, design and construction, planning, and financial management. The integration begins with unit information systems for departments such as finance, operations and maintenance, and engineering, and in the ideal case, a common database and management system can be organized. In a practical sense, sharing information and data can be difficult. Obtaining enterprise-wide databases

and GIS systems requires managers and workers to share information and authority, and might generate resistance. Nevertheless, IT seems to be forcing acceptance of these.

Examples of information products to support enterprise-wide asset management systems include: GIS, inventory and facility information, maintenance schedules, and work management systems. When these are swept together, the theory is that they form a suite of software for management, analysis, inventory, inspection, and testing.

Viewing system-wide operations is normally handled by SCADA systems. As an example, the Detroit Water and Sewerage Department and Westin Engineering developed a Web-based Utility Information Management System for the Wastewater Operations Group. An electronic Visual Management System integrates IT systems and SCADA to give a real-time view of facility and compliance status. Equipment failures had led to NPDES (National Pollutant Discharge Elimination System) violations and a consent decree. The system provided a master schedule to track projects being planned or under construction and to stay in compliance while equipment is out of service. The large wastewater treatment plant (WWTP) has been continually under construction, expansion, remodeling, or upgrading for many years (Laughlin, 2001). This was an optimistic report from a decade ago, but Detroit's financial difficulties due to a shrinking population and the current economy have created challenges for compliance. These illustrate how IT can help but not overcome overwhelming infrastructure obstacles.

Enterprise software for work and maintenance management offers many intriguing possibilities for productive work. Many enterprise systems are emerging, and the field changes quickly because it offers new business opportunities. To view these, consider the initiatives of IBM (2011) to develop a line of asset management software. The claim for the software is that it unifies comprehensive asset life-cycle and maintenance management on a single platform and covers all enterprise assets and their conditions and work processes. A few work processes included are asset deployment, specifications, monitoring, costing, and tracking. These are used in planning, maintenance, schedule management, resource optimization, and performance measurement. Other features are to track inventory for maintenance and to manage contracts for purchasing.

Enterprise systems change, and if a utility makes a commitment to a system, it should ensure that the system will continue to be supported. To illustrate how systems evolve, 10 years ago we reported on a software line by GBA Master Series. The products included

- GBA Work Master (maintenance management, customer requests, work orders, parts/materials inventory)

- GBA GIS Master (automated mapping, toolkits for map generation and data population integrated with entire suite to allow for graphical selection of infrastructure items)
- GBA Sewer Master (sanitary sewer inventory and inspection, system analysis, system rehabilitation)
- GBA Water Master (water distribution system inventory and inspection, system testing and administration)
- GBA Storm Master (stormwater system inventory and inspection, system analysis, system rehabilitation)

The idea was that the software would be integrated with mapping programs to export or import maps and used with CAD applications. The concept has now evolved, and the software is offered by Lucity (2011), which explained how the evolution occurred. In 1986, an engineering firm (George Butler Associates) was developing software to help its engineers organize and analyze data for water, wastewater, and stormwater systems. It added street and pavement modules and functionality like work orders. It decided to develop a suite of public works asset and maintenance management software, and the GBA Master Series (gbaMS) product was created. The firm became an Esri® Business Partner and added GIS integration, and it enhanced the software to comply with popular database platforms. In 2011, the gbaMS unit become Lucity, Inc., to focus the product line.

Cyber Security

There is a significant risk that someone with malevolent intentions might want to hack into a utility's IT-based operating systems, particularly SCADA systems. Therefore, IT security is critical for utilities and their infrastructure management systems. It is a broad issue, and a full treatment is beyond the scope of this chapter, but a few issues can be mentioned. Of course, the IT department has a major responsibility, and it is expected that it would control the use of computers within the utility. We find strong controls on software packages that can be used on utility computers, sometimes to the detriment of introducing an innovative new management package. Obviously, the SCADA system must be protected against hackers. As the year 2000 approached, a major concern of utilities was that computers would not even work and whole systems would fail, thus creating the "Y2K" issue. People were worried about electrical system failure, loss of natural gas and water supplies, telephone or other communications disruptions, loss of Internet, fuel shortages, chemical supply problems, economic problems, civil unrest, and associated breakdowns. These fears did not materialize, as the major efforts made by utilities to prepare paid off.

Future IT Directions for Water Utilities

It is evident that IT is changing the world of work for all businesses, including utilities. We will see a continued decline in the cost of computing and greater software power for utilities to use for management and problem solving. However, the complexity of IT and related technologies will continue to challenge us.

New Info Sources

These new tools create more possibilities for analysis of information, and there are analogies between businesses and utilities. For example, just as a business will track customer preferences, a utility might track the demand patterns of its customers and use them to introduce innovations such as time-of-day pricing for water service. Another example might be cooperative water supply systems, where a group of utilities work together to share raw water supplies. This could be similar to the way that businesses handle their supply chains.

Change Organization

IT will continue to change organizations and their work. Before computers, organizations tended to have many layers so that information could be passed smoothly down the chain to small sections of workers. Organizations were fragmented because information could only be shared among a few people at a time. Now, information can be sent over networks and be more widely available. This has tended to flatten organizations and eliminate middle-management positions that were needed to process information. Although IT has changed organizations and their work, it is still difficult to break down silos between departments and to develop shared programs such as asset management.

Integration

Computers enable sharing of information among functional departments in organizations. For example, engineering and maintenance departments need some of the same information as the finance department requires. This introduces the possibility for different departments to work together on shared cross-cutting objectives, such as asset management.

Security

The attacks on September 11, 2001, brought new concerns about water system security, and utilities are rethinking the information they post on the

Internet for open access, in the same way they are rethinking visitation policies of their systems. At the same time, Internet security technologies are improving the way that information can be sent and received over the Internet, so that the future will offer new possibilities for changing work using IT. For example, as Chapter 8 explains, utilities can share security information over a secure system under new software developed through the National Infrastructure Protection Center (NIPC).

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11

Legal and Regulatory Controls on Urban Water Systems

The water industry is highly regulated with a number of laws, regulations, codes, and standards controlling the work of managers who are responsible for the integrity of infrastructure systems. Not only are managers of a water utility constrained by legal controls, they are also affected by the risk-averse nature of the utility culture. They seek to build high-quality infrastructure systems in the first place, to operate them so as to avoid any sanctions or penalties, and to avoid problems such as main breaks, backed-up sewers, and boil-water orders.

While the legal controls affect water treatment and quality directly, for the most part, the controls on infrastructure management are indirect. That is, they do not specify exactly how to build and manage the infrastructure, but they specify how the infrastructure must perform. An example is the minimum 6 in. water-line size that prevails in many utilities. No law specifies this minimum diameter, but it has become a de facto standard through insurance practices to make sure fire flow requirements are met. While the utility must maintain flow and pressure, no one tells it what size water main to build. However, these performance requirements have translated into local codes that specify minimum pipe diameters.

In regulated industries such as water, the legal system is often used to resolve disputes. Management staff may find themselves working closely with lawyers, and expert witnesses may bring opinions about these disputes. Technical staff will also be involved and expected to be experts in the infrastructure issues that are involved in various scenarios, such as failures of sewers or water lines, for example.

Given this close relationship between utility management and legal and governmental processes, the purpose of this chapter is to survey the important laws and regulations that govern water, wastewater, and stormwater infrastructure systems. The chapter also briefly covers financial regulation.

Many water, wastewater, and stormwater infrastructure rules are also found in codes and standards. These might be design standards, for example, and have essentially the force of law if they are required by a legally binding rule. These include local land use and building codes and are often aimed at health and safety. Chapter 5 discusses codes and standards for water, sewer, and stormwater systems in more detail.

Examples of Legal Scenarios in the Infrastructure Life Cycle

During the system planning phase at the beginning of the infrastructure life cycle, land-use law, building codes, and subdivision regulations must be followed. Environmental issues must be anticipated, as they often determine the outcomes of permit processes. For example, a utility in my area is currently having difficulty planning the route of a large water supply pipeline through a local community. The opposition forces are seeking to find reasons that range from technical design codes to state law about historic preservation to ensure that the pipeline is routed away from their area.

During the design process, laws about procurement, about the practice of engineering, and about contracts will apply, along with engineering codes and standards. During the construction process, the Davis–Bacon Act may control job labor rates. Under this 1931 act, workers on federal projects must be paid local prevailing wages (WaterWorld, 2001a). For example, as part of a settlement agreement with the AFL-CIO, the U.S. Environmental Protection Agency (USEPA) resumed applying Davis–Bacon requirements to all Clean Water State Revolving Funds. OSHA (Occupational Safety and Health Act) requirements also apply, and other construction laws govern relationships with contractors.

During the operations phase, compliance with the Safe Drinking Water Act and Clean Water Act is required. Both laws contain a number of programmatic provisions that translate into requirements for monitoring, reporting, and controlling the risk of noncompliance. Utilities are vigilant about avoiding noncompliance and enforcement situations. For example, Dalton Utilities and the Water, Light, and Sinking Fund Commission of the city of Dalton entered a civil settlement with USEPA and the Georgia Environmental Protection Division. The utility was to pay a $6-million penalty and make improvements, including implementation of pretreatment, improved operations and maintenance (O&M) for its sewer collection system, implementation of a land-application system characterization plan, and discontinuance of land application of sludge in certain areas. Dalton had been subject to criminal investigation for falsification of reports (WaterWorld, 2001b).

Utilities are risk averse about infrastructure failures such as broken water or sewer lines, backed-up stormwater systems, and damage to property from failure of any infrastructure or operations system. Utilities are involved periodically in litigation, where the justice system is used to settle cases in federal, state, or local courts. They may use alternative dispute resolution (ADR) procedures in appropriate situations, such as construction disputes.

Financing systems may draw in legal requirements such as in a city code, which has limits on debt. Accounting rules must follow Governmental Accounting Standards Board (GASB), and other accounting regulations will

apply. It might be necessary to budget funds for a state-required art-in-public-works program. These are just a few examples, and operation of a utility involves other issues related to law, regulations, liability, and risk.

Types of Laws and Regulations

The starting point to study the sources of law is the enabling powers in federal and state constitutions and local charters. These overarching powers provide the authority for legislation, which in turn authorizes regulations for water systems. The U.S. Constitution is a brief document with enormous authority, but some state constitutions are much longer and can be amended more easily. Local charters authorize cities to establish utilities, which are normally governed by provisions in city codes.

Understanding of law is helped by viewing the three levels and three branches of government. Table 11.1 shows how laws and regulations come from all three levels and all three branches. The legislative branch passes the laws; the executive branch implements them; and the judicial branch interprets law and resolves disputes. The laws from the legislative branch are called statutes at the federal and state levels and are generally called ordinances at the local level. The executive branch does not pass laws in the same way, but it issues regulations and executive orders at all three levels of government. Decisions of the judicial branch at the higher levels have the force of law and are called case laws.

Laws can be classified in different ways, depending on the issue at hand. Two important categories are civil and criminal law. Criminal law involves investigation, arrest, and stages leading to possible penalties, including jail. For example, a utility executive could be charged with criminal acts in the course of a pollution incident. Civil law deals with relationships among people, such as lawsuits about rights and responsibilities. For example, if a drainage pipe breaks and causes damages to property, someone might decide to file a lawsuit.

TABLE 11.1

Laws and Regulations Come from All Three Branches at the Federal, State, and Local Levels of Government

	Legislative (Statutes)	Executive (Regulations and Executive Orders)	Judicial (Case Law)
Federal	Federal statutes	Agency regulations	Federal cases
State	State statutes	Agency regulations	State cases
Local	City ordinances	Agency regulations	Local cases

Law can also be classified according to the industry or problem it deals with, such as water law or construction law. In water, wastewater, and stormwater infrastructure situations, for example, civil procedures might resolve contract disputes or liability suits. In these, the plaintiff sues a defendant in a municipal, state, or federal court. Cases then go through stages, leading to a judgment. Liability involves tort law, when one party alleges that another party did something wrong against it. Torts are the legal system's means to compensate injured parties. Liability for injuries and failures is an example. In utility work, safety in construction is an important issue, for example. The trench construction shown in Figure 11.1 illustrates a scenario where safety is paramount.

In statutory law, the statutes authorize programs and create enabling legislation. For example, federal statutes control much of the need for water, wastewater, and stormwater infrastructure. The Clean Water Act (CWA) authorized subsidies and controls for the construction and operation of wastewater treatment plants. The Safe Drinking Water Act (SDWA) drives

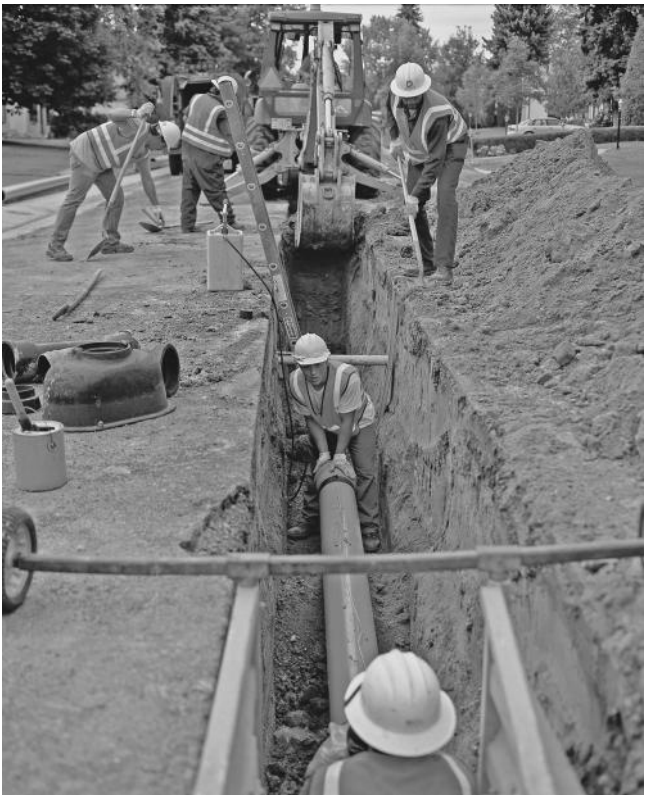

FIGURE 11.1
Trench construction. (From AWWA. Copyright 2001. All rights reserved.)

construction of new water supply treatment and other infrastructures. Municipalities may build new stormwater systems to comply with Clean Water Act rules.

The difference between authorizing legislation such as the SDWA and the CWA and appropriation bills is that the enabling legislation makes programs possible, but only when the funds are appropriated will the funds flow to the programs that have been authorized.

The cost of infrastructure is affected by legal issues that occur during the design and construction processes, and these can be considered under the broad framework of construction law. Examples are requirements for construction documents, performance and design specifications, competitive bidding, bid bonds, payment bonds, performance bonds, and other construction business issues. Situations might include scheduling, communications, subsoil conditions, suspension of work, sales of materials such as ready-mix concrete, and delays and changes. Law governing the practice of engineering, architecture, and surveying is specialized state law that enables control activities through regulatory boards.

Much of the law involved in construction is about contract compliance and is in the category of business or contract law. Categories include purchase contracts, sale contracts, buy-out agreements, employment contracts, property settlement agreements, enforcement of contracts, and leases. In addition to contracts, business law categories include business organization, regulatory rules, bankruptcy, antitrust, and labor laws. Human resources or labor-law issues also arise in construction and in dealing with other personnel issues in utilities.

Property law refers to interests in real property, such as real estate, water rights, or personal property, both tangible (example: land or vehicles) and intangible (example: stocks and bonds). Some infrastructure rules relate to land use and involve laws and regulations about subdivisions and developer contributions to pay for infrastructure. Another example might be designation of easements or rights-of-way.

Codes and standards are not the same as laws, but they determine some of the requirements for infrastructure. Without codes and standards, safety and performance would be at risk. Excess rigidity can lead to other problems, however, such as overly restrictive codes and standards that raise costs and impede construction of needed infrastructure.

Many legal issues of water, wastewater, and stormwater systems relate to health, safety, and the environment. The CWA and SDWA deal with health and safety issues, and a body of environmental law has developed with statutes and cases dealing with issues such as fish and wildlife and species protection. Examples of environmental law topics include: authorities of environmental agencies; regulatory law; environmental impact; air quality; water quality; hazardous materials; underground storage tanks; drinking water; right to know about chemicals; wetlands and floodplains; coastal zone law; dredge and fill; wildlife/wilderness; and land-use law (McGregor, 1994).

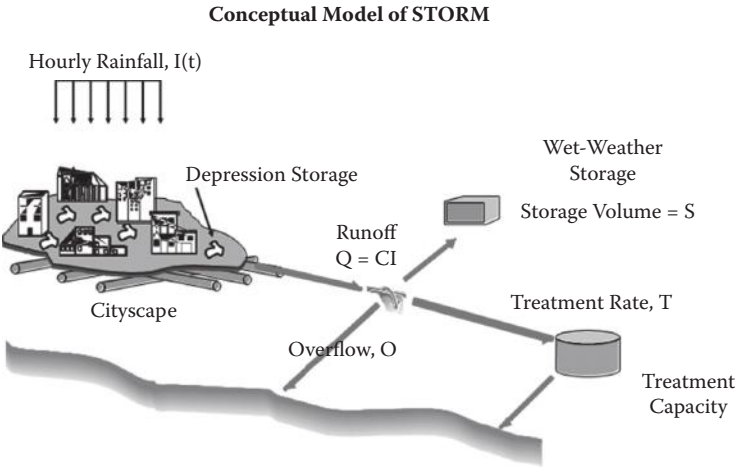

FIGURE 11.2
A stormwater planning model. (Courtesy of Larry A. Roesner, Colorado State University.)

Most environmental laws, like the Clean Water Act and the Endangered Species Act, were passed from about 1965 to 1975. However, amendments continue to be passed, and new regulations are issued periodically. The SDWA was used during the 1990s to create a Lead and Copper Rule that affects how drinking water pipelines are managed. The CWA is the authority for USEPA to enforce regulations that measure how well utilities control infiltration and inflow into sewers. It also regulates stormwater systems much more now than it did upon its inception. For example, Figure 11.2 shows the concept for a model of stormwater quality that was developed to simulate how well stormwater systems comply with regulations.

Agencies and Roles

Regulatory programs are normally assigned by statute to the logical federal agency, which works with parallel state agencies to develop rules and operate the programs. For example, USEPA and state EPAs regulate water quality. The Corps of Engineers was delegated the authority to implement Section 404 of the Clean Water Act, which covers dredge and fill and is the program under which reservoirs are permitted. The U.S. Fish and Wildlife Service and Forest Service regulate under authority of environmental statutes such as the Endangered Species Act and the Forest Service authorizing statute. The Federal Power Act regulates hydropower dam licensing and related water management issues. The National Environmental Policy Act (NEPA) is an overarching law that governs environmental planning.

At the state level, state engineer or Department of Water Resources offices regulate the diversion of water from streams and wells. Dam safety programs are also found at the state level, but they are strongly influenced by national laws.

United States Code (U.S.C.) and Code of Federal Regulations (CFR)

The overall law of the United States is placed into the United States Code (U.S.C.). After they are passed, laws such as the Clean Water Act and the Safe Drinking Water Act are entered as titles and chapters. For example, the SDWA is found under Title 42—The Public Health and Welfare, Chapter 6a—Public Health Service, Subchapter XII—Safety of Public Water Systems and is in Articles 300f through 300j. The shorthand would be SDWA, 42 U.S.C. 300f-300j. The Clean Water Act is in Title 33, Navigation and Navigable Waters, Chapter 26—Water Pollution Prevention and Control (Cornell University Law School, 2011).

After regulations are issued by executive branch agencies, such as USEPA, they are placed in the Code of Federal Regulations (CFR), which is a codification of the rules published in the *Federal Register* (USGPO Access, 2011). Many of the rules governing water and sewer systems are in Title 40—Protection of Environment, Chapter I—Environmental Protection Agency (Parts 1–799). Some of the parts of this chapter that are important to water and sewer management are in Subchapter D—Water Programs, which governs the National Pollutant Discharge Elimination System (NPDES) and the National Primary Drinking Water Regulations (NPDWR).

The regulations, or rules, come under administrative law, which is the set of rules developed by administrative agencies, such as the Environmental Protection Agency, to carry out their statutory authorities. "Rulemaking" means development and issuance of regulations that spell out how statutes are to be implemented. Also, agency officials exercise some judicial power in interpreting rules and in dispute resolution. Courts exercise judicial review of agency decisions, meaning that any decision made by an administrator is subject to review in a court of law.

The United States has an Administrative Procedure Act (APA) to serve as the organizing vehicle for rules about procedures. It covers topics such as rules and practices, administrative courts, boards and commissions, administrative regulations, administrative remedies, complaints, judicial review of administrative acts, licenses, administrative sanctions, and tax courts. Also, this area includes procedures before special courts or administrative (quasi judicial) agencies concerned with the adjudication of cases such as taxes and revenues.

Regulation of Water, Wastewater, and Stormwater Systems

Regulation of water services can take many forms. For example, water supply utilities must comply with rules, codes, and/or standards in the following areas:

- Health and safety
- Water source quality
- Fish, wildlife, and environmental flows
- Water laws or permits for withdrawals
- Rate regulation by governing boards or public service commissions
- Service quality for access to water, pressure, and volumes

As a result of the laws, regulations, court decisions, and codes and standards that govern the water industry, water supply, wastewater, and stormwater services are regulated to control behavior with rules or laws to protect the public interest. Mainly, the rules come in the form of regulations that are authorized by federal statutory law to empower agencies to issue regulations through rule making. Categories of water regulation deal with health and safety, water quality, fish and wildlife, quantity allocation, finance, and service quality.

The main laws are the SDWA and the CWA, as amended. Stormwater regulation is also handled by local rules, but regulation through the Clean Water Act has added an overlay to these. Floodplains are also regulated by local governments, but rules are also promulgated through federal flood insurance programs. Much regulation faced by utility and industrial dischargers is driven by public interest in water quality and the interrelated and shared nature of water resources. One person's waste affects the other person's drinking water.

Water quantity law affects cost because infrastructure is needed to develop water supplies and ensure safe yields, either from groundwater or surface water. In the humid states, regulation of water quantity is mostly by permit systems. Basically, a permit is like a water right and entitles the holder to use the water. Permits may be for the withdrawal of a particular quantity of water for urban use, as for example, a permit to withdraw water for a city of 50,000. Conditions on such a permit would be negotiated between the administrative agency and the diverter. In the western United States, the prior appropriation doctrine is generally followed, and a water right is a property right, rather than a permit to use the water. Security of title to water was necessary in water law in arid regions because, without it, no one would invest in water development.

Safe Drinking Water Act

The Safe Drinking Water Act was first passed in 1974, and it has been amended several times. It is the culmination of safe water legislation that began in 1914 with regulation of water on interstate carriers. The SDWA provides primary and secondary drinking water standards that apply to public water supply systems. The primary standards govern contaminants that threaten health, and the secondary standards govern those that threaten only welfare.

SDWA requirements differ for community water systems (CWS), nontransient–noncommunity water systems (NTNCWS), and transient–noncommunity water systems (TNCWS), as explained by USEPA's Community Water System Survey. Most infrastructure is in the CWSs, which comprise about 50,000 systems of all sizes in the United States.

The American Water Works Association tracks trends in the SDWA and publishes periodic review articles. Pontius (2003) reviewed the overall status of the law and showed its complexity as it covers the National Primary Drinking Water Regulations (NPDWR) for contaminants relating to turbidity, microorganisms or indicator organisms, radionuclides, inorganic contaminants, and organic contaminants. Of these, most have maximum contaminant levels (MCLs), and others have treatment technique requirements. Still other contaminants are subject to secondary standards to ensure the aesthetic quality of drinking water. In a typical year, the regulatory agenda will address current issues and rules under consideration. In Pontius's comprehensive review of 2003, for example, actions expected were proposal of the Stage 2 Disinfectants/Disinfection Byproducts Rule, the Long-Term 2 Enhanced Surface Water Treatment Rule, the final Groundwater Rule, and the final Radon Rule. Since 2003, Pontius and others have written about the regulatory agenda as new rules appear, and they have expanded the coverage to include wastewater and related water issues as well as the cost of regulations.

Most rules that stem from the SDWA relate to the quality of the water rather than the physical nature of the infrastructure, but to achieve the quality standards requires high-integrity infrastructure that works well. This can be illustrated by two examples: the Lead and Copper Rule (LCR) and the Total Coliform Rule (TCR).

The Lead and Copper Rule was developed by USEPA to control the release of harmful metals from distribution systems. It shows the clear links between distribution systems and water quality levels with implications for health effects. Figure 11.3 illustrates the linkages between the water quality itself and the chemistry that attacks the materials in the distribution system, service lines, and plumbing systems in individual premises. In the service lines, full or partial replacement of lead service lines might be required. Lead-based solder might also be a problem in the plumbing systems of private premises. Customer water use patterns may also contribute to exposure.

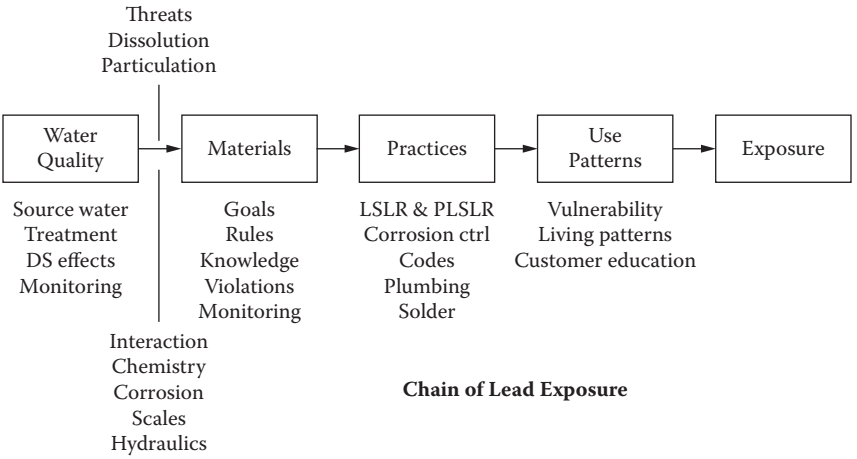

FIGURE 11.3
How lead gets into drinking water.

In terms of regulation, the LCR is based on an "action level," where lead levels in the first flush at the customer's tap must be below 0.015 mg/L. The remedy is often corrosion control treatment, which might be based on pH control or use of additives such as phosphates to passivate the metal and prevent it from being released into the water.

The Total Coliform Rule, which was developed by USEPA in 1989, is the only microbial drinking water regulation that applies to all public water systems. The rule requires systems to meet MCLs for total coliforms, including fecal coliforms, as determined by monthly monitoring. The rule outlines the frequency and timing of the testing based on population served and requires public notification according to monitoring results. It became clear that distribution-system management was a key issue in control of coliforms, and USEPA used the authority of the Federal Advisory Committee Act to establish a Total Coliform Rule Distribution System Advisory Committee to advise and recommend improvements to head off the degradation of drinking water quality in distribution systems. A long study period that included a number of working papers was implemented, and the working papers provide a great deal of information about distribution systems and illustrate both infrastructure and water quality issues. The proposed rule revision changes the monitoring frequency and the way the MCLs are prescribed. Also, the Natural Resource Council (NRC) performed a study of threats to distribution systems (see Chapter 2).

On the enforcement end of the SDWA, water supply officials can be held personally liable in drinking water cases. A federal district judge issued a ruling holding several family-owned Monterey County, California, drinking water company executives personally liable, the first time that corporate owners of a drinking water company have been liable personally for SDWA

FIGURE 11.4
Ozone towers at the Los Angeles Filter Plant. (Courtesy of Peter Garra, Los Angeles Department of Water and Power.)

violations (WaterWorld, 2000). The SDWA has led to a number of infrastructure investments. Figure 11.4 illustrates a response to the act—ozone towers at the Los Angeles Filter Plant.

Clean Water Act and Wastewater Regulation

The Clean Water Act has had enormous influence on the development of wastewater infrastructure. Prior to 1972, little concentrated attention

was given to wastewater policy, but during the 1960s, momentum was building for a new approach, and the Clean Water Act was passed in 1972. The objective of the act was to restore and maintain the chemical, physical, and biological integrity of the nation's waters, and its first goal was to prohibit the discharge of pollutants into the navigable waters (zero-discharge goal). The second goal was to provide sufficient water quality for fish, shellfish, wildlife, and recreation. The act has been amended several times since 1972, and it continues to be interpreted by USEPA and the courts.

The general provisions of the act include planning, permitting, construction, monitoring, reporting, and enforcement. It created a process where studies of stream capacities and standards lead to waste-load allocations for developing discharge permits under the National Pollutant Discharge Elimination System (NPDES). To ensure compliance with the act, ambient and effluent monitoring are required. Dischargers must report the results of their operational performance, and an enforcement program is in place to maintain the standards of the act.

CWA policies that deal directly with infrastructure include the provision of federal financial assistance for the construction of publicly owned waste treatment works (POTWs) and area-wide wastewater treatment planning. By about 1990, these programs had had a large influence on the development of infrastructure. The construction-grants program has put billions of dollars into local areas since 1972, and now the grants have been replaced with a revolving loan program (see Chapter 6).

Under the CWA, the discharge permit is the contract between the operational agency and the regulator, which is usually the state government with USEPA oversight. USEPA controls the authority of the state government to operate the permit program through a memorandum of understanding wherein the conditions of the program are set. If the state is not carrying out the full provisions of the act, then USEPA can withdraw the authority of the state and begin to operate the permit program itself. The CWA requires parallel state legislation that enables states to operate the permit program, enforcement program, and others. The Total Maximum Daily Load (TMDL) provision of the act enables the allocation of pollutant loads to dischargers where water bodies are not meeting standards. As a result of this provision, utilities are concerned that USEPA will impose end-of-pipe numeric limits on stormwater discharges where TMDLs have been certified. USEPA has also studied trading arrangements with offsets, such as pollutant trading. The National Association of Flood and Stormwater Management Agencies (NAFSMA) tracks these regulatory issues (Tucker, 2000).

Local governments are also involved in regulation under the CWA. Ordinances are required, such as a sewer use ordinance and a system of charges, especially for fair charges to industrial and commercial users.

Drainage and Flood Laws, Regulations, and Codes

Stormwater regulation differs from that for drinking water and wastewater in the sense that no national law controls it, and it involves several complementary objectives. One of its objectives—to control the quality of nonpoint urban runoff—does fall under the CWA, but the drainage-related objectives are, for the most part, controlled only by local rules. The exception is that a few states have comprehensive stormwater and/or sedimentation control programs.

Basic legal doctrines of drainage are the common-enemy rule, the natural-flow rule, and the reasonable-use rule. Under the common-enemy rule, you can do most anything to protect your property without considering the impacts on others. Under the natural-flow rule, you would not be allowed to change anything that would affect natural flows. The reasonable-use rule is the more common approach today, where you are allowed to take certain actions but not to cause unreasonable impacts.

States that have precedents either in common-enemy or natural-flow roots are moving toward compromise. In the reasonable-use approach, you would be able to modify your land somewhat, even if you affected your neighbor, but there would be a test of reasonableness. This rule recognizes that development will occur, but that there is a community obligation to work together to accommodate it. Regulations for detention storage to hold flood flows to historical levels are examples of reasonable-use doctrine. Say a city requires developers to detain stormwater up to the 2-year flow. Anything greater than that will be an altered flow, but there will be a community responsibility to deal with it.

Most municipal governments representing populations of about 10,000 or greater have stormwater control programs, and their elements would be controlled by an ordinance with provisions for floodplain districts and uses, special-use permits, nonconforming uses, cost of drainage improvements, erosion and sedimentation control, grading and drainage plans required, maintenance, and subdivision plats.

Stormwater authorities are not always clear, and the programs cut across water- and land-use issues. Typical authorities include stormwater standards; subdivision regulations; the stormwater quality control program; the erosion control and land quality programs; and programs for the control and beautification of urban areas such as stream restoration, greenbelt construction, recreation, and environmental education. All of these might be combined into one municipal stormwater agency.

If the stormwater ordinance does not include provisions for a stormwater control program, it might be established by other ordinances to include controls on impacts of urbanization. There might be a general drainage ordinance to include responsibilities for drainage, cost allocations, and performance standards as well as other aspects of subdivision regulations.

Stormwater is a different kind of service in that it provides local drainage, major flood control, and control of nonpoint source water quality. Stormwater standards might set return periods and levels of service required. Subdivision regulations might include items such as sidewalk requirements, street crowns, and inlet sizes. There might be standards to impose requirements for greenbelts, walkways, ponds, and other amenities.

Programs for control and beautification of urban areas can be integrated into the stormwater program. Examples are stream restoration, greenbelt construction, recreation, and environmental education. Flood control programs focus on protection of life and property. Trends are to emphasize nonstructural measures, but many local governments manage significant infrastructure in the form of levees, channels, and even flood control reservoirs in some cases.

Legal situations that can develop begin with land development. A new subdivision that might cause flooding in older areas lower down might induce litigation and political action. Another type of legal problem comes from floodplain zoning, where restrictions are placed on property improvement. In this case, federal regulators might seek to impose rules on local governments for stormwater quality.

Generally, the legal basis for stormwater service is the constitutional charge to local governments to provide services for the health and welfare of citizens. Special area-wide stormwater districts, such as Denver's Urban Drainage and Flood Control District, have their own enabling legislation. Except for increasing attention to nonpoint source problems, there is little regulation of stormwater service itself. Local governments do regulate developers through land-use rules for the quality of construction in new developments, and there are regulatory requirements about building in floodplains.

Some state governments have stormwater legislation with regulatory implications, mainly to require that local governments have plans to recognize interjurisdictional issues. For example, planning is the main issue in Pennsylvania's program, which requires each county to develop a plan for designated watersheds. Plans are to include surveys of existing runoff characteristics and obstructions; assessment of land development as well as impact of runoff quantity and quality; analysis of development in flood hazard areas; review of stormwater collection systems and impacts; assessment of runoff control techniques and flood control projects; designation of areas to be served by stormwater facilities within 10 years and who will construct and operate such facilities; identification of floodplains; development of criteria and standards; establishment of priorities for implementation of action within each plan; and provisions for periodic review. New Jersey also requires plans, but by municipalities rather than counties, with counties in a review role. The state also provides grants, and the program deals with pollution control and drainage (Commonwealth of Pennsylvania, 1978).

The Clean Water Act provides authority to regulate stormwater. Stormwater quality control programs are still emerging. USEPA has a wet-weather program that includes stormwater runoff, combined sewer overflows (CSOs), and

wet-weather sanitary sewer overflows (SSOs). Stormwater runoff includes pollutants such as oil and grease, chemicals, nutrients, metals, and bacteria. CSOs and wet-weather SSOs contain a mixture of raw sewage, industrial wastewater, and stormwater.

Rules issued in 1984 stated that stormwater discharges coming from urbanized, commercial, or industrial areas had to apply for permits. This attempt to require permits failed, but subsequent environmental lawsuits led to the development of a procedure applicable to larger municipalities, industrial dischargers, and construction sites. The program evolved, and now it identifies three types of regulated stormwater discharges: municipal separate storm sewer systems (MS4s), construction activities, and industrial activities. The MS4 program covers operators of large, medium, and regulated small MS4s. Under the construction activities program, operators of sites of 1 acre or larger and some smaller sites may be required to have an NPDES construction stormwater permit. Industrial groups may require an NPDES industrial stormwater permit. USEPA (2011b) is sometimes the permitting authority, and operators must meet the requirements of EPA's Multi-Sector General Permit.

The Federal Emergency Management Agency (FEMA) is involved with infrastructure because its programs influence local flood control through the National Flood Insurance Program (NFIP). The NFIP was created and shaped by the National Flood Insurance Act of 1968, the Flood Disaster Protection Act of 1973, and the National Flood Insurance Reform Act of 1994. These make the purchase of flood insurance mandatory for federally backed mortgages on structures located in special flood hazard areas. Flood insurance is mandatory for buildings in FEMA-identified high-risk flood areas or special flood hazard areas. Flood-zone determinations establish whether a structure is located in a flood hazard area. In administering the NFIP, FEMA has undertaken a large number of policy and specific-area studies of flooding.

Enforcement of Regulations

A regulatory program must have an enforcement mechanism to be taken seriously. Law enforcement is a police function that everyone understands. This is important in water management, but there are degrees of enforcement, just as there are in criminal justice systems. Utilities are strongly motivated to avoid enforcement actions taken by regulatory agencies, as they create many negative effects in public perception and trust as well as the penalties themselves.

To understand enforcement, consider the levels of laws and regulations. First, there is the law or the statute, normally either federal or state. Then, there are regulations, such as a regulation about stream water quality

standards. Then there are various reports and procedures that are administrative in nature and that are needed to implement a program. Any of these can be the subject of an enforcement action.

Most of the experience in the water field is from the Clean Water Act. The CWA gives authority to EPA to take actions to enforce its provisions. This authority includes permission to enter and inspect premises, review records, test monitoring equipment, and take samples. EPA can issue compliance orders or take action in civil court. Civil penalties can be large. EPA has developed a policy of how to compute a civil penalty: basically that the penalty should be large enough so that the discharger has no economic advantage from the violation. In a practical sense, to apply this policy, you would compute how much the discharger saved by not complying, and that would be the penalty (Eizenstat and Garrett, 1984).

Sometimes an enforcement action results in a consent decree, which is a court action where the violator consents to be submitted to a certain action in return for release of court action. The decree then requires follow-up action. An example is the Detroit Water and Sewerage Department's consent decree, which requires them to remain in compliance and to submit certain reports in return for release of charges about NPDES violations (Laughlin, 2001). Another consent decree was with General Electric on its Pittsfield–Housatonic River Site. The consent decree was issued in 1999 by the U.S. District Court of Massachusetts in Springfield, Massachusetts. Parties to it were General Electric and USEPA (2011a), the U.S. Department of Justice, the Massachusetts Department of Environmental Protection, and the attorney general and Executive Office of Environmental Affairs of the state of Connecticut.

Financial and Service Quality Regulation

There is a sharp dividing line between the control of publicly owned and privately owned water utilities. Water utilities have monopoly franchises, either because they are public agencies or because they are private companies with franchises granted by state agencies. Those owned by public entities are generally self-regulated for finances and the quality of service they provide. Under private ownership, the utilities are regulated by state public utility commissions (PUC). As the public has difficulty in determining whether they are receiving the most cost-effective water services possible, these privately owned utilities have their rate decisions made public, and comparisons of costs are easier for the public to make.

Investor-owned water utilities are subject to rate regulation by the PUCs, and like electric power utilities, their rate increases are evaluated in terms of a fair rate of return on assets. Government-owned utilities are not generally subject to this regulation, but rely on political control to hold rates

down. See Chapter 6 for a discussion of rate setting. The PUCs are working to improve their regulation of water systems, and they face many new issues as the water industry evolves. Fewer wastewater utilities than water supply utilities are investor owned and subject to rate regulation by state public service commissions. However, as this industry grows older, with increasing privatization, financial regulation will become more important.

For water supply and wastewater, utility service quality is mostly governed by industry standards and local codes. For example, minimum pressures and pipe sizes are established by industry norms and often codified in local rules. PUCs may add rules for privately owned utilities.

Politics of Regulation

The search for better regulatory models continues, but it seems certain that regulations will get tighter. The public's interest in safety and the environment is reflected in pressure from volunteers (environmental groups) and elected officials (Congress and state officials) on the regulatory process. The results are in the form of permits, monitoring, and enforcement of regulations. The press is an important factor, and courts apply pressure, sometimes in response to public opinion. All branches of government get involved: executive (agencies), legislative (Congress and state legislatures), and judicial (courts). The press is like an unofficial fourth branch that influences public opinion.

Environmental and fish and wildlife rules can affect the cost of infrastructure, mainly the cost of acquiring water supplies. For example, rules on bypass flows to maintain fisheries mean that reservoirs have to be larger and cost more. Environmental organizations are key players in regulation. They are deeply interested in laws such as NEPA, the Endangered Species Act, and various authorities given to federal and state environmental and resource agencies. The major environmental organizations have millions of members and large budgets from contributors.

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12

Managing Infrastructure in the Water Industry

The picture we get of urban water infrastructure is one of a vast system with a giant number of aging parts. The picture is actually bleak when it comes to future prospects to improve the system integrity, which is graded very low by the American Society of Civil Engineers' Report Card. Given the many public investment needs in the United States and the fact that buried infrastructure is not an attractive investment to politicians, how in the world will we be able to manage proactively so as to avoid a ticking time bomb of future crises?

There is, of course, no single answer to this vexing dilemma. Mantras such as to "do more with less," or "kick the can down the road," or "just keep getting by" are not satisfactory when we seek clean and effective solutions. It seems like a messy problem without a clear path to solution, but it is not so different from many other tough public sector problems. A few you can think of would be to upgrade public education, to provide health care, or to reform the welfare system. Thinking of it this way, we see a brighter road ahead in that we have a tough job, but by applying management's best skills and the resources available, we can create a future that works. That is the job of water managers in the 21st-century water industry.

Of course, managers face many difficult situations, and they will have to keep doing more with less as things continue to change and require different skills than in the past. Doing more with less is tiresome, but the phrase explains how managers must multitask and continually take on more and different responsibilities. In this chapter we focus on how managers can face this challenge to get the most from their infrastructure capital assets by emphasizing effective and proven management principles. The chapter also identifies the main trends and future issues facing utility managers.

The stage was set for the discussion by Chapter 1, which listed some best practices for asset management. The remaining chapters were designed to range through the most important management issues relating to infrastructure and to cover:

- System configurations, management structures, regulatory controls, interest groups, and trends for urban water systems
- Asset management
- Planning, programming, and budgeting, including life-cycle planning and capital improvement programs

- Quality in construction, project management, and control of the construction process, including design and working with engineers
- Financial management topics, including organizations, revenue and cost management, accounting, and reporting
- Operations, comprehensive improvement programs, operator training, and quality control
- Risk management, disaster preparedness, vulnerability assessment, mitigation, and reliability
- Maintenance management
- Information technology, SCADA (*supervisory control and data acquisition*), databases, information technology (IT), and accounting for fixed assets
- Legal, regulatory, and governmental processes

These topics provide a good background to focus on the core management processes needed to ensure quality infrastructure.

Management in the Public Works and Utility Environment

Many management skills required for utilities are similar to those in other industries. They require planning and directing the use of resources to get the job done and achieve the purpose of the organization. Private or public enterprises require the basic tasks of management: planning, organizing, directing, supervising, and controlling people, machines, and facilities. Peter Drucker (1976), a famous management expert, showed how, during the 20th century, application of the skills we call management has been the main factor behind our ability to run today's complex society, including both public sector and private organizations. His words still ring true.

However, the public works and utility organizations are in a highly regulated, capital-intensive industry that is largely controlled by governments. This creates an overlay on top of regular responsibilities and requires managers to deal with risk and public involvement in ways that are different from private businesses.

The context for infrastructure is set by the concept of life-cycle management, which was illustrated in Figure 1.3. This is similar to management models in any business with capital-intensive and regulated facilities. That is, the infrastructure in urban water systems is conceptually like those in manufacturing, energy utilities or corporations, and other capital-intensive industries. The difference is the vast scale and dispersed nature of the water systems.

To prepare for their tasks, some infrastructure managers were educated as engineers, and others enter the field from vocations such as construction

or operations. Whatever their starting point, after they become managers, the lines are not always clear between their former occupations and their current management activities. Engineers still dominate the employment in water utilities, and evidence shows that civil engineers work relatively more in management than other engineers do. A survey showed that 45% of civil engineers identify management as their top activity, followed by 39% mentioning design and 20% mentioning computer applications (Burton, Parker, and LeBold, 1998). This seems due to the many roles as manager the civil engineer assumes—project manager, utility or public works manager, manager in a consulting firm, and so on. Consequently, practicing engineers continually tell educators to teach more business skills.

Advice about what to teach engineers comes from practitioners such as Bergeron (2001), who wrote that failure in management knowledge leads to lost or upset clients, unprofitable projects, missed deadlines, disgruntled fellow employees, and maybe loss of job. He believes that young engineers are not adequately prepared in management, but skills can be taught at senior or graduate levels. Using Bergeron's examples, and advice we received at my university about what students should learn, I compiled the list of management topics in Table 12.1 that should be taught.

TABLE 12.1

Examples of Problems and Disciplines to Be Taught

Examples of Problems	Disciplines to Be Taught
Write scope of work; track progress, misses deadlines for drawings and specifications; behind schedule; runs over budget; schedule flow of work; coordinate with subconsultants	Project management Contracts Scheduling, checking progress Inspections, quality control
Unsuccessful bidding, no backlog of work, unprofitable projects; prepare fee budget; assemble project team	Marketing Proposals, contracts, negotiating fees, scheduling, accounting, tracking and reporting overruns and changes in scope Project teaming
Not handle employees well; city engineer has employees quit, file grievances	Communication and human resources Verbal and written communication Hiring, firing, motivation Women and diversity Equal opportunity, legal issues
Make presentation to client	Communications, presentations
Paying liquidated damages	TQM and loss prevention Liability insurance and causes of lawsuits
Failed to understand preservation issue	Ethics Government Legislation and law Regulatory controls Nonengineering issues

The Big Picture

Managers must understand the big picture of how organizations work and have a systems view. For infrastructure, the effective use of enterprise software is an example of taking a systems view, which means to look at how the entire organization works together to use its physical assets to achieve its mission in the face of external pressures. Enterprise applications of software help in operations and asset management by sharing information across the organization (see Chapter 10).

The value of the systems approach is widely accepted in management, but organizations are often too complex to embrace it totally. The essence of it is to integrate activities or to achieve integration, as described in AWWA's publication, *The Changing Water Utility* (Westerhoff et al., 1998). This book presents the views of experienced managers, who see the need for change if utility managers are to succeed in the future.

The systems view will also help in emergency planning and response. For example, McMullen used systems thinking as a metaphor to write about communication and teamwork during the response by Des Moines's waterworks to the 1993 flood (see Chapter 8). Systems thinking is a popular metaphor for looking at the big picture and considering interdependency. When you view the overall physical and organizational systems of water, wastewater, and stormwater utilities, you are doing systems thinking.

Systems thinking involves process modeling and conceptual thinking. For water systems, process modeling works at the subsystem level to model source, treatment, distribution, and collection systems. Higher level, conceptual approaches are used to frame general strategies. The approach requires a coordinated study to tell all parts of the organization what to do. For example, an emergency plan is a systems approach to planning and coordinating activities for emergencies. However, creating the climate where all units can work together effectively is not an easy task. It cannot be done using only top-down or bottom-up methods; it must be done both ways using adaptive management. While the theory of the systems approach is simple, implementing it can be difficult.

As organizational systems, water, wastewater, and stormwater utilities engage in intra- and interorganizational activities. Organization charts do not display an organization's activities very well, and many attempts have been made to portray cross-cutting organizational activities. The simplest tool to show this is probably the matrix organization, where you have not only line and staff, but also project organization.

An example of new thinking about organizations is the Organigraph concept, which involves tools to display the activities of organizations realistically. It consists of product "chains"; "sets" of objects that include constituents, organization units, programs, employees, work schedules, facilities, and support systems; "hubs," which are centers of activity; and

FIGURE 12.1
Customer service outlet of the Washington Suburban Sanitary Commission.

"webs" of relationships or interdependencies (Mintzberg and Van der Heyden, 1999).

Business process areas of a water utility have been mapped by the QualServe program offered by AWWA, which was explained in Chapter 7. This follows an approach to map business processes to improve effectiveness. For example, customer service is a business process. Figure 12.1 shows a customer service outlet of the Washington Suburban Sanitary Commission in Maryland.

Teamwork and communication are important to the big picture, such as how organizations respond to disasters. They ensure that organizations are prepared, work well as a unit, execute their missions well, and cooperate well with other organizations.

Information technology is an aid to systems thinking. For example, communication can be facilitated by the decision-support system concept. Decision makers ask questions and get answers about problems by dialog with the decision-support system, which can query databases and run simulation models, such as in SCADA systems (see Chapter 10).

Business Practices Affecting Infrastructure

As Bergeron (2001) explained, many engineers are unaware of effective business practices, such as running organizations, making them productive, and keeping them out of trouble. Obviously, if the organization doesn't run well,

the infrastructure will not be in good shape. A starting point is to know about the organizational structure of utilities. A good structure will release the capabilities of employees for maximum performance, minimize the need for reorganizations, serve as a foundation for professional development, and promote effective performance.

Organizational theory shows interactions of organizational structure, people, and psychology, with communication and coordination being key concepts. The structure should communicate the purpose and specify leadership, authority, subdivisions of responsibility, and communication patterns. Variations of organizational types include line-and-staff and matrix organizations. Other variations include functional organizations and programmatic organizations.

Communication is even more important than structure in organizations. Problems include lack of contacts between persons working on similar projects, conflict between sections of organizations, and problems with the public. Many people don't like meetings, but one reason for them is to work as a team. Meetings should have a definite purpose and be run well so that people's time is used productively and not wasted. A few guidelines on effective meetings are to have a goal and agenda; include presentations to summarize known information; start on time and conclude crisply; have a facilitator or chair, not always the boss; have someone record the results; and end with results and after-action plans.

Human Resources Management

Employee motivation is critical, especially when dealing with a long-term and hard-to-measure goal such as infrastructure integrity. Industrial psychology explains motivational factors such as design of work, influence and power, communications, decision processes, and performance evaluation. Figure 12.2 illustrates a way to improve employee morale by celebrating their work through art. The figure shows a statue at the Washington Suburban Sanitary Commission of workers opening a water gate.

Teamwork helps in employee motivation and effectiveness. Teams work together toward a common vision and focus individual effort toward organizational objectives. Team members need to be held accountable for their actions.

Good employees are the key to success, and preparing the caring for them is the subject of the field of human resources or HR. HR supports managers in finding, hiring, assigning, and managing employees. It used to be called personnel management, but with expanding arenas of professional development, employment and workplace law, and employee relations, the scope of the field has expanded (Grigg and Zenzen, 2009).

HR seeks to make relationships between people better. This involves coworker relationships as well as worker-supervisor relationships. Conflict may signal ill health in the organization. It offers work-planning systems to break jobs into tasks. Tasks are organized according to functions to avoid

FIGURE 12.2
Sculpture of utility workers opening a water gate.

duplication and confusion. Jobs lead to accomplishment of the mission. The effectiveness of employees determines success.

Work in jobs is planned and evaluated according to a cycle. This approach is sometimes called *management by objectives*, but it has other names. Objectives for a job or unit should be negotiated. This can be done annually or more often, with success connected to pay increases and other incentives. After plans are made and tasks assigned, coaching and motivating by supervisors is required.

Evaluation is necessary for everyone. Even the chief executive of an organization is evaluated by the board of directors. Evaluation is followed by rewards, promotion, and recognition. Then it is time to set new goals. This cycle of planning, coaching, evaluating, and recognizing is fundamental to human resources management.

Legal issues in HR have increased. Employee and workplace law has become a specialty area among attorneys. They deal with hiring, firing, compensation, harassment, and many other issues. Some categories of people, mainly based on race, gender, age, and disability, suffered discrimination in the past, and the goal of equal opportunity law is to cure this problem.

Strategic Planning

Strategic planning is a useful method to develop strategy for organizations. It is a structured process to identify directions and prepare a plan of action to move toward them. A strategic plan will outline goals, objectives, measures of achievement, plans of action, needs and resources, and development plans. For example, improving infrastructure might be a key strategy within a larger organizational strategic plan. As organizations have become more sophisticated, they integrate their infrastructure planning with other goals and objectives and seek "triple bottom line" (TBL) approaches to strategy. A TBL approach considers economic, social, and environmental factors together.

Project Management

Project management (PM) is the skill area to bring quality capital projects online, on time, and under budget. It is discussed in more detail in Chapter 5. As an area of management, PM is often the place where a technical employee gets a first taste of handling people, money, deadlines, and other management concerns.

Risk Management and Loss Prevention

Risk management is an important issue for water, sewer, and stormwater utilities, and is discussed in more detail in Chapter 8. Risk is tempered by margins of safety, design factors, insurance programs, performance bonds, and other instruments for risk management. Engineers working in private practice find they must carry liability insurance to protect themselves against financial loss.

Decision Making

Managers must make quality decisions on a timely basis and see that they are implemented effectively. Use of information to support decisions is important at all levels. Decision processes connect parts of organizations, because decisions affect levels and parts of organizations with dissimilar functions but with needs for the same information. This is where the concept of the decision-support system enters the picture. Chapter 10 discusses the emerging use of IT in decision support.

Often the challenge is to handle unstructured management problems, where flow charts and logic are not applicable. Unstructured problems require more experience, judgment, and analysis than structured problems. The capital planning process may involve unstructured situations, often political in nature.

Program Assessment and Management Audits

Just as in a financial audit, a management or performance audit can identify ways to improve effectiveness. Management consultants can be used for this task, and a team can visit an organization to assess purpose, customers, goals, procedures, and results. It is amazing how outsiders can bring insight to the operation of a program that insiders understand but take for granted. A management audit is like an annual review of an employee, but for an organization. Methods can include visits, interviews, surveys, inspections, review of documents, financial studies, and other tools available to management to assess performance. The QualServe program (see Chapter 7) is an example of a management audit and could be applied to sewer and stormwater organizations, just as it is to water supply organizations. In fact, APWA has also developed an organizational assessment program.

Quality Management

Management can improve from quality control programs such as Total Quality Management or TQM. The concept of quality control has expanded into a wider view of quality in all aspects of management, with the goal of continuous improvement. One writer wrote about TQM that

> Product is the focal point for organizational purpose and achievement. Quality in the product is impossible without quality in the process. Quality in the process is impossible without the right organization. The right organization is meaningless without the proper leadership. Strong, bottom-up commitment is the support pillar for all the rest. Each pillar depends on the other four, and if one is weak all are. (Creech, 1994)

Quality control (QC) means to ensure that the quality of a product or service is within acceptable limits. Sometimes the term *quality assurance* is used in place of QC. Tasks that are essential to quality control include inspection, administration and record keeping, quality control engineering, and gauging. QC is important in infrastructure, especially in construction, as original condition is the single most important determinant of long-term condition. QC functions are also easy to see in a treatment plant that must meet regulatory requirements. Another example would be in stormwater, where, if the goal is to prevent a level of flooding, the quality indicator might be absence of complaints.

Public Involvement, Marketing, and Customer Relationship Management

A utility is closely connected to customers and the public. The public should be involved in decisions and levels of service in appropriate ways. Public

involvement situations include water and sewer education for the public, dealing with crises, and support for capital campaigns and other decisions.

Public involvement is the process of including the public in planning and decision making. Creighton (1981) defined it as "a process, or processes, by which interested and affected individuals, organizations, agencies and government entities are consulted and included in the decision making of a government agency or corporate entity." Creighton traced government-required public involvement to the War on Poverty in the 1960s and the environmental legislation of the 1970s. As a result, requirements became institutionalized. Of course, it always made sense as a practice of democracy to involve people in decisions that affect them. Creighton wrote from the viewpoint of someone who had been "bloodied" in the process (by that, he probably means he has been in a lot of divisive public meetings). The goal is to present people with information and alternatives in language they can understand, and then to involve them sincerely in improving understanding of problems, of defining solutions, and in deciding what to do. That does not mean that everyone has to agree 100% with everything—they never will. It means to involve them, and then to make the best decision considering all points of view.

If the public consists only of influential citizens who have a financial stake in a decision, that is not enough. If it only consists of representatives of interest groups who are loud and visible, that is not enough. The public should be defined to include all stakeholder groups, by virtue of proximity, economic stake, use, social concern, or value systems, as with environmentalists.

There are many guides about public involvement—mostly government manuals and articles in journals such as the journal *AWWA*, which attracts people who are responsible for it. Public involvement begins with neighborhood meetings and proceeds to more formal presentations before elected boards and commissions.

Marketing offers methods for public involvement. While the term is used mainly in the for-profit world, it also applies to government and nonprofit organizations. Marketing includes a spectrum of activities, not sales alone. It begins with identification of the market and customers and the products or services they want, then proceeds through product and service development, pricing, promotion, advertising, selling, and distribution. Public relations is a support field that includes identification of target audiences, use of media to achieve objectives with them, and work with organizations to achieve objectives. A few techniques used in public relations are news releases and media relations, feature articles, newsletters, annual reports, special-events coordination, celebrity speakers, fliers, invitations to events, and other advertising materials such as posters and signs. Advisory committees and public meetings are used for some purposes.

Management in a Government Environment

The business practices just described apply across the board to organizations, but for utilities, government is for the most part the industry in which they must perform. People are ambivalent about government. Without it, society would grind to a halt. On the other hand, government sometimes gets in the way. Government is the owner of public works or civil works, which is a term some people prefer in this era of emphasis on privatization. Without civil works, civilization could not exist for long, at least in an advanced form, and civil works require that government at all levels and engineers be involved in planning, financing, constructing, operating, regulating, maintaining, and renewing them.

Administering public organizations is the subject of the academic field of public administration. The American Society for Public Administration (ASPA) offers a view of this field, which seeks to advance the art of managing public organizations by focusing on topics such as political science, administrative law, decision making in government, and other issues of public sector concern.

Government must obtain the consent of the citizenry in its work, at least in democracies. In any form of government except democracy, civil facilities do not seem to work as well. Even if it seems messy, democracy seems to be the best management framework for public works, as it is for other areas of public affairs. This is why public involvement is so important. Civic engagement is important to nurture democracy and trust in government in the United States, and public works is an ideal way to make it happen. Without civic engagement, social capital declines, and the overall health of society goes down. So, the public involvement required for public works and infrastructure is a healthy activity for a functioning democratic society.

Client groups for infrastructure range from the elderly with an interest in Social Security to environmentalists who lobby for wastewater plants. At the local level, developers watch the budget process to see what they must pay for infrastructure. The antigrowth forces want these fees to be high, of course.

Students learn about the form of government in school, but most people have a limited view of it. Government is complex, including many different functions, levels, locations, and other characteristics. The United States is a federal republic, or a nation of states held together by the federal government. It is also a representative democracy, meaning that the people rule, through their elected representatives. The government has three branches—executive, legislative, and judicial—and all three exist at the national (federal), state, and local levels. The representative government is important because utilities work directly with the people in public involvement, but also with representatives, legislators, and congressmen to make decisions.

In the executive branch, you can trace relationships between similar agencies across the three levels. Local government agencies have functions

oriented to meeting local needs such as infrastructure, police, fire, and local services. These have related agencies at the state and federal levels. For example, the local water department is regulated by the state health department (or equivalent), which is overseen by the U.S. Environmental Protection Agency (USEPA).

The work of public agencies is largely carried out by officials and workers who have been selected through a civil service or merit system. Elected officials also participate, as do appointed officials who are part of the political component of government, as opposed to the career civil service or bureaucracy. Thus, utilities work with three categories of public officials: elected, appointed through the political process, and appointed through a merit system. These categories of public officials respond to different incentive systems, and it is well to understand how they got their jobs and what they must do to keep them, or to advance.

Basic processes of government and political institutions include voting, the role of citizens, the legislative process, and the roles of public officials such as mayors, police officers, and judges. Voting is an important right in the United States and, in addition to voting for representatives, citizens increasingly have the right to vote on specific civil works projects. Utilities may be involved in campaigns to gain approval of a project. With the trend toward direct democracy, we expect more, not less, of this in the future.

Regulation of projects is a function of government. The big shift in work has been from an emphasis on just building projects to a more complex role that includes much more regulation. Projects are regulated by all three levels of government, and most regulations are in the categories of land use, environmental, health, and financial limitations.

Government is also involved in project financing, especially for large and public projects. A few ways that government is involved include: government budgeting, issuing bonds, public utility controls, state infrastructure banks, taxes and fees, government appropriations, government accounting, financial policy, and regulation of privatization.

When does government end and politics begin? Water projects involve convergence of powerful political forces. Politics has shades of meaning—from the science of government to using intrigue to maneuver within a group. Given that the purposes of government are to provide for the rule of law, for the processes of government, for services needed by citizens, and to keep order, it is natural that political issues will intrude into work arenas.

A way to view politics is as a group of agendas—those of individuals, interest groups, political parties, and stakeholders in general. Individuals and groups seek what they consider as favorable outcomes in public decisions such as where road improvement funds are spent, whether a water project is approved or not, whether taxes are raised, or even whether they are elected to office. The individuals or groups then use influence to improve their chances of gaining the outcomes they seek, and the total result is "politics."

Some of the political issues the civil engineer must consider include the influence of political campaigns on projects, the motivations of elected officials, the roles of lobbyists and interest groups, and the use of associations to influence policy. How public officials get their jobs—elections, political appointments, or civil service—illustrates the motivational factor.

Perhaps the politics faced most often by utilities is that of interest-group politics, where groups promote or oppose a particular action being worked on by the engineers. Growth and environment issues that civil engineers commonly face fall into this category. Typical issues include NIMBY ("not in my backyard") opposition to any plan and "no growth" issues. Regional competition is another example. The situation may even become one of ethics—does the civil engineer promote the project, and one or more interest groups—or does he or she remain completely objective and represent all sides?

There are other places where politics enters life, of course, such as in bureaucratic, organizational, or office maneuvering, but these are not the subject of this chapter on government. What we might say is simply that relationships and lining up support for your ideas and points of view are important in everything you do. Sometimes people define this as "politics," but it is not a negative thing at all, as long as you are ethical, aboveboard, and free of conflict of interest.

Government decision making is often characterized as incremental because each step is built on the previous one, as opposed to being a dramatic, large change in direction. Incrementalism sometimes frustrates engineers who like to set goals and move directly toward comprehensive solutions and reforms. In fact, people who are "politically aware," or think they are, are sometimes contemptuous of engineers who, they believe, are naïve and only tuned in to technical topics.

Budget politics are of concern to managers at all levels of government, especially those involved in infrastructure, where so much money is involved. In any organization, the budget becomes the focal point where agendas are worked out with internal competition. For the U.S. budget, this competition takes on global dimensions. Basically, budget politics involves the triangle of interest groups consisting of agencies, politicians, and public interest groups. The interest groups work through the agencies and politicians to try to get budget resources invested in their favorite areas. For example, at a simple level, a group wanting a street paved (interest group) may see the city engineer (agency), who may want the street paved also but lacks the budget, and then see their elected representative, who may advocate putting that item in the city capital budget, and through this triangle of interests, the project may get done.

This can be illustrated for investments in infrastructure by the triangle shown in Figure 12.3, which shows how water utility governance is affected by the political process (legislators and politicians), by interest groups and businesses, and by the actions of the water utilities themselves. All parties

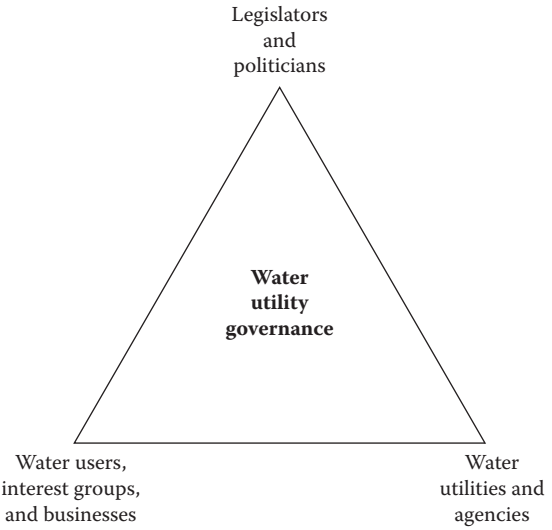

FIGURE 12.3
Iron triangle of water utility decisions.

working in tandem determine outcomes of decisions such as how much to invest in renewal of infrastructure.

Political issues in budgeting start with the agency's roles and expectations and in deciding how much to ask for and how much to spend. Then, there is competition within agencies for permission to request budget amounts, the departments versus the bureaus. The budget office has a strong role in deciding how much to recommend, and then, in the legislatures, the appropriations committees have roles and perspectives in deciding how much to give and how to respond to client groups.

Policy analysis is concerned with finding the right policies and is the aspect of planning concerned with steering big decisions correctly. The term *analysis* means to divide something into its component parts; it is the opposite of *synthesis*, which means to combine them. Thus we find many uses of the term *analysis*—mathematical analysis, chemical analysis, engineering analysis, and now, policy analysis.

Basically, policy analysis is the application of the problem-solving process to finding the best policies to implement. To do this requires us to break the problem addressed and the possible policies into their separate elements. Policies are basically courses of action in relation to particular issues. In a legal sense, they have a position in the hierarchy of rules and regulations. A company policy is a rule lacking the force of law but is still an important guideline. The field of social science has a large subdivision called the policy sciences, generally being those concerned with government and public matters.

In infrastructure, policy analysis means the analysis that is done to find lines of action for broad issues. Should the water supply be found independently or in concert with a regional agency? Should the solid-waste utility be privatized? How should the capital program be financed? What strategies should be employed to solve the community's mass transit problems? These are examples of matters that require policy analysis.

The International City Management Association has a guidebook on policy analysis in local government. In it, policy analysis is presented as a "systems approach to decision making." There are four essential features according to the author: the systems approach, the use of the scientific method, the use of mixed teams (interdisciplinary approach), and an action orientation. In this sense, policy analysis might be thought of as a variation of systems analysis (Kraemer, 1973).

Leadership Issues for Infrastructure Managers

Given the difficulty in infrastructure management, it takes more than business as usual to get the job done. The utility manager is not an elected official but still has a big leadership role in the public arena. Leading thinkers and writers have much to say to public sector managers about their responsibilities. One leading thinker, Peter Drucker, has contributed many articles and books about managing both the private and public sectors. Magretta and Stone (1999) wrote how he crystallized the discipline of management with his seminal text *The Practice of Management* in 1954.

Drucker (1976) called management the "least understood of social institutions." He thought that, with management knowledge, ordinary people and organizations could achieve better results. Consider that before 1900, 80% of people worked on farms or with their hands. Now, knowledge workers engaged in technical and professional specialties comprise the largest group of workers, and new management challenges occur continually. He also focused on the nonprofit sector, where "systematic, principled, theory-based management can yield results."

Drucker is famous for articulating the important or organizational purpose. He asked: What is our business? Who is the customer? What does the customer value? This became the "theory of the business." Drucker defined the challenge of the 21st century as raising the productivity of knowledge workers, including those in public works. Drucker helped us see that the quality of our lives and our society depends on the quality of the organizations we build, including public sector infrastructure organizations.

Bill Miller (1992) was a practicing public sector manager who wrote *Miller on Managing* to report on his service as manager of the Denver Water Department. Miller focused on the softer side of management; that is, he

sees it as leadership, communication, relationship building, compliance with law, integrity, and organizational management. By combining concepts from management writers such as Drucker and Miller, the infrastructure manager can form a successful strategy.

For example, decision making in public organizations can be structured or unstructured. Most operational decisions in water utilities are structured in nature. Operating decisions, as opposed to policy decisions, are subject to more definable rules, usually on a shorter time span, more repetitive, simpler, less risky and uncertain, and based more on knowledge of operational data.

Decisions are linked with organizational plans, activities, and tasks. An integrated information system seeks to link business to information flows and databases. One of the key issues in disaster preparedness is linking databases, and another is preserving data through a disaster.

Business system planning begins with a definition of the business, followed by delineation of business processes, independent of position on the organizational chart. These are related to data, which are also independent of the organizational structure. The matrix that relates the business processes to the data classes is the information architecture of the organization, which identifies key decision points and relates them to data.

All organizations depend on the skills, leadership, and character of their workers and managers. In addition to finding and hiring the right people, utilities will find professional and personal development programs valuable for employees. Young employees have a lifetime of development ahead, with education being the beginning, not the end, of personal development. Older employees have many needs too.

Figure 12.4 shows a leader of the water industry, Dr. Abel Wolman. His work in helping create the Washington Suburban Sanitary Commission is celebrated by a statue in his honor at the utility. Dr. Wolman also has a public works building named after him in Baltimore, and an award from AWWA is dedicated to his work.

The art of leadership fascinates many people, and the difference between management and leadership is often discussed. When confronted with problems, people say, "What we need is strong leadership." The difference between leadership and management is that the leader gets people to follow, and the manager runs things with delegated authority. While leadership cannot be easily taught, studying it can help a manager make a leadership self-assessment. Leadership qualities include many desirable qualities, such as integrity, knowledge, courage, decisiveness, emotional balance, and sociability.

One of the helpful aspects of management is the opportunity to be involved with leadership figures from the community, professional societies, other businesses and organizations, and nonprofit groups. To become involved with them, it is well to be involved in civic and business activities such as the chamber of commerce; service clubs such as Rotary, Lions, and Kiwanis; and professional societies.

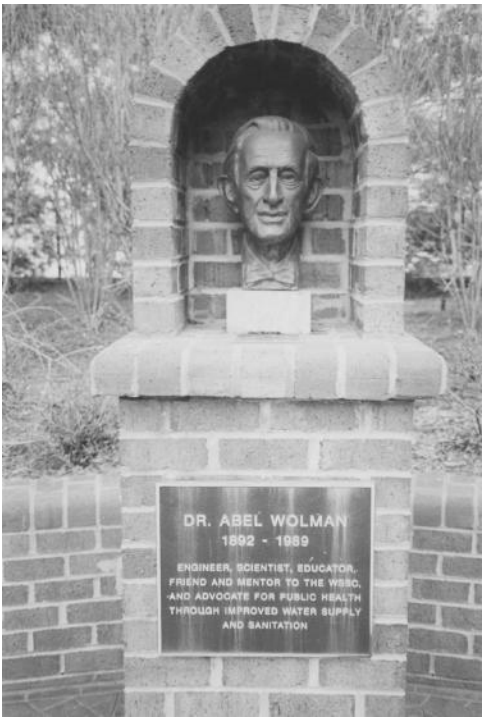

FIGURE 12.4
Memorial to Dr. Abel Wolman.

The American Water Works Association helped to spin off a humanitarian nonprofit called "Water For People." They are "a nonprofit, charitable organization in the United States and Canada that helps people in developing countries obtain safe drinking water…" and they "…work with local partner organizations to provide financial and technical assistance to communities, depending on their needs" (www.water4people.org).

For today's competitive society, the concept of the "learning organization" explains that organizations, like individuals, can learn by experience and become better and more competitive. Peter Senge's (1990) book, *The Fifth Discipline*, explains the concept in terms of five disciplines—shared vision, personal mastery, mental models, team learning, and systems thinking.

Ethics is important in water, sewer, and stormwater organizations. While knowing about codes of ethics is important, good character traits are ultimately the key to success. A good example of this issue is in the quality of construction. If shoddy construction work is accepted, or corrupt practices are involved, then water, sewer, and stormwater systems will ultimately suffer.

This chapter has brought together a number of management concepts needed for today's public sector organizations, which, after all, must work

well for infrastructure systems to have integrity. After all, people using resources determine the outcome of all ventures. The tools of management described in the book—such as asset management, capital improvement programs, and maintenance management systems—only work as well as the people who implement them. And financial tools consisting of debt instruments, rates and fees, budgets, and accounting are there to promote customer service. Ultimately, it is how well customers and their society are served that determines how well we do in managing infrastructure.

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Appendix A: List of Acronyms

ABC	Association of Boards of Certification
ACEC	American Council of Engineering Companies
ACSM	American Congress of Surveying and Mapping
ADR	Alternative dispute resolution
AIDIS	Inter-American Association of Sanitary Engineers
AMI	Advanced metering infrastructure
AMR	Automatic meter reading
AMS	Asset management system
AMWA	Association of Metropolitan Water Agencies
ANSI	American National Standards Institute
APA	Administrative Procedure Act
APDS	Alternative product delivery system
APWA	American Public Works Association
ASCE	American Society of Civil Engineers
ASDWO	Association of State Drinking Water Officials
ASIWPCA	Association of State and Interstate Water Pollution Control Administrators
ASPA	American Society for Public Administration
ASPE	American Society of Plumbing Engineers
ASR	Aquifer storage and recovery
ASTM	American Society for Testing and Materials
AWWA	American Water Works Association
AwwaRF	AWWA Research Foundation
bar	Barometric pressure (1 bar = 10.2 m of pressure)
BFO	Budgeting for outcomes
BIM	Building information management
BMP	Best management practices
BOT	Build-operate-transfer
C^3I	Command, control, communications, and intelligence
CAD	Computer-aided design
CADD	Computer-aided design and drafting
CAFR	Comprehensive annual financial report
CBO	Congressional Budget Office
CCTV	Closed-circuit television
CFR	Code of Federal Regulations
CIKR	Critical infrastructure and key resources

CIO	Chief information officer
CIP	Capital improvement program
CIP	Cast-iron pipe
CIPP	Cured-in-place pipe
CML	Cement mortar lined
CMMS	Computerized maintenance management system
CMOM	Capacity, management, operations, and maintenance
COTS	Commercial off the shelf
CPA	Certified public accountant
CSI	Construction Specifications Institute
CSO	Combined sewer overflows
CWA	Clean Water Act
CWNS	Clean Watersheds Needs Survey
CWS	Community water systems
CWSRF	Clean Water State Revolving Fund
CWSS	Community Water Systems Survey
D&C	Design and construction
DIP	Ductile iron pipe
DIPRA	Ductile Iron Pipe Research Association
DSS	Decision support system
DWSRF	Drinking Water State Revolving Fund
EBMUD	East Bay Municipal Utility District
EJCDC	Engineers Joint Contract Documents Committee
FAF	Financial Accounting Foundation
FASAB	Federal Accounting Standards Advisory Board
FASB	Financial Accounting Standards Board
FBI	Federal Bureau of Investigation
FEMA	U.S. Federal Emergency Management Agency
FM	Facility maintenance
FTE	Full-time equivalent
GAAP	Generally accepted accounting practices
GAO	U.S. Government Accountability Office
GASB	Government Accounting Standards Board
GFOA	Government Finance Officers Association
GIS	Geographic information system
GITA	Geospatial Information and Technology Association
gpcd	Gallons per capita per day
GPRA	Government Performance and Results Act
GPS	Global positioning system
HAZMAT	Hazardous material

HDPE	High-density polyethylene
HMI	Human–machine interface
I&I	Infiltration and inflow
ICS	Incident command system
IFMA	International Facility Management Association
IRP	Integrated resource planning
ISAC	Information sharing and analysis center
ISO	International Organization for Standardization
ISO	Insurance Services Office
IT	Information technology
IWA	International Water Association
LAN	Local area network
LCR	Lead and Copper Rule
LIMS	Laboratory information management system
MCDA	Multicriteria decision analysis
MCL	Maximum contaminant level
MD&A	Management discussion and analysis
MFOA	Municipal Finance Officers Association
MG	Million gallons
MMIS	Maintenance management information system
MMS	Maintenance management system
MS4	Municipal separate storm sewer system
NACWA	National Association of Clean Water Agencies
NAFSMA	National Association of Flood and Stormwater Management Agencies
NARUC	National Association of Regulatory Utility Commissioners
NASSCO	National Association of Sewer Service Companies
NAWC	National Association of Water Companies
NCGA	National Council on Government Accounting
NDT	Nondestructive testing
NEPA	National Environmental Policy Act
NFF	Needed fire flow
NFIP	National Flood Insurance Program
NIMBY	Not in my backyard
NIMS	National Incident Management System
NIPC	National Infrastructure Protection Center
NIPP	National Infrastructure Protection Plan
NPDES	National Pollutant Discharge Elimination System
NPDWR	National Primary Drinking Water Regulations
NPIC	National Infrastructure Protection Center

NPS	Nonpoint source
NRC	National Research Council
NTNCWS	Nontransient-noncommunity water system
NUCA	National Utility Contractors Association
O&M	Operations and maintenance
OMB	U.S. Office of Management and Budget
OMS	Operations management system
OSHA	Occupational, Health, and Safety Administration
PAHO	Pan American Health Organization
PB	Polybutylene
PE	Polyethylene
PI	Performance indicator
PIF	Plant investment fee
PLC	Programmable logic controller
PM	Preventive maintenance
POTW	Publicly owned treatment works
PPBS	Planning-programming-budgeting system
PPI	Plastics Pipe Institute
PRV	Pressure-reducing valve
PUC	Public utility commission
PVC	Polyvinyl chloride
QA/QC	Quality assurance/quality control
QBS	Qualifications-based selection
RO	Reverse osmosis
RRR	Repair, rehabilitation, or replacement
SCADA	Supervisory control and data acquisition
SDWA	Safe Drinking Water Act
SDWIS	Safe drinking water information system
SEC	Securities and Exchange Commission
SIMPLE	Water and Wastewater Sustainable Infrastructure Management Program Learning Environment
SSES	Sewer system evaluation survey
SSO	Sanitary sewer overflow
SWMM	Stormwater management model
TABOR	Taxpayer Bill of Rights
TBL	Triple bottom line
TCR	Total Coliform Rule
TG	Thousand gallons
TMDL	Total maximum daily load
TNCWS	Transient-noncommunity water system

UDFCD	Urban Drainage and Flood Control District
URISA	Urban and Regional Information Systems Association
USAID	U.S. Agency for International Development
USC	United States Code
USCDC	U.S. Centers for Disease Control
USDHS	U.S. Department of Homeland Security
USEPA	U.S. Environmental Protection Agency
USFEMA	U.S. Federal Emergency Management Agency
USFHWA	U.S. Federal Highway Administration
USGS	U.S. Geological Survey
USHUD	U.S. Housing and Development Department
USPHS	U.S. Public Health Service
VA	Vulnerability assessment
WaterRF	Water Research Foundation
WCD	Wastewater Collection Division
WEF	Water Environment Federation
WERF	Water Environment Research Foundation
WIDB	Water Industry Database
WISE	Water Infrastructure Standards Enhancement Committee
WSSC	Washington Suburban Sanitary Commission
WWTP	Wastewater treatment plant

Appendix B: Urban Water Infrastructure Research

This appendix provides a short summary of major sources of research information about urban water infrastructure. The background for it stems from my paper in the *Journal of the New England Water Works Association*, entitled "Water distribution systems: Six decades of research" (March 2010). The paper reviewed how understanding of water distribution systems has evolved and where technologies are heading. Major research reports about water supply infrastructure come from the Water Research Foundation (WaterRF), which is located in Denver, Colorado, and from the U.S. Environmental Protection Agency (USEPA). The WaterRF began in 1966 as a spinoff of AWWA, and it has now completed nearly 1,000 reports about infrastructure, management, water quality, and environmental protection. For many years it was known as the AWWA Research Foundation or the AwwaRF.

The USEPA (2011) research program is summarized at the website of the Office of Research and Development (see http://www.epa.gov/ord/). Over the years, the urban water infrastructure program has changed its name, but it is currently explained under the program for "Safe and Sustainable Water Resources," with projects focused on: (a) Ensure Water Quality and Availability (watersheds, coastal waters, estuaries, and other water resources) and (b) Promote Sustainable Water Infrastructure (management of the natural, green, and built water infrastructure by applying systems-integrated water-resource management approaches; producing, storing, and delivering safe and high-quality drinking water; and providing transport and use-specific treatment of wastewater and stormwater). From the USEPA website, the reader can get an overview of the research and find key reports.

Several other organizations have published extensive lists of infrastructure-related reports. These include the Water Environment Research Foundation (WERF, 2011) and U.K. Water Industry Research (UKWIR, 2011). Links to the websites of these organizations are provided in the references at the end of this appendix.

The following is a short list of infrastructure-related reports and projects from the Water Research Foundation. It is not intended as an exhaustive list, and the reader can search for additional reports at the WaterRF website (see http://www.waterrf.org).

Water Research Foundation Reports

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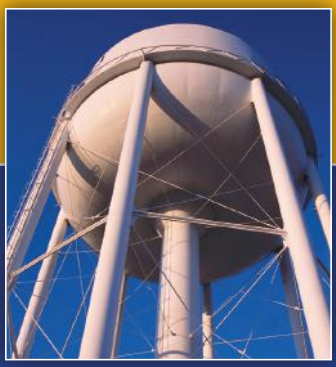
WATER SCIENCE, TECHNOLOGY AND ENGINEERING



Second Edition

Water, Wastewater, and Stormwater Infrastructure Management

"This is a well thought out and structured book. It is one that students can use to discover concepts and understand water system management, but it is also a reference that will stand them in good stead throughout their careers."

—Steve Whipp, United Utilities, UK

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