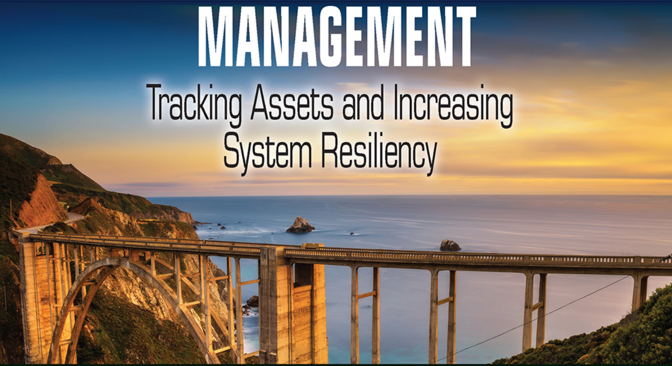
PUBLIC INFRASTRUCTURE MANAGEMENT

Tracking Assets and Increasing System Resiliency



Frederick Bloetscher, Ph.D., P.E., LEED-AP

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FREDERICK BLOETSCHER, PH.D., P.E., LEED-AP

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DEDICATION

This book is dedicated to my wife Cheryl Fox,
the love of my life. Thank you for being you!

CONTENTS

PREFACE

Training the next generation of infrastructure engineers, operators, and managers is a national priority. There is, however, a critical shortage of people educated and trained for the workforce required to build, operate, and manage the nation's infrastructure. Too often the tasks are left to those with field knowledge, but who lack the technical skills to assess, budget, manage, and argue to make repairs or replacement of critical infrastructure assets. To offset this shortage, we have seen the development of "STEM," or Science, Technology, Engineering and Mathematics programs at the high school and college level. The long-term growth and economic development of our society will rely on the ability to resolve challenges using these four key components of STEM education as they relate to the infrastructure systems that sustain our way of life. In addition to STEM programs is the continual need to think creatively when solving problems and to plan for problems before they even arise.

The intent of this book is to provide a comprehensive introduction to public sector infrastructure asset management at the local level. The infrastructure focus is on water and wastewater treatment systems, stormwater systems, and roadways, which is what most people use on a daily basis and is generally taken for granted until it fails. Typically, expenses required to operate, repair, maintain, and expand this infrastructure are too often deferred or artificially reduced to meet budget constraints by elected officials and budget managers. Unfortunately, there is a disconnect between the operational needs of the infrastructure system and the perceived budget realities. Both must be adjusted to maintain high quality infrastructure. Operations managers must develop tools to insure high quality assets are constructed, appropriate budgets to maintain them, and a means to assess future needs. Budget managers and elected officials must understand that the needs drive the budget, not vice versa. Otherwise, the deferral of maintenance will increase the risk of premature failure of the system which is always the most expensive to fix.

This text reviews the basic functions and maintenance of our critical infrastructure systems, while providing readers with an understanding of asset management. Chapter 1 is an introduction to infrastructure with a historical perspective. Chapter 2 will outline the economic benefits that investments in infrastructure can provide, based on peer reviewed literature. This chapter makes the case for why society should invest in infrastructure.

Chapters 3 through 6 will cover the infrastructure systems most commonly associated with local and state governments: water, sewer, storm water, and roadways. The chapters are designed to create a basic understanding of the system, how it operates, the major components of the system, and issues that will require maintenance attention (like corrosion, roadway base failure, etc.). Power and communication are not covered in this volume as they are generally owned by private providers which operate under different state and federal regulations.

Chapter 7 initiates a discussion of asset management—what it is and how to develop this type of system. The term "asset" can mean any physical component that makes up the type of infrastructure system being discussed. For example, water clarifiers at a water treatment plant are an asset, as are the pipes in the water distribution system. For asset management, an inventory of all assets within a particular infrastructure system must be developed. Once all the assets are inventoried, then the monetary values of the assets can be assessed, the condition of the assets assessed, the needs of the assets assessed, and then the resources to address those needs must also be assessed. The chapters following Chapter 7 outline how to develop this information. Chapter 8 includes a brief discussion about how to value infrastructure. Knowing valuation techniques will help managers and engineers shed light on financial needs of the system. Chapter 9 focuses on vulnerability assessments and risk management. This is not to say any public works official should make decisions based on the risk alone, but one should be cognizant of where potential vulnerabilities are and prioritize maintenance and repair to those assets that put the system at greatest risk. Chapter 10 outlines a means to evaluate the condition of an infrastructure system, even when parts of it are hard to access. This is a huge issue for water, sewer, and stormwater systems which have miles of buried pipe. Asset management, condition assessment, and risk management should lead to maintenance, repair, and replacement planning and funding, which is the focus in Chapter 11. Resources—money, skills, people, equipment, materials—all must be identified to develop a maintenance program. Chapters 12 and 13 will outline funding for maintaining infrastructure systems and life-cycle cost analysis, respectively, which is a useful tool for identifying when improvements should be planned.

Chapter 14 provides case studies associated with the failure of infrastructure systems (i.e., where things went wrong). Chapter 15 outlines future trends or challenges that infrastructure managers will face, beyond just the deteriorating condition of the assets themselves. These challenges include climate change and its effect on coastal infrastructure, as well as problems associated with actual water supply. Chapter 16 delves into the need for managers to provide leadership when dealing with infrastructure issues.

It is intended that people who read this book will (1) gain a very good understanding of infrastructure management and how important it is to the health, safety, and welfare of a community, (2) use the tools and resources discussed for managing infrastructure, (3) understand the need for infrastructure maintenance to ensure continuous operation of critical components, and (4) gain an introductory knowledge of fiscal constraints related to capital planning and construction of infrastructure systems.

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ABOUT THE AUTHOR

Fred Bloetscher, Ph.D., is currently a Professor of Civil, Environmental and Geomatics Engineering and Associate Dean for Undergraduate Studies and Community Outreach at Florida Atlantic University in Boca Raton, Florida. His research focus has been urban infrastructure systems, particularly public water, stormwater, and sewer systems and their sustainability. Dr. Bloetscher teaches the capstone senior design sequence at FAU, plus classes in water/wastewater, construction, environmental engineering and modeling, hydraulics, and infrastructure management.

Dr. Bloetscher received his bachelor's degree in civil engineering from the University of Cincinnati and earned his Master of Public Administration Degree from the University of North Carolina at Chapel Hill. His Ph.D. is in civil, environmental, and architectural engineering from the University of Miami in Coral Gables, FL. His experience prior to academia is helpful to his ongoing research and outreach efforts. He was a city manager for two communities in North Carolina that were undergoing significant infrastructure improvements. In Florida, he was a utility director and deputy director for several large water and sewer systems that included groundwater, aquifer storage, reclaimed water systems, wastewater plants, and miles of piping that needed to be maintained.

Dr. Bloetscher has many years of consulting experience as well. He is the President of Public Utility Management and Planning Services, Inc. (PUMPS), a company dedicated to the evaluation of utility systems, needs assessments, condition assessments, strategic planning, capital

improvement planning, grant and loan acquisition, inter-local agreement recommendations, bond document preparation, consultant coordination, permitting, and implementation of capital improvement construction. In managing both large and small infrastructure systems, and consulting for local governments, he has been involved in the construction of over $500 million in improvements—both new for expansion, and for replacement as “owner,” engineer, or project consultant.

Dr. Bloetscher has volunteered his time for many professional associations. He is the former Chair for the Water Resource Division Trustees, a member and 3-time Chair of the Groundwater Resource Committee, Chair of the Aquifer Storage and Recovery Sub-committee, and former Chair of the Education Committee for the American Water Works Association (AWWA). Currently Dr. Bloetscher is the chair of the Distribution Engineering and Construction Committee for AWWA and a former member of AWWA’s Technical and Education Council. He is the Vice Chair for the Florida Section of AWWA and has been the Technical Program Chair since 2004. He serves on several local committees. He is an LEED-AP, holds professional engineering licenses in 9 states, and operations licenses in water, wastewater, distribution, and collection systems. He has had a North Carolina General Contractor’s license for pipeline and small utility construction for over 20 years.

Dr. Bloetscher has been nominated for the “Distinguished Teacher of the Year” award a number of times by his students and has received three University-wide leadership awards including the prestigious “Presidential Award for Community Engagement” in 2018, received several national awards including the “Distinguished Educator Award” from the National Engineers Council in 2017, and has been recognized by the AWWA, the National Engineer’s Council, the Florida Section of AWWA, and the local chapters of ASCE for his contributions to the industry. In 2012, Dr. Bloetscher received the “National Council of Examiners for Engineering and Surveying (NCEES) Award for Connecting Professional Practice and Education” for his work on the Dania Beach Nanofiltration Facility, which is the first LEED-Gold water treatment facility in the world (see photo on page xv). Dr. Bloetscher was the LEED administrator for the project.

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Downloads for *Public Infrastructure Management* feature instructor materials for adopting professors, including a proposed syllabus for the course, PowerPoint lectures covering chapters in the book, end-of-chapter homework questions and answers, project ideas for the instructor, GIS data sets for students to do their own condition assessments, and sample final and midterm exams.

SECTION I

Infrastructure:
A Comprehensive Overview

1

HISTORY OF INFRASTRUCTURE

For the purposes of this book, infrastructure is defined as capital projects—things of significant value and long life. They are physical, as opposed to policy-oriented. Hence for the purposes of discussion, what is not considered infrastructure in this text, even though they may include physical components, are: information technology (the Cloud), financial institutions, health institutions, educational institutions, and any nonphysical assets. This is not to diminish any of these necessary portions of society, but the definition of infrastructure within this volume needs to be narrowed to better understand the essential systems.

INFRASTRUCTURE OVERVIEW

Dr. Brian Murray Fagan is a Professor Emeritus at the University of California at Santa Barbara. After graduating from Pembroke College in Cambridge, he used his degrees in anthropology to travel the world to study human prehistory. Dr. Fagan explained, at an American Water Works Association conference several years ago, that because he has studied water and drainage ditches across the globe, he can speak to the rise and demise of nearly every civilization in the past 5,000 years. In over 50 years of field studies, Dr. Fagan has studied more drainage ditches than anyone ever has. Based on those 50 years of study, he notes that the *development of civilization can be predicated, and its fate predicted, based on irrigation practices*. People need clean water to survive. For example, in studying the Middle East—specifically the ancient Babylonian cultures of 4,000 years ago in current day Iraq—he was able to explain the mystery of the sudden disappearance of the ancient city of Ur, one of the largest and most fabulous cities in the ancient world at the time (thought to have had a population of over one million inhabitants). The city is recorded in many ancient books, including the Bible, yet it disappeared almost overnight. Fagan surmised that the Euphrates River moved after a flood, and when it did, the drainage ditches no longer flowed as they had before, so the population rapidly dispersed, and the city fell precipitously into ruin. He suggested that the fate of the Anasazi tribes in the American southwest, a number of ancient Egyptian pharaohs, many island communities, and other civilizations from antiquity were predicated on the ability to construct infrastructure to convey water for irrigation and drinking. He makes the point that civilization relies on reliable water infrastructure to survive and thrive.

With adequate, reliable water supplies and the infrastructure to deliver it, agriculture can prosper, providing food for growing civilizations. Agricultural surpluses are available for trade, creating the need for merchants and commercial centers in the developing villages and towns. But with growth comes the need for additional infrastructure, including infrastructure for waste disposal, transportation for the movement and exchange of those goods and services being traded, public buildings for markets, and communication systems. The advent of the ability of humans to harness energy accelerated development and the growth of civilizations.

Today we live in an energy-based economy, whereby our modes of transportation, communication, and structures are unlike anything envisioned by the ancients. At the root of all modern societies is a series of infrastructure systems that provide clean water, waste removal, flood protection, energy, and transportation to facilitate the economy. Maintenance of these same systems is vital to the continued economic stability of these communities and their ability to compete in an increasingly developed world.

The difference between developed nations and those that are not developed basically comes down to the degree of infrastructure improvements that are constructed and maintained. The rise in Western Europe and the United States in the early 20th century can be traced to infrastructure investments. Many of these infrastructure systems are interconnected. Underground utilities such as natural gas, water, and sewer lines are buried beneath roadways. Roadways provide access to property and connect to other communities, rivers, and ports. Stormwater systems are designed to keep roadways passable and drain flood waters while limiting private property damage. Roadways convey stormwater along the curbs and gutters, while maintaining the continuity of traffic. Power and communication systems are often located on the same power poles along road rights-of-way or buried beneath them. The result is that these systems are interconnected and interdependent on one another.

There is a direct correlation between investments in infrastructure and economic growth (as will be discussed in Chapter 2). In more developed nations, reliable infrastructure leads to a higher quality of life that citizens enjoy and come to expect. Four hours without water a year will be long remembered by residents; yet it means the water was present 99.74% of the time, which is hardly a failing grade—unless 100% is your only acceptable rate of service provision. All it takes is one extended interruption in service for the fabric of society to begin to unravel. Ask any young person or business what happens when the internet is disrupted.

We have had more significant incidents. For example, in 2003 much of the northeast was blacked out due to a failure in a small part of the connected power grid, creating significant loss of productivity. Fortunately, the outage was short-lived, but public confidence was diminished, even being suggested by elected officials in Flint, Michigan, as one of the reasons for their desire to change water supplies and restart their own plant after 50 years, which subsequently led to the lead contamination problems there (as will be discussed in Chapter 14). New Orleans, Louisiana, was devastated from the failure of dikes during Hurricane Katrina. The city of New Orleans has not yet fully recovered; over 10 years after the storm, the population is half what it was in 2005. Billions of dollars were spent on dikes, property damage, utility repairs, etc., yet the city remains vulnerable to the next storm event. In Minneapolis, Minnesota, an interstate highway bridge failed due to lack of proper maintenance, prompting a nationwide study of bridge conditions. In Alamosa, Colorado; Flint, Michigan; and Walkerton, Ontario, public health was compromised by contaminated water systems due to a combination of errors and misjudgments by one or more of the operators, elected officials, managers, and regulatory staff involved in the management of those systems.

When infrastructure systems fail in a major way, the disruption of human life can be significant—not just in loss of life, but property, economic activity, and confidence in the governments that typically provide the infrastructure systems. Billions of dollars have been spent on these infrastructure systems (as will be discussed in Chapter 2), yet more needs to be spent, and many communities are not spending enough to prevent their overall deterioration. Trillions of dollars in economic activity are dependent on these investments working as intended. But failures will occur, and those charged with operating and maintaining our critical infrastructure must deal with pragmatic issues like funding limitations, material availability, changes in technologies, parts availability, personnel skill sets, assigned responsibility, and public expectations. The reality is that, for the most part, our infrastructure systems do function as intended as a result of the combined efforts of those who are dedicated to managing and operating the systems—which is a testament to those employees whose job it is to keep them running despite the challenges. The concern is that while these systems have long lives, they do deteriorate with the passage of time. National entities such as the American Society of Civil Engineers, the U.S. Environmental Protection Agency, and the Department of Defense have been assessing the state of U.S. infrastructure for decades, and their findings indicate that sufficient funds have not been allocated to keep infrastructure systems running optimally. The warning bells have been ringing for some time that this lack of attention will eventually impact economic growth and quality of life. The question is how to *fix* it?

INFRASTRUCTURE INVESTMENTS

It can easily be shown that progress in society depends on the presence and maintenance of physical infrastructure (as will be discussed in Chapter 2). Societies that invest in infrastructure are able to produce goods, develop trade markets, and even improve the life expectancy of their society. Improvements in sanitation and public health have allowed people to be more productive and live longer. The greatest health improvement in the 20th century was the disinfection of water where annual mortality to waterborne illness has been reduced from 1:100,000 to less than 1 in 15 million in developed countries. This combination has also increased life expectancy from just over 47 years, to well over 80 years (Center for Disease Control, 2012 via commons.wikipedia.org). Safer drinking water, better sewage disposal, and upgraded roads demanded by the automobile have also led to a general economic expansion throughout the 20th century and into the 21st century (the Great Depression and Recession aside). As a result of 20th-century investments in infrastructure, economic activity in the United States has increased from $400 billion/yr, to over $17 trillion/yr since 1900 (Isites.Harvard.edu).

While development of infrastructure systems has improved public health and facilitated economic growth, it should be noted that most infrastructure systems are related; in part because they are often co-located and work together, which is why they are designated as infrastructure *systems*. Infrastructure systems include:

- Water
- Sewer
- Stormwater
- Roads
- Other transportation modes (rail, air, ship, transit)
- Energy
- Communications

The first four infrastructure systems listed, plus rail, will be discussed in this volume. All are costly to install and require constant maintenance, but it is the failure to maintain, upgrade, improve, and rebuild them that leads to disruptions in economic growth. Thus, as infrastructure systems grow, the local economy grows because investments in infrastructure tend to benefit the local economy (see Chapter 2). Areas with more developed infrastructure systems find that their communities attract more people because the job opportunities are greater.

More precisely, at present, over 80% of people in the United States live in urban areas (Berg 2012), a figure typical of most industrialized nations. Energy usage grows as people move to urban areas because there is more industrial growth and more wealth created by industry. Thus individual income is higher and synergistic opportunities are greater due to a more diverse population when there is more modern infrastructure present. A recent U.S. Department of Agriculture study (USDA 2014) makes this point when it reports that:

- Rural areas grew 0.5% versus 1.6% in urban areas from mid-2011 to mid-2012
- Rural incomes are 17% lower than urban incomes
- The highest income rural workers (95th percentile) earn 27% less than their urban counterparts
- 17.7% of rural constituents live in poverty versus 14.5% in urban areas
- 80% of high poverty rate counties surveyed were rural
- All high income counties surveyed were urban

Social structure grows as industrialization increases because there are more people. The opposite is true when the state of the infrastructure is poor to nonexistent.

Need proof? Look no further than China, where investments in physical infrastructure have created large migrations of rural Chinese to the urban areas, which are among the fastest growing cities in the world. Major advances in technology and human development tend to occur in population centers (think Detroit for cars in the first half of the 20th century, Pittsburgh and Cleveland for steel during the same time period, and Silicon Valley for technology in the last quarter of the 20th century, etc.). People with ideas tend to migrate to urban areas, increasing the number of people and the proximity to each other. Universities, research institutions, and the like tend to grow up around these industries, further increasing the draw of talent to urban areas. However, when the infrastructure ages or is not maintained, the potential for the opposite occurs—an active area of study is Rust Belt cities of the Midwest like Pittsburgh, Cleveland, Detroit, Buffalo, Toledo, Gary, and Flint.

No one should buy a house, refuse to maintain it, and expect to live in it without problems for 50 years. Roofs leak, pipes and mechanical equipment need replacing, and appliances fail. It is part of the cost of home ownership. Home assets need routine and periodic updates. Often the new equipment is more efficient than the old equipment, saving homeowners money. So why should anyone expect anything different with critical infrastructure systems? Why defer maintenance of critical infrastructure when it is the lifeblood of the community? Even in a small community infrastructure systems may be worth hundreds of millions of dollars. That is a big asset, and it needs big maintenance and repair budgets.

THE DEVELOPMENT OF INFRASTRUCTURE OVER TIME

The development of infrastructure has occurred in spurts over time based on needs, funding, or visionary leadership. Each time, huge changes in population and/or development followed the implementation of large infrastructure projects. Let's go back to Dr. Fagan. He will tell you that 10,000 years ago people were basically hunter-gatherers. Then the only infrastructure needed was a little shelter, but that was personal, not societal. It is only when agriculture was first established that the need for infrastructure to the community was understood. Agriculture meant that people could become stationary because their needs were met in the local community. As long as crops continued to grow, people would not be hungry—a second basic personal need met. But more consistent availability of food meant more people to feed, which increased the demand for crops, which could only be met through a more concerted (societal) effort to extend irrigation systems from local farms to larger areas servicing multiple farms. Dr. Fagan (2012) will tell you that the first irrigation ditches for this purpose were in Babylonia and Egypt. The rivers supplied the needed water, and the ditches were extended as far as gravity would carry the water. Drought, river course changes, and upstream disruptions could have catastrophic impacts on the communities, but these were relatively rare. Societies flourished—until a calamity stopped the flow of water or the community outgrew its ability to feed people. Then society would collapse. Water meant food; clean water meant health and commerce.

Water was also useful for removing waste. Communities with opportunities to use floods or topography to remove the wastes benefited, although their downstream neighbors were less fortunate. The Celtic and Teutonic cultures realized that drinking water from streams would make you sick. Beer and tea were a solution, but efforts continued to improve waters supplies. The Romans built aqueducts, tunnels, and other water conveyance structures to bring in clean water from long distances to Rome, which improved urban health, fostered more commerce, and removed more waste. The entire empire benefited from these improvements, allowing commerce to flourish and create additional demands for trade and the need for defense. Both led the Romans to extensive road building. Many Roman roads are still in use today (see Figure 1.1) and we still use the Roman chariot axle dimension of 4 feet 8.5 inches in railroads, automobiles, trucks, and other vehicles.

Populations decreased after the fall of Rome, in part because the infrastructure was no longer maintained. Following the Dark Ages, populations increased slowly until the Industrial

Figure 1.1 Old Roman road still in use today leading to the ancient city of Assos in Turkey. (*Source*: image courtesy of www.HolyLandPhotos.org)

Revolution, which increased the ability to efficiently create products and develop commerce, and with it, the opportunity to increase the reach of goods and services. Both increased the attraction to urban areas and subsequently, increased the need for additional infrastructure. Safe, clean water supplies and adequate waste disposal were important community functions. It is a bit of a vicious cycle.

However, infrastructure normally is constructed as a result of a real or perceived need. A cholera epidemic from well contamination in London in 1848 caused more than 14,600 deaths. Cholera again erupted in 1854 causing 10,675 deaths (Burian et al. 2000). Many large cities in Europe started to treat water with filtration and constructed sewer lines to reduce disease as a result of these outbreaks.

In 1820 less than 5% of all Americans lived in urban areas (cities with a population larger than 8,000), but by 1860 the percentage increased to 16% and by 1880 had risen to 22.5% (Burian et al. 2000). All those people living in urban areas required more robust means to deal with the demands for water, sewer, transportation, etc.

The demand for transportation increased in the trade centers, leading to better and more numerous roads and canal systems to convey large quantities of goods from ports to inland communities. In the northeast United States, the Erie Canal was one such improvement—allowing for a more rapid and safe connection between the east coast and the Great Lakes region. Canal boats were towed by horses on paths along the canal (see Figure 1.2). But boats were slow, and so were horse- or oxen-drawn wagons.

The next generation of major infrastructure improvements were railroads (see Figure 1.3), which were developed as a faster means to transport goods and freight, but the tracks had limited geographic access. Governments facilitated the construction and expansion of rail after the Civil War, opening the western United States and many small communities to trade opportunities that did not exist before. Tunnels (see Figure 1.4) were constructed to allow trains to move more easily across the Rockies. Communities sprung up wherever trains stopped or tracks crossed. But these stops were likely to be places where there was land and water, both of which

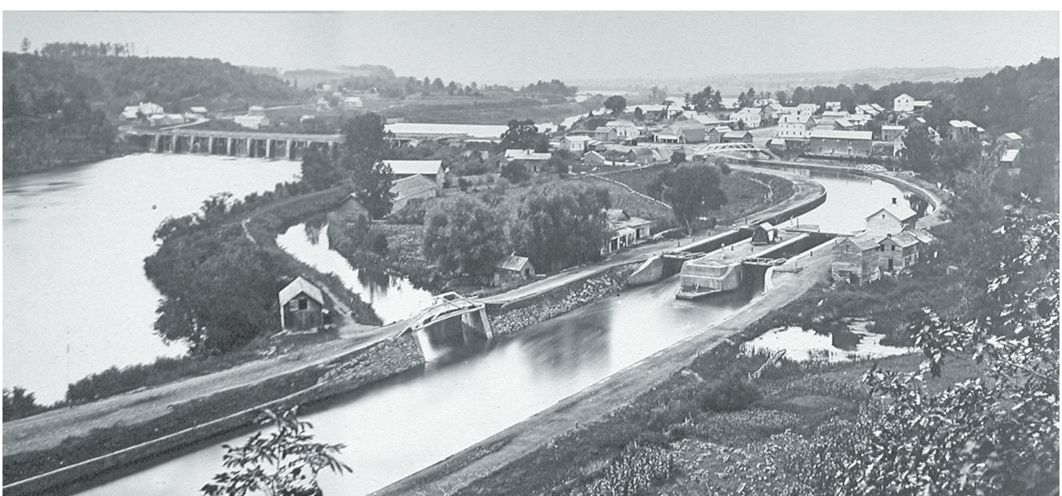

Figure 1.2 A stone aqueduct of the Erie Canal crosses the Mohawk River at Rexford, New York. (*Source*: Clifton Park Collection)

Figure 1.3 A railroad bridge built in Georgetown, Colorado, in the 1880s.

Figure 1.4 Railroad tunnel located in Winter Park, Colorado—constructed in 1927.

were needed by the locomotives and would facilitate development of the new communities. The desert and high mountains had few stops.

As cities grew, the limitations of railroads became more obvious. They could not be constructed to get people and goods everywhere. Horses and horse-drawn carts were used to address this need, but as better rail transportation increased economic activity and attracted more people to cities, the limitations of horse-drawn carriages manifested. Horses created health concerns in densely populated communities as a result of copious amounts of droppings. New York City alone employed 15,000 people to clean up horse droppings and dead animals on their streets each day (see Figure 1.5). Most major cities had similar employees. The health issues associated with this magnitude of waste in urban streets were obvious. In conjunction with pipes to remove waste, pipes to remove rainfall were constructed. Burian et al. (2000) note that in 1909, in the largest cities (populations over 100,000) there were 17,068 miles of sewers, of which 14,240 miles were combined sewers (where both sanitary sewage and stormwater were conveyed together to a water body for disposal because stormwater was assumed to flush both the streets and the sanitary sewers), 2,194 miles were separate sanitary sewers, and 634 miles were storm sewers.

The next investments came with the advent of the automobile, which was a boon for urban areas as well as individual freedom of movement. The automobile eventually eliminated the

MORTON STREET, CORNER OF BEDFORD, LOOKING TOWARD BLEEKER STREET, MARCH 17, 1893

Figure 1.5 Prior to the advent of the automobile, huge amounts of horse droppings had to be cleaned every night in large cities. This photo is from New York City during the 1890s.

horse manure problem, along with the jobs for some 15,000 people in New York alone. Despite this massive job loss from obsolescence, the feces pollution problem went away, but it was replaced by congestion, which soon demanded that urban roads have better pavement, traffic signals, signs, street lights, and wider, multi-lane roads.

The 1920s and 1930s saw a boom in the construction of dams and water conveyance systems. The Hoover Dam (see Figure 1.6) and related canal systems to move water to Los Angeles are examples of infrastructure projects that were constructed by far-sighted people. They looked at the needs of southern California and developed a canal system that enabled it to grow and develop as they hoped. Los Angeles could not grow without expansion of secure water supplies. The urban Los Angeles area now includes over 20 million people (up from under a million in 1920) that is served by these extensive canals (see Figure 1.7), some of which start at the Hoover Dam. Visionary leaders in many communities realized that with water, growth was possible—without it, the communities would stagnate. The Las Vegas area had a population of 4,800 in 1940. By 2015, the population had grown to over 2 million, not including the 42 million annual tourists.

The Great Depression of the 1930s led to the Work Progress Administration (WPA) program where thousands of Americans were hired to build water and sewer systems. Many rural communities had their original utility systems, along with recreation sites and paved roads built as a part of WPA programs. The WPA built or improved 651,000 miles of roads, 19,700 miles of water mains, 500 water treatment plants, 122,000 bridges, 1,000 tunnels, 1,050 airfields, 4,000 airport buildings, 800 pumping stations, 1,500 sewage treatment plants, 24,000 miles of sewers

Figure 1.6 Hoover Dam is a concrete arch-gravity dam in the Black Canyon of the Colorado River, on the border between the states of Nevada and Arizona. It was constructed during the Great Depression and was dedicated on September 30, 1935 by President Franklin D. Roosevelt.

Figure 1.7 A portion of the canal system that brings raw water to Los Angeles from the Colorado River.

and storm drains, 36,900 schools, 2,552 hospitals, 2,700 firehouses, and nearly 20,000 county, state, and local government buildings (The Economist 2011; Roosevelt Institute 2011). Much of this infrastructure was in the south where there were far fewer developed areas, fewer water and sewer systems, and fewer paved roadways, all factors that had delayed growth in southern communities. Most of those assets remain in service today.

Electricity was not delivered by power companies to rural areas because of the general belief that the infrastructure costs could not be recouped, so federal efforts of rural electrification began in small communities in 1936 (state efforts were even earlier in the Midwest and northeast), leading to hundreds of small dams for water supply and power production purposes throughout the country, particularly in the rural south. Prior to these improvements, industrialization of the south was limited due to the lack of infrastructure—water, sewer, roads, and power. But with these improvements, communities began to grow and diversify from farming. The Tennessee Valley Authority was one such rural electrification entity—chartered in 1933 as a result of severe economic impacts in the southeast (see Figure 1.8). Much of the dam building in the U.S. ceased in the 1950s due to increasing demands and an inability to find effective dam sites. New power plants were constructed to burn coal; then nuclear power followed in the 1960s and natural gas after 2000.

Henry Flagler built the railroad along the east coast of Florida on the high ground from Jacksonville to Miami to encourage development. However, the high ground was 2 miles inland from the Atlantic coast, so much of the early development was concentrated in this narrow corridor. Storm and water impacts from hurricanes in 1926 and 1928, and especially 1947, disrupted this plan for growth in south Florida triggering the need to address flooding in the state (see Figure 1.9). As California was running water pipes from the mountains to Los Angeles, engineers in Florida were moving water from the southern half of the state to the ocean, draining much of

Figure 1.8 A Tennessee Valley Authority dam completed in 1930 in Blairsville, Georgia.

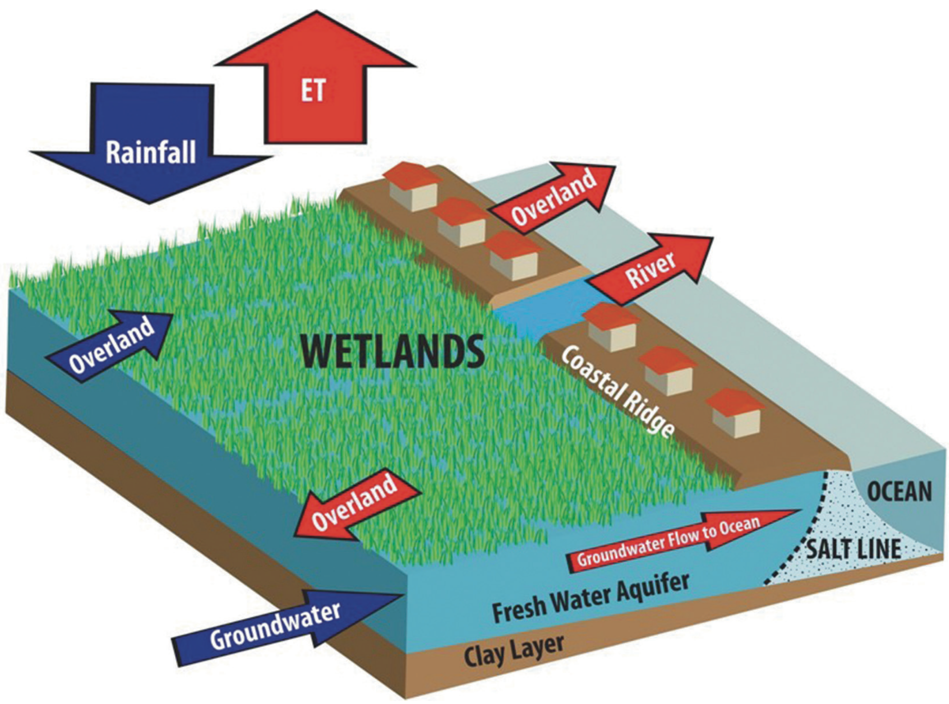

Figure 1.9 A conceptual figure of how Southeast Florida looked in 1900. (*Source*: *Journal of Environmental Science and Engineering*, 5 (2011) 1507–1525, Bloetscher et al. 2011. David Publishing.)

the historical Everglades. As a result, 1,800 miles of canals, a series of pump stations, etc., were constructed over the next 30 years to provide land for development in Florida—consisting of 6.6 million people, $7 trillion in property values, and $400 billion in annual economic activity as of 2015 (see Figure 1.10). Today, Federal and state funding trickles into Florida to address the enormous negative impacts from draining much of the Everglades ecosystem, including the loss of groundwater sources.

During World War II, General Eisenhower was impressed by the Autobahn system in Germany, so when he became President, he chose to invest in the Interstate highway system by commissioning the first 42,500 miles of the Dwight D. Eisenhower System of Interstate and Defense Highways in 1956 (FHWA 2018). Its estimated cost, in 1996 dollars, was over $329 billion. In 1960 there were 10,000 miles of Interstate opened. By 1970 there were 30,000 miles, and by 1980 over 80,000 miles were completed (McNichol 2006). These new roadways allowed people to travel farther and faster than before; and as a result, facilitated the ability of urban residents to move away from the inner city. This helped establish suburbs and urban sprawl, which necessitated a new wave of water, sewer, stormwater, roadway, and power infrastructure construction in the 1950s and 1960s. However, with more people driving today, the long commute times from the suburbs has started a return to urban environments for the younger generation. More vehicle miles traveled per person, with less reliance on public transportation, has put a congestion pressure on the interstate systems, while at the same time, more fuel efficient vehicles have reduced the revenues from the gas tax that funds maintenance and improvement programs. Hence, funding for roads has decreased since 1959.

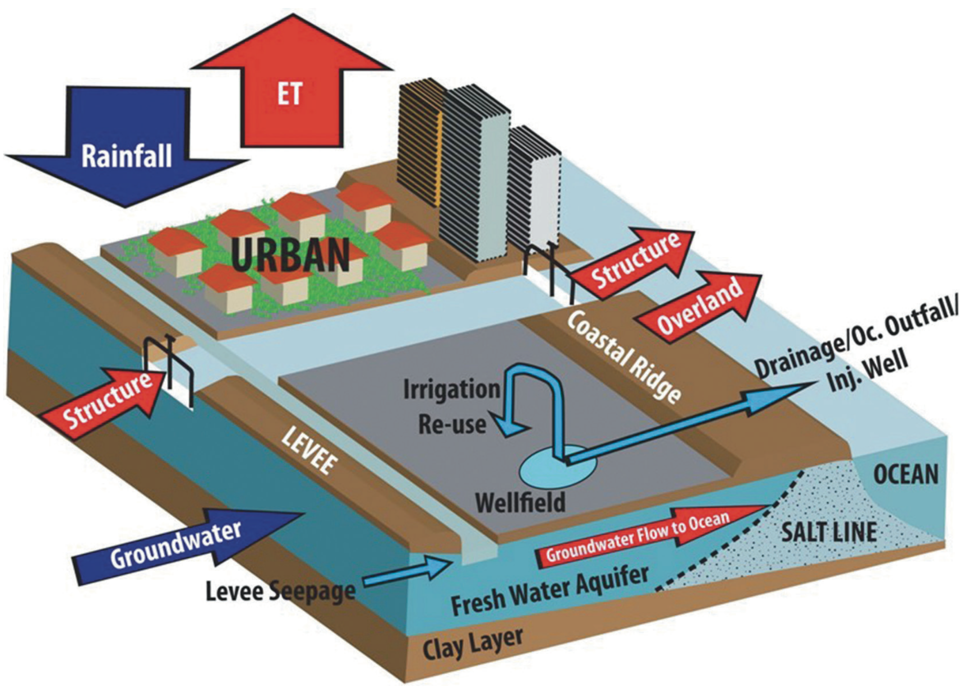

Figure 1.10 A conceptual figure of how Southeast Florida looked in 1970 after the canal improvements. (*Source*: *Journal of Environmental Science and Engineering*, 5 (2011) 1507–1525, Bloetscher et al., 2011. David Publishing.)

From the late 1960s to the early 1970s, a revolution in environmental awareness and environmental protection legislation occurred to address pollution impacts to water and air. The Clean Water Act, Safe Drinking Water Act, and Clean Air Act all required investments in infrastructure to reduce pollution to water bodies, air, and drinking water across the country. Grants were provided through 1988 for these improvements with low interest loans provided thereafter. However, the urge to deal with water and sewer infrastructure seems isolated to areas of growth, while the older, developed urban and rural systems have seen less investment. Rural systems are particularly at risk since economic growth appears to trail urban areas.

Post World War II saw the development of jet engines, which in turn increased the demand for air traffic and the need for airports. As air travel continues to increase, it facilitates economic opportunities across the world, necessitating an ongoing construction boom for both domestic and international airports. Shipping by boat remains the lowest cost option for moving goods, leading to a re-visitation of older infrastructure like the Panama Canal. The size of new ships for transport created the need for investments to expand the Panama Canal, which has also spurred changes to the east coast ports—Miami and Fort Lauderdale, for example, are expecting to spend billions to upgrade and deepen their ports to handle the larger cargo ships. Technology and commerce spurs infrastructure in these areas.

IMPACT ON THE PUBLIC

Infrastructure improvements yield major changes for the population. While the discussion about economic development is contained in Chapter 2, other impacts are just as significant. With respect to the provision of drinking water, it was previously noted that waterborne illness deaths plummeted from 100,000 per year in 1900 (of 100 million) to virtually one in 15 million people in 2010. Why? Because water treatment technology, design, and construction improved the disinfection—and improved distribution piping systems serve the majority of people in all urban and most rural areas in the U.S.

Sewer systems also permit economic development. Since the Clean Water Act was passed and that money was spent, the water quality in many rivers has improved. Likewise, the huge migration of people to the suburbs and to otherwise dry areas—like Phoenix, Denver, Las Vegas, and Tucson—was made available via roadways constructed by federal, state, and local governments, supplemented with gas tax revenues. It is easy to travel on good roads to virtually any place in the U.S. as a result.

Power is also available everywhere in the U.S., which permits not only an improved way of life via technology, but access to news, internet, social media, and other communication systems. Today, infrastructure connects us around the world and as a result, this has created expectations from the public that water will flow when they turn on the faucet, that cell phones will charge when plugged in to the wall socket, that sinks will drain, toilets will flush, and stormwater systems will reduce the potential for flooding of roads and property. The public expects that all transportation modes will work to move goods and people from one point to another. From an operational perspective we call this resiliency and reliability. Operations managers may also call it sustainability; the public calls it service.

Infrastructure is public works, which are physical structures and facilities developed or acquired to provide water, sewer, power, waste disposal, transportation, etc. The value of infrastructure in the U.S. was estimated at $37 trillion by the consulting firm ARCADIS (China was $47 trillion). However, the start of the decline in investment in the U.S. began in 1968. In part, the perception may have been—at the federal level—that the major investment needs for roads, bridges, and dam projects were complete. However, local funding for capital improvements slowed as well. But because the maintenance component of infrastructure was not budgeted, the results of deterioration started to manifest 10 years later. Today much of our infrastructure has issues associated with:

- Age
- Neglect
- Overuse
- Excess wear
- Exposure
- Mismanagement
- Obsolescence

These issues have not been dealt with due to various reasons. In an effort to control rates and taxes, along with the lack of apparent problems, elected officials have underinvested in repair, rehabilitation, and replacement of infrastructure systems. Cutbacks in budgets and deferral of expenses have been the result. Expenses have been based on available revenues, not needs. There has been a change by some officials who look more at a bottom line for investing as opposed to the need for insuring levels of service are maintained, making it more difficult to support added monies. The result is a lack of management of infrastructure systems and the failure to recognize the importance of these systems to the future economy. Developers have pushed new projects to local officials without the recognition of the impact of their projects on the level of service to existing residents. A fresh look at these policies is needed.

What is at risk? From a public service prospective, local officials risk a number of impacts from catastrophic failure of the system and deaths caused by that failure, to a disruption of way of life/economy that limit growth opportunities for the community. As an example, over 10% of the economy of the U.S. is related to transportation and shipping of goods; yet we are spending hundreds of billions less for repair and replacement than needed, which impacts our ability to grow or even sustain our current economy. For example, repair and replacement on the multi-trillion dollar transportation system was only 20–40% of the value of monies spent for new transportation construction in 1995. So what is needed to manage the infrastructure? The five major needs for infrastructure management are: (1) regulations to require assessment and investment strategies, (2) identification of capital projects, (3) more robust maintenance and repair programs, (4) people with skills, and (5) money.

The cost is high, which means there is a legitimate need for a more holistic evolution of managing infrastructure; one that is not piecemeal, not reactive, not forensic (post failure), and not without consideration of interrelationships.

CURRENT INFRASTRUCTURE IS BROKEN

The message is that infrastructure systems need to be constructed and maintained. The U.S. Army Corps of Engineers reported that the need to reinvest in infrastructure is estimated to be about 3.6% of the infrastructure value per year, but that the U.S. is spending about 2.4% (CBO 2015). The best condition of American infrastructure was in the 1980s (National Council on Public Works 1988), but decreases in reinvestment due to funding limitations have caused an ongoing decline in infrastructure value, which is why the ASCE report cards show most of American infrastructure at the D or D– level (ASCE 2001, 2009, 2013, 2017). The average score is a D.

The television program *60 Minutes* did a piece about the deterioration of bridges. The magazine *American City and County* has published articles about the risks of aging infrastructure. The discussion in Chapter 11 of this book outlines the long litany of needs. We have many issues with infrastructure in the U.S. Part of the problem is that the infrastructure operations industry does a poor job of communicating its importance. At the same time, it is hard to get into the news when the crisis is not apparent. People just are not interested when there is nothing wrong (and when there is something wrong, people will likely create issues that obfuscate the reason that something is wrong—listen to almost any election). Because communication and marketing has been so poor by the infrastructure community, the industry has been out-competed by cable television, cell phones, and Netflix for consumer dollars. Despite what the youth of today might believe, one can live without a cellphone and cable TV, but you can only live three days without water. In large part, the industry has lost its place in the minds of its customers due to its failure to market its product. The failure to market is often a time, leadership, and political issue. In addition, it is a tribute to those operating the systems—despite the needs or problems, the operators make sure the systems work. Hence—out of sight, out of mind—as long as the system works!

UNDERSTANDING THE PROBLEM

Local officials do not convey an understanding of these complex systems to the public very well. In part this may be because understanding the maintenance needs is difficult and highly variable. And many do not fully comprehend the assets they have, their condition, life expectancy, or technological needs. No one knows when things will fail, so maintenance or replacement of some equipment or pipeline is always cut in the budget with no real understanding of the consequences.

The public does not see many of the assets (or fully understand the ones they do see), assumes they will have a long life, and thus is unconcerned until they are affected; then it gets personal. When the public does not understand the impact or value that these assets have to society, they tend to be personally focused, not societally. That is a leadership issue. That leadership starts with vision and communication from those who understand the issue to the elected officials who need to advocate for their infrastructure.

Despite the infrastructure crisis, the good news is that construction of piping is increasing—both new and replacement. Every so many months, the magazine *Utility Contractor* will note current trends—and piping seems to be going up. That's good, but there is a long way to go. Better news—the construction of buildings is increasing. That could lead to more revenue. In Florida, finding experienced construction workers has recently become a problem (in 2015—more work than workers). Things are definitely better economically, but are we taking advantage of opportunities to improve the local infrastructure? And what happens when the next economic downturn hits?

UNDERSTANDING THE SOLUTION

The infrastructure crisis is a political and business leadership crisis. Asset management is practiced by few governments. The public doesn't want to foot the bill and some politicians want taxes and fees cut further. Where does it end? The reality is that local officials need to make their infrastructure systems self-sustaining and operating like a utility business whereby revenues are generated to cover needed maintenance and long-term system reliability. For example, for water and sewer utilities, the adage that *we can't afford it* simply ignores the fact that most communities cannot afford *not* to maintain their utility system since the economic and social health of the community relies on safe potable water and wastewater systems that operate 24/7; likewise with roadway, stormwater, and other infrastructure systems. Too often decisions are made by an official whose vision is limited by short-term gains as opposed to long-term viability and reliability of the utility system and community. This is why boom communities fall precipitously, often never recovering—the boom is simply not sustainable. Long-term planning is a minimum of 20 years—well beyond the next election and often beyond the reign of current managers. Decisions today absolutely affect tomorrow's operators. Dependency on water rates or taxes that fund public sector infrastructure systems may be perceived to be a barrier, but this ignores the fact that private power, telephone, cable television, gas, and internet access industries are generally more expensive than either water or sewer in virtually all communities. Better education of the public about the importance of improved infrastructure is needed for public sector agencies to obtain the funding needed. We need improved water, sewer, roads, and stormwater systems for our health and economic sustainability.

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