Chapter 4

The coevolution of infrastructure, governance, and urban ecology

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Urban infrastructure systems are critical to daily life in cities. In early North America, urban residents obtained food, water, and fuels through primarily private and often labor-intensive means. Walking was the main mode of transit. With industrialization, however, the need for resources increased. Growth was intimately tied to obtaining secure supplies of water and energy, giving municipalities a strong motivation to build infrastructure systems to feed urban needs. By the late nineteenth century, rapidly industrializing cities of North America were overwhelmingly developing public, modern, capital-intensive systems to move water, fuels, and people (Cronon 1992; Melosi 2000; Tarr 1984).

Newly acquired resources for cities were primarily imported. Expanding cities quickly outgrew their local and regional supplies of water, wood, and other fuels. They reached out to regional and distant sources for new supplies. Yet, this often had unintended consequences. For instance, water imports in cities across the U.S. actually spurred a subsequent wastewater problem on a new scale, forcing additional infrastructure building. In the expanding American west, where water was a limiting factor in growth and new supplies were hard to find, cities crossed ecological regions and territorial boundaries on a new grand scale to get imported water. By the late twentieth century, vast areas of the Western U.S. had been "re-plumbed" to bring water to the Pacific Coast from as far away as the Colorado Mountains.

Such improvements, which we describe in detail below, were intimately tied with changes in management and governance. In the late nineteenth century, cities were dynamic places, but working classes experienced squalid and often dangerous living conditions (Engels 1887; Riis 1890). Leaders of the Progressive Movement in the U.S. (approximately 1890–1920) responded with social awareness campaigns and promoted a professionalized civil workforce to deliver more efficient services (Hays 1959; Pincetl 1999; Wiebe 1967). The movement emphasized an ordered and technical approach to governing, influenced by broader shifts to maximize efficiency through centralized workflows, exemplified by the philosophies of Frederick Winslow Taylor (1911) and Louis Brandeis (Drury 1915). Hierarchical civil institutions became specialized, evolving to oversee more complex infrastructure systems with new technologies. Energy, water, transportation, and waste management functions were compartmentalized in separate departments, with managers hoping to achieve performance and efficiency. Many of today's urban institutions are legacies of Progressive Era reforms in municipal government.

These legacy institutions and infrastructure systems continued evolving through the twentieth century. Networks of infrastructure systems grew, with the sub-systems becoming more interdependent and connected even as management still operated them separately (Graham and Marvin 2001). Today, reliable infrastructure is an expected component of urban life in the modern city. Yet the ideal of efficient modern infrastructure faces challenges from population growth, environmental degradation, fiscal shortfalls, and growing maintenance needs (Graham and Marvin 2001; Pincetl 2010). In response, some municipalities looked to privatize water delivery, sanitation, or other services to deal with budget shortfalls. Amidst a broad global debate regarding privatization, such moves raised questions of public goods and private rights. While privatization debates continue, even more recent trends in infrastructure are emerging, influenced by newly available data, society's interest in sustainability and "local" usage, infrastructure funding challenges, and recognized shortcomings of compartmentalized management. Integration, decentralization, and distribution are all posed as solutions to the fiscal and environmental challenges for future urban infrastructure.

A historical review of a nonlinear process

In this chapter, we recount the history and development of modern public infrastructure systems in the U.S. as told by pioneering urban environmental historians such as Joel Tarr, Martin Melosi, and William Cronon. We extend the discussion of privatization in the U.S. urban water sector from the first edition of *Pragmatic Sustainability*, benefitted by several more years of debate and research. Emerging approaches to decentralized design, citizen engagement, and sustainable urbanism in the context of revitalizing urban cores present a new wrinkle relevant to the discussion of public and private water in cities. Questions of control over infrastructure are becoming much more complex. Urban utilities are looking to engage residents on private decisions that affect management, such as planting water-conserving landscapes. The new emphasis on *governance* rather than just *government* muddies clear delineations between public and private (Bellamy and Palumbo 2010; Rhodes 1996), offering the opportunity to consider a new way of thinking about *hybridized* systems of linked infrastructure and institutions in cities.

From private to public: early U.S. water systems (1800–1880)

In early U.S. cities, water provision was not a public service. Residents were primarily responsible for obtaining drinking water and disposing of wastes. Water collection and waste removal was labor intensive. Residents carried small amounts of water from local sources or paid private water delivery services on a daily basis. Similarly, wastes were removed from private cesspools and sometimes reused for fertilizer. Once hyper-local sources were depleted or contaminated, cities obtained water from peripheral sources using a network of carriers, whose deliveries were often of poor quality and brought over distances of several miles. The early private water provisioning from local springs and rivers created shortages, yielded poor quality supplies, and contributed to disease. Cities looked to existing institutions for options.

Private companies primarily built the first urban water systems in early America, supported by municipal charters. The companies served limited, often wealthier, neighborhoods (Swyngedouw, Kaika, and Castro 2002). Philadelphia was an early exception. In 1801, it hired Benjamin Latrobe to build the city's first municipal water supply at the Center Square Water Works, though it was ultimately unsuccessful (Blake 1956). Early corporate proprietors often had strong connections with the municipal officials making decisions regarding public financing of water. For example, in New York City, then-state assemblyman Aaron Burr, famous for his 1804 duel with Alexander Hamilton, crafted a bill in 1799 to charter a Manhattan Company that would provide water to the city. New York voters defeated the effort, but Burr altered the bill to create the Manhattan

Company (later Chase Manhattan and J.P. Morgan Chase) for banking purposes and subsequently water supply. Within a few decades, however, New York residents demanded that the city build a large-scale canal from the Croton River to replace tepid and contaminated water from the Manhattan Company (Blake 1956).

Many cities had competing suppliers. In Houston, for instance, public waterworks projects began in 1859 with construction of a few public cisterns (Green 1915). Spurred by the need for fire protection and clean water, however, the city council contracted in 1879 with a private group of individuals, the Loweree group, for the city's water needs. Renamed the Houston Waterworks Company, it drilled its first artesian well in 1888 (Melosi 2001).

Over time, residents and leaders in early U.S. cities realized the limitations of private water delivery. Initial water works companies successfully raised ample funds from enthusiastic investors, but supplying a whole city required more capital (Blake 1956). Moreover, public health and fire risks brought urgency. Yellow fever, cholera, and typhoid epidemics were all common in the quickly urbanizing cities of North America, inducing a "substantial mortality 'penalty'" for urban residents (Haines 2001). In 1900, an estimated 44 percent of deaths in major cities were due to infectious diseases (Cutler and Miller 2005). While experts and leaders mistakenly attributed this to airborne contamination or miasma theory, ultimately they believed that improved water supplies could help to reduce disease.

In addition to disease and fire, economic growth reinforced early municipal water systems. Disenchanted with private water companies, many municipal leaders across the established east and growing west argued "that cities could run their services more efficiently and effectively than private firms who were driven simply by profits" (Melosi 2001, 2). Over time, cities municipalized water delivery and sewage conveyance to create the "sanitary" city (Duffy 1990; Pincetl 2010; Swyngedouw, Kaika, and Castro 2002; Tarr et al. 1984).

Water quality: a public need (1880–1920)

The development of publicly funded urban water infrastructure in the early twentieth century is closely related to a series of water quantity and quality problems resulting from new technologies. In the late nineteenth century, migration fueled rapid expansion of industrial cities in the U.S., especially in the Northeast, Midwest, and West. Cities supported growth by funding reliable water supplies from local and regional sources. These efforts were still not enough. Cities turned to even more capital-intensive solutions by tapping distant (surface water) and deeper (groundwater) sources to replace nearby polluted ones. New York City was an early leader, beginning construction on the Croton Dam and Aqueduct in 1837. Its first aqueduct was completed in 1842, and an even larger new aqueduct was finished in 1890. In the West, the first extension of the Los Angeles Aqueduct was completed in 1913. These large-scale facilities were expensive and limited to bigger cities in need of clean water supplies from distant, relatively pristine watersheds. They also spurred early environmental debates. For instance, John Muir, founder of the Sierra Club, led a national debate over the value of inundating the Hetch Hetchy Valley in eastern California to supply San Francisco with alpine water. This debate continues today. Yet, despite such efforts, epidemics still raged. Even with new water sources, many cities still had water intakes downstream of the primary sewer outfalls of upstream cities (Duffy 1990).

New technologies helped address this problem. Filtration, including the slow-sand filter in England and the rapid-sand filter in America, offered options to purify local and imported water (Baker 1948). Scientific research into microbiology and bacteriology increased significantly, and experiments with filtration began to reduce disease outbreaks, especially typhoid fever. In 1881, the

Table 4.1 **Municipal expenditures on sewers and water filtration systems (in 1929 dollars), 1881–1910**

City	*Water filtration*	*Water chlorination*	*Sewage treatment*	*Sewage chlorination*
Baltimore, MD	1914	1911	1911	after 1936
Chicago, IL	after 1940	1916	1949	after 1949
Cincinnati, OH	1907	1918	after 1945	after 1945
Cleveland, OH	1917	1911	1922	1922
Detroit, MI	1923	1913	1940	1940
Louisville, KY	1910	1915	1958	after 1958
Milwaukee, WI	1939	1915	1925	1971
New Orleans, LA	1909	1915	after 1945	after 1945
Philadelphia, PA	1908	1913	after 1945	after 1945
Pittsburgh, PA	1908	1911	after 1945	after 1945
St. Louis, MO	1915	1919	after 1945	after 1945

Source: Cutler and Miller 2005. Original data adapted from Tarr et al. 1984, based on data from the 1975 U.S. Historical Census (Census 1975).

Note

U.S. public sector expenditures between 1900 and 1970, broken down by level of government. Data is continuous between 1955 and 1970, but represents only a subset of years between 1900 and 1955.

American Water Works Association was established to spread knowledge and expertise of urban water systems construction. Further, from 1900 to 1910, chemical treatment advances, especially chlorination, offered cities a cost-effective way to augment filtration with bacterial decontamination (Cutler and Miller 2005). By the end of World War II, larger cities throughout the U.S. were funding public infrastructure to import water from distant sources and treating local supplies (Melosi 2000).

As cities developed water distribution infrastructure to meet growing demands, increased per capita water use created a new problem: large volumes of wastewater (Melosi 2000; Tarr, McCurley, and Yosie 1980). With the advent of the flush toilet, wastewater soon overwhelmed household management capabilities. Cesspools leaked, causing soil and groundwater contamination. Sewers, meanwhile, had been designed primarily for stormwater drainage, both public and private, not for the transport of human waste. The target was to keep streets passable in the rainy season (Tarr 1984). Again, tackling the sewage quantity problem required a massive expansion of publicly funded infrastructure. Contentious debates ensued over municipal spending and infrastructure expansion (Blake 1956), but eventually, public health concerns motivated municipalities to adopt centralized, sub-surface sewage conveyance.

The public investments, however, were founded on a false premise, the "miasma" theory, mentioned above, which held that diseases were transmitted by smelly and dirty air. As early as 1845, sanitarians advocated for the link between health, cleanliness, and disease transmission. American cities adopted new approaches from Europe to build a "sanitary city" (Melosi 2011). The spread of knowledge spurred new local plumbing codes and regulations, including local health boards to oversee epidemic responses (Tarr et al. 1984). Sanitarians also advocated changes in regulations and municipal oversight (Duffy 1990). From 1870 to 1920, the percentage of the urban population with access to sewer services rose from 4.5 percent to 47.5 percent (Pearse 1938). In contrast, the percentage of rural populations with treated sewage rose from less than 1 percent in 1870 to 18 percent in 1920.

***Table 4.2* Municipal expenditures on sewers and water filtration systems (in 1929 dollars), 1881–1910**

Period	*Spending (in millions)*		*Percent*
	Sewer construction (1929 dollars)	*Water filters (1929 dollars)*	*Real sewer and water as percent of state and local construction*
1881–1885	13.12	0.08	7.60
1886–1890	17.8	0.11	8.30
1891–1995	9.3	0.47	3.60
1896–1900	11.3	0.60	3.50
1901	1	1.65	3.10
1906–1910	17.4	4.16	2.80

Source: Aldrich 1980.

Increasing use of combined sewers that carried both sewage and runoff exacerbated the wastewater problem. By 1909, 74 percent of U.S. cities with municipal sewer systems had combined sewers (Tarr et al. 1984). Yet, combined sewers also made it more difficult to recover nutrients from wastewater flows, and cities predominantly dumped the raw sewage in local water bodies:

> The irony was clear: cities had adopted water-carriage technology because they expected local health benefits resulting from more rapid and complete collection and removal of wastes, but disposal practices produced serious externalities for downstream or neighboring users.... This, then, was the primary unanticipated impact of sewerage technology—a rise in health costs where health benefits had been predicted.
>
> (Tarr et al. 1984, 239)

Thus, public infrastructure that addressed a problem of water supply inadvertently created water quality problems. The benefits of improved drinking water supply for urban residents were clear, but as cities sent wastes downstream, the problem was seen as solved, thus reducing motivation for further municipal investment. Only with greater awareness and state and federal involvement were requirements developed to promote a new era of treated wastewater.

Experts and federal programs (1920–1945)

Following reforms of the Progressive Era, U.S. municipal and industry leaders continued advocating for expanded municipal water and wastewater systems. While large metropolitan areas such as New York, Boston, Philadelphia, Cleveland, and other industrial centers built water treatment technologies through 1920, many mid-sized and smaller cities could not afford expensive systems. Sanitarians such as Abel Wolman and Linn Enslow, who together in 1926 developed improved chlorination processes, expanded the accessibility of cost-effective technologies (White and Okun 1992). Many sanitarians worked in both scientific research and practical applications.

While municipalities implemented distribution and treatment systems for water, wastewater, and stormwater, the nation as a whole was experiencing changes in its global role. In

Figure 4.1 U.S. public s expenditure between 19(1970, broker by level of government continuous t 1955 and 19; represents o subset of ye between 190 1955 (source and Miller 20 Original data from Tarr et based on dat the 1975 U.S Historical Ce (Census 1975

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response to the Great Depression of the 1930s, President Roosevelt devised a series of publi infrastructure development programs to invigorate the economy as part of the New Deal. Th Public Works Administration (PWA), Works Progress Administration (WPA), and the Tennesse Valley Authority (TVA) were just a few of the many conduits that moved federal money into publi works. Through the New Deal, the federal government took a major role in developing urban infra structure, including roads, sewers, waterworks, dams, bridges, parks, docks, airports, and public buildings (Aldrich 1980). Furthermore, the federal government began influencing sewer system design:

> [Public Works Administration] funds accounted for 35 to 50 percent of all new sewer and water supply construction during the 1930s. These projects generated a variety of benefits to local communities. New water supply systems, for instance, produced sharply reduced fire insurance premiums in addition to water supplies. Sewer construction supplied unemployment relief and also addressed the problems of water pollution control. President Roosevelt accelerated investment for sewage treatment facilities by refusing to approve PWA sewer projects that did not include treatment. Similarly, the Works Progress Administration (WPA) was not permitted to construct sanitary sewers unless they were designed to be compatible with treatment works. By 1938, federal financing had aided in the construction of 1,165 of the 1,310 new municipal sewage treatment plants built in the decade. The population served by sewage treatment increased from 21.5 million in 1932 to more than 39 million by 1939, substantially improving the quality of the waterways used for municipal waste disposal.
>
> (Tarr 1984, 41)

The PWA financed 2,400–2,600 water projects at a cost of nearly $312 million (nominal), which was "half of the total expenditures for waterworks for all levels of government" (Melosi 2011). Other agencies, including the Civil Works Administration and the WPA, spent an additional $112 million on labor related to municipal water. The funding infusion had the greatest impact on localities (Melosi 2011; Scientific American 1944). Figure 4.1 shows total U.S. public expenditures on infrastructure between 1900 and 1970 from federal, state, and local sources.

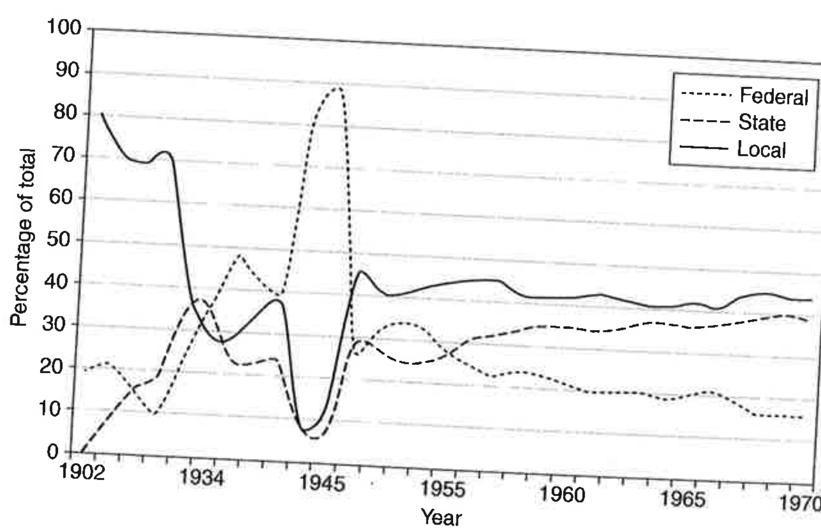

Figure 4.1
U.S. public sector expenditures between 1900 and 1970, broken down by level of government. Data is continuous between 1955 and 1970, but represents only a subset of years between 1900 and 1955 (source: Cutler and Miller 2005). Original data adapted from Tarr et al. 1984, based on data from the 1975 U.S. Historical Census (Census 1975).

Following World War II, total public investment in infrastructure resumed, increasing from $8.6 billion to $13.6 billion between 1950 and 1960 (Aldrich 1980, 59–71). Pre-treatment clarification and filtration spread to more municipal systems, while chlorination, aeration, and water-softening techniques also grew. With more spending came centralized bureaucratic control. Operations and management of water, wastewater, and stormwater systems were dispersed across departments or even across agencies. Bureaucratic fragmentation emerged from technocratic, specialized approaches to systems management.

Suburbanization, decay, and environmental consciousness (1945–1990)

In the post-World War II period, American cities expanded outward. Middle-class and wealthy residents flooded to ring suburbs, driven by available land within easy commuting distance of central districts. Building infrastructure to serve these new areas was expensive. Federal transit financing increased significantly, including the development of interstate highways that ran between and through cities. Minority neighborhoods were often targeted for demolition to make room for highways, supported by planning processes (Jacobs 1961). Additionally, many urban dwellers fled growing racial tensions in inner cities. Older, central neighborhoods degraded as tax bases collapsed and crime rose, spurring a multifaceted urban crisis.

Public entities faced difficult choices to deal with the fiscal imbalances. Major revenue bases were eroding while newly expanding areas were costly to connect to established systems. Spending for water systems during the period was motivated by growing recognition of old, ineffective infrastructure as well as the need for new systems in expanding, low-density suburban areas (Melosi 2010, 2011). From 1945 to 1965, municipal water works in the U.S. increased from approximately 15,400 systems serving 94 million residents to over 20,000 systems providing for 160 million people (Babbitt and Doland 1955; Fair and Geyer 1958).

Federal legislation for water quality expanded rapidly during this period. Beginning in 1948, several pieces of federal legislation emphasized increasingly stringent water quality standards, ultimately yielding a comprehensive revision of federal law through the Federal Water Pollution Control Act (FWPCA) of 1972 and its subsequent amendments, commonly known as the Clean Water Act (CWA). The Clean Water Act regulated discharges from point-source pollution sources. It focused on industrial sources and municipal sewage. In totality, the legislation created a blanket of regulations that forced cities to develop advanced wastewater treatment facilities to control effluent. The growth of legislation corresponded with a national and international public awakening of environmental degradation and industrial pollution.

The CWA instituted a national reporting system for water pollution. Through the National Pollutant Discharge Elimination System (NPDES), dischargers of industrial and municipal sewage were required to obtain permits (U.S. EPA 2012). The Water Quality Act of 1987 broadened the 1972 legislation to include industrial and municipal stormwater discharges, as well as smaller municipal separate storm sewer systems (MS4s), through a phased implementation program (U.S. Code 1987). This precedent would drive a new era of thinking in managing urban water and runoff.

Contemporary water issues: scarcity, environmental degradation, and funding (1990–present)

Suburban growth through the 1980s forced cities to invest heavily in distribution systems for peripheral, lower-density areas. Distribution costs to move water from treatment plants to end-users often made up two-thirds of overall system operating expenses (Clark and Stevie 1981; Larson 1966). Additionally, municipal planners in western U.S. cities recognized a shrinking base of unexploited water resources. In California, for instance, the large-scale Central Valley Project (federal) and State Water Project (state) conveyance systems provided new sources of water for Central Valley agriculture and growing Southern California cities, but they also signified the end of readily available imported water (Hundley 2001; Reisner 1993). By 1982, when then-Governor Jerry Brown proposed new projects to transfer more water to Southern California water districts through the San Francisco Bay Delta, voters rejected the project largely along geographic lines. Further, lawsuits defeated new development of alpine water sources at Mono Lake by the Los Angeles Department of Water and Power. These defeats previewed a new era. Major California cities, and later cities throughout the state, increasingly emphasized conservation, relying heavily on timely water use restrictions to manage during droughts. Since 1995, total urban water use has not grown significantly for major California cities (Hanak et al. 2011).

Yet, cities in both temperate and arid climates were still polluting watersheds both through sewers and surface runoff from streets. The 1987 Water Quality Act began focusing regulatory actions on stormwater, using a phased approach based on population. Phase I regulations (1991) controlled stormwater discharges for systems serving 100,000 people or more, while Phase II (2003) regulations required all municipalities comply with non-point source pollution requirements. In 1994, the U.S. Environmental Protection Agency (EPA) required municipalities to address Combined Sewage Overflow-related pollution problems, and Congress amended the CWA in 2000 to mandate municipal compliance with the policy through the Combined System Overflow Control Policy (U.S. EPA 2000).

Controlling stormwater runoff presented significant fiscal and governance challenges for strained municipalities. Stormwater flows are infrequent and sometimes large. Wastewater treatment plants have limited capacities and surges of flow are difficult to manage. Moreover, cities with combined sewers must spend large sums to capture or prevent runoff from relatively infrequent storms. A 2008 needs assessment by the EPA determined that U.S. municipalities must spend $42 billion on stormwater management improvements and nearly $64 billion to upgrade combined sewers (U.S. EPA 2008). Additionally, large municipal water systems (serving >100,000 people) face over $145 billion in future spending needs to maintain and upgrade drinking water systems (U.S. EPA 2013).

Seeking solutions: privatization and hybridization of urban water systems

Recent decades have seen a vigorous discussion regarding the merits of privatizing water supply, delivery, and treatment. Broadly, privatization refers to the transfer of production, distribution, or management services from public to private control (Gleick et al. 2002). Since 1990, international agencies have increasingly emphasized privatization as a way to address shortfalls in water services. For instance, the United Nations "Earth Summit" in Rio de Janeiro recognized water as both a social and *economic* good, stating that after satisfying basic needs for humans and ecosystems, water should be priced according to availability and end-uses (United Nations 1992). This view is related to theoretical shifts that see infrastructure services as private goods with alternate competitive uses (Fauconnier 1999). Interest from private companies in the U.S. water sector has motivated U.S. public water utilities to improve performance and program evaluation efforts (NRC 2002).

Privatization discussions focus on several issues. Renewal and upgrade costs stretch already strapped municipal budgets. In the U.S., while past eras saw significant federal investments to assist states and localities to build water and wastewater systems, localities inherited the long-term operational costs of the facilities, including many new duties for environmental protection (NRC 2002). Privatization advocates argue that private sector water service delivery is more efficient, can produce cost savings, and address budget shortfalls. Additionally, in some areas, the public may not trust current utilities. This is especially true for industrializing countries, but even in the U.S., poor service and demographic changes can erode confidence. In Detroit, for instance, the city's 2014 bankruptcy spurred an audit of the water agency, which discovered thousands of unpaid bills, billing errors, and poor customer service practices. The temporary city government began shutting off water services to delinquent accounts, causing significant backlash (Smith 2014). Alternatively, critics of privatization note that private sector companies seeking profits have little motivation for new system investments. Over time, geographic or economic disparities can arise in service delivery. Moreover, the global record on private companies delivering cheaper water services is inconclusive at best (Bel, Fageda, and Warner 2010).

In the U.S., privatization efforts in the water sector have yielded limited results. The volume of private delivery for all municipal services has remained fairly stable since 1980, rising from 22 percent to 24 percent (Gerber, Hall, and Hines 2004; Warner and Hefetz 2001). For water deliveries, through 2000, private companies served about 15 percent of water customers, as measured by volume of water provided (Arnold 2009 citing NRC 2002, 14–15). However, the percentage of private service delivery varies by sector. According to analysis of 2007 surveys from the International City/County Management Association (ICMA), while local governments directly provided 72 percent of water distribution services, the percentages decreased for water treatment (65 percent) and sewage collection and treatment (58 percent) (Bel, Fageda, and Warner 2010; Warner 2005). In the largest privatization effort of municipal water delivery in the U.S., the city of Atlanta contracted in 1998 with United Water, a subsidiary of the French firm Veolia, for water delivery in the metropolitan area. Yet, by 2003, the city cancelled the contract due to a combination of poor performance by the company and failure of regional governments to deal with more systematic water management problems (Arnold 2009).

Privatization of public sector duties in the U.S. is distinct in several ways. First, as noted in the United Water example, the process of privatization has shown to be highly reversible. While many local governments try privatizing one or more service sectors, contracts are temporary and duties are often reabsorbed. The 2007 ICMA survey data indicated that between 7 and 10 percent of contracts returned to sole local government providers across water distribution and water and wastewater treatment (Warner 2005). Second, public agencies often use service contracts rather than outright transfers of assets to private companies. Third, infrastructure provisioning in the U.S. is driven at the state and local level. This creates more diversity in laws and regulations that pertain to privatization (Arnold 2009; Gerber, Hall, and Hines 2004).

Privatization of water services can take several forms. Public agencies can contract out some or all operational duties to private companies, engage firms to design, build, and then manage water systems through linked arrangements, or sell assets all together to private firms (NRC 2002). Selling municipal assets can generate temporary cash flow and reduce expenses, but involves a significant loss of municipal control. Alternatively, private companies that take on service contracts may have more technical expertise to operate systems, but public agencies often have limited capacity to oversee contracts (Beecher 1997; Gleick et al. 2002). Establishing standards for efficient and equitable management is necessary under both private or public management (Wolff and Palaniappan 2004).

Private property rights to water are another important consideration of privatization discussion. Access to water rights influences how public agencies provide water services. California is a prime example. It has multiple layers of water rights that can date back to the era before statehood. Finally, water resources are increasingly treated as a commodity, especially in Western states experiencing water scarcity. Both public and private organizations emphasize efficiency and augment public-sector mechanisms such as laws and permits with contracts and trading markets (Arnold 2009). Private companies such as Nestle and Coca-Cola have also heavily increased their involvement in obtaining rights to groundwater resources for bottled water (Gleick et al. 2002).

Public-Private Partnerships (PPPs) are an emerging model to fund infrastructure development. Such partnerships attempt to combine expertise and available capital from the private sector with public sector capabilities to obtain low-cost financing and absorb risk. Advocates point to successful examples of PPPs in spurring investment such as the Transportation Infrastructure Finance and Innovation Act (TIFIA). U.S. Legislators proposed similar legislation, the Water Infrastructure Finance and Innovation Act (WIFIA), which was absorbed into the Water Resources Reform and Development Act passed in 2014. Among its provisions, the Act provides secured federal loan guarantees to support water infrastructure projects, but only up to 49 percent of the project costs, with a limit of 80 percent total funding for projects (*Water Resources Reform and Development Act* 2014). This is one example of local government motivations to seek private capital for partnership arrangements.

Current innovative practices in managing urban water services go beyond discussions of public and private management. Emerging themes emphasize integration across sectors, mitigating risks, and considering new approaches for decentralized management and design of infrastructure systems. Like in the mixed-service model of PPPs, questions of public or private are evolving to solutions of public *and* private. Driven by needs to manage water scarcity, environmental quality, and infrastructure renewal costs, such *hybridized* approaches include not only partnerships to own and control infrastructure but also the actual design and governance of physical systems.

Hybridization and thinking local

Recognizing the complexity of urban water systems with linked sociological, technological, and ecological factors requires planning that cuts across traditional sectors or disciplines. Hybridization in both design and governance of urban water infrastructure closely relates to this complexity.

Within system *design*, hybridization means cost-effective mixes of centralized and decentralized components. Decentralized or distributed approaches, as recommended in Chapter 12, use new technologies at the household- or neighborhood-scale to replace large, capital-intensive centralized systems. The need for reliable backup systems, however, means that designers must cost-effectively mix both centralized and decentralized components. Thus, a home system to treat sewage (from toilets) or grey water (from washing machines, showers, or dishwashers) could reduce the need to treat and pump imported water to users, saving energy and scarce water resources. Increasing attention, even excitement, surrounds such relationships between resource sectors, often referred to as the *energy-water nexus*. Advocates discuss "fit-for-purpose" water supplies that align sources of different water quality with appropriate end-uses, which can include drinking, industrial processes, irrigation, and more. Rather than contemporary systems that import and treat all water across end-uses to equal standards, advocates note that new technologies can utilize and improve upon ancient fit-for-purpose water management strategies (Asano 2006; Leverenz, Tchobanoglous, and Asano 2011; Sedlak 2014). Clean or highly treated water should be dedicated to uses that directly affect human health such as drinking and bathing. Grey water of intermediate quality is useful for irrigation and industrial purposes. Finally, sewage must be highly treated, either on-site or in central facilities. Backup supplies and monitoring technologies can support continuity of operations. Stormwater systems have arguably advanced the most towards a hybrid approach with distributed components, as cities increasingly use on-site green infrastructure, Low-Impact Development (LID), and Best Management Practices (BMPs) to mitigate large stormwater flows and provide potential urban amenity benefits.

Such hybridized designs raise many challenging questions. Building redundant systems may be unnecessarily expensive, while distributed solutions may not capitalize on economies of scale. Distributed systems also create highly localized design challenges. But, some of the most challenging questions may actually involve hybridization of *governance* and the mix of public and private responsibilities. For instance, in managing a decentralized stormwater system with on-site control of runoff, the responsibility for maintaining functional distributed components could be public or private. If public, municipalities would oversee hundreds or thousands of properties. This poses a significant manpower problem needing newly trained employees with improved monitoring technology. Alternatively, if cities look to residents to maintain on-site controls, incentive problems occur. Many municipalities already have building codes that limit stormwater runoff from sites as part of their overall plans to keep stormwater discharge permits.[1] This strategy distributes the cost of managing stormwater, integrating it with a larger process of building permits and alleviating some municipal financial burdens. But, it only emphasizes system design at the time of construction. Long-term maintenance plans, along with citizen engagement and education programs, become critical in this scenario, as enforcement is resource-intensive.

Similarly, within wastewater and water supply, questions of private responsibility in hybridized systems involve human health. If a household wastewater treatment or water filtration system breaks, it can have immediate health risks. Private responsibility of paying for household water or wastewater treatment would likely lead to economic or geographic disparities of access. Wealthy communities could raise more funds, while poorer communities would be left without drinking water. Such disparities, now considered issues of environmental justice, have occurred throughout U.S. history and continue. Moreover, money that residents must spend to upkeep systems competes with other household costs. Even with regulatory consequences, not all households may emphasize maintenance. Alternatively, the opportunity for neighborhood-scale decentralized systems under municipal management, as is proposed in Chapter 12, can offer economies of scale and potentially reduce costs of pumping treated water and sewage long distances. Retooling established systems, though, would take decades, much like the transition from private to modern public water systems in industrialized cities. Additionally, like how interconnected water quantity and quality problems of the early twentieth century drove infrastructure development needs, unforeseen effects of new designs would again spur technological and sociological responses.

The case of Los Angeles

Los Angeles provides a unique example of public and private governance for water supply. The Los Angeles Metropolitan Statistical Area (MSA) covers both Los Angeles and Orange counties, with a 2010 total population of nearly 13 million people (Census 2013; OMB 2013). Water management is highly fragmented across hundreds of public and private organizations (Pincetl, Cheng, and Porse under review; Hughes and Pincetl 2014; Porse et al. 2015). In the Los Angeles metropolitan area within southern Los Angeles County alone, there exist over 100 sizable water suppliers and 300 groundwater pumpers, dozens of districts for stormwater and sanitation, and regional water supply management districts at multiple scales. For water supply in particular, organizations are both public and private, including cities, municipal water districts, investor-owned utilities, non-profit (private) mutual water companies, and special irrigation districts.

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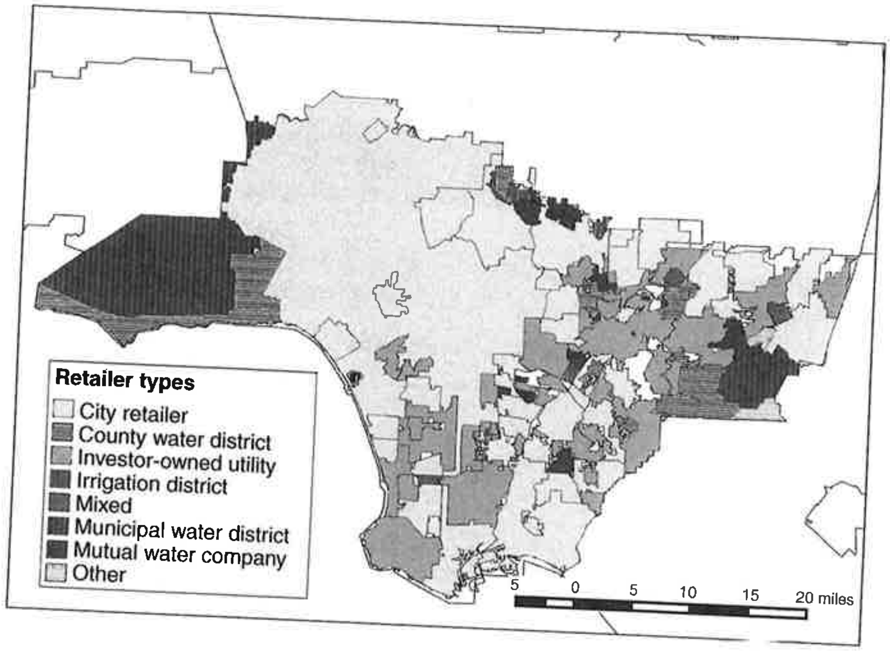

Figure 4.2
The collection of public and private water retailers in Southern Los Angeles County. Retailers receive water from local and imported sources and sell it to end-users (source: California Center for Sustainable Communities).

Los Angeles has a diverse climate and geography. Areas in the surrounding mountains receive snow and significant rainfall, while most urbanized areas receive 10–12 inches of rain in typical years. Groundwater and imported water serve as primary water supply sources in the region. The City of Los Angeles in particular, the most populous jurisdiction, imports water from the Owens Valley and connects to the larger Metropolitan Water District of Southern California (MWD), which receives water from the Colorado River Basin and California's State Water Project.

Most communities receiving water from MWD also have other sources such as groundwater or recycled water. Many groundwater basins in the region are *adjudicated*, meaning that pumpers collectively codified allowable annual pumping limits. Agreements took decades, from the 1949 finalized agreement in Raymond Basin to the Six Basins agreement in 1989. These rights to pump groundwater can be transferred among parties. Comparing the distribution of pumping rights at the time of adjudication and today, in each region of adjudicated basins, pumper rights have become increasingly consolidated among larger organizations, and controlled by organizations that are public (cities, special water districts) or publicly regulated (investor-owned utilities regulated by the California Public Utilities Commission).

The trend towards public control and oversight of groundwater in Los Angeles illustrates the complexity of assessing public and private control questions in water. Individuals, private companies, cities, and public agencies all control groundwater rights. Further, groundwater is only one supply source for the arid region. Examining shifts in public and private control of water supply in Los Angeles must also consider changes in public regulation of utilities, municipal tax laws that govern available funding, availability of imported water, and interstate politics. For instance, in 2015, a California Court of Appeal ruled that tiered pricing structures for municipal water services in an Orange County community violated a 1996 statewide proposition, Proposition 218, requiring voter-approved tax increases and local spending linked to the cost of services. Thus, while public agencies retain many duties for supplying water in Los Angeles County, they operate within a system influenced by public and private decisions along with climatic events. Municipalities face many types of constraints that go beyond discussions of public or private provisioning that influence their ability to deliver reliable services at acceptable costs.

***Table 4.3* Comparing changes in pumping rights over time for major LA County groundwater basins**

		West Coast	*ULARA**	*Six Basins*	*Raymond*	*Main San Gabriel*	*Central*
Judgment	Private	13,486	0	0			
	Public	0	55,970	6,657	29,140	9,252	35,335
	Publicly regulated	15,743	0	6,705	2,299	33,400	46,598
	Non-profit	0	0	2,972		11,025	
	Total	29,229	55,970	16,334	31,439	53,677	81,933
Current	Private	9,549	0				
	Public	19,495	279,671	12,740	36,397	22,565	86,495
	Publicly regulated	35,039	0	6,888		24,613	13,029
	Non-profit	0	0	5,467		17,747	
	Total	64,083	279,671	25,095	36,397	64,926	99,524

Source: Porse et al., 2015.

Notes

Comparison of pumping rights from judgment (1949–1998) to current (2011–13) among the top five rights' holders in selected LA County groundwater basins. Pumping rights are increasingly consolidated among larger users and under control of public agencies or publicly regulated utilities. Pumping rights include adjudicated water rights, transfers or leases, and return rights for irrigated water.

* ULARA extraction rights have significantly increased from accumulated storage accounts for the major rights holders (cities of Los Angeles, Burbank, and Glendale), but they are currently not able to extract this entire amount due to overdraft and low groundwater levels (LADWP 2010).

Conclusions

In recent decades, U.S. cities have resurged through revitalization and gentrification of older core areas. They increasingly emphasize goals of sustainability and resilience in long-term management. This offers a timely opportunity to reconsider the infrastructure systems, including water services, which shape the daily resource use patterns of urban residents. Public access to affordable, high-quality water for drinking and health is vitally important to maintain. Public agencies and utilities will continue to play an important role in providing and overseeing water services. Yet, to achieve sustainability goals in cities, private citizens must care about personal responsibilities. Strategies often discussed to improve future water management in cities, including on-site stormwater controls, water conservation, and fit-for-purpose approaches, all give residents and businesses significant responsibilities. Questions of public or private oversight become much more nuanced as we consider how to mesh the work of public agencies and private residents towards the broader goal of urban sustainability.

For further consideration

Questions

1. Particularly in California and the southwestern states, where long-term drought has become pervasive, citizen groups have lobbied for alternative methods of water sequestration and distribution at the scale of the house or city block. Public utilities have, however, rigorously opposed such *distributed systems* as unsafe and unworkable. What technical and social changes would be required to make distributed water systems both safe and workable?

2 Some observers have argued that the late nineteenth and early twentieth century infrastructure investments by older cities like Boston were too grand—too expensive to renovate as conditions changed, for example, when flush toilets introduced sanitary waste into a system designed only for stormwater. The resulting dual use system resulted in decades of public health emergencies. How and when might cities evaluate the cost of such basic systems knowing that changing ecosociotechnical conditions will require adaptation in the future?

3 Arguments for the privatization of municipal water, or electricity production and distribution generally depend on the assumption that for-profit management is more efficient, and thus more beneficial to citizens. How has recent history supported or falsified this claim?

4 How does infrastructure influence social relationships?

5 The "fit-for-purpose" approach to water supply recognizes that context matters—that maintaining a universal standard for water quality is unsustainable. In what other urban systems might a fit-for-purpose approach be applied?

A problem

At the meso-scale of a neighborhood in your city develop a phased infrastructure plan that would integrate production and consumption of water and electricity for the area. Take particular concern with the *water/energy nexus*, or how much electricity is expended in moving different qualities of water from place to place and how much water is expended in the production of electricity.

Note

1 In California, for instance, the state water quality control board, which oversees stormwater regulations, emphasizes the use of BMPs in municipal stormwater permits to retain water on-site. The County of Los Angeles goes further, promoting, whenever possible, on-site retention of runoff from all storms below the 85th percentile of likely rainfall amounts.

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