5

Natural Resource Supply and Scarcity

Securing Urban Drinking Water

> Nothing is talked of or thought of Croton in New York but Croton water; fountains, aqueducts, hydrants, and hose attract our attention and impede our progress through the streets. Political spouting has given place to water-spouts, and the free current of water has diverted the attention of the people from the vexed questions of the confused state of the national currency. It is astonishing how popular the introduction of water is among all classes of our citizens, and how cheerfully they acquiesce in the enormous expense which will burden them and their posterity with taxes to the latest generation. Water! Water! is the universal note which is sounded through every part of the city, and infuses joy and exultation into the masses, even though they are out of spirits (Diary entry of P. Hone October 12, 1842 (Hone 1889)).

Cities have faced a wide variety of resource shortage issues. Perhaps none is as profound as water supply. Without water, a city won't be able to function. Every city now present has faced or continues to face a concern over a stable and sustainable drinking water supply, and has likely faced several moments of water stress if not full out crisis. The objective of this chapter is to present case studies about how urban drinking water supply provision is a story of significant failure and success, and associated policy experimentation and transition.

5.1 Basics of Urban Water Supply Shortage

The earth is dominated by water (about 71% of the earth is covered by water), but the supply of fresh, potable water is relatively small. Only about 3.0% of the world's water is fresh water, and the vast majority of that is frozen

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in glacial ice. The amount that is flowing surface or groundwater supplies is around 0.5% of all the water in the world. And then considering that a significant amount of this supply is either in rural areas, already environmentally degraded by pollution, or in groundwater sites that might be difficult to extract, the amount of water available for city life and business is relatively small. The statistics vary depending on how it is defined, but current estimates state that about 2.1 billion people (~29% of the global population) lack access to a safely managed drinking water service and 844 million people do not even have basic drinking water service (WWAP 2019).

Water is a fundamental requirement for life. Humans need regular inputs of water to sustain bodily function. Besides this, water is needed for a variety of daily uses in cooking and cleaning, and more broadly across a range of societal uses. Urban water supply requires consideration of both water quantity and quality. Water should be of sufficient quantity and quality to meet the variety of water demands in cities. Agreements regarding water supply including formal and informal arrangements, policy, and laws often involve conflicts and compromise across a variety of interest groups and demands. The potential areas of tension are varied and include over the water rights (especially regarding access), obligations and responsibilities of upstream users versus downstream users, residential versus nonresidential uses (i.e., agricultural, commercial, industrial, transportation), common property users (e.g., commercial fishers, recreational fishers, and boaters) versus private property users, Indigenous water rights versus private property users, and current users versus future users.

Embedded within urban water conflicts and solutions is the role of the state – and how governments manage and resolve (or fail to resolve) water supply stresses and crises. Resolutions often focus on two modes of problem-solving – supply driven or demand driven. Supply-driven solutions involve large-scale adjustments to water supply infrastructure to increase supply and as a result require significant social and economic commitment to development and implementation. Demand-driven solutions focus on strategies and tactics to reduce water requirements of a specific sector or across multiple sectors. Demand-driven solutions can be initiated without large-scale infrastructure development but also typically require compromise or shifts in the overall allocation of water supply and as a result produce policy winners and losers.

Throughout history, humans have worked very aggressively to provide water for their settlements. Two basic terms are associated with this process. Water withdrawal is defined by the amount of water removed from a source. By definition, withdrawal amounts always are greater than or equal to consumption given that there is water lost during transfer. The second term, water consumption, is the volume of water withdrawn but not eventually returned to the source and no longer available for other local uses. That said, there are often conditions where water could be used and then returned to another water body as in the case of groundwater being applied to an agricultural field and then any excess washing off as surface water into a nearby stream or other water body.

The capacity to withdraw and consume water has expanded dramatically over time. Ancient civilizations built complex irrigation and water conveyance systems. For example, early Rome had about 11 major aqueduct systems, which supplied freshwater to the city from sources as far as 92 kilometers away (*57 miles*) (Khan et al. 2022). In the contemporary era, constructed water distribution systems can supply cities hundreds of miles or more from their source. Most significant is the use of interbasin transfer in which the water available in one watershed is conveyed through tunnel, pipe, or channel into another watershed. All these are mechanisms to increase the supply of water and overcome the relative scarcity of the resource. More dramatic efforts to meet water supply scarcity have been developed. Deep groundwater withdrawal into ancient aquifers and the desalination plants (which convert salt water into fresh water) are the most prominent examples.

5.2 Case Studies

The case studies presented illustrate conditions present in a variety of cities. Examples include cities in relatively water-scarce regions or where accelerated demand dramatically exceeded local supply. The case studies include Atlanta and New York City in the United States and Cairo, Egypt, and Tel Aviv, Israel, both in North Africa and Southwest Asia, respectively. Each case study will include background discussion and then an examination of how water supply emerged as an issue of stress and crisis and under what conditions a policy or management transition occurred or not, and to what extent the transition results in a transformation. The concluding discussion in the chapter focuses on the relevant analysis and implication of the case studies.

5.2.1 Atlanta, US

Metropolitan Atlanta has grown tremendously in the past half century. In 1970, the metropolitan region population was about 1.1 million and by 2020 the population was hovering around 6 million. Almost all of this growth took place in the extended suburban areas of the region. In 1970, the city of Atlanta's population was approximately 497 thousand (after a long period of growth), or just below half of the region's total population. Federal mandated racial desegregation led to a significant white residential exodus from the city. By 1990, the city had lost more than 100 thousand residents. Finally in 2020, the city had again topped its previous record with 500 thousand residents. The far-flung suburbs and exurbs brought tremendous rates of population growth in previously highly rural counties. As an example, Forsyth County north of Atlanta grew from 17.3 thousand residents in 1970 to 251.0 thousand in 2020. With this expansion also came rapid growth in residential water demand as well as a massive increase in local industrial and commercial activities as the region became a major national hub for transportation, trade, and manufacturing. Together these factors dramatically increased local water demand. The original siting for Atlanta came in response to an early 1840s ambition to site a critical railroad junction and in many ways is described as an accidental city (Borden 2014). The city and later the metropolitan region expanded across the Piedmont Region of North Georgia, where groundwater is scarce and surface water is limited to small, headwater streams with highly variable flows. Unlike many other large US metropolitan regions, Atlanta does not have access to major river tributaries or other large water bodies (Feldman 2009; Borden 2014).

5.2.1.1 Stress

The city of Atlanta and the metropolitan region have a humid subtropical climate with hot, humid summer and cool winter. The region experiences ample rain (1320 mm [52 in.] per year on average) with a consistent amount throughout the year, although slightly more during the winter months. Atlanta water supply infrastructure has been constructed around the premise of controlling headwater water resources of two large regional watersheds – the Apalachicola–Chattahoochee–Flint (ACF) and Alabama–Coosa–Tallapoosa (ACT) watersheds (see Figure 5.1). As a result, Atlanta's water supply depends heavily on two large nearby storage reservoirs at the headwaters of these watersheds built by the US Army Corps of Engineers during the mid-twentieth century. These reservoirs, Lake Lanier and Allatoona Lake, together provide much of the metropolitan region's water supply. At certain times of the year, over 90% of the supply. No reasonable alternatives to these reservoirs exist, and as a result, the metropolitan Atlanta region remained highly dependent on them. The conditions of the water detention and control by metropolitan Atlanta, and increasing downstream uses within each watershed, created a condition of chronic resource stress (Borden 2014). Atlanta's water demand was increasingly in conflict also with downstream uses in nonmetropolitan Atlanta parts of Georgia, and in the states of Alabama and Florida.

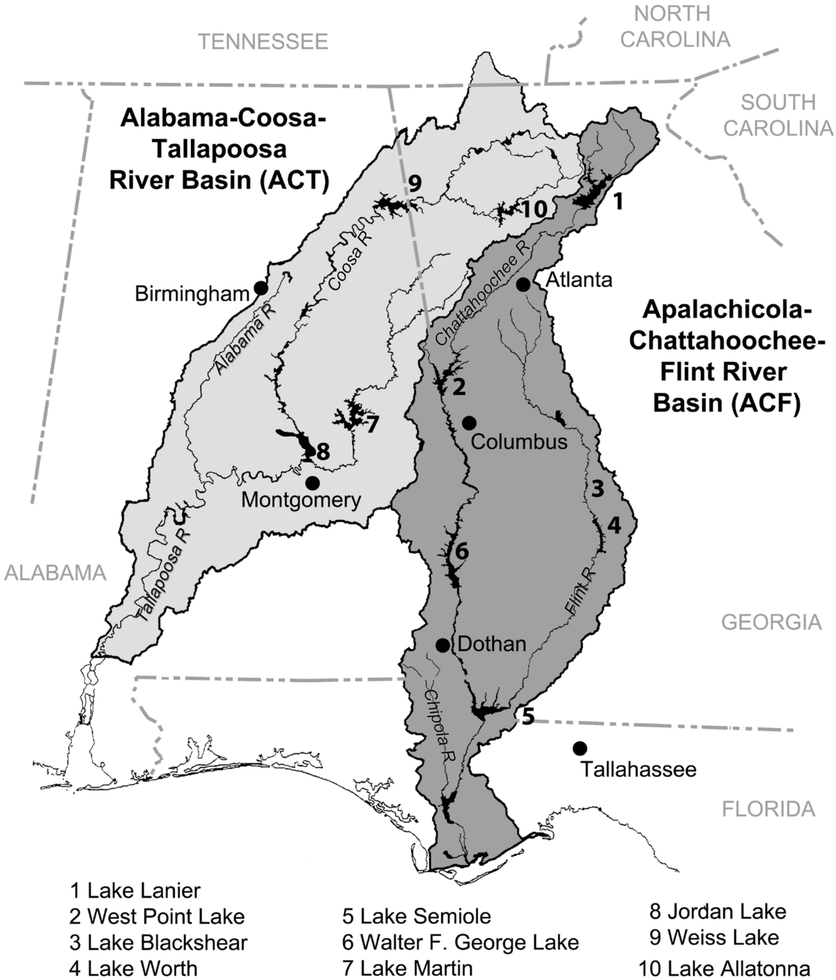

Figure 5.1 Map of ACF Basin and adjacent ACT Basin showing major urban areas and reservoirs. Source: Tri-State Water Commission

A drought in the 1980s alerted the region to the growing conflict over water and further highlighted the US Army Corps of Engineers' critical role in managing its reservoir function and meeting Atlanta's growing water supply demands. Beginning as early as 1983, the three states and the Army Corps took part in several collaborative forums in an attempt to forge a new water allocation agreement. The three states initially agreed to work together, but by 1990 Alabama filed litigation against Georgia (Ruhl 2005). Controlling the flow of water in Atlanta's reservoirs to quench its thirst meant less water for hydropower generation in Alabama, agricultural irrigation, and interrupted

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the natural flow regime critical for the Apalachicola River and Bay ecosystems and their oystering industry. By the late 1980s, these states and the Army Corps of Engineers became part of a growing litigation effort to challenge metropolitan Atlanta's efforts to impound and divert even more water (Ruhl 2005). Metropolitan Atlanta in the 1990s was able to further strengthen its policy of securing water supply to meet present and future demands (Ruhl 2005). During this decade, a series of legal judgments and agreements backed by the US Army Corps continued to support the competing allocation and riparian interests in check until the second half of the 2000s (Glennon 2010; Atlanta Regional Commission 2023).

5.2.1.2 Crisis

An extended drought beginning in 2004 resulted in Lake Lanier water levels to fall 4.6 m below its peak stage by October 2007 (Glennon 2010). Atlanta's need for ever-increasing amounts of water supply had become especially evident during an intense regional drought in 2006–2007. During this specific drought, local reservoirs already began to operate under exceptional drought operations. By 2007, the drought continued to worsen. The reduction of stored water in the reservoirs pushed the chronically stressed water region into a severe water crisis. It was predicted that Lake Lanier would go dry within 3–4 months (Corn et al. 2008). While the drought continued until 2008, its severity diminished by early 2009 as rainfall and lake stages returned, with more typical conditions returning by late 2009 (Figure 5.2). The immediate water shortage and crisis receded, but the events of the previous years set off an intense conflict in what has been defined as the "Tri-State Water Wars," pitting mostly Alabama and Florida against Georgia, generally, and metropolitan Atlanta, specifically. This reduced the release from upstream reservoirs and in turn threatened to damage the interests of downstream users and endangered species.

5.2.1.3 Transition

The crisis set off protracted additional legal battles between the three states. A central issue was that earlier legal settlements had put in place agreements that needed to be continually revaluated as Atlanta's dramatically increasing demands placed greater pressure on the system. At the same time, downstream users in Alabama and Florida argued that their water demands also needed to be met. This reevaluation and contestation led to a policy transition that was finally codified, more than four years after the end of the drought. Atlanta's right to fully utilize the Army Corps water supply and reservoir projects was not established until 2012, when the competing claims were finally formally

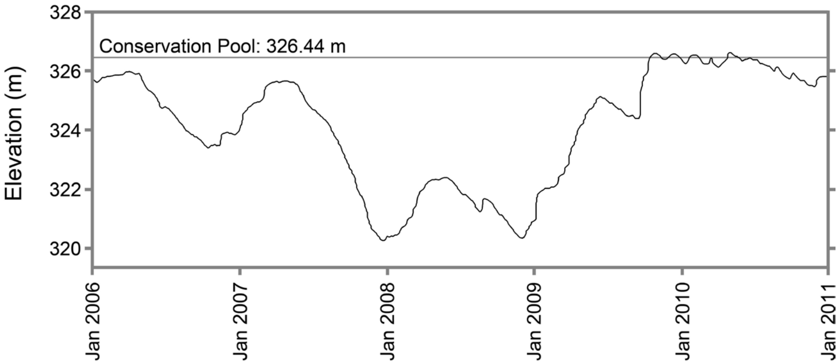

Figure 5.2 Diagram showing the stage variation of Lake Lanier from 2006 to 2011 (Anonymous 2013). Note the extremely low stage of the lake during the late 2007 and early 2008, and again at late 2008.

resolved. After a series of earlier cases, parties to the litigation against the state of Georgia appealed a lower court decision (i.e., US Court of Appeals for the Eleventh Circuit in *In re TriState Water Rights Litigation*) up to the US Supreme Court. On July 6, 2012, the Court declined to hear the appeal, thereby affirming the lower Circuit Court's decision (Tonsmeire 2012; Jones et al. 2013; Missimer et al. 2014). This, in effect, created a new policy precedent and provided Atlanta via the State of Georgia the capacity to meet its own water supply demands. On the very next day (July 7), the USACE then decided that it had jurisdiction in this situation to reallocate the reservoir water use without securing additional congressional authorization. Given this, the Corps could decide on a reallocation plan for water uses in each watershed basin and, in turn, ultimately how much water could be allocated for power production, recreational use, environmental flows and reservoir maintenance, and for water supply (Jones et al. 2013; Missimer et al. 2014).

5.2.1.4 Transformation

The droughts and 2012 judgment set in motion fundamental change in the region's water supply. In 2013, the state of Florida offered another lawsuit against Georgia to test the 2012 ruling. While elements of this suit remained unresolved, the conditions of the 2012 decision were upheld, and Atlanta continues through the action of the US Army Corps to maintain a steady supply of water. The region has not experienced any drought approaching the levels of the late 2000s. Even so, water conservation efforts were put in place and per capita water demand in Metropolitan Atlanta has declined by approximately 10% over the past decade and by more than a third since the early 2000s

(North Georgia Water 2021). This further diminishes the likelihood that Atlanta will suffer a similar water crisis in the future.

5.2.2 Cairo, Egypt

Cairo is an ancient city with settlements in the area going back several thousand years. The origin of contemporary Cairo began approximately 2,000 years ago. The city and development have always been tied to the Nile River as a site of transport and as a source of water in an otherwise desert environment in which it typically receives 25–50 mm of rain per year (1–2 inches). The city first grew on the east bank of the Nile, but soon thereafter the west bank was developed, and now new development has spread out in almost all directions. The metropolitan population was approximately 2.5 million in 1950; 13.6 million in 2000; and the 2020 population just under 21 million (UN – World Population Prospects).

5.2.2.1 Stress

In low- and middle-income countries such as Egypt, the formal water supply system infrastructure often cannot meet current and growing demands and can be understood as operating in an ongoing state of crisis in which flow interruptions, low water pressure, and other informal systems make up for the deficiencies. These systems resolutions put in place are implicit or explicit recognition that the system operates in a deficit state. The case of Cairo helps to illustrate how difficult it is for water systems to forestall critical transitions and in turn achieve positive transition after being positioned in a steady degraded state. For Cairo, Egypt, the main water supply system was originally built out to meet the demands of approximately 2 million people (El Araby 2002). Cairo's metropolitan population is now over 20 million, and the amount of water demand far exceeds the volume conveyed by the formally established system, even though the central Egyptian government and local government have made great strides to increase the amount of water supply delivery in the past several decades (Ashour et al. 2009; Mohamed and Jagannathan 2009).

Egypt and Cairo have both been described as "gifts of the Nile," and as a result, the supply of water has not been the limiting factor for city water managers – two chronic stresses have been building a robust system to convey drinking water to the city's residents while at the same time protecting the quality of water so that it maintains its potability. British engineers, in the early 20th century, were concerned about how to maintain water quality and enhance the water distribution system in Cairo (Anonymous 2008). The initial construction of the contemporary water supply system in Cairo took place during the latter part of the nineteenth and early twentieth centuries during the period of British colonial control.

5.2.2.2 Crisis

By mid-twentieth century, Egypt was going through a series of dynamic changes, including a post-World War II development boom, a political upheaval with a deeply involved socialist experiment, followed by an increased expanse of the capitalist economy. In the 1960s, the population of Cairo grew at its fastest rate at over 5% per year – equivalent to a doubling time of only 14 years. The significant population growth, largely uncontrolled urban expansion, and degraded river water quality set in motion a crisis associated with the structure and capacity of the Cairo water supply system (Raymond 2000; El Araby 2002; Sims 2003; Allen et al. 2006). In Egypt, much of the growth during this era took place without any formal planning effort or Cairo government oversight (Sims 2003). The system faced further pressure from the noted decline in the Nile River water quality and the recognition that the quality was being further compromised by uncontrolled sewer seepage into broken or otherwise deficit pipes and by the fact that many of the distribution pipes were made of or contained significant amounts of lead (Ashour et al. 2009; Mohamed and Jagannathan 2009). A late 1970s assessment of the Cairo water facilities found significant deficiencies in the water supply infrastructure and service provision. Much of the infrastructure was found to be in poor repair and lacking the necessary capacity to serve the population already connected to the networks (Hoehn and Krieger 2000).

5.2.2.3 Transition

Starting in the 1970s and accelerating into the 1980s and 1990s, the Cairo water supply system became the focus off huge capital expenditures largely coming from increased foreign aid (Hoehn and Krieger 2000). The expenditures brought a dramatic extension of the distribution infrastructure and construction and expansion of 13 water quality treatment facilities along with the building of many primary and secondary sewerage treatment plants. A master plan was presented to execute a phased-in implementation of a greater Cairo waterworks project, starting from 1977 to 2000 (ECG N.D.). The plan addressed domestic, industrial, and irrigation needs of the served areas. The effort included the development of high-priority projects that could be developed immediately to improve the existing conditions in parts of the city and region not adequately served by the existing water system.[1] The Greater Cairo

[1] The Cairo water supply system consisted of about 2,500 km of mains and branch lines (compared to New York City that had 10,950 km of water mains).

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Waterworks Master Plan attempted to address several key areas of improvement, including a 24-hour flow measurement infrastructure, inspection and evaluation of the water meter infrastructure, a comprehensive leak survey program and water wastage survey program, and recommendations for a water conservation program. By 1996 about 80% of the residents had access to piped water (Attia 1999). At the same time, 56.4% of households lived in informal settlements on former agricultural or desert land (Sims 2003), indicating a continued pressure on existing and expanding water supply provision. By the latter part of the 2000s decade, the Cairo Water Authority officially cited that over 90% of the city's residents were connected to piped treated drinking water (Mohamed and Jagannathan 2009; Ashour et al. 2009). At the same time, other major problems persisted. The extension of the municipal water network was accompanied by a lack of maintenance, which resulted in 1995 high seepage losses reaching up to 40% of the delivered water (Attia 1999).

This period of dramatic build-up of the infrastructure directly responded to the crisis. The major investment in infrastructure could have promoted a positive transition (to significantly more robust access to useable water for Cairo residents), yet the rapid and largely uncontrolled urbanization process, coupled with the limited ability to develop and/or enforce planning and regulation, particularly in the dynamic periurban areas of the city, hampered the long-term robustness of the transition (Sutton and Fahmi 2001). Across the vast metropolitan region of Cairo, it is clear that the quality and quantity of piped water vary greatly. Some neighborhoods have relatively consistent flows and in fact could be considered as quite well advanced, while many other neighborhoods do not have consistent high-quality flow and more often than not go without any flow. For those without, intermittent and often lengthy periods of low pressure/no supply/varying quality push for consistent engagement with alternative informal sources of water.

5.2.2.4 Transformation

So while on paper, the period of water infrastructure expansion signified a transition, the actual situation for consumers is generally not so positive, and the period of transformation actually led to a different trajectory. Even with the expanded infrastructure, a large number of households lacked sufficient water pressure, water of quality to safely use, or even easy access to water (i.e., water might come to one central tap in a building). The poor, often in high-density neighborhoods, were particularly at risk to water shortages (Raymond 2000). In a survey of the Cairo slum neighborhood in the early 2000s (the Ezbet Bekhit neighborhood – an informal settlement of 37,000 residents) had roughly 60% of households connected to the public water system (Sims 2003). For those connected, the water costs were relatively inexpensive, but the water pressure was frequently zero and when flowing, the water quality was low. Forty-two percent of those connected households had no monthly cost for water – meaning that they received no water through their pipes. Households not connected had to rely on a variety of means to get water, including private caterers, informal networks, and quasi-legal/illegal appropriation of water with noninfrastructure-related water delivery processes (e.g., water trucks, bottled water). In many cases, these strategies provided water in an irregular fashion (i.e., limited time, low pressure) and often contaminated water that spread illness and disease. In Ezbet Bekhit, "borrowing" water from more fortunate neighbors or purchasing water from local vendors at rates up to 27 times the national rate for metered potable water was most typical. The situation was similar for the sewerage network. Sewerage was first introduced in the late 1970s and possibly 40% of households were initially connected. The population growth made even this minimal system completely inadequate and as of the early 2000s, most households relied on "soak-away pits" – equivalent to outdoor privies that needed regular emptying by cart or suction truck.

5.2.3 New York, US

New York City is a global center for commerce and financial services. Its history as a trading site stretches back to its origin as a Dutch colonial port in the early 1600s. The natural setting of New York City generally (the five boroughs or counties that comprise it) and Manhattan Island specifically (the island onto which the initial European settlement grew) provided abundant resources for its human inhabitants. Manhattan looked out onto one of the best natural harbors in the world and was rich with forests, wildlife, and freshwater. Sanderson (2009) in his masterful recreation of the 1609 landscape of the island writes that its biodiversity and natural beauty would make the setting one for a national park or conservation area.

By the end of the American War of Independence in 1783, the city had already emerged as the major port of the new country. Its status as significant was greatly accelerated with the opening of the Erie Canal through western New York State in 1825, which opened the interior of the rapidly growing country to Atlantic trading partners by way of the port of New York. From 1790 to 1830, the population of the city grew from 33,131 to 202,589. The city remained as a highly concentrated settlement at the southern end of Manhattan, only extending approximately eight kilometers north of the Battery, the extreme southern tip of the island. This growth and associated rapid economic expansion put tremendous pressure on the local resources of the city and its immediate environs.

5.2.3.1 Stress

The original source of drinking water for the city was local streams, ponds, and springs. The first one and a half centuries of the city's existence, water supply was provided by a largely ad-hoc system of first private wells, later supplemented by public wells. Locally disposed of waste eventually polluted many of these wells. By the late 1780s, many of the local wells in the city had become polluted and cumbersome water delivery systems became necessary (Galusha 1999; Koeppel 2001). Well-water shortage was a chronic problem.

The next half century, roughly from early post-US independence through 1830, was marked by a series of failed private sector interventions to address the chronic water quantity and quality concerns. More frequent and more intense waterborne disease outbreaks began to affect the city. The idea of bringing fresh water from great distances into the city was first proposed in the late 1790s. The Manhattan Water Company was established to supply the city with fresh water and was chartered to provide fresh water from the Bronx River, approximately 40 kilometers north of the city. Instead, the company opted for developing large wells within the city near the Collect Pond (Swaney et al. 2012). As one of the main sources of local surface water, the Collect Pond also experienced a decline in water quality with increased development and a lack of water supply protection. Attempts at increasing supply via private carters and companies proved ineffective, inefficient, or fraught with corruption. Access to fresh drinking water became increasingly an issue of inequity – the wealthy could afford the clean water brought into the city while the poor and immigrants often could not. The city developed a series of local-scale actions involving the modest expansion of existing water conveyance and storage capacity to resolve the issues, all of which failed to foster a large-scale system shift. The city's water supply was in a degraded state not unlike that of contemporary lower-income countries' city water supply systems.

5.2.3.2 Crisis

The water supply crisis of the city emerged steadily through the 1820s and into the 1830s. A series of significant disease outbreaks fed by the use of foul water and building fires that spread because of a lack of adequate supply for fire suppression racked the city on a regular basis (Solecki et al. 2025).

By the early 1830s the situation had become increasingly difficult and reached a heightened level of crisis. The system had become unable to meet the increasing demands for change. The rising international and national trade through the city accelerated with the opening of the Erie Canal brought a dramatic increase in the number of disease outbreaks often associated with infected cargo – for example, cholera outbreaks hit the city in 1832, 1833, and 1834. The demands for more sustained supplies of high-quality water further grew with rapid economic and demographic expansion at the same time. The circumstances became untenable with the additional burden of providing sustained supply for water for fire suppression for a city mostly built of wood structures. It was concern for fire losses that eventually brought a coalescence of support for a new path forward, especially through an alliance of the city's new and emergent wealthy entrepreneurial classes. The fires had been ravaging their neighborhoods and businesses and it became clear to them that large-scale transformative action needed to be taken (Burrows and Wallace 1998).

The lack of sewerage removal made the situation worse. By 1830, Tarr (1996) estimates that "human sewage was being generated in privies, cesspools, or open pits and migrating, untreated, into waterways at a rate of nearly 100 tons per day." The problem was exacerbated by the significant number of horses and other livestock in the city at that time and the associated large volume of manure that was deposited on the streets every day, very little of which was removed regularly and would accumulate along with other organic wastes. Swaney and others (2012) estimate that the horses in the city in 1825 created an estimated 270 tons of manure per day.

5.2.3.3 Transition

The failure of the early initiatives and impediment to large-scale water management shifts largely emerged from an entrenched alliance of the largest and highly dominant private water company (the Manhattan Company) and the northern Manhattan property owners (Burrows and Wallace 1998). The northern three quarters of the island remained farms, fields, and forests and ready for urban development. With fresh water piped to the city, they feared that development would continue to be clustered in lower Manhattan and demand would decline for their northern Manhattan homestead properties with ample water and other positive amenities – for example, relief from the disease, dirt, and congestion of the city.

The new coalition of business leaders recognized the need to fundamentally restructure the city's water supply system and create a new system. The resulting action was the wresting of control for water provision for the city from private to public hands and a public referendum that called for funds to be raised to construct a totally new and massive reservoir and water distribution system (i.e., the Croton system in remote rural highland areas approximately 40 kilometers north of the city) to bring abundant supplies of fresh water to the heart of the city by the early 1840s. When the water was officially turned on in 1842, a five-mile parade in celebration took place.

5.2.3.4 Transformation

A series of dynamic transformations occurred as a result of the city's new reservoir and long-distance water conveyance system (Gandy 2003; Solecki et al. 2025). Water consumption immediately increased and indoor plumbing was added to many buildings or at least water pumps outside of lower-income residences soon appeared. While disease outbreaks and large-scale fires remained an issue, their frequency and intensity began to diminish. One of the genius elements of the Croton system was that it was designed to be added onto, and within decades, planning began to significantly expand the city's water supply. Two additional reservoir systems (i.e., Catskill, completed in 1924, and Delaware, completed in 1954) were developed on lands further away from the city. The current system has a storage capacity of 2.1 trillion liters and provides over 4.5 billion liters per day of drinking water for approximately 9 million people as well as the business and commercial establishments in the city and in several outlying municipalities, which are connected to the system.

5.2.4 Tel Aviv, Israel

Tel Aviv, Israel's largest city, has a metropolitan area population (Tel Aviv-Jaffa in 2021) of 4,264,000. While Tel Aviv's origin is relatively recent (founded in 1909), the history of Jaffa, or Jafa in Arabic or Yafo in Hebrew, goes back almost 4,000 years. Tel Aviv grew quite dramatically in the twentieth century, during which it eclipsed Jaffa in population and economic significance. The current population of Tel Aviv is about 460 thousand with Jaffa and numerous substantial, adjoining suburban municipalities making up the rest of the metropolitan region. The metropolitan region serves as the economic and technological center of Israel. The history of water supply in Tel Aviv-Jaffa has been deeply connected to that of the country of Israel since its founding in 1948. Feitelson (2013) describes four phases of water supply policy in Israel – each one responding to different stresses. These include the hydraulic mission period (1948–1964); the wise management era (1959–1990); the reflexive deliberations era (1990–2005); and the desalination and privatization era from 2005 to the present. Each phase has been associated with crisis, and the last phase emerging from a profound transition.

5.2.4.1 Stress

Water supply and scarcity have long been issues of concern in the eastern Mediterranean region generally and for the city of Tel Aviv and the country of Israel (Tal 2017). Much of the country can be described as a desert and as such

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receives 250 mm (10 in) of precipitation per year or less. Tel Aviv has a climate more similar to a Mediterranean climate and receives about 580 millimeters (23 inches) per year with typically all of it occurring outside of the summer months and especially in the winter months. The north of the country typically receives more rain while the south receives less with the southernmost city of Eilat getting less than 50 mm (2 inches) per year.

The threat of water shortage presents an existential threat to the security of Israel and as a result has been deeply embedded within its national agenda. The focus on securing water supply has focused three broad strategies that have emerged sequentially. Each of the three broad strategies emerged as a result of policy debates and transitions. The initial focus was on securing the maximal amount of water supply from existing surface and groundwater supplies with specific attention to reducing water loss during the bulk infrastructure transfer to a minimal amount (~3% loss). The second was on recycling and reusing water as much as possible, and the third focused on expanding the supply of water – particularly through the use of desalinization.

With the country's founding, water supply in Israel was associated with a series of substantial stresses and national strategic plans focused on national resource development. It immediately became a high-priority national security issue and in turn established direct connections to the military establishment and as a resource that needed to be heavily protected. The focus on national security was heightened when Israel was prevented by United Nations action from extracting water from the upper Jordan River and instead was required to extract water from Lake Kinneret (Sea of Galilee). As early as the 1950s, Israel began an extensive water supply development project that would convey fresh water from the Sea of Galilee southward across the country to various demand sites, including Tel Aviv at some 150 kilometers distance (Thi Hoang Duong et al. 2011). This was also designed to overcome the wide disparities in the spatial and seasonal variability of rainfall. The innovative system allowed for the storage and conveyance of water from the wetter north to the drier center and south – the main agricultural areas. Since the country is relatively small, only about 22,140 sq km (8,630 sq mi.) and comparable to the size of the US state of New Jersey, the distances to move are significant but proved not to be insurmountable.

In this early formative era, the rapid and extensive expansion of water resource infrastructure was carried out by a small and cohesive policy community of experts. Water engineers, who were affiliated with the national labor movement and the agricultural sector, dominated this community. Within this technical elite, fierce struggles emerged that resulted in a shift of the dominant view of how water resources should be managed (Alatout 2008). Water was

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no longer seen as an abundant resource that could be exploited and utilized but as a limited and scarce resource that has to be carefully managed. The notion of scarcity emerged as the central narrative of the Israeli water development community (Feitelson 2013).

Starting around 1960, Israel began an aggressive water demand management strategy to use water more efficiently. The policies included pricing and economic policies, reuse of sewerage effluents, water conservation/improving efficiency of water use, agricultural water use innovations including drip irrigation, water markets and pricing strategies, virtual water policy including the importation of high water-demanding agricultural crops (that lowered the need for domestic use of water to produce those crops), and water metering and a national water licensing and allocation system (Arlosoroff 2003). This second phase of national water planning proved to be quite successful in forestalling radical water management transitions. By the late 1980s/early 1990, the volume of water use and Gross National Product per capita had increased dramatically in Israel, but the amount used per capita only slightly increased during the same time.

5.2.4.2 Crisis

Even with its sustained state of water resource stress, it took several large-scale droughts in Israel to foster the political will to take on even more ambitious water reforms that led to a realignment of water governance and illustrated the growing importance of nonagricultural water use sector, especially in urban areas of the country. Up through 1996, the water sector was managed by the national Ministry of Agriculture. The policy priority was to rely on natural surface and groundwater resources to meet all water demands (and over-pump as needed), with the agricultural sector remaining as the largest user. Shortages or deficits were handled by reducing water supply to farmers during droughty periods and expecting a following rainy period to refill water resources. Water supply was heavily subsidized, as example tariffs on water use were held very low for farmers. Domestic water supply and wastewater collection also were heavily subsidized. The consistent population growth and an increasing diversity of demands eventually showed an approach ever less sustainable. All these factors together meant that the Israeli water sector existed in a permanent state of heightened vulnerability (Marin et al. 2017).

Within this context, three periods of water crises eventually built the momentum for major demand and supply-side reforms in the 2000s. First, in 1986, a major drought for the first time caused a significant reduction in water allocations for agriculture (15%). This drought was soon followed by the even more significant 1989/1990 drought that required severe and widely unpopular water restrictions. These conditions were rapidly forgotten because, as had been the pattern, the drought was immediately followed by an extremely rainy winter in 1991–1992 (i.e., 1 in a 150-year event) that entirely replenished natural resources. A third even more severe drought happened soon after in 1998. During this event, water shortages affected not only agriculture but also municipal and industrial consumers, resulting in severe water shortages and even rationing in most cities in Israel. The 1998 drought and water crisis created a sense of urgency and a political window for action, eventually triggering far-reaching policy changes (Feitelson 2013).

5.2.4.3 Transition

In 2000, the Israeli national government changed the policy for water sector management. It adopted a more sustainable approach to help guarantee the country's water security. The policy shift included the creation of a special committee tasked with the responsibility to develop a plan to gradually establish over the next 15 years a new institutional framework for water management. Central to this new approach is the acceptance of a technological fix – the utilization of desalination plants and a set of policy reforms, which required years of implementation and refinement in order to optimize results. These actions required difficult political decisions, such as a steep increase in domestic use water tariffs, especially in response to another major drought, which took place in 2008. The policy shift also helped generate a series of innovations that eventually restored a sustainable water balance for the country and its rapidly growing urban areas such as Tel Aviv.

5.2.4.4 Transformation

To extend these supplies, Israel actively worked to recycle its water for secondary uses. In general, urban water is sent to wastewater plants and recycled for agricultural uses. In the last two decades, recognizing the potential for future water shortages Israel began an aggressive program building water desalination plans. The new National Water Carrier pipeline conveys desalinated potable water throughout the country from five plants along the Mediterranean coast. This transport represents approximately 75% of all the potable water transmitted by the national water company – Mekorot. Desalination is expected to help meet all future growth in domestic and industrial demand. This production would also generate a significant increase in the amount of reusable treated wastewater for the agricultural sector and public works. As of 2010, Israel was the global leader in the proportion of water it recycles. Israel treats 80% of its sewage (400 billion liters a year). From the Tel Aviv metropolitan area, 100% of the sewage is treated and reused (Figure 5.3).

Figure 5.3 Israel's national water infrastructure grid. Source: Tal (2006).

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5.3 Discussion

Significant water scarcity is possibly the most important and fundamental crisis for cities. The case studies reveal how this stress and the resulting crisis can result in a policy transition and transformation. A striking thing about water crises in cities is that they have an ancient history and as a result it is an issue well understood and known to all segments of the population. It is comparative luxury of the current era that many urban residents throughout the world whose tap water is regularly supplied do not appreciate the widespread fragility of drinking water supply. The loss of sustained water supply for cities represents an existential threat, as opposed to a quality-of-life issue. In all the case studies, the response to the crisis and eventual transition was built on a series of responses to earlier stresses and pending crises. This pattern of flexible response and engagement emerged episodically in earlier moments as the situation neared an acute crisis. In these earlier moments, the solutions only partially resolved the issues, thereby requiring further future action as a new crisis, often more dire, emerged. It is interesting to note that earlier proposals to resolve the issues typically first solved by supply-side management options (i.e., focused on increasing water supply) while the eventual solutions also focused on demand-side management (i.e., reducing consumption demand).

5.3.1 Conditions of Crisis

While some crisis issues are specific to each case study, similar tendencies are present across the four city examples. For instance, all cases illustrate how the water supply issue is dynamic and requires consistent focus on it, especially as population expansion and resource demand increase take place. The studies provide evidence that stress is often not enough to motivate action and significant action occurs only with the onset of crisis. It should be recalled that in all cases, resource stress had a significant impact on a wide range of populations and interests, but neither the extent nor the intensity was enough to motivate a systemic response. The evolution from stress to crisis often was expressed as a shift from specific locations and moments of water shortage to more frequent and widespread shortages.

An interesting turn in focus also occurred during this shift from stress to crisis. In general, initial proposals and responses were more reactive during the stress and early crisis periods. The efforts became more proactive later as the crisis became more significant and the need and ambition for more larger-scale proposals emerged and were agreed to. The idea of making substantial and durable solutions became central to the transition and the evolution of the transformation. A consensus seemed to emerge that as long as change was occurring, it should be sizable enough that it would not have to be dealt with again anytime soon, given the effort and energy to create the conditions for transition in the first place.

Overall, the threat to economic development was a huge factor motivating action, in some ways more significant than health and safety concerns. Overall, business interests were significant in driving the stress to become a widespread crisis. The definition of the crisis was driven by the connection between the private sector and public sector, which typically involved the private sector seeking out the public sector to address their concerns, as especially evident in New York City. The crises were also sharpened by external factors, which became more important over time. In the case of Israel generally and Tel Aviv specifically, water was a critical security issue and any threat to it became an existential threat to the fledging nation. Cities such as Tel Aviv and also Cairo and New York benefited from their position within an extensive national and regional water supply infrastructure and from the intense concern regarding national development and stability.

5.3.2 Drivers of Transitions

In all cases, examples examined, it was eventually acknowledged that the scale of operation would have to be changed to address the crisis – that is, a need for a bigger and more extensive water supply system. The new policy regimes that emerged from the crises required the application of technology to change the scale of operation. New coalitions and governance structures were formed to address the emergent demands, and in this context, the capacity and engagement of the state (i.e., local, state/provincial, and often national government) were critical to the development and implementation of the new policy. A wide range of root, context, and proximate drivers were observed in the case studies (Table 5.1).

5.3.3 Spheres of Action and Legacies

All three types of systems – social, ecological/environmental, and technological/infrastructural – are present in the case studies and had critical roles to play in the crises and transitions. The three systems are tightly coupled with droughts playing a highly significant role in the emergence of the crisis. Given the central importance of the water storage via reservoirs and conveyance via aqueducts and piping, infrastructure systems have an oversized role to play in the case studies. The political ecology of how and under what circumstances

Table 5.1 *Key drivers observed in each case study. Source: Author.*

	DRIVERS		
Case Study	Root	Context	Proximate
Atlanta	Relative scarcity; lack of water at the Atlanta settlement site; transboundary conflicts between the states of Georgia, Alabama, and Florida	Competing economic interests; agricultural and fishing versus urbanization; legal precedent	Droughts
Cairo	Lack of governance capacity; water quality decline; rapid informal urbanization	Foreign aid, lack of adequate infrastructure	
New York	Water quality decline; failed private sector management; rapid urbanization and growth (with the Erie Canal opening)	Competition between real estate and merchant classes; economic inequity; lack of sewerage management	Inability to control urban fires; waterborne disease
Tel Aviv	Absolute water scarcity; transnational competition for water; national planning efforts to promote water supply	Shift from military control to civilian control of water; competing economic interests: agricultural versus urbanization; availability of new technology – desalination	Droughts

decisions were made to develop new infrastructure came as a result of shifts in power alliances backed by legal precedents. In all cases, the legacy of past decisions that legitimated longstanding water supply agreements played a significant role in forestalling resolutions before the widespread crises emerged. These agreements also had been directly connected to water supply infrastructure, which, as a fixed asset, also influenced how the initial stages of the crisis were understood. Thereby, the question was often asked, "Could the crisis be solved with the existing infrastructure or at most a minimal restructuring of it?" Here, the initial focus was on minimal adjustments and incremental fixes as a way of avoiding a massive restructuring of the system and equivalent investment and disruption. Once it was recognized that these steps would not be sufficient, the motivation for a larger, more substantive action and policy shift became evident.

5.3.3.1 Urban Water Supply and Climate Change

Climate change already is having observed impacts on urban water supply, and the projections are for increased impacts with more significant climate heating (Dodman et al. 2022). The physical changes include rainfall variability (more droughtiness; more extreme rainfall periods and events) as well as saltwater intrusion into coastal groundwater supplies. Vulnerability of urban water supply to climate change is dependent on existing deficiencies in the water supply infrastructure, the age of the infrastructure, the growth rate of water demand, and the response capacity of the city. Climate stresses are exacerbating existing urban water supply vulnerabilities and inequities (Dodman et al. 2022) and will continue to do more in the future.

The analysis of the urban supply crises examined here provides some insights that might be of interest for urban practitioners, managers, and other stakeholders. Specific recommendations include the following:

- Prepare local; plan regional – climate change-driven shortages often will be experienced in localized areas, either in specific neighborhoods or individual cities. While it will be important to recognize and prepare for immediate and site-specific crises, the case studies illustrate that solutions to these will be likely regional in nature. Collaborative region-scale solutions to urban water supply will be needed to resolve the chronic problem of water supply.
- Droughts and other related supply crises as windows of opportunities – water supply shocks can become powerful vehicles for the debate and progression of new policies and significant policy changes. Urban water scarcity is perceived as and remains an existential threat to city life.
- Need to focus on infrastructure – while demand-side management and reducing water consumption are important much of the attention among stakeholders and the general public during crises will be on the inadequacy and deficits of the water supply infrastructure.
- Legacy – the legacy of past decisions becomes very significant in the discussion and debate of new and emergent policies. This is especially critical for urban water supply systems that are dependent on capital- and labor-intensive projects that once built are difficult to alter or redesign. These features simply then become the foundation for future initiatives to be built on or connected to.
- Water shortages become existential – the actual or perceived water shortages will become portrayed as an existential threat to the city and broader region.

- Coalitions will form around urban water supply issues – the magnitude and importance of water supply deficits will bring together coalitions of interest groups and in some cases, these will be unusual groupings or groups that previously have not worked together. These coalitions can be quite politically powerful and collectively overturn longstanding water management regimes.
- Incremental adjustments preferred – the initial response to an emerging urban water supply crisis will focus on incremental adjustments to the existing systems. Coalition groups likely would not immediately go for large-scale, transformative changes and will try to avoid them because of the large-scale investment and other elements of disruption. Alternative options often have a difficult time gaining traction because of their novelty, uncertainty surrounding them, and massive capital expense.