I

HISTORIC PARADIGMS OF URBAN WATER/STORMWATER/ WASTEWATER MANAGEMENT AND DRIVERS FOR CHANGE

I.1 INTRODUCTION

Since the onset of urbanization millennia ago, cities were connected to water resources, which were their lifeline. Without this connection to water, there would be no cities and, ultimately, no life. When water became scarce, cities were abandoned, and sometimes entire civilizations vanished, as exemplified by the history of the indigenous Hohokam and Anasazi peoples living in the southwestern U.S. in the 15th century, in communities of more than a thousand people—communities that lasted for about a thousand years, but were abandoned, most likely because of extensive drought and the failure of their irrigation systems. Obviously, there were several reasons other than water scarcity causing ancient cities to become ghost towns, then ruins, and finally archeological excavations, centuries or millennia later. Some were related to loss of soil fertility caused by a lack of water for irrigation or poor irrigation practices, which resulted in famine; epidemics of water-borne diseases; exhaustion of the natural resource that was being extracted; or contaminated water, for example, by lead in ancient Rome. Water scarcity is sometimes a result of poor city management and institutions that were inadequate to deal with the multiplicity of conflicting uses and demands for water. Urban waters provided navigation, fish and other seafood, power to mills, laundry, recreation for kings and other nobility, defense during siege by invading armies, and religious significance in some countries and cultures (e.g., India) where certain bodies of water are worshiped.

Water also cleans cities; in historic cities, rainfall washed away the deposits on the streets containing garbage, manure from animals, and human fecal matter. Rainfall and ensuing runoff were—and still are, in many urban areas in some countries—the main and often the only means of disposal of accumulated malodorous solids. During antiquity and the Middle Ages, rivers in sparsely settled rural areas were clean and abundant with fish. In contrast, the environment of ancient, medieval, and post–Industrial Revolution cities was generally filthy and polluted. Terrible epidemics plagued medieval cities, exacerbated by wars and famine. In one medieval epidemic, during a prolonged continental war in the 17th century, 25% of the entire European population vanished.

The situation of urban water resources during the 19th century and in the first half of the 20th century worsened. As cities became industrialized, pollution from industries and loads from reinvented flushing toilets in households (communal flushing toilets were known and used by ancient civilizations of Greece and Rome millennia ago) discharged without treatment into streams resulted in bodies of water devoid of oxygen and smelly due to hydrogen sulfide emanating from decomposing anoxic sediments and water. The response of city engineers and planners was to put the streams out of sight—that is, cover them and/or turn them into combined sewers. In general, until the 20th century, the water environment was not a major interest of architects, builders, or rulers/governments of cities. The people living in the ancient and medieval cities were obviously afraid of epidemics, but the connection between polluted water and diseases was not made until the second half of the 19th century.

The impairments in many urban rivers are caused by the typical characteristics of the urban landscape: a preference for impervious over porous surfaces; fast "hard" conveyance drainage infrastructure, rather than "softer" approaches such as ponds and vegetation; and rigid stream channelization instead of natural stream courses with buffers and floodplains. Under the current paradigm of urbanization, the hard conveyance and treatment infrastructure was designed to provide protection from storms occurring on average once in five to ten years; hence, these systems are usually unable to safely deal with extreme events and prevent flooding, and they sometimes fail with serious consequences. In addition, in many urban river systems, excessive volumes of water are being withdrawn and often transferred long distances, creating bodies of water with insufficient or no flow in some locations, and bodies of water overloaded with effluent and/or irrigation return flows in other areas.

In the mid-2000s, tsunamis and hurricanes struck coastal urban areas, creating catastrophes of enormous proportions. Although these events have occurred throughout history, the human and economic costs of these events were unprecedented. It became painfully evident that the current typical urban landscape and its drainage infrastructure could not cope with these hydrologic events, and the consequences were thousands of lives lost, the suffering and dislocation of survivors during and after these events, and hundreds of billions of dollars in damages. Given that coastal cities are among the fastest growing areas in the world, it is essential to address these problems. Under the circumstance of extreme flows, the current underground urban drainage is almost inconsequential (Figure 1.1), and the hydrologic connection with the landscape is fragmented or nonexistent, providing little buffering protection. Scientific predictions indicate that the frequency and force of extreme hydrologic events will increase with global warming (SPM, 2007; Emanuel, 2005; IPCC, 2007).

On the other side of the hydrological spectrum, many cities, not only in arid zones, are running out of water for satisfying the needs of people. The balanced biota has

Figure 1.1 Impact of Hurricane Katrina in New Orleans (Louisiana) in 2005. Urban infrastructure and human response failed.

disappeared from urban bodies of water because of insufficient flow and has either been replaced by massive growths of pollution tolerant undesirable species (sludge worms, massive blooms of cyanobacteria, and other algal species) or disappeared completely. In the 20th century some cities withdrew so much water that rivers downstream from the withdrawal dried up. The traditional response by urban planners and water engineers was to tap water resources from increasingly larger distances. Bringing water from large distances is not a new concept; Romans built aqueducts up to 50 kilometers long, and the Byzantine Empire brought water to its capital city of one million people from up to 400 km (250 mi) away.

Much progress had been accomplished by the end of the 20th century in the U.S. and other developed countries, but despite the progress made in the U.S., many of the nation's urban water bodies still do not meet the chemical, physical, and biological goals established by the U.S. Congress in the early 1970s. Current research indicates that progress is not only unsatisfactory, but that it may, in fact, have stalled. The fast-conveyance drainage infrastructure conceived of in Roman times to eliminate unwanted, highly polluted runoff and sewage has produced great gains in protecting public health; however, in spite of billions spent on costly "hard" solutions such as sewers, treatment plants, pumping, and long-distance transfers, the safety of water supplies and water quality for aquatic life and human recreation still remain major concerns in most urbanized areas.

At the end of the 20th century, calls for achieving sustainability or green development grew strong and became a mantra for individuals, nongovernmental organizations, and some politicians. Terms for and opinions on "green development and technology," "smart growth," "low- or no-impact development," "LEED- or ISO-certified development," "sustainable development," and "sustainability" appeared in large numbers in the scientific literature, media articles, and feature shows, sometimes linked to "global warming" and "greenhouse emissions." Urban planners have also been promoting green- and brownfield developments. There are at least one hundred definitions of sustainability in the literature (Dilworth, 2008). Most of them have certain common intra- and intergenerational denominators—that is, human beings have the responsibility not to damage and/or overuse resources, so future generations will have the same or better level of resources, and one group's or nation's use of the resources cannot deprive others from the same rights of use (see Chapter II). Hence, sustainability means balancing economic, social, and environmental needs in an intragenerational context. Because the resources are not unlimited and some are nonrenewable, at the present pace of overuse some could be exhausted in less than one hundred years. It appears impossible, with the available and limited resources, that the rate of consumption and (over)use of resources by some, but not all, people living in developed countries could be extended to the entire and growing population of the world. Therefore, changes are coming, and the goal is to achieve a new, more equitable balance. The rate of water consumption and the magnitude of pollution are directly linked to the use of resources. On the other hand, new and better water and environmental management, reuse of resources and byproducts of urban life, and maintenance or restoration of natural resources will have many beneficial impacts on the health, living environment, economy, and social well-being of people that will extend far beyond the boundary of the cities. It has also been realized that not only natural resources and water are involved; a major component of sustainability is energy consumption and related greenhouse gas emissions causing global warming.

Cities have a significant relevance for sustainable development. McGranahan and Satterthwaite (2003) listed three major reasons why cities are playing a major role: (1) Today more than half of the world population is living in cities, and the proportion of the urban population will be increasing in the future. Cities also concentrate the largest amount of poor people. (2) Urban centers concentrate most of the world's economic activities such as commerce and industrial production, and, as a result concentrate most of the demand for natural resources and generate most waste and pollution. (3) Cities have the largest concentration of the middle class and wealthy people who work, but do not necessarily live, there; hence, a lot of energy is required for commercial activities and for people living in or commuting to the cities. Cities also impose a large demand on the power generated in fossil fuel power plants, the water brought from large distances, and the food produced in distant, often foreign, farms. Cities also require energy for moving wastes to treatment and disposal sites. All of these activities not only require energy but also emit large quantities of greenhouse gases (GHG).

At the end of the 20th century, and even more so in this century, it has become evident that the urban water infrastructure cannot cope with increasing stresses—and that, in the new millennium, this infrastructure could crumble because of its age and the inherent deficiencies of traditional designs. Now there is widespread movement towards a new interdisciplinary understanding of how the water infrastructure and natural systems must work in harmony to provide fundamental needs, and this movement is ready for success. Urban sustainability concepts and efforts at the beginning of the new millennium were still fragmented, and the role of water resources and water management was perceived differently by landscape architects, urban planners, developers, urban ecologists, and civil and water resources engineering communities. For landscape architects and developers, urban water resources provided attractions for development. For urban ecologists, development was a cause of environmental degradation. For urban planners, surface water resources often represented an obstacle to development and transportation; covering urban streams and bringing them underground used to provide additional space for development, urban roadways, and parking. The civil and environmental engineering community was caught in between. Consequently, the term "watercentric urbanism" had different meanings for these communities. For some urban planners and architects, urban waters often are associated with visual attraction or, in extreme cases, spaces that can be covered and used for more development. This concept could be called "water-attracted development" that can range from clearly unsustainable and vulnerable beachfront developments to city developments, providing visual enjoyment of water and an access to secondary recreation. In this book, "water centric" urbanism means that urban waters are the lifeline of cities, that they must be managed, kept, and/or restored with ecological and hydrological sustainability as the main goal to be achieved. Obviously, such waters would be attractive for a sustainable green development, including protection of riparian zones.

I.2 HISTORIC PARADIGMS: FROM ANCIENT CITIES TO THE 20TH CENTURY

The word "paradigm" is derived from the Greek word *paradeigma* (πάράδειγμά), which means an example or comparison. A paradigm is a model that governs how ideas are linked together to form a conceptual framework, in this case a framework by which people build and manage cities and water resources. A paradigm is first based on logic, common sense, and generational experience, and later on scientific knowledge. It is derived by a discourse in the political domain; science alone may not be the primary determinant of a paradigm. A wrong or outdated paradigm may persist because of tradition, lack of information about the pros and cons of the outdated paradigm, or lack of resources to change it. At the same time, our conceptual models of these systems and our understanding of how they should function and relate to one another have been improving. There are at least four recognizable historical models or paradigms that reflect the evolution and development of urban water resources management; these are outlined in Table 1.1.

Table 1.1 Historic paradigms of urban water/stormwater/wastewater management

Paradigm	Time Period	Characterization	Quality of Receiving Waters
I. Basic water supply	B.C. to Middle Ages; still can be found in some developing countries	Wells and surface waters for water supply and washing; qanads constructed in some parts of the world; streets and street drainage for stormwater and wastewater; animal and often human fecal matter disposed onto streets and into surface drainage; privies and outhouses for black waste; most street surface pervious or semipermeable; roofs often thatched or covered with sod.	Excellent in large rivers; in small and middle-sized streams, poor during large rains, good in between the rains. Pollutants of concern: most likely pathogens because of animal fecal matter on the streets.
II. Engineered water supply and runoff conveyance	Ancient Crete, Greece, and Rome; cities in Europe in the Middle Ages until the Industrial Revolution in the 19th century	Wells and long-distance aqueducts for public fountains, baths (Rome) and some castles and villas; some treatment of potable water; wide use of capturing rain in underground cisterns; medium imperviousness (cobblestones and pavers); many roofs covered with tiles; sewers and surface drainage for stormwater; some flushing toilets in public places and homes of aristocracy discharging into sewers, otherwise privies and outhouses for black waste; animal and sometimes human fecal matter disposed onto streets and into surface drainage; no wastewater treatment.	Excellent to good in large rivers, poor to very poor in small and medium urban streams receiving polluted urban runoff contaminated with sewage; widespread epidemics from waterborne and other diseases. Pollutants of concern: pathogens, lead (in Roman cities because of widespread use of lead, including pipes), BOD of runoff.

III Fast conveyance with no minimum treatment	From the second half of 19th century in Europe and U.S., later in Asian cities, until the second half of the 20th century in advanced countries, still persisting in many countries	Wells and long-distance aqueducts for water supply; potable water mostly from surface sources treated by sedimentation and filtration; wide implementation of combined sewers in Europe and North America; beginning of widespread use of flushing toilets; conversion of many urban streams into underground conduits; initially no or only primary treatment for wastewater, secondary treatment installed in some larger U.S. and German cities after 1920s; after 1960 some smaller communities built lower-efficiency secondary treatment; paving of the urban surface with impermeable (asphalt and concrete) surfaces; swimming in rivers unsafe or impossible.	Poor to very poor in all rivers receiving large quantities of untreated or partially treated wastewater discharges from sewers, runoff discharged into sewers, and combined sewer overflows; rivers sometimes devoid of oxygen, with devastating effects on biota; Cuyahoga River on fire in Cleveland; waterborne disease epidemics diminishing due to treatment of potable water. Pollutants of concern: BOD, DO, sludge deposits, pathogens.
IV Fast conveyance with end of pipe treatment	From the passage of the Clean Water Act in the U.S. in 1972 to present	Gradual implementation of environmental constraints resulting in mandatory secondary treatment of biodegradable organics; regionalization of sewerage systems; additional mandatory nitrogen removals required in European Community; recognition of nonpoint (diffuse) pollution as the major remaining problem; increasing concerns with pollution by urban and highway runoff as a source of sediment, toxics, and pathogens; increasing focus on implementation of best management practices for control of pollution by runoff; emphasis on nutrient removal from point and nonpoint sources; beginning of stream daylighting and restoration efforts in some communities.	Improved water quality in places where point source pollution controls were installed; due to regionalization, many urban streams lost their natural flow and became effluent dominated; major water quality problems shifted to the effects of sediment, nutrients, toxics, salt from de-icing compounds, and pathogens; biota of many streams recovered, but new problems with eutrophication and cyanobacteria (blue-green algae) blooms emerged.

I.2.1 First Paradigm

This paradigm of water management of ancient cities was characterized by the utilization of local wells for water supply and exploitation of easily accessible surface water bodies for transportation, washing, and irrigation; streets were used for conveyance of people, waste products, and precipitation. The ancient Mediterranean civilizations of Greece and their cities were built on sound engineering principles that incorporated sophisticated water supply systems and drainage. Athens in 500 B.C. had public and private wells and surface drainage (Figure 1.2). Several hundred years later, Romans conquered Greece and adopted and improved their water/stormwater systems. However, urban runoff of ancient and medieval cities was not clean: it carried feces from animals and from people.

The archeological excavations in Pompeii and Herculaneum in Italy (two Roman cities covered by ash during the Vesuvius eruption in 79 A.D.) and elsewhere provide a vivid testimony of the water engineering and management that was typical for the late period of the first paradigm. Figure 1.3 shows a major street in Pompeii which indicates that streets were used for collection and conveyance of urban runoff polluted by animal feces, overflows from fountains, and wastewater from the houses. Human fecal waste was not disposed into the street drainage.

Figure 1.2 Drainage systems in ancient Athens (ca. 500 B.C.). This 1 m x 1 m surface drainage channel is located in the agora (gathering place) of the ancient Greek metropolis (Photo V. Novotny).

Figure 1.3 The Via Abbondanza in the Roman city of Pompeii near Naples in Italy. Stepping stones document that the street was used for drainage. The street also had water fountains conveniently located along the street so citizens and merchants did not have to go far for water. Overflow from the fountains washed the streets (Photo V. Novotny).

As cities grew and local wells could not provide enough water, more sophisticated water designs allowed water to be brought from larger distances by underground delivery systems called *qanads*, constructed in southeast Asia, North Africa, and the Middle East. Typically with qanads, a large well was dug by manual labor at the foothills of nearby mountains providing abundant water, and the well was connected by a gravity flow tunnel with the city, where it provided water to the population and irrigation of crops. Some qanads brought water from distances as far as 40 kilometers, and the wells and tunnel were dug more than 100 meters deep (Cech, 2005). Cech also noted that qanads are still used today in the Middle East and parts of China.

I.2.2 Second Paradigm

As water demand increased and easily accessed local groundwater, rain, and surface supplies became insufficient to support life and commerce, the second paradigm emerged in growing ancient and medieval cities: the engineered capture, conveyance, and storage of water. This period is characterized by more advanced engineered water systems that brought water from large distances to the cities. As the economies of the states and cities—driven by slave labor—were increasing, water resources became more important for commercial and military navigation, and canals were built around the cities to enhance defense. The beginning of the Middle Ages is usually associated with the conquest of the western Roman Empire by barbarians and the subsequent

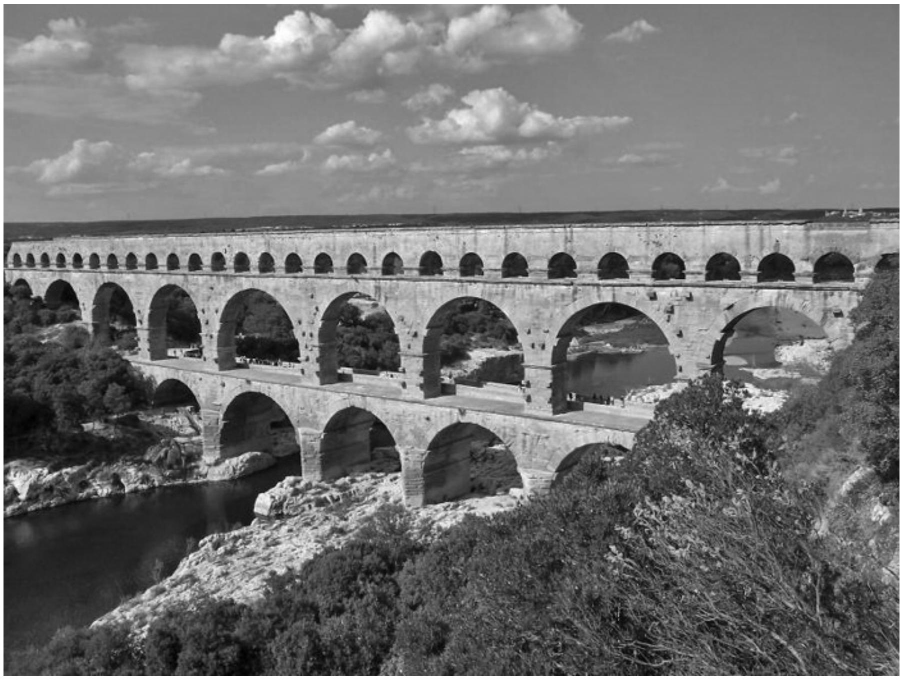


Figure 1.4 One of the largest Roman aqueducts, Pont du Gard in southern France (former Roman province of Gallia), which is today a UNESCO heritage site (Photo V. Novotny).

abolishment of slavery in most European countries. The eastern part of the Roman Empire became the Byzantine Empire and continued for another 900 years.

Over the centuries the Romans developed extensive systems for water distribution which relied both on wells and on elaborate systems of providing clean water brought from nearby mountains. The first Roman aqueduct was constructed in 312 B.C. (Cech, 2005). The aqueducts of ancient Rome brought water from mountains as far away as 50 kilometers (Figure 1.4). Water was stored in tanks and underground cisterns and distributed by lead or baked clay pipes to fountains, public baths, public buildings, and the villas of the aristocracy. Fountains were located evenly all over the towns so that each homeowner who did not have a private water supply could reach the fountains without any difficulty. Water supply pipes were laid along the streets, providing water continuously to fountains, each with an overflow directed onto the street surface. As shown on Figure 1.3, the street also provided drainage of stormwater (Nappo, 1998). Figure 1.5 shows an example of a house in Pompeii built with a courtyard (atrium) in the middle, where the rain-collecting cistern was located and all roof runoff was directed. The practice of rain harvesting and storing rainwater in cisterns was also typical in many ancient and medieval cities and is still common in many communities in dry Mediterranean regions and elsewhere.

Romans were not much concerned with the disposal of wastewater, as long as it did not pose a great nuisance. Paved streets in most cases were continuously washed

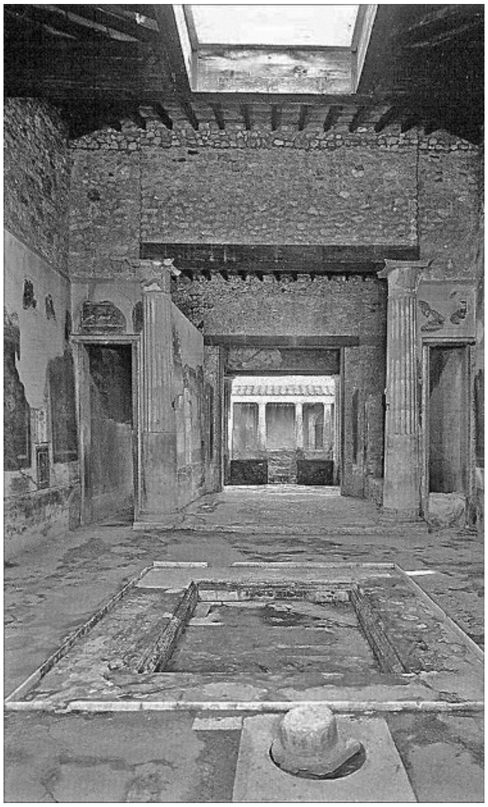


Figure 1.5 Atrium of a large house in Pompeii. Roof rainwater was directed into the basin in the center, from which it was directed into an underground cistern. Overflow was conveyed to the street (Photo V. Novotny).

by the overflow from the fountains and by rainwater. In Roman cities common people washed themselves in public baths, which were also a place for socializing. In Pompeii and other cities, laundry was done in commercial laundries and cleaning shops. Some cities also had communal flushing toilets. To handle pollution of urban runoff and the flow of wastewater from baths and public buildings, sewers were invented. This invention allowed polluted street flows and wastewater to be conveyed underground to the nearest rivers. The Roman sewer, the Cloaca Maxima, has been functioning for more than two thousand years (Figure 1.6); however, sewers were installed a thousand years later in other European cities.

In contrast, in medieval cities of Europe (with the exception of Muslim regions of Spain and the Balkans), common people and even the nobility had poor personal hygiene, rarely took baths, and had no showers. As a result, domestic per capita water use in medieval European cities was much smaller than in Roman cities or modern cities, most likely at the level that today would be considered a minimum daily use. Most excreta and fecal matter were disposed on site in outhouses and latrines. Like

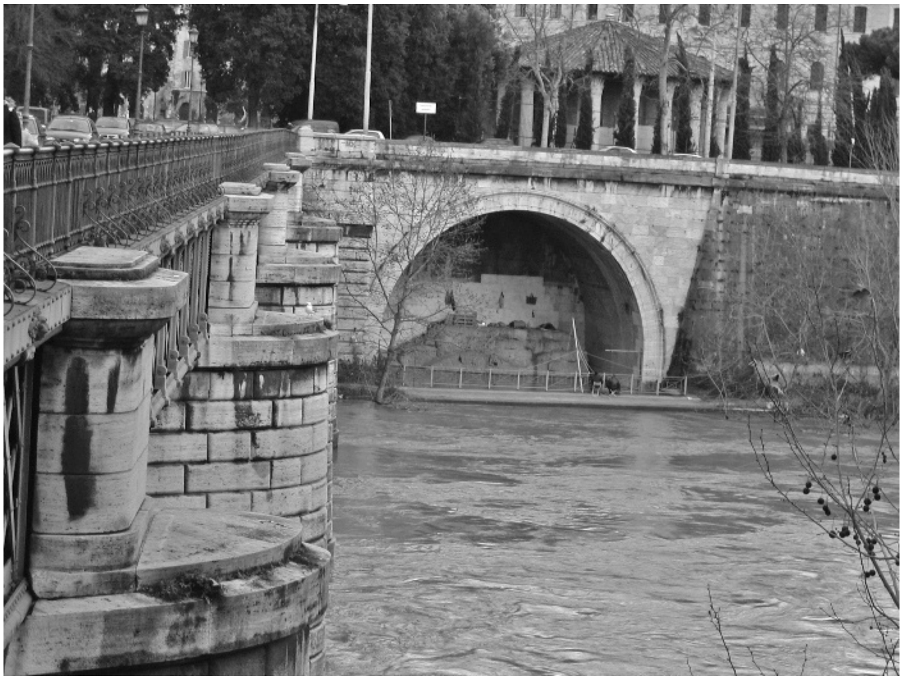


Figure 1.6 Outlet of the Roman sewer, the Cloaca Maxima (Largest Sewer) into the Tiber River. The sewer is functioning today, but a barrier was installed to prevent entry because of security concerns.

those of ancient cities, street surfaces were polluted by fecal matter and trash. Solid waste deposits on streets of medieval Paris were sometimes 1 meter high, and night chamber pots were generally emptied into street drainage.

Ancient Rome and medieval Constantinople had populations of about one million at their height, while medieval London, Paris, Amsterdam, and Prague had populations in tens of thousands, at most, and Berlin was a village. Constantinople (present-day Istanbul in Turkey) on the shores of the Bosporus was the capital of the Byzantine Empire, which lasted until the 15th century A.D., and for more than a thousand years it was the center of East European and Mediterranean civilization. After the conquest of Rome by barbarians in the 5th century, it was the cultural and commercial center of the world. This city inherited—and improved upon—Roman culture and engineering know-how when the Roman Empire split into its eastern and western parts. Its water system was similar to that of Rome, using aqueducts to provide fresh water, but also relying heavily on private and public rainwater harvesting and cisterns. The longest aqueduct (400 km) was built in the 4th and 5th centuries to provide water to this megalopolis. Water was stored in more than one hundred cisterns throughout the city that provided 800,000 to 900,000 m^3 (211 to 238 mg) of storage. In the 7th century the city built its largest underground cistern (Figure 1.7).

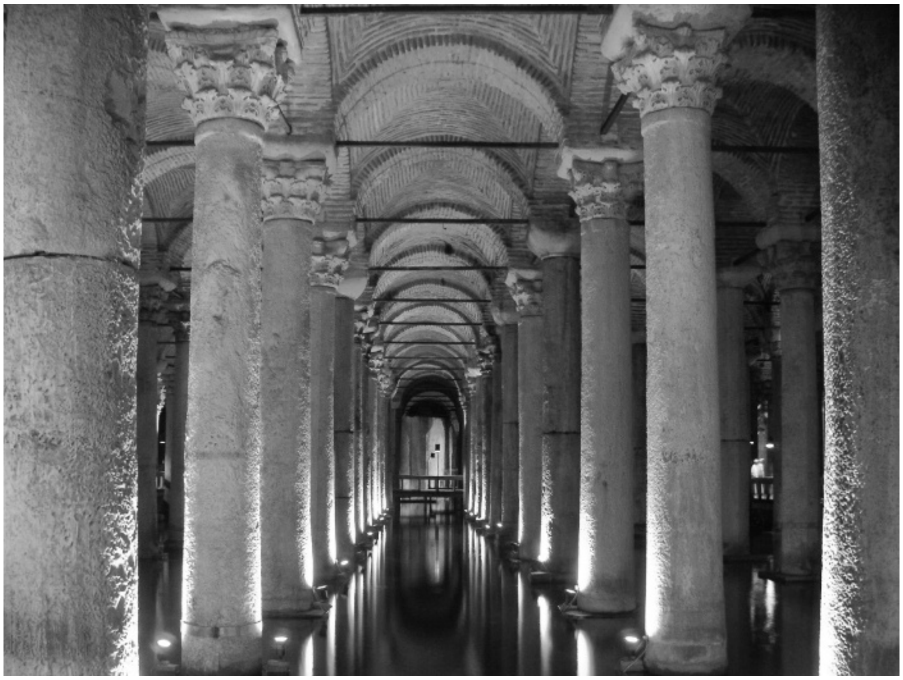


Figure 1.7 This underground Basilica cistern, capable of storing 80,000 m^3 (21.1 mg) of water, was built at the beginning of the seventh century in Constantinople, the capital of the Byzantine Empire (present-day Istanbul in Turkey) (photo V. Novotny).

Another large medieval city with more than 200,000 inhabitants was Venice (in present-day Italy), which was a center of the powerful Venetian Republic (697–1795 A.D.), competing with the Byzantine Empire over the dominance of the Mediterranean region. The city is located on 118 small islands inside the 500-km^2 Lagoon of Venice and is known for its famous canals. Historically, Venice relied on private and public wells and fountains, and all sewage was discharged directly into the canals. Essentially, the Republic of Venice, including its other cities (Padua, Verona), operated its water and wastewater disposal using the concepts of the first paradigm, although it periodically dredged the canals within the city to remove accumulated sludge. The city also built a network of canals on the mainland surrounding the lagoon and relocated two major rivers outside of the lagoon to prevent its siltation. The historic city of Venice, which today has about 80,000 permanent residents and many thousands of tourists, still discharged all wastewater into its canals with minimum treatment at the end of the last millennium. Since the beginning of the 21st century, low-level distributed treatment has been implemented in the historic city.

A pipeline system delivering water to London from the Thames River and nearby springs was built at the beginning of the 13th century, and by the end of 18th century, major European cities had a water distribution system that relied on public fountains

Figure 1.8 Caesar Fountain in Olomouc in the Czech Republic, sculpted and built in 1725 (Photo V. Novotny).

and deliveries of water by pipelines to individual houses. Many public fountains in medieval cities were pieces of art (Figure 1.8). For most of the medieval era, water supply pipelines were made of baked clay or wood (Figure 1.9), and were replaced by cast iron later in the 19th century. Large sewers were of masonry. In some cities water to individual houses was provided by private water vendors (Cech, 2005). Most houses, however, had only one faucet with a sink. Sewers were not common, and many smaller and even middle-sized cities in Europe did not have sewers until the 20th century. The use of standpipes and/or private vendors for water distribution can still be found in many undeveloped countries. The end of the second paradigm could be dated to the middle of the 19th century, when the servitude of rural people to their feudal masters in Europe and slavery in the U.S. were broken, which resulted in a massive population migration into cities. This was the beginning of the Industrial Revolution, which shifted the economic power to the cities, away from the landholding nobility who had held the rural population in servitude (or slavery).

Figure 1.9 Making wood pipes for the medieval water supply systems (courtesy: Museum of Water Supply in Prague, Czech Republic).

I.2.3 Third Paradigm

Beginning in the first half of the 19th century, the freed rural population migrated to cities and joined the labor force in rapidly expanding industries, then run more by steam and fossil fuel (dirty) energy than the clean water or air energy (water wheels or wind mills) typical for small industries and mills during the second paradigm. This change, along with the ensuing rapid expansion of cities, increased urban pollution dramatically. In the second half of the 19th century, sewers were accepting domestic and sometimes industrial black sewage loads. However, most industries clustered near the rivers discharged effluents directly into streams without treatment. Because urban water bodies served both for water supply and wastewater disposal, sewage cross-connection and contamination of wells and potable water sources caused widespread epidemics of waterborne diseases.

The third paradigm of urban water and wastewater management added a massive investment in building sewers, in trying to cope with the pollution of urban surface waters. Urban water bodies were becoming unbearably polluted and a serious threat to public health. Other monumental projects included flood controls by stream straightening, lining, and ultimately covering; building thousands of reservoirs for water supply and hydropower; navigation river projectsand canals. Even today, $30–$40 billion (in 2000 dollar value) are spent annually on new dams worldwide (Gleick, 2003), and monumental cross-country canals and water transfers are being built or planned, such as a canal bringing water from the water-rich Yangtze River to Beijing and other cities located in the water-poor Northeast of China. A transcountry canal is planned in the Republic of Korea.

Since the end of the nineteenth century communities were building combined sewers and treatment plants for potable water, as engineering methods to solve the problem of pollution of surface waters. Flushing toilets changed the way domestic fecal matter was disposed. Until then collection tanks and pits in outhouses and latrines were emptied periodically by private haulers. The introduction of flushing toilets and bathrooms conveyed fecal and other wastewater into the newly built or existing stormwater sewers. The goal of pollution control was *fast conveyance* of wastewater and urban runoff out of sight from the premises to the nearest body of water.

Wastewater treatment, at the end of the 19th century and beginning of the 20th century, was limited to sedimentation and self-purification in the receiving water bodies. This was not even remotely sufficient to resolve the nuisance problem with sewage discharges. One solution was to pump sewage and apply it onto fields for crop irrigation, which was practiced in the late 1800s around London, Berlin, Paris, and Sydney (Cech, 2005), Mexico City (Scott, Zarazua, and Levine, 2000), in China, and in many other locales. In the late 1800s, septic tanks and leaching fields were first used in the United States, and these are still used today in places without sewerage. In Europe in the early 1900s, sedimentation of solids in sewage and anaerobic digestion of the deposited solids were done in septic tanks (Figure 1.10) known as Imhoff tanks (commemorating German pioneer of sanitary engineering Karl Imhoff). Activated sludge plants, trickling filters, and sewage lagoons were invented in the early 1900s.

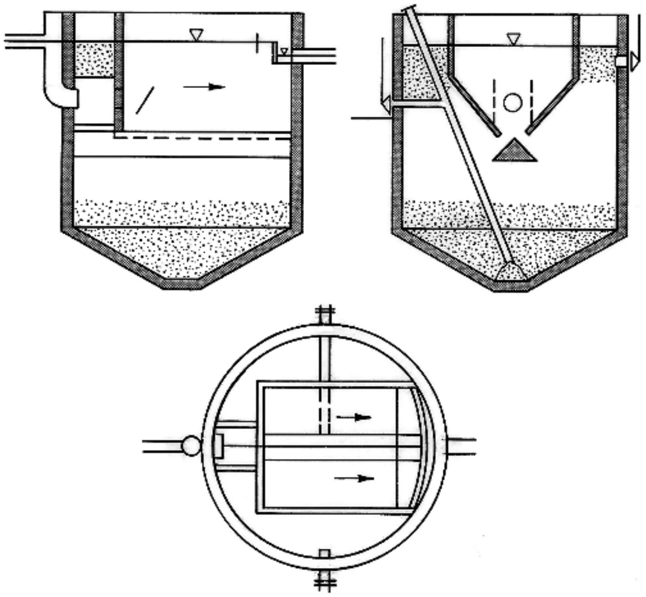


Figure 1.10 The Imhoff tank combined primary settling with anaerobic digestion of settled sludge. It was invented by Karl Imhoff in Germany at the beginning of the 20th century. The tank has an aerobic settling compartment in the middle, anaerobic sludge digestion in the lower part, and scum-collecting volume on the top (Replotted from Novotny et al., 1989).

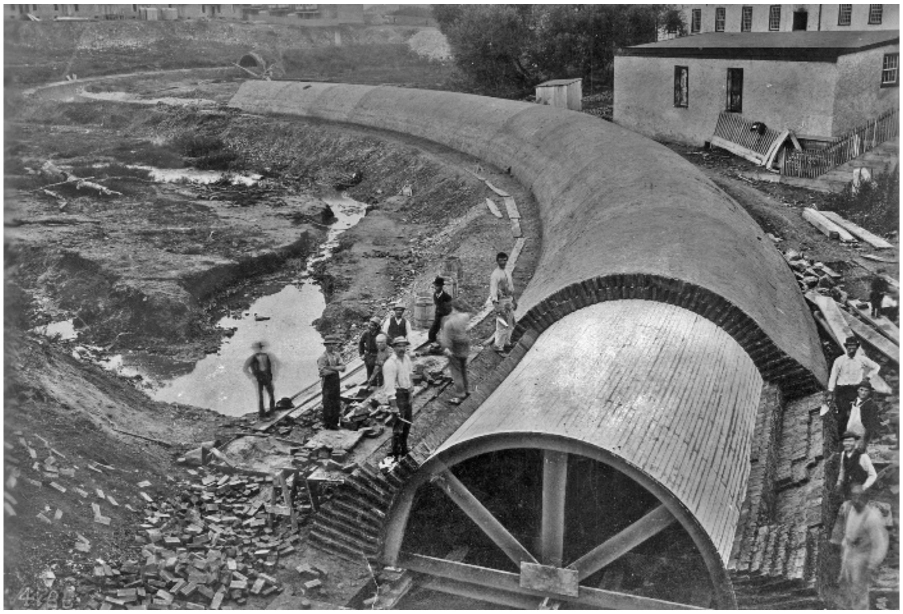


Figure 1.11 Converting Mill Creek into a sewer in Philadelphia (PA) in 1883 (photo provided by the Philadelphia Water Department Historical Collection).

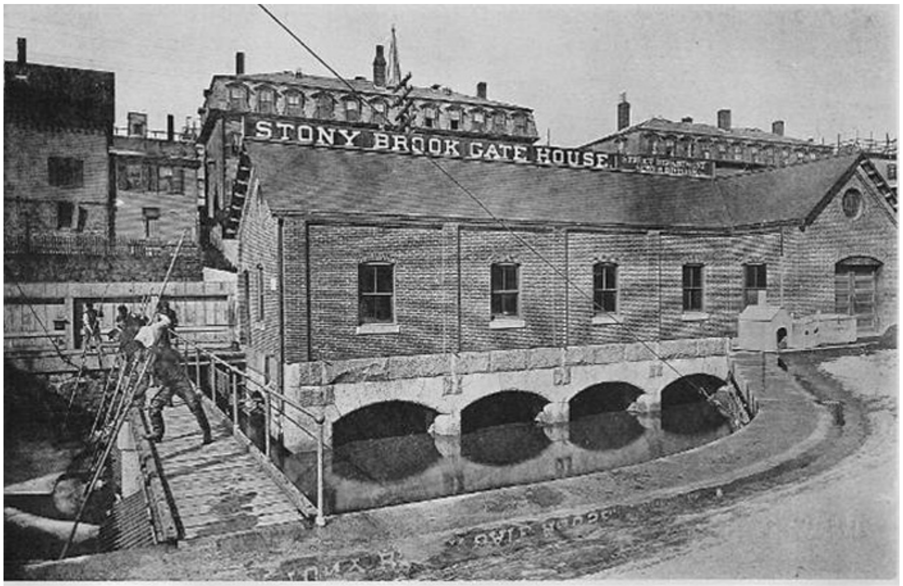
At the same time, covering streets and other areas of cities with impervious pavements was preventing rainfall infiltration and, concurrently with the increased withdrawals of water from streams, depriving urban streams of the base flow needed for dilution of pollutant loads between the rains. During dry weather, some streams carried mostly sewage and became *effluent dominated* (see Chapter IX). The solution was to put small and medium-sized urban streams out of sight and convert them to combined sewers (Figure 1.11). The aim of these *fast conveyance urban drainage systems* (sewers, lined and buried streams) was to remove large volumes of polluted water as quickly as possible, protecting both public safety and property, and discharging these flows without treatment into the nearest receiving body of water. Almost all sewers, even the old ones originally designed to carry heavily polluted urban runoff from streets, were combined—that is, they carried a mixture of sewage, infiltrated groundwater, and stormwater flows. Over a relatively short period of fifty to one hundred years, most of the urban streams disappeared from the surface, as shown on Figure 1.12.

In the absence of effective treatment technologies that would remove putrescible pollution from sewer outfalls and heavily polluted urban runoff (most of the street traffic was still by horse-drawn wagons and coaches), city engineers resorted to grandiose projects to alleviate the pollution problems. In Boston, Massachusetts, several square kilometers of the tidal marsh of the Charles River estuary called the Back Bay, plagued by standing sewage pools, were filled between 1857 and 1890 and converted to upscale urban development that more than doubled the size of the city

Figure 1.12 Disappearance of streams in the Tokyo (Japan) Metropolitan area (Courtesy Prof. Horoaki Furumai, 2007).

at that time. Approximately at the same time, a large tributary of the Charles River named Stony Brook was causing a nuisance and threatening public health. Because of public health regulation for sewer discharge points, lowlands in the neighborhoods into which the brook was discharging became terminal sewage pools. Periodic epidemics swept through the city regularly. Raw sewage from Stony Brook flowed directly into the tidal Back Bay, with environmentally destructive results. Historian Cynthia Zaitzevsky (1982) describes the effect of sewage on the Back Bay: "…the residue lay on the mud flats, baking odiferously in the sun. Eventually it became incorporated into the mud. Under these conditions, the last vestiges of the salt marsh could not remain healthy for long. When the park commissioned a survey of the area in 1877, animal life was no longer able to survive in the waters of the Back Bay." As a result, a 12-kilometer stretch of the brook through the city was buried and converted into large box culverts. Only names such as Stony Brook Park or Stony Brook subway and train station remain, and most of the Boston population does not even know that a medium-sized historic river existed in the city 150 years ago. Figure 1.13 shows the old gate house where Stony Brook went underground. After sewer separation in 2002, the relatively clean water originating in a headwater nature conservancy area upstream is now flowing in a double culvert storm sewer, while a large portion of a once very lively and important part of the city that used to surround the brook has deteriorated. The gate house shown in the figure is gone today, but the river is still underground. The practice of burying small and medium streams and converting them into subsurface sewers was common to almost every city in the world, ranging from small to large.

Because of the poor sanitation and discharges of untreated wastewater into groundwater and surface water bodies, terrible epidemics of waterborne diseases plagued the urban population throughout the Middle Ages until the end of the 19th century. The cholera epidemics in Chicago (Illinois) in the late 1800s, caused by contamination of the city's water intake from Lake Michigan, led the city government to commission the building of an engineering marvel, the Chicago Sanitary and Ship Canal (CSSC), finished in 1910. The canal reversed the flow of the Chicago River, which had originally flowed into Lake Michigan, diverting it into the Des Plaines River (Figure 1.14) that flows, after becoming the Illinois River, into the Mississippi River (Macaitis et al., 1977; Novotny et al., 2007). In this canal and the Des Plaines River, all sewage and most of the overflows from the combined sewers



HELIOTYPE PRINTING CO. BOSTON

STONY BROOK GATE HOUSE—CLEARING SCREENS DURING A FLOOD.

Figure 1.13 The gate house with bar racks through which Stony Brook in Boston (Massachusetts) entered underground into 12-km- long culverts more than one hundred years ago. *Source:* Charles Swift, BostonHistory.TypePad.com)

(CSOs) are diverted into the Illinois River, a tributary of the Mississippi River, and do not contaminate the water intakes in Lake Michigan. The CSSC is now one of the largest inland shipping waterways, larger than the Suez Canal, and the Lower Des Plaines River is also the largest effluent dominated body of water in the world (see Chapter IX).

The third paradigm period had numerous other pollution catastrophes due to unregulated or poorly regulated point source discharges and absolutely no controls of diffuse (nonpoint) pollution. Severe cases of painful and deadly mercury and cadmium poisoning of fishermen in Japan were reported in the 1960s. Minamata mercury poisoning disease was first discovered in Japan in 1956, and another outbreak occurred in 1965. As a result of fish contamination, thousands died and tens of thousands were infected. As a result of point pollution, many streams were dead, smelly water bodies with sludge deposits that could only harbor dense populations of sludge worms (Krenkel and Novotny, 1980).

By the end of the 19th century, people began to understand that unsanitary living conditions and water contamination contributed to disease epidemics. This new awareness prompted major cities to take measures to control waste and garbage. In the United States, industrial chemicals and wastes, including sulfuric acid, soda ash, muriatic acid, limes, dyes, wood pulp, and animal byproducts from industrial mills, contaminated waters. In the industrial U.S. Northeast and Midwest, and also in

Figure 1.14 The effluent dominated Des Plaines River in Joliet, Illinois, after the confluence with the Chicago Sanitary and Ship Canal. It has become one of the largest inland waterways in the U.S. Photo V. Novotny.

industrial Europe, almost all major and middle-sized rivers were severely affected by pollution. New pollutants such as household detergents formed foam on the weirs 5 meters or more thick. The Cuyahoga River in Cleveland, Ohio, which flows into Lake Erie, became so polluted that the river caught on fire (Figure 1.15) several times between 1936 and 1969. The fire was due to floating debris and a thick layer of oils floating on the surface of the river.

In the mid-1850s, Chicago built the first major primary treatment plant to treat its sewage in the United States. From 1880 until well into the second half of the 20th century, water pollution control efforts in the U.S. and industrialized countries of Europe focused on removal of objectionable solids, disease-causing pathogens, and oxygen-demanding organic substances (BOD) that were turning receiving water bodies into unsightly, oxygen-deprived black-colored smelly streams or pools. During the third paradigm period, primary and later secondary wastewater treatment technologies were introduced in several cities but did not address the overall, *uncontrolled water-sewage-water cycle* (Imhoff, 1931; Lanyon, 2007; Novotny, 2007) in which water in an upstream community is converted to sewage, discharged into a receiving water body, and reused downstream as potable water by another community (see Chapter IX). Dissolved oxygen concentrations preventing fish kills provided guidance for estimating the waste-assimilative capacity of streams. The

Figure 1.15 The fire of the Cuyahoga River in Cleveland, Ohio, in 1952. *Source:* Cleveland Press Collection, Cleveland State University Library.

primary reason for installation of treatment plants by some communities was protection of public health and avoidance of nuisance from unsightly and odorous anoxic urban waters.

Increasing imperviousness. Paving the cities and roads dates back to ancient Greece and Rome (see Figures 1.2 and 1.3). However, in medieval cities only important streets and plazas were paved with cobblestone pavement that, hydrologically, had relatively large depression storage (about 1 cm) for storing rainwater, and was partially pervious. Many side streets and squares had unpaved dirt surfaces. Roofs were obviously impervious, many covered with tiles or wood shingles, although in the early times, some were thatched or even covered with sod (in Scandinavia).

The practice of using relatively smooth concrete and asphalt pavements on a large scale dates to the first half of the 20th century. Unlike the stone pavements of ancient and medieval cities, modern pavements are highly impervious and have relatively small depression storage, of about 1 to 2 mm, to capture and evaporate rain. Some portions of historic cities became almost completely impervious.

Dropping groundwater table and subsidence. As a result of imperviousness, infiltration into underground sewers, and sump pumps draining deep construction sites, basements, and underground garages and tunnels, hydrology of urban watersheds has changed by reducing groundwater recharge by infiltration, thus increasing surface urban runoff. Consequently, peak flood flows in surface and subsurface drainage increased by 4 to 10 times (Novotny, 2003), while the groundwater recharge by infiltration diminished. Because of the dropping groundwater table, many cities built on filled wetlands—such as a large portion of Boston and Philadelphia in the U.S., Venice in Italy, Mexico City, parts of Tokyo and Osaka (Japan)—have serious problems with subsidence of their historic buildings built with wood piles foundations. Palaces were built on wood piles in Venice and elsewhere for almost a thousand years, and as long as the wood piles are submerged in groundwater they do not rot. Under these conditions, untreated wood piles can be considered to be permanently durable as long as the water table remains above the tops of the piles, and the wood and surrounding soil remain saturated. However, if the groundwater level drops below the top of the piles, plant growth and insects can attack the wood, and a greatly increased supply of oxygen, combined with moisture and moderate temperatures, facilitates the growth of fungi. Grubs or wood borers, termites, and other insects may also attack the "exposed" wood (Aldrich and Lambrechts, 1986). In Tokyo, large-scale problems with subsidence due to groundwater mining were observed first in 1914 and continued with increased intensity thereafter. Ground subsidence caused destruction of many buildings. Countermeasures against ground subsidence started in the 1960s, and the rate has slowed (Furumai, 2008).

Urban flooding. Building storm and combined sewers could not alleviate urban flooding problems, and increased imperviousness made it worse. Storm sewers are traditionally designed to carry flows resulting from storms that have a recurrence interval of once in five to ten years, and the capacity of combined sewers is generally six times the dry weather flow. This means that every rain with an intensity of approximately 3 mm/hour will result in an overflow (Metcalf & Eddy, Inc., 2003; Novotny, 2003). In part of Tokyo (Japan), which is highly impervious, floods occur with a frequency of once in two years. Because the land in cities became highly valuable for development, cities encroached into floodplains and, to minimize flooding, streams were straightened, diked, and lined to increase their velocity and capacity to carry more flow. Figure 1.16 shows the Los Angeles River, which today is a concrete fast-flow flood conveyance channel. Increasing velocity during high flows created adverse safety problems, and the streams became sometimes deadly to children playing or falling in them. The answer to this problem was fencing off the streams. Streams lined with concrete or similar materials (masonry) cannot support aquatic life, and the result is ecologically almost the same as putting them underground. Rivers converted into flood conveyance channels also received overflows from combined sewers and stormwater runoff (Figure 1.17). Lining streams and building sewers did not resolve the flooding problems. At best the problem was moved and accentuated downstream. In almost every large city, some rivers and streams were covered to make a space for parking lots and other developments (see Chapter IX).

In the 1960s, the public was rising in protest against the excessive pollution of the environment. Rivers on fire, black streams devoid of oxygen (a black color is given to water by sulphuric bacteria that thrive in anoxic waters), the stench of anoxic waters and sludge all reached a point that people could not bear. In London, summer sessions of Parliament had to be canceled because of the bad smell emanating

Figure 1.16 Los Angeles River. It was once a natural river, but it was converted into a lifeless flood conveyance channel with no connection to population living nearby. The river in some sections is a perennial effluent dominated channel; in some other sections, it has no dry-weather flow. *Source:* US Army Corps of Engineers.

from the Thames River. In 1962, Rachael Carson's famous book *Silent Spring* was published, describing the consequences of the contamination of flora and fauna by chemical pesticides. The "silence" was due to the disappearance of birds, dying because their body tissue had been contamination by DDT and other pesticides. In the U.S., the third paradigm period culminated in the passage of the Federal Water Pollution Control Act Amendments of 1972 (Clean Water Act) making end-of-pipe treatment mandatory.

Environmental awakening, which marks the end of the third paradigm, occurred years later in some advanced countries, and many developing countries (e.g., China, India, Brazil) are now, at the beginning of the third millennium, recognizing that unrestricted urban development leads to environmental catastrophes. The factors that affected the direction of urban water/stormwater/wastewater development and management during the third paradigm were mainly in the category of economic development, hampered by the lack of technologies for water and wastewater purification and the public's lack of awareness of alternatives to poor environmental quality. In the 1950s and before, the smokestacks of factories were a sign of progress, and land

Figure 1.17 Lincoln Creek in Milwaukee, Wisconsin, was a concrete-lined channel receiving combined sewer overflows, before restoration in the 1990s. Photo V. Novotny.

for development was abundant. Effective environmental restrictions were few in the more advanced countries of the West and North, and there were none in the undeveloped countries of the East and South. Institutional infrastructures, such as nationwide pollution control authorities with regulatory and enforcement powers, were nonexistent or included under public health departments or ministries. Protecting public health and avoiding deadly epidemics were the main goal of government agencies and the mission of sewerage utilities formed in large cities in the U.S. in the first half of the 20th century.

The *global warming problem* was either unknown or unrecognized during much of the 20th century. Surprisingly, the coming of a new ice age was widely published by some media in the 1970s. Nonpoint (diffuse) pollution by urban runoff was not recognized as a problem until the late 1960s, when the American Public Works Association (APWA, 1969) published a study identifying the pollution problem of urban runoff. The existence of rural nonpoint pollution was denied by the farming community. The problem of eutrophication was also recognized only at the end of the third paradigm period in the 1960s (Rohlich, 1969), in spite of the fact that Lake Erie and other water bodies were dying because of the excessive loading by phosphorus, caused mainly by agricultural runoff and use of phosphate-containing detergents.

The third paradigm era can be characterized as one of continued rapid economic development with goals of maximizing profits on the microscale and growth of the grossnational product on the macroscale, in countries under the capitalist economic system. In these countries, before 1970, the tools for remedies were restricted to protests and litigation, finally leading to a paradigm change embedded in the Clean Water Act, the Safe Drinking Water Act, and several other important laws passed by the U.S. Congress. In Central and Eastern European countries under the socialist systems, the tools of protest and litigation—as well as the concept of profit—were not available; hence, the only goal of the planned economies in those countries in the second half of the 20th century was increased industrial and agricultural production based on often unrealistic governmental quotas.

I.2.4 Fourth Paradigm

The passage of the Clean Water Act (CWA) by the U.S. Congress in 1972, over the president's veto, was the necessary impetus to change the paradigm for water and wastewater management in the United States. However, the Act passed by the U.S. Congress has also had worldwide effects because many countries adopted some of its provisions and/or used it for the development of their own water and pollution management, and legislative control acts. At the end of the 20th century, the European Parliament enacted the Water Framework Directive (WFD). Although water quality standards in most of Europe, based on a long tradition, were formulated in a form different from those of the U.S., the goals of pollution abatement shifted from protecting the public from diseases and death to broader goals of protecting the well-being of people and aquatic biota and promoting safety for those using bodies of water for recreation (see Novotny (2003)).

Meeting these goals required massive investments in building treatment plants, for achieving safe drinking water quality, and wastewater treatment facilities that would bring the receiving water into compliance with the more stringent water quality standards formulated and enacted according to the goals of the CWA: the attainment and protection of the *physical, chemical, and biological integrity of the nation's waters* and *providing conditions for safe primary and secondary recreation in and on the waters*. Integrity of water bodies was defined as *"a balanced, adaptive community of organisms having a species composition and diversity comparable to that of natural biota of the region"* (Karr et al., 1986). Physical integrity is usually interpreted as habitat conditions suitable for maintaining a balanced aquatic biota.

Drinking water protection was included in the Safe Drinking Water Act, and the provisions of both this act and the CWA were combined and reflected in the surface water quality standards. Implementing best available treatment technologies became mandatory for point sources. Nonpoint pollution controls in the U.S. have been voluntary, but mandatory nonpoint pollution abatement has been enacted in the European Community, Japan, and Korea.

Hence, the period between the enactment of the CWA in the U.S. and the present time has comprised the *fourth paradigm* of urban water management and protection, in which both point and increasingly diffuse sources of pollution were considered and addressed in many separate and discreet initiatives. This paradigm could also be called the *end-of-pipe control* paradigm, because the predominant point of control of both point and diffuse pollution is where the polluted discharge from the fast conveyance system (sewer or lined channel) enters the receiving water body. Pollution by urban runoff and other diffuse sources was recognized as a problem only about 30 to 40 years ago and was included in the CWA. In the U.S. mandatory but somewhat inefficient urban and highway storm waste discharge permitting was enacted at the end of 1990 and is currently slowly being implemented.

In the U.S., after the passage of the Clean Water Act in 1972 (fourth paradigm), the new massive program of building treatment plants was based on the "economy of scale" characterized by large regional treatment facilities with long-distance transfers of wastewater over smaller local plants. Local treatment plants built before 1970 were mostly rudimentary primary only plants, or low-efficiency trickling filter facilities, or aerobic/anaerobic lagoons (sewage stabilization ponds). In most cases these plants were unable to meet the goals of the Clean Water Act. The new large-scale activated sludge treatment facilities offered better efficiency capable of meeting the more stringent effluent standards and were managed by highly skilled professionals.

Under the fourth paradigm, the urban water/wastewater management systems are once-through flow type; that is, potable water from wells and surface water bodies is treated, brought—often from large distances—to the city where it is used, and converted to wastewater which is then collected in sewers and conveyed by interceptors to a regional public wastewater treatment facility whereby the treated effluent is then discharged into a receiving body of water. Reuse is currently still rare and was almost nonexistent before the year 2000. A notable exception in the U.S. is the system of wastewater reuse in Tucson, Arizona (see box). After 2005, Southern California found itself in a sewer drought, and several cities began implementing water conservation and wastewater reclamation and reuse, including Los Angeles, Orange County (California), and others.

WASTEWATER RECLAMATION IN TUCSON

The city of Tucson, located in the arid region of southern Arizona, is a fast-growing metropolis that in 2000 had 843,746 inhabitants, based on the U.S. Census Bureau. When the city was a desert outpost at the end of the 19th century, there were perennial rivers flowing from surrounding mountains, providing a water supply. In the second half of the 20th century, the city outgrew its surface water supply, the rivers became ephemeral, and the city began mining water from the underlying aquifer. The aquifer became the source of water, and the water table was dropping rapidly. At great cost, a canal connecting the city with the Colorado River was built. Tucson is today reclaiming 90% of its effluent and reusing it for irrigation of golf courses, parks, and other uses.

The long-distance transfers of water and wastewater dramatically changed the hydrology of the impacted watershed. Surface waters became flow deficient after withdrawals, and the water bodies receiving the effluent discharges downstream then

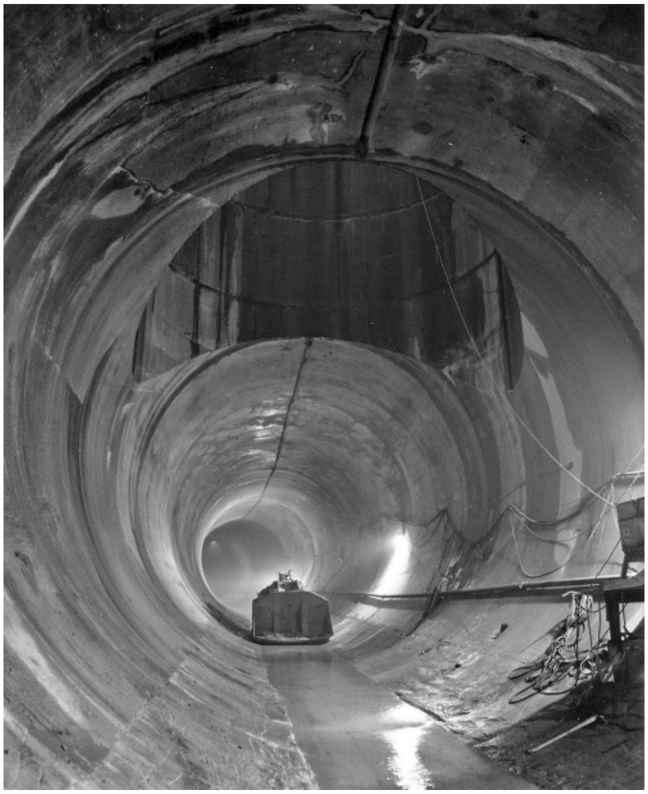


Figure 1.18 Deep tunnel storage of CSOs and SSOs in Milwaukee, Wisconsin. The stored mixture of rainwater and sewage is pumped for treatment. A similar but much larger tunnel system was excavated in Chicago, Illinois. Courtesy Milwaukee Metropolitan Sewerage District (MMSD).

became effluent dominated. However, even today, the problems with combined and sanitary sewer overflows (CSOs and SSOs) have not been and most likely will not be fully mitigated in the near future. These overflows have to be captured and stored in expensive mostly underground storage facilities (Figure 1.18) and subsequently treated. For example, many kilometers of 12-meter-diameter interceptors known as "deep tunnel" were built in Milwaukee, Wisconsin, and Chicago, Illinois, storing millions of cubic meters of a mixture of stormwater and wastewater from captured CSOs and SSOs (Table 1.2). The stored sewage/water mixture is pumped into the regional treatment plants. Each underground pumping station in Milwaukee and Chicago uses several pumps that are among the largest ever built, and the cost of energy for pumping is high. Similar tunnels with a large pumping station were completed at the end of the 20th century in Great Britain and in 2008 in Singapore. The long-distance water/wastewater transfers from source areas over large distances also require electric energy for pumping, treating (e.g., aeration), and transporting

Table 1.2 Parameters of the Milwaukee and Chicago deep tunnel storages for CSO and SSO flows (various sources from the Milwaukee Metropolitan Sewerage District and the Metropolitan Water Reclamation District of Greater Chicago)

System	Milwaukee (WI)	Chicago (IL)
Capacity (million m^3)	2.0 (in 2009)	9.1 (in 2008)
Length (km)	46	175.3
Diameter (meters)	5.2–9.7	5.2–9.7
Depth underground (meters)	100	73–106
Cost (US$, 1990 level)	1 billion +	3 billion

treatment residuals to their point of disposal. This use of energy contributes to greenhouse gas (GHG) emissions. The volume of “clean” groundwater water infiltration and illicit inflows (I-I) into sanitary sewers has to be pumped and treated with the sewage and uses more energy. The I-I inputs could, during wet weather, more than triple the volume of dry-weather wastewater flows in sewer systems and overwhelm treatment plants (Metcalf & Eddy, Inc., 2003; Novotny et al., 1989).

Results of point source pollution controls. Control of point pollution discharged from municipal and industrial sources is mandatory under the provisions of the Clean Water Act in the U.S., the Water Framework Directive in all EC countries, in Japan, Australia, and several other countries that had environmental catastrophes during the third paradigm period. As a result, the water quality of many streams in these countries has improved. The Cuyahoga River in Cleveland is still polluted, but it will not catch on fire. Fish returned to the Thames River in London decades ago, and the Vltava (Moldau) River downstream of Prague (Czech Republic) is not black anymore because of a lack of oxygen. The Charles River in Boston, which only a couple of decades ago was ranked as one of the most polluted rivers (it was acutely dangerous to fall in), had its first “swimming” days in 2007. On the other side of the world, however, the Yangtze River in China is heavily polluted, and in India pilgrims take annual baths in the Ganges River, which has a very high content of pathogens and is also heavily polluted.

Aquatic life has returned even to some effluent dominated rivers. A study of the largest effluent dominated river in the world, the Des Plaines River southwest of Chicago (Figure 1.14), found that fish have returned in spite of the fact that 90% of the medium flow and almost all of the low flow is the treated effluent from the Metropolitan Water Reclamation District of Greater Chicago (Novotny et al., 2007). Unfortunately, in the first decade of this millennium, invasive river carp (white carp, a native of Siberian rivers released into the Mississippi River) have overpopulated the Illinois and Des Plaines Rivers and decimated the ecological balance. An expensive electrical barrier is now keeping the pesky large fish from entering the Great Lakes via the Chicago Sanitary and Ship Canal.

The focus of point source pollution controls has now shifted from removing biodegradable organic pollution, suspended solids, and pathogens—the three original fundamental compounds in the National Pollution Discharge Elimination

System (NPDES) permits—to adding toxic compounds, nutrients, and other pollutants to the controlled (permitted) pollutants. In Europe, installation of Bardenpho treatment facilities has been required for cities discharging wastewater into the European coastal waters, especially those of the North, Baltic, and Black Seas, which is most of Europe. The Bardenpho system, developed by James Barnard (2007) in the 1980s, uses both aerobic and anoxic units to achieve high-degree removals of biochemical oxygen demand (BOD) and nutrients (nitrogen and phosphorus), in contrast to the traditional activated sludge plants (still prevalent in the U.S.), based on the technology of the first half of the last century, that remove BOD and suspended solids and only a small percentage of nutrients (see Chapter VII). Typical removal efficiencies of the current Bardenpho systems are 95% for BOD and suspended solids, 75–85% for nitrogen, and 85–95% for phosphorus, yielding effluent concentrations of typical municipal wastewater of 10 mg/L BOD, 5 mg/L nitrogen, and 1 mg/L of phosphorus (Metcalf & Eddy, Inc., 2003; Sedlak, 1991). These low effluent concentrations are achieved with less costly chemical additions; also, the process requires less aeration oxygen than the traditional activated sludge process. Hence, conversion of conventional activated sludge plants to the Bardenpho systems would have a positive impact on energy consumption and GHG emissions. Aeration is highly energy-demanding and has a significant carbon emission footprint. Taking a new look at the anaerobic digestion processes as treatment units either in digesters or upflow anaerobic sludge blanket (UASB) units, producing energy instead of using energy, may be the future of sustainable used water reclamation, whereby used water (not wastewater anymore) is a resource rather than waste (see Chapter VIII).

Introducing membrane filters after biological treatment results in effluent quality comparable to or better than the quality of many receiving water bodies (Barnard, 2007). Chapters VII and VIII will describe the most advanced yet affordable treatment methodologies that can be used for water reclamation, not just treatment.

Diffuse (nonpoint) pollution abatement. While the point controls have been implemented in the U.S. on a wide scale, progress with abatement of pollution caused by urban runoff has been slow in most cities and notably also on the nation's highways. Urban runoff has been found responsible for more than half of the remaining water quality problems in the U.S. Urban and highway runoff is responsible for the major part of pollution by toxic metals, polyaromatic hydrocarbons (PAHs), and salinity (from de-icing chemicals used to keep streets and roads free of snow and ice during winter driving). Urban runoff also contains pathogens and coliform bacteria that may cause violations of water quality standards; however, these may not be of human origin. Nevertheless, water quality regulations do not provide relief from the standards just because the bacterial contamination may be from animals or birds.

Best management practices (BMPs) for control of urban and highway runoff have been developed and used in many communities (see Chapters III and IV). They have been described in books by Field, Heaney, and Pitt (2000), Novotny (2003), and in many state and U.S. EPA manuals. Manuals for sustainable urban drainage systems (SUDS) have been published in the United Kingdom. SUDS and urban/highway BMPs have the same goals and cover similar practices, design, and implementation. It should be noted that the BMPs category is more broad; BMPs deal with diffuse pollution caused by precipitation and other causes and are not focused only on urban drainage. Environmental engineering classification divides BMPs into the following categories (Novotny, 2003; Oregon State University, 2006):

1. Prevention (soil conservation; ban on pollution substances—such as lead in gasoline—or on persistent pesticides; public education; change of drainage inlets, such as curbs, gutters, and drains)
2. Source controls (street sweeping, erosion control and soil conservation practices, litter removals)
3. Hydrologic modification (porous pavement, enhancing surface infiltration and retention, and evapotranspiration)
4. Reducing of delivery (increasing attenuation) of pollutants carried by surface runoff or shallow groundwater flow from the source area to the receiving waters (infiltration road shoulders, biofiltration and infiltration in swales)

Many ingenious best management practice systems for controlling urban runoff pollution and flow were developed in the last 20 years of the last century. Chapter IV will describe BMPs in more detail, focusing on new developments. Figure 1.19 shows the concepts of infrastructure of an experimental sewer system (ESS) that was a comprehensive drainage system developed and tested by the Tokyo Metropolitan Sewerage Agency (Fujita, 1984; Furumai, 2007). The goal of the system is to minimize flows and pollution from the combined sewer overflows. Because the Tokyo metropolitan area is built on a thick layer of permeable volcanic deposits, the motto of the program is that only sewage should be directed into sewers, and all surface flow should infiltrate. The system, installed early in the 1980s but never fully implemented in the entire city, consists of pervious pavements, permeable (perforated) street gutters, infiltration trenches and wells, and special manholes that provide storage and sedimentation. Each manhole is connected to an infiltration pipe. The ideas were very sound and implementable, and research continues.

Chapter IV describes the current concepts of the use of BMPs and change of philosophy over the last 30 years. The original philosophy behind the BMPs designs and implementation was to remove pollutants from the runoff flow after the fact, without addressing the factors that cause pollution generation.

During the fourth paradigm period (from the 1970s until today), regulations for controls of point sources were enacted and worked quite well. U.S. industries and municipalities obeyed the effluent standards and implemented technologies that would comply with the standards but, in most cases, would not go beyond. Only rarely did dischargers take initiatives to go beyond compliance with the effluent limitation expressed by permits. In the U.S., the Clean Water Act initially authorized subsidies to municipalities for building certain types of infrastructure, but this program was sometimes counterproductive because municipalities were bound to technologies that brought subsidies and avoided innovations for which subsidies were unavailable; hence, reclamation and reuse systems were rare in the 20th century. Notable exceptions included the production of Milorganite, which is a commercially

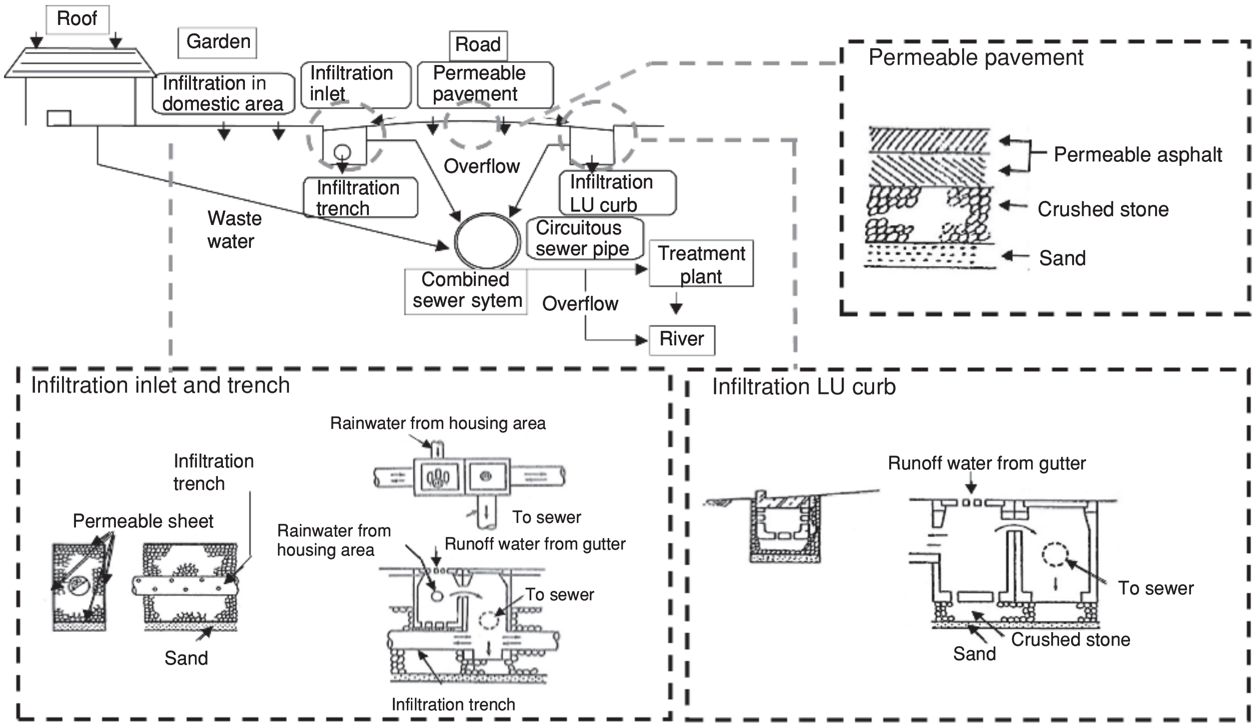


Figure 1.19 Experimental sewer system (ESS) for drainage and CSO control installed in Tokyo in the 1980s (from Fujita, 1984, and Furumai, 2007, public domain sources).

distributed fertilizer produced from sludge by the Milwaukee Metropolitan Sewerage District, and effluent reuse in several communities located in the arid parts of the U.S., in Beijing (China), in Israel, and elsewhere where water scarcity is a problem. Implementing diffuse (nonpoint) pollution control programs has relied on persuasion and incentives.

Later during the fourth paradigm period, pollution prevention was added as a factor, which then led to promotion of the concepts of reuse and recycling (Mihelcic et al., 2003). Reuse and recycling also became a popular method for reducing pollution loads from industries that used high volumes of water, such as paper mills and oil and sugar refineries. The new millennium has also brought a new look at the role of BMPs or SUDS in making a change to a new paradigm, the paradigm of sustainability. The key was the realization that BMPs—not hard infrastructures whose only purpose is to remove pollutants—are a part of the landscape, and that the landscape itself can provide buffering and attenuation; that is, it can become a part of the BMP train (Novotny and Hill, 2007; Novotny, 2007). This approach and concept will require the interdisciplinary efforts of urban planners, landscape architects, and experts in urban ecology and biology, along with environmental engineers and planners.

In general, the current fourth paradigm in the U.S., the European Community, Japan, Australia, Singapore, and a handful of other countries is continuing economic development with environmental restrictions, controls, and regulations—which, however, are still ineffective to guarantee that the legislative goals of attaining and maintaining the integrity and sustainability of water and air sources will be met. Trends that show emissions causing global warming are still increasing; new pollutants and problems such as nutrient enrichment leading to obnoxious algal blooms, toxic discharges, and new emerging pollutants—such as pharmaceutical residuals and endocrine disruptors—are growing, and the serious problems with legacy pollution in sediments have not been abated.

I.2.5 The Impact of Automobile Use

The introduction of automobiles at the beginning of the 20th century was slowly changing the way people lived, but it was not until 1960 that automobiles began to have a major impact on urbanism, hydrology, pollution, and greenhouse emissions. Before 1950, the main means of urban transportation and commuting were trains, electric light rail, and buses that were plentiful and convenient. Until the 1950s, long-distance travel by cars was actually difficult because of poor, often unpaved and narrow roads. In spite of their automobile ownership, many people lived in the cities and used automobiles far less frequently than today. A large majority of families in less developed countries owned only one automobile or no automobile. The change came with the building of arterial and ring freeways after World War II, opening distant rural areas to the development of urban subdivisions. Suddenly, people were able to buy a piece of land, build their dream house, and commute by car. The use of automobiles for commuting to work from distant subdivisions and the increasing living standards of suburban commuters spurred the need for more than one automobile per family, larger building lots, and houses with two- and later three-car garages.

Figure 1.20 Typical freeway congestion/traffic jam (Courtesy and copyright Comstock, Inc., 2000, from Texas Transportation Institute, Texas A&M). Highway runoff and especially snowmelt (in colder regions) are highly polluted and a major source of oil and grease, toxic metals, and organics. Runoff from urban streets also contains coliforms and pathogens.

Another result was traffic jams during rush hours in many cities worldwide, with an opposite effect—that is, traffic is often slowed to a standstill, resulting in freeway congestion (Figure 1.20).

Figure 1.21 shows the data on U.S. car ownership and miles driven. The Nielsen Company data reveal that nearly 9 in 10 Americans owned a car in 2000, making it the world's largest ownership in terms of car penetration and absolute numbers. Furthermore, the U.S. has enjoyed an increase of 8 percentage points in car ownership over the past five years—the highest recorded growth globally. Saudi Arabia follows the U.S. with the second-highest car ownership (86%). Because of the availability of cheap gasoline until the mid-2000s, U.S. car owners tend to drive larger cars with a lower number of miles/gallon (kms/liter) than their European counterparts, who pay higher prices for fuel. After 2008, the rate of car purchases dramatically decreased and high mileage automobiles (hybrids or plug-ins) became more popular.

Figure 1.21 also shows the increased rate of purchasing automobiles and the annual distance driven by the drivers between 1960 and 1980, which was also the period of building freeways, from and around the cities. This and inexpensive gasoline (the gas during that period was selling for less than \$0.15/liter (\$0.6/gallon)) were causes of the movement of middle- and upper-class people from the cities into suburbs,

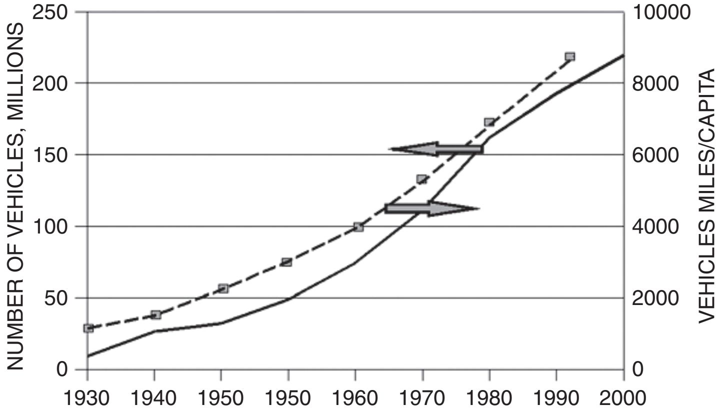


Figure 1.21 Trends in vehicular ownership and mileage driven per year (data from The Nielsen Co. statistics); 1 mile = 1.608 km.

resulting in urban sprawl. As the proximate zones surrounding the cities became saturated with subdivisions, new subdivisions were built farther and farther away, and from the end of the 20th century until 2008 this trend continued. People were driving larger distances and spending more and more time traveling to their places of work in the cities. As a consequence of this massive relocation of the U.S. population from the cities to the suburbs, the city core areas deteriorated, shopping moved from downtown stores to suburban malls, and only deprived mostly minority populations remained in the dilapidated central cities surrounded by low-density urban sprawl developments. During and after the recession of 2008–2009, car purchases dropped, and many urban sprawl subdivisions in the U.S. Southwest became ghost towns.

The sole reliance on automobile traffic had many water, water quality, and, obviously, carbon (greenhouse) emission consequences. For one, in addition to impervious roads, shopping malls, schools, apartment buildings, industries, and office buildings all use exceedingly large areas for parking. The parking lots, mostly impervious, occupy much larger areas than the establishments they serve (Heaney, 2000). The net result is that the combination of low-density residential zones, with connecting roads, and parking in residential, commercial, and industrial areas generates more than three times more urban runoff per family than the population living in the cities in pre-automobile times (before 1960). These parking and road areas are typically mandated by the authorities.

In a modern city, water infrastructure is closely tied to transportation and moving people from the places they reside to places of work and leisure. Streets and highways are the places where most of the drainage and water supply infrastructure is located, starting with drainage ditches, channels, and swales and ending with sewers. On the other hand, traffic emission, street litter and animal fecal deposits, road work, dripping oil in parking lots, and pavement wear are very significant sources of pollution. Impervious surfaces of roads and walkways also have significant hydrologic effects on flow. In some cases, roads were built over covered streams or abutted closely to the streams.

The emissions of pollutants from vehicular traffic are typically given in pollutant mass vehicle mile or kilometer. This implies that if the number of cars and the kilometer driven per year increase linearly, the pollutant loads from roads due to traffic emissions increase exponentially. Vehicular emissions include (Shaheen, 1975; Novotny et al., 1997; Novotny, 2003; Sansalone and Glenn, 2002):

Oil and grease (chemical oxygen demand (COD), BOD)
Acidity (mainly from acidified nitrous oxide from tailpipe exhaust during rain)
Toxic priority pollutants
    Toxic metals
    Polyaromatic hydrocarbons (PAHs)
    Petroleum hydrocarbons
    Asbestos
    Toxic metals (cadmium, copper, lead, nickel, and zinc)
Other pollutants related to automobile traffic are:
De-icing salts containing sodium, chloride, metals, cyanides, and PAHs

Roadways, especially those with high traffic densities exceeding 50,000 vehicles per day, are a major source of toxic pollution in highway runoff, which, in a typical large city, exceeds that from all sewage.

Carbon (greenhouse) gas emissions by vehicular traffic. Vehicular traffic is also the major source of CO_2 emissions. The U.S. EPA (2008) estimated that 1 liter of gasoline produces 2.33 kilograms of CO_2 (19.4 lbs per 1 gallon). This value is consistent with the Intergovernmental Panel on Climate Change (IPCC, 2007) report. Based on the data in Figure 1.21, each driver driving 16,000 kilometers (10,000 miles) per year in 2000 with a car that had an average mileage (fuel consumption) of 8.6 km/liter (20.3 miles/gallon) would emit

$$\begin{aligned} CO_2\ \text{emission} &= \frac{16000\ [\text{km/year}]}{8.6\ [\text{km/liter}]} \times 2.33\ [\text{kg } CO_2/\text{liter}] \\ &= 4335\ [\text{kg } CO_2/\text{year/car}] \end{aligned}$$

or 4.3 metric tons (4.8 U.S. tons) per driver per year. In addition to carbon dioxide, automobiles produce the GHGs methane (CH_4) and nitrous oxide (N_2O) from the tailpipe, as well as fluorocarbons (HFC) from leaking air conditioners. These emissions are related to kilometers (miles) driven rather than to fuel consumption and account for about 5% of the GHG emissions, while carbon dioxide accounts for 95%. Hence the GHG emissions per an average car in 2000 would have been roughly 4.5 metric tons.

Are We Running Out of Oil and Energy? In 2007–2009, oil prices increased dramatically as a result of the limits on the production and refinery capacity. Other effects on the price of oil included speculation, the fall of the value of the U.S. dollar, and increasing demand in other countries, notably China, India, and Eastern European countries, that are rapidly catching up to the developed countries—and new developing countries like Mexico, the Republic of Korea, and Indonesia will join them. It must be pointed out, however, that the U.S. is by far the largest consumer of oil, to satisfy the needs for automobile fuel, heating oil, and raw materials for chemical industries. The price of a barrel of oil on the world market, in 2003 under $30, increased in 2008, resulting in gasoline prices of more than $4/gallon ($1.3/liter), but it dropped back to less than $3.00/gallon ($0.75/liter), and the financial worldwide crisis of 2008–2009 brought the price of the oil back below $100/barrel.

Experts are estimating that the availability of easily extractable oil and gas is reaching its peak now (Figure 1.22) and that by the end of the century, if the pre-2008 trend had continued, most of the energy driving the economy would be derived from coal. Coal can be converted to synthetic fuel, as occurred during World War II in Germany and Central Europe, but this would be at the price of higher energy consumption, more GHG emissions, and more pollution (Chomat, 2008).

Other experts point out that the world, for foreseeable future (one hundred years ahead), will not run out of oil (Schipper et al., 2001; Schipper, 2008). However, the rate of producing fuel from oil is stagnant and will be decreasing, and oil is becoming more and more expensive. Apparently, there is still oil underground in tar

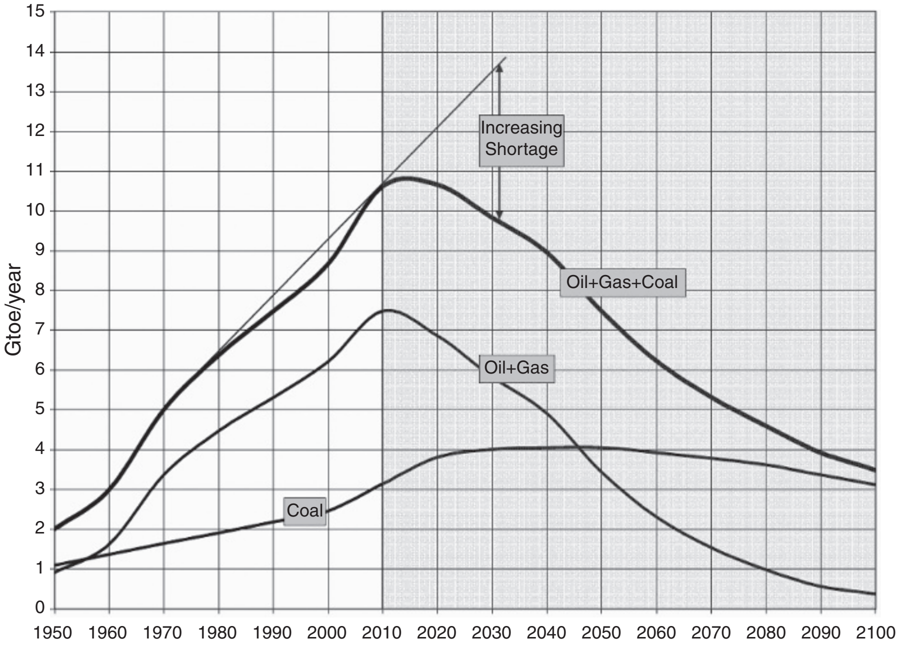


Figure 1.22 Total fossil fuel availability worldwide (from Chomat, 2008, reproduced with permission).

sand deposits, but the extraction and availability of "cheap" and easily extractable oil are diminishing. There is also a problem with oil security and with competition for oil from the new emerging powers, whose billions of people can now or in the near future afford an automobile.

As happened in Europe two decades ago, when a large tax was imposed by the governments on gasoline sales to reduce demand, \$4/gallon (\$1.05/liter) in the U.S. in 2008 was a threshold that long-distance drivers from far away subdivisions would tolerate. It should be noted that European drivers pay approximately 75% more for fuel. Many U.S. drivers commuting large distances did not have a commuting alternative, and few were able to rapidly switch to more efficient cars and abandon gas-guzzling SUVs, but, slowly, change was coming, and for the first time, gasoline use dropped in 2008. A *Time* magazine article (Ripley, 2008) reported a study that showed that housing values in cities and neighborhoods that required long commutes and provided few transportation alternatives to private automobiles were falling more precipitously than in more central, compact, and accessible places, thus slowing the rate of urban sprawl.

However, prices of \$1/liter (\$4/gallon) or more may also have some environmentally undesirable consequences, such as promoting alternate fuel from corn, which not only is environmentally unsustainable but leads to great increases of food prices, which has a devastating impact in poor countries. It also renews calls for drilling for oil offshore and in other natural areas, and for extracting oil from tar sands, which requires a lot of water and energy. Off-shore drilling may have catastrophic environmental consequences as exemplified in 2010 in the Gulf of Mexico oil rig explosion and its impact on ecology and economy of Louisiana and other Gulf states.

More promising and realistic is switching from gasoline and diesel fuel to vehicles run on electricity or hydrogen, and using public transportation provided by electric trains, light rail, or electric (trolley) buses. This method of transport has been available and widespread in Europe and, in the US, for example, in San Francisco for more than one hundred years and would bring great environmental benefits.

In 2008–2010, worldwide use of non-fossil energy was much smaller and represented only about 17% of the total energy use. This, however, may vary from country to country. For example, Brazil derives a significant portion of its energy needs from the Itaipu hydroelectric dam on the Paraná River, which also provides all electric needs to Paraguay. Similarly, in China, a significant amount of energy is derived from the Three Gorges Dam project on the Yangtze River. France derives most of its energy needs from nuclear and hydro power. Austria also has very significant and dominant energy sources in hydropower, and lately wind. In general, the worldwide use of non-fossil (renewable) energy in 2005–2010 was (Chomat, 2008):

Nuclear	5.2%
Renewable	11.3%
Hydropower	5.3%
Biomass – wood	5.2%
Geothermal	0.6%
Wind powered	0.25%
Solar powered	0.15%

It is clear now that to balance energy needs with availability, demand has to decrease (by conservation), and non-fossil energy production has to increase. Renewable energies are "clean" energy sources. Nuclear energy sources do not emit greenhouse gases; however, due to their lower efficiency of conversion of fuel energy into electric energy, heat emitted from the plants by their cooling systems is significantly greater than that from the traditional fossil-fueled plants, which leads to more thermal pollution of waters receiving cooling water discharges (Krenkel and Novotny, 1980), and the problem of safe disposal of radioactive spent fuel has not been fully resolved as of 2010. Chapter VIII discusses the water-energy nexus and has more discussion on the future energy outlook, including the increase of renewable electric energy production.

I.2.6 Urban Sprawl

After the beginning of the Industrial Revolution, in the second half of the 19th century, cities were expanding rapidly to accommodate population migration from rural areas to provide labor to expanding industries. This expansion progressed in various forms, by annexing villages surrounding the cities, building new settlements for blue-collar workers and white-collar industrial managers. This was also a period of building mansions for suddenly super-rich industrial and railroad magnates. This period of urban expansion lasted in the U.S. and European cities until 1950. Most progressive cities in the U.S. and Europe, and also some cities in Asia, provided public intra- and intercity transportation. For example, before 1950, Boston (Massachusetts) had a dense network of electric streetcars, and a subway system was built there more than one hundred years ago. Electric trolleys and trains were also widely available in the suburbs (Figure 1.23). Chicago (Illinois), Northern Indiana, and Milwaukee (Wisconsin) were interconnected by interurban electric trains, and the same was true for New York, St. Louis (Missouri), Philadelphia and Pittsburgh (Pennsylvania), and countless other larger cities in North America, Europe, and elsewhere. In the U.S., most of the intra- and intercity public transportation based on electric trains and buses was abandoned by the 1960s, while in Europe and elsewhere it was retained and modernized. Currently, China has embarked on a massive program of building an electric rapid interurban transit system and intraurban subway, light rail, and electric bus lines.

At the beginning of the second half of the 20th century, the migration pattern and expansion of the cities had changed. While the population in cities outside of the U.S. remained in the cities and nearby suburbs, and the cities developed effective and affordable means of public intra- and intercity public transportation, affluent middle- and high-income families in the U.S. moved from the central cities into the suburbs. The primary mode of transportation switched to automobiles, and the good public transportation was reduced, switched to buses, or disappeared completely. Today, many suburbs are far from the city, and people commute by automobiles, sometimes spending several hours each day commuting. In a typical U.S. suburb, lots are large, many contain large mansion type housing with very high energy use, and three-car garages are not uncommon. A modest renewal of light rail transportation

Figure 1.23 Public transportation in Boston, Massachusetts, suburbs in 1893 (Courtesy of the Newton Historical Museum, Newton, Massachusetts). These suburban and interurban electric light rails around Boston mostly disappeared after the 1950s.

in some major U.S. cities occurred at the end of the 20th century. The movement of people to distant low-density suburbs without adequate water, sewage disposal, and transportation infrastructures is called *urban sprawl*.

The movement of the U.S. population in the 20th century was generally attributed to the building of freeways, multi-lane highways, and automobile use. However, such migration to a suburbia far away from the cities where people worked did not happen on such a large scale in other countries, in spite of building freeways, sometimes earlier than in the U.S. (e.g., in Germany). It is a known fact that living in the center of Paris, London, Rome, Prague, Vienna, or any major European city is highly desirable, and the value of real estate is at a premium. Outside of the U.S., it is in the medium- to high-density suburbs where lower-income people reside and use mostly public transportation to commute to their workplaces. Consequently, people living in urban areas outside the U.S. drive far less, commute far more by public transportation, and have smaller cars. The result of the massive urban sprawl in the second half of the 20th century in some major U.S. urban areas was a partial collapse of the central cities, the demise of public transportation, and the conversion of many commercial downtowns after 5:00 P.M. into ghost towns inhabited by cleaning crews, conventioneers, and tourists. Cities were losing their population dramatically, and as more affluent people moved to suburbs, the cities lost their tax base, and infrastructure deteriorated. By early 2000, Detroit (Michigan) lost $^1/_2$ of its population and large areas of the city were converted into abandoned wasteland.

At the end of the 20th century, Dittmar (1995) made a prediction and assumptions about the future of automobile use and its effect on the pollution of urban runoff, which was corroborated by Heaney (2000), obviously reflecting the uptrends of automobile ownership and miles driven at the end of the 20th century. Dittmar stated that it was not the American driver who was choosing exurbia and long-distance driving, and that the government was not simply responding by building more roadways and parking lots, and making it possible to buy land in rural areas for subdivisions. He pointed out that people were responding to a set of signals the society was giving them by building freeways, ring roads, and beltways, subsidizing free parking and suburban development through water, stormwater, and wastewater utility infrastructure, and providing tax incentives that favored suburban living and suburban home ownership. For one thing, the main original reason for building cross-country freeways in the U.S. in the fifties was not to bring people to the suburbs, but to move the military and raw materials quickly for national defense reasons, during war. However, cheap gas, deteriorating central cities, and disappearing public transport were giving people signals favoring urban sprawl.

Urban sprawl puts a large demand on energy because of cooling and heating large homes, and on water resources used for lawn irrigation. Low-density suburbs often rely on private on-site sewage disposal by septic tanks, which have a high rate of failure. It is the middle- and higher-income households with two or more automobiles, living in low-density suburbs, that have the highest consumption of resources, far more than those with similar incomes living in cities (McGranahan and Satterthwaite, 2003; Newman, 1996). Hardoy, Mitlin, and Satterthwaite (2001) made an assessment that "one particularly wealthy, high-consumption individual or household with several large automobiles, a large inefficiently heated or cooled home, and with frequent use of air travel (for pleasure and/or work) can have a more damaging global ecological impact than thousands of urban dwellers in informal settlements (shanty towns) in low income nations."

I.2.7 The Rise of New Great Powers Competing for Resources

For most of the 19th, and especially the 20th, centuries, the U.S., Western Europe, and Japan had most of the industries and were the wealthiest. The U.S. has been the greatest industrial power. However, in the last 20 years, tremendous demographic, political, educational, and economic changes have occurred throughout the world, especially in the countries that have been identified as developing countries. The end of the colonial era in Asia and Africa in the middle of the last century, the end of the Cold War, international cooperation through the United Nations and other international organizations, and the increased impact of nongovernmental national and international organizations have all had a significant impact on the standards of living and health care in many countries that previously suffered epidemics, famine, and unjust subjugation to colonial and military/occupational rules. Improved health care and nutrition have also resulted in rapid, almost exponential, population growth in these countries, massive migration from rural areas to cities, and, sometimes, a reversal of progress.

The increased living standards are not uniform, they are more favorable in South and East Asia, where Japan, the Republic of Korea, Malaysia, China (Hong Kong and surrounding provinces in China, Shanghai and surroundings, Tianjin province, and the capital province of Beijing), parts of Thailand, Singapore, parts of India, and some countries in the Middle East have made great advances. In all rapidly advancing Asian countries, as happened a few decades before in Western Europe and the U.S., rapid economic progress has been accompanied by deterioration of the environment on the local and regional scale, and adverse impacts on public health and living conditions due to pollution.

At the end of World War II, all Asian, African, and Latin American countries were undeveloped, relying primarily on manual labor in cottage industries, agriculture, and commerce. Most of their people were living in rural areas. Japan’s economy was destroyed by the war. At the end of the 1940s and in the 1950s, China was ending its revolution and civil war, and its economy was decimated and cut off from the industrialized world. During the “Great Leap Forward,” which was a forceful policy of attempting to bring about a rapid economic advancement in communal systems, between 1959 and the first part of the 1960s, food production actually decreased and China had a Great Famine, during which millions of people died of starvation. The Great Leap Forward was followed by the “Cultural Revolution” in the later 1960s and the 1970s. These were periods of massive relocation into newly established rural communes, which decimated the economy. The period of fast economic growth in China started after the economic (and also political) reforms of 1984. India ended British colonial rule and gained independence in 1947. Today, Japan, the Republic of Korea, China, and India are the major Asian countries competing for resources, and their total greenhouse gas emissions are among the largest in the world. These countries will also have the largest increases of urban population in the upcoming years (see section I.3.1).

The annual gross domestic product (GDP) growth of China after the Cultural Revolution, in the years after the economic reform from 1984 to 2005, was 9.6%, and it reached 11.9% in 2006 (Barboza, 2007), but, as a result of the financial crisis of 2008–2009, the growth has decreased to about 9%. In the same period, the economies of the U.S. and some European Union countries were at a standstill, or a recession. Since 1984 China’s economy doubled itself more than three times. By 2002 the Chinese economy was about 8.5 times what it had been at the beginning of the economic reforms in the 1980s. China already has the world’s third-largest economy. Based on the pre-2008 estimates, China was expected to become the world’s largest economy by 2030. This could happen sooner because of the 2008–2009 recession in the U.S. and the slow growth thereafter, while China’s economy continued its rapid growth. China is a one-party socialist country that, since the economic reforms in the 1980s, has been adopting more and more of a free market system.

India is the second most populous country in the world (after China), with a continuing but slightly slowing rate of population increase. Based on United Nations population statistics and forecasts, India is expected to surpass China as the most populous country around the year 2030, yet its area is only about one-third of that of China or the U.S. The population of India is increasing by approximately 17 million annually; however, the rate of growth is not geographically uniform. Today, India has the 10th- to 12th-largest global economy, based on the total GDP; however, in 2005 India's per capita GDP of U.S. $3300/person put India at the 158th place among the nations (GeoHive, 2007).

However, the population rise in the emerging economic powers has to be considered from the viewpoint of their per capita resource use and waste generation in comparison with the developed countries. Average per capita waste generation in the urban centers of developed countries can be as much as 20 times higher, and it is as high as 1000 kg/capita-year (McGranahan and Satterthwaite, 2003). Furthermore, both China and India import and reuse waste from abroad, mainly from the U.S., for recycling—from paper, cans, and scrap metal to decommissioned large ships that are converted to scrap metal and reused in India. McGranahan and Satterthwaite also point out that it is the upper- and middle-income groups in the affluent countries that account for most resource use, most generation of household waste, and highest per capita emissions of GHG. The authors also state that it would be highly appropriate to require consumers in countries with high income, consumption, and waste production to reduce their levels of natural resource use, including water, and/or halt the damaging ecological impact of their demands for fresh water and other resources.

Countries in Asia and some in Latin America (Mexico, Brazil, Venezuela) anticipate massive changes towards urbanization by 2050. In the next 30 years, China is planning to relocate 300 million people from rural to urban areas, where the jobs are needed for the growing economy. Some of these new cities will be ecocities, and China is spending funds on ecocity research and importing know-how from other countries, including Sweden, Singapore, and the U.S.

I.3 DRIVERS FOR CHANGE TOWARDS SUSTAINABILITY

Chapter II will define, describe the concepts of, and address the needs for the new sustainable (fifth) paradigm of water centric urbanism. This paradigm will balance social, environmental, and economic factors and the resolution of stresses. There are numerous social, economic, and environmental drivers for a change and a switch to the new paradigm of sustainability such as:

1. Population increase and the resulting migration of population into cities; the emergence of megacities
2. Increasing water scarcity due to overuse and pollution, impacting both population and economy
3. The necessity to reduce emissions of greenhouse gases and the need to adapt to global warming
4. The increased frequency and magnitude of extreme meteorological events, and the need for cities to become more resilient

5. The deteriorating water infrastructure and the need to rebuild and/or retrofit cities to accommodate current and future stresses
6. Attaining and maintaining the ecological integrity of urban water resources, as mandated by environmental legislation and desired by the public in most countries
7. The increasing living standard of people in cities and suburbs, and the desirability of living near surface water bodies
8. The deleterious effects of continuing the status quo and building cities using the rules and methods of the current paradigm
9. The new technologies that have been developed and are available:
    a. Wastewater can be treated and reclaimed with a quality commensurate with or better than that in the unpolluted receiving water bodies; even potable water quality can be reclaimed in small (subdivision, commercial area, large office building) as well as large (regional) water reclamation facilities (Chapter VII).
    b. Methods for reclaiming energy from wastewater supplemented by solar, wind, and geotechnical renewable sources are available and economical. New methods of reclaiming energy based on hydrogen gas rather than carbon will be available (see Chapter VIII).
    c. Best management practices mimicking nature and blending with the urban environment have been developed and are desired by the public. After capture and treatment of rainwater and stormwater, these BMPs can provide water for reuse that can also be blended with reclaimed wastewater effluents (Chapters III and IV).
    d. Green buildings and low-impact subdivisions are now being built on a large scale that provide substantial water reuse and energy savings (Chapters III and VIII).
    e. Vehicles fueled by hydrogen or electricity are being developed and will be available for mass market in one or two decades.
    f. Living in cities, not in distant suburbs, which has always been preferred in European and other cities outside of the U.S., is now becoming a popular alternative in the U.S.
    g. Restored or daylighted urban streams stimulate the economic revival of cities and provide recreational and leisure opportunities (Chapter IX).
10. Because rainwater and wastewater will be considered as a resource and not waste, significant economic benefits will become available that, under the best-case scenario, can pay for the sustainable urban water centric developments. Urban sewage can be converted to a clean effluent for reuse, and methane gas and hydrogen for energy (Chapters VVI, VII and VIII).

The building blocks of the Cities of the Future—the ecocities—are available, and the necessity of adaptation to the future's very serious stresses calls for the change.

I.3.1 Population Increases and Pressures

The magnitude and consequences of the expected population increases have been on people's minds for decades. Demographic experts coined the term "population explosion" to describe the population growth, reviving the predictions of British economist Thomas Malthus, who predicted in 1798 that the world's population would eventually outpace food production, which would lead to massive starvation and famine. At that time the world population was several hundred million people. It reached one billion in the late 1800s, and over the last century, the earth's population has increased from about one billion to six billion—"officially" reached on October 12, 1999 (United Nations, 1999). The world population more than doubled in the last 50 years. In 2009, the world population reached 6.9 billion. Most of the growth has occurred in developing and undeveloped countries. Malthus's predictions have been shown to be overly pessimistic; although large famines have occurred in the last 50 years in China, North Korea, and Africa, the main reasons were institutional and political mismanagement and faulty demographic and agricultural policies. For example, in China during the Great Leap Forward in the 1950s, massive relocation of people from cities to rural areas and faulty agricultural policies and methods resulted in a mismanaged agricultural economy and famine.

In 2010, China was the most populous country of the world, followed by India and the U.S. China and the conterminous U.S. have about the same area; hence, the population density of China is about 4.3 times greater than that of the U.S. The world population is expected to stabilize at around 9 to 10 billion after 2050. Figure 1.24 and Table 1.3 present the population numbers of the world and of several sample countries, including the U.S., the United Kingdom (Western Europe), the Czech Republic (Central Europe), Russia (Eastern Europe and Asia), and China and India.

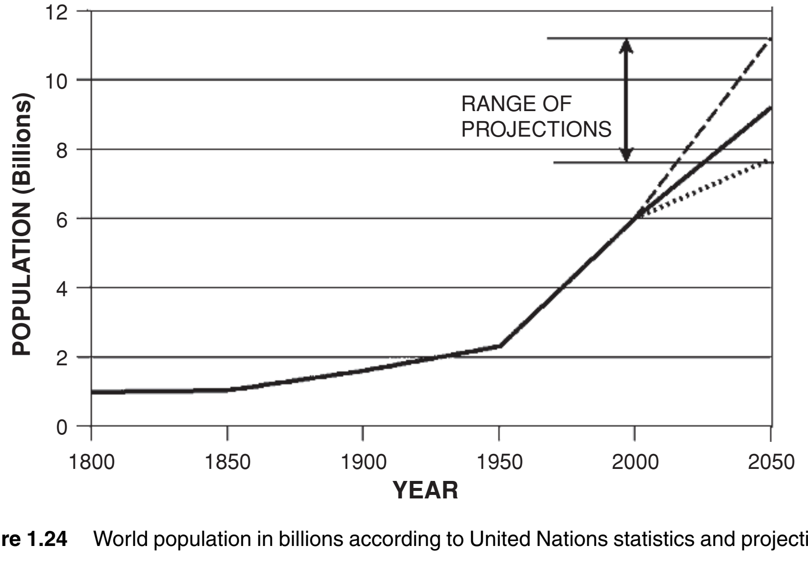


Figure 1.24 World population in billions according to United Nations statistics and projections.

Table 1.3 Population numbers in selected countries

	Population in Millions						
YEAR	World	U.S.	Czech Republic	United Kingdom	China	Russia	India
1960	3041	180.671	9.66	52.372	650.6	119.936	445.4
1980	4452	227.726	10.288	56.314	984.7	139.038	684.9
2000	6084	282.338	10.270	59.522	1268.8	146.709	1004.1
2010	6866	309.162	10.201	61.068	1347.6	139.390	1184.1
2030	8373	363.811	9.628	64.462	1461.5	124.094	1532.5
2050	9538	420.080	8.54	63.977	1424.2	109.187	1807.9

Source: U.S. Census Bureau, International Data Base, year 2008 data.

The demographic population models balance births, deaths, and migration and several factors affecting the model parameters. Traditionally in most countries, until a few decades ago, rural farming families desired and had a large number of children, who provided labor. The high death rate of children also encouraged large families. During the generational transition, the oldest son was given the farm, and the other siblings had to relocate, mostly to cities. During the industrial age there was always a movement of people from the villages to the cities in search of employment. The population explosion in the 20th century in developing countries occurred mainly because of the improvement in health care and a dramatic reduction in child mortality.

Table 1.3 shows interesting trends. First, most European countries (including Russia) and also Japan have already reached their peak plateau, and by 2050 the population is expected to stay steady or decline, which, oddly, could be caused by increased living standards and a cost of living that often requires both parents to be employed. The U.S. is expected to gain almost 40% in population numbers between 2007 and 2050, mainly due to immigration. China will reach its peak population around 2030, and then the population will remain steady or slightly decline. The biggest population increases are expected in India (60%) and also in other Asian countries such as Bangladesh, Indonesia, Thailand, and the Philippines, and in several Latin American and African countries such as Brazil, Mexico, Nigeria, Ethiopia, and Egypt.

Beyond the year 2050, the population numbers will be affected by global warming and accompanying increases in seawater levels and frequency of catastrophic events that may dramatically affect population in low-lying high-density countries such as Bangladesh.

Even under the current population numbers, some cities are already overpopulated and cannot provide even basic services to a large part of the rapidly increasing number of their citizens, especially in developing countries. The conflicts between the population numbers and the services provided by communities have reached a breaking point with the emergence of "megacities" (cities with a population of more than 10 million) in several rapidly growing countries in Asia, Africa, and Latin America. In these countries the population migration is different from that in the U.S. and,

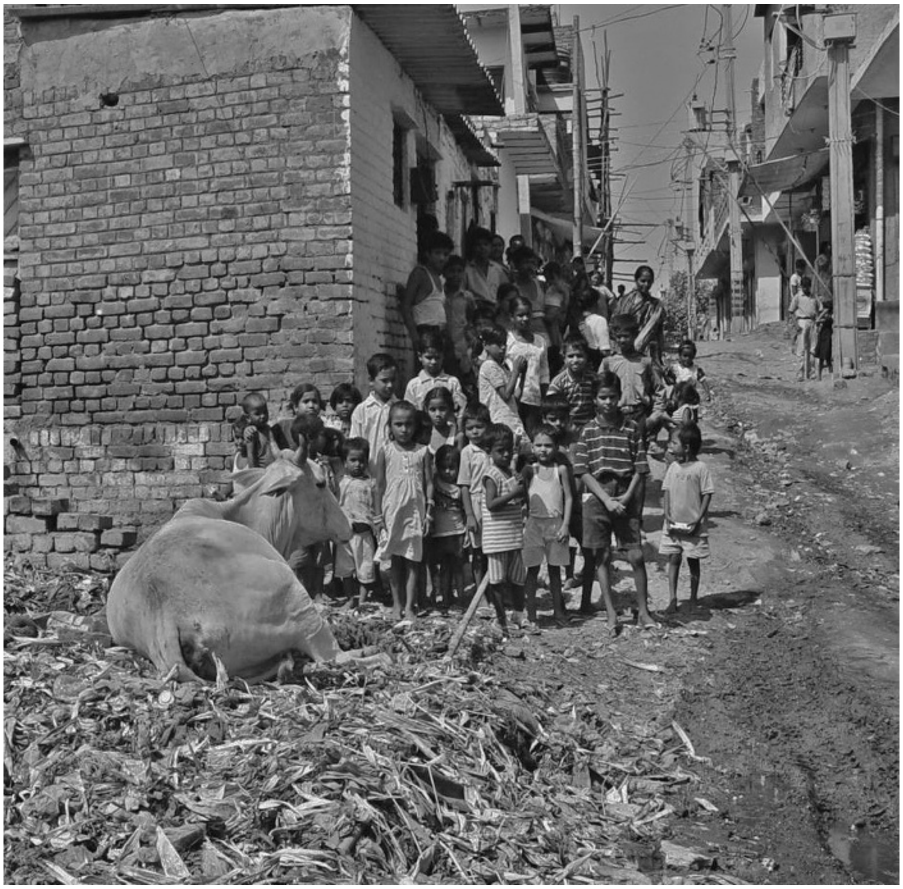


Figure 1.25 In slums in India, the street is the drainage (photo courtesy Operation ASHA www.opasha.org).

partially, in some European countries. In developing countries the net flux of population is away from the rural areas that are unable to provide a livelihood to the increasing number of rural people. This flux is often undertaken for survival and, having moved from the rural areas into cities, entire families live in small crude cardboard or tin houses, or even under tents in large shantytowns abutting the city centers. The environment in the shantytowns of some developing countries is on the same level as that in the medieval cities of Europe centuries ago (Figure 1.25).

The most serious aspect of the population increase and migration is the fact that most of the new population will be residing in the cities. Hence the population growth of the cities will be more than twice that for entire countries (Table 1.4). To put these changes into perspective, China's population is expected to increase in the next 30 years by 100 million, but the urban population increase that the Chinese planners anticipate is about 300 million, which implies that each year between 2010 and

Table 1.4 Annual population growth (geometric increase)

	Growth/Year (%)
Total world population increase	
1970–1990	1.76
2020–2050	0.72
More developed regions	
1970–1990	0.64
2020–2050	~ 0
Less developed regions	
1970–1990	2.12
2020–2050	0 (China) to 0.95 (India)
Urban areas	
More developed regions 1970–1990	1.58
Less developed regions 1970–1990	5.27

Source: U.S. Census Bureau, International Data Base; Neimczynowicz, 1996; United Nations statistics.

2040 China will have to build new cities and expand existing cities to accommodate 10 million people. This situation is even more serious in India and other developing countries of Asia, Africa, and Latin America with large population increases.

In the 1950s about 30% of the total world population lived in urban areas; the corresponding estimate for 2000 by the experts from large urban areas during the 2004 Stockholm World Water Week (Biswas et al., 2004) was 50%, and it will increase in the future to more than 60%. In some countries, the urban population will represent more than 90% of the total population (UN Secretariat, 2005).

The major difference between urbanization in the developed and developing countries is the fact that in developed countries the largest rate of increase occurred during the Industrial Revolution in the 19th and 20th centuries, and the population movement—after involuntary serfdom and slavery were abolished—was commensurate with the economic development and lasted for more than a century. However, by the end of the 20th century, industries fueling the industrial expansion were in decay, and most were abandoned. This was the period when Milwaukee (Wisconsin) lost its breweries and major manufacturing industries; Manchester (U.K.), Youngstown (Ohio), Pittsburgh (Pennsylvania), and the Ruhr area of Germany lost their steel mills and deep mines; and many cities in New England, North Carolina, and other regions of the U.S. lost their textile manufacturing. St. Louis, Missouri, on the Mississippi River, was the fourth-largest U.S. city at the beginning of the 20th century, with a population of more than 700,000, and had several large industries. One hundred years later, at the beginning of the 21st century, most industries had left the city or were sold, and the city population was around 300,000.

Megalopoli-Megacities The period after 1970 has witnessed the emergence of megalopoli/megacities—that is, cities with a population of more than 10 million. Before World War II, the largest city in the world was London, which has

Figure 1.26 One of the largest megacities, São Paulo, Brazil.

never achieved the dubious distinction of a megalopolis. New York, which was the second-largest city, became the first megalopolis in 1956 (Lewis, 2007). In 2008, the Tokyo–Yokohama conglomeration was the largest city of the world, with a population of 35 million, followed by Mexico City, São Paulo (Brazil) (Figure 1.26), New York, and Mumbai (India). However, Tokyo's rate of growth is being reduced; therefore, it is predicted that Tokyo will be overtaken by Mumbai, Shanghai (China), and Dhaka (Bangladesh) (Lewis, 2007). There were 20 megacities in 2008, and 15 of them were in developing countries. Lewis (2007) expects that even as the world's overall population will eventually level off somewhere between 9 to 10 billion, the megacities and smaller cities with populations in the millions will continue their expansion, as the rural population moves to the cities and—in most developing countries—become the urban poor.

In the U.S., the opposite trend has occurred. The net flux of population is away from the cities in the Northeast and Midwest that have been losing population for decades to the suburbs or to rapidly growing cities in the South and Southwest. Hence, the dichotomy of urban population migration is the formation of shantytowns and rapid urban growth in the developing megacities, and a loss of population and urban sprawl mainly in the U.S. Northeast and Midwest.

Of the world's megacities, the Los Angeles, California, metropolitan area has the greatest surface area (27,800 km^2), resulting in the least dense population. Cairo's population (10.4 million) is reported as being confined in 214 km^2, making it the most densely populated megacity.

Nevertheless, in spite of the fact that historic cities in the U.S. have stagnant or dropping population numbers, the cities provide the employment, and the majority of suburban areas are not rural farming communities but low-density bedroom communities connected to the city by freeways and sometimes by public transportation. One can see now and foresee in the future the development of urban megalopolis agglomerations consisting of several cities with suburbs and satellite cities between them. The most notable urban conglomerations in the U.S. are:

Los Angeles–Riverside–Orange County, in California
Chicago, Illinois–Gary, Indiana–Kenosha, Wisconsin
Washington, D.C.–Baltimore, Maryland–Northern Virginia
San Francisco–Oakland– Berkeley–San José, in California
Dallas–Ft. Worth–Arlington, in Texas
Tokyo–Yokohama, in Japan, the largest urban conglomeration in the world

In the developing world, the growth of megacities and one-million-plus cities is rapid. For example, the population of the Mexico City metropolitan area increased from 3.1 million in 1950 to 13.4 in 1980, a 425% increase in only 30 years (Biswas et al., 2004). Consequently, the infrastructure may not be available to provide adequate drinking water service, stormwater management, and sanitation. Flooding is sometimes a major problem, since the burgeoning population often settles in floodplains, either by design or by necessity, to find space for living. The number of people exposed to flooding tripled from the 1970s to the 1990s and is currently about two billion (Biswas et al., 2004), and it is expected to grow even faster due to the effects of global warming on the frequency and magnitude of floods, as experienced already in the U.S. Midwest in 1993, 1998, and 2008.

Gurjar et al. (2008) reported that Tokyo, Beijing, Shanghai, and Los Angeles have the highest CO (carbon monoxide) emissions on an annual basis, and Kolkata, Dhaka, Mumbai, Cairo, and Rio de Janeiro have the lowest emissions. Cairo, Tokyo, and Moscow rank among the highest emitters of CO per unit of surface area, and Rio de Janeiro and Los Angeles rank among the lowest emitters per unit area. CO emissions can be correlated to CO_2 (carbon dioxide) GHG emissions.

I.3.2 Water Scarcity Problems and Flooding Challenges of Large Cities

In the U.S. some large cities—such as Los Angeles (CA), Tucson (AZ), Santa Barbara (CA)—have grown in dry arid climatic conditions and anticipate droughts and water scarcity as is also true of Beijing (China). However, water scarcity problems are not limited to cities located in arid zones. The rapid growth of some cities in more humid areas that rely on relatively small water resources, such as Atlanta (Georgia), or draw water from limited groundwater resources, such as many suburbs of Chicago (Illinois), Boston (Massachusetts), and Milwaukee (Wisconsin), results

Table 1.5 Freshwater withdrawals and water use distribution in some countries (from Gleick, 2003)

Country		Per Capita Withdrawals (Liters/ Capita-Day)	Municipal and Domestic Uses % (Liters/ Capita-Day)	Industrial Use (%)	Agricultural Use (%)
Africa	Libya	1972	11 (217)	2	87
	Uganda	24.6	32 (7.9)	8	60
Americas	Canada	3918	11 (431)	80	8
	U.S.	4625	12 (555)	46	42
	Mexico	2156	17 (366)	5	78
	Brazil	878	21 (184)	18	61
	Paraguay	214	15 (32)	7	78
Asia	Bangladesh	1060	12 (127)	2	86
	China	1181	11 (130)	21	69
	India	1361	5 (68)	3	92
	Iran	2501	6 (150)	2	92
	Israel	767	16 (123)	5	79
	Japan	1981	19 (376)	17	64
	Pakistan	2732	2 (54)	2	96
Europe	Austria	833	19 (158)	73	8
	Czech Republic	764	23 (175)	68	9
	France	1619	16 (257)	69	15
	Germany	1477	14 (206)	68	18
	Italy	2693	14 (377)	27	59
	Russian Fed.	1443	19 (274)	62	20
	Spain	2293	12 (275)	28	62
	Sweden	912	36 (328)	55	9
Australia	Australia	2589	15 (388)	10	75
	New Zealand	1457	46 (670)	10	44

in an inadequate water supply, mainly due to overuse and large losses from the water distribution systems.

Gleick (2003) compiled worldwide and country-by-country water use and withdrawal statistics. Some data for selected countries are included in Table 1.5, which contains data mostly reported in the 1990s. The municipal/domestic water use in the table includes household, municipal, commercial, and government uses. The industrial sector uses includes water used for cooling and production. Agricultural uses are for irrigation and livestock. The largest use is for irrigation, especially in Asia.

Regarding domestic/municipal use, there is great disparity in water use among countries and continents. The highest municipal/domestic use is in New Zealand, which has abundant water resources throughout the entire country. The second and third highest are the U.S. and Canada, respectively, but these numbers may be misleading in the U.S., where Southwestern urban areas have severe water shortages. Lawn irrigation is the largest domestic water use in the U.S. suburbs, and often treated drinking water is used for lawn irrigation. Municipal water use in Europe is about 50% of that in the U.S., which is due to the fact that the lots on which houses are built are much smaller than those in the U.S. or Canada, and many people live in apartments. Municipal/domestic water use in large Asian countries is 25% (China) of that in the U.S., or less. Chapter V presents the concepts and data on water conservation.

Gleick (2003) also summarized the forecasts of future use and pointed out that extrapolating from past trends may be misleading. For example, in the U.S. the total water withdrawals of fresh and saline water between 1975 and 1990 increased from about 2000 liters/person-day to about 7500 liters/person-day, but between 1975 and 2000 the water withdrawals dropped to 5500 liters/person-day. The per capita water use rates have dropped in many cities also, due to mandatory or voluntary implementation of some water-saving devices and by plugging the leaks and minimizing the losses in the water distribution systems, as occurred in Chicago (Lanyon, 2007) and in Boston (Breckenridge, 2007), which realized about 20% savings on water demand, even when the population increased. Gleick (2003) surveyed the literature reporting the effect of water conservation in several municipalities throughout the world. See Chapter V for more details about water conservation.

The effect on water use of switching to sustainable water management can be seen in the prototype of a sustainable city, Hammarby Sjöstad, a district of Stockholm, Sweden (see also Chapter XI). Note that the average domestic (municipal) use in Sweden reported in Table 1.5 is 328 liters/person-day; typical water use in Stockholm in 2000 was about 200 liters/person-day. In the U.S. it is about 550 liters/person-day, as shown in Table 1.5. The municipal water use of Hammarby Sjöstad in 2008 was about 150 liters/person-day, and the goal, after the full implementation of water conservation, is to reduce the water use to 100 liters/person-day. The new ecocity (see Chapters V, VII, and XI) Masdar in the United Arab Emirates, and those planned elsewhere throughout the world can, by water conservation, reclamation, and reuse, reduce water demand from the grid or other freshwater sources or desalination to 50 liters/person-day, yet still maintain a comfortable water use commensurate with that of other cities practicing water conservation.

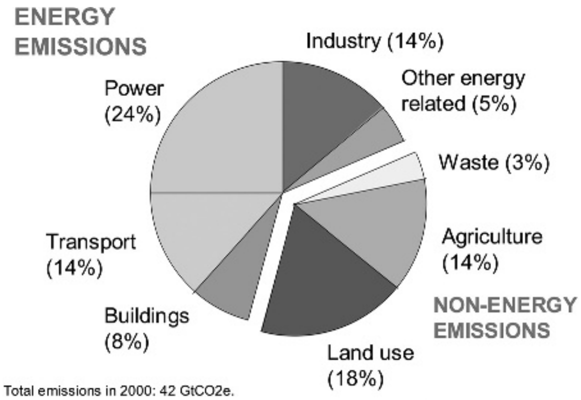
I.3.3 Greenhouse Emissions and Global Warming Effects

The recent report by the International Panel on Climatic Change (2007) outlined the challenges human beings are facing due to the effects of global climatic changes. These effects will be both global and regional. As a result of these changes, it is very likely that large and catastrophic storms will increase in magnitude and frequency, resulting in more frequent flooding. Droughts in dry zones will also be more frequent and more severe. This necessitates, on one side of the issue, the development of adaptation and risk management practices for the urban water sector and better human response management during extreme events and, on the other side, connecting water conservation and management with a reduction of greenhouse gases.

As pointed out in the preceding sections of this chapter, global warming is caused by the emission of greenhouse gases (GHGs). The principal greenhouse gases that enter the atmosphere because of human activities are:

- **Carbon dioxide (CO_2)**: Carbon dioxide enters the atmosphere through the burning of fossil fuels (oil, natural gas, and coal), solid waste, trees and wood products, and also as a result of other chemical reactions (e.g., manufacture of cement). Carbon dioxide is also removed from the atmosphere (or "sequestered") when it is absorbed by plants as part of the biological carbon cycle. The global warming potential (GWP) of CO_2 has been set as 1. Carbon dioxide (CO_2) is the most important greenhouse gas.
- **Methane (CH_4)**: Methane is emitted during the production and transport of coal, natural gas, and oil. Methane emissions also result from livestock raising and other agricultural practices, and from the decay of organic waste in municipal solid waste landfills and organic matter in wetlands. The GWP of methane is 25 over 100 years—that is, it is 25 times more potent as a greenhouse gas than carbon dioxide—but there's far less of it in the atmosphere, and it is measured in parts per billion. When related climate effects are taken into account, methane's overall climate impact is nearly half that of carbon dioxide.
- **Nitrous oxide (N_2O)**: Nitrous oxide is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste. GWP = 300 over 100 years. It is also emitted by natural and constricted wetlands.
- **Fluorinated gases**: Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halogens). These gases are typically emitted in smaller quantities, but because they are potent greenhouse gases with GWP in the thousands, they are sometimes referred to as "high global warming potential" (high GWP) gases.

Short-wave solar radiation penetrates the earth's atmosphere, and it is partly absorbed by the earth's surface and partly reflected as long-wave radiation back into space. The ratio of the reflected solar radiation to the total radiation is called albedo. Albedo depends on the color of the surface and the angle at which the radiation reaches the surface. White surfaces reflect most of the incoming short-wave radiation; dark surfaces absorb it and emit a portion of it back into the atmosphere as long-wave radiation. Greenhouse gases can prevent part of the reflected long-wave radiation from being sent back into space, which will warm up the atmosphere as a glass roof does in a greenhouse. Short-wave solar radiation can penetrate glass, but glass will keep the long-wave radiation (heat) in the greenhouse. Hence, the temperature of the atmosphere is related to the concentration of the greenhouse gases in the air. The natural concentration of carbon dioxide in the atmosphere during the



Total emissions in 2000: 42 GtCO2e.

Energy emissions are mostly CO_2 (some non-CO_2 in industry and other energy related).
Non-energy emissions are CO_2 (land use) and non-CO_2 (agriculture and waste).

Figure 1.27 Main sources of greenhouse gases according to the IPCC (2007).

pre-industrial period was about 279 ppm (parts per million) in the volume of air, or 0.028%, but currently it is significantly higher and is increasing.

Sources of Greenhouse Gas Emissions Most of the natural CO_2 and methane (CH_4) in the atmosphere originates from natural sources such as decay of organic matter, the respiration of living organisms, and natural forest fires. Volcanic eruptions today account for about 1% of the natural emission. Methane is a product of anaerobic decomposition and is emitted naturally from wetlands by the anaerobic decomposition of organic matter and by living organisms. These sources of GHG emissions are counterbalanced by sinks that include photosynthesis or dissolution in oceans and conversion into bicarbonate and carbonate compounds.

The main anthropogenic source of carbon dioxide is combustion of coal and natural gas in power plants, homes, and industries, gasoline burning in vehicles, deforestation by slash-and-burn farming, and grassland fires ignited by human beings—and these additional sources are not counterbalanced by commensurate sinks. Wastewater disposal and treatment operations represent 3% (Figure 1.27). The result is the increase of greenhouse gases in the atmosphere (Figure 1.28) that trap heat and increase the temperature on earth.

In Section I.2.5, “The Impact of Automobile Use,” we reported the U.S. EPA estimate of CO_2 emissions as being 2.33 kg of CO_2 per 1 liter of gasoline fuel consumed in driving. The conversion of energy production into carbon emissions in power plants takes into account the efficiency of the power plant to convert fuel energy into electric energy and the caloric (heat) content of the fuel. The efficiency of power plants is:

$$\varepsilon = \text{energy produced by the power plant/energy in fuel}$$

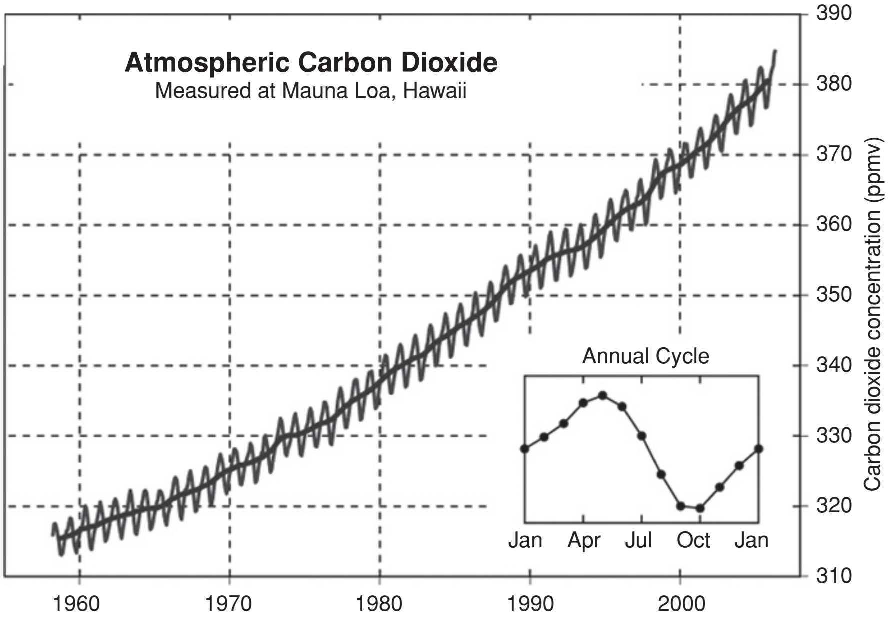


Figure 1.28 Carbon dioxide concentration in the atmosphere measured at the Mauna Loa observatory by the National Oceanic and Atmospheric Administration (ppmv = parts per million by volume = 10^{-6}).

The typical efficiency of fossil fuel power plants is 40 to 50%, which means that about 50 to 60% of the fuel energy is lost (wasted) as heat into the environment and can contribute to the thermal pollution of receiving waters that are a source of cooling water. The efficiency of nuclear power plants is less (they emit more waste heat), but these plants have a very small carbon footprint. Heat emitted from power plants may contribute slightly to global warming, but not as much as the effect of carbon dioxide emissions into the atmosphere from smokestacks.

Energy in fuel and produced by generators is today expressed in kilowatt-hours (kWh) (see also Chapter VIII). 1 kWh is 3.6 megajoules (MJ). The U.S. Department of Energy (2000) published estimates of the carbon equivalent of energy produced by fossil fuel power plants as:

0.96 kg of CO_2/kWh produced by coal-fired power plants
0.89 kg of CO_2/kWh produced by oil-fired power plants
0.60 kg of CO_2/kWh produced by natural gas power plants

Figure 1.29 shows that in the U.S., about 30% of energy is produced by processes that do not emit substantial quantities of GHGs (nuclear, renewables, and

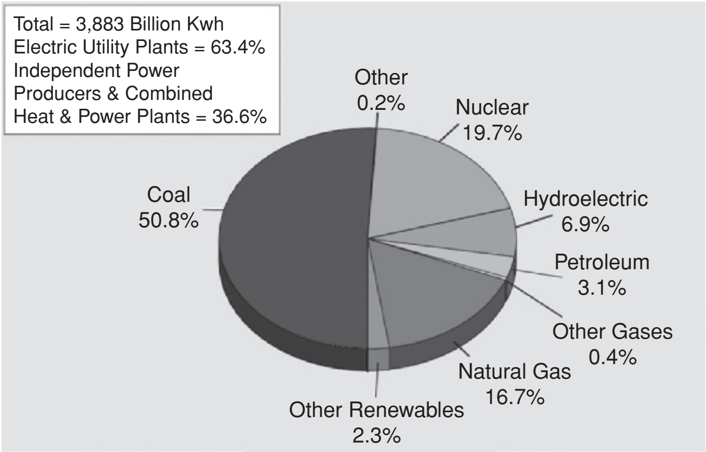


Figure 1.29 U.S. electric power generation sources. The total energy generation is for 2003. In 2008, the energy consumption increased to 4,110 billion kWh. From U.S. Department of Energy – Energy Information Administration (2008).

hydropower). Because the power plants are interconnected in a grid for GHG emission estimations in this monograph, we will consider a weighted average, which is:

$$0.62 \text{ kg of } CO_2 \text{ emitted per kWh of energy produced}$$

The proportions between the sources of energy vary from country to country. For example, in France, relying heavily on nuclear power, or Austria, relying on hydropower and renewable energy, most energy production does not emit GHGs. Austria, for example, has embarked on large-scale development of wind energy, in addition to the hydropower that is abundant in this mountainous country. In the U.S., on the other hand, sources of hydropower are almost all already developed, and no major dams will be built. As a matter of fact, there is pressure by environmental and wildlife nongovernmental organizations (NGOs) to remove some dams (e.g., on the Columbia River) that impede the movement of anadromous fish (salmon). Hence, the future of the development of the new energy sources is mainly in renewable sources and a return to the development of nuclear power. China has just about finished building the world's largest hydropower dam, the Three Gorges Dam on the Yangtze River.

Effects of Greenhouse Gas Emissions Since the beginning of the Industrial Revolution in the 19th century, the atmospheric content of CO_2 has increased by 30% and the temperature of the atmosphere by 0.8°C. However, if the anthropogenic emissions of greenhouse gases continue to increase or even remain at the present levels, including uncertainties in future greenhouse gas concentrations and climate modeling, the IPCC (2007) and Meehl et al. (2005) anticipate warming by another 0.6°C by the end of the 21st century and potentially an ultimate rise by 4.5°C (8.1°F) relative to 1990. It was noted in the IPCC report that during the last warm interglacial period, about 125,000 years ago, when the temperatures were 3–5°C warmer than during the 20th century (due to the change of the earth's rotation that exposed polar regions to more warming), sea levels were 4 to 5 meters higher.

Ocean water levels will rise due to the volume expansion caused by warming water and the corresponding decrease of volumetric density, and from melting of glaciers on dry land. The melting of ocean ice and icebergs does not contribute to the water level rise, but it is a part of the global thermal balance. Meehl et al. (2005) in *Science* estimated global temperature rise at 1–3°C by 2100 over that at the beginning of the Industrial Revolution, and corresponding sea level rises of about 15 to 25 cm due to sea volume expansion alone. Adding the effect of glacier melting, mainly from Greenland, the sea level rise will double to about 0.5 meters. On the basis of their models, the global warming scientists expect very little contribution from the ice over Antarctica, which will keep accumulating precipitation in the form of snow and ice. A similar seawater rise by the year 2100 was predicted by Gregory and Orlemans (1998) in their article in *Nature*. Under the "no action" scenario, the doomsday seawater rise of 4–5 meters, caused by the temperature rise of 5 to 8°C, could occur over centuries to millennia.

The IPCC (2007) report states that a temperature increase of 1–3°C may have both positive and negative effects, but that climatic change and a continuing increase in temperature would, in the long term, likely exceed the capacity of natural, managed human systems to adapt.

Implication of global warming for cities. At the end of the 20th century, the implications of global warming began to be felt on a wide scale. Arctic scientists and satellite observations noticed significant losses of Arctic ice, including Greenland; glaciers were disappearing from high mountains; polar bears were affected; and the summer and winter temperatures were noticeably higher, especially in polar regions.

All of these and other effects were widely reported by the media. On December 11, 1997, the Kyoto Protocol was adopted in Kyoto, Japan, and it entered into force on February 16, 2005. It set binding targets for 37 industrialized countries and the European community for reducing GHG by 5% measured against 1990 levels over the 5-year period 2008–2012. One hundred eighty nations have ratified the treaty to date, but not the United States and a small handful of other countries. The U.S. is by far the largest emitter of greenhouse gases per capita of the largest developed countries; larger per capita emissions can be found in small and wealthy Middle Eastern countries. Until recently, the U.S. was also the largest total emitter of greenhouse gases. Table 1.6 lists top countries with per capita and total annual emissions. The impact of global warming on cities will be large, especially on those located in low-lying coastal areas, where the effects will be exacerbated by increased coastal erosion due to more frequent extreme storms. US President Obama attended in 2009 the follow-up Copenhagen Global Warming Convention and more action of reducing GHG emissions in the US will ensue.

Table 1.6 Greenhouse emissions by selected countries

Per Capita Emissions in 2007 (tons person^{-1} year^{-1})		Countries' Total Annual GHG Emissions in 2007, in Tons, and Share of the Total Global Emissions, in %	
U.S.	19.1	Total GHG emissions	27,944 tons
Australia	18.8		
Canada	17.4		
Saudi Arabia	15.8		% share
Czech Republic	11.8	China	21.5
Russian Federation	11.2	U.S.	21.1
Germany	9.7	Russian Federation	6.1
Japan	9.7	India	4.6
United Kingdom	8.6	Germany	3.1
Norway	7.9	Canada	2.2
Japan	9.4	United Kingdom	2.1
		Rest of the world	39.3
China	4.6		
India	1.2		
World average	3.8		

Source: "United Nations Millennium Goals Indicators" accessed by Wikipedia (2009) http://en.wikipedia.org/wiki/List_of_countries_by_carbon_dioxide_emissions_per_capita.

Because most of the world and U.S. population will be residing and working in cities, living and production processes and commuting will produce GHG emissions and will be responsible for most of the temperature increase. Large cities and (ultra-large) megacities require large amounts of energy, and the production of energy requires large amounts of water both for hydropower and for cooling. Fossil-coal- and oil-fueled power plants produce most of the anthropogenic GHGs.

Besides the rise of temperature, especially in polar regions, cities will face, and have to adapt to, two other major serious impacts related to global warming:

- Seawater level rise due to melting of Greenland glaciers and thermal expansion of the sea volume
- Increased frequency and magnitude of extreme events

Several large cities already have a portion of their area below the elevation of the high tide, or even below the mean sea level (e.g., New Orleans in Louisiana, several cities in Holland, and Venice, Italy). Some have built or are building tidal surge dams across the estuaries on which they are located. Such dams have been built, for example, in London (UK), Boston (Massachusetts), and across several estuaries in Holland. The Dutch situation is especially troublesome because most of the country has very low elevation, and a large portion of the country was actually reclaimed from the sea and is below the main seawater level. The sea tide effects are also a problem in the historic city of Venice in Italy (Figure 1.30). This more than 1300-year-old

Figure 1.30 Thirty years ago, Venice experienced only one or two floods a year, sometimes none. In the 2000s there were on average 70 significant floods of the historic city due to tidal surges, and the increase is partially attributed to global warming. The elevation of Piazza San Marco is less than 1 meter above the average high tide. This picture shows the flooding in December of 2008, one of the largest on record. Any significant increase of sea level elevation will have detrimental effects if flood prevention controls are not implemented. (Picture courtesy of Wikimedia-common and an annonymous photographer)

city, former metropolis and a naval power in the Mediterranean during the time of the Venetian Republic (697–1797 A.D.), is located on the archipelago of 118 small islands inside the brackish 500-km^2 Lagoon of Venice. We have already said that its palaces and churches were built on wood pile foundations, and the city, because of the groundwater overdraft, has been sinking for a long time, reaching a maximum subsidence of 2 cm/year in 1970s. After bringing drinking water by a pipeline from nearby mountains on the mainland, which eliminated groundwater mining, the subsidence and the central city have now stabilized. However, seawater rises measured in 2000 had increased to 1.3 mm/year (Carbognin et al., 2000).

The city responded to this threat with a massive project of increasing (repaving) the grade elevation of all streets and walkways and closing the gaps between the barrier islands and peninsulas that separate the lagoon from the Adriatic sea. Seventy-nine mobile gates were designed to hold the high tides and tidal surges from entering the lagoon in which the historic city is located.

The chair of the U.S. president's Office of Science and Technology Policy, John Holdren (2008), summarized the problems and goals related to global climatic changes as:

- Climatic disruptions and their impact are growing more rapidly than predicted just a few years ago.
- Harm from these impacts is already significant and much more is coming.
- It is too late to avoid "dangerous anthropogenic interferences" in earth climate. The question is: "Can we avoid catastrophic interferences?"
- To avoid severe consequences of climatic changes requires stabilizing human influences on the atmosphere below 450 parts per million CO_2 equivalent.
- Not exceeding 450 ppm CO_2e requires emissions to begin falling in industrial countries by 2015, elsewhere by 2025.
- Doing this will require much better technologies and much stronger policies all over the world.

Several countries (e.g., Great Britain), as well as the U.S. president's National Science and Technology Council (NSTC) (2008) are calling for the development and implementation of net zero CO_2e emission goals for the Cities of the Future, which would include building, transportation, and also water and wastewater (used water) management (see Chapters VI to VIII and X).

I.3.4 Aging Infrastructure and the Need to Rebuild and Retrofit

Water delivery, existing stormwater drainage, and wastewater disposal infrastructure systems are now aging to an extent that is leading to problems (older components may be more than 150 years old), and some parts of the cities' infrastructures are becoming obsolete. At the same time, as performance standards for pollution control continue to become more stringent, the required sewer maintenance or rehabilitation often does not keep pace with the system requirements. To a lesser degree, these concerns also apply to stormwater management facilities built 35 to 25 years ago that are approaching the age when they require major repairs and or upgrades to meet the current expectations (Marsalek et al., 2007; Ashley and Cashman, 2006). While some urban drainage service providers may be equipped for corrective action, in other cases, the financing of rehabilitation and upgrading of drainage systems must be planned in competition with other priorities—and drainage, being in most cases out of sight, is often rated as less important (Gaudreault and Lemire, 2006). There is also a lesson to be learned from this situation by developing countries without extensive centralized infrastructures: that is, distributed systems may offer better services.

The IPCC (2007) report asks cities and society to develop a portfolio of strategies to reduce the trend and cope with global warming. These should include:

- Mitigation of GHG emissions
- Adaptation to irreversible impacts and reducing vulnerability to existing and future disasters

- Technological developments to enhance both adaptation and mitigation
- Research on climate change, impacts, adaptation, and mitigation

The portfolio must be combined with policies, including incentive-based approaches, and actions at all levels from individual citizens through local and national governments.

I.3.5 The Impossibility of Maintaining the Status Quo and Business as Usual

The International Water Association (IWA) Specialist Group on Urban Drainage convened a panel of experts that analyzed several variants of the future developments of urban water, wastewater, and stormwater infrastructures (Marsalek et al., 2007). These alternative approaches included (1) business as usual, (2) privatization, (3) technocratic, and (4) green scenarios.

The business as usual (BAU) scenario has the fundamental weakness of the lack of any explicit consideration of the risks, opportunities and needs for action; inadequate and insufficient funding and financing; low-level involvement of stakeholders; small investment in R&D and hesitation to apply innovative approaches; and, in spite of the good progress in new developments, insufficient attention being paid to older areas that were originally designed for much lower environmental performance standards (e.g., without modern stormwater controls). Thus, the BAU approach is responsible for many of the current problems and is not sustainable. The persistence of this scenario is fueled by the inertia of technical, administrative, economic, and political systems. In the absence of acute problems (catastrophes), the incentive for change is low. The prevailing water, wastewater, and drainage system architecture is a centralized but not integrated system, with some experimental use of decentralized facilities (particularly in suburbs or satellite developments). The system is managed by cities or regional public utilities, which derive their payment from users' fees and taxes.

This scenario, however, neglects the trends of global warming, population increase, and increased water scarcity. The response to these threats is more infrastructure, more imperviousness, more freeways with more traffic lanes, and continuing worsening trends of the quantity and quality of urban runoff and receiving waters. Water scarcity will be increasing not only in the arid areas of the Southwestern U.S. but also in the humid areas relying on smaller streams and groundwater for the water supply, such as the suburbs of Boston, Massachusetts, or the entire metropolitan areas of Atlanta, Georgia, or Tucson, Arizona, or Southern California (see Chapter V). The risks and acute problems of this scenario might be severe in the developed world, but they are unbearable for developing countries, where neither inherited infrastructure, nor money, nor implementation capacity is available.

The business as usual scenario using the third or fourth paradigm tradition is governed by economic targets and goals (both paradigms) and under environmental legislative constraints (fourth paradigm) that are sometimes detached from the reality of social and ecological impacts. Until the end of the 20th century, environmental constraints (criteria and standards) focused only on the chemical parameters of air and water quality.

The privatization scenario has its foundation in the belief that private enterprises are more efficient than bureaucratic public agencies and utilities. The IWA panel stated that in this scenario the private sector is systematically involved in buying or assuming a license for the entire deteriorating water infrastructure and providing water services for contracted fees with a profit. In essence, these large operators are monopolistic entities because citizens and industries do not have a choice in selecting among several providers except for patronizing small-scale haulers of septic tank sullage or buying bottled water in supermarkets. The main purpose for these large monopolistic operations is to make profit, but the result in some cases is soaring increases in the cost of the services (for example, after privatization of British watershed management agencies in the 1980s) or failure to meet the expectations.

At the beginning of the third millennium, private companies provided approximately 15% of all water services in the U.S., and this proportion has been relatively constant since 1940 (Cech, 2005). In the United Kingdom, Berlin (Germany), Buenos Aires (Argentina), Johannesburg (South Africa), and Mexico City, all water supply is provided by private companies (National Research Council, 2002). The British water utility, Thames Water, which evolved from the public watershed management agency of the same name after the privatization decrees implemented by the Thatcher government in the 1980s, has over 11.5 million customers in England and abroad, from Chile to Turkey and Australia to China (Cech, 2005). They compete with other large private companies such as Suez Environment (a parent company of United Water) and Veolia Environmental Services. Recently Siemens Corporation entered the business of developing and implementing green cities in China and Singapore.

On the regional scale, with respect to the large centralized utilities, the main risk of the privatization scenario is that the price for water service may become unreasonable, especially for developing countries (this has already happened in South America, in the case of drinking water), and water could assume the same role as energy today: no longer a natural resource, but a tradable commodity like crude oil or electricity—a situation that led to well-known failures (e.g., ENRON) in early 2000. To avoid these pitfalls the contract with a public oversight agency must be well formulated with guarantees of compliance with environmental goals and standards and protections against excessive profits and futures trading.

The IWA panel identified four major driving forces that can make this scenario happen: (1) Selling public water infrastructure assets generates large one-time income that can be used by the cities for other high-priority purposes; (2) all urban dwellers need urban water services, and water service can be a profitable business and an attractive investment for private interests; (3) actual (or perceived) failures of the conventional technocratic approach will support the opinion “private is better than public”; and (4) where privatization is one of several options (e.g., in neighboring cities), private industry will attract the best engineers and offer them opportunities and resources to apply their technical talents. However, to maximize profits and satisfy investors, the private operators may resort to cutting labor costs and looking for potential voids in the regulations with which they have to comply. For example, the permits generally are expressed in terms of limits on BOD and suspended solids, and the private company may have no interest in addressing other issues such as nutrient removal or nitrification or stream restoration.

However, privatization can be attractive if the regional systems are decentralized into smaller semiautonomous clusters, or "ecoblocks," operating in a market situation. Private companies can be and have been effective in installing and operating smaller treatment plants, providing water for reuse, heat, and other water- and energy-related services, provided there are public and institutional oversights and well-defined limits and compliance. The future water/stormwater/used water utilities will also be commercially "producing" electricity, heat, hydrogen, biogas, soil conditioning solids, and nutrients (struvite), which could make the integrated resource recovery very attractive to private investors (see Chapters VIII and X).

The technocratic scenario was defined by the IWA panel (Marsalek et al., 2007) as a situation in which engineers are fully in charge and strive for technical excellence, with a minimum involvement of the public or politicians. In some way, this scenario resembles the way public utilities used to be operated in wealthy countries, 40 or more years ago, under the late third and early fourth paradigm, but with a greater emphasis on technical excellence, performance standards, and new developments in science and technology. The main operating principle of this scenario is technological excellence, based on the application of well-proven technology coupled with redundancy and adequate safety factors for a chosen design event return frequency. The system would be protected by fail-safe devices and fallback alternatives to keep operational risks small.

Under this scenario, while traditional cost/benefit analysis is undertaken, emphasis is placed on maximizing benefits and system performance, rather than on balancing such factors against costs. Long-term planning (development of master plans) is emphasized, and such plans are frequently updated. Furthermore, retrofitting and renewal of the central drainage systems and wastewater treatment are a top priority. Responsibility for system operation and maintenance is centralized and mostly public; the provision of water services remains a monopoly. In essence, this scenario assumes that: (1) it is unrealistic to expect essential changes in individual and corporate behavior with respect to environmental protection, and consequently such changes are not needed; (2) most urban citizens are not interested in urban water, wastewater, and drainage issues; and (3) politicians are satisfied with a low level of control, as long as there is no trouble. Thus, the system could be operated largely independently of the economic, social, and political context. Such a system would be quite expensive and might not lead to a balanced sustainable solution that would consider social, environmental, and economical factors equally and equitably. The technocratic scenario is feasible (affordable) in many developed countries, but is essentially irrelevant for developing countries, where the lack of funds, engineering expertise, and operation and maintenance capacities prevents the adoption of such solutions.

Under the third paradigm, technocratic solutions chose sometimes grandiose projects wherein the goals were noble and urgent, such as the elimination of terrible epidemics of the late 19th century, saving Venice from flooding, providing land reclamation (drainage of the Everglades in Florida), the diking and channelization of the Mississippi River, tide surge barriers in Holland or the United Kingdom, or compliance with mandatory point source control standards embedded in the Clean Water Act and similar laws in Europe and other industrialized developed countries. Often money was not the problem, goals were set with high priority, funds were appropriated by governments, and the only question was how to achieve the goals at the least cost. Some of these projects subsequently caused great harm to the environment (e.g., Everglades drainage), and some turned out to be ineffective (e.g., diking and constricting the Mississippi River and other Midwestern U.S. rivers to prevent flooding of cities and farmlands) and must be redone by renaturalization in this century at enormous economic and social cost.

In 1968, the U.S. Congress passed the National Environmental Policy, followed shortly by equivalent state legislative acts, requiring government-conducted or -funded projects to prepare a comprehensive Environmental Impact Statement (EIS) that introduced more social and environmental considerations into all government projects. It is interesting to note that the developers of Disney World transformed a large portion of central Florida into amusement parks and one of the most visited man-made semiurban areas in the world, but were not required to prepare an EIS because the entire project was financed by private funds.

The green scenario concepts considered by the IWA panel included Low Impact Development (LID), smart growth, Sustainable Urban Drainage Systems (SUDS), Water Sensitive Urban Design (WSUD), and others. The main characteristics of this scenario are the replacement of conventional central water service systems by distributed systems, with more accounting for sustainability, attention to environmental concerns, restoration and renaturalization of receiving waters, and so forth. The panel did not include consideration of the integrated resource recovery and energy issues. Also, the new concepts of ecocities that were concurrently evolving in China and the Middle East (Chapter XI) were not considered. The IWA panel correctly pointed out that while these concepts are currently being promoted as “new” and “sustainable,” they were proposed and implemented in some places as early as the 1970s (e.g., The Woodland, Texas) as developments with natural drainage and best management practices conceived for diffuse pollution, efficient water use, and flood controls based on natural soft approaches.

The panel noted that the objectives and performance criteria of the green scenario are not well defined, as reflected, for example, by the existence of more than one hundred definitions of “sustainable development.” The scenario is based on appealing principles, ideas, and visions, but its sustainability, when used on a large scale, was found to be unclear at the time of the IWA panel report. Many of the perceived or real risks of the green scenario arise from the fact that it is a new concept that has not been truly tested in the field, certainly not on sufficiently large scales and for sufficiently long periods for larger urban areas. The panel identified several weaknesses of the green concepts prevalent at the beginning of the 21st century:

- The notion of "no impact" development is unrealistic and physically impossible.
- Risks arise from the fact that green solutions transfer much of the maintenance responsibility to the property owners.
- The transition from the existing centralized systems to future decentralized systems is not clear.

The first stipulation and desire—no impact developments—led to serious requirements based on superficial observations that urban developments should be kept at less than 15% of the watershed and imperviousness to less than 10% because these were the thresholds at which biotic integrity of the watershed begins to deteriorate (Schueler, 1994). If this is taken literally, only low-density developments leading to urban sprawl would be acceptable. The second weakness may lead to litigations among property owners and between the property owners and some unidentified regulators who would oversee compliance that currently has no or only very poorly defined standards. The third problem can be simply stated as "What to do with the existing medium- to high-density urban areas?" Note that the new knowledge and state of the art of planning ecocities provide answers to these questions elaborated also through this treatise.

The IWA panel concluded that the main driving force supporting the green scenario is its positive political and economic appeal (at least in the short run) to those public utilities that struggle financially. The scenario's objectives are undisputed, both internationally and locally (see Chapter II), and it receives "green political support," particularly in relatively affluent countries where stakeholders are concerned about the overexploitation of nature and want "to do something good," and it is defended by a lot of enthusiastic supporters. From the sociological point of view, it appeals to the well-educated, well-to-do part of society, often living in upscale developments or ecovillages. Furthermore, the green scenario may even be more feasible in developing countries, where large central infrastructures are almost nonexistent and their construction is hardly feasible, and low-cost "green" solutions such as constructed wetlands, waste stabilization ponds, and reuse in agriculture are available and have even been implemented.

The panel equated "green" low-density developments with the image of sustainability. Mihelcic et al. (2003) pointed out the fact that "green" development and cities based on late-1990s ideas may not be necessarily sustainable. Only a balanced *triple bottom line – life cycle assessment* will be a testament of sustainability (see Chapters II and X); however, macroscale metrics and methods to derive balanced, societal environmental and economic assessment methods and criteria were not fully available in the first decade of this millennium. Chapter XI will document that the sustainable ecocities are not low-density developments.

The solution of choice for the panel was a mix of the four alternatives. The cornerstone of a realistic future vision for the panel was decentralized wastewater treatment and localized urban drainage networks comprising mostly surface, rather than underground, systems that could then be utilized as resources. The panel concentrated mostly on urban drainage and did not consider the imperatives of coping with the future effects of global warming on the cities, the effects of running out of (cheap) oil, nor the effects of population growth.

I.4 THE 21ST CENTURY AND BEYOND

U.S. cities such as Chicago (Illinois), Portland (Oregon), Seattle (Washington), Boston (Massachusetts), New York, Philadelphia (Pennsylvania), San Francisco (California), and Milwaukee (Wisconsin), and, on the international scale, cities in Sweden (Stockholm and others), England, Singapore, China (Tianjin, Harbin, Shenyang, Beijing, Chengdu, cities cluster in the Pearl River Delta), and Australia, and parts of Canada (British Columbia) are implementing sustainable (green) development policies requiring renewable energy and green buildings, added trees, green roofs, and parks to improve air quality and reduce stormwater runoff and create a more livable urban space. They have also added bike paths and walkways to encourage biking and walking. Many of these same cities are leaders in “smart growth” development that is close to public transportation and built around commercial centers, preserves open space, reuses land, and protects mixed uses. These efforts also have significant economic development potential—from fostering new technology-based industry clusters to creating well-paying jobs in housing and construction and manufacturing (Fitzgerald, 2007). However, outside of these notable cases, most developments currently are still piecemeal efforts rather than an integrated effort of the entire community to introduce interconnected functioning ecotones into the urban area and watersheds (Hill, 2007). There is a need to expand the scope of the green development visions and plans to a metropolitan/regional scale at the intersection of urban aquatic and terrestrial ecology, society, and infrastructure.

The reality of the fourth paradigm is that after almost 40 years of extensive infrastructure building programs and hundreds of billions spent, the goals of the CWA have not been met. We have systems that are functional under normal conditions but highly vulnerable during extreme events and unsustainable. The gravity of the future plight of the water resources in the world’s cities and of their future under the “no action” or “proceed as usual” or “traditional” scenarios was recognized only less than two decades ago, and the first serious attempts to find the solutions appeared about the same time. However, there is now a consensus among experts that changes are needed and forthcoming—but what these changes will be is still uncertain on a worldwide scale. Resistance and inertia, as well as the tradition of the current urbanisms based on hard infrastructures and pavements, are persisting and will be difficult to overcome. Nevertheless, most experts agree that the water-impacted infrastructure in some cities is at a breaking point and that it will take trillions of dollars (euros, etc.) just to fix it. But no matter how many billions will be spent under the current paradigm of building new hard water/wastewater infrastructure and/or fixing old ones the old way, the ecological goals of the Clean Water Act in the U.S., the Water Framework Directive in the EC countries, and similar goals in many other countries will still not be met. There is also a need to build many new cities, especially in Asia and Latin America, to accommodate anticipated population increases and the flux of people from rural areas to the cities. Then, instead of fixing the old infrastructure the old way at an enormous price, let us do it right and make the water and other infrastructure systems sustainable and energy efficient for future generations, reduce GHG emissions substantially, and save—or even make—money doing it.

Looking far ahead (considering the impact of the "business as usual" scenario and the continuation of the current trends), we can quote from the Abel Wolman Distinguished Lecture to the U.S. National Research Council by Peter Gleick (2008), who looked into the future to 2100. Regarding sustainability and carbon imprint in 2008, he prefaced his predictions by a reference to a study by the Pacific Institute (2007):

> Things were so bad in the United State that people actually spent vast sums of money [100 billion U.S. dollars annually] to buy small quantities of water in plastic bottles, when they could get safe water from the tap at a thousandth the price. By some estimates, as much as 17 million barrels of oil equivalent were used annually just to make the plastic bottles used in the U.S., most of which were then thrown away.

Gleick then continued with his vision of 2100 (paraphrased):

- With very few exceptions of very high altitudes, all mountain glaciers will be gone, and the impact on local water supplies will be especially severe in China and parts of South America.
- Downhill skiing in resorts will be mostly gone.
- The Everglades, which were saved by restoring their natural flows and function during the early part of the 21st century, were ultimately lost to the rising seas, along with coastal aquatic ecosystems and some major cities (e.g., Venice) all over the world.
- Floods from increased precipitation and the increased intensity of storms will continue to be the leading killer of people worldwide.

Other gloom and doom predictions have been made, especially by physical scientists who projected the current trends. Engineers by their training have a tendency to "fix" problems, sometimes with unforeseen adverse effects. In general, Peter Gleick was an optimist in his presentation. He outlined several steps to avert the doom and gloom scenario, calling for a fundamental paradigm shift by rethinking water use, reducing waste and losses, and improving efficiency and productivity on the drinking water side. The new paradigm of integrated water/stormwater/wastewater and urban landscape management will enlarge Gleick's vision to other water and urban sectors. Changing the paradigm will provide immense opportunities for small and large businesses. Even today, spontaneous, localized, and limited "green" developments such as green business and government buildings (e.g., Chicago) require innovation and are beginning to generate employment opportunities (Fitzgerald, 2007). A "green" high-rise in New York (Battery Park, see Chapter VI) saves up to 50% of water through reuse (Engle, 2007). Politicians have been promising a bonanza of green benefits that would come from large- and small-scale government and private projects. The facts of the "business as usual" alternative that must be considered are:

1. Most of the water and wastewater infrastructure in cites is almost 150 years old, and is deteriorated or deteriorating rapidly and will have to replaced.
2. Combined sewer flows have been and will have to be separated, and both flows stored and treated.
3. Urban stormwater must be treated if discharged into storm sewers.
4. Building underground conduits for the conveyance for relatively clean water of buried streams and cleaner urban runoff does not make sense and does not provide protection against flooding.
5. Runoff from transportation systems will have to be captured and treated to avoid severe ecological damage.

Hence, it is clear that the first 50 years of this century will see massive investment in new urban water/stormwater/wastewater infrastructures, on the order of trillions of dollars or euros, or whatever currency the country is using. If it is not done right, if business as usual (in developed countries) or even doing nothing (in undeveloped countries) scenarios prevail this century will see increased severe inconveniences at best and human catastrophes at worst. Thus, it must be done right.

The concepts of sustainability and "Cities of the Future" have now been discussed and addressed by a number of research and outreach initiatives in Europe, Asia, and Australia, research conferences and congresses organized by the International Water Association (IWA), Stockholm Water Conferences, and NGOs, and initiatives funded by private foundations. The IWA has established an International Steering Committee and made the Cities of the Future one of its primary programmatic goals. UNESCO has funded an extensive international research and pilot implementation collaborative project, SWITCH – Managing Water for the City of the Future – (http://www.switchurbanwater.eu/about_mgmt.php), in several countries throughout the world. These initiatives are driven by the widespread public desire for "green" "sustainable" everything, from houses to urban landscapes, food and agriculture, manufacturing, cleaning products, and, finally, entire cities. The engineering and scientific communities now have the tremendous mission of responding comprehensively to these stresses and public desires for action by developing and implementing the new concepts of sustainable urbanisms that, with their water systems, would not only satisfy the present and future needs for water and sanitation but also be resilient to the stresses, demands, and extreme events of the future and have a positive impact on GHG emissions.

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