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SUSTAINABILITY GOALS FOR URBAN WATER AND SOLID WASTE SYSTEMS

1.1 INTRODUCTION TO URBAN SUSTAINABILITY

This treatise proposes and presents an integrated and sustainable system of urban water, used (waste) water, waste solids management that would save and protect quality of water, recover energy and other resources from waste solids and minimize or eliminate the need for landfills. The system, because it promotes providing more storage of water and resources during the times of excess and safe conveyance during catastrophic events, also enhances the resiliency of urban systems against extreme events such as flooding and severe droughts, which are expected to become more severe and frequent. Technologies to achieve this goal are available and their use will be profitable.

Urban development and, specifically, economic concepts in most of the twentieth century and before followed the idea that development and use of resources should be maximized at minimum cost without considering the impact on future generations and impact of the adverse effects on the environment. In some countries, smoking industrial stacks were a sign of progress. This unrestricted development and disregard for the impact on the environment and city population led to environmental and human catastrophes such as epidemics due to dirty air, poisoned water, and devastating soil losses (dust bowl conditions).

The gravity of the plight of the water and other resources in the world cities and their future under the business as usual (BAU) scenario were felt and known for more than a century but the response was either to do nothing or to convert urban streams to underground sewers out of sight. Resistance, inertia, and the tradition of past urbanism paradigms based on hard infrastructures and pavements still persist and are difficult to overcome. But no matter how many billions will be spent under the last-century paradigm of building new hard water/wastewater infrastructure and/or fixing the old, the ecological goals of the Clean Water Act in the US, the Water Framework Directive in European Community countries, and similar laws in many other countries may not be met. There is also a need to build many new cities; especially in Asia and Latin America, to accommodate anticipated population increase and flux of people from rural areas to the cities. The problems have been magnified by the ongoing global climatic changes, and gradual exhaustion of water and other resources.

There is an ongoing discussion on what is "sustainability" and how it differs from "economic progress." Is it increasing living standards by maximizing economic gains, even though it results in unsustainable use of natural resources? Or is it the naturalistic view that preserving nature in its original state is superior to economic development? The author remembers that in the 1950s, signs of "progress" in totalitarian "socialist" countries were smoking stacks of expanding heavy industries, cultivation of forests, draining wetlands, and irrigating virgin lands and deserts for agriculture, all with heavy adverse impacts on natural resources. In the US the influx of European immigrants in the nineteenth century changed Midwest forests and prairies into agricultural lands and, more recently, industrialization and population increase rapidly changed pristine and agricultural lands to urban lands and sprawl, often without considering environmental consequences.

The advocates of economy only consideration argue that in a free capitalist society a company should have no "social responsibility." "The only corporate responsibility a company should have is to maximize profits for itself and for its shareholders" (Friedman, 2002). Unrestricted development was ubiquitous in the US and other developed countries and in many larger developing countries before World War II and lasted until three decades after the war. But it was also a characteristic of totalitarian socialistic societies of the twentieth century in Europe and Asia, although the economy therein was planned and dictated by the government and not by the market. Unrestricted economic development focusing only on maximization of profits led – and still leads – to health and ecological calamities and widespread damages to air and water quality and public health. Hence, there is a "social" cost of pollution caused by unrestricted development and production focusing only on economic gains.

At the beginning of the new millennium, countries around the world almost universally agreed that environment sustainability and economic development are interconnected. However, arguments that "environmental prosperity" overrides "environmental sustainability" are still being discussed and advocated in few countries rich with fossil fuel resources. Unrestricted economic development would create "environmental diseconomy" through excessive air and water pollution, and would accelerate global warming. In reality, there cannot be economic prosperity with environmental sustainability unless the country does not have an environment to begin with or would accept a scenario that part of a large country can be environmentally devastated so that another part could be prosperous. In the doom scenario of the future under the business as usual (BAU) scenario, Rees (2014) argues that under the current global threat of climate change and limited nonrenewable resources these "resources from honeybees through petroleum to songbirds slip down the scale from abundance to scarcity." Worldwide, people have yet to acknowledge that on a planet already overburdened, there is no possibility of raising even the present world population to developed country material standards sustainably with known technologies and available resources. This situation leads to conflicts and unsustainable migration of people. Rees also warned, "No country, however virtuous, can be sustainable on its own or remain insulated from global turmoil."

Environmental economists argue that maximizing economic profits without considering environmental consequences results in "external diseconomy," which is an economic activity that imposes a negative economic effect such as air and water pollution, including carbon emissions, on an unrelated third party. Market forces alone cannot reduce pollution by the unrestricted production and urban development. Without regulations, upstream polluters would disregard downstream impact on ecology and users of water. The problem with external diseconomy effects of production could be resolved by public pressure, litigation, taxation, and enforcement of government regulations, which is most effective.

The issues, problems, and solutions of the environmental diseconomy related to pollution were extensively presented and summarized in Novotny (2003a).

The situation of unrestricted economic thinking persisted almost to the middle of the second half of the last century while the discourse was continuing. The starting point of the new sustainability concepts was the work of the World Commission on Environment, chaired by then Prime Minister of Norway G. Brundtland, which defined sustainability as follows (Brundtland et al., 1987):

> *Humanity has the ability to make development sustainable – to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs.*

The Brundtland commission's definition, which has been generally accepted since the end of the last century, does not differentiate between sustainable development and sustainability. The report expresses the desire of society to use and manage resources on the bases of economic sustainability, social equity, intergenerational justice, and intrinsic value of nature (Dilworth, 2008) and makes the intergenerational preservation of resources as paramount as economic development. It is now generally agreed that these values are not mutually exclusive; they overlap to some degree.

Howarth (2007) discussed the views that led to formulation of sustainability. One definition of "sustainability" that tried to modify unrestricted development of land and use of natural resources for economic "progress" was the so-called economic *Net Investment Rule,* stating:

> *A dynamic economy will maintain a constant or increasing level of per capita utility only if value of natural resources investments in manufactured capital exceed the monetary depletion on an economy-wide basis.*

Incorporating the loss of natural resources into economic thinking was a step forward from strictly economic monetary benefit/cost analyses. "Environmental impact statements," along with economic analyses, were attached to strictly monetary assessment of benefits and costs of development projects. This concept was included in the US in the National Environmental Policy Act (NEPA), passed by the Congress in 1969. NEPA was one of the first laws ever written that established a broad national framework for protecting our environment. NEPA's basic policy is to assure that all branches of government consider the environment prior to undertaking any major federal action that significantly affects the environment. Unfortunately, NEPA was mandatory only for federally financed projects, but some states passed their own NEPA-like rules. Large private developments were excluded. The weakness of the NEPA assessments was the inability to include intangible environmental gains and losses into the economic analyses.

As indicated previously, sustainability is evolving from gradual merging and discourse of population groups ascribing to two social views (Novotny et al., 2010a):

- The anthropogenic views regard nature as a resource that should be used and developed for economic gains.
- The biocentric views regard preserving and restoring nature as the goal for humans.

Most people subscribe to both views, meaning that they want to increase their living standard, yet they do not want to live in a polluted or severely damaged environment and want to preserve the nature and resources for the future generations. Protection of the environment and public health is a cognitive value. In the second half of the last century this dual adherence to two seemingly contradicting principles could have been one of the reasons for urban sprawl benefiting those who could afford to leave behind the deteriorating cities with their polluted air and water and be, for a limited time, closer to the nature. Yet, the same people participated in the economic activities in the cities that created the problem. This process of affluent people leaving behind degraded and abandoned urban zones and poor inhabitants is a social problem known as *environmental injustice,* which is still rampant in shantytowns of some developing countries and can also be seen in the US and other developed countries There may be other reasons for such intragenerational injustice, such as crime or quality of education.

Howarth (2007) presented the arguments and various views in the discourse leading to the present thinking and rules. The new millennium views have been expressed in the Millennium Economic Assessment (2005):

> *Fair Sharing Principle – Cateris paribus (latin for "all other things remaining equal") – each member of present and future society is entitled to share fairly the benefits derived from environmental resources. Specific stocks of environmental resources should not be depleted without rendering just compensation to members of the future generations*.

Hence, the term "sustainability" and adherence to its principles is the historical shift from "a maximum economic use model" that understood resources to be merely raw materials for production and sinks for the disposal of waste (a purely anthropogenic view), to a more biocentric optimal model that recognizes the environment as a finite resource that needs to be conserved through public stakeholder involvement and governmental regulation in order to create a long-term relationship between economy and nature. The "sustainability" is also salient to the "land ethic" (including water and watershed) expressed by Leopold (2001), who emphasized a balance between preserving nature and development.

Sustainability as an interdisciplinary science is still emerging; nevertheless, stronger calls for sustainable development and a "paradigm shift" from the public, public officials, and in the media have been heard since the 1990s and intensified in the new millennium. People who are well informed can align themselves with the movement toward sustainability, which, however, may not mean the same thing to different people. The cognitive values of sustainability are related to:

Preservation of human societies today and in the future

Preservation of nature and restoration where nature is damaged

Achieving and maintaining good economic status of present and future generations

Minimizing or eliminating risks to public health and providing healthy and green urban environment

Sustainability has three interacting dimensions: environmental, economic, and societal, and sustainability can be achieved only when these components are balanced (Figure 1.1). A change in one compartment of the trinity of sustainability affects the other two compartments. If they are not balanced, the outcomes can be numerous, such as pollution and environmental degradation but also social injustice or unsustainable development (Novotny, 2003a).

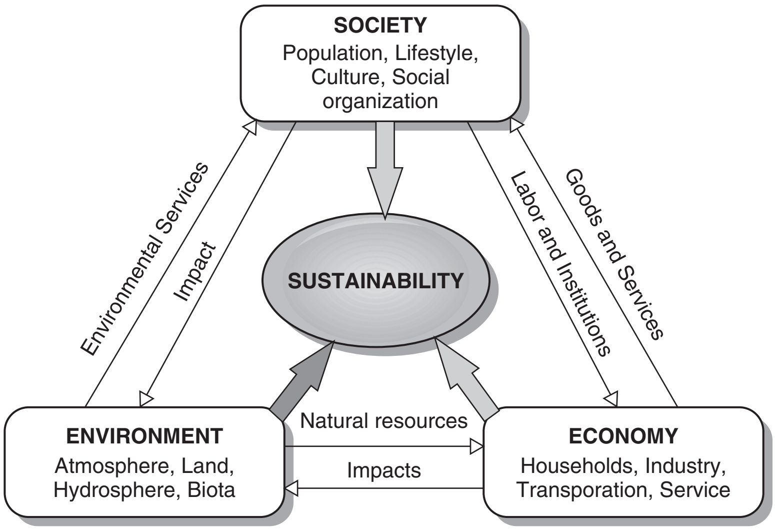

Figure 1.1. Trinity of factors and impacts determining sustainability. *Source:* Adapted from Brundtland (1987), Novotny (2003a). and Allan (2005).

It turned out that today there are hundreds of definitions of sustainability (Maršálek at al., 2007). Mihelcic et al. (2003) pointed out that sustainability is not merely a preference for economic development with some environmental protection (an anthropogenic development view), nor preserving nature with "green" development (a biocentric view). Sustainability, however, is not limited only to water or resources that would benefit humans. The serious threats from climate change to humans and other species add other components of integrity – atmosphere and marine life – that are now impacted by greenhouse gases (GHG), air pollution emissions that cause global warming of the atmosphere. In addition to global warming, GHGs in the atmosphere cause increased acidity of oceans that has been associated with dying coral reefs, loss of glaciers, and disappearing polar ice. These ecological changes will adversely affect both nonhuman organisms and human beings. As a hypothesis, this author (Novotny et al., 2010a), in defining sustainability reflecting water, resources, and society, suggested that the concept of water body integrity defined in the Clean Water Act (PL 92-500, US Congress 1972) is universal and applies to the environment in general (i.e., air, water and soil). In addition to nonhuman organisms, this also considers damages to humans, substitutes "environment" for "water," and redefines environmental integrity as:

> *the ability of the environment (air, water and soil) to support on regional or global scale balanced communities of organisms comparable to that of natural biota of the region and also provide conditions for unimpaired wellbeing of present and future human generations*.

Sustainability would then mean "restoration, preservation and maintaining integrity of the ecology, environment and resources for present and future generations." This simple definition recognizes the fact that humans are a part of the ecological system and, in addition to biota, they can also impose a damage upon themselves. According to the definitions in the US Clean Water Act (Section 5), "pollution" is caused by humans or their actions and is differentiated from changes of the quality (integrity) of the environment due to natural causes such as natural CO_2 content of the atmosphere, natural erosion, weathering of rocks, volcanic eruptions, and CO_2 emissions from natural forest fires or from natural biomass growth and respiration processes converting organic carbon to CO_2. However, converting organic carbon from fossil sources to energy and industrial products by humans resulting in GHG emissions is clearly pollution that impairs integrity.

1.2 HISTORIC AND CURRENT URBAN PARADIGMS

Loosely defined, a *paradigm* is a set of theories and associated rules that explain the way a particular subject or behavior is understood at a particular time (Cambridge dictionary). It is a set of assumptions, concepts, values, and practices based on science and/or tradition that constitutes a way of viewing reality shared by a community.

Human paradigms have changed over millions of years and could be linked to "revolutions" defined in this context as a major change in the way people gathered and produced food, built settlements, produced energy, and interacted as societies. In the seminal book *Engineering Response to Climate Change,* Watts (2013) quoted from a 1953 book by Galdon Darwin (*The Next Million Years),* which identified five revolutions, each having different paradigms:

Use of fire – separated humans from other primates about 400,000 years ago

Invention of agriculture – allowed humans to stop being nomadic hunters

Urban revolution – organized larger human settlements, center of commerce 7,500 years ago

Scientific revolution – understanding the nature and onset of Industrial Revolution

The first four revolutions of human development were fueled by energy, which was originally derived by burning wood or even dried dung of domestic animals, but at the onset of the industrial revolution humans started to use fossil fuel – coal, oil, and natural gas. The fossil fuel energies in the industrial period fueled unprecedented population increases, which became exponential, with rapid expansion of agriculture, building cities and industries, and fast transportation by trains and aviation.

More than sixty years ago, Galdon Darwin and others quoted in Watts's book (Watts, 2013, Chapter 1) envisioned the "fifth revolution" during which the fossil sources of fuel would be exhausted. They anticipated that this revolution would occur centuries from current time and would slow down the development and reduce population. They did not anticipate the global climatic changes that the burning of fossil fuels would cause and the consequences. They predicted that energy during and after the fifth revolution would be provided by sun, wind, tides, hydropower, and geothermal sources. Before 1950, nuclear power was known but its use for energy instead of for making bombs was fuzzy. Today, the consequences of fossil fuel burning and other industrial uses (e.g., making fertilizers, steel, plastics, tires, chemicals) and transportation has become a serious problem and a cause of global climate change. It has become evident that humans as well as the entire ecosystem on the Earth are at the onset of the fifth revolution, which will lead to dramatic reductions of the use of fossil fuel not because of their immediate exhaustion, but because of damaging impacts they have on life on the Earth.

Paradigms of Urbanization

This book focuses on paradigms of human urban development and settlements, specifically cities in the industrial period. There are at least four recognizable historical models or paradigms (Table 1.1) that reflect the evolution and development of urban water resources.

While humans were detected by archeologists to exist about between 1.3 to 1.8 million years ago, the first urban settlements were found in Mesopotamia around 7500 BCE. Early cities also arose in the Indus Valley and ancient China (Wikipedia). Ancient and medieval cities, from ancient Egypt and Rome 2000–4000 years ago and even until the end of the ninetieth century, were relatively filthy and miserable walled places to live for ordinary people. Even today, living in some large settlements and shantytowns in Africa or Latin America is difficult and lacking the amenities of modern cities in developed countries. After the walls surrounding the cities were removed in the nineteenth century, urban dwellers desired to live near nature, which led to developing parks. Later, in the first part of the twentieth century, "garden cities" emerged in the outskirts and wealthy suburbs. With automobiles and freeways, "green" but unsustainable suburban and even distant subdivision type communities identified as *urban sprawl* dotted with thirsty lawns were emerging, mainly in the US. This development led in the US to the reduction of forests and agricultural lands, the demise of older historic city centers, and the dramatic increase of energy use for daily long-distance commuting by fuel-inefficient cars and very high use of water for irrigating lawns. European and Asian cities were growing too but mostly kept and improved their mass transport systems and avoided urban sprawl. Meanwhile, urbanization, industrialization, and change from family farms to industrialized agriculture resulted in heavy pollution in and around cities, extended in the US as far as the Gulf of Mexico.

The physical connections (both structural and natural) between cities and their water resources and nature have changed through the centuries. At the same time, our conceptual models of these systems and our understanding of how they should function and relate to one another have changed as well. The first paradigm of water management of ancient cities was characterized by the utilization of local shallow wells for water supply; exploitation of easily accessed surface water bodies for transportation, washing, and irrigation; and the shared use of streets and roadside channels for the conveyance of people, waste products, and precipitation. Urban runoff of ancient and medieval cities was not clean; it carried feces from horses and other animals and sometimes from people, in spite of the street sweeping (by brooms) that most likely was practiced in some cities by people in front of their houses and shops.

As water demand increased and easily accessible local groundwater and surface supplies became insufficient to support life and commerce (Rome two thousand years ago had a population approaching one million), a second paradigm emerged in growing ancient and medieval cities – the engineered capture, conveyance, and storage of water. The aqueducts of ancient Roman and Byzantine cities brought water to fountains, public baths, and villas from mountains as far away as fifty kilometers to Rome and up to several hundred kilometers to the Byzantine capital Constantinople. In many ancient cities, rural castles, and villas, rainwater was collected and stored in underground cisterns, a practice still prevalent in some communities in the Mediterranean. Similarly to the ancient cities, street surfaces were polluted by fecal matter and trash and the smell must have been nauseating. The Roman sewer Cloaka Maxima has been functioning for more than two thousand years but sewers were installed centuries later in other European cities. Sewers were built mostly for conveyance of urban runoff polluted by garbage and fecal matter, but in Roman and some medieval

Table 1.1. Historical paradigms of water and solids management.

Paradigm	Time Period	Characterization	Quality of Receiving Waters
I. Basic water supply	BCE to the Middle Ages, still can be found in some developing countries	Wells and surface waters for water supply and washing, streets and street drainage for stormwater and wastewater, fecal matter from animals and sometimes humans disposed onto streets and into surface drainage, privies and outhouses for black waste, most street surface pervious or semi-permeable, thatched roofs.	Excellent in large rivers, in small and medium urban streams, poor during large rains, good in between the rains. Pollutants of concern: most likely pathogens.
II. Engineered water supply and polluted urban runoff conveyance	Ancient Crete, Greece, and Rome, Middle Ages, cities in Europe till the beginning of 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 toilets flushing in homes of aristocracy discharging into sewers, otherwise privies and outhouses for black waste, fecal matter from animals and sometimes humans disposed onto streets and nearest streams 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 US, later in Asian cities, till the second half of the 20th century in advanced countries, still persisting in many countries	Wells and 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 stream into underground conduits, initially no or only primary treatment for wastewater. Secondary treatment installed in some US and German cities after 1920s. After 1960 some smaller communities built lower-efficiency secondary treatment, paving the urban surface with impermeable (asphalt and concrete) surfaces. Swimming in rivers became unsafe.	Poor to very poor in rivers receiving large quantities of untreated or partially treated wastewater discharges, runoff discharged into sewers and combined sewer overflows. Some rivers were devoid of oxygen with devastating effects on biota. Cuyahoga River on fire in Cleveland, but waterborne disease epidemics diminishing due to treatment of potable water. Pollutants of concern: BOD, DO, sludge deposits, pathogens
IV Fast conveyance with the end of pipe treatment	From the passage of the Clean Water Act in the US in 1972 to the beginning of the 21st century	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. There were increasing concerns with pollution by urban and highway runoff as a source of sediment, toxins, and pathogens, increasing focus on implementation of best management practices for control of pollution by runoff, and 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, toxins, salt from deicing compounds, and pathogens. Biota of many streams recovered; however, new problems with eutrophication and cyanobacteria harmful blooms have emerged.

Source: Updated from Novotny et al. (2010a).

Arab cities they also received polluted flows from baths and continuously flushing public and aristocratic toilets.

The third paradigm for urban water and wastewater starting with the era of industrialization could be linked to the invention and widespread use of flushing toilets that were connected to existing streams and storm sewers, which then became combined sewers. The cities added a massive investment in sewage collection and later some controls and treatment of point sources of pollution resulting from sewer systems, and provided increased treatment of potable water supplies. These later improvements that emerged at the end of the nineteenth century were driven by epidemics of waterborne diseases caused by the cross-contamination of water supplies with raw sewage discharges and by leaking sewers contaminating wells. In Chicago, the course of the heavily polluted Chicago River was diverted from Lake Michigan to the watershed of the Mississippi River to prevent devastating cholera epidemics by contaminated lake water used for drinking. At the same time, impervious surfaces in cities were also increasing, resulting in higher volumes of stormwater runoff and more frequent flooding but also in diminishing base flow in streams. Consequently, many streams were lined with masonry or concrete and often buried underground. The aim of these fast conveyance urban drainage systems was to remove large volumes of polluted water as quickly as possible from the premises, protecting both public safety and property, and discharging these flows into the nearest receiving water body. Solid waste, including feces of horses from the streets were collected and dumped in unsanitary dumps. The third paradigm introduced first primary and then secondary wastewater treatment but did not address the overall, uncontrolled water-sewage-water cycle (Imhoff, 1931; Lanyon, 2007; Novotny, 2007a) in which water in an upstream community is converted to sewage, discharged into receiving water body, and reused downstream as potable water by another community.

The worst period of environmental pollution and degradation was from the end of the World War II till several years after the passage of the CWA in 1972. This was the period of fast and unrestricted economic development during which the industries that had been manufacturing war weapons and chemicals during the war were rapidly developing pesticides, industrial chemicals, and fertilizers; expanding the manufacture of machines and transformers that used polychlorinated biphenyls (PCBs) for cooling, rapidly increasing energy production mainly through sulfur-containing coal-fired power plants in the eastern US and Europe, which emitted sulphur oxides that resulted in acid rain. Water pollution was reaching catastrophic levels, as seen in the US with rivers on fire, such as the Cuyahoga River in Cleveland (Figure 1.2) and anoxia from excessive discharges of biodegradable pollutants from sewers. The situation was as bad or worse in Japan, where, among other catastrophes, fish were poisoned by mercury and cadmium. In Europe, pollution catastrophes occurred both in democratic capitalist and in totalitarian socialist countries. Rachel Carson (2002) described this situation in her seminal book *Silent Spring* (first published in 1962); she stated, “The most alarming of all man’s assaults upon the environment is the contamination of air, earth, rivers, and sea with dangerous and even lethal materials.” Carson described the situation resulting from excessive application of chemicals that led to the disappearance of birds because they stopped reproducing.

In the United States, the third paradigm period ended with the passage of the Water Pollution Control Act Amendments of 1972 (Clean Water Act, CWA), which made treatment of pollution mandatory. It established the Environmental Protection Agency, which was required to develop, implement, and enforce environmental protection standards and criteria. The period from the enactments of the CWA in the US and the Water Framework Directive in European Community countries until the present time comprises the fourth

Figure 1.2. Cuyahoga River in Cleveland on fire, 1952. *Source:* Cleveland Press Collection, Cleveland State University Library.

paradigm of urban water management and protection, in which increasingly diffuse sources of pollution were considered and addressed in many separate and discreet initiatives. These are also characterized as "end-of-pipe control" because the predominant point of control occurs where the polluted discharge enters the fast conveyance system (sewer or lined channel) or the receiving water body. Pollution by urban runoff and other diffuse sources was recognized as a problem only about 30–40 years ago and was included in the CWA. At the end of the twentieth century the European Parliament enacted the Water Framework Directive (WFD).

In the US after the passage of the Clean Water Act, the new massive building program of treatment plants considered mainly cost-based on "economy of scale" that preferred 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. 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. As some cities have reached their limits of water supply, reuse has been considered but not widely implemented.

The long-distance transfers of water and wastewater dramatically changed the hydrology of the impacted surface water bodies, which became flow deficient after withdrawal; after receiving the effluent downstream, these water bodies then became effluent dominated. Under the fourth paradigm 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 due to the high cost of capture, storage, and treatment in expensive, mostly underground storage facilities. For example, many kilometers of twelve-meter-diameter interceptors known as "deep tunnel" were built in Milwaukee and Chicago, storing millions m^3 of a mixture of stormwater and wastewater from CSOs and SSOs. The underground pumping stations – with several pumps that are among the largest ever built – pump the sewage/stormwater mixture into the regional treatment plants, and pumping energy use is high. Long-distance water/wastewater transfers from source areas over large distances also require electric energy for pumping, treatment (e.g., aeration), and transporting treatment residuals to their point of disposal. Large volumes of "clean" groundwater infiltration and illicit inflows (I-I) into sanitary sewers must be pumped and treated with the sewage, which uses more energy. During wet weather the I-I inputs can more than triple the volume of dry weather wastewater flows in sewer systems and overwhelm treatment plants (Metcalf & Eddy, 2003; Novotny et al., 1989).

1.3 GLOBAL CLIMATE CHANGES

The Earth is now undergoing accelerated global atmospheric warming, which could become the most serious threat to humans and ecology on the Earth unseen in geologic times for thousands, maybe millions of years. The Committee on Geoengineering Climate of the National Academies (National Research Council, 2015) summarized the forecasts by scientists who have predicted that doubling the carbon dioxide in Earth's atmosphere from preindustrial levels would warm Earth's surface by an average of between 1.5°C and 4.5°C (about 3°F to 8°F). The CO_2 concentration at the onset of the Industrial Age was stable at 280 ppm. It started to increase with expanded use of fossil fuels, first coal (heating, steam engines, making steel and syngas) in the nineteenth century, then oil (automobiles and other transportation) at the beginning of the twentieth century and natural gas after 1950. Figure 1.3 shows that in 2013 the CO_2 concentration measured by the National Oceanic and Atmospheric Administration (NOAA) exceeded 400 parts per million (ppm). If the rate of atmospheric CO_2 concentration increased linearly as indicated on the figure, the doubling of the preindustrial carbon dioxide concentrations would be reached by the end of this century. Similar increases have been measured in atmospheric methane, which is a more potent GHG than CO_2. The report from the Intergovernmental Panel on Climate Change (IPCC, 2013, 2018) concluded that, if current emissions trends continue, by the end of this century if the planet experiences a warming of up to 4.5°C, sea level will rise by as much as 1 meter and, during some years, the Arctic will be ice free in the summer by midcentury. Thermal warming increases air temperatures; 80% of the heat added by GHG gases is absorbed by oceans. Water warming causes thermal expansion and about half of the past century's rise in sea level is attributable to warmer oceans simply occupying more space. The other half of the sea water level rise is due to the melting of the permafrost over Greenland, and the Antarctic will lose a great portion of its ice cover. The melting of Arctic and Antarctic ice has been ongoing over the last 100 years, during which sea levels have risen by 10 to 20 cm. The rise is accelerating and the rate has doubled (https://www.nationalgeographic.com/environment/global-warming/sea-level-rise/). Because of physics, melting of North Pole sea ice does not increase the water level of oceans.

As part of this climatic change, society will experience an increase in the frequency and severity of heat waves (including forest fires), droughts, and heavy precipitation events. Figure 1.3 also shows the atmospheric concentrations of methane, which is also very potent greenhouse gas. Its global warming potential is 25, while that of carbon dioxide is 1.

CO_2 remains in the atmosphere for decades to centuries. Excess carbon dioxide from the atmosphere is absorbed chemically by the terrestrial biosphere by forming carbonates in water; reacting with calcium, magnesium, and silicates to form rocks; and biologically by photosynthesis. Most CO_2 emitted today will still be in the atmosphere, land biosphere, or

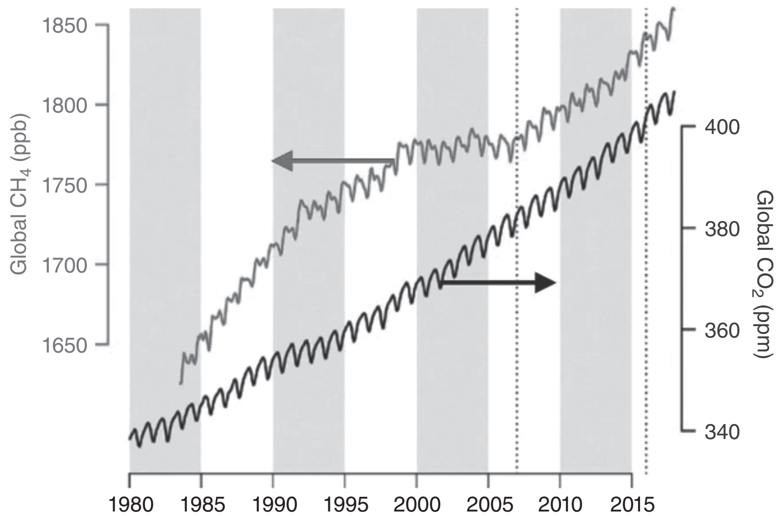

Figure 1.3. Increase of the atmospheric carbon dioxide (CO_2) and methane (CH_4) concentrations in the atmosphere between 1980 and 2018 in gas volume per million volumes (ppm) or per billion volumes (pbb) of dry air of the of the US National Oceanic and Atmospheric Administration's global monitoring network. The annual increases in atmospheric carbon dioxide over the past 60 years are about 100 times faster than previous natural increases in the last 800000 years *Source:* National Oceanic and Atmospheric Administration (NOAA), US Government Data, reprinted from USGCRP, 2018b.

ocean tens of thousands of years later, until geologic processes can form rocks and deposits that would incorporate this carbon (Archer et al., 2009; NRC, 2015). See Chapter 4 for more discussion.

The NRC (2015) report divides the atmospheric carbon-reducing actions into the following climate intervention categories intended to produce a targeted change in some aspect of the climate (e.g., global mean or regional temperature):

Carbon Dioxide Removal (CRD), which also includes other greenhouse gases (GHG), covers intentional efforts to remove GHGs from the atmosphere, including land management strategies, accelerated weathering, ocean iron fertilization, bioenergy with carbon capture and sequestration, and direct air capture and CO_2 sequestration. CDR techniques complement carbon capture and sequestration methods that primarily focus on reducing CO_2 emissions from point sources such as fossil fuel power plants. Reducing or eliminating CO_2 and methane emissions from urban water and waste solids management systems fall in this category.

Albedo (radiation reflectivity) modification concerns intentional efforts to increase the amount of sunlight that is scattered or reflected to space, thereby reducing the amount of sunlight absorbed by Earth, including injecting aerosols into the stratosphere, marine cloud brightening, and efforts to enhance surface reflectivity. Snow and polar ice have a high albedo.

The large-scale geo-engineering actions are described in the NRC (2015) report and in Watts (2013). The NRC scientists concluded, "there is absolutely no substitute for slashing fossil fuel emissions in order to prevent catastrophic disruption of the Earth's climate," but also recommended that the other large-scale geoengineering actions should be researched because in the final outcome they could help in reducing the atmospheric CO_2 to acceptable levels.

1.4 NEED FOR A PARADIGM SHIFT TO SUSTAINABILITY

Since the beginning of this millennium, experts have agreed that the current paradigms of urban water, stormwater, and wastewater management – along with disposal of municipal solid waste and used water solid residuals onto landfills and related infrastructures – are unsustainable. The fast-conveyance drainage infrastructure, most of it conceived in Roman times to eliminate unwanted, highly polluted urban runoff and sewage, has produced great gains in protecting public health and safety but, after the US has spent billions of dollars since the passage of the CWA in 1972, the water resources are still damaged or vulnerable to damage by various water quality and habitat impairment and hydrological stresses; this results in water wasting on one side and shortages on the other side. Stresses such as infestation with cyanobacteria are reappearing and spreading with increasing frequency and intensity worldwide. The present water/stormwater/solid waste management system still threatens the use of resources by future generations. The centrally managed infrastructure of underground pipes for drainage and water delivery is not resilient to extreme events such as flooding that are expected to increase because of global warming. It excessively uses energy in spite of the fact that used water and, by the same reasoning, other organic wastes, contain recoverable energy in a form of heat and electricity. The current urban stormwater paradigm could also be called the "fast conveyance/end-of-pipe control."

In developed countries, the infrastructure is crumbling and requires massive investments for repairs. Traditional subsurface stormwater drainage can only handle smaller storms with the recurrence intervals ranging from less than two years (e.g., Tokyo) to five to ten years (standards for storm sewer designs in many US and European communities). Combined sewer overflows (CSO) are still allowed, which again is unacceptable to the public because, after each storm, beaches and bathing areas are closed or permanently unsafe for swimming. These systems are not resilient to extreme events. The current unsustainable situation is being further exaggerated by global climate warming (increasing sea levels, changes in drought and water availability patterns) (IPCC, 2007, 2013) and has now become the most serious worldwide threat to sustainability (Figure 1.3). Other adverse effects and challenges are:

- *Population increase:* urban population is expected to increase by 50% in the next 20–30 years and continue to grow at a reduced rate till 2100; many new cities and megacities will be built in Asia and other parts of the world (United Nations, 2014, 2016).
- *Migration of people* from rural areas to the cities and from war-torn and poverty-ridden countries of the Middle East, Latin America, and Africa to cities in Europe and North America; according to the United Nations (UN Water, 2014) by 2050, 40% of the global population is projected to be living in areas subjected to severe water stress, defined as less than 500 $m^3 cap^{-1}\ year^{-1}$ for all uses (residential, commercial, industrial, and agricultural) and for personal residential use the minimum use is 36 $m^3 cap^{-1}\ year^{-1}$, which is 100 L $cap^{-1}\ day^{-1}$ (Damkjaer and Taylor, 2017).
- *Increasing living standards,* resulting in more demand for food and, consequently, water and other resources

- *Aging and crumbling water infrastructure* (often built more than 100 years ago) magnified by the unwillingness of public officials to increase funding for rehabilitation and adaptation to the changes
- *More frequent and severe harmful algal (cyanobacteria, red tide) bloom (HAB) outbreaks*
- *Emerging pollutants* (endocrine disruptors, pharmaceutical residuals)
- *Conversion of urban waters* into effluent-dominated water will require management of the urban water hydrological cycle and decentralization of sewerage (Novotny, 2007a, b).
- *Severe and life-threatening air* pollution in many megalopolises such Beijing in China, Cairo in Egypt, and large cities in India. New Delhi (India) is the most air-polluted city; forest fires in 2018 made some Californian cities (San Francisco-Oakland; Los Angeles) the worst air polluted urban areas in the world.
- Increased flooding due to global warming effects, imperviousness and other land use changes through urbanization in the watershed.
- Plastics accumulation in the oceans, lakes, and environment

Table 1.2 lists other worldwide threats. A large portion of water shortages, flooding, and pollution in urban areas are caused by the typical characteristics of the urban landscape: a preference for impervious over porous surfaces; fast "hard" conveyance infrastructure rather than "softer" approaches like ponds and vegetation; and rigid stream channelization instead of natural stream courses, buffers, and floodplains. Under the paradigm of the last century, the hard conveyance and treatment infrastructure was designed to provide only five- to ten-year protection, but because maximum temperatures have reached record levels in almost all years in this century and hot seasons are longer, these systems are usually unable to cope safely with extreme events. In fact, they sometimes failed with serious consequences, as with Hurricanes Katrina in New Orleans in 2005, Sandy in New York and New Jersey in 2012, and Harvey in Houston and Maria in Puerto Rico in 2017. It has become evident that despite billions (trillions worldwide) of US dollars spent on the current paradigm of water management measures and solid waste disposal, these systems are inherently incapable of becoming sustainable and resilient. Meanwhile, global temperatures have been rising in this century and average high temperatures of summer months exceeding 30°C (86°F) were measured in central and northern Europe. If this trend continues, parts of the world (India, Pakistan, Bangladesh Africa, the Middle East, parts of Australia, and the southwestern US) will become uninhabitable.

Urban developments and population migration from distant suburbs back to cities are not necessarily bad for the environment; human urban habitats can mimic nature and preserve it, as demonstrated by urban ecotones and parks designed to mimic nature, as built by Frederick Law Olmsted in New York, Boston, Chicago, Milwaukee, and other cities almost 150 years ago (Hill, 2007, Heaney, 2007). The precipitation–runoff–groundwater recharge balance in future cities (both new developments and retrofitted historic communities) can approach the natural hydrologic cycle. Even today, a typical urban dweller in the US uses about half of the energy of an average American. In some cities, such as New York and San Francisco, about half the city dwellers use public transportation for commuting and many do not own an automobile. In the first two decades of this century, the initiatives of communities toward sustainability have been local. There is even a contest among city mayors for a title of most sustainable city. Some "green" organizations and magazines provide sustainability city ranking, based, for example, on the portion of renewable energy used by the

Table 1.2. Current global threats.

Earth Process	Boundary Threatening Earth and Restricting Development	Current Status and Threat
Climate change	Atmospheric concentration of CO_2 300 ppm as a boundary preventing catastrophic changes of Earth's climate.	Significantly exceeded, CO_2 concentration is rising and use of fossil fuels is still increasing.*
Loss of biodiversity	10 species per million species extinct per year.	Significantly exceeded.
Phosphorus cycle	11 million tons of phosphorus flowing from land to oceans. Most of the lost P is replaced by mined P.	Mineral P resources could be exhausted by the end of this century.
Nitrogen cycle	35 million tons of N are removed from the atmosphere each year for human use. This process requires a lot of energy and organic fossil fuel carbon and emits GHGs.	The limit has been significantly breached.
Global freshwater use	4000 km^3 of freshwater is consumed each year by humans.	Regional water shortages are severe and some regions and states are irreversibly exhausting water resources, especially fossil groundwater sources. Reliance on desalination – a process that uses a great deal of energy – is increasing.
Chemical pollution	The levels of both atmospheric and water pollution in rapidly developing countries are reaching unhealthy and even life-threatening levels. New pollutants (pharmaceuticals, endocrine disruptors) are emerging in developed countries, along with the reappearing threats of excessive nutrients loads causing cyanobacteria blooms.	Atmospheric pollution in many cities in China, India, and other industrial countries has reached levels several times higher than the World Health Organization limits, to the point that breathing the urban air is dangerous. Extremely dangerous air pollution also comes from more frequent and more intensive forest fires.
Plastic	Plastic accumulation in oceans and some inland lakes is reaching close to catastrophic mass proportions.	This has severe impact for several reasons: fish and aquatic mammals consume plastics, coral reefs are damaged, plastics manufacturing causes GHG emissions, and large floating masses of plastic are now found in oceans and coastal lagoons.

Source: Adapted from Schoon et al. (2013)
[a] IPCC, 2013.

population, minimization of emissions from transportation, green living (parks, urban agriculture), recycling of solid waste, and other sustainability parameters (Svoboda et al., 2008).

1.5 POPULATION INCREASE, URBANIZATION, AND THE RISE OF MEGALOPOLISES

In the late eighteenth century, before the Industrial Revolution, world population was relatively small, growing at a rate of about 0.05% per year and reaching the first billion in the year 1800. World population in 2016 was 7.4 billion. Figure 1.4 shows world population recorded and forecasted from 1950 through 2050. World population in 2016 was growing at a rate of around 1.13% per year, more than 20 times faster than before the preindustrial age, and the current average population change is estimated at around 80 million per year. The rate of increase has almost halved since its peak of 2.2% reached in 1963. The annual growth rate is currently declining and is projected to continue to decline in the coming years. Currently, it is estimated that it will become less than 0.5% by 2050 (United Nations. 2017).

Future population growth is highly dependent on the path that future fertility will take, because relatively small changes in fertility behavior, when projected over several decades, can generate large differences in total population. While some earlier forecasts predicted that world population will level off after 2050 due to decreasing birth rates and diminishing resources, the revised 2015 United Nations (2017) report states that continued population growth after 2050 is almost inevitable, even if the decline of fertility accelerates. There is an 80% probability that the world population will be between 8.4 and 8.6 billion in 2030,

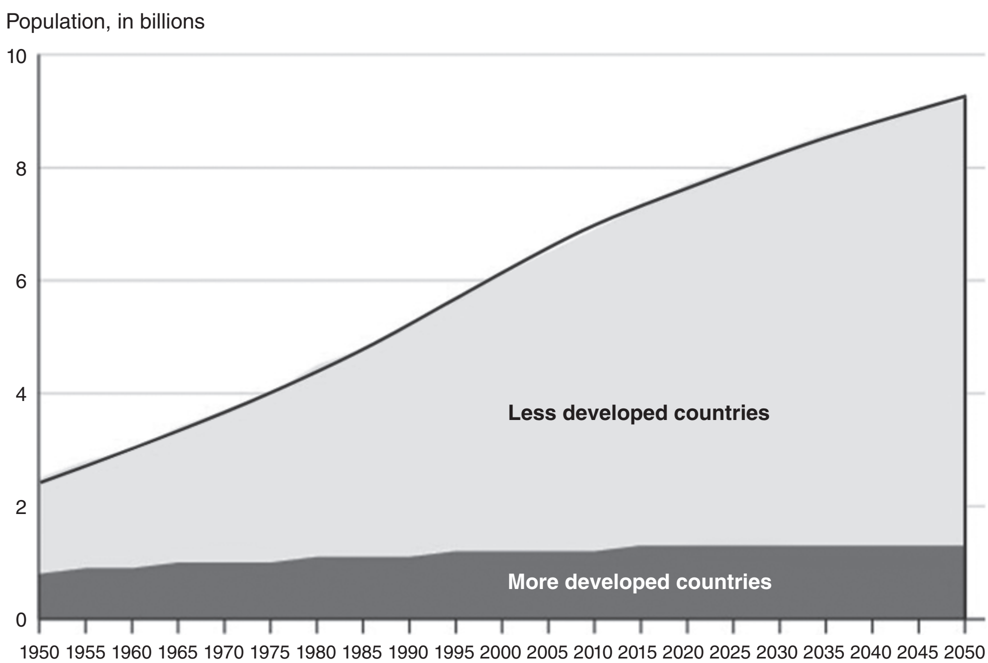

Figure 1.4. World population changes since 1950 and expected future growth, based on the optimal model. *Source:* United Nations, *World Population Prospects* (2017).

between 9.4 and 10 billion in 2050, and between 10 and 12.5 billion in 2100. The world population growth presented in Figure 1.4 represents the medium option.

The UN population statistics state that more than half of global population growth between now and 2050 is expected to occur in Africa. Thus, Africa's share of global population is projected to grow from 16% in 2016 to 25% in 2050 and 39% by 2100, while the share of population residing in Asia will fall from 59% in 2015 to 54% in 2050 and 44% by 2100. The rapid population growth in Africa will occur in the poorest 33 countries and could give rise to social upheavals and accelerated migration to Europe and wealthy Middle Eastern countries (Turkey and Arabic countries). This population increase and migration will affect mostly urban areas of the receiving countries. Less rapid but still significant growth will occur in Latin America, which will put pressure on migration to the US and Canada. As a matter of fact, most of the future population growth therein will be attributed to immigration and not to birth rates.

Population growth remains especially high in the group of 48 countries designated by the United Nations as the least developed countries (LDCs), of which 27 are in Africa. The population of this group is projected to double in size from 954 million inhabitants in 2015 to 1.9 billion in 2050, and further increase to 3.2 billion in 2100. In contrast, Europe is projected to have a smaller population in 2050 than in 2015. Several Eastern European countries and Japan are expected to see their populations decline by more than 15% by 2050 and due to the expected increase in longevity, this will represent a reduction in the proportion of the active working population over older retirees relying on Social Security payments and pensions. Forty-eight countries or areas are projected to experience population decline between 2015 and 2050. Table 1.3 shows population history and degree of urbanization.

It should be noted that the population of India is expected to surpass that of China. In 2015, the population of China was approximately 1.38 billion, compared with 1.31 billion in India. By 2022, both countries are expected to have approximately 1.4 billion people. Because of a high population growth in India and the policy of one child (changed to two children in 2015) per family in China, the population in China will stabilize around 2030 and begin to decrease thereafter. With unrestricted growth, after 2030 India will become the country with the largest population. India's population is projected to continue growing for several decades to 1.5 billion in 2030 and 1.7 billion in 2050 and then perhaps to stabilize in the second half of this century. Based on the median model, US population was expected to increase by 2050 by 67 million; however, demographers attribute this increase mainly to immigration. The effect of the 2018 US government policy changes regarding immigration is not known.

Table 1.3. Total and urban population in selected countries, in millions.*

Year	World	United States		United Kingdom		China**		Japan		India	
		Total	Urban	Total	Urban	Total	Urban	Total	Urban	Total	Urban
1950	2,525	159		51		544		83		376	
1990	5,268	255	191	60	45	1,184	308	122	94.5	853	222
2015	7,349	322	266	65	52	1,376	786	126.6	118	1,311	418
2030	8,500	356	300	70	57	1,415	902	120	114	1,527	607
2050	9,775	390	345	75	60	1,348	1,050	107	105	1,705	814
2100	11,200	550		82		1,004		83		1,659	

Source: United Nation population statistics.
*Values for some years were interpolated from the UN data.
**Not including Hong Kong and Macao.

The fraction of the population living in cities is expected to rise in almost all countries. McKinsey Global Institute (Woetzel et al., 2009) analytically described and forecasted the remarkable rapid but planned urbanization in China, which is building and expanding cities at a planned rate of almost 10 million each year until 2050. Urbanization is forecasted to increase therein from 26% in 1990 to 76% in 2050. By 2030 the policies of rapid urbanization will result in China having more than 220 cities with more than one million people. At that time (2030) the US will be about 87% urbanized. As shown on Figure 1.5, after 2015 all population increase will occur in urban areas. The economy of China has been developing rapidly in this century and cities are the places where most job opportunities are found. The rapid growth of urban areas has given a rise to megacities and megalopolises.

Examples of the megacities and megalopolises in 2015 and projected to 2030 are presented in Table 1.3. Arbitrarily defined, a megacity is a city with closely connected suburbs that has a population greater than 10 million. United Nation (2017) statistics reported that in 1990 there were 10 megacities with more than 10 million inhabitants, totaling 153 million people and representing less than 7% of the global urban population. By 2015 the number of megacities had tripled to 28, and the population they contain had grown to 453 million, accounting now for 12% of the world's urban dwellers. In 2030, there will be approximately 40 megacities and megalopolis agglomerations with a population of more than 10 million, of which 15 will be in China.

It was pointed out in the preceding section that urbanization and movement of rural people to the cities from urban sprawl suburbs in developed countries, if done right, may be beneficial for the energy and resource use and can lead to more sustainable living. Figure 1.6 shows the relation of carbon GHG emissions to population density. Similar relation can be developed for water use. Cities in the US, Canada, and Australia have the largest per capita $CO_{2\text{-eq}}$ emissions because of low density and the often still sub-standard public transportation in the US, which forces people to rely on commuting by private automobile and causes traffic jams, resulting in high fuel use. US cities also have the highest water use (footprint) because of lawn irrigation, especially in the suburbs, although there are exceptions.

Because of relatively high density, good public transportation by electric light rail, street cars, subway, and buses, and a great portion of electricity being provided by hydropower, both San Francisco and Seattle have the lowest per capita GHG emissions, at the level of

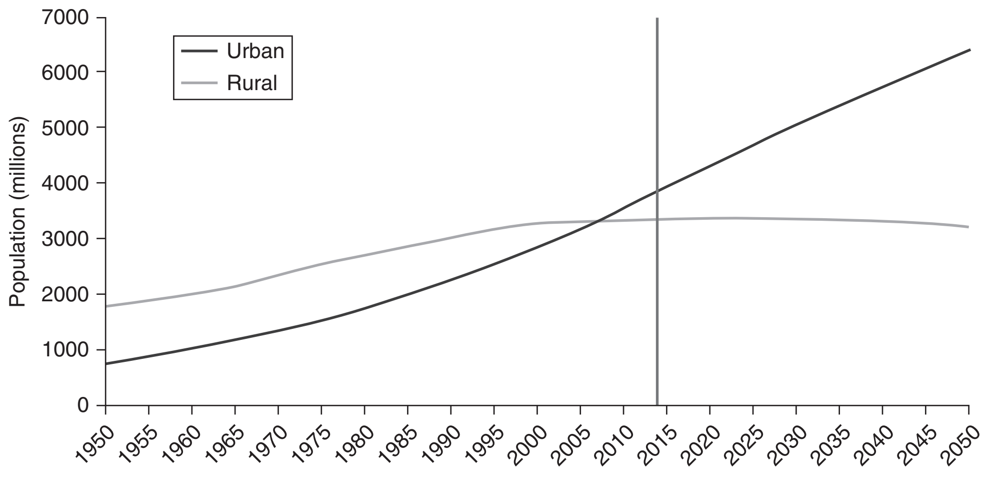

Figure 1.5. World urban and rural population. *Source:* United Nations.

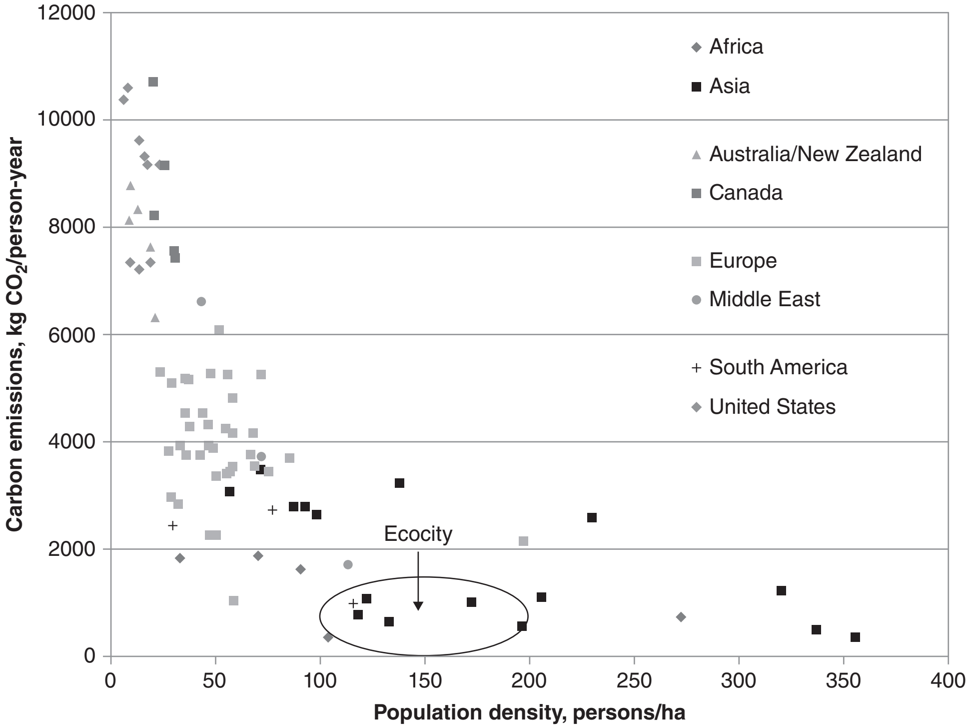

Figure 1.6. Relation of the annual GHG emissions to population density in selected world cities. *Source:* Data from various sources referenced in Novotny and Novotny (2009) and Novotny et al. (2010a).

a typical European city. Water use in some European countries is already approaching the sustainability level of 100 L/cap-day, which should also be a goal for the US.

With respect to carbon emissions, the optimum density for sustainable communities is between 100 and 200 people per hectare (Figures 1.6 and 1.7). High-density megacities with high-rises require more energy for pumping water to high elevations and for operating city

Figure 1.7. Hammarby Sjőstad (Stockholm), one of the first sustainable communities. Population density is 133 people/ha. *Source:* Wikipedia Creative Commons; picture by Peter Kulper.

lights, and more fuel for vehicular traffic in traffic jams. The low- and medium-density urban sections and suburbs will implement the low-impact development (LID) practices to reduce water use and pollution (see Chapter 3).

A McKensey Institute report (Woetzel et al., 2009) points out that by moving rural population to cities by planned urbanization and transfer, in 2025 China could cut its public spending requirement by 2.5% of GDP, or 1.5 trillion renminbi (Chinese currency; in 2018 1 renminbi = $0.16) a year, reduce SO_2, CO_2, and NOx emissions by 35%, halve its water pollution, and deliver private-sector savings equivalent to 1.7% of GDP, mainly through reduced consumption of natural resources.

Waste Accumulation

Only a fraction of waste discharged into water, emitted into air, or deposited onto land is biodegradable and eventually will be converted into harmless by-products. Many conservative and persistent pollutants entered the food web, biomagnified, and caused toxic contamination of flora, fauna, and humans. Persistent organic pollutants (POPs) possess toxic properties, resist degradation, bioaccumulate, and are transported, through air, water, and migratory species, across international boundaries and deposited far from their place of release, where they accumulate in terrestrial and aquatic ecosystems (Norstrom, 2002). Most of the chemicals that have been identified as POPs requiring elimination or restriction of use, or measures to prevent their formation as byproducts, either biomagnify in the food web of flora and fauna as unchanged chemicals (chlordane, DDT, dieldrin, hexachlorobenzene, mirex, toxaphene, PCBs, PCDDs, PCDFs), and/or form persistent, biomagnifying metabolites (aldrin, chlordane, DDT heptachlor). A US Geological Survey research report (Krabbenhoft, 1996) identified coal combustion in coal-fired power plants and waste incineration as main sources of mercury into Florida's Everglades, where fish contamination by methyl mercury is very high. Mercury can be converted in organic aquatic sediments into toxic methyl-mercury that biomagnifies in the aquatic food web from algae to small fish, to large fish, and finally to fish-eating birds and animals. Today most tuna and other large fish meats carry warning about mercury and other contamination. Because people are at the end of the food web, some contaminants are detected in humans.

There are numerous examples of "legacy" pollution, which links to the third paradigm of unrestricted discharges and emissions. The Earth is dotted with water bodies containing contaminated sediments and hazardous soils (brownfields) and abandoned but still polluting landfills. Large masses of plastics (bottles, packages, and many other items) are floating in oceans. The largest, the Great Pacific Garbage Patch, contains 80,000 tons of plastic and other garbage and in 2018 was twice the size of Texas or three times the size of France (https://www.theoceancleanup.com/). It severely interferes with aquatic life and it is expected to increase. Other important water bodies, such as the Venetian Lagoon, have the same issue. The problem with plastics has not yet been solved because they should not be incinerated and they decompose very slowly into particles (e.g., polyvinyl chloride, or PVC) that are even more harmful to the aquatic life and to humans. Nonetheless, solutions are available (see Chapter 8).

Brief Outlook Toward the Future

The revolution toward the new fifth paradigm of how cities and homes are built is already in progress. In the next 20 years, most homes and commercial houses in countries adhering to the Paris 21 agreement will have photovoltaics on the roof. The cost has already reached the breakeven level of affordability. But this is not just in the US or European countries; photovoltaic panels can now be seen on the roofs in the shantytowns of the underdeveloped world to provide electricity for TVs and other appliances when the dwellings are not connected to the electric grids, as well as on rural houses in China. Within a generation, France, Sweden, Denmark, Norway, Singapore, Austria, Israel, Iceland, Germany, New Zealand, Costa Rica, and possibly many others will be net-zero GHG impact countries.

Regarding the progress toward green technology and reduction of GHG emissions, "Global Trends in Renewable Energy Investment 2017" found that in 2016, wind, solar, biomass and waste-to-energy, geothermal, small hydro, and marine energy sources added 138.5 gigawatts to global power capacity, up 8% from the 127.5 gigawatts added the year before. The additional generating capacity roughly equals that of the world's 16 largest existing power-producing facilities combined.

In Massachusetts and some other states, subsidies are provided to homeowners to install solar power without paying any upfront costs, followed by monthly payments that are significantly smaller than the payment to the power providers before solar power installation. The state also is installing large-capacity off-shore wind power, and in 2017 it decommissioned its last regional coal power plant. In 2018, batteries were provided to communities and water utilities to store the excess energy generated during off-peak periods and save money by using it during peak hours.

1.6 WHAT IS A SUSTAINABLE ECOCITY?

Toward the end of the last century, after the major cleanup of water resources, avant-garde urbanization architects and developers realized the economic value of the intangible benefits of living closer to nature and they began to plan and implement new communities, sometimes adapting utopian visions or the ideas of early urban development giants like architects Frank Lloyd Wright or of Frederick Law Olmsted, father of the healthy urban landscape. The concept of the ecocity evolved at the end of last century and was first defined by Richard Register (1987), who coined the term *ecocity*. The following variant of Richard Register's ecocity definition has been accepted and promoted by the Ecocity Builders (2014):

> *An Ecocity is a human settlement modeled on the self-sustaining resilient structure and function of natural ecosystems. The ecocity provides healthy abundance to its inhabitants without consuming more (renewable) resources than it produces, without producing more waste than it can assimilate, and without being toxic to itself or neighboring ecosystems. Its inhabitants' ecological impact reflects planetary supportive lifestyles; its social order reflects fundamental principles of fairness, justice and reasonable equity*.

Following these developments at the end of the last century, the concepts of sustainable ecocities had been encompassed into criteria for some new and retrofitted old communities, which have been evolving as prototypes of sustainable (eco-) cities proposed, conceptualized, or built in Dongtan, Chongming, Tianjin, and Caofeidian (China); Forest City (Malaysia); Västra Hamnen and Hammarby Sjőstad (Sweden; Figure 1.7); Saadiyat Island and Masdar (UAE); Songdo International Business District (South Korea); Eko Atlantic (Nigeria); Ørestad (Denmark); Dockside Greens (Victoria, BC, Canada; Figure 1.8); and many other locations. The *sustainable city* is the most frequently occurring category, linked closely to the *ecocity* and *green city* concepts (de Jong et al., 2015). Advice and inspiration for ensuring that nature is included in the ecocity is covered in a book by Beatley (2017) that defines and describes *biophilic urbanism* (see Chapter 6), promotes well-being, creates an

Figure 1.8. Dockside Green ecocity in Victoria, British Columbia. Note 10 kW size wind turbines. *Source:* Copyright Dockside Green, Victoria, BC, Canada.

emotional connection to the Earth among urban residents, and describes urban biophilic innovations in more than a dozen global cities. The fundamental concepts of connecting urban areas with the nature and ecocities are also described by Ahern (2007, 2010), Farr (2008), Wheeler and Beatley (2014), Roberts, Newton, and Pearson (2014), and others.

Large cities are also undertaking transformation to a more suitable future. The uniform goal is to reduce CO_2 emissions by at least 80% by 2050, which also includes electrification of transportations, black and gray water reuse in coastal cities, using sea water for heating and cooling energy, recycling, and other approaches. The top cities listed in several rankings are Reykjavik, Iceland, where very soon all energy will be provided by geothermal and hydropower; Singapore, known to be greenest city-state in the world that recycles its water; Copenhagen, Denmark; Zurich, Switzerland; Stockholm, Sweden; and the three North American cities of San Francisco, California; Portland, Oregon; and Vancouver, British Columbia.

In addition to these new developments, in a more recent book dealing with ideas of cities that would be in balance with nature, Richard Register hypothesized that if "zero-car cities" like Venice, Italy, and Zermatt, Switzerland, had some solar energy retrofitting and more biodiversity in or adjacent to them, they would be very close to becoming ecological cities and villages (Register, 2006). A number of carless communities already exist, and based on this hypothesis, carless island cities such as Hydra Island, Greece; historic Venice and Capri Island, Italy; Fez, Morocco; and Mackinac Island, Michigan, would allegedly become perfect ecocities by installing blue energy and expanding local agriculture, although this might be difficult or impossible in those places. In historic Venice, cars, buses, and trucks were replaced by gondolas, water taxis, and boats (vaporeti); on Mackinac Island, by horse-drawn carriages and wagons; and on Hydra Island and Fez by donkeys, like in the Middle Ages.

These communities are more island tourist attractions than fully livable and functioning cities. Hence, such exaggeration would lead to a dead end if applied to current cities and urban zones. This idealistic striving toward biophilic future cities – which would not only be dense (thereby claiming avoiding environmentally damaging sprawl) but would also require people to accept a collectivist political philosophy of living in close neighborhoods, to use walking, bicycles (both highly recommended), and transportation incorporating donkeys and horses (highly questionable) instead of fossil-fuel vehicles – would not fit the new ecocity concepts. Furthermore, based on the experience of living and working in historic Venice for a long time, this author knows first-hand that this pearl of history and architectural beauty has serious water and sewage disposal problems, is sinking due overdraft of groundwater (reduced by bringing water from large distance by a long pipeline from the mainland), and in the last century had no sewers and only rudimentary sewage treatment mostly in the canals, as well as problems with disposal of solid waste exhibited by severe pollution by plastics and algae of the Venetian Lagoon surrounding the city, and lack of places to dispose of solid waste. Historic Venice is rapidly losing its permanent population and becoming a park where tourists come in the morning and leave at night, leaving their garbage behind.

However, the recent proliferation of expensive high-rise condominiums and apartment houses in major US cities, abandoned during the second half of the last century, proves that even well-to-do populations like “dense” but convenient locations close to work, especially when social services like daycare, schools, health clinics and hospitals, shopping, culture, areas for walking, good public transportation, and green areas with bike paths are nearby. The traditional large, dense cities like New York, Boston, Milwaukee, Chicago, Portland, Seattle, Minneapolis/Saint Paul, San Francisco, Copenhagen, Stockholm, London, and Paris are very desirable but very expensive places to live.

Based on the analysis of a census of 178 cities said to be ecocities in the first decade of this century, Joss et al. (2013) noted significant global proliferation of ecocity initiatives that have become mainstream and fashionable at various levels of government in many regions of the world. However, Grydehøj and Kelman (2016) and Caprotti (2014) noted that some of the ecocities mentioned above that are already built or are being built, including showcase Masdar in the United Arab Emirates, are indeed “island” developments that are good for testing and conceptualization of the ideas and/or socioeconomic and environmental relations, but they have not been as successful in becoming the flagship developments that would spread widely to other old and new urban developments. Some were abandoned (Dongtan near Shanghai), some slowed down or are on hold (Masdar) due to various reasons such as politics and reduced oil prices. However, in 2017, China was on the way to building many new urban communities designated as ecocities (Williams, 2017; Shepard, 2017). Shepard reported that ecocities are now being built across China, from the eastern seaboard to the fringes of Central Asia, from Inner Mongolia to the jungle hinterlands of the south. It has been estimated that in the near future, over 50% of China’s new urban developments will be stamped with labels such as “eco,” “green,” “low carbon,” or “smart.”

Meanwhile, in addition to the attractiveness of the ecocity ideas, other more urgent reasons presented in this chapter have emerged in the twenty-first century, including global warming, loss of resources, water shortages, and population growth, which the urbanization paradigm of the last century cannot handle. In addition, catastrophes such as unusually strong hurricanes and heat waves have been occurring and are expected to intensify in the future. Therefore, at the beginning of this century, it was realized that the founding blocks of the ecocity are not only a desirable green architecture but also, and above all, water resources, infrastructure, water and energy management, used and stormwater disposal, and, by the same reasoning, also treating solid and liquid wastes as resources and sources of energy that would lead to saving water, reaching net-zero GHG emissions, sustainable suburban agriculture, avoidance of landfills, and several other key sustainability components. This leads to the following expansion of the Register's original ecocity definition:

A sustainable city or ecocity is a city or a part thereof that balances social, economic, and environmental factors (triple bottom line) to achieve sustainable development. A sustainable city or ecocity is a city designed with consideration of environmental impact, inhabited by people dedicated to minimizing required inputs of energy, water, food, and waste and outputs of heat, air pollution (CO_2, methane), and water pollution. Ideally, a sustainable city powers itself with renewable sources of energy, creates the smallest possible ecological footprint, and produces the lowest quantity of pollution. It also uses land efficiently, composts and recycles used materials, and converts waste to energy. If such practices are adapted, overall adverse contributions of the city to climate change will be none or minimal below the resiliency threshold. The cities of the future (COF) will have frugal energy and water (green) infrastructure, resilient and hydrologically functioning landscape, and protected and restored interconnected natural features and water bodies within their zones of influence. Urban (green) infrastructure, resilient and hydrologically and ecologically functioning landscape, and water resources will constitute one system.

Many commonalities would characterize sustainable (eco) cities, such as:

- Many sustainable new (eco)cities are built on lands that might not be suitable for development using traditional criteria. The land is either a brownfield (Hammarby Sjőstad) or an arid land (Tianjin Ecocity in China).
- These sustainable communities are not like low-impact developments (LID) in the US. Typically, they are medium-density multiple-family mixed-use developments (for example, Hammarby Sjőstad in Sweden or Dockside Greens in Victoria, British Columbia).
- They are all frugal with their water use.
- They all use less energy and aspire to reach a net-zero carbon footprint.
- They all recycle.
- Vehicular traffic within the city is restricted; people in the cities walk or use bikes and have convenient public transportation.
- Many ecocities are water-centered (water-centric) developments surrounded by or near a body of water and restoring the natural drainage and old water courses (see Chapter 6).

The Ecocity Builders (2014) define urban ecosystem as a biological environment consisting of all the organisms living in a particular area, as well as all the nonliving physical components of the environment with which the organisms interact, such as air, soil, water, and sunlight. The urban entities (cities, towns, and villages) are urban ecosystems that are also part of larger systems that provide essential services such as regulation (climate, floods, nutrient balance, water filtration), provision (food, medicine), culture (science, spiritual, ceremonial, recreation, aesthetic), and support (nutrient cycling, photosynthesis, soil formation). A bioregional cluster of ecocities with integrated waterways and agricultural lands and connected by public transit and bikeable greenways would constitute an ecological metropolis, or "ecopolis."

Impact of Global Warming and Continuing Overuse of Resources

Professor Rees, founder of the concept of "sustainability footprints" (see Chapter 3) in his seminal essay (Rees, 2014) stated:

> *Environmental and earth scientists have shown that human demands on the ecosphere exceed its regenerative capacity and that global waste sinks are overflowing. The accumulation of anthropogenic greenhouse gases, particularly carbon dioxide, is perhaps the best-known example, but is just one symptom of humanity's frontal assault on the ecosphere—climate is changing, the oceans are acidifying, fresh waters are toxifying, the seas are overfished, soils are eroding, deserts are expanding, tropical forests are shrinking, biodiversity is plummeting. The growth of the human enterprise continues at the expense of depleting self-producing natural capital and polluting life support systems*.

The worldwide plastic and garbage accumulation in the ecosystem overload that was realized with horror at the end of the second decade of 2000s and the global warming records at the beginning of this century confirm Professor Rees's postulate that economic expansion has its limits and the world has already surpassed its limits on fossil energy and resources and is at the onset of the fifth revolution regarding sources of energy. Rees has also pointed out that ecological damage and resource scarcity is largely the result of production and consumption to satisfy just the wealthiest 20% of the world's population. Roughly half the fossil fuel ever burned has been consumed in just the past 30 years. These are serious challenges to humans. Essentially, cities must reduce consumption and overuse of resources; the general term for overuse is *mining,* which means overuse of resources that are not renewable without replenishing them or fully mitigating their adverse impact (groundwater and fossil fuels mining, deforestation, etc.). This means that society must move to a more "sober" economic regime to limit and reduce the consumption of water, energy, and natural resources (including nonrenewables) and limit waste and air pollution discharges as outlined in a French study on urban integrated management (Lorrain et al., 2018).

The UN 2015 Resolution of Sustainability

In 2015 the United Nations General Assembly (UN, 2015a) adopted a resolution establishing the sustainability goals for 2030, which expressed the intent of countries "to protect the planet from degradation, including through sustainable consumption and production, sustainably managing its natural resources and taking urgent action on climate change, so that it can support the needs of the present and future generations." This charter addressed many important topics such as poverty, global warming, and use of resources. The UN recognizes that sustainable urban development and management are crucial to quality of life and promised to work toward reducing the negative impacts of urban activities and of chemicals that are hazardous to human health and the environment, including through the environmentally sound management and safe use of chemicals, the reduction and recycling of waste, and the more efficient use of water and energy. They also made a commitment to minimize the impact of cities on the global climate system. The goals pertinent to the topics and issues covered in this book are:

- Ensure availability and sustainable management of water and sanitation for all.
- Ensure access to affordable, reliable, sustainable, and modern energy for all.

- Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all.
- Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation.
- Reduce inequality within and among countries.
- Make cities and human settlements inclusive, safe, resilient, and sustainable.
- Ensure sustainable consumption and production patterns.
- Take urgent action to combat climate change and its impacts.
- Conserve and sustainably use the oceans, seas, and marine resources for sustainable development.
- Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.

By 2030:

- Achieve universal and equitable access to safe and affordable drinking water for all.
- Implement integrated water resources management at all levels, including through transboundary cooperation as appropriate.
- Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers, and lakes.
- Ensure universal access to affordable, reliable, and modern energy services.
- Substantially increase the share of renewable energy in the global energy mix.
- Double the global rate of improvement in energy efficiency.
- Enhance international cooperation to facilitate access to clean energy research and technology, including renewable energy, energy efficiency, and advanced and cleaner fossil-fuel technology, and promote investment in energy infrastructure and clean energy technology.
- Expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries.
- Reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management.
- Provide universal access to safe, inclusive, and accessible green public spaces, in particular for women and children, older persons, and persons with disabilities.
- Achieve sustainable management and efficient use of natural resources.
- Halve per capita global food waste at the retail and consumer levels and reduce food loss along production and supply chains, including post-harvest losses.
- Achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water, and soil in order to minimize their adverse impacts on human health and the environment.
- Substantially reduce waste generation through prevention, reduction, recycling, and reuse.

These goals represent the most important UN sustainability agenda goals.