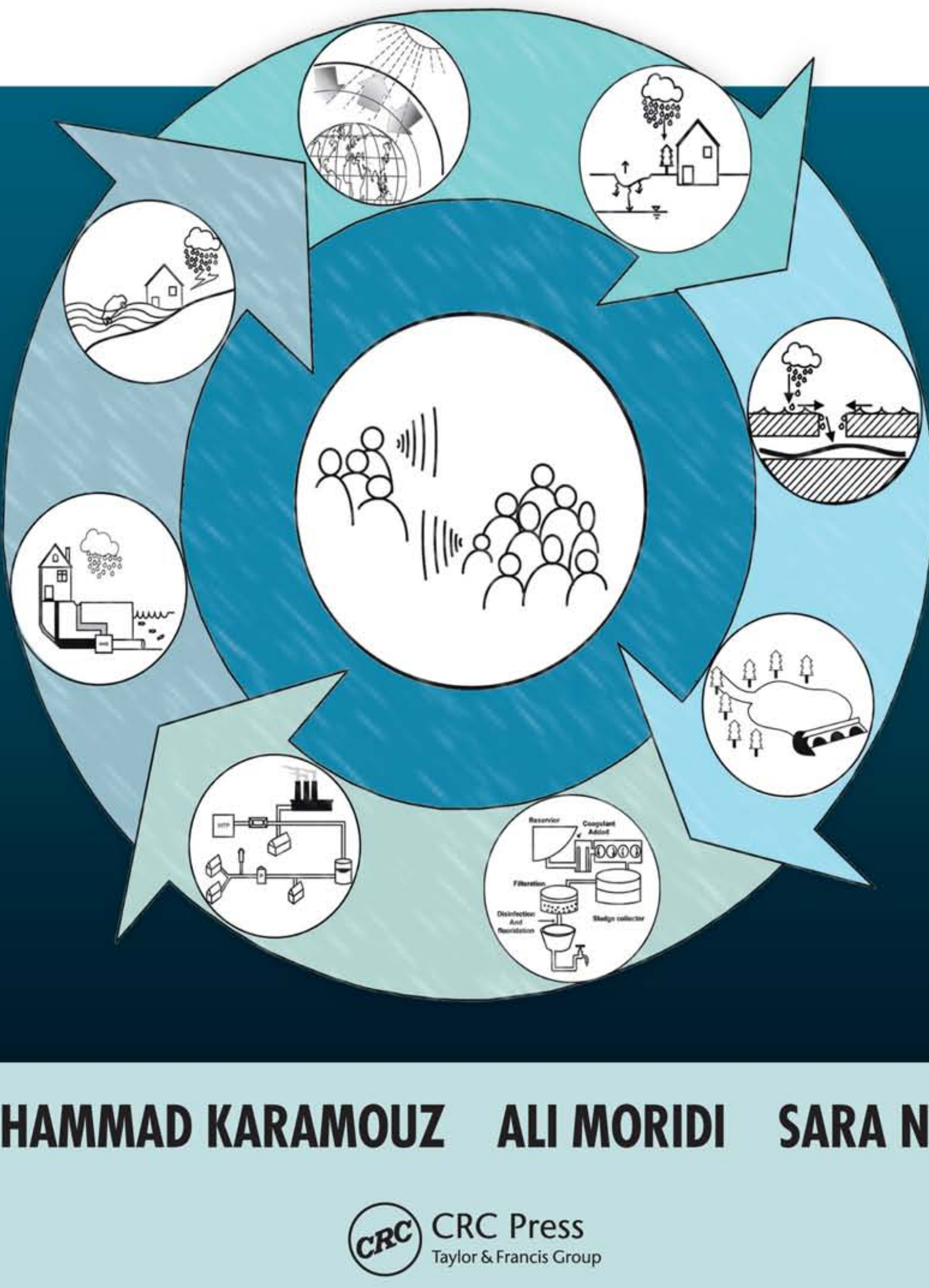
URBAN WATER ENGINEERING AND MANAGEMENT



MOHAMMAD KARAMOUZ ALI MORIDI SARA NAZIF

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To my wife, Setareh, and my children, Saba Sahar and Mehrdad M. Karamouz

To my parents, Maryam and Amir, and my wife, Elahe A. Moridi

To my parents, Azar and Mostafa, and my brother, Mohsen, who taught me how to love others

Contents

Preface

In the past few decades, urban water management practices have focused on optimizing the design and operation of water distribution networks, wastewater collection systems, and water and wastewater treatment plants. However, municipalities are facing hardships because of the aging urban water infrastructure whose operation must be improved and expanded to maintain and keep up with the current standards of living. As for best practice management, it has become clear that structural solutions for available urban systems' operation are not always the most efficient and economic alternative. Today's integrated urban water management focuses on engineering and planning solutions for integrating structural and nonstructural means to achieve the best operational schemes at affordable costs.

Current challenges go beyond utilizing the existing structures and the physical limitations on water availability to include technical, social, political, and economical aspects of better water and wastewater management in urban areas. The planning schemes should focus on sustainable urban water development and therefore ensure water security for communities.

In this book, a systems approach to urban water hydrology, engineering, planning, and management is taken. Urban water governance and disaster management in urban areas are some of the pressing issues that are discussed. Modeling of the urban water cycle, urban water supply and distribution systems that demand forecasting, and wastewater and stormwater collection and treatment are classical issues in urban settings that are presented in a systems perspective. Understanding the principles from simulation, optimization, economical evaluation, multiple-criterion decision making, and conflict resolution are prerequisites for integrated urban water management, which are covered in this book.

This book has been written for undergraduate and graduate courses in water resources in civil and environmental engineering, in urban planning, and in any selected urban system courses including infrastructure development. Junior and senior BS students can use Chapters 3, 4, 5, 6, and 7 of this book for engineering hydrology/water resources engineering, environmental engineering I, and water and wastewater courses. Engineers and planners, especially those who work on the design, planning, and management of urban systems and/or community development, can use this book in practice because it deals with a broad range of real-world urban water problems. Special features such as water governance and disaster management are useful to water managers, policy makers, and decision makers. The content of each chapter has been selected considering the latest developments in urban water hydrology and management. Modeling techniques are discussed with some field applications for a better understating.

Chapter 1 presents the urban water cycle as part of a hydrological cycle. Components of the urban water cycle have special characteristics that are affected by the growing population. Air, water, and soil pollution in urban areas are now getting intensified by climate change impacts. These components and the effects of urbanization, as well as physical, chemical, and biological impacts, are briefly discussed in this chapter. Urban development has caused some climatic and hydrological impacts such as greenhouse gases and heat islands, which are also discussed in this chapter.

Chapter 2 presents the institutional framework in the context of water governance. The paradigm shifts from Newtonian to holistic planning, and its impact on shifting from supply management to demand management are discussed. Water and its role in land-use planning have been a challenge for planners and decision makers. The suitability of land-use planning with respect to the availability of water resources has always been a major challenge. Municipalities that have coupled land-use planning with sustainable water resources allocation schemes have succeeded in meeting their long-term objectives while expanding environmental vitality toward sustainable development. Water resource assessment as a means to measure, evaluate, monitor, forecast, and bring consensus among engineers, water resources planners, decision makers, and stakeholders is also discussed in this chapter.

Chapter 3 presents urban runoff and drainage characteristics, excess rainfall calculation, and rainfall–runoff analyses. The design of rainfall and peak flow calculations are also discussed. Furthermore, an introduction to the effects of urbanization on peak discharge is given. The principal components of designing the urban water drainage system are also explained.

Chapter 4 presents the principles of urban water supply and distribution. In this chapter, water supply and distribution challenges are discussed. Moreover, the interdependency and interactions among the system's principal components are recognized and used for solving water supply and distribution problems, which are the essence of integrated urban water management.

Chapter 5 introduces urban water demand management and the key strategies for achieving the millennium development goals of supplying potable water and sanitation to all people in urban areas. In this chapter, the concepts of water demand forecasting and management are introduced and the methodologies that can be applied to achieve the demand management goals are described.

Chapter 6 discusses the basic principles of designing urban water drainage systems. In this chapter, an introduction to the design of surface drainage channels and the risks associated with floods is presented. The required hydraulic equations for storm channel design as well as hydrograph routing methods are explained in this chapter.

Chapter 7 explains the impacts of urbanization on various water and environmental components in urban areas. The urbanization impacts are focused on water and other elements interacting with urban water and the impacts of urban areas on the atmosphere, surface water and groundwater, soils, and wetlands. As stormwater is one of the main pollution sources of urban areas, the principles of urban stormwater quality modeling are also presented in this chapter. The material presented in this chapter can be used for stormwater pollution load estimation from different sources. This can help engineers and decision makers decide on structural and nonstructural means of dealing with pollutants and their possible impacts on human health.

Chapter 8 introduces the tools and techniques suitable for urban water engineering and management. They are classified as economic analysis, simulation, and optimization analysis. Engineering applications primarily use analysis and design techniques. The overlay between engineering and management tools in urban water is simulation tools, which can be used to test the performance of urban water systems.

Chapter 9 discusses urban water infrastructure management and maintenance of the structural integrity of its components, with particular focus on water mains, which are the most important component of urban water infrastructures. In this chapter, an introduction to the different parts of urban water infrastructures and their interactions, as well as life cycle assessment and sustainable designs of urban infrastructures are discussed. The application of standard integrity monitoring to water mains is also presented.

Chapter 10 introduces different methods for integrating of engineering and planning principles and sustainability in urban water management. In this chapter, system dynamics and conflict resolution as well as some case studies related to their applications are presented.

Chapter 11 discusses the principles of urban water disaster management. Water shortages, water pollution, flooding, aging water infrastructures as well as increasing demands for water, and other problems associated with water allocation that can devastate water systems and cause disasters are presented. The rapid oscillation of these problems has the gravest effects on developed countries. Developed countries are more vulnerable because of their high dependency on water. In developing countries, water disasters also impact the life of people because of the rapid expansion of water sectors and inadequate institutional and infrastructural setups to deal with unexpected situations. In this chapter, the planning process for urban water disaster management and methods for analyzing systems' readiness through some real-world examples are discussed.

Chapter 12 presents climate change impacts and their potentially significant implications on the urban water cycles. This chapter provides a basic understanding of climate change and consideration of the issues involved in developing suitable urban water planning and management responses to climate changes.

This book can serve water communities around the world and add significant value to engineering and applications of systems analysis techniques to urban water design, planning, and management. It can be used as a textbook by students of civil engineering, urban and regional planning, geography, and environmental science, and in courses dealing with urban water cycles. It also introduces new horizons for engineers, policy makers, and decision makers who are planning for the regional sustainability of future urban water.

We hope that this book will serve urban water communities around the world and add significant value to the application of systems analysis techniques for urban water engineering and management.

Mohammad Karamouz
Ali Moridi
Sara Nazif

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1 Introduction

A portrait of "A Man and His World" shows a dream town with all the technological advancement and abundance of services, utilities, and contents. With this portrait in mind, an urban population demands high quantities of energy and raw material, and removal of waste. The by-product of urban life is environmental pollution. Material and energy are the main ingredients of urbanization and all key activities of modern cities. Transportation, electric supply, water supply, waste disposal, heating, services, manufacturing, and so on are characterized by the use of energy and material. Thus, the concentration of people in urban areas dramatically alters material and energy fluxes. Drastic changes in landscape and land use have altered the fluxes of water, sediment, chemicals, and microorganisms and have increased the release of waste and heat. These changes then impact urban ecosystems, including urban waters, and result in deterioration of natural resources and degradation of supporting infrastructure. Such circumstances make the provision of water services to urban populations highly challenging, particularly in large cities. The number of these large cities keeps growing, particularly in developing countries, and this further exacerbates both human health and environmental problems on a regional scale.

For water management in time and space, the hydrologic cycle is a model of holistic nature. There are different definitions of the hydrological cycle, but it is generally defined as a conceptual model describing the storage and circulation of water between the biosphere, atmosphere, lithosphere, and hydrosphere (Karamouz and Araghinejad, 2005). Water can also be arrested in nature in the atmosphere, ice and snow packs, streams, rivers, lakes, groundwater aquifers, and oceans. Water cycle components are affected by processes such as temperature and pressure variation and condensation. The means of water movement is through precipitation, snowmelt, evapotranspiration, percolation, infiltration, and runoff.

A watershed is the best hydrological unit that can be used to carry out water studies and planning in a systematic manner. The urban setting could alter the natural movement of water. Drastic land use changes in urban areas as a subset of urban and industrial development affect natural landscapes and the hydrological response of watersheds. Although anthropogenic factors with respect to waterways, pipes, abstractions, and man-made infrastructures affect the elements of the natural environment, the main structure of the hydrological cycle remains the same in urban areas (McPherson and Schneider, 1974). But the characteristics of the hydrologic cycle are greatly altered by urbanization impacts of the services to the urban population, such as water supply, drainage, and wastewater collection and management.

As a conceptual way of looking at water balances in urban areas, the context of the urban water cycle is the total system approach. Water balances and budget studies are generally conducted on a different time scale, depending on the type of applications we are looking at in a planning horizon. For distributing water to growing populations and for coping with extreme weather and climatic variations and potential climate change, Lawrence et al. (1999) emphasized the importance of integrated urban water managements. Pressures, temperatures, and water quality buildups in urban areas have a pronounced effect on the urban water cycle, which should be attended to through best management practice (BMP) schemes.

1.1 URBAN WATER CYCLE

1.1.1 Components

Changes in the material and energy fluxes and in the amount of precipitation, evaporation, and infiltration in urban areas consequently result in changes in water cycle characteristics. The impacts of large urban areas on local microclimate have long been recognized and occurred as a result of changes in the energy regime such as air circulation patterns caused by buildings, transformation of land surfaces and land use planning as well as water transfer, waste generation, and air quality variations. These changes can be summarized as follows:

- Land use—transformation of undeveloped land into urban land, including transportation corridors
- Demand for water—increased demand because of increased concentration of people and industries in urban and nearby suburban areas
- Increased entropy on the use and redundant use of unsustainable forms of energy
- Waste production—specially solid waste and industrial hazardous wastes, and decreasing quality of different resources such as air, water, and soil
- Water and food transfer from other places to urban areas

Figure 1.1 shows the different components of the hydrologic cycle in urban areas. Each of these components is briefly explained in this section.

Temperature: The air temperature over urban areas usually exceeds that of the surrounding localities by as much as 4–7°C. These thermal variations explain the higher evaporation rates (5–20%) in urban areas. Also, convective storms can be observed in urban areas, due to higher temperatures.

Precipitation: Previous studies have shown that the total annual precipitation in large industrialized cities is generally 5–10% higher than in surrounding areas, and for individual storms, this increase in precipitation can be as high as 30%. Urban areas are more vulnerable to storms because of much higher runoff coefficients, complexity in the conveyance system as well as congestions in transportation corridors, and poor land use planning.

Evaporation: Because of the high rate of thermal and other forms of energy consumption in cities, the mean temperature and evaporation are higher in urban areas. The presence of closed conduits and storage facilities could reduce the evaporation rate compared with open and surface flow and storage in rural areas.

Transpiration: Because of land use changes and the reduction of open space and green areas, transpiration from trees and vegetation usually decreases.

Infiltration: The following factors contribute to the decrease in infiltration rate:

- Impervious areas (pavements, rooftops, parking lots, etc.)
- Man-made drainage systems

The use of compensatory devices of urbanization effects, such as infiltration trenches and pervious pavements, will increase infiltrated water flows in urbanized areas. Soil pollution caused by contaminants from surface runoff and leaking underground tanks and absorption wells as well as leaches from landfills alters the soil–water interaction. Therefore, the unsaturated zone in urban areas has different characteristics than other areas.

Runoff: The high ratio of areas covered by impervious materials results in a higher runoff rate in urban areas. Man-made drainage systems facilitate surface runoff collection and transfer; therefore, after urbanization, the peak of the unit hydrograph is greater and occurs earlier. Figure 1.2 shows the comparison between the unit hydrograph of an area before and after urbanization. It has been stated that for a drainage area of about 200 ha (1 ha = 10,000 m^2) the following change in order of magnitude could be expected after urbanization. The runoff coefficient and the peak flow increase 2–3

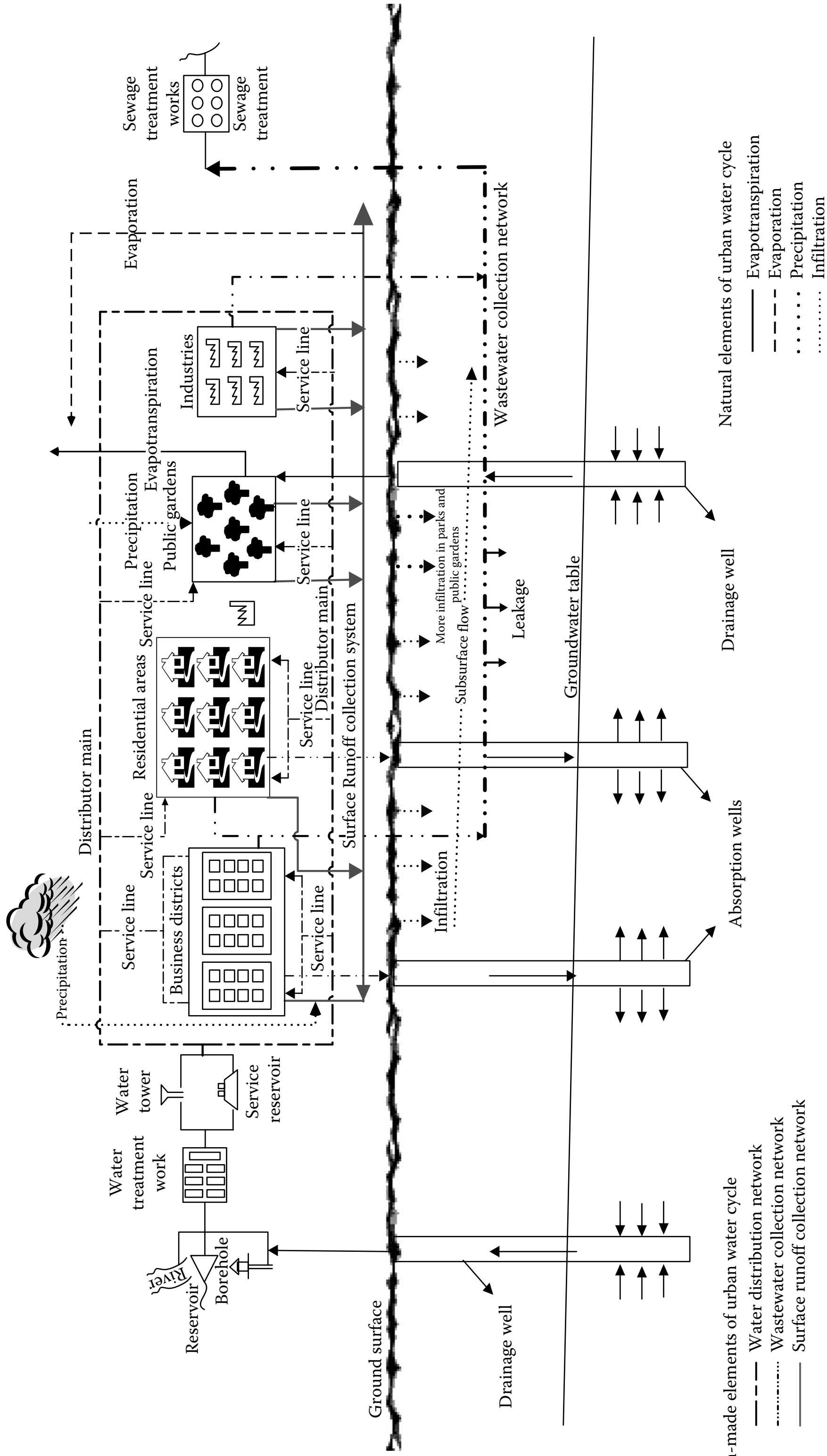

FIGURE 1.1 Different elements of the hydrologic cycle in urban areas.

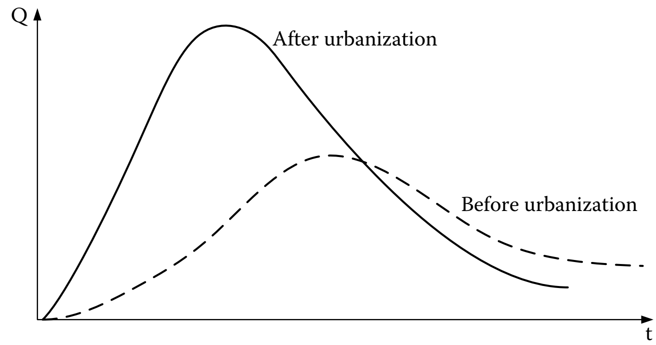

FIGURE 1.2 Unit hydrograph after and before urbanization.

times. The lag time between rainfall and runoff decreases 3 times, and the runoff volume increases 3–4 times.

Interflow: Due to very low infiltration rates in urban areas, the interflows in urban areas, as shown in Figure 1.1, are mostly supplied by leakage from water distribution and wastewater collection networks. The higher infiltration rates in parks, green areas, and areas with absorption wells are also important in increasing interflows.

Water quality: This is significantly affected by urban activities. The water quality of interflow is also adversely affected by urban life. Therefore, the effect of this important component of the hydrologic cycle is changed drastically.

1.1.2 Impact of Urbanization

Physical, chemical, and biological impacts on the water cycle have caused adverse and serious depletion of water resources in many urban areas around the world. Modifications of major drainage canals from natural to man-made structures has an impact on runoff hydrograph that affects rate of erosion and siltation. Surface runoff carries pollutants such as hydrocarbon and other organic residues, food waste, debris, and other matter. Urban drainage discharging into water bodies introduces modifications that produce different negative impacts with short- and long-term consequences on the regional ecosystem. The magnitude of the impacts depends on factors such as the condition of the water body before the discharge occurs, its carrying capacity, and also the quantity and distribution of rainfall, land use in the basin, and type and quantity of pollution transported. The problems cause esthetic changes as well as pollutions from toxic substances.

The impact can be categorized as physical, chemical, and biological. Physical impacts are those that affect the amount of surface runoff and those that affect the urban water cycle such as impact on soil consolidation. The latter impacts the specific storage of aquifers in urban areas. Air pollution from SO_2 and CO_2 is a common problem in many big cities. When mixed with precipitation, it causes acid rains that destroy trees in urban areas and have adverse effects on surface and groundwater resources.

Many infectious enteric diseases of humans are transmitted through fecal wastes to rivers or lakes. These revelations are accelerated in urban areas. In most biological reactions, oxygen is an important factor. When the rate of biological reactions increases, the dissolved oxygen in water decreases, which affects aquatic life. Industrial and municipal wastewater disposal to rivers and lakes changes water quality and causes significant changes in the hydrologic cycle in urban areas. For example, when water is polluted, its color becomes dark and it absorbs more energy from the sun. This increases the water temperature and changes the evaporation rate.

In urban areas, because of the high density of buildings and other structures, soil will be consolidated and, therefore, the porosity of soil decreases and the amount of water that can be stored and discharged from urban aquifers decreases. Another impact of urbanization on urban aquifers is the decreasing recharge to the aquifer because of decreasing infiltration. There are certain urban areas with a large number of absorption wells that are subject to a high rate of wastewater infiltration to the aquifer. Groundwater resources have been polluted by urban activities in many cities of the world. For example, landfill leakages and leakage from wastewater sewers and septic tanks are most well-known point sources that cause pollution of groundwater in urban areas.

The hydrological response of urban areas involves the determination of surface runoff hydrographs, which are then routed through the conduits and channels constituting the drainage network to produce outflow hydrographs at the urban drainage outlet. The physical characteristics of a catchment basin regarding the rainfall–runoff process can vary significantly in different parts of an urban area. The unit hydrograph is a traditional means of representing linear system response, but it suffers from the limitation that the response function is lumped over the whole catchment and does not explicitly account for spatially distributed characteristics of the catchment's properties. Schumann (1993) presented a semidistributed model where the spatial heterogeneity of the hydrological characteristics within a basin has been modeled considering each subbasin separately using geographical information system (GIS). Wang and Chen (1996) presented a linear spatially distributed model where the catchment is treated as a system that consists of a number of subcatchments, each assumed to be uniform in terms of rainfall excess and hydrological conditions. Using these approaches, different precipitation patterns and land covers, and their effects on surface runoff can be modeled. These approaches are of significant value in urban areas because of the latter's complexity and land use.

Drought and flood severity, and their impacts on urban areas are more significant. After urbanization, the peak of the unit hydrograph increases and occurs earlier and the flooding condition is more severe. Also, because of high water demand, urban areas are more vulnerable during hydrological drought events. Due to high rate of water use in urban areas, social, political, and economic issues related to water shortage in urban areas are intensified.

Water distribution and wastewater collection systems: The objectives of a municipal water distribution system are to provide safe, potable water for domestic use, adequate quantities of water at sufficient pressure for fire protection, and industrial water for manufacturing. A typical network consists of a source and a tank, treatment, pumping, and a distribution system. Domestic or sanitary wastewater refers to liquid discharges from residences, business buildings, and institutions. Industrial wastewater is discharged from manufacturing, production, power, and refinery plants. Municipal wastewater is a general term applied to the liquid collected in sanitary sewers and treated in a municipal plant. Storm runoff water in most communities is collected in a separate storm sewer system, with no known domestic or industrial connections, and is conveyed to the nearest watercourse for discharge without treatment. In many urban areas, the stormwater and wastewater collection systems are getting mixed and they operate at low efficiency and with a high ratio of system failure.

1.2 INTERACTION OF CLIMATIC, HYDROLOGIC, AND URBAN COMPONENTS

1.2.1 Climatic Effects

The interaction between large urban areas and local microclimate has long been recognized and occurred as a result of changes in the energy flux, air pollution, and air circulation patterns, which are caused by buildings, land transformations, and release of greenhouse gases. These factors contribute to changes in the radiation balance, and the amounts of precipitation and evaporation, and consequently changes in the hydrologic cycle.

Climate is defined as the long-term behavior of weather over a region. There are five climate categories in the world: arid and semiarid, tropical, subtropical (continental), rain shadow, and cool coastal. Hydrologic processes in urban areas under different climates are affected by hydrometeorological variables, which have different ranges in different climates. Different climates are known under the following definitions:

Arid and semiarid areas (e.g., arid areas of Asia and western USA): These areas have seasonal temperatures that range from very cold winters to very hot summers. Snow can occur; however, its effectiveness may be low. Rainfall in summer is unreliable in this climate. Thompson (1975) lists high pressure, wind direction, topography, and precipitation as four main processes that explain aridity.

Tropical areas: Interaction of climate in urban areas located in tropical and subtropical areas can be categorized by the amount of rain and rainy seasons, regional water balance over the year. According to Tucci and Porto (2001), rainfall in tropical regions usually has some of the following characteristics:

- Convective rainfall is more frequent, with a high intensity and a short duration of time, covering small areas. This type of rainfall is more critical for an urban basin that has a short time of concentration (high flow velocity due to gutter and pipe flows) and a small catchment area.
- Long periods of rainfall with high volumes of water result in water depth in the streets. This situation is critical for detention systems. Since the wet periods are concentrated in only a few months (e.g., 500 mm in 15 days has a return period of about 15 years) and there is a storage system, its critical design condition is mainly based on rainfall volumes of a few days rather than on a short period of rainfall.

Climatic conditions in the humid tropics make the urban area more prone to frequent floods, with damage aggravated by socioeconomic factors. On the other hand, the larger mean volumes of precipitation and the greater number of rainy days lead to more complex management of urban drainage. Since larger volumes must be routed somewhere, the mean transported loads of solids are larger (because runoff continues for a longer time), there is less time for urban cleaning (more sediment and refuse remain on the streets) and for maintaining drainage structures, and there is more time to develop waterborne vectors or diseases (Silveira et al., 2001).

Subtropical areas (e.g., Sahara, Arabia, Australia, and Kalahari): These areas are characterized by clear skies with high temperatures. The climate has hot summers and mild winters; hence seasonal contrasts are evident with low winter temperatures due to freezing. Convective rainfall only develops when moist air invades the region (Marsalek et al., 2006).

Rain shadow areas (e.g., mountain ranges such as the Sierra Nevada, the Great Dividing Range in Australia, and the Andes in South America): A rain shadow, or, more accurately, a precipitation shadow, is a dry region of land that is leeward of a mountain range or other geographic features, with respect to the prevailing wind direction. Mountains block the passage of rain-producing weather systems, casting a “shadow” of dryness behind them. The land gets little precipitation because all the moisture is lost on the mountains (Whiteman, 2000).

Cool coastal areas (e.g., Namib and the Pacific coast of Mexico): These areas have reasonably constant conditions with a cool humid environment. When temperate inversions are weakened by moist air aloft, thunderstorms can develop. Cold ocean currents are onshore winds blowing across a cold ocean current close to the shore, which will be rapidly cooled in the lower layers (up to 500 m). Mist and fog may be resulted, as found along the coasts of Oman, Peru, and Namibia, but the warm air aloft creates an inversion preventing the ascent of air, and hence there is little or no precipitation.

1.2.2 Hydrologic Effects

Urbanization increases surface runoff volumes and peak flows, and such excess rainfall may lead to flooding, sediment erosion and deposition, habitat washout (Borchardt and Statzner, 1990), geomorphologic changes (Schueler, 1987), and reduced recharge of groundwater aquifers. These effects may be divided into two categories: acute and cumulative. Flooding and stream channel incision belong to the first category and lowering of groundwater tables and changing the morphology belong to the second category.

In arid climates (as defined in the previous section), the urban surface collects heat, which causes the heating of stormwater runoff and increasing of temperatures in receiving water bodies by up to 10°C (Schueler, 1987). In highly developed watersheds, these processes may lead to algal succession from cold-water species, impacts on invertebrates, and cold-water fishery succession by a warm-water fishery (Galli, 1991).

Urban stormwater ponds, or small lakes, become chemically stratified during winter months (Marsalek et al., 2006), mostly by chlorides originating from road salting. The resulting environmental effects include high levels of dissolved solids and densimetric stratification, which inhibit vertical mixing and transport of oxygenated water to the bottom layers, and may also enhance the release of metal bounds in sediments.

In arid areas, the physical process of soil formation is active, resulting in heterogeneous soil types, with properties that do not differ greatly from the parent material and with soil profiles that retain their heterogeneous characteristics. Soils in arid lands may contain hardened or cemented horizons known as pans, and are classified according to cementing agents such as iron and so on. The extent to which the horizons affect infiltration and salinization depends on their thickness and depth of formation as they constitute an obstacle to water and root penetration. In salt media, salt crusts can form at the surface under specific conditions. Salt-affected and sodic soils have a very loose surface structure, making them susceptible to wind erosion and water erosion.

1.2.3 Qualitative Aspects

Urbanization is immediately associated with the pollution of water bodies due to untreated domestic sewage and industrial discharges. Recently, however, it was perceived that part of this pollution generated in urban areas also comes from surface runoff. Surface runoff carries pollutants such as organic matter, poisons, bacteria, and others. Thus, urban drainage discharge into water bodies introduces modifications that produce different negative impacts with short- and long-term consequences on the aquatic ecosystem.

Pollution caused by the surface runoff of water in urban zones is called diffuse, since it comes from pollution-depositing activities, sparsely, over the river basin contribution area. The source of diffuse pollution is very diverse, and abrasion and wear of roads by vehicles, accumulated refuse on streets and sidewalks, organic wastes from birds and domestic animals, building activities, fuel, oil, and grease residues emitted by vehicles, air pollution, and so on contribute to it. The main pollutants carried in this manner are sediments, organic matter, bacteria, metals such as copper, zinc, magnesium, iron, and lead, hydrocarbons from petrol, and toxic substances such as pesticides and air pollutants that are deposited on surfaces. Storm events may raise the toxic metal concentrations in the receiving body to acute levels (Ellis, 1986).

Stormwater runoff becomes polluted when it washes off concentrated and diffused pollution sources spread across the catchments. In addition to soil erosion caused by raindrop impacts and shear stress action, two major sources contribute to stormwater pollution in temperate climate zones:

a. Diffused sources originating primarily from atmospheric fallout and vehicle emission
b. Concentrated sources originating mostly from human activities, such as poor housekeeping practices, industrial wastes, and chemicals spread washoff by urban storm runoff

Both the processes generate soluble and suspended material. Throughout the process of transport, depending on hydraulic conditions, settling and resuspension take place on the surface and in pipes, as well as biological and chemical reactions. These processes are often considered to be more intense in the initial phase of the storm (first flush effect); however, due to the temporal and spatial variability of rainfall and flowing water, first flush effects are more pronounced in pipes than on surfaces.

1.2.4 Greenhouse Effect

The heat generated by the sun is partly absorbed by the earth, but a substantial part of it is radiated back into space. The heat absorbed is radiated by the earth as infrared radiation. Greenhouse gases such as water vapor, carbon dioxide, methane, nitrous oxides, and others absorb this infrared radiation and in turn reradiate it in the form of heat. The amount of greenhouse gases in the atmosphere is increasing, and has been scientifically established. Recent research enables us to state that it is human interference that is changing the global climate. Owing to the emission of greenhouse gases, humans are contributing actively to global warming. The most well-known effect of the greenhouse effect is the increasing average atmosphere heat by 2–5°C, which is expected to occur by the year 2050. As the concentration of greenhouse gases increases, further climate change can be expected. In urban areas, some scientists suggest that the magnitude of the effects of changing climate on water supplies is more than in rural areas due to the added heat in flux in urban areas, but may be much less important than changes in population, technologies, economics, or environmental regulations (Lins and Stakhiv, 1998).

1.2.5 Urban Heat Islands

Urban heat islands (UHI) have been forming over a period of time around the world. The UHI phenomenon occurs when air in the urban city is 1–5°C (2–8°F) hotter than the surrounding rural area. Scientific data have shown that the maximum temperature of July during the last 30–80 years has been steadily increasing at a rate of 1.5°F every 10 years. Each city's UHI varies based on city layout, structure, infrastructure, and the range of temperature variations within the island. The urban area will have a higher temperature than the rural area as a result of the absorption and storage of solar energy by the urban environment and the heat released into the atmosphere from industrial and communal processes (Ytuarte, 2005). The UHI effect can adversely affect a city's public health, air quality, energy demand, and infrastructure costs (ICLEI, 2005). Attention should be paid to the following issues in UHI:

- *Poor air quality*: Hotter air in cities increases both the frequency and the intensity of ground-level ozone (the main ingredient in smog) and can push metropolitan areas out of compliance. Smog is formed when air pollutants such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs) are mixed with sunlight and heat. The rate of this chemical reaction increases when temperature exceeds 5°C.
- *Risks to public health*: The UHI effect prolongs and intensifies heat waves in cities, making residents and workers uncomfortable and putting them at increased risk for heat exhaustion and heat stroke. In addition, high concentrations of ground-level ozone aggravate respiratory problems such as asthma, putting children and the elderly at particular risk.
- *High energy use*: Higher temperatures increase the demand for air conditioning, thus increasing energy use when demand is already high. This in turn results in power shortages and raises energy expenditures at a time when energy costs are at their highest.
- *Global warming*: Global warming is in large part caused by the burning of fossil fuels to produce electricity for heating and cooling buildings. UHI contribute to global warming by increasing the demand for electricity to cool buildings. Depending on the fuel mix used in producing electricity in the region, each kWh of electricity consumed can produce up to 1.0 kg of carbon dioxide (CO_2), the main greenhouse gas contributing to global warming.

Mitigating UHI is a simple way of decreasing the risk to public health during heat waves, while also reducing energy use, the emissions that contribute to global warming, and the conditions that cause smog.

Cities in cold climates may actually benefit from the wintertime warming effect of heat islands. Warmer temperatures can reduce heating energy needs and may help melt ice and snow on roads.

In the summertime, however, the same city may experience the negative effects of heat islands. Fortunately, there are a number of steps that communities can take to lessen the impacts of heat islands. These “heat island reduction strategies” include the following:

- Reducing the high emission from transportation through traffic zoning and well-managed public transportation
- Installing ventilated roofs and utilizing passive sources of energy in buildings
- Planting trees and other vegetation

1.2.6 Cultural Aspects

Sustainable solutions to water-related problems must reflect the cultural (emotional, intellectual, and moral) dimensions of people’s interactions with water. Culture is a powerful aspect of water resources management. Water is known to be a valuable blessing in most arid and semiarid countries and by most religions. There are two cultural characteristics that cause direct impacts on water resources management in urban areas: urban architecture and people’s lifestyle.

The practice of architecture in urban areas is often reflected by the climate characteristics of the area. However, the traditional architecture in many large cities is going to be replaced by modern architecture because of population increase and globalization. This may also cause many changes in urban hydrology. The density of population and buildings, rainwater collection systems, material used in construction, and wastewater collection systems are major factors, among others, that alter the urban hydrologic cycle. The change in design paradigm has made major changes in architecture and moves it toward ecological-based design.

Lifestyles in urban areas affect the hydrologic cycle through changes in domestic water demands. Water use per capita and water used in public centers such as parks and green areas are the main characteristics that define the lifestyle in large cities. Even though economic factors are important in determining these characteristics, the patterns of water use, tradition, and culture have more significant effects on the lifestyle in urban areas.

1.3 URBAN WATER INFRASTRUCTURE MANAGEMENT

There are three main urban water infrastructures: water supply, sewerage, and stormwater drainage. Managing urban water infrastructures is an extremely complex issue. While values and technology have changed, the nature of water infrastructure prevents the system from keeping pace with changes. Generally, in the last two decades, increased emphasis has been placed on environmental outcomes of water infrastructure. Previously, social and economic outcomes dominated decisions on water infrastructure.

This change in focus has led to a perception that centralized, large-scale systems ought to be converted to alternative systems. This perception is not always correct, as the best results usually come from using a mix of systems, and this mix will change with location and time. Centralized, large-scale systems will still dominate water infrastructure in many regions for the next few decades, partly because they are there and because it is difficult to change them due to engineering, environmental, economic, and social reasons. For example, headwater dams and other facilities will be too difficult and costly to alter to any significant degree. The smaller alternative systems will have an increasingly important role, but their role will be limited by the source of supply in most cases. The more congested the site and the more the property interests involved, the harder it will be to replace centralized systems with other alternatives.

The challenges of introducing alternative systems include the following:

- Ensuring public health protection
- Increasing the environmentally sensitive water infrastructures such as natural treatment facilities

- Introducing water pricing that reflects its true values
- Publicly accepting demand management measures

The challenges of improving water infrastructure include the following:

- Allocating sufficient money for infrastructure construction, repair, and replacement—financial planning and appropriation
- Allocating resources on the basis of priorities—highest property to the basic needs in the most affected areas
- Developing a standardized data set of water infrastructure

The increasing population of urban cities around the world will eventually outstrip the available sources of water if the current supply and demand conditions do not seek equilibrium. To ensure that water demand does not exceed supply, efficiency improvements, demand and supply management initiatives, and alternative technologies must all be employed. Improvements are also needed for sewerage systems. This may be easier to implement as these systems are more frequently modified because they require more maintenance. People's perception is that urban water authorities cannot keep up with new technologies as these are advancing faster compared to the actual water supply systems enhancements (Howells, 2002).

1.3.1 Life Cycle Assessment

An ecological way of thinking emphasizes on the urban water system of a city as a complex system characterized by continuous processes of change and development. Aspects such as energy, natural resources, transportation, and waste that are directly or indirectly included in an urban water cycle can be regarded as flows or processes in this system. Acts of maintaining, restoring, stimulating, and closing cycles contribute to sustainable development of an urban area. The measurement of urban water system performance raises specific methodological problems, in particular concerns about physical and operational limits, time horizons, and uncertainties associated with functional units operation. Conceptually, it is necessary to know the full environmental consequences of each decision or action made on water resources performances and usage in order to evaluate different performances or compare options. One of the basic methods for this is life cycle assessment (LCA). This constitutes a basis for estimation of the medium- and long-term outcomes of urban water resources planning and management, particularly those related to economic consequences of these actions. Measures of urban water system performance provide an improved basis for decision makers to evaluate their decisions efficiently.

LCA can be defined as a systematic inventory and analysis of the environmental effect that is caused by a product or process starting from the extraction of raw materials, production, and use up to waste treatment. For each of these steps, there will be an inventory of the use of material and energy, and emissions to the environment. With this inventory, an environmental profile will be set up, which makes it possible to identify weak points in the life cycle of the urban water system, including resources, water supply, treatment, distribution, wastewater collection and treatment, and drainage systems. These weak points are the focal points for improving the performance of the urban water system from an environmental point of view and in the movement toward more sustainability.

LCA establishes the relation between objectives and indicators, where one objective can relate to several indicators and one indicator can be used to assess the fulfillment of several objectives. Furthermore, LCA can enlarge traditional system limits in space, in time, and in the number of concerned aspects. LCA can be directly and structurally related to life cycle cost as well as to other types of social and cultural impact assessment methods. LCA proceeds in four steps: (1) goal and scope definition, (2) inventory of extraction and emissions, (3) impact assessment, and (4) evaluation and interpretation.

The application of LCA to the urban water system is only relevant if situated within the larger conceptual framework of sustainable urban development. Furthermore, the traditional focus on environmental impacts has to be completed by taking into account aspects of the long-term water resource conservation of urban areas.

The extension of LCA to water resources must respect and take into account cultural limitations in order to be effectively utilized. The sustainable development of available urban water resources is certainly at the beginning of a longer development. Its objective cannot be to close the debate by simplified procedures before a larger discussion has taken place. The urban water system has unique physical and social characteristics. It furthermore has a continuity that is both spatial and temporal. This continuity constitutes a basic value; it is a fundamental urban resource and must be protected. Protection is required to ensure sustainability through the continuity of development and the embedded social and physical values for urban residents (Hassler et al., 2004).

1.3.2 Life of Urban Water Infrastructure

The life of urban water infrastructure is related to its original design and construction, its maintenance, and its ability to meet water related demands of increasing population. Most urban water infrastructures have been designed to last for a specific time, determined at the time of construction by predicting its economic life (the time at which replacement is more cost effective than repair) and its structural life (the time at which material failure will occur).

In nearly all cases, the life of urban water infrastructure extends beyond that originally planned. This has been achieved by the careful maintenance, preservation, renovation, and appropriate replacement of structural systems. The pressure on the life of water infrastructure caused by ever-increasing water demand can be slowed down by employing demand management strategies. This involves tools such as water efficiency devices, publicity campaigns, and introducing water use and wastewater charges.

Issues of concern with the life of water infrastructure include the following:

- There is considerable variability in the quality of maintenance and replacement programs for water supply and sewerage systems in water authorities and local councils.
- Maintenance attention may focus disproportionately on areas where failures are readily noticeable and consequently attract considerable negative comment. This can result in the other areas taking substantially longer time to resolve.
- Stormwater systems, notably those designed to cope with fairly rare flood events, are maintained less rigorously. Management of these assets is hampered by inadequate funding and current administrative arrangements that occur on local government boundaries rather than on catchment boundaries. Standards vary considerably between the local councils. Most asset management systems are inadequate. The current administrative arrangements also promote a reactive rather than a proactive approach to maintenance.
- There are problems in maintaining environmental assets such as waterways and facilities designed to protect them, including gross pollutant traps and bank protection works.
- The difference in the expected life and the economic life of infrastructure results in systems being designed in a manner whereby future changes are not excluded, but may not be the most economical at the initial stage of planning.
- Most of the net present value or benefit to cost assessments are irrelevant once the planning horizon exceeds 10 years.
- Local councils are establishing asset management systems for stormwater drains, flood protection works, and stormwater treatment facilities, but few are allocating adequate funds for anticipated replacements and renewals.

1.3.3 Environmental, Economic, and Social Performances

The environmental, economic, and social performances of urban water systems vary considerably in time and space, and their performances have been judged differently over time as community values change. Previously, water infrastructure development was seen to increase economic prosperity and social production of water resources and environmental consequences were not seen as important. Such views have changed with the increase in environmental awareness. In addition, the necessity of greater efficiency in water usages due to social and environmental aspects, has changed the perspective of what economic benefit of water infrastructure development delivers.

Given that values have changed since most water infrastructures were built, the performances of water infrastructures are now viewed by many as unacceptable. While some problems such as the discharge of partly treated sewage on the shoreline have been fixed, others such as the failure of some sewerage systems to meet their original technical specifications have not. Given that perspectives have changed over time, it is not productive to linger over the past and to fix blame. Rather we should see the urban water systems in place and seek to preserve their desirable features and transform them into more appropriate systems where possible.

1.4 URBAN WATER CYCLE MANAGEMENT

The urban water cycle starts with water extracted from streams and aquifers, stored in reservoirs, and then processed to potable quality before delivery through an extensive pipe system to consumers. Some of this water is then used to transport wastes through a network of sewers to treatment plants that discharge effluent into receiving waters such as rivers, lakes, and oceans. Rainfall on the consumer's allotment contributes to the urban catchment's stormwater, which is collected by an extensive drainage system for disposal into receiving waters (Figure 1.3) (UNU-INWEH, 2006).

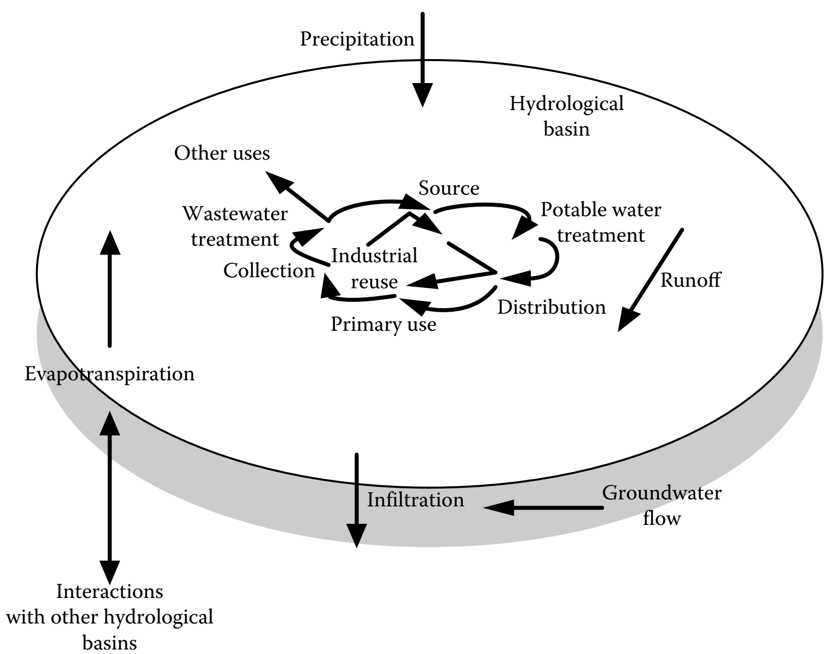

FIGURE 1.3 The urban water cycle consists of (1) source, (2) water treatment and distribution, (3) use and reuse, and (4) wastewater treatment and deposition, as well as the connection of the cycle to surrounding and adjacent hydrological basins. (Adapted from United Nations University, International Network on Water, Environment and Health [UNU-INWEH]. 2006. Four pillars. Available at http://www.inweh.unu.edu/inweh/).

The cycle concept is a useful tool for stakeholder and community education and for consensus building around an action plan. The goal, that of restoring and maintaining the balance between the current demands of the community for water and the need to preserve the aquatic ecosystem for the benefit of future generations, becomes understandable. Table 1.1 lists some of the enabling systems and practices that can be developed within an urban community.

The starting point for wise water stewardship is the understanding that urban water, from source to final disposition, flows through a series of four interrelated stages, listed in Table 1.1, in a continuous cycle. The cycle concept illustrates some important facts about urban water:

- Waste and contamination at any stage negatively affect the sustainability of the cycle as a whole and the health and safety of the community using that water.
- Urban planning, without considering the water cycle, results in water supply shortages, deteriorating aquifer water quality, groundwater infiltration into the distribution system, endemic health problems, and other symptoms of an unsustainable situation.

TABLE 1.1
Examples of Community-Based Enabling Systems for a Sustainable Urban Water Cycle

1. Source
   - A long-term urban and watershed management master plan
   - A source water quality and quantity monitoring system
   - A geographic information and decision support system
   - An inspection and enforcement system to protect source water
   - A community education program
2. Use/reuse
   - A metering and billing system
   - An industrial discharge control program
   - Regulations and bylaws
   - An industrial incentive program
   - A community education program on water conservation
   - A network of supporting laboratories
   - A monitoring and control system
   - An emergency spill response system
3. Treatment/distribution
   - A potable water quantity and quality monitoring and control system
   - A utility operation and maintenance system, including training and accreditation of operators
   - A financial, administrative, and technical management structure
   - A flexible water treatment process
   - An operation, maintenance, leak detection, and repair system
   - Continuous pressurization
4. Treatment/disposition
   - An effluent quality monitoring and control system
   - A utility operation and maintenance system, including training and accreditation of operators
   - An environmentally sustainable biosolids management program
   - A financial, administrative, and technical management structure
   - A flexible treatment system
   - An end-user market

Source: United Nations University, International Network on Water, Environment and Health (UNU-INWEH). 2006. Four pillars. Available at http://www.inweh.unu.edu/inweh/ (visited in March).

- Every citizen, institution, agency, and enterprise in the community has a contribution to make toward the goal of sustainability.

It should also be noted that all components of the urban water cycle meet with water consumed and stormwater and wastewater discharge. Source control through management of the cycle at this level offers the opportunity to provide benefits for the consumer and the environment. The philosophy of source control is to minimize the cost of providing water and collection of stormwater and wastewater. Source control can be implemented through retention of roof rainwater (rainwater tanks), stormwater detention, on-site treatment of gray water (laundry, bathroom, and kitchen) and black water (toilet), use of water-efficient appliances and practices, and on-site infiltration.

1.5 SUMMARY AND CONCLUSION

In this chapter, the urban water cycle has been introduced as part of the hydrological cycle. Components of the urban water cycle are the same as those of the hydrological cycle, but they have special characteristics that must be attended to for successful management and design of urban water. These components and effects of urbanization as well as the physical, chemical, and biological impacts have been discussed. Urbanization disturbs and changes different natural processes. The effects of urban area developments in different aspects such as climatic, hydrologic, cultural, and other special effects such as greenhouse and hot islands have been discussed in this chapter. These effects must be considered for future designs and decision making about urban development, especially regarding water supply, because these effects result in change of water need, availability, and accessibility.

Urban water infrastructures are a major part of the urban water cycle and have three main categories: water supply, sewerage, and stormwater drainage. Managing these widespread systems is complex and there are many challenges and obstacles. The management of the urban water cycle and urban water infrastructures have been briefly introduced in this chapter. In the following chapters, different aspects of water governance, the urban water cycle and hydrology, urban storm drainage concepts, and water quality issues are described. Then planning concepts, the application of system dynamics, and conflict resolution as well as urban infrastructure are presented. Finally, stormwater pollution and disaster management and the impact of climate change on the urban water cycle are discussed.

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2 Governance and Urban Water Planning

2.1 INTRODUCTION

In the past decades, management of the urban water cycle has been largely based on large-scale, centralized systems, which have been successful in improving the quality of life, particularly through the reliable provision of clean water acts, and reducing the risk of infectious diseases. Nevertheless, the change of paradigm from Newtonian to holistic has changed urban water governance globally. New changes in community values, technology, and economic circumstances have resulted in many challenges and changes in the course of action in urban water management. A consensus is emerging that the long-term continuation of traditional urban water management practices is "unsustainable" on a variety of social, economic, and environmental grounds. This viewpoint seeks the development and implementation of alternative approaches to urban water management that are part of a broader framework of "ecologically sustainable development" (McAlister, 2007). The challenges of traditional urban water management are as follows:

- Building new dams to meet the growth in water demand in urban areas is no longer possible, especially in developing countries.
- Increasing the importance of environmental issues and significant regional interest in the reinstatement of "environmental flows" in streams and into estuaries is a must. Traditional water infrastructure systems have significant hidden costs, including the degradation of rivers, wetlands, oceans, and fisheries.
- Increasing public life standards leads to the need for higher standards of treatment for stormwater and sewage discharges.
- Capacity building or extending conventional water infrastructure systems to expanding outer suburbs is increasingly problematic.
- Water infrastructure aging and the increasing cost of maintaining and rebuilding existing water infrastructure systems is problematic.
- Looking at urban stormwater and wastewater as potentially useful resources rather than undesirable waste products and usage of potable-standard water for low-quality purposes such as laundry, toilet, and outdoor use is a highly wasteful use of water resources and treatment infrastructure.
- Efficient drainage systems are also effective in transporting pollutants from impermeable urban surfaces to receiving waters.
- Urbanization affects groundwater processes, contributing to rising groundwater and urban salinity problems.
- Advances in technology give the potential for greater localization of water infrastructure.

As a new vision for urban water management, using stormwater and wastewater for different water usage in urban areas has become a new concept in urban planning and management, which is called Water Sensitive Urban Design (WSUD). Since this new approach in urban planning and management needs communication between different departments in many countries, this chapter discusses the institutional change in water governance. The change in the direct result of new planning concepts and their evolution has also been discussed. A paradigm shift from Newtonian to holistic has been explored and its impact on shifting from supply management to demand management has been addressed. Water and its role in land use planning has been a challenge for planners and decision makers.

The suitability of land use based on availability of water resources has always been a major obstacle, and only those societies and municipalities that have coupled land use planning with water resources sustainable allocation schemes have succeeded in meeting their long-term objectives and have maintained environmental integrity and vitality toward sustainable development. Water resources assessment as a means of measuring, evaluating, monitoring, forecasting, and bringing consensus into water resources planning is also discussed. Technology has always been a scapegoat for planners. In the Newtonian paradigm, decision makers and planners look at technology as a way of salvation of many performance shortcomings. The holistic view of planning requires developing tools and methods that are adaptive and sensitive to the nontechnical aspects of planning such as social, cultural, and environmental factors, and that can be used with the current state of local knowledge and water infrastructure.

2.2 WATER SENSITIVE URBAN DESIGN

WSUD was originally coined in Western Australia (Whelans and Halpern Glick Maunsell, 1994) to describe a new Australian approach to urban planning and design, and was first referred to in various publications in the early 1990s (as summarized in Lloyd, 2001). The emergence of WSUD in Australia has paralleled a wider international movement toward the concept of integrated land and water planning and management, which is discussed in this chapter. The main goal of this shift is the need to provide more economical, and less environmentally damaging, ways of providing urban water, wastewater, and stormwater solutions.

WSUD is part of the contemporary trend toward more "sustainable" solutions that protect the environment. It seeks to ensure that development is carefully designed, constructed, and maintained so as to minimize impacts on the natural water cycle.

Utilizing WSUD can help counteract many of the negative impacts of urban development on the natural water cycle. By utilizing appropriate measures in the design and operation of development, it is possible to maintain and restore the natural water balance, reduce flood risk in urban areas, reduce the erosion of waterways, slopes, and banks, improve water quality in streams and groundwater, make more efficient use of water resources, reduce the cost of providing and maintaining water infrastructure, protect and restore aquatic and riparian ecosystems and habitats, and protect the scenic, landscape, and recreational values of streams.

As mentioned above, traditional water supply, stormwater, and wastewater practices are largely based on centralized collection, conveyance, treatment, and disposal of water flows. But WSUD is more attuned to natural hydrological and ecological processes and promotes a more local and decentralized approach. It gives greater emphasis to on-site collection, treatment, and utilization of water flows as part of an integrated "treatment train" that may be applied in addition to or in lieu of conventional stormwater measures. Elements in the treatment may include the following:

- Rainwater harvesting and the use of roof water for toilet flushing, laundry use, hot water systems, or irrigation
- Surface runoff and gray water reuse for irrigation purposes
- Groundwater recharge by infiltration of stormwater to underground aquifers
- Cleansing runoff and conserving water by specially designed landscaping
- Protection of native vegetation to minimize site disturbance and conserve habitat
- Protection of stream corridors for their environmental, recreational, and cultural values

Designers should respond to the constraints and opportunities of each individual site based on WSUD concepts. Consequently, careful consideration must be given to site characteristics such as soil type, slope, groundwater conditions, rainfall, and the scale and density of development.

Fundamental to the philosophy of WSUD is the integrated adoption of appropriate best planning practices (BPPs) and BMPs and its objectives are more than simply constructing a lake or wetland system. WSUD calls for an enhanced, or more considered, approach to the integration of land and water planning at all levels in the urban development process, for example strategic planning and concept planning to detailed design. A BPP refers to a site assessment, planning, and design component of WSUD and it is defined as the best practical planning approach for achieving defined management objectives in an urban situation. A BPP includes the site assessment of the physical and natural attributes of the site and capability assessment. The next step is integrating water and related environmental management objectives into site planning and design (Dahlenburg, 2003).

BPPs may be implemented at the strategic level or at the design level. At the strategic level, BPPs may be the decision to make provision for arterial infrastructure or to include water-sensitive policy provisions or design guidelines in town planning schemes. At the design level, BPPs refer to specific design approaches.

In the following, some topics for BPPs are described (McAlister, 2007):

- Planning for an integrated stormwater system, incorporating storage locations, drainage and overflow lines, and discharge points
- Land use planning and identification of developable and nondevelopable areas
- Planning for public open space networks, including natural drainage lines, and recreational, cultural, and environmental features
- Planning for the use of water-conserving measures at the design level for road layouts, housing layouts, and streetscapes

This chapter presents an introduction about land use management as an important component of this new approach of urban planning and design, which has a pronounced effect on urban water governance. The structural and nonstructural elements of a design that perform the prevention, collection, treatment, conveyance, storage, and reuse functions of WSUD are referred to as BMP.

2.3 WATER GOVERNANCE

The term "governance" generally refers to the relationship between a society and its government or between an organization and its governing entity. It is often referred to as the "art of steering societies and organizations." Other definitions of governance could be stated, depending on its context.

Ottawa's institute definition of governance* is used here, as follows:

> Governance is the process by which stakeholders articulate their interests, their input is absorbed, decisions are taken and implemented, and decision makers are held accountable.

It is known that water is essential for our survival, and yet more than 1 billion people today cannot meet their basic human needs because of the lack of access to clean water (UNESCO-WWAP, 2003). Water scarcity plagued 27 nations, and an additional 16 nations are considered to be water stressed (WRI, 2003). Water scarcity is one of four major factors to threaten human and ecological health over the next generation. Since public health, development, economy, and nature are suffering, the importance of ensuring access to clean water has become a high priority for governments.

All governments throughout the world are facing the common problem of how to address the growing water crisis. It is necessary to manage water in ways that are efficient, equitable, and environmentally sound. A great deal of capital investment and legal and economic reforms are needed to be able to improve water efficiency, which is often beyond the capacity of members of the public

*The Institute on Governance, based in Ottawa, is a nonprofit organization founded in 1990 to promote effective governance. For more information, see http://www.iog.ca/.

who are directly impacted by the lack of clean water. A detailed understanding of interrelated hydrodynamic, socioeconomic, and ecological systems is also required for the equitable allocation and stewardship of water resources. Often those responsible for such decisions at the local, provincial, and national scales lack the necessary knowledge.

Although critical knowledge about water management has been distributed across different groups, organizations, and the water users themselves, a broad understanding for each initiative is required by regional water managers. Governments need to gather early participation in order to effectively realize such water initiatives. The next step is to actively involve other segments of the society, including those with the most vulnerability to water limitations. Tools to support such efforts are becoming readily available. However, the lack of awareness about these tools has severely limited their application. It is for these reasons that the world has become unified in integrating public participation in the implementation and decision making of urban water management.

The current goal is to further global understanding, techniques, and approaches for the integration of public participation and improvement of water management. Sound water management is the main requirement of policies and activities that serve to provide clean water to meet human needs and sustain the water-related ecological systems that we depend on. Water management generally aims to address interests and integrate usage across hydrological units, such as watersheds. A broader geographical scope may be required in some management aspects, such as transboundary flow across multiple basins and interbasin water transfers via channels or virtual water.

Public participation is described by the International Association for Public Participation as "any process that involves the public in problem solving or decision making and uses public input to make better decisions." It should be noted that this term is slightly different from "stakeholder involvement," which involves those affected by a decision as well as those able to effect its intended outcome. Public participation should also include the interests of those who are usually marginalized.

It was emphasized in the 1992 Rio Declaration on Environment and Development (UNCED, 1992) that environmental issues such as water management "are best handled with the participation of all concerned citizens." Nations are urged to facilitate public participation by increasing transparency, participatory decision making, and accountability. These elements are respectively described as (a) informing people of water management issues that may affect them, (b) involving the public in the decision making, and (c) attempting to provide compensation to those adversely affected by these decisions and activities.

2.3.1 Consequences of Poor Governance

The consequences of poor governance in water supply can be life threatening. Communities are now realizing the extent of problems facing the water sector. These problems have mostly arisen from poor governance, although some of the issues are clearly technical. Low investment, low quality of service, and low revenue are examples of the problems created by poor governance in municipal water supply systems. Some water utilities have become trapped in a cycle of such problems. Low levels of revenue relative to costs result in a low quality of service, which makes it politically difficult, in many cases, to justify raising the water rates. When water companies do not adjust water rates to recover all of their costs, these problems become particularly critical. In addition, it may take a decade to plan, design, and build water and wastewater infrastructure, and even longer to measure the impacts of water abstraction or effluent release on the environment and on water quality; therefore, political cycles, which are often much shorter than the infrastructure life span, may sometimes work against long-term planning and development.

2.3.2 Water Governance at the Regional Level

Water management on an operational level will now be discussed. On behalf of the public, ownership of water is vested in provincial and territorial governments. Governments have created licensing regimes under which water use licenses are issued to individuals and corporations, although legal frameworks vary. The basis on which these permits are issued varies in some parts. For example, rights to use water are based on property ownership in eastern Canada, whereas in western Canada, water rights are allocated on the basis of first come, first served. The allocation of water rights is based on a hierarchy of public purposes established by statute in different territories. As with water rights, laws governing municipal water supply, including the range of business and governance models that are legally permitted, vary from one province or state to the next.

Given these differences, municipal business structure and governance models vary from place to place. The following sections provide general information that outlines good principles of governance as well as good governance models for restructuring water supply systems.

2.4 GOVERNANCE MODELS

A workable description of the principles of governance along with responsibilities and relationships among stakeholders is given through a governance model. Governance models are usually considered when organizations wish to improve governance. A set of structures, functions, and practices are usually determined, which defines who does what, and how. For example, a governance model in the case of municipal water supply would specify the distribution of decision-making authority between the community and operational managers.

There are many governance models, for both the profit and nonprofit sectors, that can be applied to internal governance of organizations as well as the provision of having business plans. Even though information on governance has increased, there is still no single model that can be applied to all circumstances.

2.4.1 Generic Governance Models for Water Supply

Governance and business models are closely interrelated. Sometimes good governance can guide business models and sometimes it may constrain it, and vice versa. The distribution of risks and responsibility for all aspects of water supply management can be determined with governance and business models together.

The three main models of resource management that are at the center for debate over water supply governance and control sharing are the planning model, the market model, and the community model (Table 2.1). These three stakeholder governance models also apply to public services more generally. Many public services have elements of more than one model; however, Table 2.1 simplifies this more complex picture.

Some hybrid models are as follows: municipal services boards or commissions, delegated management contracts, and corporative utilities that adopt elements of both the planning and market models. In all cases, balanced interests of the public and private sectors are needed.

In France, for example, private sector management of municipally owned water supply infrastructure via long-term management contracts is common practice. Municipal governments are, however, forbidden by law to sell their infrastructure, but in many cases they retain control over long-term strategic planning.

In England, where the water supply and wastewater industry were fully privatized in 1989, the market model was chosen. However, like most jurisdictions that employ the market model, England has created extensive regulatory frameworks and regulatory agencies for the water sector to protect consumers and public health. Companies are forbidden from disconnecting domestic consumers (even for nonpayment of bills) and are required to create special, low tariffs for vulnerable consumers.

Strategic financial plans as well as resource development and water supply management plans should be submitted by companies to an economic regulator and an environmental regulator for review. Despite being privatized, the water industry in England has been reregulated rather than deregulated, and many high-level decisions are characterized by planning governance attributes (Bakker, 2003).

TABLE 2.1
Example of Governance Models for Local Public Utility Services

Public Service Elements	Planning Model	Market Model	Community Model
Asset owner	Government	Private corporation	Users
Asset manager	Government	Private corporation	Users
Consumer role	Citizens	Customers	Community members
Organizational structure	Civil service	Corporation	Association/network
Accountability mechanism	Hierarchy	Contract	Community norms
Primary decision makers	Administrators, experts, public officials	Individual households, experts, companies	Leaders and members of community organizations
Primary goals of decision makers	Minimize risk Meet legal/policy requirements	Maximize profit Efficient performance	Serve community interest Effective performance
Key incentives for good performance	Expert/managerial feedback in public policy process Voter/ratepayer opinion	Price signals (share movements or bond ratings) Customer opinion	Community norms and shared goals Community opinion/sanctions
Key sanctions for failure to maintain services	State authority backed by coercion Political process via elections Litigation	Financial loss Takeover Litigation	Livelihood needs Social pressure Litigation (in some cases)
Participation of consumers	Collective, top-down	Individualistic	Collective, bottom-up
Associated business venture	Municipally owned utility	Private corporate utility	Community cooperative

Source: Adapted from McGranahan, G. et al. 2001. *The Citizens at Risk: From Urban Sanitation to Sustainable Cities.* Earthscan, London. With permission.

There are major differences between the planning, market, and community governance models, from the standpoint of consumer representation; accountability and how it is structured in each model; and the goals under each model and how goals will lead to distinct policy and management outcomes. Different models also incorporate stakeholder preferences.

When making a transition and creating a hybrid between two models, governments must carefully consider the implications of changes in the role of consumers, incentives, penalties, and accountability structures. This is particularly important when considering a hybrid model, as problems are likely to arise when the function and component of a governance model are incoherent. For example, a disjuncture between (shorter) political time cycles (2–4 years) and (longer) infrastructure life cycles (10–50 years) can compromise the sustainability of financing.

2.4.2 Building a Governance Model

Organizations will find it useful to define principles of good governance and to articulate responsibilities and relationships between stakeholders. This is particularly important during periods of rapid urban and industrial development and significant social change, when expectations may not be clear.

Although there is a widespread acknowledgment of the importance of governance, definitions and models of good governance vary considerably. In this section, general criteria for good governance are discussed. The detailed structure of a governance model will vary, depending on the type and charter of different organizations.

2.4.2.1 Choosing Principles

Good governance is characterized by a set of principles that guide decision-making processes and management practices. For example, in making recommendations on the role of municipal governments in water supply management, it could be argued that public safety is paramount, and four principles can be considered (O'Connor, 2002):

- Public accountability for decisions relating to the water system
- Effective exercise of owners' oversight responsibilities
- Competence and effectiveness in the management and operation of the system
- Full transparency in decision making

Principles of good governance and prioritization principles vary between organizations and jurisdictions due to a broader framework of political governance. In Great Britain, regulation is relatively nonlegalistic and discretionary compared to North American governance models.

Good governance implicitly makes assumptions about the legitimacy of different stakeholders and decision makers and about accepted processes of decision making. Making robust decisions is a challenge. Good governance is thus to some degree dependent on how a society interprets the democratic practice. There is, accordingly, no one receipt for good governance options; Tables 2.2 and 2.3 list several examples of governance principles for water supply management.

2.4.2.2 Good Governance Processes

Some of the most frequently occurring good governance principles in water management, according to O'Connor (2002) (in no particular order), include

- Protection of public health and safety
- Environmental protection
- Accountability for stewardship and performance
- Transparency
- User participation
- Balancing equity, efficiency, and effectiveness in performance
- Financial sustainability

Some of the organizations surveyed included only some of these principles. Some chose to rank the principles in order of priority, whereas others chose to balance them.

2.4.2.2.1 Coherency and Prioritization

Internal consistency between the different principles creates coherency. Corporatization as an example of hybrid models should ensure coherence between different aspects of the governance model. However, there is conflict among operational management situations, policies, and objectives that flow from governance principles. For this reason, it is important to prioritize governance principles.

For example, the first principle in choosing any management or operational structure for water and wastewater could always be safety (i.e., public health) (O'Connor, 2002).

2.4.2.2.2 Create Objectives and Policies

Governance principles, by themselves, are insufficient for good governance. Concrete objectives or goals must be specified in order to enable the practice of good governance. Chapter 18 of Agenda 21

TABLE 2.2
Selected Examples of Governance Principles for Water Management

Source	Principles
O'Brien et al. (2002)	• Accountability • Responsiveness • Effectiveness • Efficiency • Transparency • Participation • Respect for the rule of law
Dublin Principles (1992) International Conference on Water and the Environment in Dublin set out a statement on Water and Sustainable Development, which is known as the "Dublin Principles"	• Freshwater is a finite and vulnerable resource, essential to sustain life, development, and the environment • Water development and management should be based on a participatory approach, involving users, planners, and policy makers at all levels • Women play a central part in the provision, management, and safeguarding of water • Water has an economic value in all its competing uses, and should be recognized as an economic good
Agenda 21 (2002)	• Full public participation • Multisectoral approach to water management • Sustainable water use
Federation of Canadian Municipalities (2002)	• Quality of life • Shared responsibility (between governments) • Municipal government leadership • Adaptability • User pay • Maintenance and rehabilitation • Continuous improvement • Partnerships

on water resources is an example of a detailed set of objectives flowing from a set of governance principles.* For example, a good governance principle of public participation might lead to an objective of community involvement in standard setting. In turn, this might lead to specific policies, such as multistakeholder participation in a drinking water advisory role.

Similarly, a good governance principle of accountability might lead to the following objectives: clear lines of accountability, good communication, and trust. In turn, this might lead to specific policies, for example: a consumers' right to know (access to information) policy; holding service providers to a statutory standard of care. O'Connor (2002) recommended in a report that "since the safety of drinking water is essential for public health, those who discharge the oversight responsibilities of the municipal government should be held to a statutory standard of care."

*Chapter 18 of Agenda 21 deals with the Protection of the quality and supply of freshwater resources: application of integrated approaches to the development, management, and use of water resources. Agenda 21 is a plan of action adopted by more than 178 governments at the United Nations Conference on Environment and Development (UNCED) held in Rio in 1992. Agenda 21 was reaffirmed at the World Summit on Sustainable Development held in Johannesburg in 2002.

2.4.2.2.3 Responsiveness

Responsiveness implies a capacity for and commitment to self-reflection, in which stakeholders learn and feed lessons learned back into an evolving vision. This might imply, for example, the need to carry out periodic reviews of management and operating structures for water supply systems. This is recommended by O'Connor (2002): "Municipal governments should review the management and operating structure for their water system to ensure that it is capable of providing safe drinking water on a reliable basis." Table 2.3 shows a summary of the characteristics of a good model.

2.4.2.2.4 Sound Information

Governance bodies in all sectors must have access to sound information. Decision makers need it to provide accountable governance, while those who are governed need to hold decision makers accountable. Decision makers must use information to analyze the need for change and then act when necessary. Of particular importance when restructuring governance, is the considerations of reporting requirements, and timely flows of information to and from decision makers. In assessing the restructuring options open to municipal governments, the cost of regulation and oversight should be factored into the assessment. O'Connor (2002) notes that "the cost to a municipal government of due diligence before entering a contract, and of compliance monitoring over the term of a contract, is an important part of its oversight responsibilities and, as such, the full cost of water services." Information is required by the municipal government not only on the restructuring options, but also on the broader cost and quality implications for municipal governments.

2.4.2.2.5 Transparent Decision-Making Process

A good governance process is one that enables stakeholders collectively to design and implement policies and management strategies that meet their goals effectively and acceptably. Given the importance of water supply for public health, the Walkerton report emphasis should be placed on the need for openness in water supply governance. The following three recommendations of particular relevance can be made:

1. Municipal contracts with external operating agencies should be made public.
2. All service contracts between the corporative agencies should be publicly available.

TABLE 2.3
Applying Good Governance Principles to Water Management

Principle	Example of Application
Accountability	Demonstrating adherence to capital plans for water and sewage infrastructure through publicly available audited financial statements
Responsiveness	Developing a long-term plan to ensure water and sewage system capacity to accommodate future growth
Effectiveness and efficiency	Scheduling water main repairs at the same time as road repairs
Transparency	Making results of raw and treated water quality testing publicly available
Participation	Soliciting public comments about restructuring options
Financial sustainability	Full life cycle investment needs are the basis for program spending
Respect for the rule of law	Ensuring that minimum chlorine residuals are maintained in the water distribution system

Source: Adapted from O'Brien, J. J. et al. 2002. Governance and methods of service delivery for water and sewage systems. Commissioned Paper 17, The Walkerton Inquiry. Queen's Printer for Ontario, Toronto.

3. The provincial government should require all owners of municipal water systems to have an accredited operating agency, whether internal or external to the municipal government.

In O'Connor's (2002) view, this accredited operating agency should operate in accordance with provincially recognized management standards, should be periodically evaluated or independently audited, and the results of such review or audit should be made public.

2.4.2.2.6 Participation of Stakeholders

The participation of stakeholders in decision-making processes—including users—is a critical factor in good governance. This does not imply that participation is always necessary or that more participation is better; some authors even question whether participation might be the "new tyranny." Participation can be structured along a "ladder" of options, from public information, through consultation, to full-fledged representation. Good governance processes will incorporate different levels of participation when and as appropriate.

Participation is important for three reasons. It can help make decisions more effective; it may increase the political acceptability of decisions; and it fosters accountability. After a decade of experimentation, the British and Welsh water industry have evolved a multistakeholder model of participation in water policy making that seeks broad representation and formalizes public participation through customer committees known as Water Voice (formerly Customer Service Committees). Figure 2.1 shows the role of stakeholders in British policy-making process. A summary of the characteristics of a good governance model is as follows:

- The model articulates a set of governance principles or expresses a vision.
- The governance principles are coherent and are ranked in order of priority.

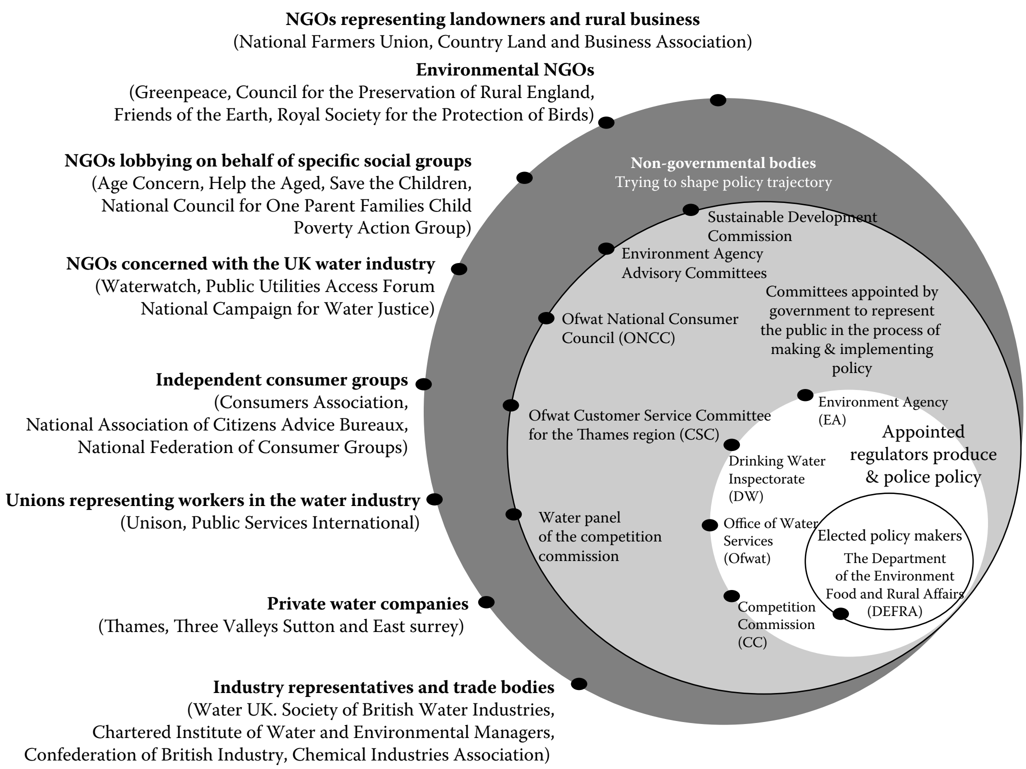

FIGURE 2.1 Stakeholders in the British water policy-making process. (Adapted from Bakker, K. 2004. *Good Governance in Restructuring Water Supply: A Handbook*. Federation of Canadian Municipalities, Canada.)

- The model builds on the governance principles to create objectives and policies.
- The model is responsive; learning and reviewing options will inform restructuring.
- The model enables the production and dissemination of high-quality information.
- The model includes an open, transparent decision-making process.
- The model facilitates the participation of stakeholders.

In many cases, the result of this process will be a detailed description of the governance of the water supply utility, including routine decision making and higher-level policy process. Governance attributes will vary, depending on the business model chosen.

2.5 ABSENCE OF PUBLIC PARTICIPATION

Quite often people are denied the right to participate in water management decisions and policies that concern them. For instance, large dams for water supply and irrigation have forcibly displaced tens of thousands, even millions of intended beneficiaries, across India, Mauritania, Brazil, and many other places around the world. Numerous news reports also highlight how inadequate governance continues to allow industries to degrade the environment and damage their neighbors through water supplies pollution in China, Indonesia, and elsewhere. Meanwhile, some governments have even intentionally used water policy to harm the disenfranchised, such as Iraq's years of draining the wetlands upon which its Marsh Arabs depended for millennia.

These examples illustrate how inadequate public participation in governments' water management can result in tremendous social upheaval and the violation of the basic human rights of their citizens. How can public participation in water management provide for our basic human need for water and ensure no thirst? Three approaches explored by participants in the United Nations symposium are summarized in the following sections (UNCED, 1992).

2.5.1 CONVENTIONAL APPROACHES

Approaches that utilize processes to inform, consult, involve, collaborate with, and empower the public are considered conventional approaches to public participation. Public participation will achieve by informing the public about the actions that will be decided in a participatory manner. Sometimes, even with the best intentions, governments face challenges of including participatory management of water resources under conditions of limited institutional capacity and substantial spatiotemporal variability in water quantity. The timing and manner in which participatory mechanisms are incorporated into the Environmental Impact Assessment (EIA) process can have a tremendous impact on the ultimate utility of the resulting water management regime.

To date, there has been little transfer of public participation practices or lessons between water management initiatives. As a result, there remain many potentially useful, though underutilized, tools [such as Transboundary Environmental Impact Assessment (TEIA), consensus building, and joint fact findings]. Furthermore, it is often unclear how to measure and determine the success of conventional public participation initiatives (UNCED, 1992).

2.5.2 INFORMATION TECHNOLOGY APPROACHES

The main question is how information technology (IT) can be utilized to promote public participation in the management of water. The Internet and its various applications as well as nonnetworked decision support and geographical information systems are kinds of tools and technologies. IT should be followed as an end instead of a means to improve participation and effective water management. Other pertinent externalities and misconceptions are also presented. Public involvement initiatives should also be based on a set of culturally and politically relevant principles. With respect to public participation in international waters management, in particular, the International Waters Learning

Exchange and Resource Network (IW: LEARN) has established a collaborative platform for the international waters community, which is accessible on-line. GEF IW (Global Environmental Facility International Waters): LEARN and its partners invite international water managers, interested members of the public and private sectors, and civil society at large to participate in the workshop series design, development, and evaluation.

There are developments in decision support systems (DSS) for use in water resources management recently in the literature. As DSS expands from desktop to the Internet, along with concurrent increases in IT processing and storage, there is great potential for applying DSS in real time to both long-term structural decisions (Planning DSS) and short-term operational decisions (Operation DSS). One of several challenges considered is how to meld intuitive user interfaces effectively with powerful databases and valid computational models. These IT narratives collectively indicate an emerging "toolbox" for increasing public awareness and participation in urban water management. A common challenge will be to adapt and apply appropriate IT or ICT (information and communication technologies) tools to the specific needs of urban water managers in real time (UNCED, 1992).

2.5.3 International Approaches

International organizations play a vital role in enhancing public participation around transboundary water resources management. The goal is to extend public participation across political boundaries and to empower the broader public to participate in decision making and monitoring relating to projects and actions that concern two or more countries. International financing of water management projects may catalyze the inclusion of participatory processes, as is the case with policies of the Global Environment Facility (GEF). According to GEF's policy, public involvement consists of three related, and often overlapping, processes: information dissemination, consultation, and stakeholder participation. Permanent international basin organizations also play a long-term role in promoting public participation to improve watershed management. Conflicting interests between civil society and modern development and between local and national priorities and contexts have escalated through both participatory and extraparticipatory processes.

Ending global thirst depends on providing the public with a voice in water-related decisions that directly affect them. Where the public are not included in decisions that affect their welfare, they may resist change, protest, or otherwise obstruct the implementation of such decisions (UNCED, 1992). Those living along international watercourses, near international borders, and far removed from central governments are particularly difficult to include in such decision making. Yet, for the stakeholders, transboundary participation is also critical. However, improving public participation across international boundaries also requires addressing difficult transboundary challenges such as sovereign water rights, migratory populations, linguistic and cultural differences, and distinct political, economic, and legal frameworks among riparian nations. Nonetheless, public involvement, associated with ongoing reform in governance, holds the promise of improving the management of watercourses and reducing the potential for national and international conflict over water issues.

To realize this potential will require a more comprehensive understanding and systematic application of public participation processes across all boundaries. This should begin, first and foremost, with a review of existing approaches and available tools. Other tools should be tailor-made for specific application based on technical and nontechnical suitability of the tools in a regional urban or rural setting or across an international network of cities and communications with water dependencies (UNCED, 1992).

2.6 REMAINING ISSUES

It is clear that much progress has been achieved in water management, as new approaches and methodologies have been developed to promote participation across local and regional and transboundary political boundaries and watersheds. Participatory processes are recognized as important in water management from project identification through design and implementation to monitoring and evaluation.

Capacity building for participatory water management is one of the most needed parts of development projects. In this respect, it is being recognized that there is a need for improved understanding and identification of the institutional and organizational arrangements required for effective decision making and operational process. There is a need to define more clearly and adapt key terms to promote public participation in water governance. The governing factor could also include the following five attributes: (1) level of public participation, (2) process of public participation, including who initiated the process and who participated at each stage, (3) the communication platform for public participation, (4) role of facilitation and consultation, and (5) role of science and technology (UNCED, 1992).

Each of the above five spheres has its own speed of functioning, and these different levels are connected vertically and not horizontally. This way of thinking is needed when dealing with resources management so that adaptive management can be used for implementing ideas in the real world. These various characterizations should be scrutinized in adapting a definition of public participation that is pertinent to water management, in particular. The result should clearly describe how public participation fits into adaptive water management regimes at local city-wide, national, and international natural and political boundaries (watershed) scales.

Although water management has historically used the river or lake basin as its unit of management, the growth in population and urbanization has placed increasing pressure on water resources across multiple basins in a region. It is equally important to learn from local people to respect different attitudes and experiences and to seek out win–win situations based on such learning. Even in the twenty-first century, there continues to be a strong need for respected experts and decision makers to solicit and accept the different viewpoints of the affected public.

Monitoring and evaluation indicators are frequently used to measure the progress and impact of water resources management activities. Such indicators of success are also needed to track the success of public participation as it contributes both to water management and to broader societal goals, such as good governance. Specific public participation indicators should measure both progress (e.g., the development of and timely adherence to a stakeholder involvement plan, broad acceptance of a collective "watershed vision," the creation of basin-wide citizen advisory committees, etc.) and its impact (e.g., the public are generally satisfied with the result, or indicate being better off thereafter). As mentioned earlier, transparent, participatory, and accountable governances are essential foundations for sustainable development. When linked to a clear vision or description of success, ongoing measures of such indicators will be key to determining the overall success of the public participation process.

Finally, public participation may provide the means for making the transition from dependence to empowerment. Local people and government officials may cynically consider "public participation" as a key to getting more funds from donor agencies. Experience also shows that foreign aid from donors can lead to a culture of dependence on the part of recipient countries. Fortunately, developing formal processes for public awareness and participation can be an effective means to increase local ownership, thereby laying the basis for locally sustained stewardship of water resources. Moreover, active oversight by donors and civil society may also ensure that water resources management projects and basin organizations are not spoiled or co-opted by corruption.

2.7 URBAN PLANNING

One of the greatest opportunities for promoting sustainable outcomes for the urban water cycle occurs in the "plan making" or "strategic" phases of the planning process. The planning applies to both the redevelopment of existing urban areas and to the development of "greenfield" land on the urban margin (McAlister, 2007). Because of the variety of local conditions within different council areas, and the variety of relevant planning documents, the following matters are considered:

- Regional and local strategies
- Local environmental plans
- Urban investigation and release process
- Master plans

2.7.1 Regional and Local Strategies

In order to outline a policy approach to planning at the regional or local scale, regional and local strategies should be planned. These documents seek to influence development generally by establishing broad principles and they do not directly "control" individual development proposals. Furthermore, they set targets or create coordination mechanisms. These plans are flexible documents that help to form the shape of statutory plans such as local environmental plans, but they are not legally binding.

Regional strategies prepared by the agencies involved in infrastructure, planning and natural resources, and water boards and authorities address a comprehensive range of planning issues affecting a region. Other strategies are prepared in relation to specific issues at the regional or local level, often drawing upon similar strategies prepared at the state or national levels such as biodiversity strategies, catchment blueprints, water cycle strategies, stormwater management plans, housing and infrastructure strategies, economic development strategies, and tourism strategies. Such documents provide a broad direction for urban structure within a policy context.

2.7.2 Preparing a Land and Water Strategy

In order to provide an overall policy direction to manage land and water resources considering their interactions, a land and water strategy should be provided by councils. This kind of strategy should be prepared in conjunction with an extensive community engagement process to elicit community views, involvement, and partnerships in urban water policy making.

The strategy should contain the visions, objectives, and targets and provide important directional statements that guide the content and implementation of more detailed policies and programs. They should be reflected in important corporate and statutory planning documents, such as the watershed council's management plan and the local environmental plan. Purpose, issues, visions, objectives, targets, and action plans are important, would need to be addressed by the strategy using the following questions (Dahlenburg, 2003):

- Why is the strategy necessary?
- Which matters are of public importance, concern, or contention, and why?
- What are the desired future outcomes that the community needs and wants for land and water resources?
- Which values are to be pursued and which attainments need to be achieved in the future?
- Are there any detailed or quantitative statements of outcomes against which the success of the strategy should be measured and evaluated?
- Which programs and actions are needed to implement the strategy?

Water utilization and efficiency, flood risk management, stream protection and restoration, water balance and stream flow, salinity and other groundwater-related issues, water quality, water-dependent ecosystems, erosion and sedimentation, and contaminated land management are examples of objectives and targets that should be considered in the strategic plans of urban areas.

The visions, objectives, and targets are developed through appropriate community engagement and scoping processes. Suitable visions, objectives, and principles can generally be drawn from existing policy documents, such as catchment blueprints, stormwater management plans, flood risk management plans, and so on.

The principles of ecologically sustainable development and other compatible principles should provide a cornerstone for watershed council decisions affecting the water cycle. As part of a watershed council's charter to properly manage, develop, protect, restore, enhance, and conserve the environment, such principles should be considered when

- Planning new or existing urban areas
- Undertaking regulatory functions, such as approving development applications
- Undertaking service functions, such as roads and stormwater drainage
- Setting rates and charges
- Managing community land, such as parks and reserves

A local water cycle strategy should be implemented through more detailed strategies and plans relating to specific issues such as stormwater management plans, flood risk management plans, coast and estuary management plans, environmental improvement programs, and stream and riparian restoration programs.

2.7.3 Master Plans

In order to implement large-scale development projects such as greenfield residential estates, high-density residential precincts, and commercial and industrial areas, a guideline for each area is necessary, which is called a "master plan." Such projects occur incrementally over long periods of time, and thus need to be strategically planned and coordinated.

Master plans serve to (Dahlenburg, 2003)

- Determine the outline of the desired location, layout, form, and staging of development.
- Provide a long-term planning framework, particularly where staged development and approvals are involved.
- Determine the way in which development should respond to relevant planning policies and strategies and the way in which the site's constraints, opportunities, and context should be expressed.
- Help the public understand the project's future outcomes.
- Assist councils when considering development applications.

Master plans provide a critical, one-off opportunity to ensure that the structure and configuration of new development support sustainable water cycle outcomes. For example, they can be used to ensure that land allocations for water management purposes are both sufficient in area and suitably located. It is generally not possible to allocate land for such purposes at the later subdivision and building phases since the overall configuration for the area has already been established. Achievement of desired water management outcomes may be severely constrained if the necessary land requirements are not met early in the planning process.

Water cycle management is one of many issues addressed by master plans. In the master plan, the proposed management responses will need to be compatible with other important issues, including the layout and configuration of infrastructures, streetscape, and local character.

In order to provide a sound basis for water-sensitive design at the subdivision and street and lot levels, master plans should cover the following statements, as mentioned by Dahlenburg (2003):

1. Determine the strategies at regional and local scales and their implications for water management.
2. Determine a vision for how the water cycle will be managed on the site, and how this will determine, in broad terms, the structure, layout, and design of development.

3. Incorporate and respond to a site analysis of natural and built conditions.
4. Water-sensitive design principles for landscape structure and open space system, street layout and design, major stormwater systems and building design and sitting.
5. Allocate sufficient land for water infrastructure in suitable locations by a conceptual urban structure model.
6. Resolve conflicts and tensions that may exist between water management and other planning imperatives that influence layout design.
7. Incorporate with an integrated urban water plan.

2.8 URBAN WATER PLANNING

2.8.1 Paradigm Shift

In the last three decades, the "ecological" paradigm comes to the forefront as a new alternative to solve man-made problems. This new way of thinking began from new discoveries and theories in science, such as Einstein's theory of relativity, Heisenberg's uncertainty principle, and chaos theory. Contrary to Newton's mechanistic universe, these new theories have taken away the foundation of the opposing paradigm, the Cartesian model. Because our way of thinking has been based so much on the Cartesian paradigm, this paradigm shift demands to change the way in which we perceive and understand our world.

Water resources management is not an exception in this dramatic shift of the paradigm. Throughout the history of water resources management, many methodologies have reflected some aspects of ecological thinking and have been shaping the water version of the new paradigm.

2.8.1.1 Shift from the Newtonian Paradigm to the Holistic Paradigm

In the ongoing theoretical debate on environmental planning, it seems to be far-reaching consensus concerning one thing: There has been a great shift in planning thoughts during the last 50 years. Some researchers refer to this as a paradigm shift from rational (Newtonian) to communicative (holistic) planning. This shift is often combined with a reference to the change of modernity, with a statement that the communicative planning paradigm is adapted to new postmodern times. In water resources planning, this shift has occurred, which is the basis for integrated approaches as well as environmental consciousness and the notion of sustainable development in water-related activities. It has also triggered the shift from supply management to demand management. In the following sections, Newtonian and holistic paradigms are discussed in a broad fashion.

2.8.1.1.1 Newtonian Paradigm

The worldview that laid the basis for modern culture was created in the early stages of the Renaissance. Before this change, the primary worldview was holistic, organic, and ecological. People lived their lives in small communities and had a holistic, spiritual relationship with nature. Even the nature of science at that time was quite different from that of modern science. Rather than using means of prediction and control, the main goal was to understand the existential meaning of things.

The medieval approach was transformed radically in the sixteenth and seventeenth centuries. The idea of the holistic, organic, and spiritual universe was replaced by a world-machine metaphor. This metaphor became a major part of the modern way of thinking. This transformation came with the Scientific Revolution involving Galileo and Newton, and a new method of reasoning by Bacon and Descartes.

With his scientific observations of celestial phenomena, Galileo was the first to combine scientific discoveries with mathematical explanations to formulate the laws of nature. These two aspects of Galileo's work, his experimental approach and his mathematical description of nature, became the dominant character of science in that time and have remained the same to date. However, because

Galileo's strategy was so successful in a quantifiable domain, nonquantifiable properties, such as subjective and mental projection of human beings, were excluded from the domain of science. This trend has become a major hurdle to integrating all human properties as a whole.

In England, Francis Bacon introduced the inductive method that used experiments and drew general conclusions from them to make usable knowledge. The new reasoning method heavily changed the character and objective of science. From ancient times, the main goal of science had been to gain wisdom and to understand nature in harmony with science. Since Bacon, the goal of science has been to gain knowledge to control and exploit nature. Nature, in his view, had to be "hounded in her wanderings," "bound into service," and made a "slave." This kind of attitude represents the prevalence of patriarchal attitudes in science fields.

The shift of worldviews was completed by Descartes and Newton. Descartes doubted everything he could until he reached an indubitable conclusion, the being of himself as a thinker—*Cogito, ergo sum*. From this he deduced that nothing but thought was the essence of human nature. This deduction led him to the conclusion that mind and matter are separate and totally different entities. This Cartesian division has made us think of ourselves as isolated entities inside material bodies.

Descartes saw the material world as a machine that had no life or spirit. The natural world functioned according to mechanical laws and everything could be explained in terms of the mechanical movements of their parts. This mechanical image of nature became the dominant model of science since Descartes. Even Descartes applied his mechanical worldview to living organisms. Plants, animals, and even human beings belonged to a machine category. The human body became a container activated by a soul connected through the pineal gland in the brain.

The man who undertook Descartes' task was Isaac Newton. With his new mathematical method, differential calculus, Newton came out with a mathematical formulation that fully completed the mechanical worldview. This deterministic character gave birth to a belief that if you know the state of a system, such as time and location, with respect to all details you could predict the future of the system with absolute certainty.

The Newtonian universe produced the image of absolute space and time—both independent of each other, and indivisible units, atoms. Absolute space was the space of Euclidean geometry—an unchangeable three-dimensional container. Absolute time flows evenly with no respect to external phenomena. The drastic change from organism to machine in the image of nature greatly affected the way in which people viewed the natural world.

The Newtonian paradigm has governed the way in which water resources planners and managers viewed water management for many years. However, it suffers from a number of serious shortcomings. Its applicability as a framework for recent theories of water resources management is increasingly questionable. As our understanding of the behaviors of complex adaptive systems increases, the complex framework becomes more relevant to studies of water resources management than the Newtonian paradigm. The principal reason may be found in the concepts of linearity and nonlinearity: Water resources management is an inherently nonlinear phenomenon. The Newtonian paradigm rests firmly on linear principles, whereas the holistic paradigm that follows complexity theory embraces nonlinearity.

Linear systems played an important role in the development of science and engineering, as their behaviors are easily modeled, analyzed, and simulated. A linear system has two defining mathematical characteristics. First, it displays proportionality. If some input X to the system gives an output of Y, then multiplying the input by a constant factor A yields an output of AY. The second characteristic of linear systems is superposition. That is, if inputs $X1$ and $X2$ give outputs $Y1$ and $Y2$, respectively, then an input equal to $X1 + X2$ gives an output of $Y1 + Y2$. Systems that do not display these characteristics are called nonlinear systems. Importantly, linear systems of equations can be solved analytically or numerically. Given a set of linear equations and initial conditions, we can calculate the future values of the variables. Consequently, if we can describe a system by a linear mathematical model, we can determine its future states exactly from its given initial state. A large body of mathematics has grown up around linear systems and techniques for their solution.

Nevertheless, the vast majority of systems and phenomena in the real world are nonlinear. As the name implies, nonlinear systems do not display linear characteristics of proportionality and superposition. Analytical solutions to nonlinear equations are generally the exception rather than the rule. Thus, the future states of nonlinear systems can often only be approximated. One method of approximating the behavior of nonlinear systems involves linearizing them, and then employing linear systems analysis on the approximated system. Unfortunately, such techniques suppress or even eliminate many of the important dynamical characteristics of nonlinear systems; for example, chaos cannot exist without nonlinearities. However, the advent of modern digital computers has brought about a revolution in the study of nonlinear systems. Computers have made it possible to simulate their rich dynamical behaviors such as chaos that might otherwise not exist in linearized approximations.

Linearity is the cornerstone of the Newtonian paradigm. This has several important ramifications for water resources management. First, the condition of water resources under the Newtonian paradigm is deterministically predictable, as effects are in principle calculable from their underlying causes. Given enough information about the current state of water resources and demand with "laws" of planning, a commander should be able to precisely determine the outcome of the management. Determining the outcome of water management becomes a simple exercise if a sufficient amount of precise information is available, much as the future states of a linear system of equations can be exactly computed. With intelligence and situational awareness approaching perfection, the Newtonian paradigm reduces fog and friction to a bare minimum just as chaos is banished from linear systems.

Reductionism is a second important consequence of the Newtonian paradigm. This is a methodology for solving problems. The analyst breaks the problem into its constituent pieces, solves each piece separately, and then sums the results from the pieces to obtain the overall solution to the problem. This is a natural consequence of superposition. The history of water resources management covers a range of examples of reductionism. For example, managers generally break the water systems into a series of separate systems with different goals, analyze each system independently of all others to determine aim points, and then sum the results to generate the overall plan. Historical analyses of water resources are frequently reductionism—what is the isolated, independent cause (or causes) that led to the outcome of the conflict? As linearity allows and even encourages this mindset, reductionism is a principal characteristic of Newtonian management.

A third consequence of the Newtonian paradigm is the view of systems as closed entities, isolated from their environments. Outside events do not influence such a system; the only dynamics are those arising from its internal workings. The analyst thus has an inward focus, with a concentration on efficiency. The emphasis on efficiency is especially noteworthy for water resources operations. How can the planner obtain the desired objectives with the least cost? What targets must the planner select to most efficiently and economically accomplish the objectives? Isolated, closed systems are perhaps easier to analyze, as outside forces and influences are of no consequence. However, isolated systems form only a small fraction of the physical universe.

The Newtonian paradigm creates a simplified, idealized view of water resources management. It is an appealing, comfortable framework as it offers simple means for analysis, methodical rules for planning and executing operations, and the illusion of predicting the future given enough information about the present. However, water resources management is intrinsically more complicated than this simplistic framework allows.

2.8.1.1.2 Holistic–Ecological Paradigm

Ecological thinking is in heavy debt to the feats of modern physics. The advent of electromagnetics, Einstein's theory of relativity, quantum physics, and the newly born chaos theory are major contributors to this new paradigm. The discovery of electric and magnetic phenomena by Michael Faraday and James Clerk Maxwell was the first step to undermining the mechanistic world model. The real collapse of the Newtonian worldview came with relativity theory and quantum theory.

In atomic physics, several discoveries unaccountable in terms of classical physics appeared, such as the discovery of the subatomic world and the duality of the subatomic entity. One of the most fascinating discoveries was the fact that "depending on how we look at subatomic units, they appear sometimes as particles, sometimes as waves; and this dual nature is also exhibited by light which can take the form of electromagnetic waves or of particles."

Quantum theory showed the holistic nature of the universe. In a different context, the discovery of evolution in biology challenged the illusion of a deterministic Cartesian world. Instead of thinking that every single element is created in the beginning of this universe and run by a system of laws, evolutionary concepts opened the possibility of development from simple forms to complex structures.

However, the evolutionary idea contrasted with the laws of thermodynamics in physics, which means that every phenomenon moves from the orderly state to the disorderly. Thermodynamics was a double-edged sword, since it at once denied the reversible time flow of the Newtonian universe and contrasted with evolution theory. This problem remained until the advent of "nonlinear revolution" with Chaos and Self-organization Theory.

Self-organization Theory demonstrated that "far from equilibrium," unlike "near equilibrium," a system of matter tends to self-organize itself through positive feedback. Once fed by this constructive loop, this system starts to evolve to a higher level of organization. In other words, the "far from equilibrium" state has a high sensitivity to even a tiny change in the system. This means that on the earth, a typical example of the "far from equilibrium" state, every entity is interdependent and interconnected to others and even a tiny transformation has the possibility of changing the whole world. Because this leap to another level of system is unpredictable, the deterministic predictions of the Cartesian worldview lost its validity.

One of the interesting discoveries in the "far from equilibrium" system is a unique structure of the system, fractal. "Fractals have an internal 'microstructure' that exhibits the phenomenon of scaled self-similar layering. Finer and finer magnification of a fractal reveals smaller and smaller versions of the same structure at all levels. Therefore, fractals are infinitely complex. No matter how small a piece you take, it is an equally complex microcosm of the whole. Fractal self-similarity and scaling are particularly important because they repudiate two Newtonian assumptions." One is that reducing and segmenting methods make problems simple, and the other is that we can measure everything objectively with an absolute scale.

The "nonlinear revolution" not only stopped the illusive universality of Cartesian worldview but solved the problematic coexistence of Newtonian and new physics in different domains. Because it shows the dynamic and diverse nature of the universe from microcosms to macrocosms, even the Newtonian method can survive in a specific range, the middle range of the ecological world.

All these developments in science revived the original image of the world, which is holistic, organic, ecological, and spiritual. The Cartesian–Newtonian paradigms caused a dramatic scientific revolution that gave us at once enormous prosperity and problems. The new ecological thinking will change again the way in which we perceive the world and will give us a new alternative to cure the fallacy of the old paradigm.

The holistic paradigm offers a broader, far more useful framework for water resources management. This paradigm is based on open, nonlinear systems in far-from-equilibrium conditions. A complex adaptive system has several defining characteristics. First, it is composed of a large number of interacting parts or "agents." The interactions between the agents are nonlinear. The interactions and behaviors of the agents influence the environment in which the system exists. Changes in the environment in turn influence the agents and their interactions. The agents and environment thus continuously affect and are affected by each other. Second, the agents characteristically organize into hierarchies. Agents at one level of the hierarchy cluster to form a "superagent" at the next higher level. Third, there are intercommunicating layers within the hierarchy. Agents exchange information in given levels of the hierarchy, and different levels pass information between themselves as well. Finally, the complex system has a number of disparate time and space scales. For example, water resources operations at the low level are highly localized and may occur very rapidly compared to events at the high level. Complex adaptive systems in widely varying disciplines appear to share these four characteristics (Figure 2.2).

Complex adaptive systems exhibit a number of common behaviors. The first is emergence: The interactions of agents may lead to emerging global properties that are strikingly different from the behaviors of individual agents. These properties cannot be predicted from a prior knowledge of the agents. The global properties in turn affect the environment that each agent "sees," influencing the agents' behaviors. A synergistic feedback loop has thus created interactions between agents to determine emerging global properties, which in turn influence the agents. A key ramification of emergence is that reductionism does not apply to complex systems. Since emergent behaviors do not arise from simple superpositions of inputs and outputs, reductionism cannot be used to analyze the behaviors of complex systems. The emergence of coherent, global behavior in a large collection of agents is one of the hallmarks of a complex system.

A second fundamental behavior of complex systems is adaptive self-organization. This appears to be an innate property of complex systems. Self-organization arises as the system reacts and adapts to its externally imposed environment. Such order occurs in a wide variety of systems, including, for example, convective fluids, chemical reactions, certain animal species, and societies. In particular, economic systems are subject to self-organization.

A third important behavior of complex systems is evolution at the edge of chaos. Dynamical systems occupy a "universe" composed of three regions. The first is an ordered, stable region. Perturbations to the system tend to die out rapidly, creating only local damage or changes to the system. Information does not flow readily between the agents. In the second region, chaotic behavior is the rule. Disturbances propagate rapidly throughout the system, often leading to destructive effects. The final region is the boundary between the stable and chaotic zones. Known as the complex region or the "edge of chaos," it is a phase transition zone between the stable and chaotic regions. Systems poised in this boundary zone are optimized to evolve, adapt, and process information about their environments. As complex systems evolve, they appear to move toward this boundary between stability and chaos, and become increasingly more complex. Evolution toward the edge of chaos appears to be a natural property of complex systems.

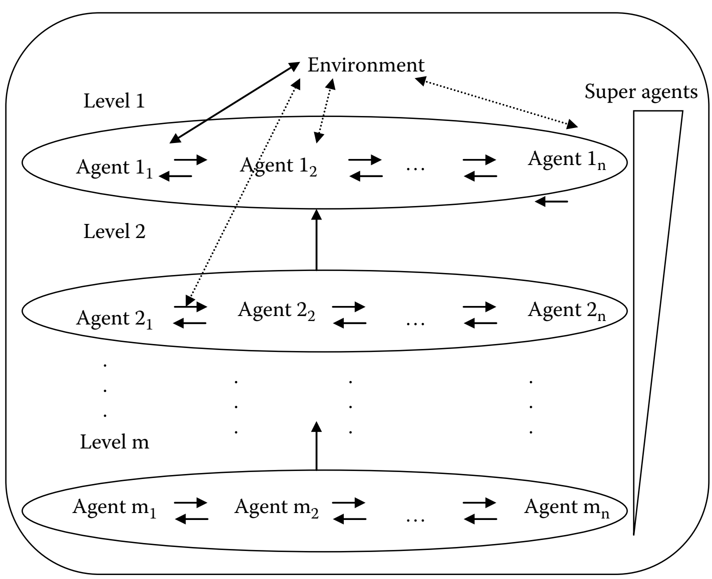

FIGURE 2.2 Schematic of a complex adaptive system.