Chapter 14
Principles for Managing the Urban Water Environment in the 21st Century

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14.1 Introduction

14.1.1 Revisiting the Urban Water Environment

One of the key ideas of this book is the holism of the urban water environment and its importance to human well-being. As we have seen in Chapter 2, the urban water environment interconnects the built environment—the water delivery and sewage infrastructure and the impervious surfaces that alter hydrology—with the natural environment, comprising surface streams, rivers and lakes, and underground aquifers. Though conceptually simple and logical, these components are rarely considered a whole system.

We have also seen that the urban water environment includes the fabric of human society—laws and institutions. Modern cities now employ several types of water management institutions, such as regional water or sewage districts, multifunctional watershed districts, or groundwater management districts (Chapters 10, 11, and 12). Most explicitly focus on one or a few aspects of the urban water environment, and none are designed to manage all aspects of the entire urban water environment. Water markets and prices, the interplay of supply and demand, also shape how we use water and the costs and benefits of that use (Chapter 13).

Finally, water affects our psyche. As we have seen, the human relationship with water goes far beyond the physiological and sanitary functions of water; the integration of water features and water-using landscapes into the urban water environment is integral to our quality of life (Chapter 7). Managed well, water delights and sooths; managed poorly, it can be an unpleasant eye-sore.

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14.1.2 Chapter Goal

The goal of this chapter is to synthesize what we have learned from this book. This synthesis arose from a three-day workshop convened after the core chapters had been written. We assembled to review what each of us had written, to exchange ideas, and to synthesize what we had learned. What emerged were five core principles that can help guide management of the urban water environment of post-industrial-era cities in the 21st century.

14.2 Principle 1: Influence of Urbanization

The urban environment profoundly and comprehensively affects water quantity and quality. Therefore, water managers should systematically consider all aspects of the hydrologic cycle, including the interactions between land, water and atmosphere, within both the natural and built environments.

One can lose sight of the natural environment in the city. Yet it is there, even in the most densely populated and intensively developed city centers. Basic hydrologic processes—precipitation and evapotranspiration—wield their influence on the urban setting, and they must be carefully considered in the management of the urban landscape and, particularly, the management of urban water. The complex mix of the built and natural environment that creates the city requires water managers to consider all aspects of the hydrologic cycle, including the interactions between land, water, and atmosphere, all in the context of both the natural and built environments. Such consideration requires robust tools and a systematic approach.

14.2.1 Use Water Balances to Guide Urban Water Management

We now have the technical capacity to develop hydrologic balances for cities. To consider all aspects of the hydrologic cycle, the urban water manager must necessarily operate within the construct of the water balance (Chapter 2). Certain fundamental principles emerge from this approach. First, a complete water balance for the city must include the upstream "hydroshed", which includes the local "natural" watershed as well as areas that contribute water to the city via constructed conduits (Chapter 2). For New York City, for example, the upstream hydroshed includes the Croton Reservoir watershed; for Phoenix, Las Vegas and most of Southern California, it includes the Colorado River watershed (Chapter 12).

A complete urban water balance must incorporate the hydrology of both the surface and subsurface, including ground water (Chapters 2 and 3). Not only is ground water linked to both surface waters and the human infrastructure within the city, but it also may provide all or part of the city's water supply. Further, there are many instances in which ground water interacts with and even adversely affects urban infrastructure (Chapter 3).

As explained in Chapter 2, urban infrastructure is a third major consideration for the urban water balance. While water-supply lines, sanitary sewers, and stormwater sewers and conveyances are components of the urban infrastructure with obvious implications for the water balance, other urban features are also important. These include large areas of impervious surfaces, physically altered rivers and streams, and the subsurface drainage systems at underpasses, subways, and building basements. All of these profoundly alter the movement of water through the urban environment.

Finally, the urban water balance must consider not only the upstream hydroshed and within-city watersheds but also the fate of water downstream of the city. Providing water to major cities has had implications not just for the upstream suppliers but also for downstream users and ecosystems. Urbanized watersheds generally increase the potential for downstream flooding. In desert cities, rivers may be virtually dried up as the result of water withdrawals and upstream dams. In both wet and dry climates, the water that leaves a city is often the worse for wear: It is contaminated effluent or stormwater rather than a pristine resource. Water management for the city thus necessarily entails water management both upstream and downstream of the city.

Similarly, competing water uses must also be considered. Providing water to southwestern U.S. cities like Phoenix or Denver can only be done when water is taken from other uses such as agriculture, energy or the environment; or by mining groundwater. These tradeoffs, and their social and economic effects, need to be evaluated. Water balances provide the first step in the calculation of those effects (Chapters 4 and 5). For cities in the southwest, expanding urban water supplies nearly always comes from agricultural water supply. This new urban water supply often comes from conversion of agricultural land to urban land, with transfer of water rights. In hot climates like Phoenix, the amount of water needed to support an acre of new residential development is roughly equal to the amount needed to irrigate the same acre when it was cropland. Prior agricultural land use often implies legacy contamination of surface water and particularly ground water by nitrate, salt, herbicides and pesticides. New urban land and water uses must recognize these potential compromises to the local water supply. However, urban wastewater can represent a source of water (through recycled wastewater) and soil amendments (wastewater biosolids) of value to agriculture. Nearly all "new" wastewater effluent generated in SW cities is now recycled, used for landscape irrigation, cooling towers, and other purposes. Recycled wastewater is now a significant "source" of water for urbanizing cities in the arid SW.

A carefully developed and reasonably accurate water balance is a tool for analysis of many aspects of the water environment of the city. Because it shows the total flow of water for the city, it can be used to plan for long-term water supply. On similarly long time scales, we can forecast trends in ground water levels to plan for conjunctive use of ground- and surface-water supplies and manage to prevent land subsidence and ground-water intrusion into subsurface infrastructure. If the water balance is developed with consideration of how water flows vary over time, it can be used to examine flooding of the city and downstream areas. Similarly, by looking at periods of low flow, the water balance provides the means to plan for protection of aquatic ecosystems and maintenance of both the quantity and timing or seasonality of the flow regime.

14.2.2 Manage Pollution at the Ecosystem Level

The traditional management of urban pollution has been an "end-of-pipe" approach. But, as discussed in Chapters 4 and 5, we cannot simply look at the effluent that exits the pipe from the city's wastewater treatment plant; we must also consider the redistribution and storage of pollutants within the city. The tool for this is comprehensive mass flows analysis (MFA). In Chapter 4, this type of holistic analysis for the city of Scottsdale, Arizona, led to the surprising conclusion that the city is steadily accumulating salt. This kind of mass redistribution over an extended period of time has potentially disastrous implications for the future city. Such consequences can be foreseen and averted through integrated modeling of the entire urban water system.

Holistic management of pollutants requires that mass balances be developed in conjunction with water balances. One must identify the sources of mass to the city's urban water system, how mass is transferred between components within the city system, where is it accumulated within the city system, and how it is passed from the city to the downstream and neighboring environment. Our description here is generic—we talk in terms of "mass" or "materials"— however, the approach is broadly applicable. Chapter 5 explored its application to phosphorus and lead in cities as examples of the multitude of pollutants that could be examined using this approach (see Table 5.2 in Chapter 5). A robust analysis must account for the role of all environmental media including the land and atmosphere as well as surface and subsurface water. MFA could be particularly helpful in managing nonpoint sources of pollution.

14.2.3 Practice Adaptive Management

Another tool of holistic management is adaptive management—using systems of sensors, data storage and analysis, and real-time controls to facilitate rapid assessment, managerial action, and feedback from the environment. Adaptive management has applications to many aspects of the urban water environment, including groundwater management (Chapter 3), pollution management (e.g., road salt, in Chapter 5), and stream morphology (Chapter 6).

14.2.4 Value Physical and Ecological Integrity

In addition to pollution management, urban water management must also address the physical and ecological integrity of urban rivers, lakes, and riparian areas if the city is to be provided with the desirable ecosystem services and recreational opportunities discussed in Chapters 6 and 7. We are becoming increasingly aware that impairment of ecological function of urban streams is caused as much, or more, by hydrologic alteration than by pollution. Limiting the potential adverse effects of the built environment on the natural environment is thus a multifaceted problem that requires broad integration of hydrological, biological, and chemical factors.

14.3 Principle 2: Change is Inevitable

Changes in urban water environments are inevitable but not always predictable. Water management should anticipate change and plan for it.

Hydrologic changes result from predictable variability (wet and dry cycles) and predictable trends (population growth), as well as uncertain long-term phenomena (global climate change) and the timing of "unpredictable" catastrophes (floods and droughts). Water managers need to plan for and design water systems to work under a variety of short- and long-term conditions and water demands. Building such adaptive and resilient systems first requires identifying and understanding the drivers of change and the approaches that can be taken to anticipate change.

14.3.1 Understand Drivers of Change

A first step in effective water management is being able to distinguish between three different types of changes; (1) normal variability around an average, which can be predicted with statistical techniques, (2) random events such as catastrophes, which can be anticipated and prepared for but not accurately predicted, and (3) truly uncertain events, such as global climate change, which we are just beginning to understand. Within this context, the drivers of change can be organized into five categories: biophysical, built environment, governance, behavior, and economics. Multiple and at times complex feedback mechanisms also operate within and between each of the five categories of drivers. For example, a change in climate could impact regional hydrology. The response to this change by institutions and individuals could reduce or exacerbate these impacts. Because change is ubiquitous in urban water management, understanding the driving forces of change and the relationships between these forces will be increasingly important for managers.

Biophysical factors (Chapters 2, 3, and 6) include natural resources and both hydrologic and climatic processes. Water systems have been designed to accommodate historic climatic variability. Now with global climate change, both variability as well as the long term averages may be changing. Additionally, how cities manage water resources affects the biotic environment around cities, which in turn significantly impacts water resources and the ecosystem services provided by water. The resiliency of these resources will determine how they respond to changes. Cities that are located on the outer edge of climatic or hydrologic tolerances during normal conditions, such as deserts (Chapters 4 and 12) or environments with shallow groundwater systems (Chapter 3), will likely be less resilient to change than cities located in more moderate environments.

The built environment and other land-use factors (Chapters 4, 6, 7, and 8) include everything from buildings to water management infrastructure (canals and dams), to the technology we use for water management, to our overall urban design (land use and transportation systems). Understanding the potential impacts of accidents, infrastructure failure, and shifts in climate, as well as how to respond to such challenges, is critical for water management.

Governance and institutional factors (Chapters 9, 10, 11, and 12) include our laws, policies, social customs and values. Laws and institutions affect how we respond to change, either locking us into inflexibility or providing great resilience. For example, the development of regional water management institutions (Chapters 11 and 12) can greatly improve the ability of an urban region to respond to changes. On the other hand, adhering rigidly to a water rights system based on prior appropriations (Chapter 10) could reduce resilience to long-term drought.

Human behavior (Chapters 7, 8, 12, and 13) and individual choices form the foundation for all water management activities. Our individual lifestyles and consumer choices determine the per capita demand for water. What we demand from our governments and other institutions in terms of water quality, recreational and amenity uses for water, and protection of ecosystems constitute much of the remaining water demand and the constraints on water supplies. Public support, principally through our elected officials, shapes public policy and public investments for water management. Experience with water conservation education efforts, as well as research into changing perceptions and behavior on environmental issues, provides significant information on how human behavior may respond to change.

Economic factors include competition between different water users (e.g., homeowners, farmers, and electric utilities) as well as broader economic forces (Chapter 13). Water prices alter water consumption and supply; however in many cases, water is an allocated commodity for which there is not an open market with prices determined by supply and demand. The development of water markets and additional reliance on economic signals and incentives, though controversial, could be an approach for designing adaptable water management. Finally, the ability of local, state or perhaps even the federal governments to invest in water infrastructure can, in itself or in combination with other drivers, drive change in the urban water environment.

14.3.2 Anticipate and Manage Change

The effectiveness of long-term water management depends on being able to anticipate and manage change. Collecting data, planning for the long range, managing adaptively, building redundancy and resilience into urban water systems, and building transparency are all key steps for anticipating and managing future changes that are explored in Chapter 12 and summarized below.

Collect and track data: Good data are essential to knowing what types of change are occurring, identifying areas of concern, and strategically targeting resources.

Data collection is essential to provide feedback for adaptive management (see below).

Plan for the long term: Long-range planning should include predictive scenarios that include both well-known and uncertain changes that can cause threats to the urban water environment. By identifying a range of both best and worst case scenarios, water planners can understand the potential impact of alternative future trends, identify the events to which they are most vulnerable, and prepare for responding to such events.

Incorporate adaptive management: Adaptive management should combine the knowledge gained from data tracking and scenario planning, as well as evaluating how current water management programs are working. This information can be utilized to develop program modifications before changes become critical. Building such an ongoing feedback and adjustment process for modifying water management efforts, based on data from hypothesis-driven monitoring programs under changing conditions, can be a key step in effectively building the capacity to handle future changes.

Design for resiliency: Urban infrastructure can be designed to be resilient to hydrologic change. Resilient practices include building a diverse water supply portfolio with backup supplies, building redundant infrastructure (such as cross-connections between adjoining municipal water systems), and relying on diverse management approaches to respond to crisis.

Build transparency: Transparency means making information and knowledge readily available to all interested parties. This information might include transcripts of public meetings, maps of environmental characteristics (such as groundwater tables), interactive models, etc. Transparency will be increasingly critical for anticipating and managing change. Political decision makers and water managers need to recognize the importance of transparency and design it into their water systems and institutions. For example, readily accessible data on groundwater systems would allow politicians, agencies and citizens to visualize changes that are occurring, allowing them to respond before crisis occurs. As explained in Chapter 3, "out of sight, out of mind" does not create a resilient system, particularly in the face of unanticipated change.

Some institutions have organized this knowledge in ways that can be used to communicate results in readily understandable formats. An example is Arizona State University's Decision Theater and their WaterSim project, where stake holders can readily visualize long-term changes in water supply under various climate and growth scenarios (Fig. 14.1).

14.4 Principle 3: Water and People

People affect water and water affects people. Water managers should recognize and engage the multiple parties and interests that affect and are affected by water systems.

Fig. 14.1 Photo of ASU's Decision Theater. An interactive online version can be found at http://watersim.asu.edu/

A key theme of this book is the idea of the urban water environment as a core element of cities. Central to this idea is the interaction of people with their water environment, which provides not only physiological sustenance, but also opportunities for recreation, aesthetics and stress reduction (Chapter 8), broader urban resilience (Chapter 12) and even enhanced property value (Chapter 13). Achieving an optimal urban water environment therefore requires intensive interaction of water managers with citizens and organizations.

14.4.1 Engage the Public Broadly

A wide variety of people get involved in urban water issues. The list of course includes water managers, but it also includes federal, state, and municipal agencies, real-estate developers, planners, environmental activists, politicians, homeowners, and citizens. The water system is shaped by these multiple actors making independent and sometimes conflicting choices and decisions. The water manager must engage these parties and referee the public process to create effective policies.

At the base level, individuals make decisions that affect water. They help to decide the relative importance of competing decisions such as how much water is consumed, how landscape is managed, how erosion is controlled, how much impervious surface is created, and how many tax dollars are provided for water management. However, water managers are not powerless in the face of individual decisions—they have tools to influence the public's choices. For example, water managers can structure water rates to encourage efficient water use (Chapter 13) and sponsor public information programs to inform citizens of choices that are environmentally sound (Chapter 5). Thus, while individuals can make choices, managers can influence those choices. The water manager who understands the underlying individual behaviors that affect water decisions can develop "soft" policies to help the public make informed choices and ultimately achieve wise and efficient public investment and public policy.

14.4.2 Develop a Public Vision

A desire for wise and efficient policy decisions and reasonably free choice for individuals implies that effective water management is something of a balancing act. Water managers can provide direction, but ultimately individuals and communities will make their own choices. Thus, effective water management must necessarily engage individuals and communities in determining a vision for water management and the implementation of that vision in the context of comprehensive, long-term regional planning (Chapter 8). This is no mean task: Not only must public participation be sustained over long periods, but also the public needs to be educated in the arcane concepts and language of water management. Engineers and scientists must be able to communicate notions of water and mass balances with planners and stakeholders from the public at large in ways that are readily accessible and understood.

14.4.3 Visualize Change

Communicating among various stakeholders requires simple visualization tools. Simulation tools, such as the WaterSim models used in Chapter 4, enable scenario management tools for experimenting with alternative management scenarios and visualizing their results. However, more must be done to develop simulation tools that provide quantitative results to planners and the public as a foundation for planning and management. The various simulation-based computer games on the market for many years demonstrate that such tools can be made accessible to the public. Simulation tools could be implemented on the web, in decision theatres, or through other venues. Moreover, some means of interactive response from stakeholders is also essential. This could take traditional forms such as public meetings and focus groups, or new approaches such as computer gaming or web-based feedback. Regardless of the form, a shift to planning that uses analytical tools such as water and mass balances also requires a corresponding shift to more sophisticated methods to bring the resulting information to the public planning process (Chapter 8).

14.4.4 Never Forget Sanitation

Urban dwellers in the United States enjoy safe, potable water and efficient sewage disposal. Improved water and sanitation have been enormously successful in reducing mortality and increasing lifespan since its development in the late nineteenth century. Chapter 1 points to this as perhaps the most important contribution to improved human health since modern urbanization. Where water once affected urban dwellers very negatively by providing a medium for the spread of disease, modern water infrastructure now has a very positive effect, protecting the populace from sources of disease. Modern wastewater collection and treatment, however, have also transferred some pollutants from the immediate environs of the city to the peripheral environment of the city's waterways. Wastewater thus becomes a problem for downstream users, who must deal with any unaddressed residual health and environmental problems associated with treated wastewater. The potential for disease transmission via water has not disappeared. A failure in water treatment can produce disastrous outcomes, as occurred in Milwaukee in 1993, when 143,000 people became ill from *Crytosporidium*. Untreated sewage from combined and sanitary sewer overflows continues to contaminate urban waterways. We have not yet developed a mature approach for dealing with newly identified micropollutants. Finally, the use of septic systems in peri-urban areas remains a problem. These frequently fail, contributing high loads of bacteria, organic matter and nutrients to surface waters and groundwater. The failure to install sewers as population density increases in urbanizing areas can lead to serious contamination problems.

14.4.5 Value Aesthetic and Ecological Functions of Water

While protection of human health is probably the most fundamental service provided by water systems, the water environment also can provide a sense of place, recreation, wildlife, biodiversity, ecosystem, and aesthetic values. It is hard to imagine many of our cities without their defining water features: Chicago's Lake Michigan waterfront, Seattle's Pier District, or Boston's Charles River. The high value of riparian or shoreline reflects the value that society gives to these aesthetic and natural features. Similarly, as discussed in Chapter 7, most of our residents visit or recreate in waterside areas and greatly appreciate those opportunities. Water also provides important urban wildlife habitat, as long as some semblance of natural conditions area maintained (Chapter 6).

While good water quality supports all of these water-dependant values, polluted water has a deleterious effect on the urban aesthetic sense, water recreation and landscape, and even drinking water. Chapter 3 discusses the potential for urban pollution to contaminate the drinking-water aquifers that supply some cities and Chapter 5 gives a technical context to the city-wide materials fluxes that can give rise to both surface- and ground-water pollution. Cities often depend upon lakes and reservoirs for urban recreation, water landscapes, and even water supply, but those resources can be severely impaired by the nutrient fluxes created by urban and suburban living.

Urban rivers and coastlines can similarly suffer under poor environmental management. Chapters 9 and 10 explain how laws and institutions can provide protection of the water environment from pollution, and thereby also protect secondary uses of water that provide places to recreate, ecosystem services, and a sense of place.

14.5 Principle 4: Water Management Institutions

Multiple institutions affect water management. Urban water should be managed through institutions that are responsive to the hydrologic setting; capable of working across political, social, and functional boundaries; and effective at engaging all stakeholders.

Multiple entities, as described throughout the preceding chapters, shape water management. They are a diverse group of public and private interests, ranging from individuals to institutions, from farmers to major industrial users, from small communities to multi-state agencies. They include local and regional water providers, local and regional planning agencies, regulatory agencies at all levels of government, and public interest groups. Water users engage in various ways on water-related concerns. The challenge for water management institutions is to engage all of these various stakeholders and to improve the inclusiveness, efficiency and effectiveness with which we set and achieve water management objectives. Current institutions and policies too often focus on only one or two specific water management functions. For example, it is common for one public utility to manage municipal water supply and an entirely different utility (perhaps operating at a different scale) to manage wastewater (Chapter 11). Additionally, institutions operate within natural and physical (Chapters 2–6), social (Chapters 7 and 8), legal (Chapter 9), political (Chapters 10, 11, and 12), and economic (Chapter 13) contexts. These contexts create both opportunities and constraints for institutional efforts to reduce barriers across jurisdictions within a region, between different levels and functions of government, and across interrelated water management functions. As we pointed out in Principle 3 above, people are affected by water; yet in many cases, institutions mediate this relationship.

14.5.1 Develop Effective Water Institutions

We recommend the following criteria for developing effective and responsive institutions:

Address water issues at the scale of watershed and groundwater basins (see Principle 1): This will require coordination among overlapping jurisdictions. Water management is fragmented geographically across federal, tribal, state, regional, and local governmental units and private utilities with different missions, authorities and jurisdictions. A key role of regional institutions is to provide resource protection and facilitate coordination for issues that span such boundaries (Chapters 10, 11, and 12).

Manage all aspects of water in urban environments (see Principle 1): Water management is fragmented by function—water quantity versus water quality versus land use versus stormwater/flood control versus economic development—and by different rules for groundwater, surface water and effluent. Effective institutions need to recognize and avoid the types of unintended consequences that can occur when dealing with just one functional aspect of a diverse yet integrated resource such as water.

Maintain a high level of communication across agencies and disciplines: Communication is critical to overcome both the political and functional fragmentation identified above. A key part of communication is creating transparency, ensuring that all urban water management programs and institutions can acquire and understand information needed to make informed decisions.

Focus on who makes key decisions and how to impact those decisions (see also Principle 3): Key decisions in water management are made by water users and those actually building infrastructure. Most agencies work by altering the climate of public perception within which these decisions are made, through education, incentives and regulations.

Design flexible approaches for effective and efficient management: Institutions need to creatively and comprehensively integrate education, incentive programs, and regulations. Each of these approaches affects the decision-making environment in different ways, and each approach has varying strengths and weaknesses, including political acceptability. An often difficult challenge is dealing with the perception of a conflict between private property rights and projects designed to benefit the public health, safety and quality of life (Chapters 11 and 12).

Utilize sound science and adaptive management approaches: These approaches increase the flexibility, effectiveness, and legitimacy of both regulatory and non-regulatory policies (see also Principle 2). Water management institutions should take advantage of technical and managerial innovations, such as real-time monitoring, visualization of data, web-based data tools, and partnerships with universities and other research institutions to make adaptive approaches rigorous and viable.

Engage all stakeholders, including the general public, early and often: Non-governmental organizations (e.g., conservation and environmental groups) and industry associations, as well as the general public, play an increasingly important role in water policy and management. Engaging stakeholders at the very beginning and ensuring completely open and transparent public processes will help to ensure public support for difficult decisions and build the relationships that can be critical for responding to future challenges.

14.5.2 Develop the Right Type of Water Management Institutions

Institutions based on hydrologic boundaries, such as watersheds or groundwater basins, can be more effective than traditional units of government in managing regional water resources. Watershed-based organizations could, in some cases, replace previous institutions. However, new activities are also commonly designed to complement the preexisting jurisdictional based entities. Chapter 11 identifies four different models for watershed management efforts:

1. *Top-Down Agency-Led Watershed Management*: In this approach, state or federal agencies establish watershed based efforts with little local input. Notable examples would include Arizona's Active Management Areas (Chapter 12), Michigan and North Carolina.
2. *Agency-Coordinated Watershed Management*: These efforts are initiated by state agencies, but the focus is on coordinating local parties who are typically expected to pick up the leadership and perhaps the funding of programs. Massachusetts and New Jersey are examples of this approach.
3. *Watershed Management Authority*: These are independent entities that typically have taxing or regulatory authority and appointed or elected boards. Minnesota and Florida are notable examples.
4. *Locally Led Community-Based Entities*: Watershed councils and partnerships based on this model are often non-governmental organizations or informal coalitions. Such organizations exist throughout the United States.

Most states and regions employ a mix of these different models, or in some cases may even develop hybrids. Some key considerations (Chapter 11) that might lead to the formation of an effective organization include: (1) What scale of institution is needed? (2) What scope of activities is needed? (3) What level of technical sophistication is required? (4) Is a permanent taxing authority needed?

14.6 Principle 5: Interdisciplinary Framework

The urban water environment is a product of hydrology, ecology, history, land use, design, infrastructure, society, law, and the economy. Effective water management should incorporate multiple perspectives and varied expertise in an interdisciplinary framework.

As we have seen throughout this book, piecemeal management of the urban water environment has often resulted in very serious problems and, sometimes, crises. A few examples from previous chapters include the spread of cholera and typhoid following installation of sewers (Chapter 1), salt contamination from ecosystem accumulation (Chapter 4) and road salt (Chapter 5), continued lead pollution of inner cities (Chapter 5), rapid groundwater depletion, leading to subsidence, followed by rising groundwater, causing structural problems (Chapter 3), degradation of groundwater quality (Chapter 3), and increased downstream flooding and loss of ecological health caused by destruction of stream channels during urbanization (Chapter 6). These examples point toward a profound need for holism—a consideration of the entire urban water environment—to avoid these types of calamities.

14.6.1 Connect the Dots

Fortunately, we are at a point in history when we have the technological and scientific capacity to craft ecosystem-level management strategies to manage urban systems in a more sustainable fashion. What remains to be done is "connecting the dots" between parts of the ecosystem, a step that requires integration of expertise across a wide variety of disciplines. We now understand, for example, that groundwater and surface water are really one resource that should be managed conjunctively (Chapters 2 and 12), the pollutants should be managed at their source (Chapters 4 and 5), and that we can predict, within limits, the consequences of urban development on the ecological health of urban streams (Chapter 6). Understanding these connections can help us avoid unintended consequences, largely by working with natural processes. This idea of "designing with nature" is not new, but it can now be implemented more effectively than when McCarg (1969) first brought the idea into the mainstream of urban design as the result of improved science and vastly improved technology tools, from remote sensing to data storage.

14.6.2 Think Across Disciplines

This holistic vision of an urban water environment requires experts from many disciplines, working together in new ways. Traditionally, urban development was largely the purview of planners and engineers working independently of each other. This book shows that experts from many other disciplines need to be intimately involved—ecologists, hydrologists, geologists, environmental psychologists, economists, lawyers and others. To accomplish this will require breaking down the barriers that discourage multidisciplinary teamwork. In academia, these barriers include rigid disciplinary focus on tenure evaluation, lack of rewards for interdisciplinary or applied research, a reluctance to engage in "messy" politics, obsolete budget models that discourage sharing funds across departments and colleges, project funding periods that are too short to allow interdisciplinary research to flourish, and compartmentalization of research funds along traditional disciplinary lines. Fortunately, some of these barriers are being torn down. Similar problems occur throughout the "real" world. Bureaucracies are often compartmentalized along disciplinary boundaries, with narrowly prescribed mandates; communication across governmental agencies is often discouraged, or at least, not rewarded; and the funding model is often not responsive to changes in needs. An additional problem with governmental bureaucracies is that innovation is often discouraged.

Institutional changes can also promote multidisciplinary thinking. Examples include new types of planning processes (Chapter 8), the creation of bureaucracies based on watershed boundaries (Chapter 11) or groundwater regions (Chapter 12), and the development of water markets (Chapter 13). Some technical approaches also promote greater holism, for example, the development of regional water or pollutant balances (Chapters 3, 4 and 5). Finally, transparency tools can enable broad communication among agencies and stakeholders.

14.7 In Closing

The five core principles put forth in this chapter seek to guide management of the urban water environment of post-industrial-era cities in the 21st century. Each principle identifies an intrinsic aspect of the urban water system, and responds with a recommendation:

1. Urban environments profoundly affect water—thus, managers must be systematic in considering urban hydrology.
2. The urban water environment will inevitably change—thus managers must plan and prepare for change.
3. People are an integral part of the urban water environment—thus managers must engage the public in decisions about water.
4. Multiple parties play a role in deciding urban water systems—thus, managers must create effective decision-making and management institutions.
5. The urban water system is a complex product of nature, engineering, and society—thus, managers must incorporate all of these perspectives.

The onus of these recommendations falls upon you, our target audience, those who will create and manage the cities and water systems of the future.