THE GRANITE GARDEN

Urban Nature and Human Design

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PART VI
THE URBAN ECOSYSTEM

Prologue

The Granite Garden

SEEN FROM SPACE, the earth is a garden world, a planet of life, a sphere of blues and greens sheathed in a moist atmosphere. At night, lights of the cities twinkle far below, forming constellations as distinct and varied as those of the heavens beyond. The dark spaces that their arcs embrace, however, are not the voids of space, but are replete with forests and farms, prairies and deserts. As the new day breaks, the city lights fade, overpowered by the light of the sun; blue seas and green forests and grasslands emerge, surrounding and penetrating the vast urban constellations. Even from this great distance above the earth, the cities are a gray mosaic permeated by tendrils and specks of green, the large rivers and great parks within them.

Homing in on a single constellation from hundreds of miles up, one cannot yet discern the buildings. But the fingers and patches of green—stream valleys, steep hillsides, parks, and fields—swell and multiply. The suburban forest surrounds the city; large lakes and ponds catch the sunlight and shimmer. Swinging in, now only a few miles up, the view is filled by a single city. Tall buildings spring up toward the sky, outcrops of rock and steel, and smaller homes poke up out of the suburban forest. Greens differentiate themselves into many hues. Silver ribbons of roadway flash across the landscape, and stream meanders interrupt and soften the edges of the city's angular grid.

Flying low, one skims over a city teeming with life. The amount of green in the densest part of the city is astonishing; trees and gardens grow atop buildings and in tiny plots of soil. On the ground, a tree-of-heaven sapling is thriving in the crack between pavement and building, and a hardy weed thrusts itself up between curb and sidewalk. Its roots fan out beneath the soil in search of nutrients and water. Beneath the pavement, underground rivers roar through the sewers.

The city is a granite garden, composed of many smaller gardens, set in a garden world. Parts of the granite garden are cultivated intensively, but the greater part is unrecognized and neglected.

To the idle eye, trees and parks are the sole remnants of nature in the city. But nature in the city is far more than trees and gardens, and weeds in sidewalk cracks and vacant lots. It is the air we breathe, the earth we stand on, the water we drink and excrete, and the organisms with which we share our habitat. Nature in the city is the powerful force that can shake the earth and cause it to slide, heave, or crumple. It is a broad flash of exposed rock strata on a hillside, the overgrown outcrops in an abandoned quarry, the millions of organisms cemented in fossiliferous limestone of a downtown building. It is rain and the rushing sound of underground rivers buried in storm sewers. It is water from a faucet, delivered by pipes from some outlying river or reservoir, then used and washed away into the sewer, returned to the waters of river and sea. Nature in the city is an evening breeze, a corkscrew eddy swirling down the face of a building, the sun and the sky. Nature in the city is dogs and cats, rats in the basement, pigeons on the sidewalks, raccoons in culverts, and falcons crouched on skyscrapers. It is the consequence of a complex interaction between the multiple purposes and activities of human beings and other living creatures and of the natural processes that govern the transfer of energy, the movement of air, the erosion of the earth, and the hydrologic cycle. The city is part of nature.

Nature is a continuum, with wilderness at one pole and the city at the other. The same natural processes operate in the wilderness and in the city. Air, however contaminated, is always a mixture of gasses and suspended particles. Paving and building stone are composed of rock, and they affect heat gain and water runoff just as exposed rock surfaces do anywhere. Plants, whether exotic or native, invariably seek a combination of light, water, and air to survive. The city is neither wholly natural nor wholly contrived. It is not "unnatural" but, rather, a transformation of "wild" nature by humankind to serve its own needs, just as agricultural fields are managed for food production and forests for timber. Scarcely a spot on the earth, however remote, is free from the impact of human activity. The human needs and the environmental issues that arise from them are thousands of years old, as old as the oldest city, repeated in every generation, in cities on every continent.

The realization that nature is ubiquitous, a whole that embraces the city, has powerful implications for how the city is built and maintained and for the health, safety, and welfare of every resident. Unfortunately, tradition has set the city against nature, and nature against the city. The belief that the city is an entity apart from nature and even antithetical to it has dominated the way in which the city is perceived and continues to affect how it is built. This attitude has aggravated and even created many of the city's environmental problems: poisoned air and water; depleted or irretrievable resources; more frequent and more destructive floods; increased energy demands and higher construction and maintenance costs than existed prior to urbanization; and, in many cities, a pervasive ugliness. Modern urban problems are no different, in essence, from those that plagued ancient cities, except in degree, in the toxicity and persistence of new contaminants, and in the extent of the earth that is now urbanized. As cities grow, these issues have become more pressing. Yet they continue to be treated as isolated phenomena, rather than as related phenomena arising from common human activities, exacerbated by a disregard for the processes of nature. Nature has been seen as a superficial embellishment, as a luxury, rather than as an essential force that permeates the city. Even those who have sought to introduce nature to the city in the form of parks and gardens have frequently viewed the city as something foreign to nature, have seen themselves as bringing a piece of nature to the city.

To seize the opportunities inherent in the city's natural environment, to see beyond short-term costs and benefits, to perceive the consequences of the myriad, seemingly unrelated actions that make up daily city life, and to coordinate thousands of incremental improvements, a fresh attitude to the city and the molding of its form is necessary. The city must be recognized as part of nature and designed accordingly. The city, the suburbs, and the countryside must be viewed as a single, evolving system within nature, as must every individual park and building within that larger whole. The social value of nature must be recognized and its power harnessed, rather than resisted. Nature in the city must be cultivated, like a garden, rather than ignored or subdued.

PART IV

Water

CHAPTER 6

Floods, Droughts, and Poisoned Water

POISONED WATER, floods and droughts plague the city. Brown rivers loaded with sewage, sediment, bits of garbage, and poisonous chemicals flow through the city, a dirty soup from which many cities draw their drinking water. In some years, floods alone account for more property damage in the United States than any other single natural hazard, yet drought is an increasingly common urban phenomenon. All cities, even those in humid climates, must soon face the loss of their most precious resource—an abundant supply of uncontaminated water.

Water is the city's life blood: it drives industries, heats and cools homes, nurtures food, quenches thirst, and carries waste. Cities import more water than all other goods and materials combined. Sufficient water is not only a prerequisite for health, it is essential for life. Despite their desperate need for water, and despite the fact they are forever short of water, cities befoul and squander it. Every rain sweeps dirt, debris, heavy metals, and animal feces from streets and parking lots into rivers and lakes. The storm sewers which drain the city's paved surface aggravate floods and prevent groundwater recharge, and the resultant lowered stream flows concentrate pollutants. Even as the city water supplies dwindle, drinking water irrigates drought-sensitive lawns and landscaping.

Taken together, urban activities, the density of urban form and the impervious materials of which it is built, the pattern of settlement and its relation to the natural drainage network, and the design of the drainage and flood control system produce a characteristic urban water regime. Abundant and rapid storm water runoff creates extremely high stream flows during and immediately after storms and lowers stream flow between them. Pavement and storm sewers reduce infiltration and lower the level of water beneath the ground. Urban activities and their location, and urban form and materials, influence the degree of flooding and where it occurs, the degree of pollution and where it is concentrated, and the amount of water consumed. The characteristics of urban water dynamics, pollution, and use are well understood, their causes and effects well known, but that knowledge is too seldom applied. The planners, designers, builders, and managers of cities all too often treat the problems of flooding and storm drainage, water pollution, water use, and water supply separately.

Increased Floods

All but the largest creeks and streams of the pre-city landscape have vanished from a modern map. Covered and forgotten, old streams still flow through the city buried beneath the ground in large pipes, primary channels of a subterranean storm system. Their muffled roar can still be heard beneath the street after a heavy rain; they are invisible, but their potential contribution to downstream floods is nevertheless unabated and magnified. Floods increase in magnitude and destructiveness with each increment of urban growth; urbanization can increase the mean annual flood by as much as six times.[1] Rapid stormwater runoff and narrower, shallower floodplains, constricted by buildings and levees and clogged with sediment, are the cause. As urban storm drainage systems drain water efficiently from roofs, streets, and sidewalks, the flood control system must be continually augmented to prevent flooding downstream.

The concrete, stone, brick, and asphalt of pavement and buildings cap the city's surface with a waterproof seal. Unable to penetrate the ground and unimpeded by the city's smooth surface, the rain which falls on roofs, plazas, streets, and parking lots runs off the surface in greater quantities, more rapidly than the same amount of rain falling on the spongy surface of a forest or field. The densest parts of the city increase storm water runoff the most; runoff decreases in the less densely populated parts of the city, and drops off sharply in wooded parkland. Gutters, curbs, and drains collect rainfall and direct it to sewers, which transport it rapidly to streams and lakes. The denser the city, the higher the proportion of pavement to plant cover, and the more efficient the storm drainage system, the greater the quantity of storm water that reaches streams and rivers in a short space of time. Storm sewers transport water from one point to another; they do not reduce or eliminate water, they merely change its location. Traditional storm drainage practice protects local streets, basements, and parking lots from flooding, while contributing to major flood damage downstream.

The torrential peak flows of urban storm water overwhelm the capacity of storm-swollen streams, their floodplains filled and constricted by buildings, roadways, levees, and floodwalls. The resulting floods are higher, flow more rapidly, and are more destructive than floods from comparable storms before urbanization. The 1973 flood of the Mississippi River at St. Louis was similar in magnitude to the flood of 1908; yet the flood waters were more than eight feet higher in 1973. The 1973 flood was the highest in the 189 years that records had been kept, even though experts estimate that it had a recurrence interval of only thirty years.[2] It was not the magnitude of the flood itself, but rather the confinement of the river by levees and the deposition of sediment in the river channel that contributed to the height of the 1973 flood. As urban floodplains and river channels are confined to control floods and enhance navigation, they are also made shallower, as a by-product of other human activities. Construction and demolition expose soil to erosion, and storm water carries sediment into streams. A construction site produces ten to one hundred times the amount of eroded sediment that is produced by farms and forests.[3] More than 4,500 tons of soil was eroded during a five-year period from a single twenty-acre construction site in Montgomery County, Maryland.[4] The cumulative impact on urban water bodies is substantial. Eroded sediments silt stream channels and harbors, decreasing their flood capacity.

The river and its floodplain are a unit. The floodplain is the relatively flat area within which the river moves and upon which it regularly overflows. Unobstructed, the dynamic flow of water constantly erodes one bank and deposits sediments on the opposite bank. River channels do not remain forever at the same location; unless confined, the channel, over the course of time, eventually occupies every location within the floodplain. The shape and size of a natural river channel reflects the size and frequency of floods to

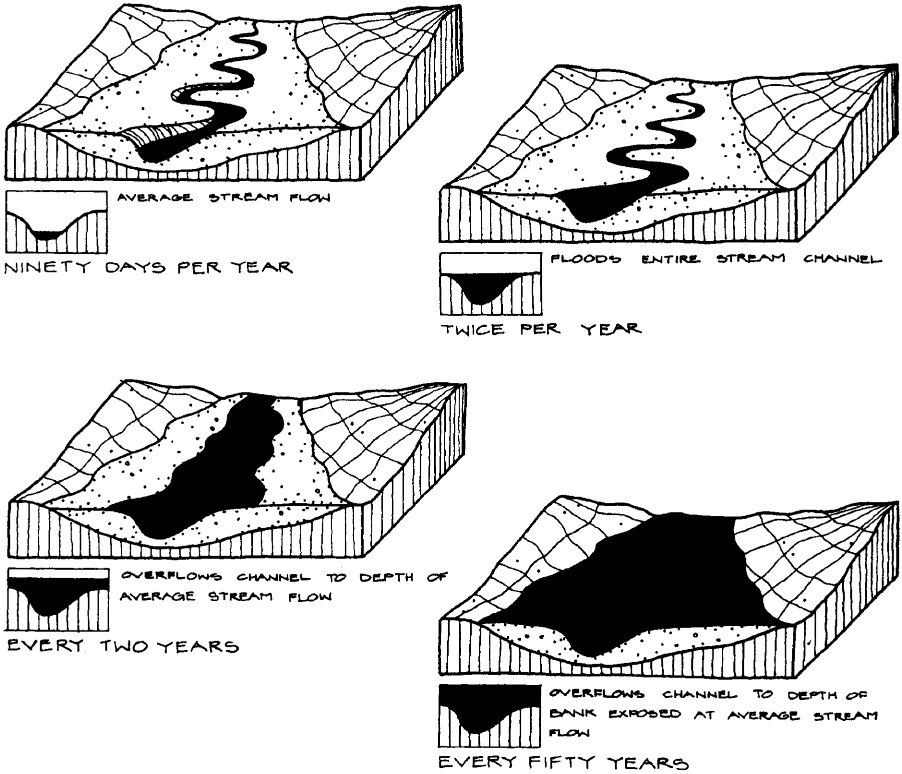


FIGURE 6.1
Floodplain dynamics. Rivers overflow onto their floodplains with predictable frequency, and structures built within the floodplain area risk destruction.

which it is subjected, and two times every year, the river fills its channel, brimming to the banks; about once every two years, the river overflows onto the floodplain to the depth of the average flow in the channel (see figure 6.1).[5] When homes and businesses occupy the floodplain, they not only risk destruction, but also cripple the ability of the floodplain to contain flood waters. In some cities, buildings, parking lots, and other urban development occupy much of the floodplain: 89.2 percent of the floodplain in Phoenix, Arizona; 83.5 percent in Harrisburg, Pennsylvania; 62.2 percent in Denver; and 53.3 percent in Charleston, South Carolina.[6]

When the storm drainage system increases peak stream flows, and homes and businesses occupy the floodplain, flood control structures are usually built to protect them. The reliance upon massive engineering works, like dams and levees, minimizes the damage from frequent floods, but may contribute to deaths and greater destruction from less frequent major floods.[7] Extensive flood protection works inspire an illusion of safety that may promote dense occupation of flood-prone areas. The stage is then set for enormous loss of life and property when these flood protection works fail or are overtopped or inundated by extremely heavy rains. A 1972 flood in Rapid City, South Dakota, killed 237 people and injured 3,057 when flood waters overflowed the storage reservoir and breached the dam upstream of the city. Many residents, confident of the dam's ability to protect them, stayed in their homes despite warnings to evacuate. The river rose fourteen feet in four hours and as much as 3.5 feet during a single fifteen minute period.[8] The flood devastated 1,335 homes and demolished 5,000 automobiles. Of the estimated $160 million in property damage, less than $300,000 was insured.[9]

Cities are not at equal risk to floods. A city's regional climate and seasonal pattern of rainfall, the amount of floodplain within the city, and the extent to which the floodplain is developed all contribute to the relative degree of flood hazard. Coastal cities in the eastern United States lie in the path of hurricanes and are prone to flooding from a combination of heavy rainfall and surging flood tides. Flood hazards on the West Coast of the United States are increased by the added threat of earthquake-generated tsunamis. Cities in semiarid and arid climates may also have flood hazards; their shallow, wide floodplains, relatively dry much of the year, may be deceptive. James Michener described the South Platte River that flows through Denver as a "sad, bewildered nothing of a river . . . a sand bottom, a wandering afterthought, a useless irritation, a frustration, and when you've said all that, it suddenly rises up, spreads out to a mile wide, engulfs your crops and lays waste your farms."[10] Most of the year, the South Platte consists of a shallow trickle engulfed in a wide, flat, sandy floodplain, but heavy seasonal rains convert the river into a raging torrent. In June 1965, fourteen inches of rain fell over parts of Denver within a few hours. Flood waters rose quickly, overflowed the banks and slammed debris against bridges, forming dams so that the flood surged around them into the adjacent city. When the storm had passed, most of Denver's bridges were destroyed, and highways and buildings buried in tons of silt. The flood was the worst disaster in Denver's history, taking twelve lives and costing $300 million in damages.[11]

The extent to which the floodplain is constricted and built upon can aggravate the city's natural flood hazard. The amount of floodplain a city contains and the proportion of that area that is developed varies from city to city. Eighty-one percent of Monroe, Louisiana, and 40 percent of Charleston, South Carolina, lie within the floodplain, while floodplain comprises only 2.4 percent of Spokane, Washington.[12] The design of a city's storm drainage system can also aggravate or alleviate flood hazard. The faster stormwater reaches streams and rivers, the more floods increase; the more stormwater is retarded, the more floods are reduced.

The effect of a storm drainage system is not limited to flood hazard; it can also increase water pollution and water use. Typically, the storm drainage system aggravates pollution by delivering slugs of sewage and runoff after storms and by decreasing stream flow between storms so that discharges from industry and treatment plants are undiluted. Cities that draw their water supply from urban rivers must then contend with vacillating flows and increased contamination. When sewage and stormwater systems are combined, as they are in many older cities, the surge of stormwater following a rain frequently overwhelms the capacity of sewage treatment plants, so that both rainwater and untreated sewage dump directly into water bodies. Since the ground, sealed by pavement and drained by pipes, absorbs little water, the amount of water stored in the ground, from which plants obtain their supply, is reduced. The lowered groundwater is insufficient to maintain stream levels between storms and sustain plants during dry spells.

Poisoned Water

The disgusting odor and appearance of water in the wells and rivers of dense cities has been a source of concern for centuries. Although, in the fourth century B.C., Hippocrates had warned that polluted water posed a serious health hazard, it was not until 1854, when John Snow, a London physician, traced the source of a cholera outbreak to polluted water from a single well, that the link between water and disease was definitively established. In thirteenth-century London, both the Crown and the City attempted repeatedly and ineffectively to halt pollution of the Thames, but the river continued to be an open sewer (figure 6.2).[13] The Thames was a grossly polluted river in 1855, when Michael Faraday complained in a letter to the *Times* that "the whole of the river was an opaque pale brown fluid . . . near the bridges the feculence rolled up in clouds so dense that they

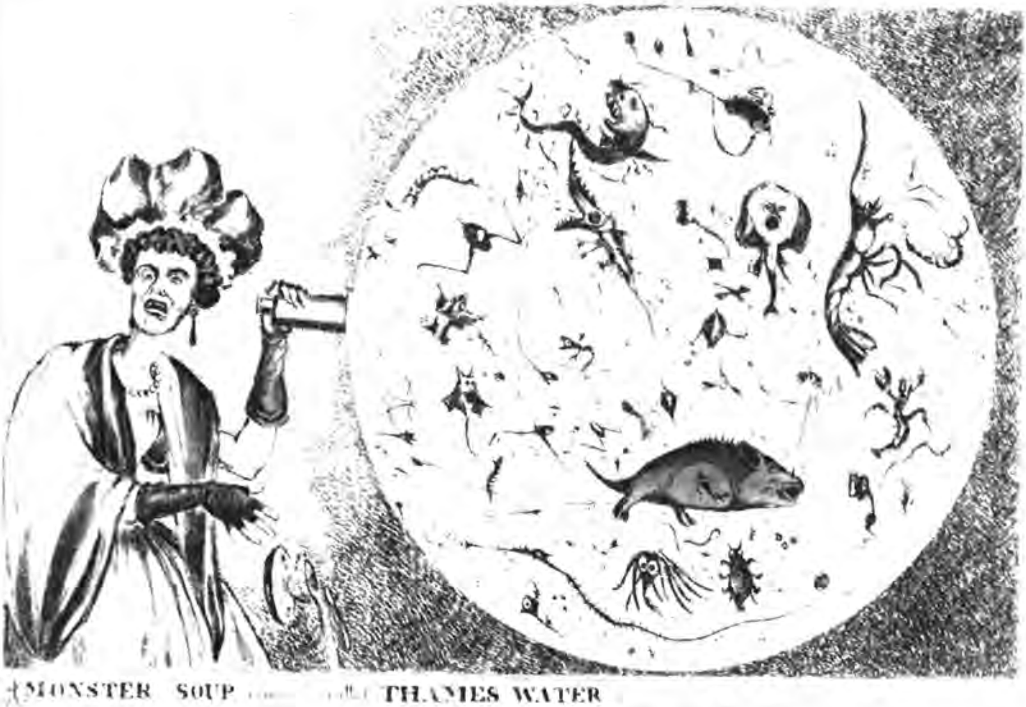


FIGURE 6.2
"Monster Soup commonly called Thames water. Being a correct representation of that precious stuff doled out to us. Microcosm dedicated to the London Water Company." A cartoon by Paul Pry, 1829.

were visible at the surface."[14] The following year, 1856, was the "Year of the Stink," and sheets soaked with disinfectant were hung in Parliament to combat the stench of the river.[15] A century later, in the 1950s, the Thames was still so polluted that it was virtually fishless for a forty-three mile stretch in the proximity of London.[16]

Recurrent epidemics swept nineteenth-century European and North American cities with terrifying frequency. Cholera epidemics hit London in successive outbreaks: in 1832, 1848, 1849, 1853, and 1854. Cholera killed 3,500 New Yorkers between June and October of 1832; during the height of the epidemic, 100,000 people, approximately half the population, fled New York.[17] Pathogenic organisms—bacteria, protozoa, worms, viruses, and fungi—are responsible for outbreaks of waterborne diseases. The diseases they cause range from potentially deadly bacterial infections, like cholera and typhoid fever, to intestinal parasites and skin rashes. Most pathogens enter surface water via human and animal feces. Inadequately treated sanitary sewage and urban runoff account for nearly all water contamination by pathogens. As municipal sewage treatment improves, the pathogens present in urban runoff assume a new, until recently unrecognized, importance. Urban runoff has the bacterial contamination of dilute sewage and often exceeds concentrations considered safe for water sports by two to four orders of magnitude.[18] The city's dog population contributes an enormous load of untreated sewage to urban runoff. The water near storm and sanitary sewer outfalls exhibits the highest concentration of pathogens, and is most contaminated immediately after a storm.

The specter of waterborne epidemic disease which haunted cities of the past has been laid to rest in the twentieth century by sewage treatment and the chlorination of public water supplies, but new poisons now threaten drinking water. The impact of cholera and typhoid fever was felt overnight, and their cause, once recognized, was swiftly eradicated. In contrast, the effects of the new poisons are gradual and cumulative. The diseases they generate and the genetic change they precipitate will not become fully evident for years, at which point they may not be readily removable from the environment. To complicate matters further, many of these pollutants have synergistic effects which increase their toxicity; some combine with chlorine to produce new, toxic compounds.[19]

The Environmental Protection Agency has identified 129 "priority toxic pollutants," including heavy metals, pesticides, and organic toxicants. Many are poisonous even in extremely small concentrations, and in low doses over a long period of time can cause neurological damage, cancer, miscarriages, and birth defects. Extremely low, but harmful, concentrations of heavy metals, pesticides, and organic chemicals are often difficult to detect and to remove from water.[20] The existence of so many toxicants also complicates both their measurement and impact. Toxic chemicals are a by-product of modern industrial processes, agricultural practices, and fuel consumption. Toxic pollutants enter streams, rivers, and lakes in industrial discharges, in urban stormwater runoff, and in the fallout of urban dust; they leach into groundwater from sanitary landfills, toxic waste disposal sites, and chemical spills. A 1977 study of surface water quality by the U.S. Environmental Protection Agency demonstrated that heavy metals and synthetic organic pollutants are a significant and widespread problem in water near industrial areas.[21] As industry processes waste more effectively, urban runoff is emerging as a major source of toxic pollutants. Every heavy rainfall sweeps the dirt and debris of the city streets into storm sewers, and with it heavy metals and other toxic materials, oil, and grease.

Turbidity and warmer temperatures, the increase of nutrient salts, and the loss of dissolved oxygen degrade the water quality in urban rivers, streams, and lakes. These factors have less dramatic effects on human health than do pathogens and toxicants, but drastically affect aquatic life and may produce smelly, dirty water with a strange taste. Urban rivers are turbid; the suspended sediment in urban runoff is the major cause of turbidity, but solids from domestic sewage and industrial discharges are also factors. When nutrients like nitrogen and phosphorus reach rivers and lakes in large quantities, they trigger a prolific bloom of algae that chokes waterways with living and decaying plants. As plants decay, they consume dissolved oxygen and produce an unpleasant smell. Fish and many aquatic plants require oxygen, and the most sensitive species die as dissolved oxygen decreases. Lack of oxygen was the major cause of the lack of life in the Thames River in the 1950s. Nutrients enter surface water in sewage and urban runoff containing animal feces and fertilizers.

The character and severity of the water pollution problem varies from city to city. A city's major industries, the degree and type of air pollution, the nature of its sewage treatment and storm drainage systems, and the existence of industry, agriculture, or other cities upstream all determine which water pollutants are a problem. The most unfortunate cities are those, like New Orleans, which are located near the mouths of major rivers, downstream of millions of pollutant sources. The fate of New Orleans' water supply is beyond the city's control.

In 1977, the Council on Environmental Quality studied EPA records of water quality in 159 cities. The average concentration of bacteria exceeded levels considered safe for drinking water in one-quarter of the samples.[22] In Philadelphia, Charlotte, Roanoke, Omaha, and Denver, bacteria exceeded safe levels over 90 percent of the time.[23] Cities which draw their water from lakes and rivers polluted with such high levels of bacteria are caught in an increasingly difficult dilemma. On the one hand, water must be treated with chlorine to prevent the spread of epidemic disease; on the other hand, chlorine combines with some organic pollutants to produce new carcinogenic compounds. Mercury is a problem in all of the twelve major United States river basins sampled by the Environmental Protection Agency in 1977; concentrations exceeded water quality criteria in more than three-fourths of the sample stations, with median values ranging from eight to forty times the standards set by the EPA for the protection of aquatic life.[24] Concentrations of cadmium and selenium also exceeded the proposed EPA criteria for water quality in at least 10 percent of all the samples.[25]

A city's regional climate and precipitation patterns, its underlying geological conditions, the character of water circulations in its rivers, streams, lakes, ponds, and marshes, the types of land uses occupying flood-prone areas, the pattern of its sewage system, and its urban form—all these factors influence where, when, and how water pollutants are concentrated or diluted. Lakes may be more susceptible to pollution than rivers. Water in a river moves steadily toward the mouth; water circulation in lakes is more complex. Circulation time, the time it takes the water in a lake to be completely replaced, varies with the size of the lake's drainage basin, the amount of rainfall it receives, and the depth and surface area of the lake. Circulation time determines how susceptible the lake or pond is to pollution. The longer the circulation time, the more sensitive the lake to contamination, and the more difficult its recovery. Urban harbors and marinas, whether on lakes or rivers, are protected from currents and wave action and have reduced water circulation; therefore, like small lakes and ponds, they are highly sensitive to pollution. Trash and other pollutants accumulate in slips and canals that receive little flushing.

Although lakes and rivers are generally more contaminated than groundwater, they exhibit pollution more quickly and respond to improvement more rapidly. The quality of groundwater is less easily monitored than surface water. Pollution may go undetected until it reaches a well, at which point the source of contamination may be difficult to locate. Water moves very slowly through the ground, and abandonment may be the only alternative when a well becomes contaminated. Leaks from sewers, disposal of toxic industrial wastes, leaching from sanitary landfills, salt from highway de-icing, fertilizers and pesticides, leaks from chemical storage tanks, and the intrusion of sea water or saline groundwater are increasingly polluting groundwater. The pollution of groundwater by hazardous waste now threatens the public water supplies of Tampa, Florida, and Atlantic City, New Jersey, a reservoir in King of Prussia, Pennsylvania, which supplies drinking water to 800,000 people, and the water supplies of countless other communities, many of them as yet undocumented.[26]

Dwindling Water Supplies

Without water, a city cannot survive. Disputes over water rights were among the most bitter and violent struggles in the history of the American West. Today, cities separated by a third of a continent, Denver and Los Angeles, dispute the use of the same Rocky Mountain water. Within the next decade, many cities will face a major water crisis.

The combination of contamination and lowered groundwater has always threatened city water supplies. Privies and graveyards befouled wells, and garbage and sewage polluted rivers and lakes. Until the twentieth century, Chicago dumped its sewage into and drew its water from Lake Michigan. In 1891, typhoid fever took 2,000 lives, a death rate of 173 out of every 100,000 citizens. Chicago cut this death rate by almost 90 percent by diverting its sewage away from Lake Michigan.[27] The construction of the Chicago Drainage Canal in 1900 reversed the flow of the Chicago River, so that sewage flowed to the Mississippi River. This proved a fine solution for Chicago, but created new problems for other cities downstream on the Des Plaines, Illinois, and Mississippi rivers. Other cities, like Boston and New York, had earlier opted to abandon local wells and to import water from distant reservoirs.

The alteration of the city's hydrology by pavement and sewers and their effect on both water availability and water quality had been recognized well before the twentieth century. Benjamin Franklin left a legacy to the city of Philadelphia, recommending that it be used to secure a public water supply. His will, read in Philadelphia in 1790, stated:

> And having considered that the covering of the ground-plot of the city with buildings and pavements, which carry off most of the rain, and prevents its soaking into the Earth and renewing and purifying the Springs, whence the water of wells must gradually grow worse, and in turn be unfit for use, as I find has happened in all old cities, I recommend that at the end of the first hundred years, if not done before, the corporation of the city Employ a part of the hundred thousand pounds in bringing by pipes, the water of the Wissahickon Creek into town, so as to supply the inhabitants . . . [28]

Franklin's prophecy regarding the pollution of urban wells was borne out in Brooklyn, New York. From its initial settlement until 1947, Brooklyn depended on well water. To avoid contamination by surface cesspools, wells were drilled to ever-increasing depths. By 1936, following the installation of sewers and pavement of streets, accompanied by increased pumping, the water table dropped more than thirty-five feet below sea level.[29] The saltwater contamination that resulted led to the abandonment of virtually all the wells by 1947. With pumping halted, the water table gradually rose again, flooding basements and subway tunnels constructed when the water table was lower and causing hundreds of thousands of dollars in damage. Brooklyn, like many suburban communities whose wells have become contaminated, tied into the larger metropolitan water supply system, further increasing the demand for distant water sources. The problem repeats itself in the remainder of modern Long Island, completely dependent upon groundwater, whose wells are continually threatened by contamination and salt-water intrusion.

Approximately three-quarters of all American cities obtain their water supplies from groundwater and three of the thirty-five largest rely on local groundwater alone—Miami, San Antonio, and Memphis. Of the remaining thirty-two, fifteen tap either the Great Lakes or water from major rivers, and twelve garner water from a combination of sources, often importing water from great distances.[30] Each city not only competes with other cities for water but also with local industries that obtain their own water. Supply has never kept pace with demand. Cities must constantly search further and further afield to appropriate water. Only cities which draw from a vast, uncontaminated reservoir of groundwater or from a large, freshwater lake or river are exceptions. Much of New York City's water comes from the Catskill Mountains over one hundred miles away; Boston's water from the Quabbin Valley in central Massachusetts sixty-five miles away; and Los Angeles diverts some of its water from the Colorado River, with its source on the west slope of the Rocky Mountains over six hundred miles away. As growing, dispersed suburban and rural settlements obscure the boundaries between cities, and as the central city loses political power, cities find it more difficult to appropriate distant water supplies.

At the same time urban water supplies are threatened by contamination and depletion, water is squandered. Americans have long used more water per capita than Europeans. The average per capita use in London, Berlin, and seven other European cities was only 39 gallons per day before World War II. During that same period, the average daily consumption in ten American cities was 155 gallons, or nearly four times that amount.[31] By 1975, per capita water use in the United States had reached 168 gallons per day.[32] The average American uses 20 to 80 gallons per day at home. It takes approximately 6 gallons to flush an average toilet, 20 to 40 gallons for a bath, and 20 to 30 gallons to run a washing machine. A leaky faucet dripping one drip per second wastes 4 gallons per day. Watering a garden of 8,000 square feet requires 80 gallons a day in a humid climate and 500 gallons per day in an arid climate.[33]

Uncontaminated fresh water is a diminishing resource. Using drinking water to flush toilets and water lawns is a scandalous waste. Increased industrial demand for water, the invention of domestic appliances like washing machines, and the popularity of a pastoral landscape which requires extensive irrigation, have all contributed to spiraling water use. On the average, domestic use of water accounts for approximately one-third of the water withdrawn from municipal water supplies. Industry utilizes water mainly for cooling and accounts for over a third of the water demand, on the average, but may represent a much greater proportion in some cities. Commercial and public use of water and water lost through leaks in underground pipes account for the remainder. The amount of water lost through leaks is probably equal to the sum of all public water use: for fire fighting, street cleaning, park irrigation, and water for public buildings, swimming pools, and fountains.[34]

Together, dwindling, poisoned water supplies and flooding represent the most significant threats to health and safety of city residents. Water comprises approximately three-quarters of our body. No other resource affects the health of every citizen so intimately and thoroughly, yet cities continue to operate, as they have throughout history, with marginal water systems. Cities respond to each water crisis with narrow solutions which address immediate needs at minimum cost, but ignore the need to promote water conservation and to overhaul overtaxed and outdated collection, storage, and distribution systems. Even as the city thirsts, rainfall is not permitted to enter the ground, but is quickly diverted by the storm drainage system. Parks are built with more pavement and fewer trees, permitting less water to infiltrate the ground. Storm sewers drain the rainfall from parks, and water sprinklers irrigate plants. A water-demanding aesthetic of trees and lawns proliferates in the parks of cities in semiarid and arid climates, further straining the paltry water supply and polluting it with fertilizers, pesticides, and herbicides.

Toxic heavy metals and organic chemicals represent the greatest waterborne threat to health since the epidemics of infectious disease in the eighteenth and nineteenth centuries. Industry and waste disposal sites are located on aquifer recharge areas, and contaminants seep into groundwater. Storm sewers deliver their complement of toxicants to surface water.

As new development locates in headwaters, and houses and businesses crowd and constrict the floodplain, the magnitude of flooding and the damages it inflicts increase. Cities must manage their water resources more wisely. At stake is survival itself.

CHAPTER 7

Controlling and Restoring the Waters

WATER is a source of life, power, comfort, and delight, a universal symbol of purification and renewal. Like a primordial magnet, water pulls at a primitive and deeply rooted part of human nature. More than any other single element besides trees and gardens, water has the greatest potential to forge an emotional link between man and nature in the city. Water is an element of wondrous qualities. It is a liquid, a gas, or a solid. It absorbs energy and transforms it. It transports other elements in suspension and solution, shaping the landscape and nurturing life. It permeates the terrestrial environment—air, earth, and all living organisms. Pure, in the right place, and at the right time, water is an essential resource; impure, and at the wrong place and time, water is a life-threatening hazard.

An abundance of potable water is a crucial concern of all cities. To this concern, we owe some of the greatest architectural monuments of human history and some of the most impressive engineering works: the aqueducts of Rome and Nîmes and the qanāts of Persia. Eleven aqueducts, bringing water from ten to fifty-nine miles away, supplied Imperial Rome with approximately 35 million gallons of water per day.[1] The aqueducts delivered water to reservoirs from which it was distributed to all parts of the city. Pliny described this feat as one of the greatest achievements of Roman civilization: "But if anyone will note the abundance of water skillfully brought into the city, for public uses, for baths, for public basins, for houses, runnels, suburban gardens and villas; if you will note the high aqueducts required for maintaining proper elevation; the mountains which had to be pierced for the same reason, and the valleys it was necessary to fill up; you will conclude that the whole terrestrial orb offers nothing more marvelous."[2]

Water availability not only determined the site of ancient cities, but also the arrangement of buildings within them. More than 3,000 years ago, the Persians first built qanāts—tunnels many miles long and up to three hundred feet deep—to carry water from mountain slopes to cities at the desert's edge. The hydraulic gradient was a measure of status. The houses and fields of the wealthy were uphill and received the water first. They used the water and passed it on. The poor, whose homes and fields were at the lowest elevations, received the water last. Stone-lined conduits, similar in design to their ancient predecessors, provide many Iranian towns with water today. The wealthy residential districts are still elevated, the poor districts depressed.

Aristotle recognized that an ample water supply was essential to both military security and health: "There should be a natural abundance of springs and fountains in the town, or, if there is a deficiency of them, great reservoirs may be established for the collection of rain water, such as will not fail when the inhabitants are cut off from the country by a war . . . for the elements which we use most and oftenest for support of the body contribute most to health, and among those are water and air."[3]

Urban civilizations have long grappled with the problems of water supply and use, sewage disposal, storm drainage, and flood prevention. Together, these have probably received more sustained attention throughout history than any other single urban problem. There is no lack of models for successful resolution to these problems. Urban cultures that arose in the arid and semiarid climates of Persia and the Mediterranean have developed a landscape art that both conserves and displays water. Cities like Denver, Colorado, that have reclaimed their rivers for recreation, while implementing flood prevention and water quality measures, illustrate the many social and economic benefits such projects generate. Cities that have exploited the flood storage and water treatment potential of wetlands demonstrate how parks and urban wilds can serve many uses. Most of these models, however, consist of solutions to a single aspect of the water problem: either storm drainage and flood control, sewage treatment, or water supply and conservation. The comprehensive, natural drainage system of

Woodlands, Texas, a new town thirty miles north of Houston, exemplifies the advantages of considering storm drainage, flood control, water quality, and water conservation in a single scheme. Whatever the scale—from the design of a drain or a fountain to a plan for an entire metropolitan region—the key to devising efficient, effective, and economical solutions is an understanding of the many ways water moves through the city.

Water in Motion

"All the rivers run into the sea, yet the sea is never full; unto the place from whence the rivers come thither they return again."[4] The hydrologic cycle is a grand process by which rain falls on the land, is absorbed by the earth and the plants that grow in it and runs into streams and oceans, then evaporates, returning once more to the air. The power of the sun and the force of gravity drive the hydrologic cycle. The way water moves through the hydrologic cycle determines the distribution of water supplies, the occurrence of floods, and the fate of contaminants disposed of to the air, water, or land.

Only a fraction of the rain that falls on rural woods and fields runs rapidly into streams, rivers, and lakes. Leaves intercept some rain, and soil soaks up much of the remainder. Of the water that soaks into the soil, some is sucked up by plants and later returned to the atmosphere via evapo-transpiration, some evaporates directly from the soil's surface, and the remainder moves slowly through the soil as groundwater. Groundwater may eventually intersect the land's surface at stream beds and springs or may remain deep beneath the surface in vast underground reservoirs or aquifers (see figure 7.10). Only on steep slopes, on bare rock or ice, or when the soil is saturated, does water run off the ground's surface. The great capacity of soil and the organisms within it to absorb water and to filter and use the elements suspended or dissolved within it prevents floods, protects water quality, and conserves and restores water supplies.

Traditional urban storm drainage systems short-circuit this portion of the hydrologic cycle, with disastrous results. Some cities have attempted to reestablish that link in the cycle by retaining stormwater and permitting it to infiltrate the soil; others have merely detained stormwater until the flood hazard has passed and water can be treated or safely released.

Some of the sources of water pollution—factories, sewage treatment plants, erosion from construction sites, urban runoff from storm sewers, and the fallout of dust from the air—can be pinpointed to the discharge from a specific pipe or ditch; others are more diffuse. "Point" sources are readily monitored and regulated. One can identify and measure the specific pollutants discharged, plot the precise location where they enter the water, and, given the depth and size of the water body and the circulation pattern of the water within it, predict the likely pattern of their distribution. New "point" sources, like factories or treatment plants, can be located in areas with adequate water circulation, distant from swimming beaches.

As more and more industries and municipalities conform to federal water standards, "nonpoint" sources, like air pollution and urban runoff, will become more critical water pollution problems. Nonpoint sources are extremely difficult to regulate except by collecting and treating all stormwater. Flood prevention strategies that involve the retention or detention of stormwater promise to benefit water quality, since most of the suspended solids settle out in standing water and many of the nutrients, oil, and grease are filtered out as water moves through the soil.

Storing Floodwaters

The past decade has seen a profusion of outstanding, innovative approaches to flood control by American cities. Rooftops, plazas, parking lots, and parks have been designed to store stormwater, and woods and wetlands in the headwaters preserved for their natural storage capacity, thereby reducing floods and the cost of storm drainage systems and, in some cases, permitting the treatment of urban runoff. This has generally been accomplished with little or no extra construction cost, with minimal inconvenience, and has resulted in the acquisition of new recreation land. The key to preventing floods and minimizing the destruction they wreak lies in a dual strategy of storing stormwater until flooding peaks and eliminating obstacles to floodwaters within the floodplain. These principles apply whether designing a rooftop to pond and detain rain water or designating undeveloped urban wetlands as parkland to soak up and hold water in soil and plants; whether designing a pedestrian bridge so as not to block debris in floodwaters or establishing land use and building regulations in floodplains.


DIAGRAM
ADAPTED TO PLEASURE TRAVEL
PARK DEPARTMENT · CITY OF BOSTON
MAP
BACK BAY FENS
COMMONWEALTH AVENUE
BEACON STREET
AUDUBON ROAD
a
b
c

Floodwater storage and recreation are compatible in large urban parks. Parks that exploit the natural flood storage capacity of floodplains capture the water's edge for the public landscape. The recent profusion of urban parks that serve multiple purposes of flood control, water quality improvement, and recreation do not reflect a new idea, but rather the rediscovery of old solutions. Many nineteenth-century and early-twentieth-century parks, now valued for their access to urban rivers and lakefronts, were originally designed as flood control and water quality projects.

Landscape architects and urban historians regard Boston's "Emerald Necklace" park system as a landmark in American park planning, but few appreciate that a third of the system was designed as a flood control and water quality project and not primarily for recreation. The designer, Frederick Law Olmsted, created the Fens and the Riverway to combat the flooding and pollution problems of Boston's Back Bay tidal flats; public recreation was an incidental benefit and Olmsted himself objected to the use of the word "park" for the Fens, since he did not consider it an appropriate spot for any recreation beyond a stroll or drive along the border of the marsh. The statement printed on Olmsted's 1881 map, "General Plan for the Sanitary Improvement of the Muddy River," declares this intent:

> The primary design of the scheme here shown is to abate existing nuisances, avoid threatened dangers and provide for the permanent, wholesome and seemly disposition of the drainage of Muddy River Valley. This is proposed to be accomplished chiefly by embanking, contracting and deepening the existing creek and ponds and excluding sewage and tides. The secondary design is to make use of the embankments required for the above purpose to complete the promenade here shown, of which the Common, Public Garden and Commonwealth Avenue would form about one-third already prepared and in use, and the Back Bay, now half-formed, and in progress, another third . . . [5]

Until recently, historians have admired Olmsted's Boston park system chiefly for its connection of the central city with outlying suburbs, in a series of parks and connecting parkways, forgetting the flood control and water quality purpose that portions of it originally served. Olmsted designed the Fens as an irregularly shaped depression scooped out of the tidal flats (see figure 7.1). The configuration

FIGURE 7.1

Plan for the Fens, Boston, 1887, showing retention basins (a) and dredged river channels (b) designed to prevent flooding in adjacent areas, and a tidal gate (c) to prevent water stagnation. Modern, "innovative" projects in Chicago and Denver are based on some of the same principles.

and size of the thirty-acre basin permitted the amount of water to double without raising the water level more than a few feet; during floods, twenty additional acres could be covered with water. Gently sloping banks and an irregularly shaped edge reduced waves. A tidal gate at the entry to the Charles River regulated the flow of the tides to prevent flooding and to enhance flushing of the basin. Part of Olmsted's plan was the restoration of the former salt marsh; he planted the banks of the basin with plants that could tolerate both salt and brackish water and withstand changing water levels. Olmsted felt that the juxtaposition of salt marsh and city

> would be novel, certainly, in labored urban grounds, and there may be a momentary question of its dignity and appropriateness . . . but [it] is a direct development of the original conditions of the locality in adaptation to the needs of a dense community. So regarded, it will be found to be, in the artistic sense of the word, natural, and possibly to suggest a modest poetic sentiment more grateful to townweary minds than an elaborate and elegant gardenlike work would have yielded.[6]

Portions of the Fens were planted by 1884 and within ten years had the look of a landscape that had always been there. The rapid success was largely due to the sheer quantity and diversity of vegetation planted: more than 100,000 shrubs, vines, and flowers in one area of two-and-a-half acres.[7]

The Muddy River flows into the Fens, its current alignment and shape the nineteenth century's artificial creation. The banks of the Muddy River were regraded, lined with walkways, crossed by bridges for pedestrians and vehicles, and planted with grasses, shrubs, and trees to form the "Riverway" (figure 7.2). Like the Fens, within a few decades of construction, the Riverway had the appearance of a natural floodplain penetrating the city (figure 7.3). Depressed below street level, with steep, wooded banks between the roadway above and the path below, it is still a retreat in the middle of modern Boston. The Muddy River survives more intact than the Fens. After the Charles River Dam was constructed in the early twentieth century, the salt marsh declined, the Fens lost the aid of the tides in enhancing water circulation, and ultimately became a dumping ground for fill from the subway and other projects.

Chicago, built on a flat plain only slightly higher than Lake Michigan, has been plagued by drainage and flooding problems throughout its history and has responded with ingenious solutions. In the mid 1800s Chicago raised its street level twelve feet, jacked up and elevated existing buildings, and installed a new storm sewer system. After 12 percent of the city's population died in 1885 from cholera,

FIGURE 7.2
The Riverway, Boston, ca 1892, showing graded embankments ready for planting. To the right, a mound separates the park from a recently installed trolley line.

FIGURE 7.3
The Riverway approximately thirty years after construction, having achieved a wholly "natural" appearance, the adjacent trolley line now hidden behind mound and plants.

typhoid, and dysentery contracted from a polluted water supply, Chicago established an autonomous regional agency, the Metropolitan Sanitary District of greater Chicago. For nearly a century, this organization has coordinated Chicago's flood control, storm drainage, and sewage treatment. Chicago has a combined sanitary and storm sewer system and now uses stormwater detention basins located throughout the city in floodplains to detain stormwater before it reaches storm sewers, along with an extensive system of deep, underground tunnels to store the overflow from the sewer system until it can be treated. The Melvina Ditch Detention Reservoir is one of the many large detention basins operated by the Metropolitan Sanitary District and used for both flood control and recreation. Steps lead down the basin's side slope to playfields and volleyball and basketball courts in the bottom of the basin. Children ski and toboggan down the slopes of a large earthen mound at the corner of the basin and skate on an ice rink created by flooding a large, paved area near the basin's inlet. When flooded, the reservoir holds 165 acre-feet of water.[8]

Parking lots, which account for much of the open, paved land in American cities, can also be designed to detain or even retain stormwater, as one was at the First National Bank in Boulder, Colorado, where a section of the lot can hold up to two feet of water. Consolidated Freightways in St. Louis, Missouri, constructed its parking lot to detain storm flows and netted a $35,000 savings in the cost of the storm drainage system.[9] Outside the downtown, in less dense parts of the city, it may be preferable to retain water long enough for it to infiltrate the soil. Porous pavement—porous asphalt, modular paving, and gravel—over well-drained soils or in combination with dry wells will permit more rainfall to soak into the ground rather than run off into storm sewers. A pavement of lattice concrete blocks, with soil and grass in the interstices, is widely used in European cities, and has been employed in parts of some American cities such as Los Angeles and Dayton (see figure 3.11).

Restoring and Conserving Water

The restoration of water is also an essential function. A sewage treatment facility can be attractive and, in certain phases of its operation, compatible with recreation. In 1967, after the state of Michigan threatened to cite the city of Mt. Clemens for pollution of the Clinton River, the city combined a new sewage treatment system with a park.[10] Combined storm and sanitary sewers comprised 90 percent of the Mt. Clemens sewer system, and sewer overflows during rainstorms had been responsible, in part, for pollution of the river. After several years' study, the city determined that collecting, storing, and treating the combined overflow was more feasible, more efficient, and less costly than separating the storm and sanitary sewer systems, and that it also offered an opportunity to create new parkland. The city constructed its new sewer overflow treatment facility with three small lakes and a park on a former sanitary landfill site. Sewer overflows remain in the first lake for anywhere from one to four days, until they can be treated in the processing building, then the water is released for aeration to the second lake for an additional seven days. By the time the treated effluent reaches the third lake, 2.3 acres and 9 feet deep, it is appropriate for boating and fishing and for irrigating the park's landscape. In winter, when the third lake freezes, it is used for skating and ice hockey. The city plans to stock it with fish and construct a dock for summer recreation.

Arcata, California, exploits the properties of plants and soil to assimilate wastes, by using a wetland as part of its wastewater treatment process. Arcata renovated and reconstructed a degraded, existing wetland adjacent to its sewage treatment plant to enhance the quality of its water after treatment.[11] The reconstructed wetland serves other functions including wildlife habitat and recreation (see chapter 13). Other cities, including Austin, Texas, have experimented with natural or constructed wetlands to treat sewage effluents. Because wetland or aquatic plant systems to treat wastewater require more land area than conventional treatment methods, they are likely to be most appropriate for small-to-moderate-sized cities. The danger of introducing concentrated heavy metals and toxicants into the food chain rules out the use of such systems when effluent is heavily contaminated by these pollutants. Wetland treatment systems will be most useful in providing advanced treatment where traditional chemical methods are too costly, and they are likely to become more common as current successes become better known.[12]

Sewage treatment can both conserve water and create an aesthetic resource. Five miles out of Santa Fe, New Mexico, a resort named The Bishop's Lodge has built a package sewage treatment facility to provide irrigation water for the resort's pasture and garden (figure 7.4). It forms an unusual amenity in this water-poor landscape. Treated wastewater tumbles down waterfalls and cascades through

FIGURE 7.4
A rocky cascade at Bishop's Lodge, New Mexico, part of a man-made system of waterfalls and sculpted channels designed to treat sewage effluent.

sculpted channels and streams from high ground into a large pool. These "seven magic pools" provide tertiary treatment to the wastewater by aerating it and exposing it to sunlight.[13] The water cascades a hundred feet to the resort's entrance; landscaping and earth mounds screen the treatment plant from view. Water conservation is an important benefit. Formerly, The Bishop's Lodge used 10,000 gallons of well water per day to irrigate its lawns, nearly one-third of the total daily consumption. Irrigation water now consists entirely of treated sewage effluent, an example to inspire cities to explore waste treatment that is beautiful as well as economical.

Irrigation is used routinely to maintain lawns and trees in the city, but as water shortages increase, the city must explore a more water-conserving and drought-tolerant landscape. The landscape tradition that arose in the urban civilizations of the arid and semiarid regions surrounding the Mediterranean offers many models for the modern city, for example, the protected courtyard garden or patio. The courtyards nurture lush vegetation with minimal irrigation by protecting plants from dehydrating winds and radiated heat; the barren streets of the city heighten the aesthetic relief of the courtyards. The garden art of the Mediterranean and the Middle East also exploits the many physical properties and aesthetic qualities of water with great economy. A Persian garden accomplishes a great emotional and aesthetic effect with only a trickle of water. The subtle, refined, and profound treatment of water in the Hispano-Islamic garden makes a 100-foot jet of water elsewhere seem a vulgar display of power. An art that developed over the course of thousands of years and spread with the Moslem religion west across North Africa to Spain and east to Pakistan and India, the Islamic garden takes many forms. Each form, however, reflects the inspired manipulation of water, employing the sight and sound of water to engender a cool atmosphere of serenity and retreat. Water cascades down sculpted channels or through plain runnels into brimming basins. Slight variations in the shape of the channel produce wave patterns that catch the light in diverse ways. Water may appear precious, like a gem, as it flows over blue tiles. Water may bubble up from below the surface, or trace a graceful arc, or flow as a sheet over a molded edge. Water-poor cities should conserve their water by reserving irrigation for special or symbolic places or protected spaces where plants require minimal water. The importance of these places will thereby be heightened. Paley Park owes much of its success as an urban retreat to the contrast between its environment and the noisy, hot, dry city surrounding it.

The design for Foothill College, in the semiarid climate of Los Altos, California, as originally conceived, created an oasis garden to exploit the aesthetic impact of the contrast between irrigated and nonirrigated landscape. The architects designed the college as a compound of buildings, surrounding a central courtyard, on a hilltop, with parking below. The courtyard was designed as an oasis garden with lush vegetation sustained by irrigation; the hillside was seeded with drought-tolerant grasses. The contrast between the dry, brown hillside and the green, protected courtyard lent to the interior an atmosphere of comfort, retreat, and renewal. Since the college began to irrigate the hillside also, however, this atmosphere has been largely lost. It may be recaptured when water shortages in Northern California force the college to reduce irrigation.

In cities of a temperate, humid climate, enough rain falls to support a diverse community of plants without irrigation, so long as that water is permitted to infiltrate the soil and plants are protected from winds and radiant heat. Chestnut Park in downtown Philadelphia is paved and landscaped with plants native to that region. Rain falling within the park seeps between cracks in the pavement to the soil below. A deep layer of gravel beneath the topsoil serves both as a drainage device and as a reservoir, storing the water until plant roots can absorb it and preventing roots from becoming waterlogged. The plants have flourished and require no irrigation. Meanwhile, the park contributes no stormwater runoff to the city's sewers.

Designing the City to Conserve and Restore Water and to Prevent Floods

The prevention of floods and the conservation and restoration of water will only be accomplished by the cumulative effect of many individual actions throughout the city. But the impact of each will be insignificant, and might even be counterproductive, if not part of a comprehensive plan that takes into account the hydrologic system of the entire city and its region. Water pollution or flooding problems at one place may be generated somewhere else, and a solution to the water supply problem may, in the end, aggravate water pollution. The most effective, efficient, and economical solutions to urban water problems are frequently found upstream of where the problem is felt most forcefully.

The Charles River watershed is the most densely populated river basin in New England. Its headwaters are sparsely developed, but the cities of Boston and Cambridge crowd the banks of its lower basin. The U.S. Army Corps of Engineers, in a 1965 flood control study of the Charles River watershed, concluded that a new dam must be built across the mouth of the Charles River to control flooding from urban runoff in the lower basin and that over the next thirty to forty years flood-control measures upstream must be taken to prevent flooding in the lower basin. They estimated that upstream flood-control structures would cost $100 million and, instead, recommended an action requiring one-tenth the cost:

> The flood control management plan recommended by this Corps' study calls for federal acquisition and perpetual protection of seventeen crucial natural valley storage areas totalling some 8,500 acres. The logic of the scheme is compelling. Nature has already provided the least cost solution to future flooding in the form of extensive wetlands which moderate extreme highs and lows in stream flow. Rather than attempt to improve on this natural protection

mechanism, it is both prudent and economical to leave the hydrologic regime established over the millenia undisturbed. In the opinion of the study team, construction of any of the most likely alternatives, a 55,000 acre/foot reservoir, or extensive walls or dikes, can add nothing.[14]

The effective role of the wetlands in flood prevention was demonstrated while the Corps of Engineers was engaged in its study. In 1968 a large storm hit Boston, and urban runoff in the lower basin crested at the old Charles River Dam within hours. The upstream peak took four days to reach the dam. The wetlands in the headwaters filled with water, gradually releasing it over the course of a month. One stretch of the river widened from fifty feet to nearly a mile.[15] Boston's second circumferential interstate highway was under construction at the time, and because rapid urbanization threatened the wetlands, the Corps decided that acquisition of the wetlands was the most effective method of preserving their flood storage capacity. They selected seventeen natural storage areas,

FIGURE 7.5

Natural Valley Storage Areas, Boston: wetlands purchased as part of a flood control program to store floodwaters until peak flows subside downstream. The 8,500 acres of wetlands cost one-tenth the price of dams and levees a more traditional approach would have entailed.

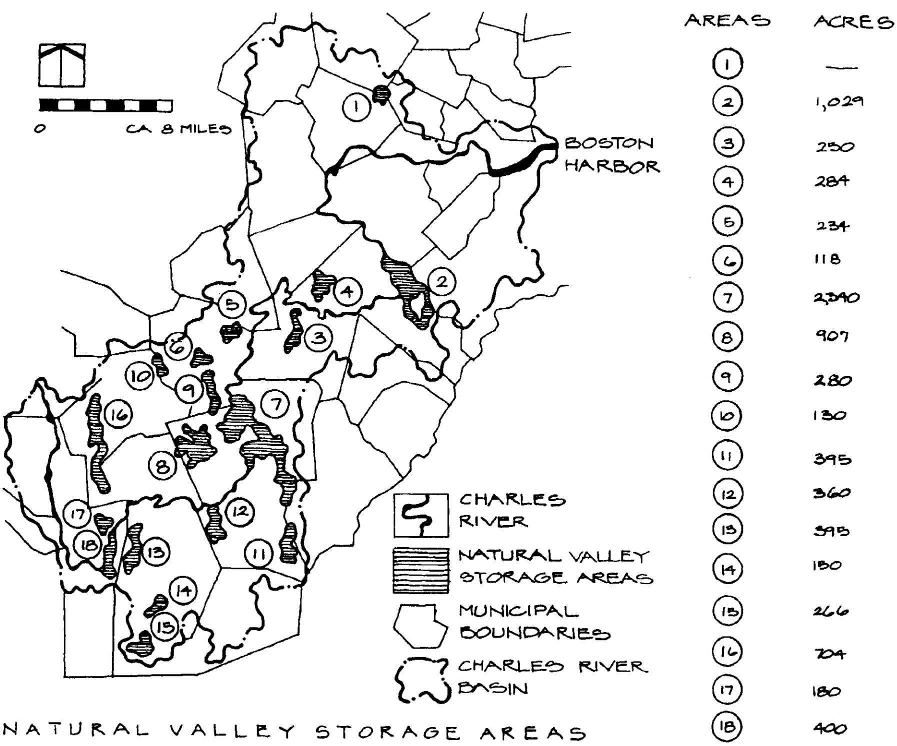


FIGURE 7.6(a)
Natural valley storage area in summer, with both the Charles River and adjacent wetlands clearly visible.

FIGURE 7.6(b)
The same area after spring floods, the river channel and wetlands now a single entity. Wetlands not only provide overflow space, but also absorb floodwaters. Had these wetlands been built upon, this water would have flooded downtown Boston.

ranging in size from 118 to 2,340 acres, from among 20,000 acres of wetlands in the middle and upper reaches of the Charles River (see figures 7.5 and 7.6). In 1974, Congress approved and appropriated $10 million to buy the wetlands for nonstructural flood control. The Corps of Engineers made the first purchase in 1977. It will retain ownership of the land, and the Massachusetts Fisheries and Wildlife Division will manage the areas as wildlife refuges.[16]

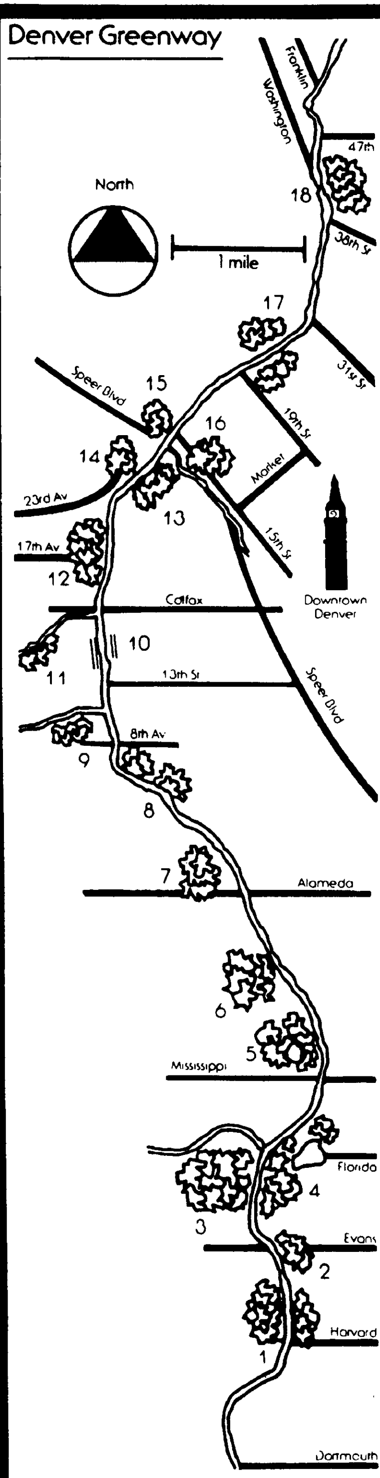
Denver, Colorado, is an outstanding example of a city that has implemented a comprehensive, coordinated set of strategies for managing its water. The devastating property losses caused by the 1965 flood provided the incentive for the formation of the Urban Drainage and Flood Control District in 1969. Earlier, each of the region's thirty-four independent local governments had employed different methods for calculating flood risks and for designing the capacity of their storm drainage systems. Some had designed storm drainage systems to accommodate a fifty-year storm; others had provided for floods from a two-year storm.[17] The Urban Drainage and Flood Control District now works with local governments to insure the adoption and implementation of adequate and consistent floodplain regulations and to undertake master plans for individual watersheds. The *Urban Storm Drainage Criteria Manual*, published in 1969, guides the work in the district and insures consistent, state-of-the-art drainage and flood control across the entire metropolitan region. The manual covers issues of policy, law, and planning related to flood control and storm drainage, the calculation of stormwater runoff, the design of the storm drainage system, and the mitigation of flood damage.

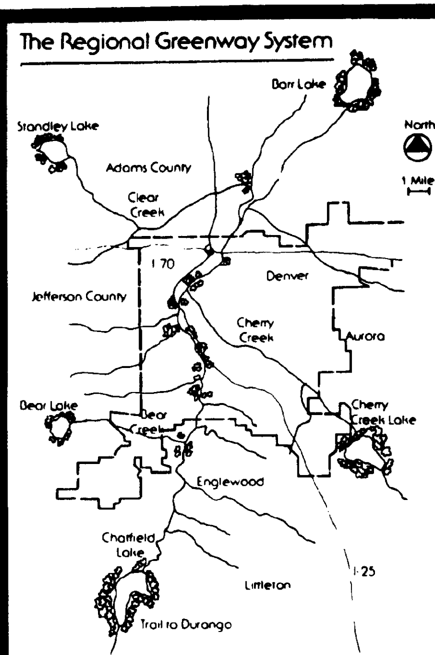
Each year Denver's Urban Drainage and Flood Control District compiles a list for master planning of between five and ten projects for which district aid has been requested by local governments. The project must be multijurisdictional, and local governments must agree to pay half of the cost of the study and half the cost of construction, and to assume ownership after completion.[18] The district maps the one hundred-year floodplain, prepares an outline of the work to be done, and coordinates consulting engineers on behalf of the local governments. The studies cover an entire drainage basin, rather than piecemeal projects. The master plan spells out where flood problems exist and recommends remedial measures. Its recommendations will include the adoption of floodplain regulations and the implementation of such projects as stormwater detention, channel improvements, and check dams along streams to create ponds and slow stream flow. The city and county of Denver now require property owners to pay a storm drainage service charge to help finance the construction and maintenance of the stormwater system. The amount of building and paved surface on the property determines the rate billed. In 1981, when the service charge was enacted, the city estimated that annual revenues would amount to $4.7 million.[19]

Citizens of Denver have transformed a ten-mile stretch of the South Platte River, which flows through downtown Denver, from a rubble-strewn, filthy, open sewer, lined by garbage and derelict land, into a landscaped park for water sports, public gatherings, bicycling and hiking, and nature study. Like the Urban Drainage and Flood Control District, the development of Denver's South Platte "Greenway" has its roots in the disastrous flood of 1965. A flurry of investigations and reports followed the 1965 flood, but little was done about the South Platte itself until a flood in 1973, an election year, brought the issue of the river and flood hazard under the public eye again. A nine-member task force, the Platte River Development Committee, appointed by Denver's mayor and backed by over $2 million in seed money from the city, proceeded to lay plans for the river, raise additional money from public and private sources, and implement park projects.[20]

The Platte River "Greenway" (figure 7.7) now links eighteen parks with fifteen miles of interconnected trails; with 450 acres, it is Denver's largest single park. When complete, the "Greenway" will extend twenty-five miles upstream to the foot of the Rocky Mountains and twenty miles downstream to a state recreation area on the Colorado plains. Proponents hope that suburban communities will develop trails along the Platte's tributaries, so that eventually 120 miles of continuous river trails would lace the metropolitan region. The entire ten-mile Platte River "Greenway" is now a regional center for boating, lined by bicycle and hiking trails, and punctuated by parks. Check dams in the South Platte were designed to create white water "staircases" for canoes, kayaks, and rafts. Competitions are now held along the man-made "Challenge Run" and slalom kayak course. At one spot, where an eight-foot dam needed to retain water for a power plant made the river impassable by boat, a boat chute was created to permit boats and rafts to negotiate the dam without portage and to serve simultaneously as a flood control device. Care-

FIGURE 7.7
The Platte River Greenway. Designed to accommodate both floodwaters and recreation, the Greenway is now Denver's largest single park with 450 acres and fifteen miles of interconnected trails.





1. Frontier Park
2. Pasquinel's Landing
3. Ruby Hill Park
4. Overland Pond
5. Vanderbilt Park
6. Habitat Park
7. Valverde Park
8. Frog Hollow
9. Weir Gulch Marina
10. Zuni Whitewater Chute
11. Lakewood Gulch/ Rude Park
12. Gates-Crescent Park
13. Centennial Park
14. Fishback Landing
15. Confluence Park
16. Cherry Creek Park
17. Riverfront Park
18. Globeville Landing

The Greenway Foundation
1421 Court Place
Denver, Colorado 80202
(303)623-2252

fully arranged weirs and rocks were placed to create a series of pools, riffles, and eddies ideal for recreational boating.[21] The central channel of the Platte was excavated and large boulders and rocks placed to create a deeper stream during periods of low river flow. Water is now released from the upstream Chatfield Dam, a major flood control facility, in "recreation slugs" timed to enhance river flow for water sports during peak weekend recreation periods.

The many new parks along the Platte provide places to launch boats and to watch their progress through the chutes and slalom run. The Platte River Development Committee built the first park along the "Greenway" at the confluence of Cherry Creek and the South Platte River, where the city of Denver was originally founded. The large, terraced plaza of Confluence Park steps down to the river and provides an overview of part of the slalom run (figure 7.8). Engineers designed the shape of the plaza and the opposite bank with a smooth profile to present minimal resistance to floodwaters, and designed the foundation to resist the river's hydrodynamic forces, by laying it directly on the riverbed and securing it with piles to the underlying shale bedrock.[22] Years of accumulated rubble,

FIGURE 7.8
Confluence Park, a flood-proof plaza near the heart of downtown Denver, affording a place to launch rafts and kayaks and an overview of the slalom run.

which had blocked floodwaters and increased flood depth, were used in the construction of paths, boat chutes, and bank improvements. An amphitheater across the river from Confluence Park was created with fill from river debris and the ruins of a bridge demolished by the 1973 flood. Pedestrian bridges, which link Confluence Park with the amphitheater and opposite banks in other parts of the "Greenway," are designed to pose no obstruction to floodwaters, since a major cause of past flood damage was the piling-up of debris at bridges in dams which diverted floodwaters into adjacent parts of the city. The wooden pedestrian bridges are designed to come loose from their concrete piers when floodwaters reach the bridge deck. Cables attached to the bridge will hold it against the downstream bank until flooding subsides.[23] All of the parks along the floodway are designed not only to resist flood damage, but also to provide flood storage. The grading for a new bicycle path at Centennial Park, for example, was based on flood hydraulics.

With increased use of the river for walking, bicycling, and boating has come a heightened awareness of the river's water quality and a strong constituency for improving and maintaining that quality. Many sources of water pollution have been removed from the river banks as a consequence: a dump has been converted to a nature preserve; a highway maintenance yard piled with salt and sand has become Frog Hollow Park. Pressure has been brought upon the city to cease dumping street sweepings and salt-laden snow in the river. The residential neighborhoods bordering the South Platte, several of them Denver's poorest, have gained new parks and a river environment free from former nuisances and hazards.

The Platte River "Greenway" was accomplished through the coordinated efforts of public and private organizations and individual citizens. The Platte River Greenway Foundation, established as a nonprofit, tax-exempt institution, ultimately collected over $6 million from federal, state, and local governments, from private foundations, and from individuals. The foundation, though private, cooperated closely with the city from its inception; funded and coordinated the implementation of projects on behalf of the city; and then turned over the responsibility of maintenance to the city's parks department.[24]

Rooftops, plazas, and parking lots often provide the only space to detain stormwater in densely built downtown areas, and Denver is no exception. The city of Denver requires new and renovated buildings in the Skyline Urban Renewal District to detain stormwater on site. The alternative, upgrading the existing storm sewer system to

FIGURE 7.9
Skyline Plaza in downtown Denver ponds up to several inches of stormwater, releasing it gradually. There is space to detain stormwater even in the most congested parts of cities.

accommodate the increased runoff, would have been prohibitively expensive and would have increased flooding in the nearby South Platte River. Developers have used a combination of rooftops, plazas, and parking lots to detain stormwater. Roofs in the Denver area are designed to support a snow load equivalent to approximately six inches of water. Engineers designed a "detention ring" to fit around the drain of a flat roof, which ponds up to three inches of water, then releases it at the rate of one-half inch per hour. A safety feature permits a severe storm to overflow the ring. Denver-area plazas and parking lots have been designed to store stormwater runoff with minimal inconvenience to pedestrians (figure 7.9). One depressed, downtown Denver plaza, constructed above three floors of underground parking, accommodates runoff from the ten-year storm; stormwater drains directly to the sewer at the rate of one inch per hour. Ponding does not disrupt use of the plaza, since elevated portions of the plaza permit pedestrians to walk across it when lower portions are flooded.

Existing building codes in most American cities require that roofs be designed to withstand the equivalent of six inches of water over a short period (usually twenty-four hours), and a few cities have incorporated rooftop detention of stormwater into building codes. European cities like Stuttgart have applied the use of "wet roofs" to reduce the building's heat load as well, and thus decrease energy consumption for air conditioning. If incorporated into roof garden design, stormwater detention can also become an aesthetic amenity.

In little more than one decade, Denver has achieved considerable success in reclaiming its waters. Consider how much might be accomplished in the construction of a new city unhampered by existing buildings, streets, and drainage systems. Such a case is the new town of Woodlands, Texas, with a projected ultimate population of 150,000. When developer George Mitchell first decided to build a new town on 20,000 acres of pine–oak woodland north of Houston, he envisioned a city that would spring up in the midst of the woods, in harmony with the forces of nature. He formed the Mitchell Energy and Development Corporation and hired an interdisciplinary team of planners, engineers, scientists, and market specialists. Initially this team consisted of four firms. Over the following decade the team was expanded to include a well-staffed corporation with dozens of consultants. By 1971, when the preliminary ecological planning study and parallel market research were complete and a general plan for the new town was underway, water had emerged as the critical factor. The Woodlands' "natural drainage system" exploits the capacity of natural, wooded floodplains to accommodate stormwater runoff and of well-drained soils to soak up and store rainfall. It reduces the combination of increased flooding and lower stream flows normally associated with urbanization, it maintains water quality, and recharges the aquifer that underlies neighboring Houston (figure 7.10). The wooded floodplain, drainage channels, and recharge soils form a townwide open-space system, a natural drainage system that represents a substantial savings over the cost of constructing a conventional storm sewer system. When it was originally proposed, engineers compared the cost of the natural drainage system to that for a conventional storm system and estimated that the natural drainage system would save the developer over $14 million.[26]

Much of the Woodlands site is very flat, with extensive areas of poorly drained soils. The construction of a traditional storm drainage system would have entailed clearance of extensive woodlands, and lowered water tables with loss of trees. It would also have in-

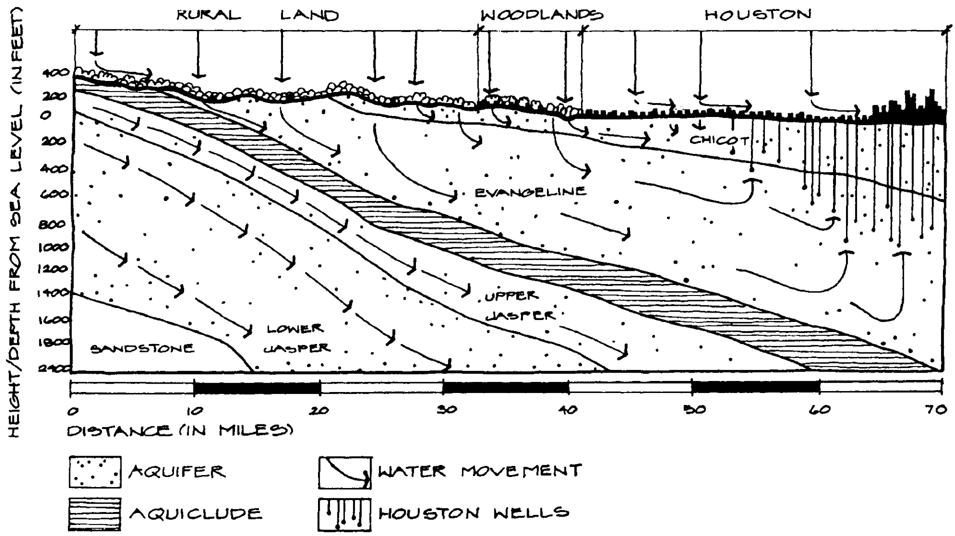


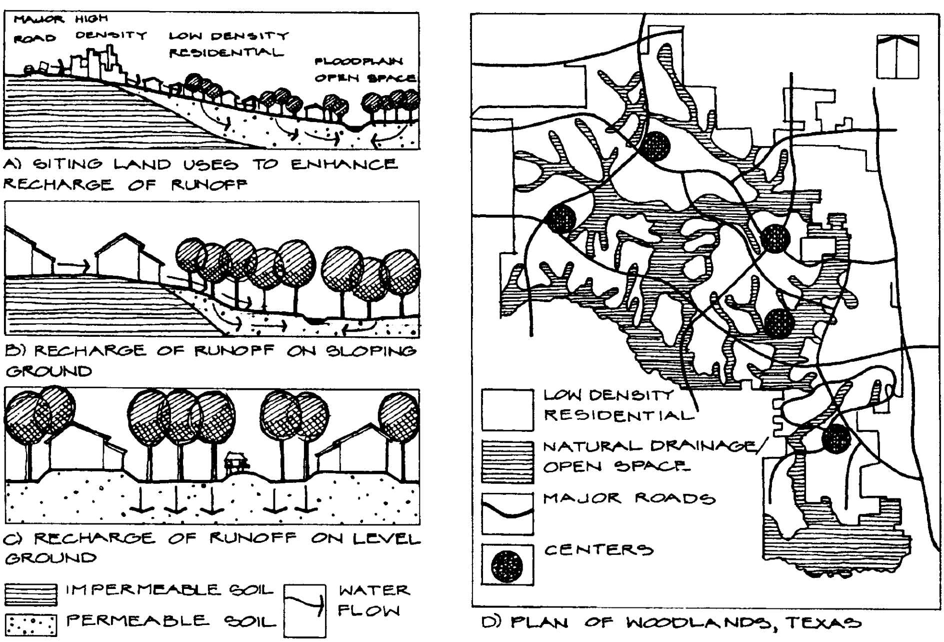
FIGURE 7.10
Aquifers underlying Houston and Woodlands, Texas. The new town of Woodlands was designed so that rain would continue to soak into the ground to replenish the Chicot and Evangeline aquifers, from which nearby Houston draws its water supply.

creased flooding and degraded water quality downstream and, combined with an estimated 15 million gallons per day withdrawal from underlying aquifers, might have contributed to further ground subsidence under the city of Houston (see chapter 4). The firm of Wallace McHarg Roberts and Todd, landscape architects and ecological planners, conceived a natural drainage system to resolve these problems and enable the developer to retain his vision of the future city.[26]

The natural drainage system is composed of two subsystems: one stores and absorbs rainfall from frequent storms; the other drains floodwater from major storms (see figure 7.11). The general plan responded to the major drainage system by locating large roads and dense development on ridge lines and higher elevations, while preserving the floodplains in parks and open land, and allocating low-density housing to the intermediate area. Use of the floodplains and drainage channels as open space works well from both ecological and social standpoints. Most of the spectacular trees on the site occur within the floodplains of two major creeks—large, evergreen magnolias, water and willow oaks, and towering pines. These same floodplains also harbor a diverse, abundant native wildlife, including white-tailed deer, opossum, armadillos, bobcats, and many birds, and provide the corridors along which they move. The wooded easements required for drainage and flood control purposes are in most cases sufficient to insure that all but the most sensitive wildlife species may remain. A continuous system of hiking, equestrian, and bicycle trails runs along the drainage network, linking all parts of the new town.

Although this larger floodplain network drains runoff from major storms, well-drained soils and ponds absorb or store rain close to where it falls, either in private yards or in nearby parks. This local drainage system responds to subtle changes in topography and soils. Roads, golf courses, and parks are designed to impound stormwater and enhance its absorption by well-drained soils. Maintaining the structure of these soils, so essential to their ability to absorb water, required strict regulation of construction activities. Areas designated as "recharge soils" were left wooded. In some cases, building construction proceeded within a fenced-off zone that extended only a few feet on all sides from the building foundation. This practice has

FIGURE 7.11
The "natural drainage system" at Woodlands, Texas, exploits well-drained soils to absorb rainfall and wooded swales and stream valleys to carry off the stormwaters, thereby preventing floods downstream. Using existing, wooded floodplains for the storm drainage system secured a linked system of parks and trails throughout the town and saved millions of dollars.



produced a new town with the appearance of having literally sprung up within the woods.

Models estimating the increase in peak flows generated by development at the Woodlands revealed that they will increase by only 55 percent, as compared to the 180 percent increase resulting from current "normal" development in Houston.[27] Studies indicate that the water quality of urban runoff in the phase one portion of the new town is much better than that of other Houston residential areas. The final test of the natural drainage system occurred when a record storm hit the area in April 1979. Nine inches of rain fell within five hours, and no house within the Woodlands flooded although adjacent subdivisions were awash.[28]

The economic benefits of a natural drainage system may not elsewhere be as dramatic as in Woodlands with its extensive flat areas and poorly drained soils, but they will accrue nonetheless. The Woodlands is and will continue to be a showpiece of drainage design, from the most mundane details of pavement and channel design to the coordination of soils, ponds, swales, and floodplains into a comprehensive drainage system.

A Plan for Every City

The successful management of water in the city will require comprehensive efforts, many individual actions, and the perception that storm drainage, flood control, water supply, water conservation, waste disposal, and sewage treatment are all facets of a much broader system. Every city should construct a framework within which both the consequences of major metropolitan efforts and the cumulative effect of individual actions can be appreciated.

The flow of water into and through the city—including where it comes from, how and where it is used, treated, and released, and the seasonal variation of this pattern—varies from city to city, depending on regional climate, topographic setting, pollution sources, and urban form. Do floods threaten a major portion of the city; and is development upstream the greater problem or constriction of the floodplain within the city? Is the city's water supply threatened by pollution of groundwater or surface water, or by competing demands with other towns and cities in the region? Are large, industrial pollutors the problem, or combined sanitary and storm sewage overflows? Are extremes of high flows and low flows a problem, or limited water circulation? Identifying the areas at most risk to flood hazard and those that currently provide flood storage will help in devising a comprehensive flood control strategy. Identifying the major sources of water pollution within the city, the dispersion patterns of pollutants within surface and groundwater, and water bodies with poor circulation will aid in singling out the most severely contaminated places. Knowing the most significant water resources, those that currently provide the city with water or have the potential to do so in the future, and the areas that are most sensitive to water pollution, like aquifer recharge areas, headwater streams, lakes, and ponds, will help to preserve those resources.

A comprehensive plan to prevent floods and conserve and restore the city's water should:

- address the city's most critical problems of flooding, water pollution, and water supply, with particular attention to reducing risk in the most flood-prone or contaminated areas
- protect the city's most important water resources, both those currently used for water supply and those with potential to satisfy increasing demand
- locate new parks and other landscaped open space to preserve flood storage in the headwaters and the floodplain downstream, and to enhance recharge of groundwater
- encourage new industry, waste disposal sites, and other polluting land uses to locate outside floodplains and groundwater recharge areas that are highly vulnerable to water pollution
- locate new public buildings outside flood-prone areas and encourage new residential and commercial development to do the same
- provide a plan for relocation and reconstruction after a major flood
- explore settlement patterns that would facilitate the reuse of wastewater after treatment
- exploit the flood protection and water-restoring abilities of existing wetlands
- increase the visibility of water in the city as well as public access to it.

Every new building, street, parking lot, and park within the city should be designed to prevent or mitigate flooding and to conserve and restore water resources. Every project should:

- address the relationship between the project's site and the city's critical flooding, water pollution, and water supply problems, as well as specific hazards and resources that exist on the site and in its immediate neighborhood
- site and design buildings and landscaping to avoid flood damage
- exploit the ability of rooftops, plazas, parking lots, and the earth to detain or retain stormwater runoff

- design parks in floodplains to store floodwater and withstand flood damage
- design the size, depth, shape, and shoreline of urban water bodies to enhance water circulation and store stormwater
- select hardy plants that require little, if any, irrigation, fertilizers, or pesticides, and protect plants from desiccating winds
- utilize stormwater, if sufficiently uncontaminated by salts and pollutants, or treated wastewater to meet plant water needs
- exploit the aesthetic properties of water without wasting it.

Water problems and their severity vary from city to city, but every city must manage its own water resources. Cities of the past and present plagued by water problems have pioneered solutions to flood control, water conservation, and water restoration. Many of these models are applicable to every city, not just those with semiarid climates or with intensely developed floodplains. Opportunities for preventing floods, for preserving water quality, and for conserving water exist in the design of every new building and park as well as every metropolitan plan, at the center of downtown and at the urbanizing metropolitan fringe. When the urban water crisis comes, it will probably hit fast-growing cities in arid regions first, but it will extend inevitably to cities in humid regions as well. Eventually, every city will have to design a comprehensive plan for water management, including the regulation of urban form and density in headwaters and floodplains, the regulation of water use, with attendant implications for landscape design, and the careful siting of waste disposal sites and industrial and sewage outfalls.

The knowledge for such a plan exists today; the underevaluation of water is the major obstacle to its implementation. Once the water crisis forces cities to charge full value for water, the support for water conservation will follow. When cheap water is a thing of the past, rainfall will be cherished, runoff utilized, and flooding reduced. Cities will protect their water from contamination and reuse it after treatment. City parks and private grounds will acquire a drought-tolerant landscape. The use of water in public spaces will be restrained, but the impact will be powerful.

In the next decade, the dilapidated, outmoded water supply, wastewater treatment, and storm drainage systems in many older American cities will have to be overhauled. This will entail the expenditure of billions of dollars and considerable upheaval in dense urban centers. Short-term expediency must not prevail; the opportunity for redesign must be seized.