# Chapter 8
# Urban Design and Urban Water Ecosystems

**Kristina Hill**

## 8.1 Background: Cities, Rain and Water Systems

This chapter addresses the role of urban design in the performance of urban water ecosystems, with an emphasis on urban rainwater runoff and future urban infrastructure systems. The main thesis is that new designs must be supported by an integrative framework for analysis and application in order to significantly change overall urban hydrologic performance. Designers, planners, and scientists do not currently share such a framework. A straightforward landscape-based heuristic is proposed here which uses simple categories of hydrological function to sort, map, and propose changes to diverse urban land uses within an urban drainage basin.

Urban stormwater drainage systems carry significant amounts of pollution to streams, rivers, lakes and marine shorelines across the world. For instance, the US National Research Council estimated that urban runoff in North America carries 1.4 million metric tonnes of oil and grease products to the sea each year, produced primarily by the consumption of oil in motorized vehicles (NRC 2003). That amounts to 44 times the oil released into the sea by the 1989 Exxon Valdez oil spill of 11 million gallons. In addition, urban runoff contains bacterial pathogens, drives sewer overflows full of untreated human wastes (EPA 1999), and carries significant loadings of nutrients and metals to aquatic environments (Gobel et al. 2007). These contaminants severely alter conditions for the survival of native plant and animal species over increasing miles of the North American coastline, and prevent millions of people from having access to safe swimming and fishing areas (Tallis et al. 2008).

In response to federal legislation such as the Clean Water Act and the Endangered Species Act, municipalities across the United States have begun to implement strategies to remove these pollutants from urban stormwater runoff (Novotny and Hill 2007). The management of water in and around urban areas that does not originate at an industrial site, but rather from rooftops, lawns, driveways, parking

K. Hill (✉)
University of Virginia, Charlottesville, VA, USA
e-mail: keh3u@virginia.edu

L.A. Baker (ed.), *The Water Environment of Cities*,
DOI 10.1007/978-0-387-84891-4_8,

lots, and roads (known as non-point source pollutants), has become critical to the ecosystem health of rivers and oceans and to the industries that harvest fish and shellfish. In 2004, states reported that about 44% of assessed stream miles, 64% of assessed lake acres, and 30% of assessed bay and estuarine square miles were not clean enough to support uses such as fishing and swimming (US EPA 2007).

The problem of urban water pollution is significant, and appears to be expanding as the rapid urbanization of US coastal regions continues. Roofs are a source of metals in runoff such as zinc, which can be toxic to humans, or copper that makes its way to rivers and is often toxic to fish. As we expand urban areas, we typically also increase the miles of roadway and the average number of vehicle miles traveled to get around in those urban areas. The simple version of the problem is that the farther we spread out, the more we drive – making urban roads and parking spaces an ever-increasing source of pollution by metals worn off of brakes, leaking or spilled motor oil, de-icing salts, and nutrients (Beach 2002, Alberti et al. 2007).

Some writers have called for limits on the percentage of land that can be developed in any given watershed (see for example Beach 2002). But where these functions already occur, or cannot be limited in the future, planners and designers must approach them in new ways. Each roof, driveway, roadway, and parking lot can be designed to produce a much lower net change in the amount of runoff it produces, and can be designed to act as its own "kidney", filtering pollutants before they enter the larger water system in and around cities. Designers and planners have begun to experiment with these possibilities, and by monitoring some of their experiments, have developed a body of knowledge about how cities can be built and retrofitted to perform differently. The functional performance of buildings, parking lots, road rights-of-way, lawns, and open space can all be improved. In the process of addressing these functions, designers can reveal the flows of water and contaminants to the citizens of a democracy that must support these changes in order for them to be meaningful and widely implemented. Without broad implementation of new urban design standards, future generations of humans will have increasingly limited access to seafood and swimmable beaches.

### *8.1.1 Strategic Context*

The high probability of climate change over the next 25–100 years will most likely produce new rainfall patterns and an increased rate of sea level rise that will make urban design interventions in water systems more difficult and/or more expensive (Ashley et al. 2005, Barnett and Hill 2008). Yet civic infrastructure must address these environmental trends, since transportation structures and piped water systems in particular are typically designed to have a useful lifetime of 25–75 years. It is surprisingly rare in the United States to find any recent infrastructure planning work or coastal development that considers the likely impacts of climate change and sea level rise. Meanwhile, the World Bank, global insurance companies, and planners in many other cities of the world have already begun this very serious work of assessing opportunities to adapt (Perkins et al. 2007, London Climate Change Partnership 2006).

Several regions of the United States have become international leaders in proposing and implementing new design approaches for urban water systems, with an emphasis on changing the way cities deal with rainwater runoff. Seattle, Washington; Portland, Oregon; and smaller communities in Prince George's County, Maryland, as well as the State of Maryland itself have set new standards in this area. Similarly ambitious efforts are being made more recently in Stockholm and Helsingborg, Sweden, and in Glasgow, Scotland. Many other communities in the United States and around the world have begun to allow or encourage experimentation with these design approaches, collectively referred to in the United States as LID (Low Impact Development) or NDS (Natural Drainage Systems), and in the United Kingdom as SUDS (Sustainable Urban Drainage Systems).

There is no longer any question that these approaches can function, although the extent of benefits may be debated. The large strategic questions are, first, what would it take to implement these designs broadly in cities in order to alter their overall hydrologic performance? Second, will these design approaches help cities adapt to climate change trends? And finally, are there barriers that prevent planners, engineers, urban designers (landscape architects and building architects), and policy makers from sharing a conceptual understanding of where the greatest benefits can be obtained from altering urban drainage systems?

## 8.2 Historical Questions and Examples

In the last third of the 19th century, the American designer Frederick Law Olmsted established urban park systems as a form of infrastructure that combined water systems, transportation systems, health concerns, biodiversity goals, and social goals. Particularly in his design for Boston's Emerald Necklace, Olmsted engaged in the activities of what is now considered the separate discipline of civil engineering, combining it with horticulture, public health, political economy, and design to propose a system that was uniquely American at the time. The Boston Fenway design was intended to control flooding that periodically stranded raw sewage on the grassy banks of a park where children and their care-givers were exposed to its bacterial pathogens. Tide waters from the Charles River estuary would block the flow of freshwater carrying sewage, causing it to back up onto the banks. Olmsted designed the entire corridor of the Muddy River through the Fenway, creating greater capacity within the channel and ending it with a floodgate that would prevent brackish water from entering the Muddy from the Charles. He experimented with using zones of native plants as well as zones of non-natives on the banks, and advocated for parks as social promenades where people from all economic classes could meet and, at least in theory, provide support to a shared system of political democracy. What we think of today as innovations in "natural drainage", or "green infrastructure", or in some circles referred to as "landscape urbanism", is actually one of the most successful and unique historical strategies of American urbanism dating from the 19th century (Meyer 1997, Hill 2002).

In early 20th century, Patrick Geddes of Scotland invented the geographical idea of an urban "region", a mappable entity connected by flows of people, water, goods, culture, and capital. Geddes went on to become an influential academic writer and an urban reformer, working to improve access to light, air, and education for working class people in Edinburgh and other cities. He participated in the planning and design of cities in British colonial India, and later in the founding and planning of Tel Aviv in Israel. Geddes was the first to abstract the analysis of flows in a way that crossed disciplinary boundaries and brought ecology, sociology, and economics together in looking at the city and its region as a system, and then apply those ideas to actual urban plans. Geddes rejected the idea that cities were necessarily unhealthful, which was the prevailing belief of his time. He was actively offended by the idea that disciplinary boundaries might restrict his ability to address the city and its region as a whole, and brought his work to the largest public audiences he could with lectures and exhibitions.

Chicago produced the next urbanist whose integration of form and function challenged the status quo of morphological thinking about cities. Kevin Lynch studied with the architect Frank Lloyd Wright at his Taliesin studio, then attended MIT and in 1948 began to teach in MIT's Urban Studies program. During the early 1960s, Lynch began to follow the work of psychologists who were exploring the idea of an ecological psychology – one that emphasized the role of environment on the development of cognition and self-awareness. Building on the Chicago School's approach to cities as sociological ecosystems, Lynch applied the methods of cognitive mapping to cities, asking his study participants to identify landmarks and paths they used to navigate urban districts and their city as a larger whole. This work linked the individual to the collective via the physical environment, leading Lynch to argue that the fundamental purpose of urban design was to increase the legibility of the city as a tool for healthy individual development and the parallel development of a collective civic life. His fundamental approach was to analyze movement through the city, beginning with those flows and the semiotics that informed them, and then evolving a sense of morphological structure only in relation to the flows. Lynch also anticipated that one day urban design would have to address the development of non-human species (Lynch et al. 1990).

A few years after World War II, a Scot arrived at Harvard to study landscape architecture in a department founded on Olmsted's ideas, and from which the discipline of urban planning had emerged only a few decades before. Ian McHarg worked to invent a way of planning and designing cities that would integrate them with flows of water and organisms, in order to support human health and the myriad links between humans and the ecosystems that support us. Inspired by Rachel Carson's writing about a connected web of species and the consequences of human actions in that web, and influenced by his own experiences as a tuberculosis patient, McHarg became an advocate for urban planning that integrated water systems and biodiversity into the infrastructure of cities and new towns at multiple scales. He persuaded a major client who was building a new town north of Houston to implement some of his ideas, and the first "natural drainage" system of the 20th century was constructed at The Woodlands in the late 1960s, early 1970s. The idea of such an infrastructure would have been familiar to McHarg from his studies in Boston, but the connection he made at The Woodlands contained a unique innovation. McHarg linked private parcels to public infrastructure with a shared responsibility to improve the hydrological and ecological performance of a city. He went on to re-map the city of Philadelphia using water systems and public health as themes, popularizing his ideas in an extremely successful book titled "Design with Nature" (McHarg 1969).

In Berlin during the same decades, a wetland ecologist named Herbert Sukopp began to realize that urban ecosystems contained surprising diversity, and seemed to have characteristic patterns that were unique to urban contexts. Sukopp was confined to a restricted geography by the Berlin Wall, but turned that restriction to his advantage when he conducted some of the earliest studies in the scientific field of urban ecology in the early 1960s. His detailed investigations of species diversity and local microclimatic patterns led to the establishment of endangered species lists in European conservation practice. Sukopp used isoline maps to study everything from humidity to precise flowering times for plant species, pioneering the extension of analytical ecological methods to urban space and inventing unique representations of the urban – rural gradient that unified knowledge about geology, climatology, hydrology, economics, and plant biology. These landscape-based sectional representations played a central role in Sukopp's conceptualization of urban spaces and the flows of energy, organisms and materials that occur in and through cities, not unlike the conceptual power of Geddes diagram of the Valley Section from 50 years earlier (for an overview of Sukopp's work, see Lachmund 2007).

Contemporary designers and theorists such as Michael Hough and Anne Whiston Spirn, both former students of Ian McHarg, developed and popularized the idea that cities can be designed to incorporate and mimic desired ecological functions. Spirn is noted for originating the idea of using "catalytic frameworks" in ecological urban design, which she described as structures that change intentionally over time in response to interactions with external processes. Similarly, designer and planner Joan Iverson Nassauer developed an intensive focus on the relationships between human perception and landscape ecology in the American Midwest. Her best-known work addressed the question of how some pre-development ecological functions can be returned to areas dominated by human activities, using strategies that make them visually appealing to the people whose decisions control the future of these landscapes (Nassauer 1995). Like Lynch, Nassauer identified visual perception as a critical influence on human choices that affect design and planning. Her early work studied the role of what she called "cues to care", referring to visible design elements that identify landscapes as intentionally maintained (fencing, signage, etc.). Although the ubiquity of these elements may make them appear mundane, Nassauer's work drew attention to their potential to allow changes in the way human-dominated landscapes are maintained and in the way they function. An urban application of Nassauer's observations can allow new design approaches to become more geographically widespread by making them acceptable to a broader public audience.

The ideas of 20th century designer-academics, from Geddes to Nassauer, have added important innovations to the original approach pursued by Olmsted in the 19th century. These include the recognition of the urban metropolitan region as a component of urban systems, the use of forms that are obviously constructed as well as naturalistic forms, the use of the scientific method to investigate both urban ecological relationships and the perception of those environments. The incorporation of recent scientific knowledge and concepts has also produced some significant changes in the original design approaches, such as the recognition of energy flows that support a continuum of river ecosystems. But the fundamental idea that cities can and should make infrastructure that serves multiple purposes as positive social spaces, as a vehicle for legibility, and in support of biodiversity, is an American invention that went largely unrecognized in its time and has been re-discovered in ours.

## 8.3 Establishing an Ecological Frame for Watershed Analysis in Urban Design

Many important strategic questions in design and policy are answered within narrow analytical frames. These narrow frames create crucial disadvantages when they exclude variables that will ultimately determine the success or failure of contemporary and future efforts to retrofit cities.

In contemporary urban design and planning, there are three distinct ways of trying to define and alter the urban water system. Each approach is practiced by a group that has (or could have) a significant influence on the future of urban water systems. These analytical frames are not mutually exclusive, but they are often applied as if they were. My goal in describing these different analytical frames is to establish a position from which we might integrate them, and thereby produce physical designs that improve the overall performance of urban water systems significantly. The key concept is that designers, scientists and planners may miss significant opportunities to alter urban performance because they lack a framework based on landscape function.

A landscape-based framework that creates substantial overlap among the analytical frames of scientists, designers, and planners will also position them to better persuade elected decision-makers that new or different investments should be made. If the conceptual approaches of experts in different fields could be hybridized within a simple spatial heuristic or analytical approach, that heuristic could become a useful vehicle for integrating science and design. My purpose in this section is to review the three dominant frames, and then propose a simple hybrid heuristic that would allow practitioners and academics from different fields to integrate their observations and proposals.

### 8.3.1 The Regulatory Frame

The first is a regulatory frame, in which social and legal structures such as parcel types, land uses, and development trends are mapped, described and assessed (qualitatively and quantitatively). It is focused on the present, and on assessing the political risks and practical benefits of changing present-day standards. If the analyses indicate acceptable risks and probably benefits, thresholds are set that trigger specific rules as development and re-development occur. These rules are implemented as private and public proponents of change seek required land development permits from a municipality, county, state, or federal agency, depending on whose administrative jurisdiction is engaged by a particular proposal. This is an unusually weak system of land use control compared to the relatively hierarchical regional planning that occurs in most other countries, but Americans often succeed in using the political system within particular jurisdictions to strengthen it. The leverage generated comes from the proponents' fear that citizen involvement will slow the permit process to such an extent that a private investor will not be able to afford to wait, and a public project will lose momentum and perhaps lose its proponent in a re-election campaign.

The statistically descriptive approach to land use that is employed by this regulatory concept of urban water systems allows policy makers to identify the degree of political risk inherent in choosing a particular threshold for proposed permit regulations, and also to identify the likely benefits (in hydrologic function, tax base, additional density, or other goals) that may accumulate as new rules are applied to a jurisdiction or district. Since multiple goals are involved and calculations of political risk can be conservative, it is likely that using this frame alone to evaluate and implement changes would fall short of moving a regional water system to a higher-functioning state, or even to conserve present-day functions. The EPA's Chesapeake Bay Program, as well as state-level efforts to conserve Puget Sound, are cases in point.

Since it begins with a statistical orientation, the regulatory frame is relatively likely to incorporate statistical observations from the environmental sciences, which in some cases become guiding elements of policy. Research in the 1990s, for example, showed a relationship between the amount of total impervious area within a watershed and the relative diversity of aquatic organisms that are taken as an indicator of system health. A threshold of 10% imperviousness was widely discussed among policy and planning professionals as a marker of a watershed that could sustain a high-quality aquatic environment. But this threshold represents a kind of hind-casting, since it includes measurements of existing development and does not consider that future development might perform differently than the designs of the past.

While this may be a reasonable argument for limiting the expansion of future development by placing land in private trusts, conservation easements, or public ownership, it does not address the need to improve performance in watersheds that have already exceeded the 10% threshold of total impervious surface. The millions of people who live in existing cities and suburbs would, in effect, be left out of the conversation about investing in improved performance; while all of the political and economic pressure would be placed on rural land owners who sometimes perceive their role in generating pollution as less than the urban contribution.

The regulatory frame has shifted recently in some areas, notably in Prince George's County, Maryland and the Pacific Northwest, to emphasize intervention in the runoff generated by small storms instead of demanding that development detain the runoff from ever larger storms. This represents a change in attitude about what really causes the changes in system state within streams that receive stormwater – very large flooding events that happen very seldom, or common, small flooding events that typically happen every year, or several times each year? Practitioners and regulators in some regions have begun to shift to the smaller storms in part because of evidence that they have a major impact on the morphology and the water quality of streams (Chapter 6). The emphasis on detention of larger and larger storms emerged from an analytical frame that assumes detention is good and more detention is better; the new emphasis on smaller storms matches a regulatory frame based on the concept of "eco-mimicry"– the idea that urban areas can and should perform more like pre-development landscapes (Hill 2002). In order to do this, cities can incorporate some of the disturbance events and dynamics of those non-urban conditions, such as unusually large floods, while limiting the everyday negative effects of urbanized conditions such as runoff from paved surfaces and pollutants generated by automobile use.

### *8.3.2 The Site-Based Frame*

The second analytical frame is site-based, and seeks to demonstrate cumulative benefits at the site scale by combining as many "best practices" as possible. It is future-oriented, seeing each site in terms of its potential rather than its current state. Applying this frame is often a vehicle to establish new models of how to enhance human aesthetic experiences and the legibility of critical urban systems. There are clear strategic advantages in being able to show decision-makers and the public the built evidence of new approaches, when those projects are successful both functionally and aesthetically.

The practitioners of the site-based analytic frame often rely on metrics such as those that are incorporated into the US Green Building Council's rapidly-evolving LEED certification levels, in order to persuade owner/clients and permitting agencies that new models will succeed and will justify what is often an extra expense. Although most metrics are designed to evaluate building designs, a new standard for sites themselves is in the testing phase (known as the USGBC Sustainable Sites Initiative), as is a new standard for districts (LEED for Neighborhoods). These metrics can be seen as a badge of accomplishment for owners, and even for cities, as they incorporate them into their permitting incentives for property owners and begin to think of public LEED projects as a portfolio of investments in higher long-term performance.

The costs of these projects are seen within this frame as justified by the value of having demonstrable models that can be seen and touched, first of all. Once built, these projects can also be tested and used as a basis for improvement, which is the goal of most practitioners who use this analytical frame. They are aware that learning comes from building under real project conditions, if the limits to implementation are similar to other projects and if those experiences can be shared with other professionals. Since the number of "best practice" elements included tends to raise the LEED rating of a project, there may be a tendency to add components that may or may not be strategically useful in a given location or jurisdiction. And the ultimate value of a built prototype is in its ability to persuade visitors that it should become a new standard, or at least very common.

Practitioners who operate within the site-based frame may sometimes forget this, and enjoy the uniqueness of the design more than its ability to become common. Or they may forget that the more expensive elements of the prototype design are unlikely to ever become a new standard without a dramatic decrease in cost. The enduring advantage of this unique frame is that it pre-supposes that conventional development can become something very different from what it is today, and understands the value of tangible, sensate experience in persuading the majority of people that a particular change is positive.

### 8.3.3 The Geography-Based Analytical Frame

The third analytical frame is fundamentally geographical, approaching the water system as a network within a dynamic mosaic. The priorities and capabilities of a given part of that system may be defined as much, if not more, by the past than by the present. This can be observed in the influence of topography, geomorphology, and soils, but also in the legacy of existing infrastructure. This approach would consider the functional characteristics of pre-existing elements of the landscape, and pre-existing capital investments, before setting goals for the jurisdiction, for an individual parcel, or for a water body.

Starting with the physical geography of the landscape, a practitioner who uses this analytical frame to represent the urban water system might use measurable characteristics to ask questions about, for example, where streams might be expected to have once supported a particular species that is now of conservation concern, such as salmon in the cities of the Pacific Northwest. A stream with a steep longitudinal slope, for instance, may never have had salmon in it in the pre-urban era, and both a single reach and the larger watershed would probably make a poor choice for investments in present or future salmon habitat restoration. There may be other goals that justify those investments, such as downstream water quality benefits in the nearshore marine environment, but those should be clearly defined and examined in the light of other geographical concerns.

Similarly, the infrastructure history and current condition of a particular area have implications for the priorities that should be embodied in a jurisdiction's regulations, and in the goals set for site-scale designs. The most important distinctions are among urban drainage basins that drain directly to a large water body versus those that drain to a small stream versus those that drain to a sewage treatment plant. In the first two cases, the drainage pipe system is generally referred to as "separated", meaning that it uses different pipes than the sanitary pipe system that carries human wastes. A particular basin may also be referred to as partially separated, if roof runoff, for example, goes in to the sanitary sewer pipes but street runoff does not. Systems that use the same pipes for both human waste and stormwater runoff are known as "combined" systems.

The US EPA has stated that there are approximately 1000 communities in the United States with combined systems somewhere in their jurisdictions (EPA 1999). Many of these cities have been slowly separating their sewers since the 1960s and 1970s, but a recent EPA study of the gap in infrastructure performance to support clean water makes it clear that overflows from combined sewer systems are still a major cause of water quality problems in and around cities, and that the problem may be worsening as a result of deferred maintenance and other factors (EPA 2002). Urban drainage basins that have combined sewer systems need to make stormwater flow rate and volume control their first priority, in order to limit the number and magnitude of overflow events that dump untreated sewage into water bodies large and small. The faster rainwater moves into the sewer pipes, and the greater the volume of that rainwater that runs off of the surface instead of infiltrating the soil, evaporating, or being used by people and plants, the more raw sewage will be forced to overflow from pipes that are at full capacity. This is a very significant issue in urban water systems. EPA has estimated that if current trends continue, water quality will soon decline in urban areas to problematic levels not seen since the 1970s (EPA 2002).

Urban areas that use separated systems differ in important ways if those pipes drain to a large water body, such as a lake or marine bay, or to a small river or stream. In the first case, the volume of water discharged to the lake or bay is not likely to cause significant problems relative to the existing large volume of water. But water quality is an issue, since the location of the discharge point along the shoreline is not ideal to promote mixing and dilution of the contaminants that enter the lake, even if the lake ecosystem can theoretically absorb that pollutant load. The nearshore environment in lakes and marine bays has been found to be critical habitat for many deep as well as shallow-water species at some stage in their life history, and should be treated as the nursery environment of the lake or ocean it borders (Botsford et al. 2001). Animals such as Chinook salmon that spend their juvenile life stage in this shallow water zone may be even more vulnerable to the harmful effects of pollutants than they would be in an adult stage. For these reasons, regulations and designs that are evaluated for urban drainage basins that discharge to lakes and bays should address runoff water quality improvements as their primary priority.

Separated systems that discharge to small rivers and streams represent the most difficult situation, since water quality, water volume and the rate of discharge can all have severe negative effects on a stream or river ecosystem. The morphology of streams can be altered by high flow rates and volumes so that the stream bed does not provide habitat for species characteristic of the region (Walsh et al. 2005, Chapter 6). This has implications for the entire river and estuary system, since the absence of certain organisms that do the work of shredding leaves and other detritus in small streams can reduce the amount of energy that is transported downstream to the larger system, with consequences for fish and other animal populations. Water quality pollutants such as nitrogen or metals also have both local and downstream cumulative effects, as do physical changes such as increased water temperature or decreased groundwater inputs to streams (Booth 2005). Regulations and design interventions in urban systems that rely on separated storm drains that discharge to small rivers and streams must accomplish all of the goals of runoff management, improving water quality, detaining water volumes, and slowing the rate of water discharge.

This geographical frame of analysis can make effective use of social variables, such as income levels, home ownership rates, or ethnicity, that are associated with a lack of political influence and may help to justify public expenditures that could produce the benefits of additional recreational space, flood hazard mitigation, or water quality improvements in particular districts. Family size and the number of children in different age groups would also be useful information available through census data to display geographically, that is, using a high-resolution spatial map. Car ownership rates, traffic volume data, fixed transit stop locations, and the recent budget history of infrastructure investments would also be useful information to see in a spatial context, so that planners and designers can weigh the question of who pays for and who benefits from specific infrastructure expenditures as part of a social equity analysis.

Perhaps the most significant value of this geographical frame of analysis is in its ability to bring together the questions of ecological effectiveness and social equity, both of which are arguably essential to achieve successful human adaptations to environmental change.

## 8.4 Implications and Integration

Although it is rare for any agency, designer, or scientific researcher to take an approach that integrates all three of these analytical frames, it is necessary for each practitioner to consider them to some degree and include them in their analyses. Public agencies must contribute to requiring this integration as they make recommendations to elected officials, and professional societies can provide guidance to their members on how best to do this type of analytical work. If an integrated approach did become more standard, the necessary information could be assembled in places that are easy for practitioners of many types to access. It is not easy to erase more than a century of disciplinary specialization, and perhaps in some situations it is not even desirable. But in order for professionals to give the best possible advice under given resource conditions, it is nevertheless essential that we find efficient ways to bridge these frames.

### 8.4.1 Heuristics

Integration of these different analytical frames requires specific changes in approach; simply stating an intention to be holistic or comprehensive is not sufficient. Many disciplines, including physics and engineering as well as the fields of planning and design, have found it useful to develop heuristic diagrams in order to prompt changes in how practitioners approach their work. In this sense, "heuristic" refers to a tool for teaching oneself; a conceptual thinking tool that can lead to an integrative solution or insight that is not based on previous examples alone. Both Patrick Geddes and Herbert Sukopp used a section diagram to summarize their knowledge and ask new questions about processes that influence or are changed by urban dynamics. The type of heuristic diagram they both chose was a cross-section (Geddes' diagram dates from 1909, as described in Welter, 2003; Sukopp's section is presented in Sukopp 1973).

The "cross-section" represents a two-dimensional slice through a three-dimensional volume. Cross-sections emphasize vertical and horizontal relationships in space. Geddes used them to show the topographical relationships that link a waterfront town, where goods are shipped, to the mountains at the top of its watershed, where some key natural resources originate (wood and coal for fuel, building stone and minerals) (Fig. 8.1). It allowed him to speak about the controlling role of topography on both water flow and transportation, which was particularly significant in a regional economy that relied on boats and trains to transport people and goods. Sukopp used the cross-section to emphasize horizontal and vertical gradients in temperature, air quality, humidity, topography and landform changes created by humans, as well as depth to groundwater, all of which he saw as potential drivers of plant and animal population distributions (Fig. 8.2).

As a contemporary example of a diagram that was useful in highly integrated work with an urban water system, the staff involved in capital projects and planning at Seattle Public Utilities (SPU) in the early years of SPU's Natural Drainage program sometimes used a section diagram to represent the urban landscape in terms of water flows and functions, as they planned new components of their award-winning stormwater projects (Fig. 8.3, courtesy of M. Maupin, SPU). They used a section drawing to engage senior policymakers and technical staff in the effort to

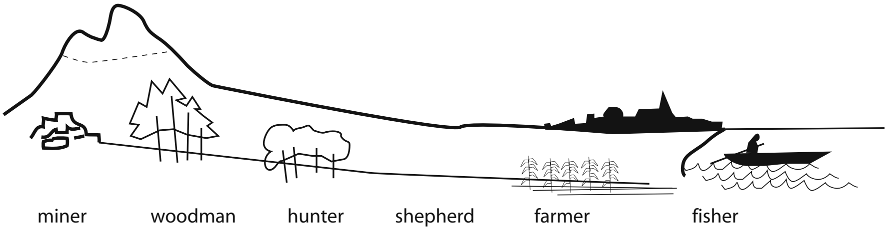

**Fig. 8.1** Abstraction of Patrick Geddes' valley section, the first representation of an urban region

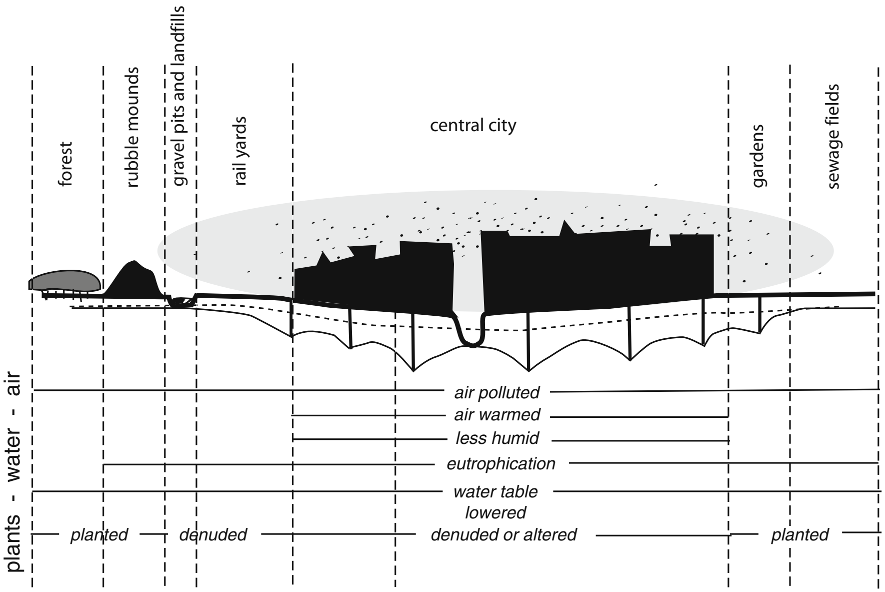

**Fig. 8.2** Urban ecological section showing alterations caused by urban conditions, translated and simplified from Sukopp (1973)

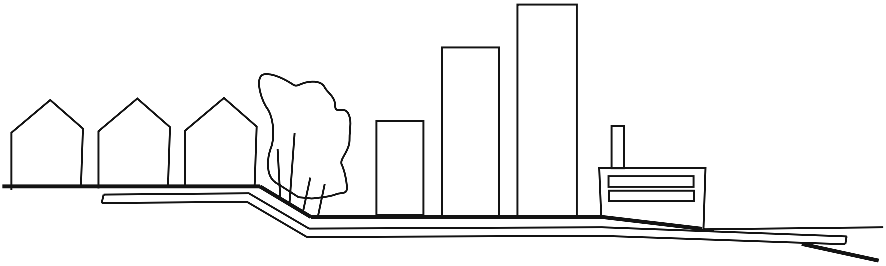

**Fig. 8.3** A simplified section through an urban drainage system, showing sewered as well as unsewered areas, residential districts, parks, downtown, and shoreline industry/wastewater treatment plants, discharging to a large water body

mimic certain pre-development characteristics of landscape hydrology, while also acknowledging the infrastructure realities of the contemporary city.

### 8.4.2 Proposal for an Integrative Heuristic

In order to address the need for a simple but powerful integrative frame to re-examine urban water systems, I propose that planners and designers should approach the urban landscape as divisible into three categories that could match

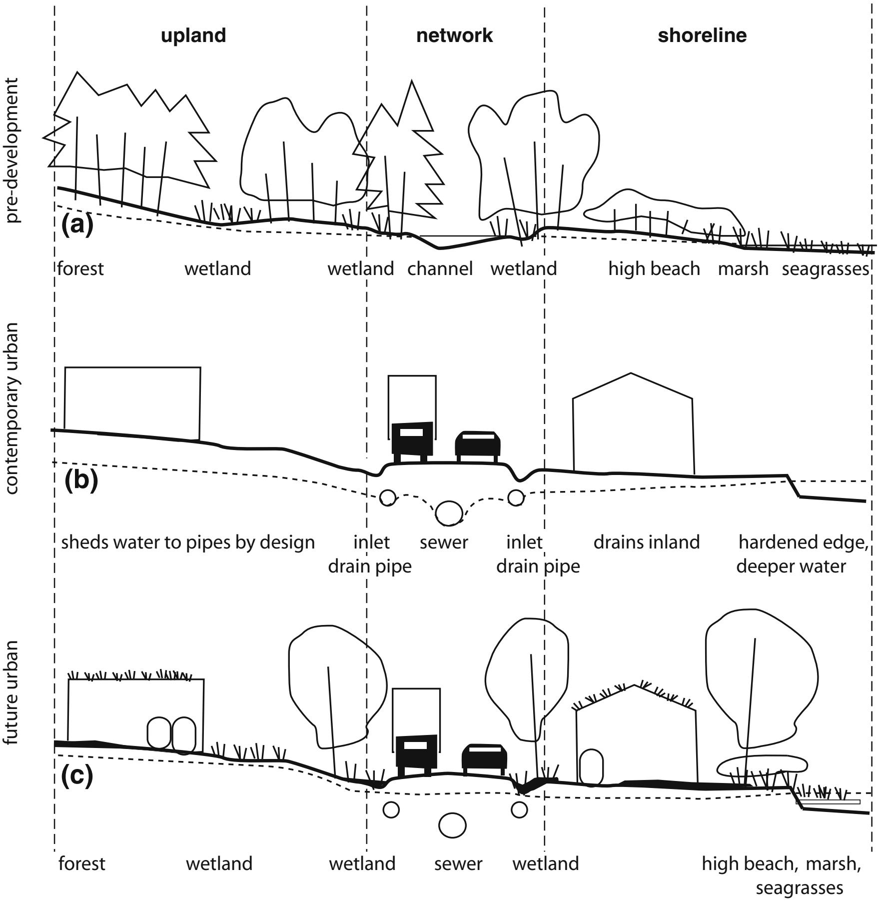

**Fig. 8.4** Cross-sectional heuristic for water-based urban design, comparing pre-development patterns of water storage and flow to contemporary urban development and an improved future condition of urban development with cisterns, ROW rain gardens, private rain gardens, green roofs, and a restored shoreline edge. (**a**) indicates the pre-development water table height, (**b**) marks the lowered water table of traditional urban development, in which pipes siphon off groundwater, and (**c**) marks the raised water table of development with rain gardens, mulched soils, and pipes that have been internally sealed

portions of a cross-section diagram. Together with the cross-section, these categories are useful in providing a spatial organization of goals for hydrologic function within a fully constructed urban landscape (Fig. 8.4; Table 8.1).

The value of this heuristic for organizing urban land and water systems is that it is based on the pre-development hydrologic functions of landscapes and ecosystems, but can also incorporate urban landscapes quite readily within the same classification. It allows the user to immediately identify the primary functional goals for

**Table 8.1** Categories for a function-based approach to urban water systems

| | |
|---|---|
| Upland: | All locations where rainwater falls and can be collected, infiltrated, or dispersed as runoff, but where no significant runoff flows through from adjacent sites. This category includes building roofs, parking lots, driveways, and vegetated areas of private yards and public lands. Most urban land would fall in this category. |
| Network: | All locations and systems that convey significant amounts of stormwater runoff, including constructed pipe systems, roadway surfaces and roadside ditches, and streams. |
| Shoreline: | All locations that are adjacent to rivers, lakes, bays, and ocean beaches, or are subject to flooding from those waterbodies, would be included in this category. |

a given area of land, and helps to remove conceptual barriers to thinking of constructed urban landscapes as ecosystems. It also allows the user to integrate the three analytical frames discussed above: regulatory, site-based, and geographical, in ways that lead to proposals for improvements in function as well as a recognition of political, economic, and geographic concerns. These other concerns can be brought into the classification as sub-categories, allowing the functional goals to remain as the primary concern for structuring the classification.

### *8.4.3 The Standard Approach Versus an Integrative Approach*

Urban watersheds are typically dominated by privately-owned residential parcels when described in terms of percent area. For example, more than 50% of the largest watershed in Seattle, the Thornton Creek watershed, is made up of single-family residential lots. About 38% is made up of the public rights-of-way (ROW) for streets, which includes planting strips and sidewalks as well as paved street surfaces. The other 12% is a mix of multi-family residential parcels (<3%), private commercial parcels, and public land (including both public buildings and park lands). By taking a regulatory approach, we might identify the regulation of private single-family lots as the best "target" for changing the function of that urban watershed, since these are the typical land use by area. A political calculation might tilt that analysis to an emphasis on street rights-of-way, which are already controlled by the government sector, but which already have many other functional demands placed on them by transportation needs, cultural uses, and safety standards. At that point, voluntary action on residential parcels anywhere in the watershed might be seen as the initial path that bears the least political cost and has the potential for the greatest effect.

By taking a functional and geographical approach, we might target urban land that produces the largest volume of contaminants, such as roads and parking lots or in a combined sewer watershed, we might focus on parcels with permeable soils and relatively flat slopes that allow for high rates of safe infiltration (i.e., infiltration that is not likely to contribute to triggering a landslide on steep slopes nearby). We might also consider the socioeconomic patterns of ownership versus rental in order to determine where residents are more likely to control structural decisions about pollution-generating surfaces and drainage flows on their parcel, or we might use census information about economic status as a way to direct public investments toward neighborhoods where residents may be less able to make investments on their own. Income data might also be helpful to identify areas where residents are more likely to save money by changing their own engine oil in cars and trucks, making education about oil disposal a high priority.

From a site-scale design perspective, we might target sites that are visually accessible to a broad audience, hoping that changes on those sites would influence more people's decisions to change their own land or support new taxes and fees that would allow public lands to be transformed. Designers might also work opportunistically, using a willing client as an opportunity to experiment and build in as many different water management or design features as the client would be willing to purchase. The outcomes of these unique experiments often influence the choices made in future designs that can improve effectiveness or reduce costs, providing insights that are not available without full-scale applications.

*Upland sites*: If we used an integrative classification instead, sorting these parcels into upland, network, and shoreline, it would be possible to see not only space, but direction – the directionality of water flow. Without directionality, interventions tend to focus on the interior of developed land and not the shorelines – where all the pollutants and biological effects come home to roost. First, we would group all of the parcels where stormwater is first generated (public or private, commercial or residential) into the category of "upland" sites, before sorting them by use or by socioeconomic characteristics. In a Seattle urban watershed, the "upland" category might include 55–65% of the watershed by area. It would also include most of the land that generates certain kinds of pollutants, such as sediment or nutrients from lawn and garden fertilizers, pesticides and herbicides, pathogens from bird and pet wastes, or zinc from galvanized metal on roofs. Parking lots would also typically be included in this category, generating pollutants such as oil pan drippings and metals from car brakes. One common feature of all "upland" urban sites is that they are often the right place to encourage small-scale retention of stormwater, by using everything from rain barrels to mulch on landscape areas, and by turning parking lots into the hydrologic equivalent of wetlands by setting stringent storage and filtration goals for each one when re-development occurs.

In the Pacific Northwest, Portland and Seattle (and their surrounding county jurisdictions) have made successful efforts to use public sites as models for upland water management. Green roofs on public as well as private buildings are becoming relatively common, and valuable lessons about performance and soil specs are being learned and shared (BES 2006).

As one example, King County's Maple Valley Library outside Seattle was designed so that the building and parking lot would retain most of the second-growth woodland on site. The designers focused their efforts on keeping the footprint of the building small, distributing parking stalls into small groups set among the trees on a loop drive, and emphasized biological soil conservation. The building architect (James Cutler Architects) drained the roof toward the center of the U-shaped building, and into a round gravel-filled infiltration area that becomes a significant aesthetic feature of the design. The landscape architects (Swift and Company) stored and re-distributed soil that contained mycorrhizal fungi from the site, once construction was over. These fungi can play an important role in the trees' ability to survive changes in rainfall and soil nutrient levels. The designers also produced extremely constrained site access plans, so that a minimum of equipment traffic and materials storage would occur over tree roots close to the soil surface. The site engineers (SvR Design) distributed a series of stormwater "sumps" across the site to infiltrate additional runoff generated by the parking clusters, in order to mimic the pre-development capacity of native Douglas Fir (*Pseudotsuga menziesii*) forests to retain 6 centimeters or more of rainfall across an entire site.

The Maple Valley Library project represents a number of best practices for upland sites, such as forest retention and soil ecology that are often ignored by a single-minded focus on stormwater alone. Upland sites in regions that were forested before development should be designed and regulated so that, to the greatest extent possible, these landscapes mimic the ecological functions of a forested site that contains a gradient from dry to wet soil conditions. In a prairie region, upland sites should be designed and regulated to mimic the replicable components of that ecosystem type. The goal is to bring as many functions back to urban landscapes as possible, with the highest priority placed on those functions (such as stormwater transpiration by plants, infiltration, and detention) that affect ecosystems downstream. Categorizing urban lands as "upland" sites allows us to focus on their role in a cumulative set of processes first, and then expand our goals to include other processes and values.

*Network sites*: Surface water that runs off upland sites moves into channelized networks of flow. Those channels include everything from ruts or curbs along a roadway, grassy ditches, or underground pipes. In effect, extensive urban street networks have replaced what is often a widespread system of perennial streams and permanent streams in pre-urban landscapes (Chapter 2). The street is "the stream", although the flows are typically relocated underground. Depending on the basin's infrastructure history, the artificial streams created by urban streets may drain to a surface stream, a river, a lake, a marine bay, or a sewage treatment plant.

Categorizing street rights-of-way as network sites captures much of the opportunity to alter a public landscape to improve the hydrological function of a city and its urbanized region. Streets and their underground pipe systems are either the source or the conduit for most of the destructive pollutants that characterize non-point source stormwater runoff, such as petroleum byproducts, metals, biological pathogens, some nutrients, and sediment discharges. Studies have shown that with greater traffic flow, the volume of pollutants is higher (Patel 2005). Water-borne pollutants that escape a private parcel typically drain to this network as well, unless the private parcel drains directly to a waterbody or to the groundwater table. Network sites are places where flow concentrates, making them excellent strategic locations for intervening in those flows to reduce the downstream impact of many upstream acres of public and private land.

For example, Seattle's natural drainage program began with a street right-of-way project known as Viewlands Cascade (Fig. 8.5). Located on a cul-de-sac next to a public school in a relatively low-density residential neighborhood, the site provides detention, filtration and infiltration for stormwater that runs off of approximately 26 acres of land upstream. Its hydrologic performance has been monitored by a team of faculty and students from the University of Washington, who found that it was capable of reducing runoff and pollutant loading to nearby Piper's Creek by a factor of three, compared to a pre-existing ditch. The location of the Viewlands Cascade was strategic within the drainage network of Piper's Creek, allowing a cost-effective intervention in the sense that 26 acres of land were treated with a one-block vegetated swale system at a cost of about $225,000 USD (Horner et al. 2002). Subsequent SPU projects, such as the High Point community redevelopment, have

**Fig. 8.5** Viewlands Cascade, Seattle's first natural drainage project. This vegetated swale receives runoff from approximately 26 acres of urban land, reducing the total runoff volume that enters a salmon stream below this location. Photo by K. Hill

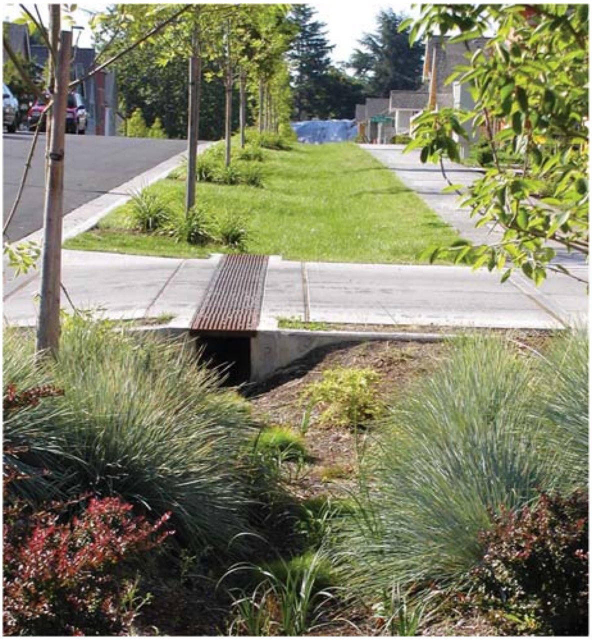

**Fig. 8.6** Network site design for detention and filtration at High Point, a community redevelopment project in Seattle, Washington with a density of approximately 16 residential units per acre. The planting strip within the street right-of-way contains an 8’ deep installation of structural soil to hold and filter rainwater, but is designed as a lawn that children can play on. Photo by K. Hill

allowed the utility to experiment with designs in much denser residential districts (16 dwelling units per acre at High Point) (Fig. 8.6).

The Meadowbrook Pond project is another example of a strategically located network site. Between 1996 and 1998, SPU used the nine-acre site of a former sewage treatment plant to build a shallow pond and wetland complex that acts as an overflow area for an urban stream, along with planted areas that serve as a new park for the immediate neighborhood. The pond traps some of the excess sediment that would otherwise flow to Lake Washington, where shallow shoreline waters provide an important link in the passage of juvenile salmon through the region. The pond was built adjacent to a surface stream, a “network site” in this classification. It was intentionally designed to receive excess floodwaters and sediment that are produced by urban developments upstream, taking advantage of its strategic location where excess flows and pollutants are concentrated.

Many urban sites that may appear to be upland sites are actually network locations. Underground pipes convey not just stormwater and sewage water, but also often convey water that once flowed in surface streams. They can also convey groundwater inadvertently because of cracks in the pipes (known as inflow and infiltration, or “I and I”), and become critical influences on stream baseflows and the depth of a local water table. Interventions in urban water system design should recognize these hidden network sites and the important role they can play in improving the overall hydrological performance of cities.

One such site was recognized in Seattle, under a parking lot just south of the Northgate Mall. An underground pipe six feet in diameter conveyed a fairly constant stream of water measuring about one cubic foot per second (cfs), with storm-driven high flows that were predicted by watershed-scale modeling to reach up to 500 cfs. Neighborhood groups saw the re-development of the parking lot as an opportunity to "daylight" what they considered an upper branch of the local stream, Thornton Creek. The city did not consider this pipe a stream, and planned to treat it as a stormwater drainage pipe. Bringing the baseflow inside the pipe to the surface would be difficult, because the pipe was covered with up to 30 feet of fill that was used to level the parking lot when it was constructed. An eventual compromise was established to use new buildings on the site to step down to a lower grade, and allow the pipe's baseflow to be drawn out by a side pipe located at a weir inside the pipe. High storm flows in the pipe would still be allowed to flow above the weir and down the large pipe, as they had in the past.

The interesting thing about this design process was that the city's utility staff compared three alternatives in a quantitative analysis, intended to identify the strategy that would produce the greatest benefits in terms of the total amount of pollutants that could be prevented from entering Thornton Creek downstream of this site. The proposal for draining off the baseflow (referred to in public documents as the "water quality channel" design) was compared to daylighting the stream (building an exposed channel and removing the pipe altogether), or introducing a set of new surface bioswales in the area immediately around the parking lot that drains to the underground pipe. The conclusion of this comparison process was that the "water quality channel" would have significant benefits because the weir inside the pipe would trap a large quantity of fine sediment that would otherwise make its way into the streambed of Thornton Creek. The water quality channel itself would also provide some benefits, along the lines of a bioswale but with reduced efficiency because water would flow through without always achieving the ideal residence time for water quality improvements. Overall, trapping sediments behind the weir and periodically vacuuming them out was enough of a benefit that the water quality channel strategy was adopted.

By treating this large parking lot as a network site, design strategies were identified and benefits were achieved that an upland site could not accomplish. The special value of what seems to be an ordinary parking lot only becomes apparent when its role in a larger network is evaluated. This analysis is prompted using categories organized by hydrologic function (upland, network, and shoreline), not categories of human land use alone (parking, commercial, etc.). Categorizing urban sites by their present hydrological function, not just their historical role or their political significance to a community, is critical in altering the overall hydrological performance of cities.

*Shoreline sites*: Large lakes and marine areas are the ultimate recipients of urban stormwater pollutants, and of the ecological impacts of runoff on streams and wetlands. Yet most maps and datasets, such as topographic data, use waterbody boundaries as limits; terrestrial and aquatic systems are treated as if they were separate, when in fact they are directly connected by flows of water and materials. In spite of all the attention that stormwater has received, very little regulatory attention has been directed toward shoreline sites with regard to stormwater impacts and potential design strategies. The strategic question for urban design and planning is not whether "end-of-pipe" interventions are better than starting at the source, but instead, whether interventions at the shoreline can produce any additional benefits that interventions upstream do not provide. In other words, can design interventions at the end of the pipe add value to a broad set of interventions upstream?

In order to answer the question of what can be done at the shoreline itself, the problem must be re-framed to consider new scientific research that has emerged about ecological dynamics in shallow-water marine environments. A pattern is emerging in recent studies that links the spatial patterns of shallow sub-tidal and intertidal habitat, along with freshwater inputs and salinity gradients, to the successful reproduction and development of critical marine species (see Pineda et al. 2007, as one example). Research in the Pacific Northwest has shown that juvenile salmon not only travel along shallow waters at the edges of lakes and marine bays, but they also congregate at the mouths of freshwater streams where they discharge into larger water bodies (Tabor et al. 2006). Marine researchers have known for decades that crabs and other animals orient their movement in part by sensing salinity gradients in salt water that are created by freshwater inputs (Johnson 1960). Larval dispersal of marine organisms can be affected by nearshore habitat patterns as well (Gerlach et al. 2007). Shoreline development must begin to support and enhance this set of relationships as it expands to affect more and more of what is now undeveloped coastline, and as we re-evaluate the importance of older urban shorelines in regional dispersal patterns. Human benefits can also result, both in terms of enhanced tourism and a renewed focus on swimmable and fishable waters around cities.

In a few short decades, the broad environmental trends of rising sea levels, disrupted storm patterns, and changes in temperature or water supply that affect these biodiversity issues will link them to urban water management as a whole. Sea level changes will inundate shallow intertidal habitat areas if they do not accumulate sediment with a parallel increase in rate. Similarly, the number of tidally-influenced drainage outfall pipes will increase, as will the number of coastal water supply intakes that are affected by saltwater contamination. As cities and other jurisdictions begin to address flooding, drainage system changes, and water supply challenges, the physical structures associated with shoreline designs will become critical components of adaptation. Sea walls, pipe outfalls and intakes, piers, wetland conservation areas, artificial islands, and even storm surge barriers will be manipulated as coastal developments adjust to new relationships with storms and tidal processes. Urban areas that can adapt their shorelines to support the biological as well as physical needs of coastal systems will be in the best positions to maintain the special resources associated with water-based economies, from residential property values to tourism and fishing industries.

For example, urban seawalls and fixed storm surge barriers typically eliminate sub-tidal, inter-tidal, and supra-tidal ecosystems. Recent scientific work has observed that these gaps in what were once relatively continuous corridors of shoreline or submerged vegetation can be very significant to the dispersal and reproductive success of aquatic organisms. Coastal areas that will experience increased rates of sea level rise or storm surges are likely to expand these structures. It is possible that such structures could, in the future, include systems of buoyant modular planting beds, designed to float at the surface or at key depths to support specific animals and plants. This strategy could also overcome some of the effects of increased algal densities in marine water that have prevented successful restoration of submerged aquatic vegetation in some coastal regions, by allowing sub-tidal plants to become established at ideal depths.

It is also likely that key transportation structures may be raised or re-located as an adaptation to storm surge and sea level changes, creating opportunities to re-design coastal landscapes to include these key ecosystems. Although state Departments of Transportation have not yet released adaptation plans, a US Transportation Research Board report identified the need for them (TRB 2008). European countries and World Bank researchers are actively studying alternative coastal designs. The San Francisco-based Bay Area Conservation and Development Council has begun planning for adaptations that will enhance aquatic systems while protecting two major airports and associated transportation lines. In non-governmental organizations across the United States, citizen activists have begun to link infrastructure and ecology along shorelines. In New York City, citizen groups are advocating for the removal of a 1960s-era highway segment along a tidal section of the Bronx River, creating opportunities for new tidal wetlands. Activists in Seattle are working for the removal of a highway viaduct along a marine bay, proposing that it should be replaced with a series of shallow inter-tidal beaches. The key point here is that investments will be made in infrastructure adaptation in the future, and as this occurs the health of marine species and ecosystems can also benefit.

### *8.4.4 Strategic Implications for Science and Design*

The three basic objectives of urban design that supports the health of aquatic systems are (1) to mimic the pre-development hydrology of an urbanized landscape, (2) to limit the movement of pollutants into aquatic systems that would undermine the health of humans and other species, and (3) to re-establish or sustain a nearshore environment that supports the biodiversity of river, lake and ocean ecosystems and human fisheries. The main strategic question is, how can we accomplish those goals as quickly as possible with a limited budget of money and political resources?

Physical design is a sub-category of urban strategies, in which each instance embodies specific objectives and proposes social, material, and spatial tactics. Scientific rigor should be employed to help identify these specific objectives based on the historical and contemporary patterns and processes of an urban ecosystem, including its human community. Designers need scientists to help them know what processes have changed significantly, what the future trends might be, and how these changes are linked to other important processes and patterns. The rigor of design as a cultural action, seeking to achieve aesthetic performance as well as functional and ethical goals, should be employed to produce proposals of material, social and spatial tactics that represent a cohesive design strategy. The likelihood of success for any given design strategy can be evaluated by reflecting on a record of past attempts, or using knowledge of present interactions. The design strategy itself can be treated as an experiment as it is first tested and then implemented, ideally in a staged process through which initial lessons are incorporated in future expansions. This partnership between science and design has historically been the basis for engineering, and can be a much more vital basis for urban design and planning.

The key here is that uncertainty alone cannot justify inaction. Larger environmental trends such as increased flooding inland and sea level rise on the coasts will force that action eventually. Imperfect but reversible design strategies must be tested in actual cities in order for better solutions to be developed incrementally. Once identified, affordable solutions that contribute to achieving significant goals must be implemented in as many relevant locations as possible, or overall urban performance will remain unchanged and may even decline. The use of a shared conceptual and analytical frame among planners, designers, and scientists should be helpful in generating the political will to make these investments as quickly as possible.

### *8.4.5 Value of Visibility/Public Awareness*

Interventions in the physical design of cities, whether in uplands, on network sites, or at shoreline locations, must be primarily designed to achieve functional performance benefits. As noted above, they must also be designed for replication, in order to have significant cumulative benefits. The need for replication creates two additional criteria: First, these designs must be both cost-effective and inexpensive enough to fit the current and future maintenance and capital improvement budgets of municipalities and other public authorities which are typically funded by development or user fees. Second, they must be supported by the public in order for elected officials to approve the expense and tolerate the inevitable construction disturbances (Hill 2003).

Prototypical design interventions can help to establish the widespread public support that is needed to achieve replication, if they are designed with that explicit goal. Seattle's SEA-Street project has become a classic case in point, in which a one-block demonstration project helped to establish a multi-million-dollar public program of investments in roadway runoff improvements. Neighbors and elected officials who visited the demonstration project expressed satisfaction with its aesthetic and functional characteristics, allowing the city's public utilities and transportation departments to continue a successful partnership on similar projects. Similarly, Portland Oregon has experimented with urban street designs that have become quite popular (Fig. 8.7). Ecologists, planners, engineers and designers who advocate for interventions that would not receive similar approval are likely to face difficult implementation battles that become more challenging with each instance of implementation, and can lead to an eventual abandonment of strategies that may be functionally

**Fig. 8.7** Downtown street design in Portland, Oregon, that filters runoff water from traffic and parking lanes. Grates cover the channels that bring water from the street into the planting areas. Photo by K. Hill

successful, but are not aesthetically or politically acceptable (for additional examples and solutions to this dynamic, see Nassauer 1995).

## 8.5 Current Drivers of Innovation

Although larger political and economic trends, as well as new scientific insights, provide specific openings for change, individuals must drive the initial phases of change in the way cities are designed and built. Innovation in urban design related to urban water systems has been lead by a few creative and dedicated practitioners over the past twenty years, who mastered the factual arguments and have persuaded their jurisdictions to make and monitor changes. In particular, practitioners in Seattle, Washington; Portland, Oregon; Prince George's County, Maryland; and Los Angeles, California deserve recognition for their successful work to establish demonstration projects. Elected officials in a few states have become advocates as well, and the work of public agency staff in these states is now supported by larger professional societies and other non-governmental organizations that disseminate knowledge of successful case studies.

These individuals and organizations were supported by federal and state legislation that sought to protect aquatic systems, such as the federal Clean Water Act (CWA), Endangered Species Act (ESA), and to a lesser extent, the Coastal Zone Management Act (CZMA). Much of the water-related urban design innovation in the Pacific Northwest was driven by a need to respond to the listing of Chinook salmon as a threatened species under the federal ESA in 1998. Advocates linked this goal to others in order to build successful demonstration projects. For example, Seattle's SEA-Street project linked ESA goals with the city's political commitment to provide sidewalks in neighborhoods that had been annexed to become part of the city in the 1950s. Another award-winning Seattle project, the High Point housing re-development effort of 2003-6, linked the ESA goals for stormwater that drained to a salmon stream and a marine bay to federal goals for public housing that were part of the Hope VI funding program.

Other major trends that might be described as driving change in the relationships between urban design and water systems include increasing public awareness of climate change and aquatic ecosystem degradation, increasing advocacy or actual proposals by elected officials, evidence from European countries and cities that are taking action to adapt, and an increase in the number of cases available that can be used to argue by example. Changes within the design and planning disciplines are also happening, in which civil engineers are learning more about decentralized system design, building architects are learning more about keeping water on the roof instead of shedding it, landscape architects are bringing more ecological rigor to expanding their recent role in urban design, and planners are re-considering the value of physical planning using spatially-explicit tools such as geographic information systems. Legislation in some states is promoting the use of physical design as a new tool in addressing cumulative environmental problems, such as Maryland's revision of its stormwater act to include innovative site design as a requirement, not merely an option (see the State of Maryland stormwater website for further information on this program, cited as Maryland Department of Environment, 2007).

Future trends that will drive innovation are likely to include an intensified awareness of the need for adaptation to climate change, the need to invest in infrastructure that has been subjected to deferred maintenance for decades, and the need to expand transportation options within urban regions. If a new national administration instigates an era of greater international cooperation, the approach is likely to accelerate these trends, as social and political norms from outside the United States will most likely reinforce the need for rational planning and design related to climate change and water resources.

## 8.6 Conclusions

The most important general lesson discussed in this chapter is that, while similar broad trends drive the need for innovation in the relationships between urban design and water systems, practitioners and academics from different fields may conceptualize the problem very differently. While there is no single best approach, the hybridization of several analytical frames is likely to provide more valuable insights than the choice of any one frame alone. In particular, urban designers and planners would benefit from using a spatial analytical approach that reminds them to look for intervention opportunities in network sites and shoreline sites, as well as the more typical upland locations.

The history of these ideas extends to at least the late 19th century, when American city design and planning was re-shaped by Olmsted's efforts to piggy-back social and ecological functions onto the spatial patterns of water systems. It has evolved significantly since that time, particularly through the establishment of more specific knowledge of the patterns and mechanisms of ecology and of the psychology of perception. But the simple, direct strategy of constructing a land-based infrastructure to manage water flow and water quality which also serves as a recreational infrastructure dates back to a critical 19th century urban innovation.

In practical terms, this chapter has proposed that a very simple set of three categories (upland, network, and shoreline) can be an effective basis for an integrative approach to urban design for water systems, especially in combination with a cross-sectional representation of larger urban patterns. Examples are provided of recent experience with urban design that explicitly addresses water systems, and that demonstrate the value of the proposed landscape-based analytical frame. Taken as a whole, these examples provide a vision of how the hydrological performance of cities and urbanizing landscapes can be altered on a large scale – from upland to shoreline.

The insight gained from reviewing these cases of successful design interventions, or in the case of shorelines, a set of proposed strategies, is that implementing demonstration projects can create many benefits. The first is to test whether the demonstration can achieve its functional goals. The second is a test of whether the design meets the aesthetic and political needs of its social context, the latter of which includes measures or estimates of its costs and benefits.

In terms of current trends and future drivers of innovation, increases in both public awareness and political courage to address adaptations to climate disruptions, and to channel development pressures, are most likely to influence the future of urban design related to water systems. Several regions of the United States have established themselves as leaders in the development of voluntary and mandatory design and planning standards, including the Pacific Northwest, southern and central California, and the state of Maryland. While these models have generated new initiatives in other regions, national leadership and international partnerships are needed to move to broader implementation – within those regions as well as nationally. Leadership is also needed to inspire regional leaders to continue to expand those initiatives, especially with regard to shoreline design and development.

## 8.7 Research

As Winston Churchill is reported to have said, "However beautiful the strategy, you should occasionally look at the results." The most important need for urban runoff systems research is in the area of monitoring. If new urban approaches either fall short of their goals or surpass them, this is critical information for future design strategies. Yet very few jurisdictions or practitioners engage in monitoring. There are obvious disincentives – for instance, few jurisdictions are willing to create public documents that identify design failures that lead to the continued pollution of streams or other water bodies by runoff from public streets. Previous case law has established the vulnerability of governments to lawsuits for such pollution. In practice, while most practitioners make the argument that past experience establishes their firm's expertise, evidence of a major design failure would undermine that argument. And if the client doesn't pay for the monitoring, the firm would be paying for evidence that undermines its credibility. Evidence of success would be very valuable, but very few firms see themselves as able to dedicate the financial or staff resources to demonstrate that success.

In addition, there are several areas in which better information or more innovation is needed, including:

- assessing benefits to property values and operating costs (this would provide support to the idea of using local improvement districts as a financing tool for water system improvements);
- developing better methods for oil/grease removal;
- studying urban retrofit benefits in different regions (such as the recent Washington DC study of green roof retrofits and tree planting; Deutsch 2007);
- testing proposals for shorelines designs, especially in relation to habitat support that can be adapted as sea level rises or storm patterns change;
- detailed regional assessments of sea level rise and storm surge impacts on drainage and other infrastructure along the coasts, and rain/snowfall changes inland;
- comparative studies of alternative implementation plans for replication (financing, cost, performance, maintenance, etc.).

Linked to these research needs, there is also a need for expanded education within the urban design professions (civil engineering, planning, landscape architecture, and building architecture). Students need to enter their professional careers with greater knowledge of landscape-based strategies for improving hydrologic performance. This can be taught using case studies, and by framing discussions of the performance of those cases in a bioregional context. Students also need an enhanced focus on shorelines as the ecosystem at the end of the pipe, or protecting systems like the Chesapeake Bay, the Great Lakes, or Puget Sound will not be understood as the fundamental reason for (and test of) efforts to improve urban performance. Finally, students need to participate in developing innovations related to "positive impact re-development" – in order for urban design to move beyond the current focus on the development of new urban areas, and re-center professional attention on urban infill and brownfield re-development. The market of design clients will continue to push for the development of new land, but new professionals need to see this type of development as inextricably linked to central cities and their performance (especially in terms of fiscal performance and infrastructure systems).

### 8.7.1 Implementation

In order for any of the ideas or approaches mentioned in this chapter to make any difference to urban performance as a whole, broad implementation is necessary. While a discussion of municipal public finance and infrastructure budgets is beyond the scope of this chapter, implementation requires a new approach in both these areas that will, like all major urban changes, sometimes involve political and financial risks as well as social and environmental benefits. For example, most large jurisdictions have manuals that set standards for street design, and have code language that sets standards for parking lot design on public or private sites. These two areas of public administration are the "low hanging fruit" of an urban revolution in water quality and aquatic biodiversity. But barring a dramatic change in federal contributions to local infrastructure budgets, any plan for investing in improved streets and parking lots must be paid for through a combination of local public and private dollars. As different jurisdictions try experiments in funding, anti-tax organizations or groups that seek to represent the narrow financial interests of utility rate-payers often challenge these innovations in court as well as in a political arena. In other cases, higher levels of government – such as the state versus the city – may block financing instruments as a political maneuver designed to create or demonstrate leverage, not as a way of achieving environmental goals.

Non-governmental organizations can exert a significant and important influence on these political outcomes, as can changes in the incentives established by federal funding programs, or implementation of federal laws like the CWA and the ESA. A sustained alignment of interests must be established to achieve the creation of new standards, as well as the financing and enforcement of those standards, if cities are to improve their cumulative hydrological and ecological performance. Benefits to human health issues, transportation, recreation, the fishing industry, and tourism will have to be aligned with efforts to improve aquatic health more generally.

A combination of inspiration, regulation and common sense will be needed to change any particular city. Individuals as well as non-governmental groups and public agencies will be responsible to create that combination of characteristics. In the end, it comes down to how many miles of roadway, how many roofs, how many parking lots, and how many miles of shoreline can be held to a different standard as communities develop, re-develop, and adapt to changes in climate and the rates of sea level rise.

**Acknowledgments** The author wishes to thank the editor, Larry Baker, and two reviewers, Doug Johnston and Lance Neckar, for suggestions that improved this chapter significantly.

## References

Alberti, M., D. Booth, K. Hill, C. Avolio, B. Coburn, S. Coe, and D. Spirandelli. 2007. The impact of urban patterns on aquatic ecosystems: An empirical analysis in Puget lowland sub-basins. Landscape and Urban Planning **80**(4):345–361.

Ashley, R.M., D.J. Balmforth, A.J. Saul, and J.D. Blanskby. 2005. Flooding in the future: predicting climate change, risks and responses in urban areas. Water Science and Technology **52**:265–273. IWA Publishing.

Barnett, J. and K. Hil. 2008. Design for Rising Sea Levels. Harvard Design Magazine, Number 27, Winter 2008.

Beach, D. 2002. Coastal Sprawl: The Effects of Urban Design on Aquatic Ecosystems in the United States. Pew Oceans Commission, Arlington, Virginia.

Booth, D. 2005. Challenges and prospects for restoring urban streams: a perspective from the Pacific Northwest of North America. North American Benthological Society **24**:724–737.

Botsford, L.W., A. Hastings, and S.D. Gaines. 2001. Dependence of sustainability on the configuration of marine reserves and larval dispersal distance. Ecology Letters **4**:144–150, 2001.

Bureau of Environmental Services (BES). 2006. 2006 Stormwater Management Facility Monitoring Report Summary. Sustainable Stormwater Management Program, Portland, Oregon, September 2006.

EPA. 1999. Combined Sewer Overflow Management Fact Sheet. EPA 832-F-99-041. US Environmental Protection Agency, Washington, D.C., September 1999.

Deutsch, B. 2007. The green build-out model: quantifying the stormwater management benefits of trees and green roofs in Washington, DC. Casey Trees Foundation and LimnoTech, Washington, DC.

Gerlach, G., J. Atema, M.K. Kingsford, K.P. Black, and V. Miller-Sims. 2007. Smelling home can prevent dispersal of reef fish larvae. Proceedings of the National Academy of Sciences of the United States of America **104**:858–863.

Gobel, P., C. Dierkes, and W.G. Coldewey. 2007. Storm water runoff concentration matrix for urban areas. Journal of Contaminant Hydrology **91**: 26–42.

Hill, K. 2002. Urban Design and Ecology. In CASE: Downsview Park Toronto, ed. by Julia Czerniak, Prestel Publishers.

Hill, K. 2003. Green Good, Better, Best: Effective ecological design in cities," Harvard Design Magazine, Number 18, Summer 2003.

Horner, R., H. Lim, S., and Burgess. 2002. Hydrologic monitoring of the Seattle ultra-rrban stormwater management projects. Water Resources Series, Technical Report No. 170, University of Washington, Seattle, WA, September 2002.

Johnson, M.W. 1960. The offshore drift of larvae of the California spiny lobster *Panulirus interruptus*. California Cooperative Oceanic Fisheries Investigations Reports **7**:147–161.

Lachmund, J. 2007. Ecology in a walled city: researching urban wildlife in post-war Berlin. Endeavor **31**:78–82.

London Climate Change Partnership. 2006.Seattle: Managing stormwater, pp. 34–45. In: Adapting to Climate Change: Lessons for London. Greater London Authority, London.

Lynch, K., M. Southworth, and T. Banerjee. 1990. City sense and city design: writings and projects of Kevin Lynch, MIT Press, Cambridge, MA.

Maryland Department of the Environment. "Maryland Stormwater Act of 2007," http://www.mde.state.md.us/Programs/WaterPrograms/SedimentandStormwater/swm2007.asp, accessed June 2008.

McHarg, I. 1969. Design with Nature, Natural History Press, Garden City, NewYork.

Meyer, E. 1997. Ecological Design and Planning. Wiley, New York.

Nassauer, J.I. 1995. Messy ecosystems, orderly frames. Landscape Journal **14**:161–170.

National Research Council. 2003 Oil in the Sea III: Inputs, Fates, and Effects. The National Academies Press, Washington, DC.

Novotny, V., and Hill, K. 2007. Diffuse pollution abatement – a key component in the integrated effort towards sustainable urban basins. IWA Publishing, London, UK.

Patel, J. 2005. Briefing: review of CIRIA Report 142 on highway pollutants. Proceedings of the Institution of Civil Engineers, Transport **158**(TR3):137–138.

Perkins, B., D. Ojima, and R. Correll. 2007. A Survey of Climate Change Adaptation Planning. The Heinz Center, Washington, DC.

Pineda, J., J.A. Hare, and S. Sponaugle. 2007. Larval transport and dispersal in the coastal ocean and consequences for population connectivity. Special Issue on Marine Population Connectivity, Oceanography, **20**(3):22–39.

Sukopp, H. 1973. Die Großstadt als Gegenstand Oekologischer Forschung. Schriften des Vereins zur Verbreitung Naturwissenschaftlicher Kenntnis zu Wien. Bericht ueber das 113. Vereinsjahr, 90–139.

Tabor, R., H. Gearns, C. McCoy, and S. Camacho. 2006. Nearshore habitat use by juvenile Chinook salmon in lentic systems of the Lake Washington Basin. Annual Report, 2003 and 2004, U.S. Fish and Wildlife Service, Western Washington Fish & Wildlife Office, Lacey, Washington, DC.

Tallis, H., Z. Ferdana, and E. Gray. 2008. Linking terrestrial and marine conservation planning and threats analysis. Conservation Biology **22**:120–130.

Transportation Research Board (TRB). 2008. Special Report 290: Potential Impacts of Climate Change on U.S. Transportation. The National Academies, Washington, DC, March 2008.

US EPA. 2007. National Water Quality Inventory: Report to Congress, 2002 Reporting Cycle, EPA 841-R-07-001, October 2007.

Walsh, R., A. Roy, J. Feminella, P. Cottingham, P. Groffman, and R. Morgan. 2005. Urban stream syndrome: current knowledge and the search for a cure. Journal of the North American Benthological Society **24**:690–705.

Welter, V. 2003. Biopolis: Patrick Geddes and the City of Life. MIT Press, Cambridge, MA.