17

Green infrastructure for cities: The spatial dimension

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Summary: Planning for sustainable cities is a complex process addressing the fundamental areas of economic, environmental and socially-equitable sustainability. This chapter focuses on the environmental area, with theories, models, and applications illustrating possible spatial configurations of a green infrastructure to support ecological and physical processes in the built environment including: hydrology, biodiversity, and cultural/human activities. Green infrastructure is an emerging planning and design concept that is principally structured by a hybrid hydrological/drainage network, complementing and linking relict green areas with built infrastructure that provides ecological functions. Green infrastructure plans apply key principles of landscape ecology to urban environments, specifically: a multi-scale approach with explicit attention to pattern:process relationships, and an emphasis on connectivity. The chapter provides theoretical models and guidelines for understanding and comparing green infrastructure approaches. International examples at multiple scales are discussed to illustrate the concepts and principles introduced.

INTRODUCTION

The aim of this chapter is to introduce and explore the concept of urban green infrastructure as a means of spatially organizing urban environments to support a suite of ecological and cultural functions. In contemporary urban planning and design literature there is a convergence of research and case applications addressing sustainable cities and sustainable urbanism (Low et al., 2005; Moughtin and Shirley,

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2005; Wooley, 2003; Steiner, 2002; Beatley, 2000; Van der Ryn and Cowan, 1996; Hough, 1995). This emerging focus reflects a broader international awareness of sustainability across its basic tripartite dimensions: economy, environment and (social) equity – often known as the "three E's" of sustainability (Wheeler and Beatley, 2000). As the sustainable development concept has matured and gained greater acceptance over the past two decades, it has directly and increasingly influenced regional and municipal policy and plans (Benedict and McMahon, 2006). As with the tripartite principles of sustainability, the policies and plans developed to advance urban sustainability through policy and practice address the economic, social, and environmental dimensions of sustainability. This chapter focuses primarily on the environmental dimension of urban sustainability, and more specifically, the role of spatial configuration of the urban environment in supporting key ecological functions through a "green infrastructure" in a sustainable manner. In addition, green infrastructure is also presented as a strategy to achieve abiotic, biotic and cultural goals. The chapter starts with a review of key ecological processes and principles of landscape ecology, with respect to sustainable planning, and of the particular importance of spatial configuration of urban environments.

KEY ECOLOGICAL PROCESSES AND FUNCTIONS

Ecological processes are the mechanisms by which landscapes function – over time, and across space – and are therefore appropriate to use as the goals for – and the indicators of – sustainability. Landscape ecology provides a theoretical perspective and the analytical tools to understand how complex and diverse landscapes, including urban environments function with respect to specific ecological processes (Pickett et al., 2004).

The Ecological Society of America defines ecological functions as those that provide "services" that moderate climatic extremes, cycle nutrients, detoxify wastes, control pests, maintain biodiversity and purify air and water (among other services) (ESA, 2006). The ecosystem services concept helps to place value on ecological functions, often to the direct benefit of human populations in physical health, economic or social terms.

A widely accepted resource model for landscape planning is the Abiotic, Biotic and Cultural (ABC) resource model (Ndubisi, 2002; Ahern, 1995). This comprehensive and inclusive model is consistent with the landscape ecology perspective that explicitly recognizes the needs and reciprocal impacts of humans on biotic and abiotic systems and processes. The ABC resource model is applied here to articulate the key ecological functions of a green urban infrastructure (Table 17.1).

The ABC functions described in Table 17.1 are intended to be illustrative, but not comprehensive. It is important to note how this broad, multipurpose, and multifunctional suite of ecological and cultural functions supports the broad principles of sustainability, in contrast with single-purpose policies or plans that address more focused goals (e.g. managing water quality, endangered species protection or pollution remediation). And because this suite of functions spans an abiotic-biotic-cultural continuum – it is inherently more likely to enjoy a broad base of

Table 17.1. Key abiotic, biotic and cultural functions of a green urban infrastructure

Abiotic	Biotic	Cultural
Surface:groundwater interactions	Habitat for generalist species	Direct experience of natural ecosystems
Soil development process	Habitat for specialist species	Physical recreation
Maintenance of hydrological regime(s)	Species movement routes and corridors	Experience and interpretation of cultural history
Accommodation of disturbance regime(s)	Maintenance of disturbance and successional regimes	Provide a sense of solitude and inspiration
Buffering of nutrient cycling	Biomass production	Opportunities for healthy social interactions
Sequestration of carbon and (greenhouse gasses)	Provision of genetic reserves	Stimulus of artistic/abstract expression(s)
Modification and buffering of climatic extremes	Support of flora:fauna interactions	Environmental education

This figure articulates what a green urban infrastructure can explicitly do to contribute to sustainability.

public support – an essential characteristic for a successful urban sustainability program.

LANDSCAPE ECOLOGY PRINCIPLES FOR GREEN URBAN INFRASTRUCTURE

Key ideas from landscape ecology that are relevant to green urban infrastructure for sustainable cities include: a multi-scale approach with an explicit recognition of pattern:process relationships and an emphasis on physical and functional connectivity.

A multi-scaled approach is based on hierarchy theory that addresses the structure and behavior of systems that function simultaneously at multiple scales. For example, hierarchy theory is widely used in transportation planning, for to understand the dynamics and capacity of local road traffic, one must understand the larger highway system with which local roads are connected. The same applies to landscapes which are also hierarchical systems. While landscapes are, by definition, broad heterogeneous areas of land, they are also by definition “nested” within larger areas of land that often constrain, or control the ecological processes – particularly those associated with species movement or hydrological processes. In applied landscape ecology, a multi-scaled approach – addressing spatial patterns and ecological processes – is the accepted norm (Leitão and Ahern, 2002; Ndubisi, 2002). The multi-scaled approach involves assessment and planning of spatial configuration of landscape patterns and ecological processes at multiple scales, and how these patterns and processes interact. This analysis typically indicates key points for physical linkages, where important connections exist, or where connections should be made. In urban environments the appropriate scales are: the metropolitan region or city, the districts or neighborhoods, and individual sites.

The pattern:process dynamic is arguably the fundamental axiom of landscape ecology because the spatial composition and configuration of landscape elements directly determines how landscapes function, particularly in terms of species movement, nutrient and water flows (Turner, 1989). Because landscape pattern and process are highly interrelated and interdependent, both must be understood to plan for sustainability. Landscape architects, and applied landscape ecologists have advanced theories, guidelines and models for landscape patterns that support a desired, or maximum level of ecological functions in a sustainable manner (Dramstad et al., 1996). The ecological network concept, in particular, has been implemented worldwide to address the intriguing promise of an optimal spatial strategy at broad scales including continents, nations and regions (Jongman and Pungetti, 2004). The ecological network concept, however, has aimed primarily at maintaining biodiversity and has been rarely applied in urban contexts. This trend is changing with a focus on urban environments through the green infrastructure movement.

Connectivity is a property of landscapes that illustrates the relationship between landscape structure and function. In general, connectivity refers to the degree to which a landscape facilitates or impedes the flow of energy, materials, nutrients, species, and people across a landscape. Connectivity is an emergent property of landscapes that results from the interaction of landscape structure and function, for example: water flow, nutrient cycling and the maintenance of biological diversity (Leitão et al., 2006). In highly modified landscapes, and especially in urban environments, connectivity is greatly reduced, often resulting in fragmentation – the separation and isolation of landscape elements with significant impacts on the ecological processes that require connectivity. The concept of connectivity applies directly to water flow, arguably the most important flow in any landscape, particularly in human-dominated and urban environments. Disruption of hydrologic connectivity is a major concern when planning for sustainability. Because human culture relies on water in many respects, maintaining a connected and healthy hydrological system supports multiple ABC functions. In urban, or built environments, roads represent the greatest barrier to connectivity and are the primary contributor to fragmentation (Forman et al., 2003).

Spatial configuration

With an understanding of ecological processes, the pattern:process dynamic and the importance of connectivity, spatial configuration is the point of integration. In applied landscape ecology, the mosaic model for describing and understanding the spatial configuration of landscapes is almost universally accepted. The model uses three fundamental landscape elements to define landscape structure: patches,

Table 17.2. Examples of Urban Landscape Elements Classified in the Patch-Corridor-Matrix Model

Urban Patches	Urban Corridors	Urban Matrix
• Parks	• Rivers	• Residential Neighborhoods
• Sportsfields	• Canals	• Industrial Districts
• Wetlands	• Drainageways	• Waste Disposal Areas
• Community Gardens	• Riverways	• Commercial Areas
• Cemeteries	• Roads	• Mixed Use Districts
• Campuses	• Powerlines	
• Vacant Lots		

Table 17.3. A typology of planning strategies, illustrating the range of actions that planners and designers routinely practice (Ahern 1995)

Protective	Defensive
Taking preventative actions to preserve well functioning, intact landscape elements before they are threatened by change or development:	Implementing actions to defend landscape elements that are suffering from development pressure:
• World Heritage Areas • National Parks • "Big" patches of native vegetation • Nature preserves	• Regional, local parks • Buffer zones • Environmental impact mitigation • Corridors that are pressuredfrom adjacent land use(s)
Offensive	Opportunistic
Taking remedial or restorative actions to reintroduce Abiotic, Biotic or Cultural functions where they do not currently exist:	Recognizing the potential for non-contributing landscape elements to be managed or structured differently to provide specific functions.
• Ecological restoration • Brownfields • Daylighted streams • Bioremediation	• Many greenways • Most urban/green infrastructure • Transportation and utility infrastructure

corridors, and the matrix. A patch is a relatively homogeneous nonlinear area that differs from its surroundings. Patches provide multiple functions including wildlife habitat, aquifer recharge areas, or sources and sinks for species or nutrients. A corridor is a linear area of a particular land cover type that is different in content and physical structure from its context (Forman, 1995). Corridors serve many functions within the landscape including habitat for wildlife, pathways or conduits for the movement of plants, animals, nutrients, and wind, or as barriers to such movement. The matrix is the dominant land cover type in terms of area, degree of connectivity and continuity, and control that is exerted over the dynamics of the landscape (Forman, 1995; Forman and Godron, 1986). Table 17.2 provides examples of urban landscape elements classified in the Patch-Corridor-Matrix Model.

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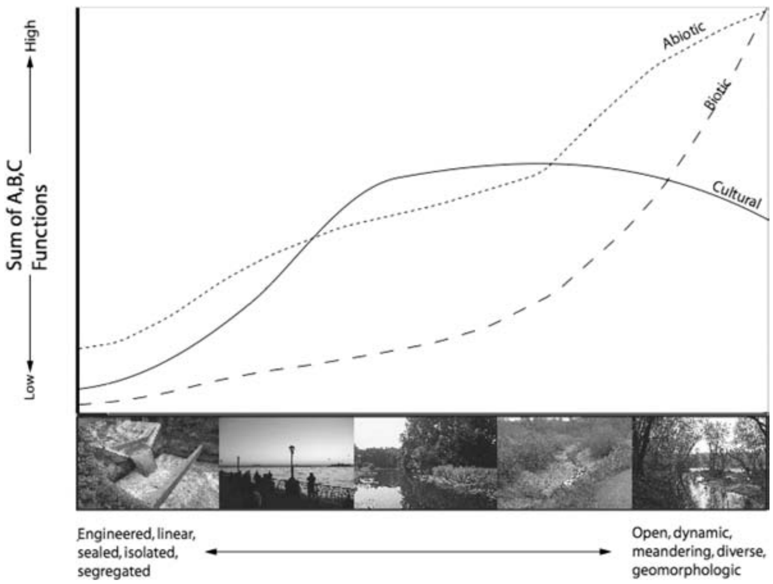

Figure 17.1. A continuum of hydrological/stream types and associated abiotic, biotic and cultural functions

Figure 17.1 presents a continuum of urban water courses from highly engineered, linear sewers to diverse meandering river channels. Note how the associated ABC functions respond differently across the continuum. For example, streams with lower biological value may have relatively high cultural value, and high biological functions may have lower cultural functional value. The implications being that planning and management need to consider, and employ a mixed range of hydrological types to provide a complete suite of ABC functions as part of a sustainable urban landscape. And important to accept reduced or minimal values on one category if valued functions are provided in other areas.

Forman's "indispensable patterns" are perhaps the most succinct, compelling and memorable of the landscape ecology-based guidelines (Forman, 1995) as shown in Figure 17.2. These indispensable patterns are equally relevant in urban environments as they are in landscapes that are less dominated by human development and built infrastructure. Forman argues that these patterns are fundamental, for without them specific ecological functions will not be supported.

GUIDELINES FOR PLANNING AND DESIGNING A GREEN URBAN INFRASTRUCTURE

As discussed above, landscape ecology provides scientifically-based principles for landscape planning including a multi-scaled perspective, recognition of

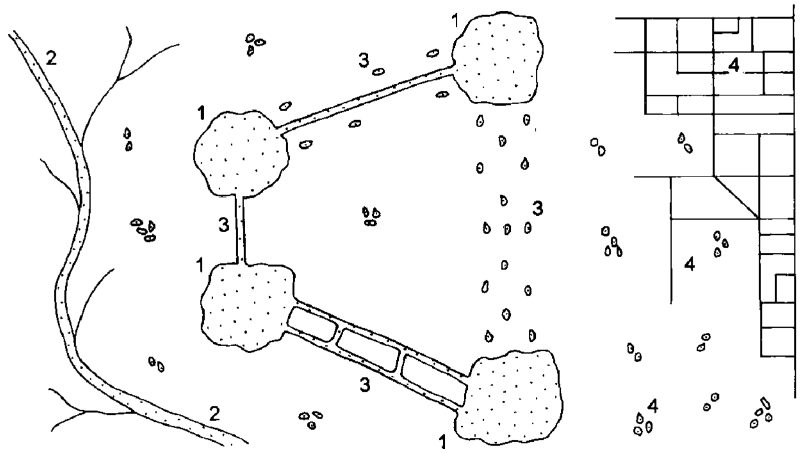

Figure 17.2. Forman's "indispensable" patterns for planning a landscape: (1) large patches of natural vegetation, (2) stream/river corridor, (3) connectivity between patches and stepping stones, and (4) small "bits of nature" (Forman, 1995, p. 452)

pattern:process relationships, the fundamental importance of connectivity and specific guidelines for planning the spatial configuration of landscapes. To successfully apply these principles in landscape or urban planning, they must be associated with, and related to planning guidelines which enable the "good science" of landscape ecology to be effectively applied in the service of sustainability. Following are five proposed guidelines for planning and designing a green urban infrastructure based on landscape ecology principles.

1. Articulate a spatial concept

Spatial concepts guide, inspire and communicate the essence of a plan or planning strategy to provide for specific ABC functions. Spatial concepts are often articulated as metaphors that are highly imaginable and understandable by the public, but which also can support and inspire the planning process (Zonneveld, 1991). Examples include: "green heart", "ring city", and "edge city". The green heart spatial concept, for example, has guided national and regional planning in the Netherlands for decades by protecting a mostly agricultural "green heart" surrounded by a ring of urbanization including the cities of Amsterdam, Rotterdam and Utrecht. Spatial concepts are well understood in planning, but less so in science. They represent an important interface of empirical and intuitive knowledge through which rational knowledge is complemented with creative insights. Spatial concepts are essential tools for proactive, or innovative planning, and can structure and inspire the planning process, particularly with respect to achieving genuine and effective public participation.

2. Strategic thinking

Employ a strategic approach, appropriate to the spatial context and planning goals, potentially including: protective, defensive, offensive or opportunistic strategies (Ahern, 1995). Defining these strategies also helps to place the planning activity within a broader context that is particularly relevant when planning methods are transferred or adopted for use in different locations, contexts or for different applications. A planner should be aware of the macro drivers of change in a given landscape with respect to the goals of a particular plan. This awareness is the basis for informing a planner's choice of, or combination of, methods, and for engaging the appropriate participants in the planning process.

When the existing landscape supports sustainable processes and patterns, a protective strategy may be employed. Essentially, this strategy defines an eventual, or optimal landscape pattern that is proactively protected from change while the landscape around it may be allowed to change. Benton MacKaye's (1928) vision of a metropolitan open space system structured by a system of protected "dams" and "levees" is a classic example from North America. It can be effective to prevent landscape fragmentation in urbanizing landscapes by pre-defining a patch and corridor network for protection. This strategy employs planning knowledge, regulation, and land acquisition to achieve the desired spatial configuration (goal).

When the existing landscape is already fragmented, and core areas already limited in area and isolated, a defensive strategy is often applied. This strategy seeks to arrest /control the negative processes of fragmentation or urbanization. As a last resort, the defensive strategy is often necessary, but it can also be seen as a reactionary strategy which attempts to "catch up with" or "put on the brakes", against the inevitable process of landscape change, in defense of an ever-decreasing nature (Sijmons, 1990).

An offensive strategy is based on a vision, or a possible landscape configuration that is articulated, understood and accepted as a goal. The offensive strategy differs from protective and defensive strategies in that it employs restoration, or reconstruction, to re-build landscape elements in previously disturbed or fragmented landscapes. The offensive strategy relies on planning knowledge, knowledge of ecological restoration, and significant public support/ funding. It requires, by definition, the displacement, or replacement of intensive land uses (e.g. urbanization, agriculture) with extensive land uses, green corridors or new open spaces in urban areas.

A landscape often contains unique elements or configurations that represent special opportunities for sustainable landscape planning. These unique elements may or may not be optimally located, but represent the potential to provide particular desired functions. The opportunistic strategy is conceptually aligned with the concept of green infrastructure by seeking new or innovative "opportunities" to provide ABC functions in association with urban infrastructure.

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3. The greening of infrastructure

To achieve sustainability in urban landscapes, infrastructure must be conceived of, and understood as a genuinely possible means to improve, and contribute to sustainability. If one only thinks about avoiding or minimizing impact related to infrastructure development, the possibility to innovate is greatly diminished. Stormwater management provides a good example. Until recently, stormwater management aimed at controlling development-related stormwater management at pre-development levels. This "damage control" mentality produced the familiar sterile, unvegetated, inaccessible stormwater retention and detention ponds that are common throughout the USA. While this stormwater infrastructure accomplished the primary goal of controlling runoff, it failed to provide other ABC functions (water quality, ecological integrity). In contrast, consider a "green infrastructure" stormwater system that incorporates green roofs, infiltration wells, vegetated bioswales, small ponds and created wetlands. This infrastructure adds a wealth of ABC functions to the stormwater system and improves liveability (van Bohemen, 2002).

4. Plan for multiple use

As discussed above under planning strategies, planning and implementing urban infrastructure presents a fundamental spatial challenge: how can new functions be added when the built environment has already displaced or replaced "natural" areas and functions? It is naive and impractical to believe that stakeholders and decision-makers will make sweeping substitutions of built forms with green areas, regardless of how committed to sustainability they are. The political, economic and social costs of such wholesale replacements are too great. Rather, it is incumbent on planners and designers to think strategically to find new ways to reconceive "grey" infrastructure to provide for sustainable ABC functions. This can be accomplished by intertwining/combining functions (Tjalllingii, 2000), as described above for stormwater management. Another design strategy is vertical integration, where multiple functions can be "stacked" in one location, as with wildlife crossings under/over roads, infiltration systems beneath building or parking lots, or green roofs on buildings (van Boheman, 2002). Innovative scheduling can also be employed to take integrate and coordinate the time dimension of ABC functions. Examples of infrastructure scheduling include limited human use of hydrological systems during periods of high flows, restrictions of recreational use of habitat areas during sensitive breeding periods, or the closing of roads at night when nocturnal species movement is concentrated. Planning for multiple use of green infrastructure can also be a useful strategy for cost effectiveness and for building a broad constituency of public support.

5. Learn by doing

A fundamental challenge and impediment to applying landscape ecology-based principles is the common lack of empirical evidence of the effectiveness of a given intervention in a specific location. Wildlife corridors provide an example. While corridors have been implemented across the world to move species across agricultural and suburban locations (Bennett, 1999), the recommendations for corridor width, length or structure are specific to the particular species and the landscape context involved. Thus, a corridor system for Koalas in Australia, has questionable transferability for planning a moose corridor in the northeastern USA. The dilemma faced by planners is that the specific recommendations needed to implement a corridor system cannot be proven by applications elsewhere for different species. Unfortunately, the result is too often, inaction. Adaptive planning provides an alternative strategy. Under an adaptive approach, plans and policies are based on the best available knowledge, structured as experiments and monitored to learn how the actions result in specific goals for ABC functions. For example, to monitor cultural functions, surveys and observations of green corridor users can be kept systematically over time to track not only numbers of users but their motivations, their expectations and their impressions of the resource. Implicit in the adaptive approach is the potential to fail, but also the possibility to succeed. An adaptive approach requires a transdisciplinary effort involving, scientists, stakeholders, decision makers and planning and design professionals.

The adaptive approach is promising for green infrastructure because the knowledge to plan and implement these systems is evolving. If experimental applications can be practiced routinely, the potential to build empirical knowledge, while exploring sustainability is quite profound.

EXAMPLES OF GREEN URBAN INFRASTRUCTURE

Landscape ecology holds great potential to guide and inform the application of green urban infrastructure at a range of scales and in diverse contexts. Following are examples that illustrate green urban infrastructure across a range of scales: metropolitan/city, neighborhood/district, and site scale. The examples have been selected to also explore a broad geographical range including Asia, Europe and North America.

Taizhou City China: Metropolitan green infrastructure

Taizhou is a metropolis located on the southeast coast of China that occupies about 1000 square kilometers and has a current population of 5.5 million people. The metropolitan region is expecting a 115% population increase in the next 25 years. In response to routine flooding, the city historically developed an extensive water network integrating natural water courses, wetlands and human-made ditches. The water system significantly defined the cultural landscape character of this region, but is now suffering disturbance and destruction from rapid and extensive infrastructure construction to serve the booming economy.

An ecological infrastructure plan was designed by Landscape Architect Kongian Yu of Turenscape and Bejing University to support important abiotic, biotic and cultural resources, while structuring future urban development and to

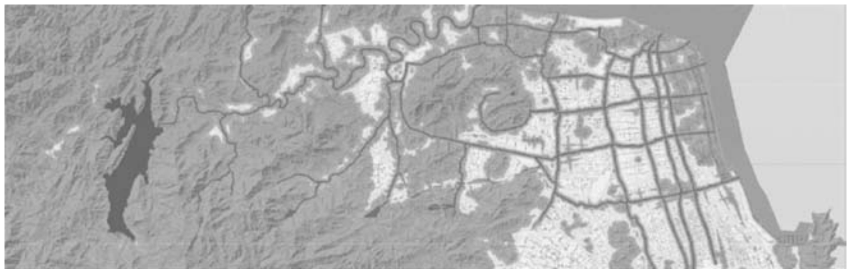

Figure 17.3. Alternatives for the Taizhou regional ecological infrastructure at three "security levels", dark green minimal security, apple green, medium security and willow green high security. The medium security alternative was adopted (Turenscape, 2006)

avoid sprawl. The ecological infrastructure is conceived to support abiotic, biotic and cultural functions, here defined as security patterns to provide sustainable ecosystem services. Security patterns represent the areas that provide important ecosystem services (flood protection) and therefore provide "security" against disturbance. Each security pattern was separately assessed, then synthesized into three alternatives (Figure 17.3).

The Taizhou plan demonstrates the application of landscape ecology guidelines including a multi-scaled approach with plan alternatives developed at regional and district scales, a linkage of pattern and process through the security patterns, and an emphasis on connectivity, particularly with respect to the multipurpose water systems. The plan also illustrates the green infrastructure guidelines proposed earlier in this chapter. The plan's security patterns present a clear spatial concept that communicates the essence of the plan effectively. The plan applies multiple planning strategies, including the defensive security patterns, and the opportunistic integration of water throughout the urban area. The ecological infrastructure is conceived as beneficial, and even essential to the city's future. Multiple use is demonstrated in many of the plan's components including the water system and green fingers that penetrate neighborhoods (Figure 17.4). There was not an adaptive component identified in the research on this example.

The Taizhou ecological infrastructure plan is an innovative and proactive response for a metropolitan region that is experiencing extreme pressure for urbanization. Although the metropolitan region includes 5.5 million people, important decisions remain to made about the future regional and urban form, influencing future sustainability. The concept is potentially transferable in urban areas where the impacts of expected population growth can motivate decision makers to explore and implement innovative ideas.

The staten Island bluebelt: neighborhood/district green infrastructure

Staten Island is the least populated borough of New York City and has a relatively intact mosaic of undisturbed wetlands. In the 1980's New York City started

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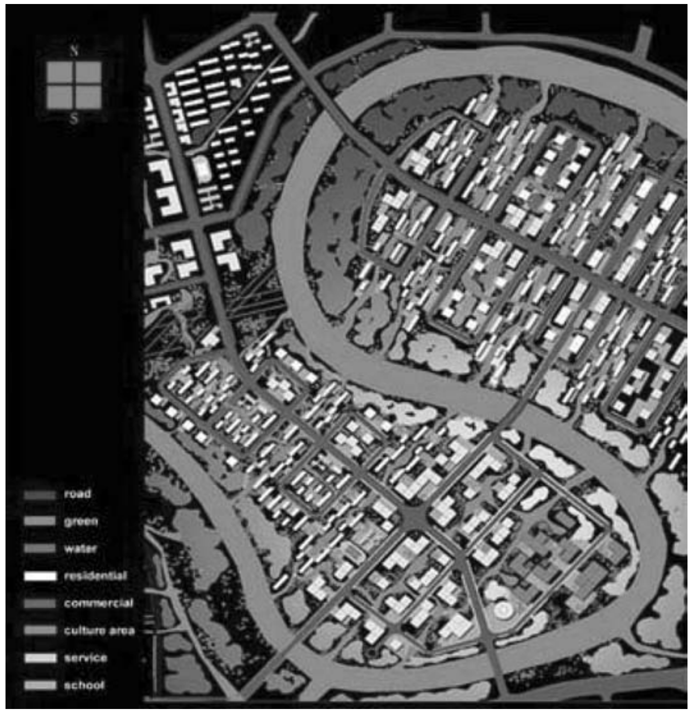

Figure 17.4. In the Taizhou "water town" alternative plan, the river is split and diverted through the city, managing the flood hazard and distributing the ecological functions provided by the river to residential neighborhoods (Turenscape, 2005)

planning to address flooding and water quality problems, including a major combined sewer overflow (CSO) problem. Unlike most cities addressing the CSO problem, New York City integrated the extensive existing wetlands into their water management plans for a 4000 hectare section of southwestern Staten Island involving some 16 small urban watersheds (Figure 17.5). The resulting Bluebelt plan was a direct result of Ian McHarg's Staten Island Study (McHarg, 1969). The Bluebelt plan has proven successful from a water quality and economic perspective, with over $80 million in savings to date (New York City DEP, 2003).

The plan had two principle components, construct a separate sanitary sewer system, and build a separate stormwater system using existing wetlands and best management practices. The stormwater system was conceived as an early example of green urban infrastructure by integrating multipurpose stormwater and wetland systems thoroughly into the fabric of the city. The Bluebelt has been successful in reducing the quantity and velocity of runoff, and removing contaminants from the runoff by introducing aquatic plants for bioremediation.

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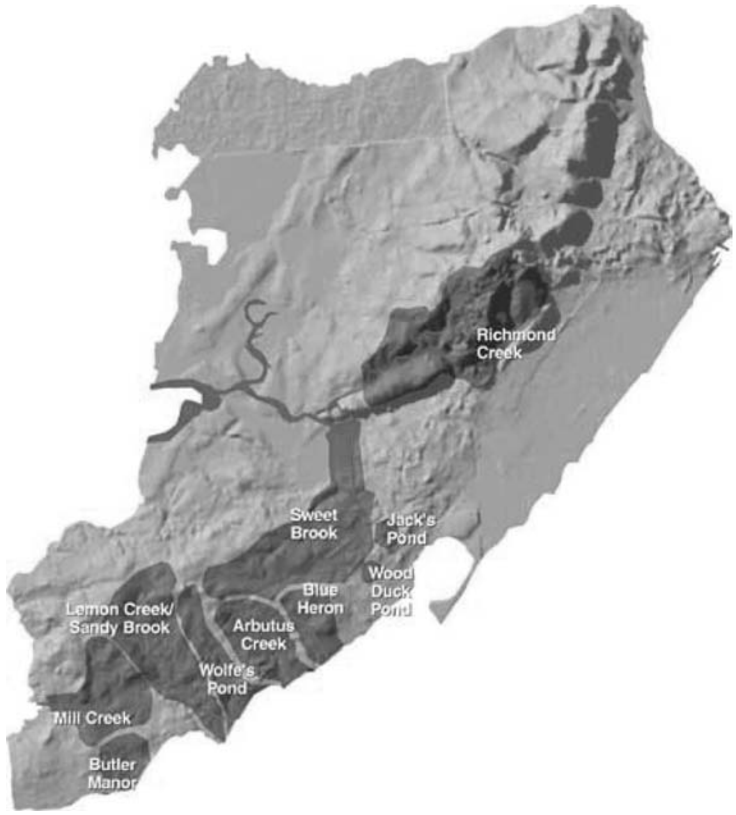


Figure 17.5. The Staten Island Bluebelt includes 16 sub watersheds and 2500 hectares on Staten Island, New York. (http://statenislandusa.com/2004/bluebelt.htm)

The Staten Island Bluebelt anticipated many of the principles of landscape ecology. It employed a multiscale approach addressing watersheds, subwatersheds and isolated wetlands. With its focus on water management, it successfully applied a pattern:process understanding to mitigate problems and advance beneficial opportunities. The bluebelt is a model of understanding the importance of connectivity in a complex and hybrid hydrological system. It employed a logical spatial concept based on the district's hydrological patterns, which were revealed and interpreted by pioneering ecological designer Ian McHarg. Although initially motivated and focused on water quality issues, it recognized the potential to provide multiple functions, including wildlife habitat, recreational trails, and the protection of wetlands within the city. It combined a protective strategy for existing wetlands with offensive and opportunistic strategies to integrate the system with stormwater management infrastructure (Figure 17.6). The plan demonstrates the potential of "beneficial infrastructure" and has learned by doing, through water quality monitoring and the application of emerging and evolving best management practices.

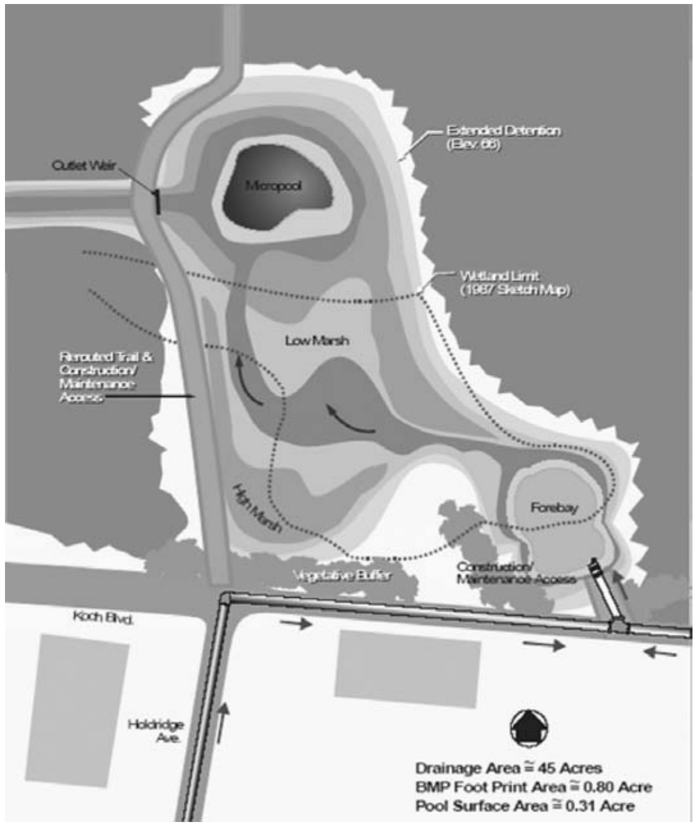
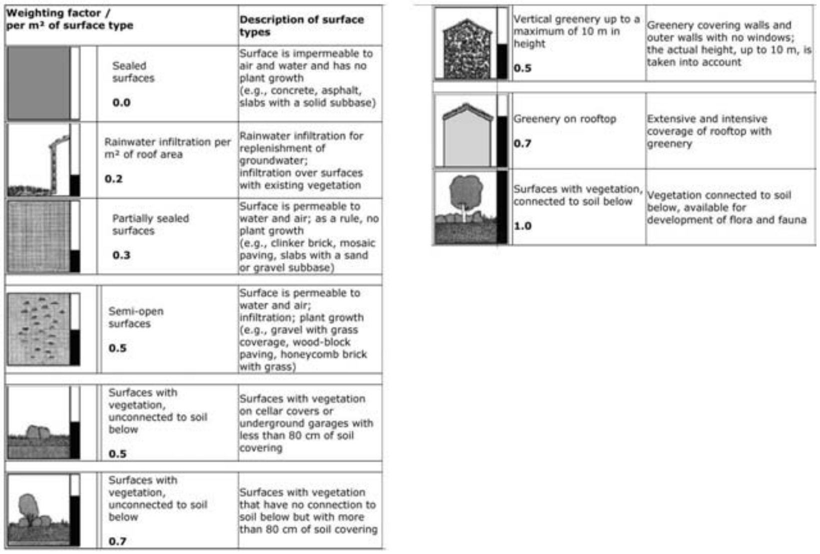


Figure 17.6. The neighborhood scale of the Staten Island Bluebelt showing the integrated stormwater collection system, stormwater best management practices, and a pre-existing wetland. http://www.ci.nyc.ny.us/html/dep/html/news/bluebelt.html

The Berlin biotope/green area factor, site scale green infrastructure

The Biotope/Green Area Factor program of Berlin, Germany is an innovative example of green urban infrastructure implemented at the parcel or building scale. From 1945 until 1990, West Berlin was an urban island within the German Democratic Republic and this unique isolation motivated research and public interest in urban ecology. Since the 1980's West Berlin has had an active green movement, reflecting national policies such as the National Environmental Protection Law that empowered local authorities to develop landscape plans for urban areas, including the Biotope/Green Area Factor program.

The Biotope/Green Area Factor program is based on the principle that modest, incremental and decentralized green infrastructure can have a significant cumulative effect to improve the urban ecology. Under the program, each parcel



Weighting factor / per m² of surface type	Description of surface types
Sealed surfaces 0.0	Surface is impermeable to air and water and has no plant growth (e.g., concrete, asphalt, slabs with a solid subbase)
Rainwater infiltration per m² of roof area 0.2	Rainwater infiltration for replenishment of groundwater; infiltration over surfaces with existing vegetation
Partially sealed surfaces 0.3	Surface is permeable to water and air; as a rule, no plant growth (e.g., clinker brick, mosaic paving, slabs with a sand or gravel subbase)
Semi-open surfaces 0.5	Surface is permeable to water and air; infiltration; plant growth (e.g., gravel with grass coverage, wood-block paving, honeycomb brick with grass)
Surfaces with vegetation, unconnected to soil below 0.5	Surfaces with vegetation on cellar covers or underground garages with less than 80 cm of soil covering
Surfaces with vegetation, unconnected to soil below 0.7	Surfaces with vegetation that have no connection to soil below but with more than 80 cm of soil covering
Vertical greenery up to a maximum of 10 m in height 0.5	Greenery covering walls and outer walls with no windows; the actual height, up to 10 m, is taken into account
Greenery on rooftop 0.7	Extensive and intensive coverage of rooftop with greenery
Surfaces with vegetation, connected to soil below 1.0	Vegetation connected to soil below, available for development of flora and fauna

Figure 17.7. The weighting system of Berlin's Biotope/Green Area Factor program is based on the percentage of imperviousness and the amount of vegetation present per square meter at the building or site level. http://www.stadtentwicklung.berlin.de/umwelt/landschaftsplanung/bff/en/bff_berechnung.shtml

must mitigate its impacts on-site. A primary goal of the program is to counteract "creeping impermeability" by mandating that new or renovated buildings achieve a prescribed green factor rating. The "greening" is intended to provide several functions: evapotranspiration of water, retain and infiltrate stormwater, remove airborne particulates, support natural soil functions and provide plant and animal habitat. The program is implemented at the neighborhood level, where priorities are decided, technologies selected and performance data collected and evaluated to measure progress towards goals.

The program sets green area targets based on land use: residential 60%, mixed use 40% and commercial/city center at 30% – recognizing that the targets must differ in response to land use intensity. When the policy is activated by a property sale or renovation, the owner is required to meet these targets by implementing greening techniques selected from a menu. Each technique is assigned a weight based on its contribution to the program goals and calculated as a poercentage of site area to determine the green factor. Techniques include: green roofs, bioswales, façade greening, pervious paving and plantings (Figure 17.7).

The Biotope/Green Area Factor demonstrates a "bottom-up" decentralized approach to green infrastructure planning (Keeley, 2004). While it aims at multiple goals and emphasizes the beneficial aspects of infrastructure, it does not have an explicit spatial concept. The program employs a fully opportunistic strategy and includes an adaptive component realized through monitoring of the cumulative effectiveness of the greening techniques (urban climate recording, urban species diversity, and water quality and total runoff) .

CONCLUSIONS

Green urban infrastructure is an evolving concept to provide abiotic, biotic and cultural functions in support of sustainability. Examples cited in this chapter illustrate how the green infrastructure planning and design benefit from landscape ecology principles, and how they tend to follow and support the five guidelines proposed. For green infrastructure to advance and to make legitimate contributions to urban sustainability, it must be practiced in a transdisciplinary manner – for it must meet the needs of stakeholders, benefit from the support of decision makers, engage scientists and engineers and challenge planners and designers to innovate. The proof of its success depends on the extent to which monitoring and systematic evaluations of long and short term results are made. To those who understand the green infrastructure concept, and its promise, the needs and opportunity to apply it in the pursuit of sustainability are quite profound.

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