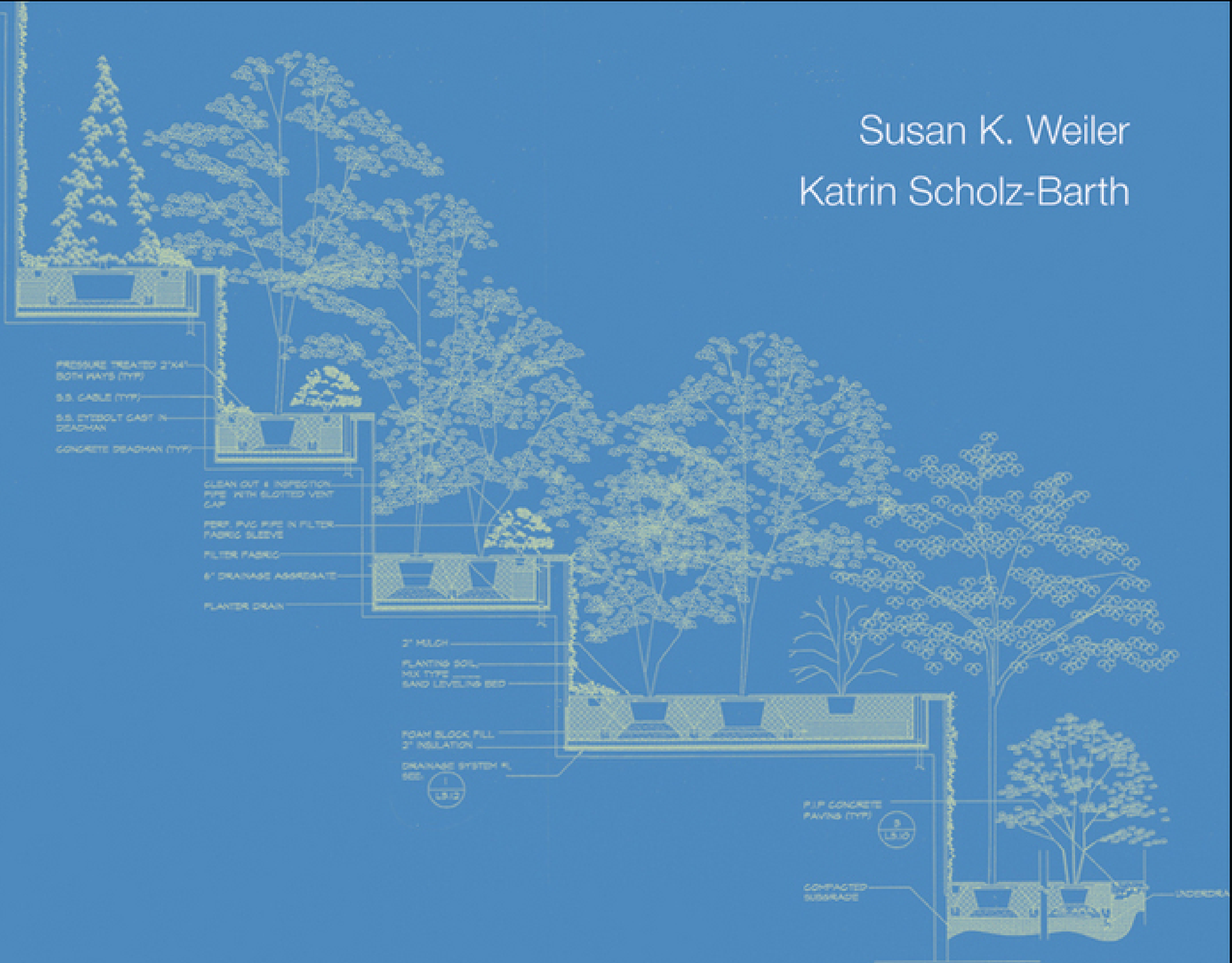
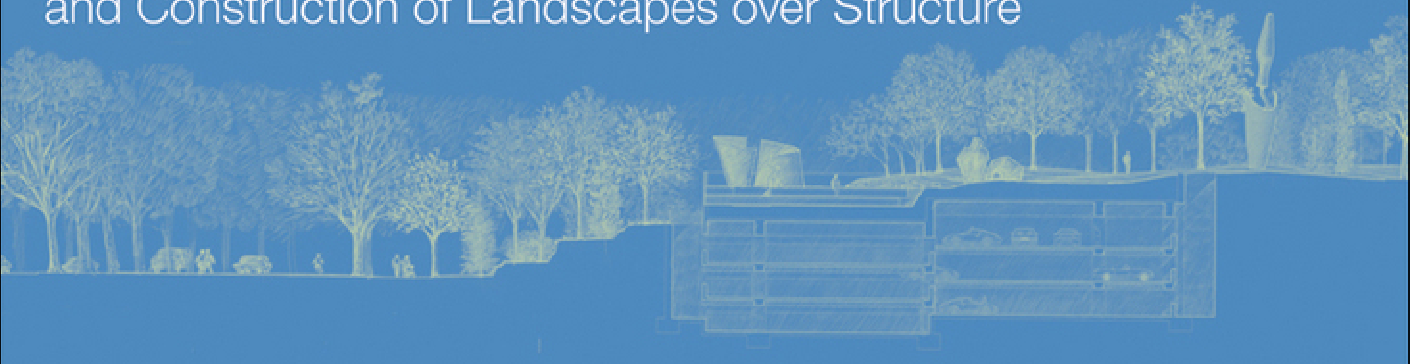


Susan K. Weiler

Katrin Scholz-Barth

Green Roof Systems

A Guide to the Planning, Design, and Construction of Landscapes over Structure



Green Roof Systems

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A Guide to the Planning, Design, and Construction of Landscapes over Structure

Susan K. Weiler

Katrin Scholz-Barth

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Contents

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Susan K. Weiler

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Katrin Scholz Barth

Chapter 1

Replenishing Our Diminishing Resources: Integrating Landscape and Architecture

The world is a glorious bounty.

—Ian L. McHarg, *Design with Nature*

The technology and materials for vegetating roofs and creating usable open spaces over structure have been known for centuries. Since 4000 BC, practitioners of building and agriculture have utilized the knowledge and materials of their time to construct sacred places such as ziggurats, simple vegetated roofs, and remarkable gardens over elevated surfaces.

The *building green* movement is not new, nor is the practice of using natural resources responsibly to sustain life and encourage the regeneration of natural resources.

In the last five years, the term *green roof* has taken on ecological and social significance beyond its seemingly simplistic description. As commonly understood, the term has become an epithet for the reduction of pollution and urban heat islands, for large-scale mitigation of stormwater runoff, and for maximum utilization of urban land.

Justifiably, the concept of the green roof as a way to add pervious surface and usable open space without taking up additional land is easy to understand and should be equally easy to implement. Consequently, many clients, municipalities, architects, landscape architects, and planners have come to consider them as an integral element of sustainable building practice.

More recently, many European municipalities have mandated the incorporation of green roof systems as standard building practice. Even without legislative mandate, landscape architects and architects have, with the personal will and mandate of their clients, successfully built numerous green roofs as stormwater management systems and as comfortable, accessible, open spaces over structure. This has happened without fanfare, perhaps because many of these spaces have been imperceptibly integrated with the architecture and surrounding urban fabric, and perhaps because much of what sustains green roof functionality is invisible to the user.

Most roofs as we know them, however, are not invisible, and as cities grow so do the number and sizes of rooftops. So too does the amount of land used for roads, parking lots, and pavement. At issue is the fact that conventional rooftops and paved surfaces are impermeable, which in turn affects the quality of our water and air. The use of more and

FIGURE 1-1 Gardens at the United Nations, viewed from the East River, illustrate extensive portions built over the FDR Drive.

more land for building affects the way we live. As our cities grow we need to be thoughtful about how we use our limited natural assets.

One of many strategies for replenishing our diminishing resources and integrating landscape and architecture is the green roof, and its wide-scale utilization is the focus of this book.

FIGURE 1-2 Outside Geneva, Switzerland, where vast meadows grow over the roof of a reservoir, a rich palette of plants provide a diversity of habitats for insects and small animals, as well as nesting places for birds.

FIGURE 1-3 Even a small individual effort can help ameliorate the negative impacts of unplanned development and urban growth in the Netherlands. (Photo: Joyce Lee)

This book aims to provide a comprehensive, systems-based approach to understanding, designing, and constructing green roof systems in an urban environment. The following chapters will:

- Broaden the reader's understanding of the deleterious effects that conventional roofs can have on the environment

FIGURE 1-4 West Ferry Circus, a lush garden of canopy trees, shrubs, lawns, and walkways, is one of the numerous interconnected open spaces at Canary Wharf in London. This part of the project was built over a highway, service roads, mechanical equipment rooms, and major utilities. Other open spaces were built over three to five stories of parking, a shopping center, and a tube stop.

- Challenge conventional thinking about the design and development of our built environment and foster innovative solutions that change the perception, appearance, and use of roofs for the benefit of our natural and cultural environment
- Identify the environmental, social, and economic benefits of turning the underexplored surfaces of roofs into multifunctional systems for stormwater management and the creation of usable landscapes over structure
- Provide detailed insight into their design, construction, and maintenance

Defining and Redefining the Roof: Traditional Roofs and Green Roof Systems

In traditional building terms, the roof is considered the lid or top of a habitable structure that keeps the unwanted weather elements outside and helps maintain the most comfortable conditions and temperatures for human habitation inside. For as long as there have been humans seeking shelter beyond a cave or a tree canopy, some type of protective weatherproofing material was overhead to provide protection from the sun, wind, rain, and snow. This has evolved from natural materials such as leaves, thatch, and sod to more durable materials such as slate, wood shingles, asphalt shingles, EPDM (ethylene propylene diene monomer) membranes—and contemporary green roof systems.

In traditional building terms, roofs can be sloped or flat. (Flat roofs actually have a slight slope to them even though to the naked eye they appear flat.) Regardless of its overall configuration and architectural type, a sloped roof sheds rainwater, snow, and ice more quickly than a flat roof, and it is generally more suited for the application of smaller overlapping units for weather protection such as slate, wood, or asphalt shingles, clay tiles, thatch, or sheet metal. Sloped roofs, for some, have greater aesthetic appeal, which may be attributed to a more interesting architecture, size, scale, and the richness of traditional building materials used for weatherproofing.

Flat roofs are more practical for covering long spans of horizontal surfaces, but they can also be used to cover smaller structures. Because of the simpler surface configuration, weather protection for flat roofs can be accomplished more economically through using large pieces of protective membrane.

Both sloped and flat roofs become extraordinarily hot in direct sun exposure, especially in summer. The variation in temperature of the roof surface, even in moderate climates, can cover more than 70 degrees from morning till afternoon. The heat gain is more severe on flat roofs because the entire roof is exposed to the sun at all times. Even so, it is generally easier to build, inhabit, and maintain green roof systems that are constructed on flat or slightly sloped roof decks (the surface supporting the roof) than on ones with slopes because on flat roofs the loosely laid soil and vegetation layer is not subject to gravity and shear forces that pull on them. The primary advantages of constructing green roof systems on low-sloped roof decks are their applicability as stormwater retention systems, their reduction of heat gain, and their ability to be developed for usable open spaces in urban areas without taking up more land.

The technologies of each age add to our ability to live more efficiently and productively. Just as city builders of 4000 BC used the technology of their age to build beautiful rooftop gardens and other needed places, contemporary practitioners of design and building use the knowledge and materials of this time to construct our needed places.

We just need to think more carefully about how we can build our needed places *and* replenish our diminishing resources. This requires thinking about roofs in a different way. The roof, usually a leftover space, sitting unused and absorbing heat, can be transformed into a floor—a platform for activity—while providing insulation for the living spaces below.

Designing with Nature

In the first pages of *Design with Nature*, a seminal treatise on the importance of understanding and integrating natural, economic, and social systems, Ian McHarg points out that "the world is a glorious bounty" from which we benefit and for which we must serve as guardians.

Land and the natural resources it yields have enormous value, but more often they are commodities that have a price; all can be owned, bought, and sold. Land as real estate has its price, water has its price, and energy has its price.

Assigning a Value to Open Space

It is more challenging to assign a dollar value to land as open space. Whether it is under public or private ownership, open space with its intricate, interconnected elements of earth, animals, plants, water, and air provides the armature for the way we live. Well-cared-for open space is itself a valuable commodity and must be envisioned as such. It plays a pivotal role in improving water and air quality. It positively influences real estate values, and it can help to diminish energy consumption in the surrounding area. Yet we seem to take it for granted, and the responsibility for its stewardship is not always taken at individual,

FIGURE 1-5 Bryant Park provides enormous value as an urban open space and has significantly increased peripheral property values. The central lawn panel is built over the stacks of the New York Public Library.

municipal, federal, or global levels. Globally, the amount of open space continues to shrink and our natural resources continue to be diminished in extent and quality. Ozone depletion, air and water pollution, and acid rain have caused local and, cumulatively, global environmental problems. Deforestation and desertification, ground water depletion, and degradation of other natural resources have led to a loss of habitat and biodiversity.

As we develop land for building, we eat up at an alarming rate valuable open space that could be used for our own recreation or for providing connected corridors of habitat and a balanced diversity of vegetation and wildlife. More importantly, we are not carefully planning for the preservation of land we need for growing food or for the replenishment of clean water and air.

Unplanned development resulting from continued population growth may be seen as a root cause of consumption of land for building. This is not exclusively a problem in the developing world; North America has its very own disturbing track record. As an example, between 1973 and 1992 alone, metropolitan Atlanta, Georgia, grew at the expense of 380,000 acres of trees. This amounted to an average destruction of 55 acres every day for nineteen consecutive years. This rapid rate of urbanization in Atlanta prompted NASA to study the impact of development on the overall urban environment, focusing primarily on the regional climate and air quality. The study tied the development of the urban heat island phenomenon and elevated smog levels to the replacement of forests and agricultural land with dark surfaces of the built environment.[1] In our own country, which has some of the best agricultural soils in the world, farmland is being replaced at a rate of nearly 6,000 acres per day by housing, industry, and the services required to support them.

Cumulative Environmental Impacts of Urban Sprawl

When undisturbed forests, meadows, and prairies are replaced with buildings, along with asphalt and concrete roads and parking lots, the built surfaces become impervious to rainwater. Such a widespread trend has spiraling, deleterious consequences beyond removal of the plants and soils that act as natural sponges. Water and air quality is compromised directly and immediately by impervious surfaces. Water can no longer infiltrate the ground and is washed into streams and rivers when it rains, carrying with it nonpoint-source pollutants, nutrients such as phosphorus and nitrogen, and sediments deposited on the impervious surfaces. Dark, hard surfaces absorb solar radiation and store heat, making roofs and roads hot during the day; the stored radiant heat dissipates into the air at night, ultimately warming our globe. On a more recognizable level, regional climate changes can also be attributed to these significant changes in land cover and land use.

For example, Chesapeake Bay was once the most environmentally, socially, and economically diverse estuary in North America. In the last quarter century, unplanned development around the Washington, D.C., area has had deleterious effects on the health of the aquatic ecosystem, and in turn on the sociology and economy of the bay area. The leading cause of this has been the transformation of adjacent and regional open space to impervious surfaces, which has increased the amount of urban stormwater runoff into the bay. Sediment, nitrogen, and phosphorus input has degraded the water quality and with it

USA TODAY Snapshots®

Farmland shrinks

Total acreage of farms in USA: (in millions of acres)

2000 945

2006 932

Source: U.S. Department of Agriculture

By David Stuckey and Keith Simmons, USA TODAY

08

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Oil closes above $100 a barrel for first time

Prices at gas pump could surge to $3.75

By James R. Healey
USA TODAY

Oil closed above $100 a barrel Tuesday for the first time in history – a surprise price surge that leaves experts and motorists wondering if there's no limit.

The closing price of $100.01 a barrel, combined with gasoline prices that already had begun rising before the oil spike, could push the U.S. average for gasoline to $3.75 a gallon by Memorial Day – more than 50 cents higher than the record $3.227 set on May 24.

"You can make a much more legitimate case now for $3.50 to $3.75 a gallon as the spring peak," says Tom Kloza, veteran analyst at the Oil Price Information Service, a consultant. "But $4? No."

The about-face for prices is "unexpected, based on what appears to be falling consumption by consumers," says Geoff Sundstrom, spokesman for AAA.

Forecasts of petroleum demand this year have been lowered by the U.S. Energy Department and the International Energy Agency. "It shows we're still at the mercy of those who choose to supply our market, or not," he says.

"Wow. We were talking 12 days ago about going down into the $70s. Now we're talking about $105, $110," says Peter Beutel, president of Cameron Hanover, an energy risk management consultant.

Prices were in the high-$90 range most of the day, then zoomed as high as $100.10 after reports, later denied, that a Nigerian emancipation leader was shot and killed by Nigerian authorities. Unrest in oil-rich Nigeria can lead to shortages that drive prices up.

Also behind oil's record:

► A Monday explosion at Alon USA Energy's refinery in Big Spring, Texas, will keep the facility closed longer than expected. Alon's goal is to resume partial operations in about two months. Although it's not a huge refinery, the U.S. petroleum supply network is tight enough that it doesn't take much to create worries about supply shortages.

► Venezuelan President Hugo Chávez had threatened to cut oil to the USA over a dispute with ExxonMobil, although he said Sunday that he doesn't plan to do so. Exxon won a court judgment freezing $12 billion in Venezuelan assets in return for oil facilities Chávez nationalized.

► Representatives of the Organization of Petroleum Exporting Countries have suggested the cartel won't vote to increase production when OPEC meets in two weeks.

► Oil is priced worldwide in dollars. A weak dollar means it takes more to buy the same amount of oil.

The government's weekly survey showed the U.S. average for regular gas at $3.042 a gallon, up 8.2 cents in a week.

Familiar territory

The U.S. average gasoline price has bounced back above $3.

$3.00
$2.50
$2.00
0
$3.109
Tues.: $3.042
1/7/08
2/19/08

Source: Energy Information Administration

By Julie Snider, USA TODAY

FIGURE 1-6 This graphic from the front page of *USA Today* shows that 13 million acres of farmland were lost in the United States between 2000 and 2006. This information is juxtaposed with an article about oil costing more than $100 a barrel for the first time.

the bay's crab and oyster habitat. This means that the livelihood of fishermen and crab and oyster farmers along with their local history and traditions are at risk of disappearing—all as a direct result of increased pollution and diminished water quality stemming from development and urban runoff.

Vast and intact open spaces such as forests and prairie grasslands provide ecosystem services, the combined actions of the species in an ecosystem that perform services of value to society and that support the processes and functions on which human culture depends. Until recently, these were taken for granted and were not perceived as having value. Few people consider that our grocery stores are stocked with fruit because of the pollination services insects provide. In the nineteenth century, wetlands were viewed as disease-causing areas from which yellow fever and malaria emanated, and they were eliminated from the urban environment wherever possible. Now we marvel at wetlands' water-storage capacity and their role in preventing flooding as well as their critical role as sources of rich biodiversity. Freshwater wetlands hold more than 40 percent of the world's species and 12 percent of all animal species. In the nineteenth century, elaborate infrastructure for supplying fresh water and removing stormwater and sanitary wastes were built in our urban areas to eliminate disease and improve the health of residents. They were indeed marvels that demonstrated humankind's technology and ingenuity. Nature was revered for her beauty but not for her ecosystem services. Recently that view has changed. Today, New Jersey estimates the value of those services at between $8.9 billion and $19.8 billion per year.[2] Green roof systems can be a part of ameliorating the consequences of urbanization—the decline or destruction of these ecosystem services, specifically water systems.

The depletion of our natural resources and the degradation of our ecological, social, and economic environments, if taken in toto, are serious enough to make you want to stay in bed with the covers pulled tightly over your head. But there are ways of breaking the spiral. Despite these alarming trends, many individuals and communities are beginning to recognize the diminution of our natural resources and are doing much to minimize and even reverse it.

It is unlikely that our populations and in turn our cities will stop growing. We can, however, be more cognizant of the adverse environmental impact of unbridled, unplanned development sprawling well beyond urban centers. In turn, the risks of concentrating the built environment can be mitigated by making our cities livable and vibrant as well as socially, economically, and environmentally sustainable. One way is to superimpose green spaces onto surfaces that would otherwise be impervious to natural and climatic occurrences. This book seeks to explore the positive impacts on our environment that can be derived from the singular and cumulative application of green roof systems and to consider issues involved in their design, construction, and maintenance.

Roof as Floor

The term "green roof" today is often used as an umbrella term for a number of sustainable systems built over a structural decking that serves as a roof to that specific portion of the structure. As a "roof garden," "eco-roof," "extensive green roof," or "intensive green roof," the system acts and is perceived as a roof or lid. As a "roof garden," "open space over structure," or "intensive green roof," the system may serve as either a "roof" or a grade-level "floor."

This ambiguity and confusion of terminology is exacerbated by current jargon derived from European usage of "extensive" and "intensive," two words used within the fabrication, supply, and design industries. These terms, which may seem counterintuitive to English speakers, describe the depth of growing medium and level of effort required to maintain the green roof.

- *Extensive* is loosely used to describe a system that typically has a very shallow depth of soil or growing medium and is primarily used for its environmental benefits such as stormwater management and insulating properties. It is seldom irrigated; it is expected to require minimum maintenance; and it is not usually intended to be accessed directly for use as a garden or open space, though paved walkways and seating areas accommodate use as open space as well.
- *Intensive* is loosely applied to those systems that have a greater depth of soil or growing medium, which allows for a greater diversity in size and type of vegetation. This diversity usually implies a need for supplemental irrigation and, overall, a more intensive level of maintenance.

A disadvantage to using "extensive" and "intensive" as blanket terms is that neither clearly reflects the system's expected purpose or use nor adequately conveys design or maintenance requirements. Furthermore, a terminology-driven, rather than use-driven, approach to the design and construction of green roofs can lead to additional confusion and inaccuracy in design, documentation, and client expectations.

Ironically, in the design and construction of green roof systems, which comprise both living green roofs and landscapes over structure, the roof has to be thought of as a floor, above which a green roof system is built. If the definition of a roof is expanded to be a covering for any built structure at any elevation—such as a parking structure, academic or assembly facility, or any commercial or residential structure—and thought of as being programmed and designed for supporting a thin layer of vegetation to mitigate stormwater loss and heat gain or as usable, comfortable open space, the possibilities for beneficial uses of an otherwise vapid space become positively multiplied.

Coming to Terms with a Green Roof

While the generic term "green roof" already may have become too much a part of the green movement jargon for a clearer or new use of terms to take hold, describing specific applications of different types of green roofs is necessary.

Thus, for clarity, throughout this book, terms are defined as follows:

- *Green roof system* is used as an overarching description of a more environmentally, culturally, and economically sustainable use of a roof at any elevation.
- *Living green roof* is used to describe a thin-profile system where the growing medium is less than 8 inches deep and where the primary use is to effectively satisfy stormwater management requirements in lieu of conventional stormwater engineering methods.
- *Landscape over structure* describes a system where the growing medium is deeper than 8 inches; based upon programmatic requirements, it may be designed to accommodate its use as accessible open space. The combined depth of component parts may exceed several feet, and related systems required to support the uses often are more complex.

Living green roof and *landscape over structure* are not competing or contradictory strategies. Rather, large-scale ecological and social benefits can be recognized in the

FIGURE 1-7a–b Living green roofs can merge landscape and architecture by expanding beyond the conventional notion of roof. (Photo: Kai-Hennik Barth)

FIGURE 1-8 This is one of many gardens at the J. Paul Getty Center. All of them are over various structures used as garages, shipping and receiving facilities, storage areas, mechanical rooms, and portions of the scholars' libraries and studies.

appropriate application of either, as well as their combined use to reduce stormwater runoff, bind dust and pollutant particulates, reduce energy consumption, increase biodiversity, improve the visual quality of conventional roofs, and provide valuable, beautiful, comfortable, usable open space. The selection of the most suitable application should be defined by varied use and design goals.

Application of Living Green Roofs

Living green roofs offer ecological, aesthetic, and economic advantages. From an ecological standpoint, a major benefit of a living green roof is that it slows and detains stormwater runoff by providing a pervious, vegetated surface, thus preserving water resources and eliminating the need for monetarily and environmentally costly stormwater management systems. The growing medium and vegetation cover also help to shade the roof surface, preventing solar heat gain or loss and thereby lowering consumption of energy to heat and cool the building below. The transpiration of the vegetation provides an evaporative cooling effect that can lower the air temperature locally to below ambient temperatures, helping to reduce the urban heat island effect locally with global implications.

From an aesthetic standpoint, a primary application of a living green roof is to provide a visually interesting vegetation layer of diverse texture and seasonal color, in contrast to a rock ballast or dark surface.

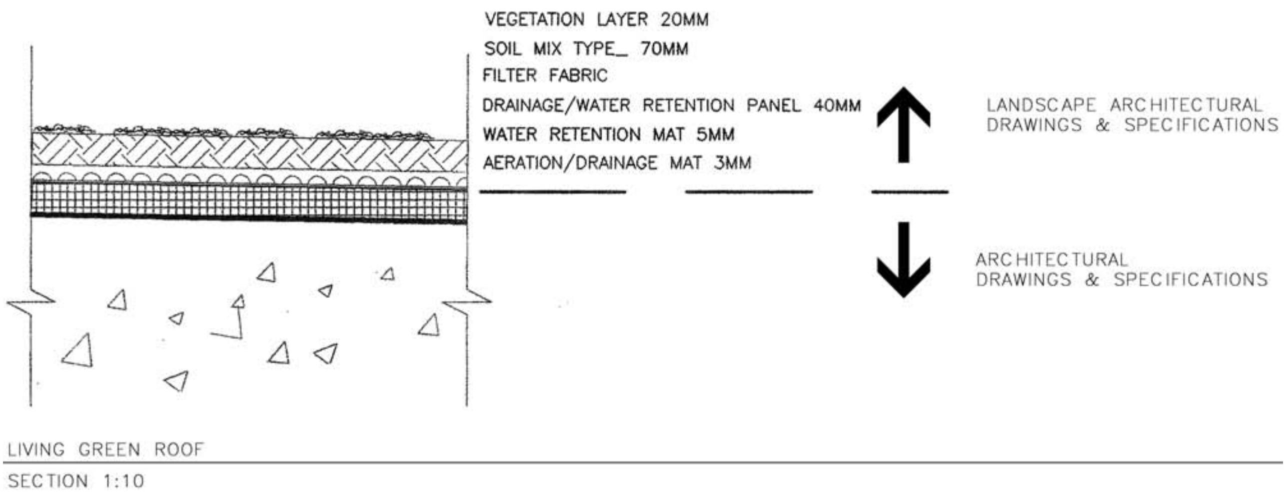

FIGURE 1-9 Detail section for a living green roof.

Economically, living green roofs may satisfy local governments' stormwater management requirements, which will reduce the cost of conventional methods of conveying stormwater from roof drains to ultimate outfall. This reduces not only owner construction costs but also the enormous costs to municipalities for infrastructure and operations associated with stormwater management. That is why today many municipalities offer

FIGURE 1-10 Although a number of species of the genus *Sedum* may be utilized, a balanced matrix of genera should be included in the plant palette of a living green roof.

incentives such as tax credits and larger allowable floor area ratios in exchange for implementation of living green roof systems.

The depth of growing medium required for a living green roof is typically 3 to 6 inches but may be as thin as 1 inch. Since the primary purpose of a living green roof is to detain stormwater runoff, irrigation typically is not employed. The lack of consistent supplemental watering, shallow soil depth, and exposure to intense and desiccating sunlight and wind require vegetation capable of surviving these harsh, dry conditions. Low-growing, horizontally spreading, water-storing plants, which occur naturally in alpine environments, have proved to be the hardiest and most suitable for these conditions. Generically this type of plant is known as a succulent: a plant that can store water in its leaves and stems for extended periods of drought conditions. Most often, but not exclusively, plants are selected from the hundreds of species in the genus *Sedum*, many of which are succulents. The dominance of their use in the overall plant selection of living green roofs has led to the occasional use of the misnomer "sedum roofs." Like most successful planting plans, the selection of plants for living green roofs should include a matrix of plant genera and species that provide adequate horticultural diversity and are suitable to the artificially created roof environment desired.

The maintenance required for such plant mixes is limited and might include initial hand-watering during installation and the establishment period as well as occasional weeding, fertilizing, and spot repair.

The relatively thin profile of the components of a living green roof generally weighs 12 to 15 pounds per square foot. Although each application of a living green roof usually will have specific design requirements determined through a structural analysis, structural upgrading of standard roof decking is usually not required because the weight of the living green roof profile is about the same as the weight of the stone ballast applied to protect and preserve the waterproofing membrane of a conventional roofing system. A living green roof, therefore, can be employed in place of stone ballast when, structurally, limited or no additional weight can be added to the deck. Also, because generally there is little or

FIGURE 1-11a Utilization of roofs for stormwater management systems at a manufacturing plant. (Photo: re-natur, 24601 Ruhwinkel, Germany)

FIGURE 1-11b This living green roof is over a parking structure that is part of a shopping center in the central business district of Nürtingen, Germany. The living green roof is primarily used for stormwater management, but it also adds a visual amenity for the residents and office workers in the adjacent building. Additionally, it offers limited access for shoppers, residents, and workers wishing to walk through the living green roof garden. (Photo: re-natur, 24601 Ruhwinkel, Germany)

FIGURE 1-12a Long views across living green roofs maintain the visual integrity of the rural landscape and provide part of the stormwater management system for this Swiss poultry farm.

FIGURE 1-12b A traditional vegetated roof insulates the coop at a Swiss poultry farm while also helping to integrate the roof into the surrounding rural landscape.

no additional cost to provide increased structural support for new buildings, it can also be a cost-effective way to provide greater visual amenity and environmental quality. (Chapter 5 addresses structural considerations for both living green roofs and landscapes over structure.)

Although living green roofs are not intended or designed to be physically accessible for use as an open space amenity, they can be combined with areas of the roof that are designed for active use. Clear demarcation of restricted use should be incorporated into the overall design.

Application of Landscapes over Structure

Depending on the amount of vegetation, most of the same ecological and environmental benefits may be derived from the construction of landscapes over structure as from living green roofs. The greater the density and coverage of the vegetation, the greater is the capacity of a landscape over structure to intercept, absorb, and slow stormwater runoff. Likewise, landscapes over structure offer the collateral benefits of more vegetation on the earth's surface.

Depending on planned use and the ultimate physical expression of the design, landscapes over structure, like any built landscape, can take many forms and have the potential for a wide range of ecological, aesthetic, and social benefits.

With a growing medium typically deeper than 8 inches, landscapes over structure can support a greater diversity in size and type of vegetation. Greater size and diversity of plants usually requires a deeper soil profile, supplemental irrigation, and a more complex infrastructure to support and sustain plant growth in an artificial environment.

In a landscape over structure, the structural system required to sustain the additional weight of growing medium, vegetation, site elements, and potential live loads is significantly

FIGURE 1-13 Vila Olimpica, in Barcelona, merges architecture and landscape, blending the adjacent buildings and their spaces below with lush exterior spaces of varied use. Landscapes were built over a hotel, shops, and a multistory garage.

more substantial and complex in terms of design, size, and cost than that required to support a living green roof. And invariably, the need to coordinate the various professional disciplines throughout the process of design, documentation, and construction has cost implications that must be balanced against the benefits of the end use. (This is addressed more fully in Chapters 3 and 5.)

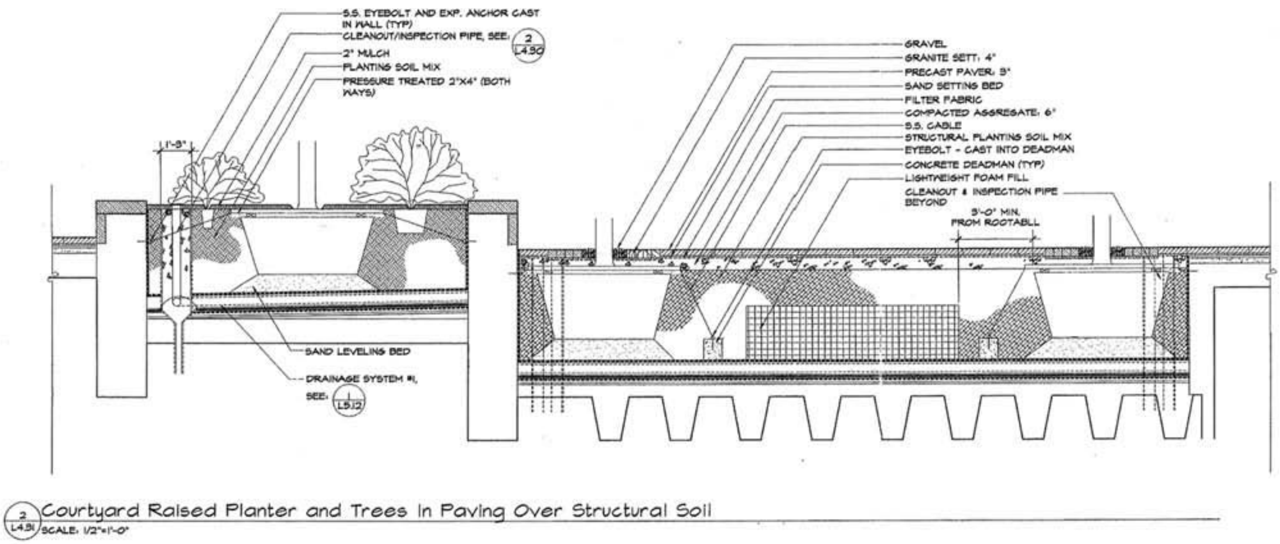

FIGURE 1-14 Detail section for a landscape over structure.

Maintaining Healthy Cities

It is clear that living green roofs and landscapes over structure are not a panacea for ameliorating the negative environmental impacts resulting from increased development or the loss of open space. They cannot and will not replace our forests and prairies, will not remediate the degradation of all stream corridors, and will not stop global warming by themselves.

However, living green roofs and landscapes over structure can act as buffers to mitigate the impacts of unbridled and unplanned urban growth and development. Reducing building roofs generates less stormwater runoff, reduces the heat gain that affects our indoor and outdoor environments, and mitigates the continued degradation of air and water quality. Programming for, building, and maintaining well-designed and constructed landscapes over otherwise unutilized roof decks provides additional usable, comfortable open space.

If municipalities provide incentives such as allowing developers to increase the floor area ratio, or lowering or even forgiving taxes, living green roofs become cost-effective immediately. The immediate cost-effectiveness of landscapes over structure is more difficult to derive if the benefits are measured only as cost savings. However, for either type of green roof system to become as commonplace in North America as they are in many parts of Europe, both need to be conceived as common elements of city planning and urban design.

Doing so also requires a departure from conventional approaches to design and construction, as well as collaboration and coordination among numerous disciplines of

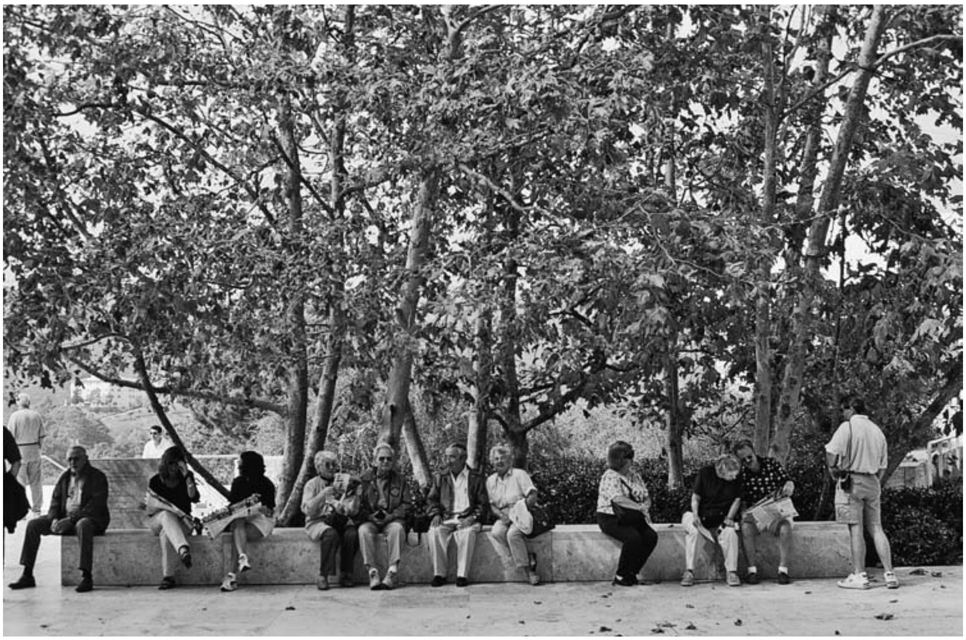

FIGURE 1-15 Numerous gardens, courtyards, and seating areas for serendipitous encounters at the J. Paul Getty Center provide many places for comfort and respite.

FIGURE 1-16a–b Numerous individual installations of living green roofs in central Stuttgart and individual installations in the community of Hegeweisse, Germany, make a cumulative positive impact visually and environmentally.

design professionals. Architects, landscape architects, and structural engineers will need to determine the infrastructural needs to support the building and site program. Civil engineers will need to calculate water retention capacities of differing growing media at various depths on a site-specific basis. Mechanical engineers will be required to quantify the mass of the growing media and vegetation at various moisture levels and incorporate variant insulating values into the sizing of heating, cooling, and air-conditioning systems. Contractors and construction trades must depart from traditional practices of cost estimating,

FIGURE 1-17a–b Children explore their environment through the plants of a living green roof and the fountains of a landscape over structure.

project sequencing, and selection and installation of construction materials. And clients must be courageous in their programming, clear in their expectations, committed, and able to finance the project through completion, occupation, and continued maintenance.

The examples used throughout this book are typically derived from urban contexts because cities have the greatest potential for impacting our natural environments, both positively and negatively. The topics and methods are equally applicable to rural, suburban, and residential-scale situations; however, it should be kept in mind that every project is unique in its program, design, and construction requirements.

Summary

Regardless of the location and extent of a living green roof or landscape over structure, the benefits of a single installation are great. When the planning and design process considers effects beyond the limits of a project's property line, the potential positive, cumulative impact of individual initiatives upon our natural, cultural, and social environment is enormous.

Endnotes

1. Dale A. Quattrochi and Jeffrey C. Luvall, "High Spatial Resolution Airborne Multispectral Thermal Infrared Data to Support Analysis and Modeling Tasks in EOS IDS Project ATLANTA," available at http://www.ghcc.msfc.nasa.gov/atlanta.
2. New Jersey Department of Environmental Protection, "Valuing New Jersey's Natural Capital," April 2007.

Chapter 2

Beyond the Property Line: Ecological, Economic, Spatial, and Social Benefits of Green Roof Systems

> *A well-known scientist . . . once gave a public lecture on astronomy. He described how the earth orbits around the sun and how the sun, in turn, orbits around the center of a vast collection of stars called our galaxy. At the end of the lecture, a little old lady at the back of the room got up and said: "What you have told us is rubbish. The world is really a flat plate supported on the back of a giant tortoise." The scientist gave a superior smile before replying, "What is the tortoise standing on?" "You're very clever, young man, very clever," said the old lady. "But it's turtles all the way down!"*
>
> —Stephen Hawking, *A Brief History of Time*

Our world is interconnected. Only recently, however, have we developed an awareness of global interconnectedness and how changes in one part of the system affect changes in every other. The emergence of climate change as a critical global issue highlights these interconnections. What was possible to ignore when the population of the earth was a few hundred million people is impossible to ignore when the population is 6.6 billion presently and is expected to be almost 8 billion by 2025.

The decision to incorporate a green roof system into a project may seem quite separated from the global implications of climate change. Yet the platitude "Think globally, act locally" is apt. Green roof systems can provide valuable usable open space and help to ameliorate deleterious impacts on our urban environment by reducing stormwater runoff, lowering ambient temperatures, and reducing energy consumption. While an individual action may seem minuscule on a global scale, the cumulative effect of positive actions can have a large impact.

This chapter considers our air and water systems and their interconnectedness, particularly in our urban environments. The phrase "beyond the property line" refers to the fact that every project must be considered as part of a watershed and an airshed and thus as part of a regional system and ultimately a global one. Green roof systems can have positive effects on our air and water locally, and by extension their cumulative impact can be global. These positive impacts can be seen in the measurable improvement in air and water quality.

In order to understand the impacts—both positive and negative—of urbanization on our environment, it is helpful to have a basic understanding of applicable concepts and terminology used in the engineering and design fields. While some of these terms and concepts are becoming commonplace, sometimes they are used interchangeably or are improperly applied, thus limiting the discussion of the benefits of green roof systems to a surface treatment of the issue. An overview of the basic concepts of stormwater management has been included to provide a basis of informed language in the discussion of appropriate application of green roof systems.

From Green to Gray: The Effects of Urbanization

William Cronon, in *Uncommon Ground*, describes the core myth of Judeo-Christian tradition as "nature as Eden" and the resulting "Edenic narratives" of the loss of an original pristine nature through some human culpable act that results in environmental degradation and moral jeopardy. Thomas Jefferson celebrated the virtues of the agrarian way of life, viewing urban areas with distrust as sores on the body politic. Today, though, the majority of the world's people do not live in pristine nature or in a pristine agrarian society. While cities, in the support and sustenance of their society, can effectively concentrate the

FIGURE 2-1 Stormwater runoff severely impacts national waterways such as the Chesapeake Bay.

use of our natural and economic resources, they more often disrupt the natural systems of their environment through the patterns of unplanned urbanization. Many people rue the spiritual and metaphorical losses of both urban and rural environments.

The majority of the American population lives in the large megalopolises of the twentieth century, spanning the range from dense central cities to semirural exurbs. Sprawl consumes land, often former agricultural land or second-growth woodlands, disrupting or completely destroying ecosystem services. Similarly, modern agricultural practices, while sustaining the larger society, have led to serious environmental problems, including a loss of topsoil that is undermining our food security and nutrient-laden runoff that threatens the economic and ecological health and welfare of some of our most precious waterways and largest watersheds.

The Delaware River, the largest undammed river in the United States, supplies drinking water to approximately 14 million people. It has experienced decreased water quality and increased and more severe flooding in the last 20 years as its watershed becomes increasingly urbanized. No one needs to be reminded of the devastation and loss of life wreaked upon New Orleans by Hurricane Katrina in 2005. The disruption of the natural hydrological system by diversions, levee building, and draining of wetlands, originally built to protect New Orleans, increased the damage. Even prior to this nationally devastating hurricane, floods accounted for over 40 percent of all natural disasters, and the Federal Emergency Management Agency carried $524 billion in total coverage for flood insurance.

Urbanization and development bring profound changes to the preexisting hydrological system. The aforementioned examples are only some of the largest and most tragic. Communities undergoing urbanization rarely express emotion over the loss of ecosystem services or the predevelopment condition of the hydrological system. Instead, they usually express these in more wistful and metaphorical terms about the loss of what was. Old approaches such as green roof systems are being rediscovered and implemented to

North Carolina State University

A study conducted at North Carolina State University confirms the positive stormwater control performance of a living green roof. Monitoring data published from this study also are consistent with the findings of earlier research at both Pennsylvania State University and Michigan State University. Over an 18-month period, the 750-square-foot, 3-inch-deep green roof at Wayne Community College in Goldsboro, North Carolina, retained an average of 63 percent of the total rain and reduced the total runoff by 87 percent. The greater runoff reduction takes into account the peak flow rate reduction and is based on the distribution of rain events over a certain period of time, whether rain occurred after a profound dry period or on consecutive days. In a second project for which there were only three months' worth of runoff data available (July to September 2004), a 4-inch-deep, 1,400-square-foot living green roof retained an average 55 percent of the rainfall and reduced runoff by 57 percent. In this study, not only was the performance of the green roof measured in absolute terms of runoff rates and runoff volumes, but the resulting runoff coefficient was computed. For a 1.5-inch storm event, the volumetric rational runoff coefficient for the 3-inch-deep living green roof was 0.53, which is comparable to meadows and pastures. Even during a major 3.1-inch storm event, the green roof achieved some volume and flow reduction and runoff delay, with a runoff coefficient of 0.87, compared to 0.95 for conventional roofs. This indicates that even during a large rainfall event and full saturation of the growing medium the living green roof outperformed conventional roofs and provided 9 percent additional storage capacity.[1]

address and ameliorate these problems. While no one technology such as living green roof systems will entirely solve the problem, each becomes a part of a portfolio of management practices that together will have a cumulative positive effect.

Stormwater and the Hydrological Cycle

Stormwater replenishes our groundwater, lakes, rivers, and streams. It provides water to the root zones of the plants in undisturbed natural environment, for agricultural crops, and for plants used for shade or pleasure in our urban environments. To understand how green roof systems help sustain a healthy hydrological cycle, which in turn sustains the global climate, it is helpful to have a basic understanding of the current issues associated with stormwater. They include surface characteristics determined by vegetation and soils, storm characteristics including duration and intensity, and the management of stormwater as it runs off from our urban environments.

The natural hydrological cycle is simply the constant exchange of water between the atmosphere and the ground in the form of precipitation and evapotranspiration (the combination of evaporation and transpiration from plants). When precipitation in the form of rain or snow falls, it finds its way downhill if not intercepted. Foliage intercepts and disperses the energy of raindrops, protecting the ground surface by lessening the raindrop's erosive force. Healthy, vegetated soils slow precipitation down, further allowing water to soak in or infiltrate. In essence, vegetation and the soils supporting them act as large sieves or sponges. Unintercepted precipitation is called *stormwater runoff.*

Runoff can be categorized as either surface runoff or subsurface runoff. *Surface runoff* is water that moves on the ground by gravity until it finds an outlet to a pond, stream, river, lake, or ocean. *Subsurface runoff* is stormwater that infiltrates the soil moving through it both horizontally and vertically. The way stormwater moves and the rate at which it moves, as either surface or subsurface runoff, depends on the characteristics of the surface on which the precipitation falls and on the duration and intensity of the storm.

The goal of stormwater management practices is to minimize and effectively control surface runoff and maximize infiltration and subsurface runoff. Control of surface runoff is necessary because of the erosive power of water and the damage it causes. The Grand Canyon was formed by the erosive power of water; so are the deep gullies seen in urbanized areas. Maximum infiltration is desired so that water is available in the soil for plant growth and aquifer recharge.

Some cities lose as much water to stormwater runoff as would supply 3.6 million people with their average annual household needs. Table 2–1 below summarizes annual water loss for the top eighteen land-consuming U.S. metropolitan areas.

Surface Characteristics

Surfaces are referred to as either impervious (impermeable) or pervious (permeable). *Impervious* surfaces are surfaces that water cannot penetrate, such as paving or roofs. When precipitation hits an impervious surface such as a roof or pavement, runoff is immediate and follows the gravitational pull downhill. *Pervious* surfaces are those that water

TABLE 2-1: Groundwater Infiltration Loss[2]

Metropolitan Area	*Water Loss (billion gallons/year)*
Atlanta, Georgia	56.9–132.8
Boston, Massachusetts	43.9–102.5
Philadelphia, Pennsylvania	25.3–59
Washington, D.C.	23.8–55.6
Nashville, Tennessee	17.3–40.5
Charlotte, North Carolina	13.5–31.5
Pittsburgh, Pennsylvania	13.5–31.5
Houston, Texas	12.8–29.8
Greensville, South Carolina	12.7–29.5
Seattle, Washington	10.5–24.6
Chicago, Illinois	10.2–23.7
Raleigh-Durham/Chapel Hill, North Carolina	9.4–21.9
Orlando, Florida	9.2–21.5
Minneapolis/St. Paul, Minnesota	9.0–21.1
Detroit, Michigan	7.8–18.2
Tampa, Florida	7.3–17
Greensboro, North Carolina	6.7–15.7
Dallas, Texas	6.2–14.4

can penetrate. When precipitation hits a pervious surface such as soil, permeable paving, or a green roof system, the stormwater infiltrates this surface until it is saturated. After saturation, water follows the gravitational pull finding the shortest route downhill.

The amount of stormwater vegetation and soils can intercept and hold depends upon the type and extent of the vegetation, the topography of the ground plane, and the composition of the soil beneath it. The denser the mass of vegetation, the flatter the slope, and the more permeable the soil, the greater the system's ability to disperse and intercept stormwater before it hits the ground plane and to hold or detain it once it does hit. In a well-stratified forest consisting of different layers—canopy, subcanopy, shrub, and ground cover—some water is intercepted by each layer. This interception both reduces the impact of the raindrop and the amount of runoff. Topography is also a major factor. On steeper slopes, more water runs off faster than on flatter slopes. Likewise, sandy soils absorb more water than dense, clay soils. A well-stratified, mixed-species forest on a flat slope with sandy loam soils can detain or hold more precipitation than a coniferous forest on a steep rocky slope. A prairie with a diverse matrix of thickly matted grasses and perennials on a shallow slope slows down the movement of surface runoff more than a flat lawn. A mature lawn with uncompacted soils underlying it, even

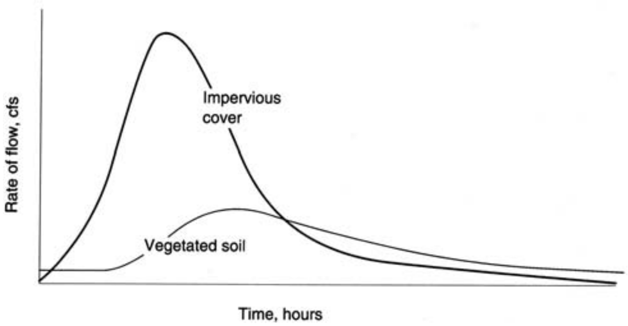

FIGURE 2-2 Vegetation and soil intercept stormwater before it can run off. The greater the permeability of the vegetative cover and soils, the longer it takes stormwater to become runoff and the more slowly it will move.

FIGURE 2-3 This living green roof has a 6-inch soil profile and is covered with a matrix of grasses. (Photo: Kai-Henrick Barth)