The Green Roof Manual

The Green Roof Manual

A Professional Guide to Design, Installation, and Maintenance

Edmund C. Snodgrass and Linda McIntyre

Timber Press
Portland ■ London

Frontispiece: This extensive green roof at Penn State University uses a few perennials and grasses to increase the ornamental value.

Published in 2010 by Timber Press, Inc.

The Haseltine Building
133 S.W. Second Avenue, Suite 450
Portland, Oregon 97204-3527
www.timberpress.com

2 The Quadrant
135 Salusbury Road
London NW6 6RJ
www.timberpress.co.uk

Printed in China

Library of Congress Cataloging-in-Publication Data
Snodgrass, Edmund C.

The green roof manual : a professional guide to design, installation, and maintenance/Edmund C. Snodgrass and Linda McIntyre.

p. cm.

Includes bibliographical references and index. ISBN 978-1-60469-049-1

1. Roof gardening. I. McIntyre, Linda, 1964– II. Title.

SB419.5.S65 2010

635.9’671dc22 2010005074

A catalog record for this book is also available from the British Library.

Contents

Campanulas light up a green roof on a dormitory at Swarthmore College outside Philadelphia.

Acknowledgments

This book would not have been possible without the generous help of all the people who have given time and support solely to advance green roof technology. Penn State University, Michigan State University, Oregon State University, The University of Maryland, The University of Auckland, The California Academy of Sciences, The Lady Bird Johnson Wildflower Center, and the cities of Portland, Oregon, and Chicago have all shared their research and their time and opened their facilitie for photographic visits. The American Society of Landscape Architects headquarters, the Library of Congress’ National Audio Video Conservation Center, Swarthmore College, and Dansko gave me an open invitation to show up any time with my camera. Many thanks to all the people—too numerous t mention individually—from all corners of the industry who shared their insights and gave us feedback.

Thanks to the crew at Emory Knoll Farms who supported my time away and who are the most fabulous folks to work alongside. Big thanks to my wife, Lucie, who supports me always without fail

Most of all, this book would not have been written without my coauthor, Linda McIntyre, who has put in countless hours writing, interviewing, and sweating all the details to produce what we hope wi be a book of value.

Writing this book was a truly collaborative process—not just between Ed and me, but among us and a slew of generous and patient experts. Properly thanking everyone who deserves it would require an additional book, but I’m obliged to give a special shout-out to a few of these experts. Charlie Miller o Roofscapes has been the go-to engineer for this English major since my first acquaintance with green roofs as a staff writer and editor at *Landscape Architecture* magazine. While I have not had the opportunity to take his classes, I know from experience that Rob Berghage of Penn State University’s Center for Green Roof Research is a great teacher. Peter Philippi and Jörg Breuning of Green Roof Service unstintingly shared the expertise they developed on both sides of the Atlantic. All of these busy people withstood my incessant questioning with good grace and provided the substance that fill these pages.

Bill Thompson, my former boss and the steward of *Landscape Architecture* until autumn 2009, encouraged me to pursue my interest in green roofs, demanded critical analysis rather than superficia cheerleading, and impressed on me the importance of providing readers with useful, accessible, and well-organized information. His comments and suggestions, as well as those lessons, improved this book immensely.

I would also like to acknowledge the help of the following individuals, whom graciously shared insights from the field: Jason Abbey, Associate, FXFOWLE Architects; Glen Abrams, Philadelphia Water Department, Office of Watersheds; Paul Bassett, founder of Hydro-Logix Solutions, Inc.; Ed Beaulieu, Chief Sustainability Officer, Aquascape, Inc.; Michael Berkshire, Green Projects Administrator, City of Chicago; Jeffrey Bruce, President, Jeffrey L. Bruce & Company, Landscape Architects and Planners; Jim Burton, Construction Services; Stephen Bushnell, Product Director, Fireman’s Fund Insurance Company; Ayehlet Cooper, Horticulturist, Furbish Company; Patrick Cullina, Vice President of Horticulture and Facilities, Brooklyn Botanic Garden; Lance Davis, Sustainable Design Expert, U.S. General Services Administration; Darren De-Stefano, Horticulturist, U.S. General Services Administration; Laura Dickinson, graduate student, Columbia University; ~~Angie Duhrman, Green Roof Manager, Tecta America Corporation; Michael Furbish, President,~~ Furbish Company; Stuart Gaffin, Associate Research Scientist, Center for Climate Systems Research, Columbia University; Drew Gangnes, Director of Civil Engineering, Magnusson Klemencic Associates; Mark Gaulin, Senior Vice President and Chief Operating Officer, Tecta America, and founder of Magco; Dusty Gedge, wildlife consultant and cofounder of livingroofs.org; Robert Goo, Environmental Protection Specialist, U.S. Environmental Protection Agency; Alan Good, Landscape Exhibits Supervisor, California Acade my of Sciences; Chris and Lisa Goode, owners of Goode Green green roof design and installation; Denis Gray, owner of Denis Gray Horticulture; Ken Hercenberg, Associate Vice President and Specifications Leader, Cannon Design; Elizabeth Kennedy, Elizabeth Kennedy Landscape Architects; Nancy Kiefer, Director of Facilities and Office Services, World Resources Institute; Jason King, Landscape Architect, Greenworks; Peter Kjellerup, founder of Dansko; Chris Kloss, Senior Environmental Scientist, Low Impact Development Center; Michael Krawiec, Project Manager, URS Corporation; Tom Liptan, Portland Bureau of Environmental Services; John Loomis, SWA Group; David MacKenzie, owner of LiveRoof LLC; Hanna Packer, Design Associate, Town and Gardens Ltd.; Matt Palmer, Department of Ecology, Evolution, and Environmental Biology, Columbia University; Daria Payne, Facilities Manager, Dansko; Greg Raymond, Managing Member, Ecogardens; Steve Sawyer, Plant Manager, Sidwell Friends School; Mike Saxenian, Assistant Head of School and Chief Financial Officer, Sidwell Friends School; Mark Simmons, Ecologist, Lady Bird Johnson Wildflower Center; Jennifer W. Souder, Assistant Director and Director of Capital Projects, Queens Botanical Garden; Jim Stamer, President, Prospect Waterproofing Company; Jeanette Stewart, founder and President, Lands and Waters; Brian Taylor, Civil Design Engineer, Magnusson Klemencic Associates; Dennis Wilde, Principal, Gerding Edlen Development; Mary Wyatt, Executive Director, TKF Foundation; and Jennifer Zuri, Marketing Communications Manager, Aquascape, Inc.

My coauthor's vast knowledge and experience, and his calm in the face of my own flappability, made the difficult task of wrestling this book into shape not only possible but fun. I'll miss the regular sessions with the crew at Emory Knoll Farms (and the frequent ice cream breaks at Broom's Bloom dairy, just up the road). Ed and I also want to thank Tom Fischer and the rest of the team at Timber Press and our excellent editor, Lisa DiDonato Brousseau, for their guidance, support, and expertise.

Finally, I could not have finished this project without my husband, Jeff, whose love, support, patience, kindness, and dinners sustained me throughout the process.

Green roofs are increasingly popular on college campuses. This dormitory at Swarthmore College has green roofs on two levels, on
of which is visible from inside the building.

Introduction

In their 2006 book *Green Roof Plants*, Ed and Lucie Snodgrass provided North American readers wit the first comprehensive guide to selecting and planting species that can survive on a rooftop, and in doing so introduced many readers to the concept of green roofs. Though only a few years have passec since that book was written, it seems appropriate now, as green building enters the mainstream and economic trends force a reassessment of priorities, to take a broader view, going beyond green roof horticulture and looking at how far the industry has come since the first extensive green roofs were built in North America a little over a decade ago. We wrote this book for a wide audience including everyone who might be involved with a green roof project: the client, architect, landscape architect, roofing contractor, ecologist, nurseryman, property manager, and maintenance team.

More green roofs in more places have added breadth as well as depth to what we know about how this technology, mature in Europe but less tested in our more variable climate and more freewheelin regulatory and building cultures, performs in North America. While it's still early in the life of Nort America's green roof industry, the performance of those roofs over time has to some extent clarified the trade-offs among different approaches and underscores the importance of maintenance. And as more projects are built, the obstacles encountered by industry pioneers, and their successes, can inform the choices made by those who follow.

The pool of information available to people interested in the topic or considering green roofs for their projects is expanding rapidly. A lot of this information, however, has been published only in government reports or scientific journals such as *Hort-Science,* and much of it is anecdotal, held by people too busy designing and building green roofs to write articles or books. Some of the informatic available in the general-interest media or online is misleading or applicable only in a particular regic or in narrow circumstances. Our goal was to harvest the most pertinent lessons from the field and its leaders and to make those lessons accessible to both casual and serious readers.

In addition to assessing the conventional wisdom, we have put it to the test by asking designers, builders, scientists, and the people who live and work under green roofs what they have learned from those projects. We have talked with experts in every aspect of the industry to find answers to questions we hear again and again: How do you design and build a green roof that will last without extraordinary intervention over the long term? What are the most common factors in unsuccessful projects? Which parts of North America are best suited to green roofs? Are there places where green roofs are unlikely to thrive in any circumstances? How can designers and builders make sure that clients are prepared for the aesthetics of a just-planted green roof, and that they understand the commitment involved over time to ensure a green roof's success? What is the relationship between a green roof and the surrounding landscape at grade? Can native plants thrive on a green roof? Is it possible for a green roof environment to accommodate herbs, fruits, and vegetables?

High-profile projects such as Millennium Park in Chicago have generated interest in green roofs.

We have visited green roofs throughout North America and around the world, taking note of which approaches have been most successful and which design objectives have been consistently difficult t achieve and maintain. We have discussed with designers and builders how to integrate a green roof into a project, at both the building and the site scales, and how to most effectively integrate green roofs with other measures to mitigate a building's impact on the landscape. We have asked scientists about the extent to which research and monitoring have confirmed and quantified the benefits of gree roof technology. We have asked clients whether their expectations have been met or exceeded. We have asked the staff maintaining green roofs—when there is such a staff—what their greatest challenges are, how they solve common problems, and how they keep those roofs healthy and thrivin

Green roofs are well established in some European countries, such as Switzerland.

Our intention is to help people navigate the green roof design, installation, and maintenance ~~processes, not to provide all of the answers. If there is one thing we have learned during the process~~ o writing this book, it is that there are few certainties in the world of green roofs. A green roof takes a form for which there are hundreds, even thousands, of variables—a building—and imposes on it a form even more fluid—a living landscape. The appearance of a successful project will change over time, and its performance might vary with climatic changes. Green roof design and installation is, to some degree, a leap of faith. But a growing number of people believe the result is worthwhile, whethe the desired outcome is less sewage discharged into local rivers and streams, a softening of the urban hardscape, or simply a garden in the sky.

We've presented our findings in a way that we hope will be useful to readers with varying needs. A brief discussion of green roof benefits and components comes first. An update on the industry and incentives being put in place by more and more local governments also comes early in the book. Keeping up with the rapidly changing regulatory landscape is challenging—it will have changed ever since this book went to print—but some trends are apparent. For example, stormwater management infrastructure is overburdened in many cities, and green roofs are one way to take some of the pressure off by mitigating runoff into those systems. Cities are experimenting with innovative ways t encourage the private sector to go green, including tax incentives, density bonuses, and green-space requirements. What are the early results of these programs?

We also discuss how to put together your green roof project team. This is a truly interdisciplinary technology—in effect a system engineered to live and breathe, comprising architecture, engineering, horticulture, and ecology, as well as other disciplines depending on the scope and objectives of the project. While a weekend hobbyist might want to build a green roof on his or her garage to see what happens, most people will not want to use a green roof project as an opportunity for experimentation.

Those who have already decided to use a green roof in their own projects can, if they wish, go directly to chapters 4 and 5 to examine different design paradigms including examples of each and lessons to take away. A lot of green roof construction has been and will continue to be driven by stormwater regulations, but those who want a greater emphasis on aesthetics have options, too. Anyone considering a green roof, simple or elaborate, would be well served by firming up their objectives as early as possible in the process. To help them along, we examine the pros and cons of each approach.

Even the merely curious reader should make sure to read the chapter on maintenance, which often makes the difference between a thriving green roof and a failed one. As an unusual hybrid of engineering and ecology, a green roof has a particular set of needs, which can in many cases be met with regular observation and limited intervention. Despite the promises one sometimes encounters in the field, green roofs are not maintenance-free, and people define "low maintenance" in very differen ways. Those who hesitate to commit adequate resources to this unexciting but critical function might want to reconsider whether a green roof is right for their project.

Maintenance keeps a green roof healthy and attractive.

Readers in search of more information can find our suggestions in the Resources section. We've gathered sources, most available online, for general and industry information, policy and incentives, academic research programs, certification and accreditation, and other helpful references.

Why aren't all new roofs green?

These days you can find a lot of literature rhapsodizing about how wonderful and environmentally friendly green roofs are and how sustainable design can save the planet and even the distressed economy. But it will take more than high hopes and feelgood slogans to bring about the widespread adoption of green roof technology and other complementary sustainable building practices.

That will take a frank discussion of the challenges, commitment, and costs involved as well as the benefits. It will require clients and designers to make choices and trade-offs. It will involve the collection and dissemination of data that show that, from a life-cycle accounting standpoint, green roofs and other low-impact designs are less expensive and more efficient that pipes and detention basins, even though they might cost more at the outset. It will require research into the nitty-gritty of construction and the sometimes difficult, but usually necessary, work of maintenance and a clear-eye appraisal about what works and what does not. We hope this book will make a modest but meaningfu contribution to this process.

1 Green Roof Basics

Intensive green roofs have deep soil that can support trees, shrubs, and lots of visitors.

Key Points

- A green roof is not a typical roof garden.
- Potential benefits include:
  - stormwater management
  - longer life for the roof membrane
  - reduction in energy costs
  - mitigation of the urban heat island effect (if widely implemented)
  - habitat for urban wildlife
  - amenity value, aesthetics, and marketing appeal.
- Green roofs are relatively new in North America but popular and proven in Europe.

What is a green roof?

Green roofs, also known as eco-roofs, living roofs, planted roofs, or vegetated roofs, use plants to improve a roof's performance, its appearance, or both. Green roofs are often described as falling into one of two categories: intensive and extensive.

There are no technical definitions of these terms, but as generally understood intensive green roofs are more like conventional roof gardens. They have deeper, more organic growing medium or soil capable of supporting a wide variety of plants, often including shrubs and small trees. They are usually accessible for regular use and often designed as amenities for people who live or work in the building.

Extensive green roofs are simpler, lighter, and thinner in profile. They usually have a depth of abo 6 inches (15 cm) or less of coarse, mineral-based growing medium and are usually planted primarily with sedums and other tough, drought-resistant, low-growing plants, though more colorful accent plants might be mixed in. This kind of green roof is a popular ecological building tool in Europe. In Germany, where green roofs are plentiful, more than 80 percent of them are extensive (Philippi 2006

This book focuses largely on the latter category because we believe that extensive green roofs produce the greatest return on investment in both economic and ecological terms—they are, or shoul be, easier and less expensive to design and build. If built on a large scale in cities, they show promise for significant energy savings and other environmental benefits as well as a less tangible improveme in the quality of urban life. Furthermore, there are few practical resources available for those seeking information about designing, building, and maintaining extensive green roofs outside of Europe and adapting the technology to different climates. Readers interested in more complex roof gardens migh find some of the information in this book of use, but for more detailed information they should consult one of the books on that subject that have stood the test of time, such as *Planting Green Roof and Living Walls* by Nigel Dunnett and Noel Kingsbury (2008, Timber Press) and *Roof Gardens: History, Design, Construction* (1999, W. W. Norton) by Theodore Osmondson.

Green roofs adorn all kinds of buildings in Europe.

Extensive green roofs, especially when installed on a wide scale, provide a range of benefits including stormwater management.

Green roof benefits

While even the most basic extensive green roofs usually look better than their tar- or asphalt-clad conventional counterparts, they are most often built for reasons other than aesthetics. Green roof benefits have been well documented in Europe. A growing body of data from North America, Asia, and Australia suggests that, with a carefully considered design intent, a design adjusted for both the regional climate and the roof's microclimates, proper installation, and a maintenance program to ensure long-term viability, they can work equally well in other places. Green roofs make more sense, of course, in some climates than in others (desert areas, for example, might present special challenges).

Flat black roofs are ugly, hot, dirty, and often short-lived.

But more research is needed, in part to overcome resistance based on fear or lack of knowledge. A lot of the existing data come from small test plots in controlled situations, not large green roofs on buildings whose performance over time has been measured and analyzed. The efforts underway represent a good start, but validated performance in the field is what will make or break green roofs a a tool in the sustainable construction arsenal.

It's difficult to make a lot of generalizations about green roofs because the actual benefits provide on a particular site depend on many variables. Climate conditions in North America are much more heterogeneous than in western Europe. Few standards for design details and materials exist here, and most projects are not monitored, so data are scant and reliable prediction of performance is difficult.

A green roof can be designed to maximize one kind of benefit, but that improved performance might come at the cost of another or make the project significantly more complex and expensive. While some individual projects do provide some benefits to the building owner and its residents or employees, others, such as reduction of the urban heat island effect, can only be maximized if the approach is implemented on a broad scale. However well intentioned or unintentional it is, the overselling of potential benefits by uncritical advocates will only undermine the reputation of green roofs in the marketplace over the long term.

Green roofs are easily installed on many flat-roofed buildings. Even simple designs are attractive as well as functional.

Keeping those caveats in mind, it’s becoming clearer that green roofs *can* be good tools to achieve many ecological objectives. Potential benefits include stormwater management; longer life for the roof membrane; lower energy costs; mitigation of the urban heat island effect; habitat for urban wildlife; and amenity value, aesthetics, and marketing.

Stormwater management

Stormwater runoff carries pollutants. When it rains, water running off conventional roofs and paved areas picks up and carries deposited pollutants to rivers, streams, and other local bodies of water. Contaminants in stormwater runoff can include fertilizers, herbicides, and insecticides from both farms and residential developments; oil and grease from roads and energy production facilities; sediment from construction sites, farmland, and stream banks; salts and acid drainage from farmland and abandoned mines; and nutrients and bacteria from farm animals, pet waste, and malfunctioning septic systems (U.S. Environmental Protection Agency [EPA] 1994). In the United States alone, mor than 10 trillion gallons (38 trillion L) of this untreated runoff flow into receiving waters every year (EPA 2004a). The resulting contamination harms aquatic life, reducing the diversity of insect and fis populations (Center for Watershed Protection 2003). It can also make water unsafe for humans: Stormwater runoff is the greatest contributor to beach closings and advisories based on unsafe levels of bacteria (Natural Resources Defense Council 2008).

Runoff interferes with natural hydrology. The increased quantity of runoff during storms, and the rate at which that water is discharged from sewer systems into rivers and streams, also cause problen including floods, increased sediment loads, and erosion of stream banks. The increased flow from smaller, frequently occurring storms is of particular concern because it has not been effectively addressed by regulation or traditional stormwater management measures aimed only at large, infrequent storms (Pitt 1999; National Research Council 2008). In addition, stormwater runoff durin hot summer months contributes to higher temperatures in rivers and streams—temperatures can rise as much as 5 to 12°F (3 to 7°C)—potentially compromising the health of temperature-sensitive aquatic species (EPA 2004b).

Combined sewer overflows send stormwater mixed with pollutants, including raw sewage, into receiving waters.


Stormwater runoff impairs water quality and increases the quantity, velocity, and temperature of water running through rivers and streams. Photograph by Linda McIntyre


The increased flow through rivers and streams after storms can erode and destabilize banks. Photograph by Linda McIntyre

Land development produces runoff. Before land is developed, natural systems accommodate stormwater and runoff is not a problem. Leaves and undisturbed soil absorb rain, sustain plant life, and recharge groundwater levels. Rough and uneven topography, plants, and other features of the unbuilt landscape slow the flow of water running over its surface into rivers, streams, lakes, and ponds. Less fertile areas with fewer plants have their own adaptations to handle stormwater. But as more and more remote suburban and rural areas are developed, with attendant increases in pavement, buil~~dings, and other impervious surfaces, runoff volume increases dramatically, and managing i~~t becomes more urgent.

Land has been developed at an aggressive pace in recent years. From 1997 until 2001, rural land in the United States was developed at an average rate of 6000 acres (2400 ha) every day (National Resources Conservation Service 2003). A 2004 study by the National Oceanic and Atmospheric Administration's National Geophysical Data Center estimated that the impervious surface area of the contiguous United States was roughly the size of Ohio, and slightly larger than the area covered by herbaceous wetlands (Elvidge et al. 2004). Without porous surfaces through which it can filter throug soil and recharge groundwater, stormwater becomes a problem rather than the replenishing resource i should be.

Stormwater runoff has little impact on less developed land. It infiltrates uncompacted soil or travels slowly over rough and vegetate surfaces toward rivers and streams.

Impervious surfaces in developed areas, including roofs and parking lots, contribute to stormwater runoff.

Unfortunately, most traditional control measures do not work very well. Stormwater runoff can als overload local water treatment systems, which in many cases treat sanitary sewage from showers and toilets and stormwater in the same facilities. Water coming in during a rainstorm can exceed the system's capacity, resulting in discharges of mixed sewage and stormwater directly into local lakes, rivers, and streams. In the United States, these combined sewer overflows (CSOs) discharge about 85 billion gallons (3.2 trillion L) of untreated sewage and stormwater in thirty-two states and the Distric of Columbia every year (EPA 2004a).

CSO discharges can contaminate drinking water supplies, beaches and waterfront parks, and sea~~food stocks, threatening public health as well as environmental quality. While they are most~~ often found in the Northeast and Midwest, CSOs occur throughout the United States. New York Harbor alone receives more than 27 billion gallons (1 trillion L) of sewage and polluted runoff from an average of 460 CSOs every year (Storm Water Infrastructure Matters [SWIM] Coalition 2008). In King County, Washington, including the city of Seattle, 815 million gallons (3.1 billion L) from eighty-seven CSOs were discharged into local water bodies from June 2007 to May 2008 (King County Department of Natural Resources and Parks 2008). Separate sanitary and stormwater sewer systems do not, unfortunately, magically solve water pollution problems. Sanitary systems can also become overloaded during heavy storms and discharge sewage; the EPA (no date) estimates that this happens about 40,000 times every year.

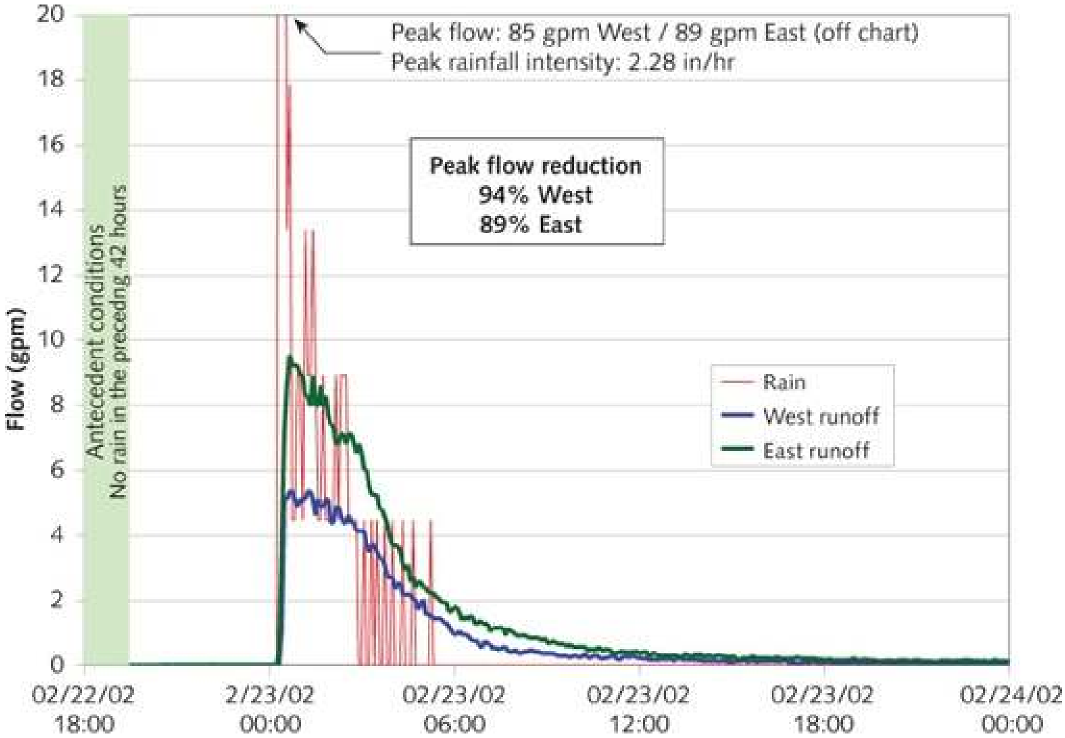
Green roofs can be part of a more effective approach. Management of stormwater runoff is the green roof benefit that has been most amply documented and validated by research, and stormwater management has been a leading driver of green roof construction in North America as well as in Europe. Green roofs can help to minimize runoff from rooftops in all but the worst storms, and even then, while there will be runoff, there will almost always be less of it from a green roof than from a conventional roof. Rain that is not held by the assembly runs off a green roof more slowly than off a conventional roof, and it moves over a longer time frame, attenuating the intense peak flows of runoff during storms. Water used by plants and evaporated back into the atmosphere never runs off at all.

In temperate areas of North America, such as the north-eastern, midwestern, and northwestern United States, even thin green roofs, with about 4 inches (10 cm) of growing medium, usually capture at least half of the annual rainfall and most of the rain that falls in the summer months, when some areas experience frequent storms. In areas with more extreme rainfall patterns, such as the arid regions of the southwestern United States or the frequent large rain events of the tropics, the average percentage of runoff potentially captured by a green roof might be higher or lower (EPA 2009a).

Sewage discharges contaminate water in many urban areas. Photograph by Tom Liptan

Traditional stormwater infrastructure projects using pipes and conveyance are expensive, disruptive, and often ineffective at protecting water quality.

In areas where air- or rain-borne pollutants cause problems, stormwater that does drain off a green roof is cleaner in some respects owing to the filtering effect of the plants and medium. Green roofs also help to neutralize runoff from acid rain. Decreasing the volume of runoff and delaying its releas also takes some of the pressure off both treatment systems and the bodies of water into which the systems discharge. Runoff from green roofs can carry elevated concentrations of some pollutants, such as phosphorous, potassium, calcium, and magnesium, but these effects might diminish as the roof assembly ages (EPA 2009a). For more detailed information on green roofs and stormwater management, see "Designing for stormwater performance" in chapter 4.



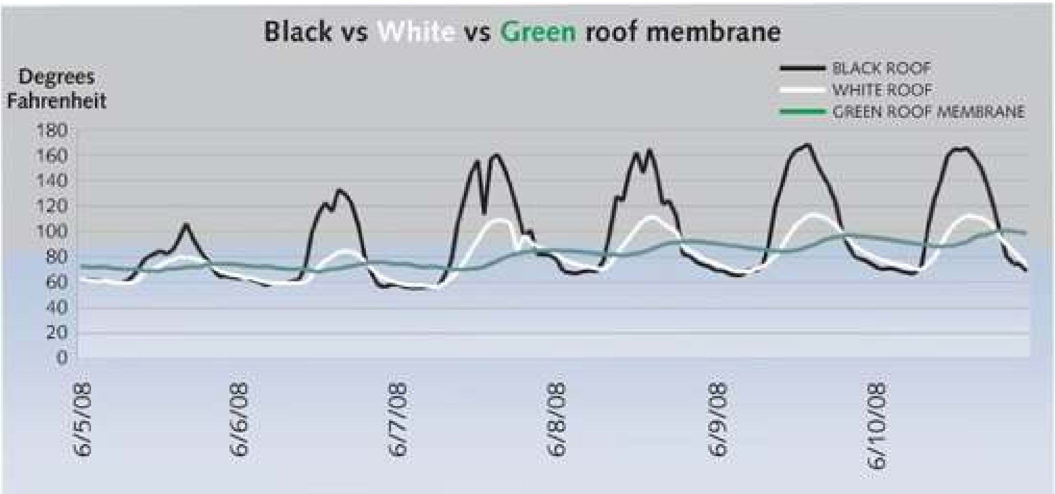
Green roofs can retain most of the rainfall from all but the largest storms and attenuate peak flows of runoff, easing the burden on sewage systems. This graph shows the runoff from the eastern and western sections of a green roof in Portland, Oregon (gpm, gallo per minute). The green roof reduced the flow of runoff when rainfall was most intense, and it held some of the rainwater and releas it at a slower, steadier rate. Graph by Tim Kurtz, City of Portland

Longer life for the roof membrane

If you have ever been on a roof deck on a hot summer day, you know that the effects of the sun are stronger on top of a building than they are on the ground. The plants, growing medium, and other components of the assembly moderate the temperature on a green roof, not only making it a more

pleasant place to be but also protecting the roof's crucial waterproofing membrane from the degradin
effects of extreme temperatures and the sun's ultraviolet rays.

The membrane on a conventional flat roof, if not protected by insulation in an inverted application or ballast, often has to be replaced frequently, perhaps after fifteen or twenty years (Luckett 2009a). I Germany, however, the membranes under green roofs built decades ago are intact, and designers ther typically plan, conservatively, for a life span of at least thirty to forty years. Other protective approaches, such as insulation installed above the waterproofing membrane and landscapes built ove underground structures, also prolong its life. In Portland, Oregon, an intensive planting at grade on to of a parking garage on a federal building has been functioning flawlessly without a leak in its membrane since 1975 (U.S. General Services Administration [GSA] 2008b). While it is too early to make a conclusive judgment about the life span of green roof components in North American applications, these experiences are encouraging.



This graph illustrates the surface temperature fluctuations on a green roof, a reflective white roof, and an unprotected black roof between 5 and 14 June 2008. Even on very hot days, the temperature on a green roof remains cooler than on a white roof and muc cooler than on a black roof. Graph by Stuart Gaffin

Unprotected membranes are subject to harsh weather conditions, extreme temperature fluctuations, and ultraviolet light. Plants help maintain the integrity of the green roof assembly that protects the membrane. Ballast is not as stable and can erode, exposing the membrane.

Less frequent roof replacement is better for the environment as well as the property owner. Currently about 6 to 9 million tons (5.4 to 8.2 million tonnes) of discarded roofing materials are add to landfills every year in the United States (Cavanaugh 2008).

Lower energy costs