

## Description

Green roofs could be defined as "contained" living systems on top of human-made structures. This green space can be below, at, or above grade involving systems where plants are not planted in the ground (Source: Green Roofs for Healthy Cities).



**Photograph GR-1.** EPA Region 8 building in downtown Denver. Photo courtesy of Weston Solutions.

There are two main types of green roofs: extensive and intensive. Extensive green roofs are shallow, usually with 4 inches of substrate, and do not typically support a large diversity of plant species because of root zone limitations. Intensive green roofs are more like rooftop gardens with deep substrate (from 4 inches to several feet) and a wide variety of plants. Most buildings are not designed to withstand the additional weight loading for intensive roofs. For this reason, they are typically limited to new construction. Extensive green roofs are shallower and generally much better suited to the structural capabilities of existing buildings and therefore, are installed more often. Because of this, extensive green roofs are the focus of this design guidance.

The design of a green roof involves many disciplines in addition to stormwater engineers, including structural engineers, architects, landscape architects, horticulturists, and others. This Fact Sheet is intended only to provide an overview of green roof information relative to stormwater quality and quantity management that is applicable in the Denver Metropolitan area. *Design Guidelines and Maintenance Manual for Green Roofs in the Semi-Arid and Arid West*, prepared by the University of Colorado Denver with input from UDFCD, should be used as a more comprehensive design and maintenance document. This document is available at [www.growwest.org](http://www.growwest.org).

As Low Impact Development (LID) strategies have been emphasized increasingly throughout the U.S., green roofs have been implemented in some parts of the country, most frequently in areas with humid climates and relatively high annual rainfall. Although there are some green roofs in Colorado, they have not been widely installed, and research is in progress regarding the best design approach and plant list for the metro Denver climate. Colorado's low annual precipitation, low average relative humidity, high solar radiation due to elevation, high wind velocities and predominantly sunny days make growing plants on a roof more difficult than in other climates. Because of this, plant selection, growing medium, and supplemental irrigation requirements are key considerations for which design criteria continue to evolve. Because the technical community has expressed interest in exploring the water quality and volume

Green Roof <sup>5</sup>	
<b>Functions</b>	
LID/Volume Red.	Yes
WQCV Capture	Yes
WQCV+Flood Control	No
Fact Sheet Includes EURV Guidance	No
<b>Typical Effectiveness for Targeted Pollutants</b>	
Sediment/Solids	Unknown
Nutrients	Unknown
Total Metals	Unknown
Bacteria	Unknown
<b>Other Considerations</b>	
Life-cycle Costs	Unknown
<sup>5</sup> Water quality data for green roofs are not yet robust enough to provide meaningful conclusions about pollutant removal. By reducing volume, green roofs have the de facto capability to reduce pollutant loads; however, on a concentration basis more data are needed to better define effectiveness.	

reduction benefits of this technique, information on green roofs is provided in this Fact Sheet based on industry literature and academic research.

It should be noted that the U.S. Green Building Council LEED rating system recognizes a second kind of green roof that includes reflective, high albedo roof materials that are not designed for stormwater purposes.



Green roofs provide multiple environmental, social, economic, and aesthetic benefits that extend beyond stormwater management objectives.

## Site Selection

Green roofs can be installed on commercial or residential buildings as well as on underground structures such as the parking garage shown in Photo GR-6. Green roofs may be particularly well suited for ultra urban areas where development is typically lot-line-to-lot-line and garden space is at a premium. Green roofs are particularly valuable when their use extends to a place of enjoyment for those that inhabit the building. Several Colorado examples are provided at the end of this Fact Sheet.

For existing buildings, the structural integrity of the building must be verified prior to consideration of retrofitting the building with a green roof. For both existing and new construction, it is essential that the design team be multi-disciplinary. This team may include a structural engineer, stormwater engineer, architect, landscape architect, and horticulturist. It is recommended that all members of the design team be involved early in the process to ensure the building and site conditions are appropriate for green roof installation.

## Benefits

- Reduces runoff rates and volumes.
- Reduces heat island effect in urban areas.
- May qualify for multiple LEED credits.
- May extend roof lifespan by reducing daily temperature fluctuations and providing shading from ultraviolet light.
- May provide energy savings from additional insulation & evapotranspirative cooling.
- Provides aesthetically pleasing open space in ultra urban areas.

## Limitations

- Limited experience in Colorado.
- Initial installation costs are greater than conventional roof (although lifecycle costs may be less).
- Supplemental irrigation required in semi-arid climate.
- Maintenance during vegetation establishment (first two years) may be significant.

## Designing for Maintenance

Recommended ongoing maintenance practices for all BMPs are provided in Chapter 6. During design, the following should be considered upfront to ensure ease of maintenance for green roofs over the long-term:

- Access for equipment and inspections following construction.
- The irrigation system, growing media, and plant selection are critical factors determining long-term maintenance requirements and survival of the green roof vegetation under hot, dry conditions; otherwise, vegetation may have to be repeatedly replanted and/or the irrigation system replaced.
- If an underdrain system is used, provide cleanouts as appropriate for both inspection and maintenance. There is potential over the long term for the roof underdrain system to become clogged with soil/media that migrates down beneath the plant root zone. The ability to access the underdrain system for cleanout is important.

## Design Procedure and Criteria

Green roofs contain a high quality water proofing membrane and root barrier system, drainage system, filter fabric, a lightweight growing media, and plants. Green roofs can be modular, already prepared in trays, including drainage layers, growing media and plants, or each component of the system can be installed separately on top of the structure.

As shown in Figure GR-1, basic elements of green roof design include:

- **Structural Support:** Roof structure that supports the growing medium, vegetation, and live loads associated with rainfall, snow, people, and equipment.
- **Waterproof Membrane:** This prevents water from entering the building.
- **Root Barrier:** This protects the waterproof membrane by preventing roots from reaching the membrane.
- **Drainage Layer:** This is sometimes an aggregate layer or a proprietary product.
- **Filter Membrane:** This prevents fine soil and substrate from being washed out into the drainage layer.
- **Growing Medium:** Although the growing medium is typically not "soil," the terms *soil matrix*, *soil media* and *growth substrate* are sometimes used.
- **Vegetation:** Native/naturalized, drought-tolerant grasses, perennials, and shrubs with relatively shallow root depths are possibilities for roof plantings.
- **Irrigation:** Even vegetation with low water requirements will require supplemental irrigation in Denver.

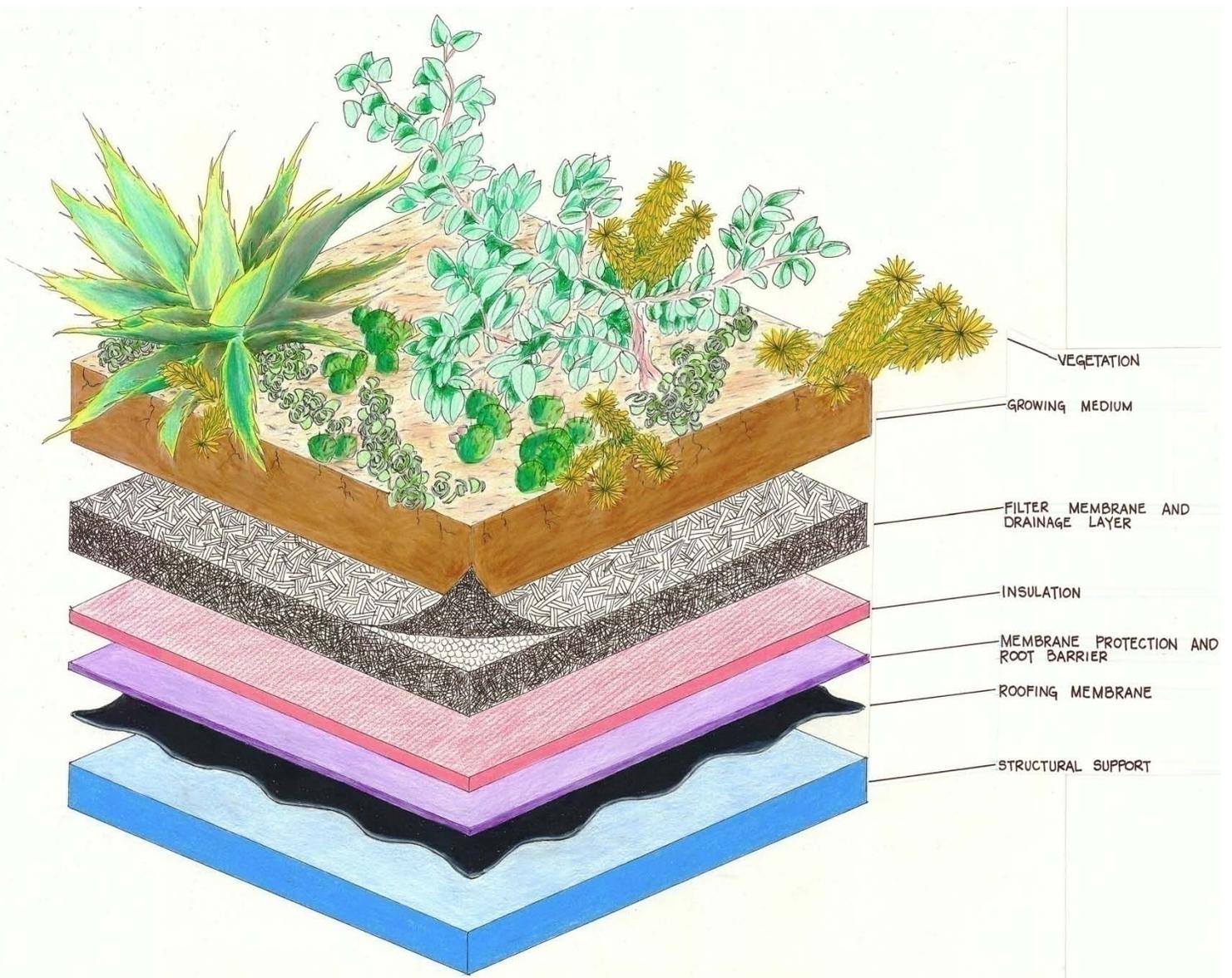


Figure GR-1. Typical Green Roof Cross Section. Graphic by Adia Davis.

Design considerations for green roofs include:

1. **Providing Stormwater Treatment and Slow Release:** An early version of the USDCM provided guidance on rooftop detention. This was removed because rooftop controls can be easily modified by maintenance personnel unfamiliar with its purpose. In contrast, green roof vegetation benefits from stormwater detained in the growing medium and the volume the system detains should be recognized when designing for the water quality capture volume (WQCV).

The WQCV for the Denver area is the runoff resulting from a storm event of approximately 0.6 inches of rainfall. Based on the data that the EPA has collected to date from the Region 8 green roof in Denver, it appears the green roof retains and evapotranspires 98 to 100% of the WQCV even without a restriction on the outlet for drain time control. This is largely due to wetting and subsequent evapotranspiration in the growing media. The data show few exceptions to this, which may be attributed to successive rain events. For this reason, UDFCD recognizes green roofs as a volumetric BMP, able to capture the WQCV for the area of the green roof, without constructing a controlled release at the outlet. This is for roofs that meet or exceed the EPA green roof section, which is a modular system using trays that allow for 4 inches of growing medium. An intensive roof should also be considered to capture the WQCV.

### Volume Reduction Data for the EPA Green Roof in Denver

Stormwater performance data collected from the EPA Region 8 office green roof in Denver, Colorado has indicated that green roofs can be effective at detaining and infiltrating stormwater runoff. This is especially true for snowmelt events and for smaller precipitation events (generally <1" rainfall in a 24-hour period).

Data from the EPA green roof are available for download and analysis at [www.epa.gov/region8/greenroof](http://www.epa.gov/region8/greenroof). These data may be useful in considering additional volume reductions associated with the growing media and evapotranspiration from the vegetation.

A green roof can also be designed to accept runoff from a traditional roof. This can be done for additional water quality and/or irrigation benefits or, if designed with a slow controlled release, the green roof can provide the WQCV for an area in excess of the area of the green roof. Use Figure 3-2 located in Chapter 3 to determine the WQCV (watershed inches) based on a 12-hour drain time. The design volume can be calculated as follows:

$$V = \left[ \frac{WQCV}{12} \right] A \tag{Equation GR-1}$$

Where:

$V$  = design volume (ft<sup>3</sup>)

$A$  = the watershed area tributary to the green roof (ft<sup>2</sup>)

The volume should be provided within the void space of the drainage layer and the growing media. This is a function of the material selected. The outlet can be controlled by an orifice or orifices located at one central location or at each roof drain. This is also a function of the overall drainage design.

2. **Structural Integrity:** Consult a structural engineer to ensure the load bearing capacity of the existing roof is adequate for the system to be installed. If new construction, the green roof should be part of the building design.

3. **Impermeable Membrane and Waterproofing:** Check waterproofing warranty and consult the warranty company to ensure the policy will not be voided by a green roof application. A leak test is recommended following installation of the impermeable membrane.

4. **Drainage System:** A filter membrane is required to keep the growing media from clogging the drainage media; however, roots can pass through the filter membrane. Roots are not expected to pass through the

waterproof/repellant membrane. Other components of the drainage system must be kept free of debris and plant material in order to convey drainage properly.

Photos GR-2 and Photo GR-3 show a stainless steel edge that separates growing media from the rock that surrounds the roof drains. This provides both material separation as well as a root barrier. The plate is perforated to allow the growing media to drain.

Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated, or joins with vertical structures.

5. **Growing Medium:** Growing medium is a key issue with regard to plant health, irrigation needs, and potential stormwater benefits. The growing medium is not the same thing as "soil." Most extensive green roof substrate is predominantly made up of expanded slate, expanded shale, expanded clay, or another lightweight aggregate such as pumice. However, such lightweight aggregates have some limitations. These materials typically drain very quickly and leave little water or nutrients available to plants. Therefore, additional research is necessary on substrate mixes appropriate for use on extensive green roofs in Colorado. For intensive green roof applications where weight is explicitly factored into the structural design, the soil matrix can include materials with higher water retention characteristics such as organic matter (e.g., compost), provided the structural design accounts for the saturated load.



**Photograph GR-2.** The metal edge shown in Photo GR-2 has perforations near the bottom to allow flow into the drain.



**Photograph GR-3.** Metal edging separates growing media from rock that surrounds the roof drain. It also serves to facilitate regular maintenance by limiting plant and root growth near the drain.

6. **Planting Method:** In general, the planting method will be either "modular" (tray approach) or "continuous" (planted *in situ*).
- Modular systems are self-contained trays, which can vary in size, and have relatively shallow depth (2 to 8 inches deep). When modular trays are planted with groundcover and placed close together, the roof often has the appearance of a continuous system once the vegetation is established. Due to the variations in green roof designs, it is important to consult with a multi-disciplinary team to determine the type of roof design most appropriate for the short-term and long-term conditions expected at the site.
  - Continuous systems are "built in place" on the roof with layers designed to work together to provide a healthy environment for plants. Continuous roof approaches range from rolled sedum mats to hand-planted buffalograss plugs.
7. **Plant Selection:** General categories of potentially viable plants for Colorado green roofs include native, alpine (grows in shallow rocky soils), and xeric plants (e.g., sedum). Plants must meet certain criteria to optimize their chance of survival on a green roof. Due to the shallow, well-drained materials in extensive green roof systems, plants must be drought resistant. However, not all drought resistant plants are well-suited for green roofs. For example, some plants avoid drought by rooting deeply to access a more stable supply of water. Such plants would not be suitable for a shallow green roof. Grasses with strong rhizome growth such as bamboo and varieties of Chinese reeds should be avoided, as these have the potential to compromise the roof membrane. While there are several species that could potentially adapt to extensive green roof systems, the most commonly used species are stonecrops or sedums because of their prostrate growth form, shallow root systems, and drought tolerance. Another favorable attribute of sedums is that the foliage tends to remain greener than grasses throughout the entire year, even in northern climates. However, drawbacks to a monoculture for green roofs are the same as for a monoculture in agricultural applications – risk of widespread vegetation loss if conditions (e.g., drought, disease, temperature, etc.) change from the anticipated range.

Characteristics of plants, which tend to work well on green roofs in a semi-arid climate include:

- Self seeding,
- Perennial,
- Low or compact growth format,
- Diffuse or fibrous root system,
- Low water use, and
- Cressulacean Acid Metabolism (CAM), which is common in sedums (stonecrops) where plant stomata are closed during the day to conserve water.

### Growing Media Research by Colorado State University at the EPA Green Roof in Denver

CSU researchers are evaluating alternative growing media for green roofs and report that most extensive green roof media are predominantly made up of expanded slate, shale, or clay. While these materials are generally very well-drained, lightweight, and resistant to blowing away and decomposing, they do have some limitations. They typically drain too quickly (too much macro-pore space, not enough micro-pore space) and do not hold nutrients very well (low cation exchange capacity [CEC]). A material that has all of the benefits of expanded slate, shale and clay, while having more micro-pore space and higher CEC is ideal. One example of a material that may fit this description is zeolite. Zeolites are currently being utilized as amendments for shallow, well-drained golf greens (see <http://greenroof.agsci.colostate.edu/>).

8. **Irrigation:** Irrigation is needed for successful green roofs in Colorado. The decision to use drip or overhead spray irrigation is determined based on growing media characteristics and plant needs. Drip irrigation is more efficient when installed below the vegetation layer to avoid heating of the drip line and to get a more effective watering of the roots. Overhead irrigation should be considered for shallow depth applications because drip irrigation may not spread laterally when applied over a rapidly draining media. Current CSU experiments are determining the extent of irrigation requirements for various plants. Initial results suggest non-succulents dry out faster (need more frequent irrigation), whereas the sedums and other succulent plants require less frequent irrigation; however, sedums and succulents tend to die rather than go dormant during prolonged dry periods.
9. **Wind:** Select growing media and install material layers in a manner to withstand expected average and storm wind conditions.
10. **Roof Microclimates:** Consider the effect of roof microclimates on the vegetation, including factors such as shading, localized strong winds, and reflected solar radiation from surrounding buildings. Solar panels can provide partial shade to vegetation that may not perform well when exposed to the typical green roof environment.
11. **Roof Gradient:** Green roofs may be installed on flat or steep roofs. For flat roofs (e.g., roof slopes less than 2%) a deeper drainage course is recommended to avoid water logging. For steep roofs (e.g., slopes greater than 30%), structural anti-shear protection will normally be needed to prevent sloughing of materials.
12. **Protection of Roof Drainage Features:** Drainage features on the roof such as area drains, scuppers, downspouts, etc. must be kept free of debris and plant material in order to convey drainage properly. Roof outlets, interior gutters, and emergency overflows should be kept free from obstruction by either providing a drainage barrier (e.g., a gravel barrier between the green roof and the emergency overflows) or they should be equipped with an inspection shaft. A drainage barrier should also be used at the roof border with the parapet wall and for any joints where the roof is penetrated or where the roof joins with vertical structures.

Combining solar panels with green roofs is mutually beneficial. Solar panels stay cooler and vegetation receives partial shade, reducing irrigation requirements.

## Additional Design Guidance

Until more experience is gained in Colorado with regard to green roofs, the following design guidance documents may provide additional assistance; with the understanding that the guidelines may need adjustment for Denver's climate:

- **"FLL Guidelines"**: The FLL Guidelines are green roof standards developed by the German Research Society for Landscape Development and Landscape Design. (FLL is derived from the German title: "Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e.V.") These guidelines include the planning, execution and upkeep of green-roof sites. The 2002 edition of these widely consulted guidelines is available for purchase in English through <http://www.roofmeadow.com/technical/fll.php>.
- **ASTM Book of Standards, v. 04-12, 2005:**
  - ASTM E2396-E2399: ASTM has recently developed a new set of standards for green roofs; however, it is important to recognize these standards were developed outside of Colorado.
  - ASTM E2396-05: Standard test method for saturated water permeability of granulated drainage media (falling-head method) for green roof systems.
  - ASTM E-2398-05: Standard test method for water capture and media retention of geocomposite drain layers for green roof systems.
  - ASTM E2397-05: Standard practice for determination of dead loads and live loads associated with green roof systems.
- **BOCA Codes, International Code Council (ICC):** Building Officials and Code Administrators International Inc. (BOCA), now known as the International Code Council (ICC), publish codes that establish minimum performance requirements for all aspects of the construction industry. BOCA codes at the Library of Congress are located in the Law Library Reading Room. Some state codes are available at no cost through the eCodes sections of the ICC Website, while others must be purchased <http://www.iccsafe.org/>.
- **Leadership in Energy and Environmental Design (LEED):** The LEED Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED standards are available through the U.S. Green Building Council: <http://www.usgbc.org/DisplayPage.aspx?CategoryID=19>. Attainment of a desired LEED building rating (e.g., gold, platinum) is based on accumulation of "points" achieved by implementing practices in six different credit categories. A variety of LEED points are potentially achievable through use of green roofs. For example, under the "Sustainable Sites" category, eligible points could include Site Development credits for protecting or restoring habitat and maximizing open space, Stormwater Design credits for quality and quantity, and Heat Island Effect credits for roofs. Green roofs may also contribute to achievement of "Energy and Atmosphere" points for optimizing energy performance for buildings. Green roofs may play a supporting role in a variety of other credits, as well as being eligible for "Innovation in Design" credits.

**Websites for Additional Design Ideas****Colorado**

Colorado State University: <http://greenroof.agsci.colostate.edu/>

Green Roofs of Colorado: <http://www.greenroofsco.com/>

Denver Botanic Gardens: <http://www.botanicgardens.org/content/green-roof>

**Other Research Programs and Resources**

Pennsylvania State University

Michigan State University

North Carolina State University

Southern Illinois University

LBJ Wildflower Center/University of Texas at Austin

Green Roofs for Healthy Cities

**GreenRoofs.com**

American Society of Landscape Architects: <http://land.asla.org/050205/greenroofcentral.html>

Low Impact Development Center: <http://www.lid-stormwater.net/>

**Construction Considerations**

Success of green roofs depends not only on a good design and maintenance, but also on construction practices that enable the BMP to function as designed. Construction considerations include:

- **Permit Requirements, General Coordination, and Warranties:** Investigate permitting requirements for green roofs in the local jurisdiction. Significant coordination between architects, engineers, roofers, and landscapers is needed. Contractually, it is common to have the roofer warranty the impermeable membrane, whereas the landscaper would be responsible for the growing media, vegetation, and other landscaping. Typically, irrigation systems have warranties, but plants do not, with the exception of situations where a maintenance contract is in place. Where a maintenance contract is in place, some landscapers or greenhouses will provide plant warranties.
- **Roof Membrane:** Inspect the roof membrane (the most crucial element of a green roof) and conduct a leak test prior to installing the remaining layers of the roof.
- **Installation Safety:** Most landscapers are accustomed to working on the ground, so safety training is important. If the green roof will be accessible to the public, safety at roof edges should be of paramount concern.

## Colorado Examples

There are several green roof installations in Colorado designed to achieve varying goals that include reductions in stormwater volume, pollutants, and/or urban heat island effects, as well as aesthetic goals. These are briefly described below.

- **EPA Building (Denver):** Installed in 2006, this is a modular, 20,000 square foot, extensive green roof, currently planted primarily with sedum and equipped with spray irrigation. This roof is designed to be monitored for several purposes:

- Biological/horticultural viability,
- Stormwater benefits, and
- Heat island reduction effects.

The extensive planting scheme consists of sedums selected in accordance with USDA hardiness zone classification in 2-inch by 4-inch modules with a 4-inch depth.



- **Denver Botanic Gardens:** Located inside Denver Botanic Gardens, this publicly accessible green roof, installed in 2007, is a semi-intensive retrofit of a 1950s structure. The main purpose of the roof is to identify and test a broad palette of plants that may be feasible for Colorado green roofs. The roof is fully exposed to the south and currently features approximately 60 genera.

The roof is fitted with both drip and spray irrigation. Four irrigation zones are monitored and adjusted according to weather and temperature. All green roof irrigation is recorded and stored in a central database.



**Photograph GR- 4:** A modular, extensive green roof in the spring on the Environmental Protection Agency Region 8 Headquarters in downtown Denver. Photo courtesy of Jennifer Boussetol.

**Photograph GR-5.** A continuous green roof system at the Denver Botanic Gardens. It is a predominantly extensive system with some intensive areas. Photo courtesy of Denver Botanic Gardens

- **REI Parking Garage Roof (Denver):** This is an example of an intensive roof, where a deeper growing media is present. The roof is irrigated.
- **Denver Museum of Contemporary Art:** Installed in 2006, this intensive green roof was designed for aesthetic appeal more than stormwater benefits. Also known as the "Sky Trapezium," it was designed primarily as an art exhibit inspired by the prairie and features native grasses. This roof is equipped with irrigation.
- **CSU Building Roof (Fort Collins):** A small modular extensive green roof installed in 2008 is present on the microbiology building at CSU.
- **Residential Applications:** There are numerous residential applications in Colorado; however, information on the design, vegetation, and performance has not been compiled.



**Photograph GR-6.** Intensive green roof installation above a parking garage.

## References

- Dunnett, N. 2004. *Planting Green Roofs and Living Walls*. Timber Press, Inc: Portland, Oregon.
- Green Roofs for Healthy Cities website. <http://www.greenroofs.org/index.php/about-green-roofs> accessed 17 March 2010.
- Snodgrass, E. 2006. *Green Roof Plants: A Resource and Planting Guide*. Timber Press, Inc.: Portland, Oregon.
- Werthmann, C. 2007 *Green Roof: A Case Study: Michael Van Valkenburgh Associates' Design for the Headquarters of the American Society of Landscape Architects*. Princeton Architectural Press: New York, New York.