Green Infrastructure Options to Reduce Flooding

Definitions, Tips, and Considerations

OFFICE FOR COASTAL MANAGEMENT

Green Infrastructure Options to Reduce Flooding

The practices described in this handout can be used to reduce flooding and help communities design a green infrastructure strategy. It should be noted that while green infrastructure practices make communities more resilient, flooding might not be totally alleviated.

This document is a companion piece to the *Process Guide for Assessing Costs and Benefits of Green Infrastructure for Flood Mitigation*. Step 3 in this publication, which involves identifying how a flood reduction target can be met with green infrastructure, is addressed here. The larger process guide is available by sending an email request to *coastal.info@noaa.gov.*

Information in this handout includes

- **Section 1 - Green Infrastructure Practices.** Most communities implement a variety of approaches to reach their flood reduction goals. Basic information about the most common is described here.
- **Section 2 - Considerations for Planning and Implementation**. Numerous tips and considerations are provided to help community planners develop the best green infrastructure plan for their unique situation.
- **Section 3 - Estimating Storage Potential and Costs.** Cost and capacity matter. Use this chart and the examples provided to start the calculations.
- **Section 4 - For More Information.** This document provides a good overview, but additional information resources are provided for those ready to dive deeper into this topic.

NOAA — National Oceanic and Atmospheric Administration — U.S. Department of Commerce

About NOAA's Office for Coastal Management
This federal organization is the nation's leader in efforts to protect coastal communities and the natural environment. For more information, visit the website at *www.coast.noaa.gov.* For additional resources related to green infrastructure, visit NOAA's Digital Coast at *http://coast.noaa.gov/digitalcoast/topic/green-infrastructure*.

SECTION ONE

GREEN INFRASTRUCTURE PRACTICES

EXISTING FORESTS AND WETLANDS

Description: The most economical way to absorb and clean water is to protect existing forests and wetlands. These areas should be protected in perpetuity and expanded where possible.

Benefits: Such protections help absorb and store floodwaters; reduce erosion along stream banks; improve water quality through filtration; improve air quality; increase groundwater recharge; provide recreation; provide wildlife habitat; and preserve vistas and aesthetic appeal.

Limitations: These steps require conservation of undeveloped forest and wetland areas. If land is in private hands, communities will need to work with the landowner to get conservation agreements. Land acquisition can be expensive. Healthy and larger forests and wetlands will provide more protection.

Maintenance required: Measures include controlling pollution and invasive species and conducting controlled burns.

STORMWATER WETLANDS

Description: Stormwater wetlands consist of a properly designed basin that contains water, a substrate (e.g., soil, sand), and wetland plants. This technique stores floodwater during a storm and releases it slowly, reducing peak flows. There are several variations of the stormwater wetland design. The designs are characterized by the volume of the wetland in deep pool, high marsh, and low marsh, and whether the design allows for detention of small storms above the wetland surface.

Benefits: This technique reduces peak discharges; provides flood control for higher-magnitude storms; improves water quality through pollutant removal; provides aesthetic appeal; increases property value; and improves air quality.

Limitations: It requires a lot of space and is not well-suited for urban areas.

Maintenance required: Participants must control invasive species and ensure planting survival and density.

GREEN AND BLUE ROOFS

Description: Green roofs are flat or gently sloping roofs that contain a planting medium and vegetation on top of the roof material. Typically, a green roof has a filter membrane, drainage layer, waterproof membrane, support panel, thermal insulation, and vapor control layer.

Blue roofs, also known as non-vegetated roofs, detain water on the surface or in engineered trays. These surfaces or trays slowly release the water through a flow-restriction device around a roof drain. From there the water travels to a storm sewer system or to a green-infrastructure cistern or bioretention area.

Benefits: Both green and blue roofs reduce stormwater peak flood and runoff volume; provide pollutant removal through uptake and filtering; and can be designed for public access. In addition, green roofs reduce the cooling and heating needs of buildings; improve air quality; extend the life of the roof membrane; decrease the heat island effect; and reduce water demand by reusing the collected rainwater.

Limitations: Both green and blue roofs require flat or gently sloping roofs that are structurally engineered to withstand the necessary weight for these systems.

Maintenance required: Participants must ensure planting survival by watering until plants are established; control invasive species; and inspect yearly to remove problematic shrubs and reduce the potential for leaks to develop.

TREE PLANTINGS AND CONSERVATION

Description: Planting native trees or conserving existing trees can slow down, capture, and store runoff in the canopy and release water into the atmosphere through evapotranspiration. Tree roots also create soil conditions that promote infiltration.

Benefits: Tree plantings reduce stormwater, pollutants, temperatures, and noise; absorb carbon dioxide; provide habitat for urban wildlife and recreation; increase property values; and reduce costs of clearing and grading by keeping areas natural. Larger, older trees can intercept more stormwater.

Limitations: Trees need adequate space and soil to ensure their health. Check with local ordinances to see which species are allowed for planting in the proposed area. Trees need to be maintained, especially near powerlines.

Maintenance required: Participants must water and prune; control pests; and maintain fringe landscaping.

STORMWATER TREE TRENCHES

Description: A stormwater tree trench is a row of trees that are connected by an underground trench engineered with layers of gravel and soil that store and filter stormwater runoff. They work well in streets and parking lots that have limited space to manage stormwater.

Benefits: These trenches maintain water balance and provide groundwater recharge; reduce runoff; promote pollutant uptake through vegetation; improve air quality; and provide aesthetic appeal.

Limitations: This technique requires specific conditions. These include a careful selection of tree species and appropriate root zone areas and an absence of conflicts with utility structures (such as electric wires and signs) or other structures (such as basements or foundations).

Maintenance required: Participants must water, mulch, and ensure plant survival and density; control invasive species, maintain inlets, and collect garbage, removing litter as needed; inspect annually for erosion, sediment buildup, and proper vegetative conditions; and inspect inlets, outlets, and cleanouts twice annually.

BIOSWALES AND RAIN GARDENS

Description: Bioswales convey stormwater at a slow, controlled rate, and the flood-tolerant vegetation and soil act as a filter medium, cleaning runoff and allowing infiltration. Bioswales generally are installed within or near paved areas such as parking lots or alongside roads and sidewalks. In locations with low infiltration rates, underdrains can be used to collect excess water and discharge the treated runoff to another green infrastructure practice or storm sewer system.

Rain gardens are composed of drought-tolerant shrubs, flowers, and grasses, and they lack a complex soil matrix and underdrain. They are well-suited for installation in residential lots.

Benefits: Bioswales and rain gardens reduce stormwater runoff volumes and increase groundwater recharge; promote pollutant uptake through vegetation and soil; reduce peak discharges; improve air quality; and provide aesthetic appeal.

Limitations: These features are best for smaller sites or neighborhoods and can be expensive for large areas. Colder climates experience frozen soils, which limit infiltration rates. Colder climate use requires adjustments and will add to the cost.

Maintenance required: Steps must be taken to ensure plant survival (watering) and density; control invasive species; rake mulch annually; remove litter; and clean filter. Maintenance costs and time are higher initially and then taper off once established.

PERMEABLE PAVEMENT

Description: Permeable pavement includes both pavements and pavers with void space that allows runoff to flow through, and be temporarily stored in, an underground stone base prior to infiltrating into the ground or discharging from an under drain.

Permeable pavers use blocks of brick, stone, or concrete in a grid; permeable sand or gravel in spaces between the blocks; and a gravel or aggregate sublayer. Porous concrete and asphalt looks similar to traditional pavement but is coarser, with similar-sized stone and less fine material to increase void space.

Permeable pavement reduces annual runoff volumes by approximately 60 percent; reduces peak flows; and improves water quality by removing oil and grease, metals, and suspended solids. It typically does not remove nutrients.

Benefits: This pavement reduces runoff quantity during storm events; reduces surface ice formation in cold climates; and improves water quality from filtration through pavement or pavers and underground media.

Limitations: Snow plowing can catch the edge of pavers and damage pavement surface. Applying sand and salt can clog pavement pores. Soil substrate below the pavers must have adequate filtration rates to allow water to dissipate.

Maintenance required: It is important to sweep or vacuum and reduce the application of sand and salt in cold climates. Porous asphalt might require less maintenance than regular pavement, especially in cold climates where heaving cracks traditionally impact asphalt and concrete.

RAIN HARVESTING: RAIN BARRELS AND CISTERNS

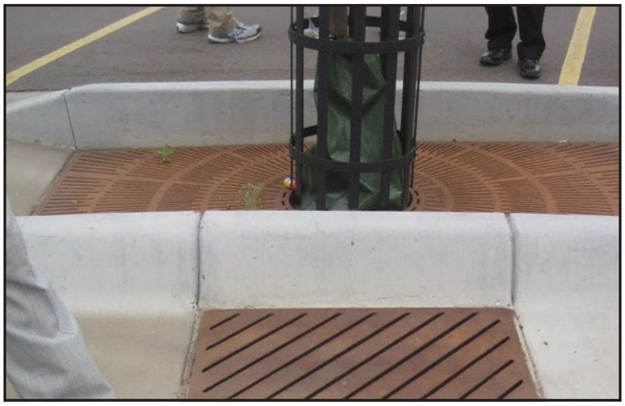
Description: Rain barrels and above-ground cisterns are closed containers that retain runoff for non-potable reuse purposes such as landscaping and car washing. Roof runoff is directed into a downspout and then to the barrel or cistern. Rain barrels typically store about 50 to 100 gallons of stormwater.

Cisterns can store thousands of gallons of stormwater. However, costs for installation can be significantly higher depending on size, location, and siting configurations. For both barrels and cisterns, manual or electronic flow-control valves can be used to control storage.

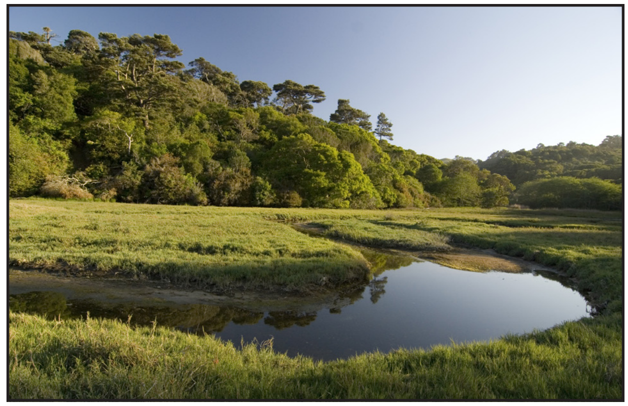
Benefits: The containers reduce water demand; reduce runoff volume to conventional stormwater facilities; require minimal space; increase community engagement; and manage stormwater on site.

Limitations: The containers are only useful when empty, so water collected needs to be used between rain events. Rain barrels collect only a small amount of water. Water collected is not suitable for drinking.

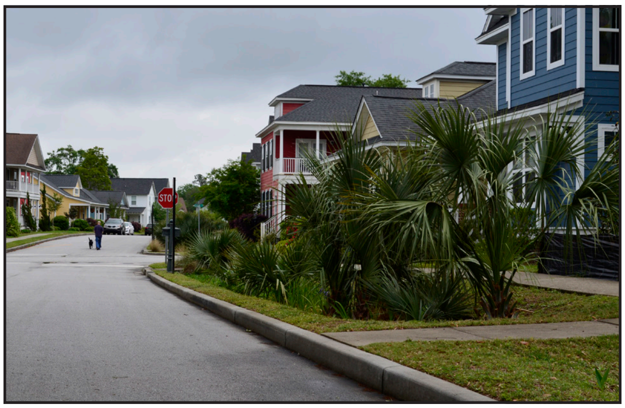
Maintenance required: Check for cracks, ensuring that hoses and lids are properly attached and that no yard pests are in the barrel. In cold climates rain barrels must be disconnected during periods of freezing temperatures to prevent damage.



Stormwater tree trench.
Source: Alisa Goldstein



Forest and wetlands.

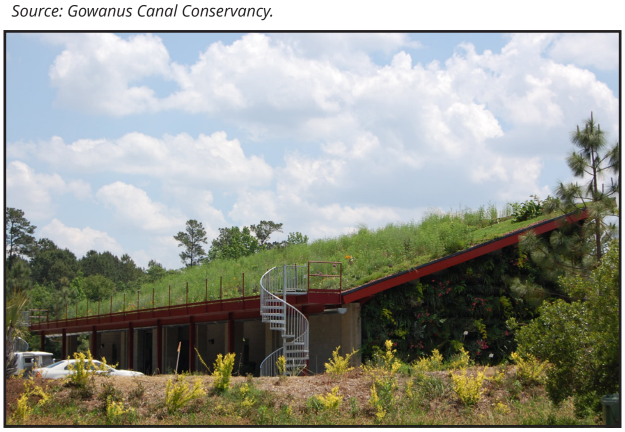


Bioswale.

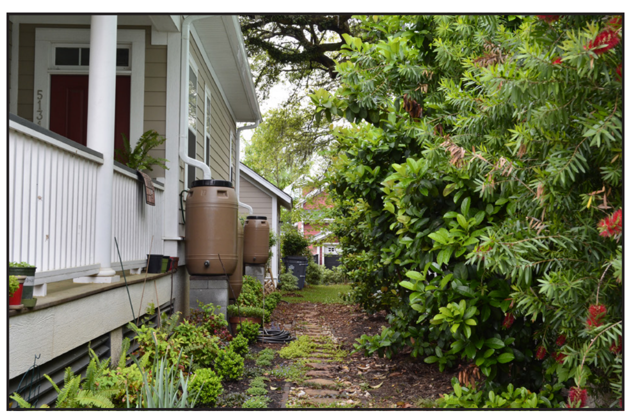
Porous pavers.

Blue roof.
Source: Gowanus Canal Conservancy.

Porous asphalt.



Green roof.
Source: South Carolina Department of Natural Resources.



Rain barrel.

SECTION TWO

CONSIDERATIONS FOR PLANNING AND IMPLEMENTATION

Green infrastructure practices can be effective in reducing flooding impacts in communities but, to increase the success of practices, consider the following:

PLANNING

- Consider a watershed approach to planning instead of a plan that only accounts for a municipality's portion of the flooding or a subwatershed. This will enable a comprehensive look at the area's hydrology.

- Identify a flood storage target, which is the amount you want to reduce the peak flow of a certain flood event. The result will be a certain volume of water that needs to be stored using either green infrastructure practices or a combination of green and gray (built) practices. To learn more about estimating a flood storage target, see "Select a Flood Reduction Target," which is Step 3 in the process guide.

- Know the community's characteristics. Climate characteristics, for example, include precipitation amounts and storm frequencies and intensities. Land use and land cover considerations include vegetation, current zoning, and high-density development. Additional areas to consider include topography, slope, and soil (for instance, sandy soil tends to have more infiltration and less runoff, while tight clay tends to have less infiltration and more runoff). Community interests are also important to consider if maximum flood reduction benefits are to be achieved.

- Account for construction costs such as moving utilities or reinforcing roofs as well as ongoing maintenance.

- The cost of constructing any green infrastructure technique is variable and depends largely on site conditions and drainage area. For example, if a green infrastructure technique is constructed in very rocky soils, the increased excavation costs might substantially increase the cost of construction. Also, land acquisition costs vary greatly from site to site.

- Take a staged approach to implementation. Look for opportunities to include green infrastructure practices in ongoing or planned capital improvements, new development, and redevelopment. Look for opportunities to weave green infrastructure into comprehensive planning or zoning code updates.

- Include monitoring components to help determine if the approach is working.

- Several cities use zoning codes to encourage green infrastructure to reduce runoff in new development and redevelopment projects. The following examples illustrate this point:

  A new discharge permit condition requires that the Milwaukee Metropolitan Sewerage District add green infrastructure to capture one million gallons of water annually in the region. This is the first permit in the country with a green infrastructure requirement in the body of the permit. See *www.freshcoast740.com/PDF/final/MMSDGIP_Final.pdf*.

  Duluth, Minnesota, just passed a new stormwater ordinance that requires post-development peak flow rates at each discharge point not to exceed 75 percent of pre-development peak flow rates for 10- and 100-year events. For a two-year storm, post-development peak flow rates cannot exceed 90 percent of the pre-development peak flow rates. And for all storm events, post-development peak flow rates cannot exceed pre-development peak flow rates.

PARTNERSHIPS AND FUNDING

- Use other people's money. There are many grants available to help with proof-of-concept projects. Funding sources can be found here at *http://water.epa.gov/infrastructure/greeninfrastructure/gi_funding.cfm*.

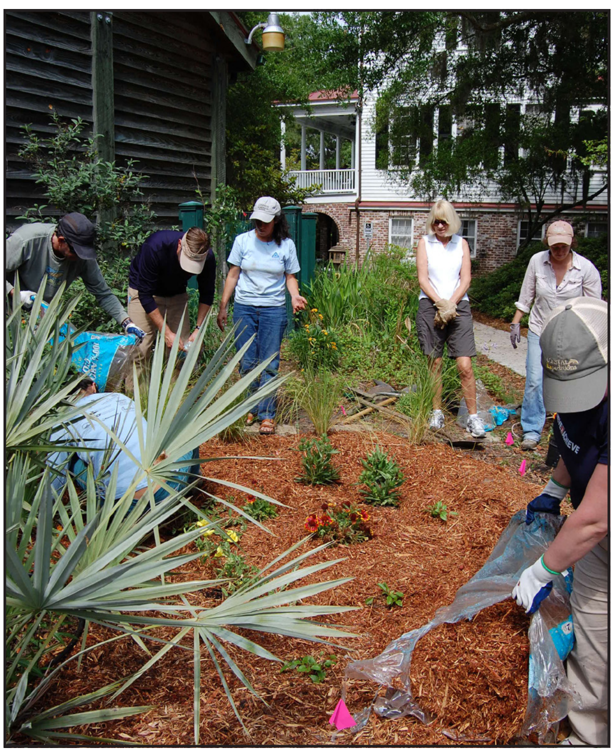
- Build partnerships with universities, non-profits, homeowner associations, and other government agencies that have time, experience, and access to helpful resources.

- Talk to people living in cities such as Milwaukee, Philadelphia, and Portland who have been doing comprehensive green infrastructure strategic planning.

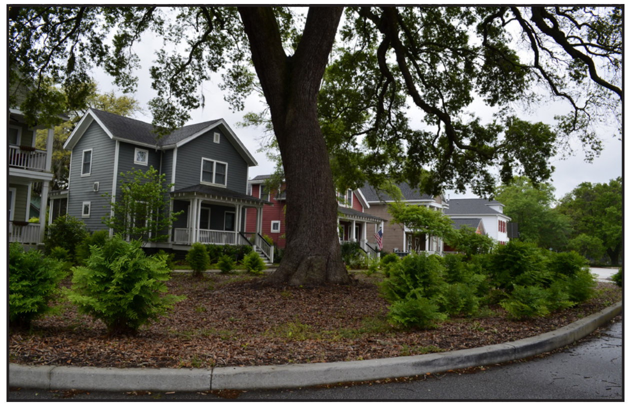
- Start a task force focused on using green infrastructure to help manage flooding.

MAINTENANCE

- Note that some practices require more extensive maintenance (for instance, permeable pavers that can become clogged). Maintenance could be worked into existing municipal maintenance activities or into annual homeowner association fees at a neighborhood scale to keep costs down.



Rain garden.
Source: South Carolina Department of Natural Resources.



Native tree conservation.

- Consider including public works or other maintenance departments during the planning and design stages of the project. This ensures that staff members understand the function and long term maintenance requirements and will head off potential conflicts with existing maintenance practices.

- Maintenance costs can range from 1 to 10 percent of the capital or project cost.

CHOOSING GREEN INFRASTRUCTURE APPROACHES

- Choose practices that have a longer lifespan to see a higher return on the investment.

- Tailor green infrastructure approaches to the type of flooding the community experiences. For example, some practices such as rain gardens will not store large quantities of water created by larger extreme precipitation events. If large events are the major source of flooding, an alternative or a mix of approaches should be considered.

- Maximize the cost-benefit ratio of implementing green infrastructure by considering economies of scale, sequencing, leveraging other infrastructure investments, and mixing and matching various practices to achieve the total storage needed. Implementing a green infrastructure practice in multiple places within the community can drive down costs.

SECTION THREE

ESTIMATING STORAGE POTENTIAL AND COSTS

It's unlikely that just one green infrastructure practice will meet all flood storage needs, so consider mixing and matching approaches to create the strategy that will best meet the flood storage and infiltration target.

Cost also is a consideration. Below are rough estimates of what storage could cost for each green infrastructure practice included in this reference, followed by an example calculation showing how to determine the cost to meet a flood storage target. The common unit of cubic feet (ft3)* enables you to compare one green infrastructure practice to another and also estimate how much floodwater storage that practice can provide.

Green infrastructure practice	Cost estimate**
Existing forests and wetlands	It depends on value of land, opportunity costs.
Stormwater wetlands	Capital cost: $1 to $2 per cubic foot of storage provided.
Blue roofs	Capital cost: $2 to $10 per cubic foot of storage provided ($1 to $5 per square foot with a 6" depth).
Green roofs	Capital cost is $18 to $64 per cubic foot of storage provided ($9 to $32 per square foot with a 6" depth).
Tree plantings	Capital cost: Tree cost is about $175 to $400.
Tree box filter	Capital cost is about $270 to $330 per cubic foot of storage provided (includes tree box filter and additional soil). Trees are an additional cost.
Permeable pavement	Capital cost: For sidewalks, the cost is about $16 to $17 per cubic foot of storage provided.
Bioretention (bioswales, rain gardens)	Capital cost is about $7 to $60 per cubic foot of storage provided (depending on the type of bioretention).
Rain barrels	Capital cost is about $7 to $13 per cubic foot of storage provided. An average rain barrel holds about 55 gallons or 7.3 cubic feet.

**A cubic foot of storage is about 7.5 gallons of water.*

**The cost estimates do not account for construction costs or maintenance. Maintenance estimates can be found on the Center for Neighborhood Technology Green Values Calculator cost details sheet, where information is provided in costs per square foot of storage (*http://greenvalues.cnt.org/national/cost_detail.php*).

EXAMPLE

A community has a goal to reduce the peak discharge from the one-percent annual chance flood by 10 percent. This means they need to find 1,307,000 cubic feet (30 acre-feet***) of flood storage. The urban community is considering commercial rooftop space to help store water. They are interested in using blue roofs, which cost about $6 per cubic foot of storage. To estimate the storage potential of the commercial rooftops and what it could cost to obtain that storage, the following calculations were used.

Commercial rooftop dimensions:

Area: 2,500,000 ft^2 of commercial rooftops in the watershed

Depth: 6 inches (0.5 ft)

Coverage: Assume 75 percent of roofs could be retrofitted with blue roofs

1. Calculate total storage volume

(area of rooftop space) x (depth) x (percentage of roof used) = volume

For example: 2,500,000 ft^2 X 0.5 ft X 0.75 = 937,500 ft^3

2. Estimate cost per cubic foot of storage

(blue roof volume) x (unit cost of blue roof) = cost of storage

For example: 937,500 ft^3 x $6.00/$ft^3$ = $5,625,000

RESULTS

To obtain 938,000 cubic feet (ft^3) (or 21 acre-feet) of storage using blue roofs, it would cost about $5.6 million; with full implementation of blue roofs, this community would have fulfilled 70 percent of their flood storage target with this one practice.

***An acre foot is a unit of volume used in reference to large-scale water resources such as reservoirs and river flows. It is the volume of water that covers one acre, one foot deep. It equals 43,560 cubic feet, or 325,851 gallons.

SECTION FOUR

FOR MORE INFORMATION

The following resources provide greater detail regarding green infrastructure practices; the first two represent the primary sources for this document.

Economic Assessment of Green Infrastructure Strategies for Climate Change Adaptation: Pilot Studies in the Great Lakes Region – http://coast.noaa.gov/digitalcoast/publications/climate-change-adaptation-pilot. Document provides additional supporting information and sources and was the basis for this quick reference.

The National Green Values – Calculator – *http://greenvalues.cnt.org/national/calculator.php*. This tool quickly compares the performance, costs, and benefits of green infrastructure (or low impact development) to conventional stormwater practices.

National Low Impact Development Atlas – *http://lidmap.uconn.edu/index_original.php*. The atlas provides examples of on-the-ground green infrastructure throughout the U.S.

Environmental Protection Agency's Green Infrastructure for Resiliency Website – *http://water.epa.gov/infrastructure/greeninfrastructure/climate_res.cfm*. This website provides information and resources for implementing green infrastructure to improve resilience.

Best Management Practices Construction Costs, Maintenance Costs, and Land Requirements – *www.pca.state.mn.us/index.php/view-document.html?gid=17.134*

Stormwater wetland. Source: Alisa Goldstein.

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