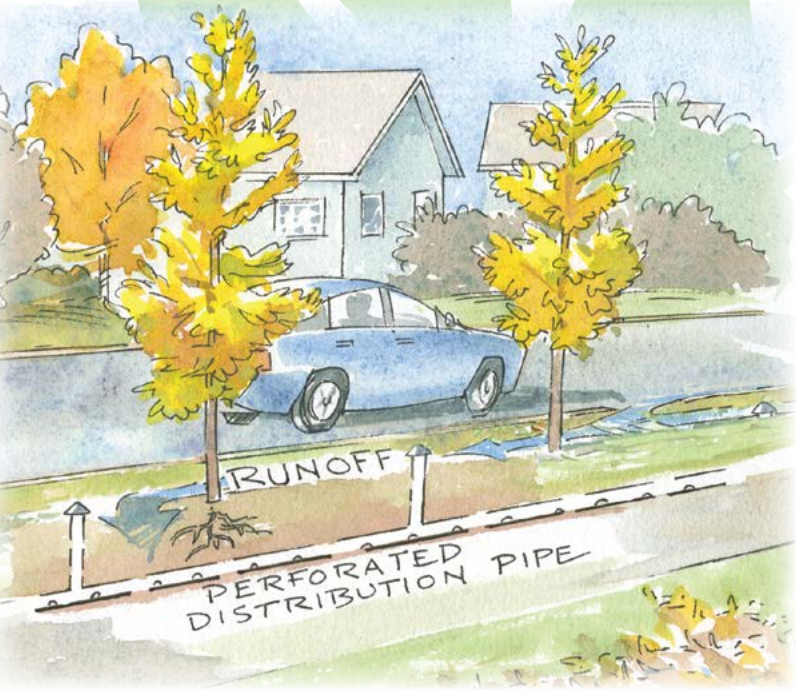
# Green Infrastructure Primer





## A Delaware Guide to Using Natural Systems in Urban, Rural, and Coastal Settings


# Acknowledgments

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This document would not have been completed without the advice, input, time, talents, and insight of state agency staff and conservation partners throughout the state.

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# Green Infrastructure Primer for Delaware

## Contents

# Introduction to Green Infrastructure

Green infrastructure is a nature-based approach to address environmental challenges such as stormwater runoff, flooding, erosion, and water and air pollution. Green infrastructure uses natural processes to manage water and improve environmental quality.

Green infrastructure can be used at different scales. At the site scale, green infrastructure functions by mimicking the processes that occur in larger, natural systems. These natural processes include using vegetation and soils to:

- filter pollutants from surface and stormwater
- improve infiltration of water into soil and groundwater
- reduce the volume of stormwater during high-intensity events
- moderate air and water temperatures by shading and through evapotranspiration[1] by plants

*Green infrastructure incorporates both the natural environment and engineered systems to provide clean water, conserve ecosystem values and functions, and provide a wide array of benefits to people and wildlife.*

— American Rivers

Green infrastructure can be used in many different settings. For example, trees can be used in urban, suburban, and rural settings, in plantings of one or two trees, or in a 100-foot-wide forested buffer along a river shoreline. Rain gardens of less than an acre can help manage stormwater runoff from roofs and parking areas, while a larger expanse of wetlands can provide flood retention, carbon storage, and wildlife habitat.

## Benefits of Green Infrastructure

Green infrastructure can serve many functions and provide multiple benefits—environmental, economic, social, and aesthetic. A wide variety of green infrastructure practices have been developed and used for managing stormwater runoff. These practices benefit water quality by filtering or absorbing sediment, nutrients, and other pollutants. For example, stabilizing stream banks to protect structures and habitat in shoreline areas prevents or reduces erosion and improves water quality.

The impacts of a changing climate—with increasing temperatures and variable rainfall—underscore the potential benefits of green infrastructure. Many green infrastructure practices can help:

- provide flood retention during high tides or heavy rainfall events
- moderate high temperatures by shading buildings and waterways
- provide habitat by retaining existing vegetation or expand habitat by planting native flowers, trees, and shrubs

1 Evapotranspiration is the combination of two processes: evaporation and transpiration, both of which release moisture into the air. Through evaporation, water is converted from liquid to vapor and evaporates from soil, lakes, rivers, and even pavement. Through transpiration, water that was drawn up through the soil by the roots evaporates from the leaves. (http://water.usgs.gov/edu/watercycletranspiration.html)

- capture carbon dioxide from the atmosphere and store it in plant tissues and soil, which helps to reduce greenhouse gas emissions to the atmosphere
- absorb air pollutants such as ground-level ozone, carbon monoxide, and sulfur dioxide, and particulate matter

In addition to environmental benefits, green infrastructure can offer economic benefits, in some cases with lower capital or operating costs compared to conventional "gray" infrastructure[2]. By increasing water storage and filtration in the landscape, green infrastructure can decrease the amount of runoff going into sewers and wastewater facilities. This can help reduce the risk of costly damage to water infrastructure from high-volume rain events. Homeowners, businesses, and residents can also benefit from the aesthetic value of green infrastructure, enhancing property values and contributing to community quality of life.

Green infrastructure can also support public health and provide social benefits, particularly through air quality improvements. For example, vegetation barriers along high-volume roadways capture dust, soot, and other particulate matter, leading to improved air quality and reductions in health risk. In urban settings, trees can reduce heat stress by shading buildings and paved surfaces, lowering air temperatures, and resulting in reduced energy bills.

This former brownfield site along Concord Ave. in Wilmington now functions as a stormwater bioswale and beautifies this major corridor as a gateway planting.

**PHOTO:** Delaware Center for Horticulture

One aspect of green infrastructure that distinguishes it from gray or "hard" infrastructure is that the living components of green infrastructure can change and adapt to changing environmental conditions. The flexibility of these living systems to tolerate and recover from extreme conditions is an important part of their value in increasing resiliency to climate change and its impacts.

## Types of Green Infrastructure

Two types of green infrastructure are described in this primer. Green infrastructure practices at the "***site scale***" include a wide variety of small construction designs that are generally used in landscaping and site development around or adjacent to existing structures, including buildings, roads, and parking lots. Some practices, such as riparian buffers and living shorelines, are suited for sites along waterways.

2 "Gray infrastructure" generally refers to engineered structures composed of man-made materials.

*Done right and under the right conditions, green infrastructure can reduce risks to people and property as effectively as traditional "gray" infrastructure can, while potentially providing a number of additional benefits.*

— The Nature Conservancy

Green infrastructure at the "***landscape scale***" includes the protection, restoration and enhancement of large, natural systems such as wetlands, forests, shorelines, and floodplains. Wetland and forest habitats provide many benefits by filtering and storing surface runoff, providing important wildlife habitat, and storing carbon.

Green infrastructure practices may be similar in design or function to other kinds of "best management practices" (BMPs) used for water quality management and other goals. Many agricultural operators have used agricultural BMPs[3] such as vegetated swales. Some community planners and private developers have experience with low impact development (LID)[4] standards that incorporate green infrastructure practices, such as bioretention or rain gardens.

## Practical Considerations

Green infrastructure can be used to meet one or more of a range of objectives. The choice of types and designs for green infrastructure depends on many factors, but should begin with the primary outcomes you want to achieve. What is your main objective? Many of the green infrastructure practices described here can be used to achieve multiple benefits, can be used in combination, and can be adapted to existing site conditions in both developed and undeveloped settings.

### *Site Conditions*

The application of green infrastructure practices should fit the site conditions, including existing structures and vegetation, and consider the uses and activities on the site. For example, the design for a living shoreline needs to consider potential wave action as well as intended shoreline access for boating or recreational use. Site conditions that should generally be evaluated also include:

- Geographic setting: slope; exposure to wind or wave action; adjacent waterways or drainage features
- Soil types: infiltration rate and storage capacity; soil wetness
- Impervious surface[5]: a higher percentage of impervious surface typically produces more runoff
- Vegetation: native or nonnative plants; invasive plants; existing forests, trees and shrubs
- Contaminants: polluted sites may require remediation prior to, or as part of, the installation of green infrastructure

3 Agricultural best management practices are conservation practices that also provide water quality benefits. Source: US Department of Agriculture

4 Low impact development (LID) is an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible. Source: US EPA.

5 Impervious surface refers to land area covered by roads, buildings, or pavement, where rainfall cannot be absorbed by soils or filtered by plants. Source: US Geological Survey

- Access: vehicle and equipment access during construction; access for public or private use of the site after installation
- Utilities: location of both overhead and underground utilities, such as electricity transmission, gas lines, and water/sewer lines may limit or affect the suitability of a given site

### *Sizing*

Green infrastructure practices for stormwater management are typically sized to manage runoff from frequent, smaller storm events (most often in the range of 1–2 inches of rainfall over 24 hours). The size of green infrastructure at the site scale application should be determined according to the character of the drainage area and local hydrology. For infrastructure with an expected lifespan of 30 years or more, consider the potential effects of changing climate conditions on the long-term function and capacity of the infrastructure in its design and location.

The size and location of landscape scale green infrastructure also play a role in the environmental benefits provided by natural systems. Connected areas of native vegetation will generally offer greater benefits than isolated or fragmented units of natural habitat. Landscape scale natural systems that lie in or adjacent to flood-prone areas may provide flood retention and reduce erosion and damage from flood events.

> *Green infrastructure can not only help improve water quality by better managing stormwater—sometimes even at a lower cost than conventional alternatives—but also can attract investment; help revive distressed neighborhoods; encourage redevelopment; provide recreational opportunities; and help achieve other social, economic, public health, and environmental goals.*
>
> — U.S. Environmental Protection Agency

### *Construction*

The functionality of green infrastructure can be impaired by common construction mistakes, such as soil compaction from heavy equipment, especially when it is used on saturated soil conditions, and erosion and sediment accumulation. Construction practices should include steps to minimize site disturbance and ensure installation success:

- Establish a protective zone around valued natural areas and trees that will be preserved.
- Ensure accurate grading for any green infrastructure practices designed to manage stormwater.
- Apply appropriate erosion controls to minimize soil erosion as areas are cleared and graded.
- Minimize the use of heavy equipment or vehicles that may compact soils and decrease infiltration rates.
- Inspect all construction phases to ensure proper installation, especially critical drainage structures such as outlets and overflows.
- Enhance soils as needed to improve plant establishment; soils in urban settings may have inadequate organic material and require addition of topsoil or compost to support vegetation, or may require customized soil mixes to enhance filtration properties.
- Time the planting to reduce plant stress during establishment.

## *Maintenance*

All types of infrastructure require maintenance to ensure that it functions properly under both normal and extreme conditions. Green infrastructure maintenance is no exception. Maintaining green infrastructure can include tasks that are typical to landscape maintenance, as well as additional monitoring and care.

- Weed, mow, and prune vegetation if needed so that it remains healthy and does not pose other hazards.
- Mowing, if needed, should be timed to avoid impacts to habitat and wildlife; recommended timing for mowing is late winter or very early spring (February – March).
- Maintenance may require a shift in practices, from mowing turf to maintaining diverse plantings of trees, shrubs, and perennials.
- Train maintenance personnel to distinguish native plants from weeds. Controlling invasive species may require physical control methods when herbicide methods are not appropriate.
- In some communities, local ordinances may need to be amended or revised to allow for native plants in rain gardens or vegetative buffers.
- In addition to routine maintenance, inspections should be made after any severe weather event or disturbance that could damage the function of the green infrastructure practice.

The effectiveness of green infrastructure is a function of its location, design specifications, maintenance procedures, and performance expectations. Maintenance personnel should be familiar with the characteristics and intended function of the green infrastructure practice so they can recognize problems and know how they should be resolved. The life span of green infrastructure varies, depending on proper maintenance as well as exposure to environmental stresses. For example, living shorelines in areas with moderate wave action will likely require more frequent maintenance and repair than those in quiet waters. Green infrastructure practices designed primarily for stormwater management are generally expected to have a lifespan of 20 years.[6]

## *Costs*

The costs of installing green infrastructure practices depend on many factors, including the materials and source of labor, whether a project requires professional design and construction, and the size and scale of the project. Permit and inspection fees may also apply, and projects that require engineering or use of heavy equipment for installation are likely to be costly. Costs can also vary depending on whether the project is part of new construction or retrofitted into existing development. Projects, such as installing rain barrels or rain gardens, which can be completed by the property owner or with volunteer labor, may be relatively inexpensive.

6 US EPA – Coastal Stormwater Management through Green Infrastructure: A Handbook for Municipalities (2014). http://water.epa.gov/type/oceb/nep/upload/MassBays_Handbook_combined_508-opt.pdf

Regular maintenance for this rain garden at UD's Lewes Campus in spring and late summer includes mulching, weeding, thinning mature and invasive vegetation serves dual role of garden as attractive and functional green infrastructure through the year.

**PHOTO:** Delaware Sea Grant

It is also important to consider funding sources such as cost-share grants that may be available (see Resources section). For example, a living shoreline project installed in Lewes, Delaware, cost just under $50 per linear foot for materials, including coir logs, coir matting, stakes, oyster shell, and seedling plugs of native *Spartina grass*.[7] This project was supported by grants from the Sussex County Conservation District and DNREC.

The costs of using green infrastructure are often evaluated in comparison to conventional gray infrastructure. Gray, or hard, infrastructure includes a wide range of engineered techniques for managing stormwater, surface runoff, and shoreline erosion. Although hard systems can be effective, there are economic and environmental trade-offs, such as high construction, maintenance, and repair costs; reduced habitat values; and increased impermeable surface area. Weighing the difference between green and gray infrastructure options can be complex, involving a number of variables, including maintenance costs, expected life span, and long-term functionality. Qualified designers and engineers should be consulted to consider the costs and benefits of any large infrastructure project. The US Environmental Protection Agency also has many good resources that offer in-depth information on costs and benefits of green infrastructure (see Resources section).

7 Shoreline Restoration of Lewes Ball Field (DNREC) http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Lewes%20LS%20Handout.pdf

*Green infrastructure is an important and underutilized tool for increasing community resilience to the effects of climate change and natural disasters.*

— U.S. Department of Housing and Urban Development

### *Stormwater Requirements*

When green infrastructure is used to meet stormwater management regulations, specific review and approval processes must be followed. State or local agencies are responsible for Sediment and Stormwater Program elements consisting of plan review, construction inspection, and maintenance inspection for their geographic boundaries (see Resources section).

### *Permitting and Local Planning*

Before selecting any green infrastructure practice, a project planner should investigate what permits or planning approvals are needed. When green infrastructure is added to an existing, built site, local planning and natural resource agencies should be consulted early in the process. Green infrastructure practices that involve modification of shorelines or wetlands will generally require review and approval by state and/or federal agencies. Authorization from the DNREC, Division of Water, Wetlands and Subaqueous Lands Section is required for activities in tidal wetlands as well as tidal and nontidal waters in the State of Delaware (see Resources section).

## Getting Started

This Primer offers an introduction to understanding what green infrastructure is and how it can be beneficial—at both the site scale and the landscape scale.

Part II includes fact sheets for eight site scale green infrastructure practices: rain gardens; vegetated swales; tree boxes and tree trenches; rain barrels, cisterns, and downspout disconnection; green roofs; urban trees; riparian buffers; and living shorelines. Each fact sheet includes a photo of a Delaware site utilizing one or more of these practices. The benefits, site and design considerations, maintenance concerns are also summarized. This selection is not a comprehensive guide, but provides an introduction to techniques currently used in urban, rural, and coastal settings in Delaware.

Following the eight fact sheets, three case studies provide examples of site scale green infrastructure practices in urban, coastal, and rural settings. A state government building in Dover illustrates the use of green infrastructure retrofitted into the site of an existing, historic structure. The Blackbird Creek living shoreline project demonstrates the use of natural materials and living plants to help restore habitat and reduce shoreline erosion. The Cow Bridge Branch riparian buffer in Sussex County is an example of stream restoration in a rural setting.

Part III describes the importance of protecting, enhancing, and restoring green infrastructure at the landscape scale. This section provides a brief summary of forests, wetlands, shorelines and floodplains.

Part IV offers a range of resources to further your understanding and help you learn how green infrastructure can be incorporated or enhanced in your area. This includes information on whom to contact for regulatory assistance, planning and technical assistance, permitting information, and funding resources. Also included is a list of selected documents that provide technical guidance for planning and site scale practices. Finally, several mapping resources are listed.

# Green Infrastructure at the Site Scale

## Introduction

This section includes fact sheets describing a selection of eight site scale green infrastructure practices:

- Rain gardens
- Vegetated swales
- Tree boxes and tree trenches
- Rain barrels, cisterns, and downspout disconnection
- Green roofs
- Urban trees
- Riparian buffers
- Living shorelines

Green infrastructure practices at the site scale can provide multiple benefits. The performance of these practices depends on specific site conditions, the project design, and the construction and maintenance of the installed practice. In addition, green infrastructure can enhance landscape aesthetics and add to community quality of life. Using vegetation also offers air quality benefits as plants absorb pollutants, help moderate high temperatures by shading buildings and pavement, and store carbon, thus helping to mitigate greenhouse gas emissions. Costs also vary greatly with the size, scale, materials, labor, and engineering needs for the specific project. The table below summarizes some of the benefits and relative costs.

| *Green Infrastructure Practice* | *Environmental Benefit* | | | | | |
|---|---|---|---|---|---|---|
| | *Stormwater Runoff Reduction* | *Flood Infiltration* | *Improved Water Quality* | *Erosion Control* | *Wildlife/ Pollinator Habitat* | *Cost* |
| *Rain Garden* | ✔ | ✔ | ✔ | | ✔ | *$* |
| *Planter/Tree Box* | ✔ | ✔ | ✔ | | ✔ | *$$* |
| *Vegetated Swale* | ✔ | ✔ | ✔ | ✔ | ✔ | *$$* |
| *Green Roof* | ✔ | ✔ | ✔ | | ✔ | *$$$* |
| *Rain Barrel, Cistern, Downspout Disconnection* | ✔ | | ✔ | | | *$* |
| *Urban Forest* | ✔ | ✔ | ✔ | ✔ | ✔ | *$* |
| *Riparian Buffer* | ✔ | ✔ | ✔ | ✔ | ✔ | *$$* |
| *Living Shoreline* | | | ✔ | ✔ | ✔ | *$$$* |

# Rain Gardens

A rain garden is a shallow depression with vegetation that allows the rainwater and stormwater to collect and infiltrate into the ground. Typically installed in community and residential areas, rain gardens are designed to hold rainwater in place. Rain gardens and bioretention systems collect and filter stormwater through layers of mulch, soil, and plant root systems where pollutants are retained and absorbed using a specially engineered soil media. Bioretention systems often have a drain system at or below the surface, but rain gardens generally do not.

## *Benefits:*

- Manage stormwater by allowing it to infiltrate into the soil and the plants which:
    - Reduces pollution
    - Reduces volume of water discharged to sewer systems
- Provide natural habitat for pollinating insects
- Beautify a local community

## *Site and Design Considerations:*

- Slope of the landscape is important; rain gardens function best on gentle slopes ranging from 1 to 10 percent.
- Rain gardens are best located where surface water drains off paved surfaces or turf grass, such as the downhill slope of a driveway or patio.
- Avoid areas with poor drainage that will not support infiltration.
- Avoid compaction of soil by heavy equipment.

**RAIN GARDEN, UD LEWES CAMPUS** The rain garden at the University of Delaware's Hugh R. Sharp Campus in Lewes was designed to provide infiltration of surface water runoff from the adjacent parking area. The garden was installed in 2010 with assistance from Delaware Sea Grant and DNREC.

**PHOTO CREDIT:** Delaware Sea Grant


**ILLUSTRATION:** Jeffery Mathison

- Make sure that the rain garden is installed at least 10–30 feet away from any building. Be sure to check building codes and local setback ordinances.
- Plant selection should include native species that tolerate both wet conditions and drought.

### *Maintenance:*

- Remove any trash or debris that has accumulated in the garden.
- Monitor vegetation for damage by insects and other pests.
- Control invasive species.
- Provide regular irrigation and weed control until plants are well established.
- Maintain proper trimming and pruning of the plants, and remove any weeds that appear in the rain garden.
- Add mulch to the rain garden to preserve soil moisture and reduce soil erosion.

### Resources:

Rain Gardens for the Bays Mid-Atlantic National Estuary Programs website
http://www.raingardensforthebays.org/

University of Delaware – Cooperative Extension Fact sheet – Rain Gardens (2009) – 8 pages
http://ag.udel.edu/udbg/sl/hydrology/Rain_Gardens.pdf

Center for Neighborhood Technology – Rain ReadyFor homeowners:
http://rainready.org/for-homeowners/your-yard

# Vegetated Swales

A vegetated swale, or bioswale, is a shallow channel with dense vegetation that conveys and slows down stormwater runoff and helps it infiltrate the ground. Usually located near a road or a parking lot, swales can be utilized to increase stormwater filtration.

## *Benefits:*

- Reduce stormwater runoff through infiltration
- Reduce the flow velocity of stormwater into the local drainage system
- Trap particulate pollutants from roadways, parking areas, and other paved surfaces
- Provide habitat benefits for native species, including birds and pollinating insects
- Increase urban tree canopy and enhance the aesthetic value for the community

## *Site and Design Considerations:*

- Swales can be placed and modified in many ways alongside roads and paved areas.
- Roads and parking lots should be engineered to have a gradient that allows water to flow into the swale. The swale is then constructed usually with a 6 percent slope to allow the water to flow along the swale and infiltrate as much as possible.
- Dense vegetation must be established and maintained to help retain water and promote infiltration. Plant selection should be based on maintenance, habitat, and pollution control objectives.
- Swales can be incorporated into a site drainage plan, and often work most efficiently in combination with other stormwater practices. For example, swales can provide effective pretreatment of stormwater before it flows to wetlands.

**WASHINGTON STREET BIOSWALE, SEAFORD** This vegetated swale in Seaford diverts runoff away from the existing storm sewer, reducing flows in the stormwater system and increasing flood protection in the adjacent roads and neighborhoods. The project received funding through Delaware Clean Water State Revolving Fund (CWSRF) Green Project Reserve loan program.

**PHOTO CREDIT:** Environmental Finance, DNREC

**ILLUSTRATION:** Jeffery Mathison

- Sites with very flat or very steep topography, or with poorly drained soils, may not be suitable for vegetated swales. Areas with high-volume or high-velocity runoff will be vulnerable to erosion and may require a more rigorous engineered design.
- Swales located next to a road or pedestrian area should be designed with a culvert or walkway to allow access over the swale. Pedestrians or vehicles can damage the swale by disturbing the vegetation and by compaction of the soils.

### *Maintenance:*

- Check frequently to remove any trash or debris accumulating in the swale.
- Monitor vegetation for decline or mortality.
- Monitor and control invasive species and unwanted vegetation.
- Periodically mow or trim vegetation as needed to protect plant health and maintain safety and visibility. Mowing should be timed to avoid impacts to habitat and wildlife; recommended timing for mowing is late winter or very early spring (February – March).
- Add mulch and soil to damaged or eroded areas and replace dead or declining trees or shrubs.

### Resources:

Delaware Department of Natural Resources and Environmental Control Fact sheet – How to maintain private roadside swales
http://www.dnrec.delaware.gov/swc/SiteCollectionDocuments/Soil/Sediment%20Stormwater/SwaleBrochure.pdf

# Tree Boxes and Tree Trenches

Tree boxes and tree trenches are types of bioretention systems. These systems collect and filter stormwater through layers of mulch, soil, and plant root systems where pollutants are retained and absorbed. Tree boxes and tree trenches are generally designed to manage stormwater runoff from frequent, small-magnitude storms, but may provide stormwater detention from large storms or prolonged periods of rainfall.

A tree box is a precast concrete structure installed below ground level. It can be installed where space is limited in urban settings, and functions as a compact bioretention system. The soil media added to a tree box is a mixture designed for rapid infiltration, such as 80 percent sand and 20 percent compost. Other media may be designed to filter out specific pollutants. Tree boxes are generally designed with a swing tree gate, which protects the vegetation and helps filter storm debris.

A tree trench is a system of trees that are connected by an underground infiltration structure. Typically planted as a line of street trees, a tree trench has an engineered system under the surface or sidewalk designed to manage stormwater. Stormwater runoff flows into the tree trench through porous pavement, surface grates, or curb drains. The runoff is stored in the soil medium, watering the trees and slowly infiltrating through the bottom. Tree trenches may be designed with stone underlying the soil, to store stormwater until it can infiltrate.

## *Benefits:*

- Remove pollutants and nutrients from stormwater runoff by filtering them through the soil and absorption by the tree
- Reduce stormwater runoff by collecting and retaining water that would otherwise be discharged into sewer systems or surface waters of streams or rivers
- Increase tree canopy and enhance the aesthetic value of the community

**LOCUST STREET TREE TRENCH, WILMINGTON** The Locust Street tree trench utilizes adjacent public open space to divert storm water flow, while capturing street flow in the trench itself.

**PHOTO CREDIT:** Delaware Center for Horticulture

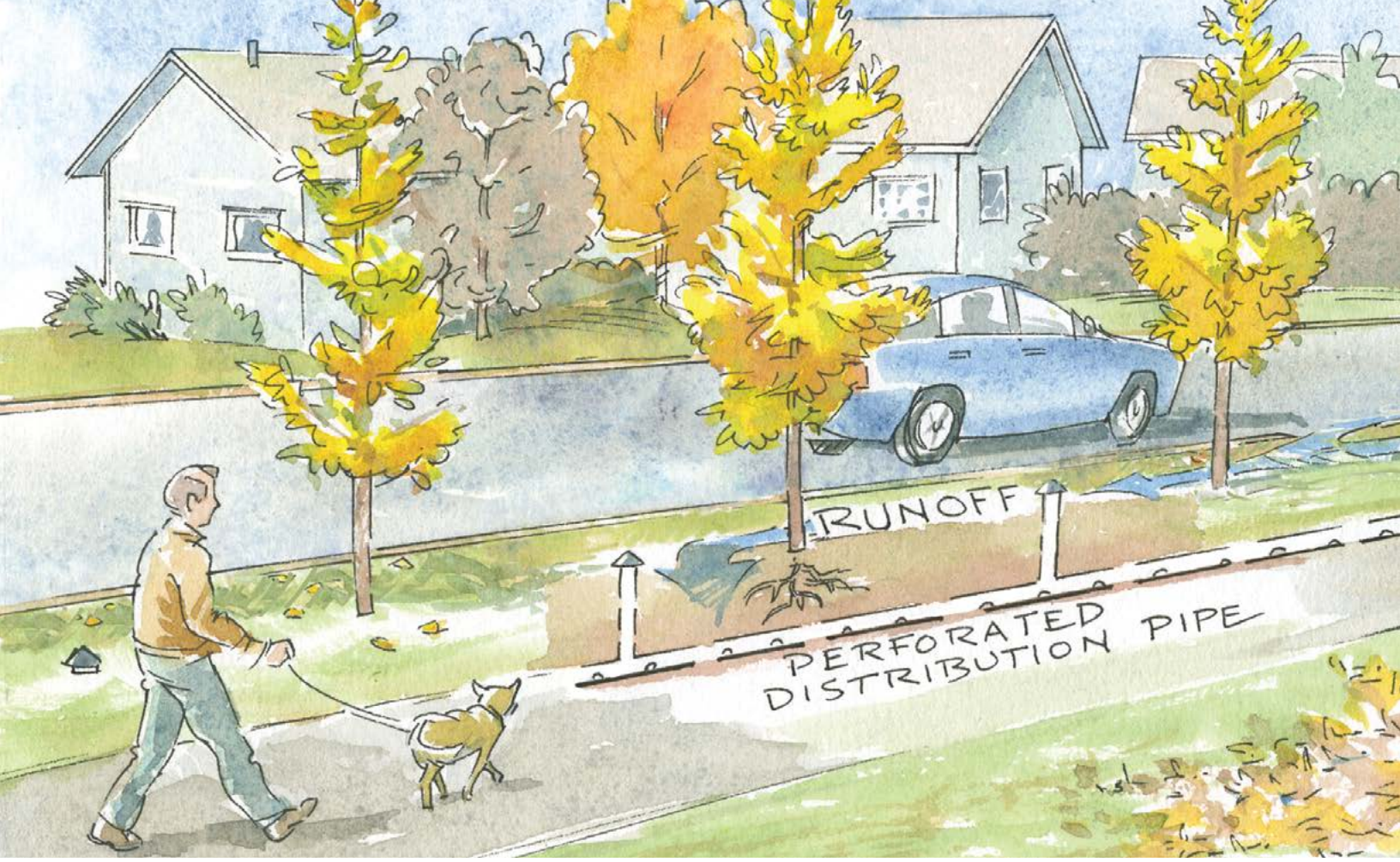


**ILLUSTRATION:** Jeffery Mathison

## *Site and Design Considerations:*

- Bioretention systems are not suitable in areas with high water table or within designated floodplains.
- Tree boxes and tree trenches should be located to avoid interference with underground utilities, particularly water and sewer lines.

## *Maintenance:*

- Provide regular irrigation and weed control until trees are well established.
- Prune trees once they are established to prevent safety hazards to pedestrians, overhead utility lines, or adjacent buildings.
- Remove any accumulated trash or debris.
- Monitor vegetation for damage by insects and other pests.
- Control invasive species.
- Remove trees that are in decline.

## Resources:

Delaware Department of Natural Resources and Environmental Control Post Construction Stormwater BMP Standards and Specifications
http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx

New Jersey Cooperative Extension Green Infrastructure Practices: Tree Boxes
https://njaes.rutgers.edu/pubs/fs1209/

City of Lancaster Green Infrastructure Plan Fact sheet – Tree Trench
http://www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_004822.pdf

# Rain Barrels, Cisterns, and Downspout Disconnections

Rain barrels and cisterns are "rainwater capture" systems that collect and store rainwater from a roof that would otherwise be lost to runoff and diverted to storm drains and streams. A rain barrel usually consists of a 55-gallon drum that can sit conveniently under any residential gutter downspout.

A cistern is a larger tank that holds up to several hundred gallons and uses a small pump to distribute the water throughout the landscape.

In communities where gutters and downspouts are connected to the public storm sewer, downspout disconnections can be an effective strategy for reducing sewer volumes and redirecting stormwater onto lawns, rain gardens, or other landscaping. This allows rainwater to filter into soils on-site, reducing stormwater volume and increasing infiltration to groundwater.

## *Benefits:*

- Reduce stormwater volume by capturing runoff from impervious roof surfaces
- Redirect runoff to infiltration systems instead of into storm sewers
- Decrease and delay peak runoff by storing rainwater for later use
- Reduce water pollution by reducing stormwater runoff, which can contain pollutants such as sediment, oil, grease, bacteria, and harmful nutrients
- Conserves water and lowers water bills by reducing the use of potable water for landscape irrigation and other uses such as washing windows or cars

## *Site and Design Considerations:*

- Rain barrels must be raised or placed above gradient of infiltration area to allow gravity flow of water for use in landscaping or other uses.
- For rain barrels with overflow valves and with downspout disconnections, make sure water drains away from structures and does not flow onto pavement, sidewalks, or neighboring properties.

**APPOQUINIMINK ENVIRONMENTAL CLASSROOM** The Appoquinimink School District's Environmental Classroom in Middletown installed rain barrels connected to a hydration system that waters the demonstration garden filled with vegetables and herbs. The project is one of the first in the nation focusing on conservation and cutting- edge green technologies and teaching methods.

**PHOTO CREDIT:** Eric Crossan, Gilbert Architects, Inc.

- Rain barrels are primarily designed for small storm events. In a half-inch storm a 1,000 square-foot roof can capture roughly 300 gallons of water, but most rain barrels hold only about 55 gallons. Rainwater capture systems can be designed for added capacity or provided with overflow valves or structures to divert water away from a full container.
- Downspout disconnections require an adequate receiving area, such as a garden, planter, or vegetated swale with good infiltration.

- A cistern can be designed for aboveground or underground locations. A pump is generally required, and emergency overflow systems may be needed in case of power outage.
- Rainwater collected from rooftops is not potable and should not be used for drinking, cooking, or bathing. It may be contaminated by residue or debris on the roof surface, or by the breakdown of roofing material.

### *Maintenance:*

- Rain barrels and cisterns must be emptied between storm events to prevent overflow. Installation of flow bypass valves may also be used to manage larger storm events.
- Rain barrels should be drained and disconnected from the downspout during winter months to prevent ice damage. It is recommended that you remove the existing downspout and elbow in late fall, store it intact during the winter months, and reinstall it in the spring.
- Fine mesh screen should be used to cover any openings in the rain barrel to prevent mosquitoes, shield from small animals, and trap debris. For added mosquito protection, add a tablespoon of vegetable oil to the water or use a mosquito dunk that kills mosquito eggs but is not toxic to plants and animals.

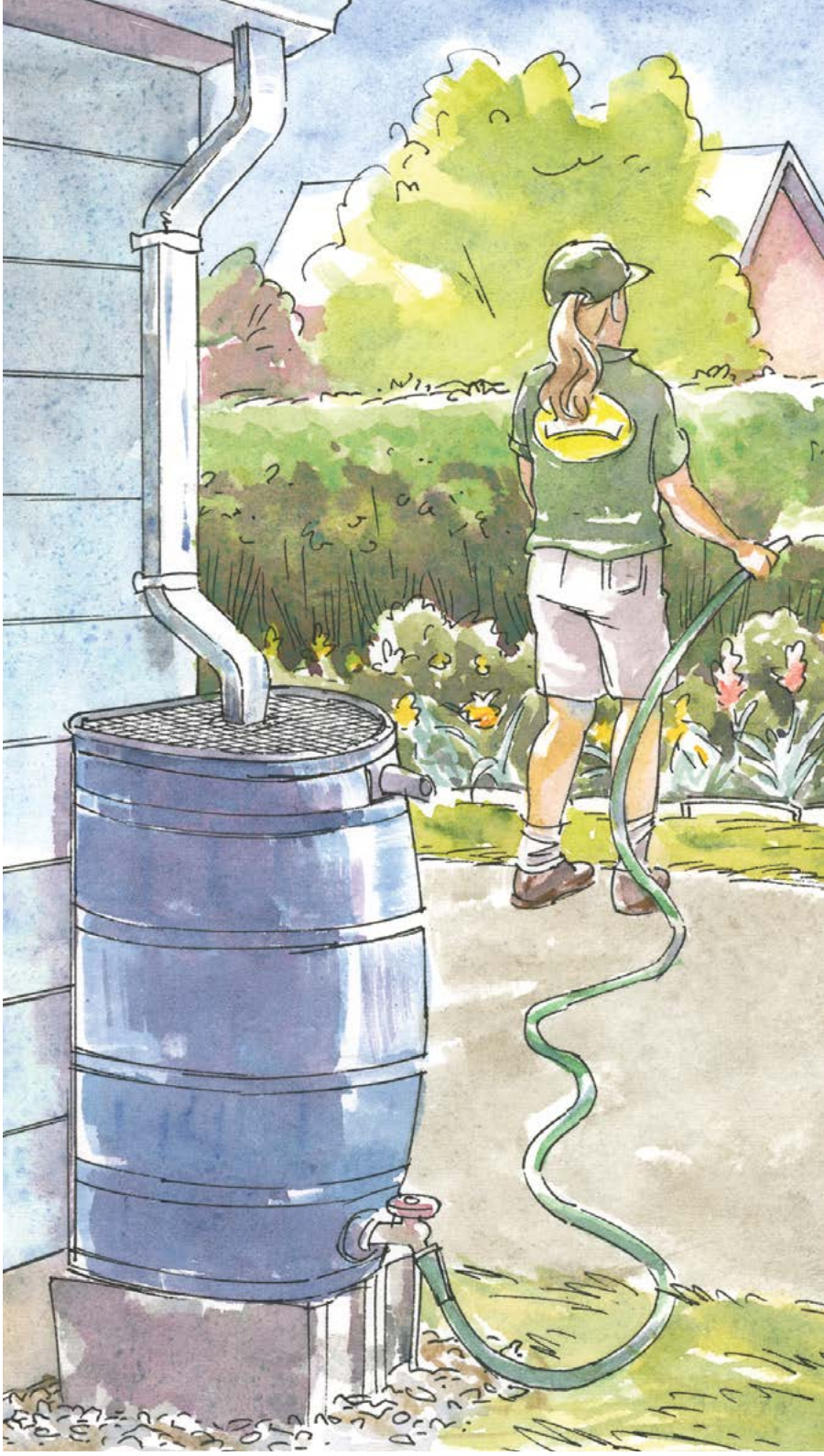

**ILLUSTRATION:** Jeffery Mathison

- Periodic inspection of valves, hoses, and screens is necessary to address clogs or leaks.

## Resources:

University of Delaware Cooperative Extension Fact Sheet: Rain Barrels
http://ag.udel.edu/udbg/sl/hydrology/Harvesting_Water.pdf

University of Delaware – Sea Grant: Report on Natural Stormwater Management
http://www.deseagrant.org/products/protecting-water-quality-smart-growth-strategies-and-natural-stormwater-management-sussex

# Green Roofs

A green roof is a roof partially or completely covered with living plants and soil or other growing medium. Green roofs help reduce temperatures on the roof surface and the surrounding air during hot summer months, and can absorb and filter rain water, thus reducing the amount of stormwater runoff.

**DOVER LIBRARY GREEN ROOF** The green roof was installed on the Dover Public Library building in 2012. It is planted with native plants that thrive without the use of irrigation. The rainwater from the building's roof is collected through the Green Roof and is used as Grey Water in the Family Restroom which is located under the Green Roof in the Children's Department.

**PHOTO CREDIT:** Dover Library and the City of Dover

"Extensive" green roofs use a thin layer of low-growing, herbaceous plants. This design has a shallow depth of soil or growing medium, requires little maintenance once established, and can be adapted to many roof types.

"Intensive" green roofs are designed with larger plants (trees and shrubs, 3–15 feet) with deeper soils. They have greater maintenance requirements. These are often designed as rooftop gardens with public access and walkways, and thus have greater engineering requirements to support their weight.

## *Benefits:*

- Reduce energy needed to cool and heat buildings by absorbing heat and acting as insulation
- Capture and manage stormwater, reducing the volume of runoff and improving water quality by filtering and binding pollutants
- Improve air quality by removing air pollutants
- Provide habitat for pollinating insects and birds

## *Site and Design Considerations:*

- New or existing buildings must be engineered properly to support the extra weight of the green roof, which varies depending on design:
    - Extensive green roofs generally weigh between 12 and 50 pounds per square foot, compared to 10-12 pounds per square foot for a conventional roof.
    - Intensive green roofs are considerably heavier, weighing 80-150 pounds per square foot.
    - Robust engineering design and materials are essential to prevent leaks into the structure.
- The slope of the roof is a factor for both design and function:
    - If the roof is inclined too much, the plants will not be able to absorb the water effectively.
    - Flat or gently sloping roofs are most accommodating, but roofs with as much as 40 percent slope can support vegetation with appropriate design and engineering.
- Plant selection must include perennial species that are heat-tolerant and drought-resistant due to the constant exposure to the heat, cold, and wind. For extensive green roofs, succulents generally perform well due to their drought tolerance, ability to take up large amounts of water, and low maintenance requirements.


**ILLUSTRATION:** Jeffery Mathison

- Green roofs can be designed in combination with conventional roofs. Even buildings that cannot accommodate an entire green roof may still able to fit a small one on a portion of the roof. This "hybrid" approach is important when designers are trying to reduce a building's total area of impermeable surface. Although the roof will not be entirely green, it will still be able to reduce energy uses and control a fair amount of stormwater.

## *Maintenance:*

- Plants require regular irrigation and weed control until they are established (about two years).
- Extensive green roofs are designed to be self-sustaining, once established, with annual maintenance checks and minimal fertilizer applications.
- Intensive green roofs require regular landscape maintenance, including weeding, pruning, and watering. The level of care will depend on the design and species selection.
- Vegetation should be monitored to remove and replace dead or diseased plants.
- Invasive species should be controlled.

## Resources:

University of Delaware – Cooperative Extension:
Fact sheet on Green Roofs
http://ag.udel.edu/udbg/sl/hydrology/Green_Roofs.pdf

US EPA – green roof info
http://www.epa.gov/heatisland/mitigation/greenroofs.htm

Green Roofs for Healthy Cities: Green Roofs policy brochure
http://greenroofs.org/index.php/about/green-wall-benefits/2-uncategorised/328-policy-brochure-2014

# Urban Trees

Planting and maintaining trees in urban settings—from large cities to small towns—provides a wide range of economic, environmental, and social benefits, particularly due to air quality improvements. For example, adding trees in urban neighborhoods can lead to reductions in particulate matter concentrations and other pollutants.

**URBAN FOREST, WILMINGTON** Volunteer tree planting projects, like this one completed in October 2015 along Wilmington's Matson Run, help to manage storm water and mitigate minor flooding, provide for mature tree canopy in the future, increase species diversity, beautify the neighborhood, and engage the public in promoting green infrastructure solutions.

**PHOTO CREDIT:** Delaware Center for Horticulture

In urban settings, trees can reduce heat stress by lowering air temperatures and shading buildings and paved surfaces. During peak temperature periods, shaded surfaces may be up to 45°F cooler than unshaded surfaces, a difference that can help reduce air temperatures by 2–9°F. Even in suburban areas, landscapes with mature trees can be 4–6°F cooler than suburbs without trees. These climate regulation services can improve public health and reduce energy costs. In New Castle County, urban trees provide an estimated annual savings of more than $400,000 in residential building energy costs.

## *Benefits:*

- Reduce stormwater runoff and flooding by intercepting and storing rainwater
- Improve water quality by filtering surface runoff and improving infiltration
- Improve air quality by absorbing pollutants through the leaves of trees
- Shade buildings and pavement, reducing energy demand for cooling in summer
- Buffer buildings from wind, reducing energy demand for heating in winter
- Capture carbon dioxide from the atmosphere and store it in plant tissues and soil
- Reduce soil erosion by diminishing the volume and velocity of rainfall as it falls through the canopy, lessening the impact of raindrops on bare surfaces
- Increase aesthetic value and increase property values

## *Site and Design Considerations:*

- When selecting tree species, consider site and environmental factors, including:
    - Size of planting space
    - Overhead and underground utilities
    - Heat and drought stress
    - Road salt used in winter
    - Exposure to high volumes of wind
- Successful establishment, growth, and health of trees depend on soil volume. Larger trees provide greater benefit—more shade and rainwater absorption—but

**ILLUSTRATION:** Jeffery Mathison

need greater soil volume. For example, a tree with a canopy spread of 30 feet generally requires 1,000 cubic feet of uncompacted soil.

- Specific siting of urban trees can increase their benefits:
    - Trees planted on the south or southwest side of a building provides natural cooling and helps reduce energy use for cooling in summer.
    - Trees planted on a side where there is continuous wind can help buffer winter winds and reduce energy use for heating in the winter.

### *Maintenance:*

- Water newly planted trees to alleviate drought stress and monitor for diseases and/or insect damage.
- Use mulch to retain moisture.
- Have trees pruned by an International Society of Arboriculture (ISA) certified arborist.
- Once trees are established (3-5 years), pruning may be needed to remove any diseased, dead, or damaged branches.
- Control invasive species.

### Resources:

Delaware Center for Horticulture
http://urbanforest.dehort.org/download-full-report

US Environmental Protection Agency Stormwater to Street Trees: Engineering Urban Forests for Stormwater
http://water.epa.gov/polwaste/green/upload/stormwater2streettrees.pdf

Watershed Forestry Resource Guide
http://forestsforwatersheds.org/planting-and-maintaining-trees/


**ILLUSTRATION:** Jeffery Mathison

## Riparian Buffers

Riparian buffers are vegetated areas adjacent to waterways that help filter rainfall and runoff, absorb and retain high stream flows, and provide important wildlife habitat. Buffers link terrestrial uplands to stream, river, or wetland ecosystems. Buffers include a variety of planted, restored, or enhanced natural habitats, hosting different types of vegetation.

Protecting or expanding existing buffers is the best option for achieving green infrastructure benefits, but creating new buffers in areas where native vegetation has been removed or degraded can help improve habitat and water quality, and provide protection from flooding and erosion.

The width of buffers can vary greatly; a minimum buffer width of 100 feet is generally recommended to minimize impacts to water quality, but smaller buffers can still provide important water quality benefits in areas that are already developed (e.g. along a stream in an urban environment). Larger buffers are recommended for areas adjacent to certain habitats. For example, buffers of 450 feet or more in width are recommended for areas near coastal plain seasonal ponds and vernal pool wetlands, due to the habitat requirements of sensitive species.

## *Benefits:*

- Improve water quality by filtering pollutants, nutrients, and sediment from surface runoff by allowing the water to flow through the buffer zone and absorbing harmful substances
- Reduce damage from flooding by slowing the velocity of floodwaters and providing increased flood storage capacity
- Stabilize stream banks and reduce shoreline erosion
- Moderate water temperatures and oxygen to protect fish and other aquatic species
- Enhance wildlife habitat for terrestrial and aquatic species

## *Site and Design Considerations:*

- Vegetation in the buffer should consist of native species tolerant of soil type and environmental conditions of the site.
- Diverse plants in a buffer, including trees and shrubs, provide more effective pollution reduction and soil stabilization than a simple grass filter strip.
- Site conditions that may require larger buffer widths include:
    - Rare or sensitive habitat types, such as vernal pool wetlands
    - Steep slopes and/or highly erodible soils
    - Altered hydrology from development on adjacent uplands
- Buffers are beneficial in areas with dispersed surface flow (sheet flow) but may not be suitable for areas with concentrated flow from a pipe or channel, where runoff velocity is too high to allow filtering and absorption.

## *Maintenance:*

- Control weedy or invasive species that may affect native species in the buffer zone.
- Mowing, if needed, should be timed to avoid impacts to habitat and wildlife; recommended timing for mowing is late winter or very early spring (February – March).
- Monitor health and growth of vegetation, checking for insect pests and diseases. Control measures should consider potential environmental, water quality, and wildlife impacts.
- Monitor vegetation in flood-prone areas after storms and extreme high tides. Restoration or replanting may be needed to replace plants damaged by flooding or saltwater intrusion. Areas of the buffer that experience repeated damage may require a more robust engineered design to better withstand storms and high tides.

## Resources:

University of Delaware – Sea Grant: *Delaware NEMO Guide Chapter 3 – Maintaining Riparian Areas and Wetlands*
http://nemo.udel.edu/manual.aspx

Delaware Riverkeeper – Fact sheet: Riparian Buffers
http://www.delawareriverkeeper.org/resources/Factsheets/Riparian_Buffers.pdf

Delaware Department of Natural Resources and Environmental Control
Riparian Buffers brochure
http://www.dnrec.state.de.us/DNREC2000/Library/RIPARIANBUFFERS1.PDF

# Living Shorelines

A living shoreline provides shoreline stabilization and erosion control while also preserving or enhancing habitat and water quality. Living shorelines are designed with living plants (emergent and submerged aquatic vegetation) and structures made with natural materials (oyster shells, earthen materials, or plant fiber logs) to help protect the shoreline from storms and waves. Living shorelines may also incorporate oysters, mussels, or other shellfish that form stable reefs and help filter water as they feed.

**LEWES CANAL LIVING SHORELINE** The goal of the Lewes Canal living shoreline is to protect the property from further erosion due to boat wake and wave energy and prevent the eroding sediment from building up in the canal. The project structures, including coconut fiber coir logs, coconut mats, and oyster shell bags, were installed in April 2014 and planted in April 2015.

**PHOTO CREDIT:** Wetland Monitoring and Assessment Program, DNREC

## *Benefits:*

- Reduce erosion and allow sediment accumulation to support habitat
- Restore habitat that has been degraded by erosion
- Filter surface runoff from adjacent uplands, improving water quality
- Promote a higher abundance and diversity of plants and animal species
- Help shorelines keep pace with sea level rise by reducing wave energy and flooding

## *Site and Design Considerations:*

- Physical environment
    - Soil type, bank elevation and slope, erosion rates
    - Water depth, salinity, prevailing wind direction, tide cycle
- Existing structures
    - Hard shoreline stabilization structures such as bulkheads or breakwaters
    - Docks or boat ramps
- Vegetation
    - Presence of existing vegetation (type and structure) will influence project design and plant selection
    - Living shoreline projects should include native species that are suited to salinity and water depth
- Shoreline wave action
    - No wake/Low wake– "Low energy" shorelines where the wave action is minimal, such as streams and tidal creeks, can be good locations for living shorelines using plants, fiber logs, and shellfish
    - Medium wake–In tributaries and rivers with higher wave energy, a living shoreline may require a "hybrid" design using "oyster castles", log breakwaters, or other structures parallel to the shoreline to help reduce wave action
    - High wake–Shorelines with high wave energy, such as near deep water and greater boat traffic, may require additional structures to diminish wave energy, or may not be suitable for a living shoreline


**ILLUSTRATION:** Jeffery Mathison

## *Maintenance:*

- Perform installation and maintenance at low tide, when the plants and structures are exposed and accessible
- May need to backfill "cells" (area between coir logs) with sand and topsoil to enhance natural filling of sediment
- May need to adjust the cell height with additional coir logs if they sink or settle to keep elevation in the optimal plant growth range
- Weedy or invasive species should be controlled before and after installation
- If dry days occur after planting, water plants on the upland edge to keep them from wilting and dying
- Immediately remove and replace plants that die or are diseased so they don't affect the other vegetation
- Monitor the fiber logs and matting; because they are biodegradable, fiber logs and support posts may need to be replaced if they rot or break down before the shoreline is stabilized
- Install temporary fencing if needed to control waterfowl, because they are known to feed on freshly planted vegetation

## Resources:

Partnership for Delaware Estuary
http://delawareestuary.org/living-shorelines

Delaware Natural Resources and Environmental Control Education and Outreach web page
http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/Library_Education_Outreach.aspx

National Oceanic and Atmospheric Administration (NOAA) Living Shoreline Planning and Implementation
http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html

## Case Study: Green Infrastructure in the Urban Setting

# Richardson & Robbins Building – Dover (Kent County)

A slow drip irrigation line was installed at the bottom of the second rain barrel so that the captured rainwater can be used for landscape watering in the building's courtyard.

One of these flows leads into the rain garden to provide irrigation. The other flow connects to the sewer system and is opened in winter.

**PHOTOS:** Michael Skivers, Wesley College

The "R&R Building" is the state office building in downtown Dover that houses the Department of Natural Resources and Environmental Control (DNREC). The building was originally built as a cannery in the 1800s, and has been adapted over the years as a state office. Since the building is historic, it did not originally have any stormwater management controls, but DNREC has added practices to reduce the amount of runoff and pollution coming from the building and entering the St. Jones River watershed.

The R&R Building provides an example of how green infrastructure practices can be retrofitted to an existing building. These practices include downspout disconnections, rain barrels, planter boxes, and a rain garden. Because of the size of the building roof area and the small lot, the practices do not fully manage the site's runoff, but cumulatively these practices help to reduce the effects.

Rain barrels capture rainwater from roofs and allow for water reuse instead of that water entering the storm sewer. The rain barrels at the R&R Building that connect to the roof downspouts quickly fill up, so a second barrel is used to capture overflow from the first.

On the south side of the building, downspout disconnections were engineered to allow for a two-way flow controlled by a lever. One of these flows leads into the rain garden to provide irrigation. The other flow connects to the sewer system; this is opened in winter, when the rain garden cannot support infiltration due to freezing temperatures.

The rain garden consists of a wide variety of drought-resistant, native plants, but can also tolerate the roof runoff during rain storms. Installation required excavation and addition of prepared soils to ensure adequate infiltration. This reduces the amount of runoff entering directly into the storm sewer and into the St. Jones River by infiltrating the runoff and returning it to groundwater. The garden provides a receiving area for roof runoff, and also provides pollinator habitat and an aesthetic addition to the building landscape.

After excavation and addition of compost and mulch, the rain garden was planted in April 2012. The downspout disconnections on the side of the R&R Building provide runoff to the rain garden.

The rain garden is well established 3 years after planting. Native plants provide habitat for pollinator species.

**PHOTOS:** Sara Esposito, DNREC (top); Michael Skivers, Wesley College (bottom)

## Case Study: Green Infrastructure in the Coastal Setting

# Blackbird Creek National Estuarine Reserve (New Castle County)

Blackbird Creek is a tidal stream that flows through Blackbird Creek National Estuarine Reserve into Delaware Bay. As the tide rises and falls, and during storms, the shoreline is subject to erosion. The loss of sediment affects vegetation and begins cutting the shoreline inland. Erosion also contributes to water quality problems by adding sediment to the tidal waters. At Blackbird Creek Reserve, erosion is degrading the shoreline on either side of a boat ramp that provides water access for recreational canoe and kayak use.

To prevent further loss of sediment on this section of Blackbird Creek, living shorelines were installed in May 2015. This project utilized a technique for rebuilding a shoreline that begins with placement of coir logs made of coconut fibers. The logs of coconut husks act as a filter, trapping sediment that would otherwise wash downstream. Once the tide has reached the maximum peak, the sediment that has flowed over the logs is trapped within the shoreline, replenishing the sediment that has eroded.

Over time, the living shoreline will continue layering the sediment from the high tide onto the topsoil. The design of this living shoreline gives a jump start by filling in the zone of erosion with sand, then covering with topsoil. In this project, native grasses and shrubs were planted soon after the coir logs and sand were installed. Cordgrass was planted directly into the logs to help dissipate the wave energy and stabilize the shoreline once the coir logs biodegrade. Other plants were placed behind the coir logs where the backfill was added. The plants help trap sediment with each high tide, building the living shoreline habitat over time.

These photos show the two installations on either side of the kayak launch. Top: Existing vegetation was enhanced with additional planting. Bottom: Sand was added prior to planting.

**PHOTOS:** Mark Biddle, DNREC (top); Michael Skivers, Wesley College (bottom)

## Case Study: Green Infrastructure in a Rural Setting

# Cow Bridge Branch Riparian Buffer – Georgetown (Sussex County)

Located in the forest of the state-run Stockley Center near Georgetown is Cow Bridge Branch, one of the Inland Bays' most pristine tributaries in the Indian River watershed. This restoration project addressed erosion and runoff problems in a stream channel that flows through the Stockley Center property. To help protect water quality in Cow Bridge Branch, the Delaware Center for the Inland Bays completed a project in 2014 to enhance the stream channel along part of an unnamed, degraded tributary. The stream channel is an intermittent stream which flows during the winter and spring and during periods of heavy rainfall.

Natural buffers of vegetation along the shorelines of waterways are an important defense in protecting and improving water quality in the Inland Bays. To restore the channel, 5,000 native plants including trees, grasses, shrubs, and wildflowers, were planted to create a buffer along the channel banks to slow and filter runoff before it entered the stream. Approximately 900 feet of stream channel and two acres of riparian buffer were restored.

The Delaware Center for Inland Bays engaged the support of many volunteers and partners, including DNREC, Ducks Unlimited, Wesley College, USDA Natural Resources Conservation Service, Sussex County Conservation District, and Sussex Landscaping. Funding for the project came from DNREC's Community Water Quality Grant Program and the US Environmental Protection Agency.

**Top:** Sussex Central High School students collect data in the restoration area. **Bottom:** Prior to the start of the project, the area had been mowed during dry periods and was almost entirely comprised of turf grass which was ineffective at slowing down and filtering storm-water that entered the channel.

**PHOTOS:** Delaware Center for Inland Bays

# Green Infrastructure at the Landscape Scale

## Introduction

Green infrastructure functions at different scales. At the site scale, green infrastructure mimics the processes that occur in larger, natural systems. These processes include filtering surface runoff, slowing and storing storm- and floodwaters, providing wildlife habitat, and storing carbon. However, green infrastructure is not limited to engineered or human-built constructions. At the landscape scale, green infrastructure can be described as a "network of natural resource lands, particularly forestlands, wetlands, grasslands and other plant communities that perform valuable services which benefit people, wildlife and the environment."[8] Protecting and managing existing green infrastructure is the first and most important step to ensuring that natural habitat can provide a wide range of benefits.

The basic concept behind green infrastructure at the landscape scale is to link large ecologically significant natural areas with natural corridors that protect water quality, provide habitat for resident and migratory species, and increase the resilience of the landscape to storms and flooding. Green infrastructure at the landscape scale can also buffer homes, businesses, buildings, and roads from the impacts of extreme weather and long-term climate change.

The interconnected nature of green infrastructure at the landscape level allows these natural ecosystems to function at a higher level. When areas of natural habitat are fragmented, in small or isolated pieces, they may still provide some benefits as green infrastructure, but retaining connectivity can help to offset the functional losses caused by fragmentation.

## Benefits of Green Infrastructure at the Landscape Scale

Green infrastructure at the landscape scale provides a wide array of environmental, social, and economic benefits. It can help reduce the volume and velocity of stormwater flow and decrease the impact of flooding during storm events; prevent or reduce nutrient and sediment pollution from reaching waterways; protect groundwater quality and support groundwater recharge; support diverse plant and animal populations; and improve air quality. For example, saltwater marshes, which cover Delaware's coast from the upper margins of Delaware Bay south to the Inland Bays, have well developed root systems that hold marsh vegetation in place, filter pollutants, absorb and store water, and provide for coastal defense against strong wave action and storm surges.

Green infrastructure at the landscape scale also generates economic benefits through farming, forestry, fishing, nature-based tourism, and recreation and contributes to the health and quality of life for communities and people. In addition to economic and public health benefits, green infrastructure can help develop a strong sense of place and provide educational and research opportunities.

8 Burke, D. G., and J. E. Dunn (eds). 2010. *A Sustainable Chesapeake: Better Models for Conservation.* The Conservation Fund, Arlington, VA.

## Management of Green Infrastructure at the Landscape Scale

Ensuring high quality green infrastructure at the landscape scale requires some effort. Just as maintenance is necessary for site scale practices, management of natural landscapes supports their healthy function. The guiding principles of green infrastructure management at the landscape scale are:

- Protect existing habitat from development, degradation, or fragmentation.
- Enhance natural lands that have been degraded or damaged.
- Restore natural areas to improve their ecological function and connect existing natural habitat.
- Monitor natural lands to ensure that management needs are addressed.

Options for protecting natural lands from development or damage can include purchase of land or easement by a conservation entity (government or nongovernment), or land use restrictions such as local ordinances and zoning measures.

Enhancement of green infrastructure involves using conservation practices to maintain healthy soil; promote infiltration and protection of surface and ground water; avoid development in floodplains and other flood-prone areas; and provide buffers between natural habitat and built structures. Restoration and enhancement at the landscape scale includes on-the-ground actions that improve the function and resilience of those ecosystems. For example, controlling invasive species is an important maintenance task for green infrastructure at all scales. Physical changes, such as removal or redesign of water management structures, may also be needed to maintain ecosystem health.

Monitoring is an important component to managing green infrastructure, to help identify long-term trends or track changes in the landscape over time. This can include regular site inspections as well as scientific data collection and analysis.

## Green Infrastructure in Delaware

A sizeable portion of Delaware's land area is covered with natural habitat, including forests, wetlands and aquatic systems, shoreline, and floodplains. These natural lands represent valuable green infrastructure at the landscape scale. Much of this habitat is protected in state forests, parks, wildlife areas, and beaches:

- More than 75 percent of Delaware's shoreline and coastline along the Atlantic Ocean and Delaware Bay and River is in protected conservation ownership.
- DNREC protects and maintains more than 90,000 acres in state parks, wildlife areas, research reserves, and greenways.
- The Delaware Forest Service manages more than 19,000 acres of forest land.
- Approximately 26,000 acres of wetlands and upland habitat in Delaware are federally protected by the US Fish and Wildlife Service.

In addition to state-managed lands, nonprofit organizations, such as the Delaware Nature Society, Delaware Wild Lands, and The Nature Conservancy, are among the leading stakeholders in the

preservation of Delaware's natural landscapes. Natural lands in private ownership also contribute to green infrastructure at the landscape scale. Privately owned forests and wetlands managed in ways that protect their ecological function offer many of the environmental and economic benefits described above and are an important component of the state's green infrastructure.

## Forests

Forests include the forest floor (soil, organic matter, and small plants such as grasses and wildflowers), the understory or shrub layer (small trees or bushes), and the canopy (the leaves and branches of the trees that dominate the forest). Forests cover approximately 30 percent of Delaware's land area with a diverse variety of forest community types.

The Forest Service of Delaware manages three state forests: Blackbird Forest near Smyrna, Taber Forest near Harrington, and Redden Forest near Georgetown. Forest preserves are also owned and managed by not-for-profit organizations, such as the Flint Woods Preserve, managed by the Delaware Nature Society, and the Pemberton Forest Preserve, managed by The Nature Conservancy.

Delaware's forested lands have declined greatly since European settlement in the 17th century. Precolonial forests covered an estimated 1.1 million acres—roughly 90 percent of the state's land area. Today, approximately 371,000 acres of the state is in forest habitat. Although the state's total forest acreage has remained relatively stable in the past three decades, forest assessments indicate that the average forest tract size is declining and forest habitat is becoming more fragmented, largely as a result of residential and commercial development. The Delaware Forest Service estimates that only 20 percent of all forest parcels are 500 acres or larger. Protecting and managing the state's remaining forest resources is essential to green infrastructure at the landscape scale.

Piedmont Oak Forest (William A. McAvoy)

Successional Maritime Forest (William A. McAvoy)

Late successional forest (William A. McAvoy)

Forested wetland (William A. McAvoy)

## *Benefits*

As landscape scale green infrastructure, forests provide many benefits.

Forests support water supply and water quality by:

- Filtering surface runoff, thus preventing or reducing nutrient and sediment pollution from reaching waterways
- Slowing water flow, allowing greater opportunity for plants and microbes to take up nutrients
- Protecting groundwater quality and supporting groundwater recharge areas

Planting trees to enhance forest habitat

**PHOTO:** James White, Delaware Nature Society

Forests also provide flood and stormwater management benefits by:

- Reducing the impact of heavy rainfall through the multilayered leaf canopy
- Absorbing more water during storm events through root systems and forest soils

Other benefits of forest systems include:

- Storing carbon in leaves, branches, and roots, reducing the amount of carbon dioxide in the atmosphere
- Shading land and water surfaces, moderating air temperatures, and protecting aquatic habitats
- Providing habitat cover and corridors used by wildlife

### *Management*

Delaware's forest lands are managed for a variety of objectives including timber production, wildlife habitat enhancement, forest management demonstration, and recreational opportunities. Proper management of forests depends on the condition, age, and diversity of the forest ecosystem, and on the management objectives. These general management guidelines[9] are aimed at helping to maintain healthy forests and woodlands while considering changing climate conditions:

- Manage for a healthy density and structure of trees, with a diversity of species. Timber stand improvement, thinning, harvesting, and planting all provide opportunities to create diversity.
- Consider managing selected forests for old-growth characteristics — including dead standing trees or snags, large woody debris on forest floor, and light gaps in forest canopy — to preserve biodiversity and provide habitat for songbirds and wildlife species.
- Build connectivity by creating habitat corridors that allow wildlife to migrate more easily, which encourages greater diversity.
- Control invasive species, including invasive weeds, vines, and insects.
- Consider flooding, storm surges, and sea level rise when managing forests near the coast or along rivers. Plan for species with higher flooding and salt tolerance in flood-prone tidal and nontidal areas.
- For long-term management planning, consider species that will be resilient to changing climate conditions, including higher temperatures and longer growing seasons.
- Monitor forest condition in all seasons; healthy trees are better able to resist pests and survive extreme weather events.

## Wetlands

Wetlands are natural transition areas between aquatic and upland habitats that serve as green infrastructure at the landscape scale. Primarily low and marshy, wetlands may be saturated, submerged, or appear dry part of the year, with soils that support unique plant and animal life. Wetlands can be found in fresh or salt water, and vary widely in vegetation type, geographic location, and connectivity to other wetlands and other landforms.

A number of wetland types are found in Delaware, which include seasonal freshwater wetlands such as freshwater tidal marshes, swamp forests, floodplain hardwood swamps, wet meadows, and coastal plain ponds. Salt and brackish marsh types include salt marshes, scrub-shrub wetlands, Atlantic white cedar swamps, and bald cypress swamps.

Delaware has approximately 320,000 acres of wetlands, about one-third of which are tidal wetlands. Since European settlement, the state has lost about 54 percent of its historic wetlands. This significant loss of wetlands underscores the importance of protecting the remaining wetland habitats, and enhancing and restoring wetlands where possible.

9 US Department of Agriculture (2013). Helping Your Woodland Adapt to Climate Change. http://www.fs.fed.us/nrs/pubs/jrnl/2013/nrs_2013_saxby_001.pdf

The condition of wetland habitat has a direct effect on its benefit as green infrastructure. A recent assessment of Delaware's wetlands from 1992 to 2007 concluded that between 40 and 65 percent of the state's wetlands provided high or moderate levels of ecosystem functions. These functions or "ecosystem services" include flood retention, erosion control, and carbon storage. Enhancement of wetland habitat, as well as protection from further habitat losses, is important for maintaining and improving the functional performance of wetlands.

## *Benefits*

Wetlands protect and enhance water quality and water supply by:

- Recharging groundwater and replenishing local aquifers
- Filtering excess nutrients and contaminants from surface runoff

Wetlands provide flood and stormwater management benefits by:

- Absorbing floodwaters and buffering storm surges
- Dampening wave action and reducing erosion

Other benefits of wetlands:

- Capturing carbon dioxide from the atmosphere and storing it in plant tissues and soil
- Providing habitat for shorebirds, waterfowl, and other valuable wildlife and plant species

Freshwater wetland: Peatland fen (William A. McAvoy)

Riverine wetland (DNREC-WMAP)

Tidal wetland: Milford Neck Wildlife Area (DNREC)

Tidal marsh (DNREC-WMAP)

## *Management*

Protecting and conserving wetlands involves slowing the loss of wetland acreage and function, improving the health of remaining wetlands, and monitoring environmental conditions. Considering that 80 percent of Delaware wetlands are privately owned there is a significant opportunity and need for landowners to conserve wetlands on the property or enroll in preservation programs. The use of sound management practices and restoration techniques followed by regular monitoring serves to increase healthy wetlands across the state. Specific management actions should be guided by the type of wetland, physical conditions (such as soils, surface water, and groundwater), and land uses. General management guidelines[10] for wetlands focus largely on protection strategies:

- Prevent filling of wetlands by sand, gravel, solid wastes, or structures.
- Protect wetland water supply by controlling pumping of streams and groundwater.
- Protect wetland soils from dredging, removal of topsoil, or compaction from use of heavy equipment and vehicles.
- Maintain natural circulation of wetland waters by avoiding the use of dikes, dams, and ditches.
- Prevent degradation of wetland vegetation by controlling invasive plants or encroachment of nonnative species.

10 Delaware Department of Natural Resources and Environmental Control (2013). *Land Use Decision Making and Wetland Protection: A Guidebook for Public Participation.* http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Delaware%20Wetlands%20Public%20Participation%20Guidebook%20Final.pdf

## Shorelines and Floodplains

The term "shoreline" includes the ocean coastline, bay shorelines, and the tidal portion of rivers and creeks. It is made up of wetlands, upland and riparian lands, nearshore waters, and in some cases beaches and dunes. Floodplains are low-lying lands adjacent to rivers, streams, ponds, lakes, and oceans. Both shorelines and floodplains perform many ecological functions, such as improving water quality, supporting wildlife habitat, protecting uplands from erosion, and providing a buffer from the impacts of storms and flooding. Flooding, which occurs naturally in river and coastal areas, causes the deposit of sediments that contribute to a fertile environment for vegetation.

Floodplains provide storage and conveyance of water during high tides, storm surge, and heavy rainfall. Floodplains are also important as recharge areas for groundwater, and create a safety zone between people and the damaging waters of a flood. It is important to keep floodplains in their natural condition as much as possible, avoiding the addition of pavement or structures that would reduce the capacity to filter and store water. When flooding occurs, water bodies receive a greater volume of water than they can handle at one time. Flooding is a natural part of the water cycle and can even be beneficial, as discussed above. However, by building on floodplains and draining wetlands, the likelihood of flooding and the extent of damage done by floodwaters, such as erosion, loss of property, loss of frontage, loss of habitat, and loss of life, increase.

One of the best practices for protecting the green infrastructure functions of floodplains is the use of floodplain management standards. Floodplain standards are adopted by most municipal and county governments to ensure the safety of people, property, and infrastructure in flood-prone areas. Flood damage is significantly reduced when structures are located outside of floodplains or elevated above predicted flood levels. Enforcement of floodplain standards lowers the cost of flood insurance and reduces damages and expensive drainage solutions. Recommended floodplain standards[11] in Delaware include:

- Conducting or updating flood studies in designated floodplains.
- Requiring 12 or more inches of "freeboard"[12] to any structure in the floodplain.
- Prohibiting subdivision or new, non-water-dependent development in the floodplain.
- Using base flood elevation in all building permitting.

11 Delaware Department of Natural Resources and Environmental Control (2013). *Delaware Floodplain and Drainage Standards and Recommendations.* http://www.dnrec.delaware.gov/swc/Shoreline/Documents/Floodplain%20and%20Drainage%20Code%20WG/FDAC%20Report%20Rev%20032613.pdf

12 Freeboard means elevating the lowest floor, including basement and all equipment and machinery, a certain number of inches above the predicted flood elevations (known as "base flood elevation").

## Next Steps

This Primer offers an introduction to understanding what green infrastructure is and how it can be beneficial—at both the site scale and the landscape scale.

Consider how green infrastructure might fit into your site, project area, community, or region. Take the next step by asking some basic questions:

- What is the scale of my site/area of interest? Is site scale or landscape scale green infrastructure the right fit?
- What are the current uses on the property? On adjacent property? What existing structures or infrastructure should be considered?
- What are my long-term goals? Protect existing structures? Maintain access to recreational resources or waterway? Restore and enhance natural ecosystems that provide resiliency to climate change?
- What green infrastructure benefits are of greatest value for my site? Erosion control? Flood retention? Stormwater management? Habitat value?
- What are the costs to develop and maintain the green infrastructure practice?
- What permits or approvals do I need?
- Who can I contact for more information? Local planning agency? State resources agency? Technical guidance resources?

To further your understanding and learn how green infrastructure can be incorporated or enhanced in your area, the Resources section offers a range of information sources. This includes information on whom to contact for regulatory assistance, planning and technical assistance, permitting information, and funding resources. Also included is a list of selected documents that provide technical guidance for planning and site scale practices. Finally, several mapping resources are listed.

# Green Infrastructure Primer for Delaware: Resources

## Regulatory Assistance

### *Stormwater Requirements*

**DNREC Sediment and Stormwater Program**
*(302) 739-9921*

DNREC Sediment and Stormwater Program is responsible for all aspects of administration of the state sediment and stormwater management program under the Delaware Sediment and Stormwater Law and Regulations, issuance of National Pollutant Discharge Elimination System (NPDES) Construction General Permit, and plan review, construction inspection, and maintenance inspection of State and Federal projects.

The following agencies have delegation of Sediment and Stormwater Program elements consisting of plan review, construction inspection, and maintenance inspection for their geographic boundaries:

**Delaware Department of Transportation**
(302) 760-2251
800 Bay Road
P.O. Box 778
Dover, DE 19903
http://deldot.gov/information/business/drc/stormwater.shtml

#### NEW CASTLE COUNTY

**New Castle County Department of Land Use**
*(302) 395-5400*
87 Reads Way, Corporate Commons
New Castle DE 19720
http://www.nccde.org/174/Land-Use
**Delegated Area:** All unincorporated areas of New Castle County

**New Castle Conservation District**
*(302) 832-3100, Ext. 3*
2430 Old County Road
Newark DE 19702
http://newcastleconservationdistrict.org/
**Delegated Area:** All incorporated areas of New Castle County (except City of Newark, City of Wilmington, and Town of Middletown).

**City of Newark**
*(302) 366-7040 or (302) 366-7045*
Public Works & Water Resources Department
220 S. Main Street
Newark DE 19711
http://www.cityofnewarkde.us/index.aspx?NID=237
**Delegated Area:** City of Newark

**Town of Middletown**
*(302) 378-9120*
19 West Green Street
Middletown DE 19709
http://www.middletownde.org/
**Delegated Area:** Town of Middletown

**City of Wilmington**
*(302) 576-3060*
Department of Public Works
800 North French Street
Wilmington, DE 19801
http://www.ci.wilmington.de.us/government/publicworks
**Delegated Area:** City of Wilmington

### KENT COUNTY

**Kent Conservation District**
*(302) 741-2600 (Ext. 3)*
800 Bay Road, Suite 2
Dover, DE 19901
http://kentcd.org/
**Delegated Area:** Kent County

### SUSSEX COUNTY

**Sussex Conservation District**
*(302) 856-7219*
23818 Shortly Road
Georgetown DE 19947
http://www.sussexconservation.org/programs/sediment-and-stormwater
**Delegated Area:** Sussex County

## Permitting Information

### *Delaware Department of Natural Resources and Environmental Control*

**Regulatory Advisory Service**
*(302) 739-9909*
The Regulatory Advisory Service (RAS) provides an opportunity for developers or business owners seeking to relocate or expand within the state to consult with DNREC agencies about environmental permitting and design considerations. The RAS provides a one-stop shop for information about necessary permits and regulations but can also help individuals understand and mitigate potential future flood risk at a particular site.
http://www.dnrec.delaware.gov/SBA/Pages/RegulatoryAdvisoryService.aspx

**Wetlands and Subaqueous Lands Section**
*(302) 739-9939*
The Wetlands and Subaqueous Lands Section provides permitting services for activities in Delaware's wetlands, bays, rivers, streams, lakes, ponds, and other waterways that might require a permit pursuant to Delaware law. These activities include marina construction and operation, as well as the construction of docks and piers, shoreline stabilization projects, dredging, filling, bridge or culvert construction, utility crossings of streams, and myriad other projects that could affect Delaware's waters and wetlands.

Permits are required for activities in tidal wetlands as well as tidal and nontidal waters.
http://www.dnrec.delaware.gov/wr/Services/Pages/WetlandsAndSubaqueousLands.aspx

Authorization under the Statewide Activity Approval (SAA) for Shoreline Stabilization Projects is available for living shorelines in Delaware. For projects under 500 linear feet using native marsh vegetation, this expedited permitting process costs half the regular price and is issued sooner than standard permits. A federal permit is also required, meeting the requirements to be permitted using Army Corps Nationwide Permit No. 27 for "Aquatic Habitat Restoration."
http://de.gov/wetlandpermits

## Planning and Technical Assistance

### *Delaware Department of Natural Resources and Environmental Control*

**Flood Mitigation Program**

*(302) 739-9921*

DNREC's Flood Mitigation Program provides flood-related assistance to individuals and communities to reduce the state's vulnerability to flood damages. Specifically, the program helps communities comply with floodplain standards and flood insurance requirements. It also assists individuals and communities in obtaining funding for projects that reduce vulnerability to flooding. http://www.dnrec.delaware.gov/swc/drainage/pages/flooding.aspx

**Shoreline and Waterway Management Section**

*(302) 739-9921*

DNREC's Shoreline and Waterway Management Section regulates coastal construction and implements beach and dune management practices. Their mission is to protect and enhance the state's beaches for recreational use and to improve resilience to storm events and erosion. The section has a variety of resources and publications to assist communities and individuals in understanding and adapting to coastal hazards, including sea level rise. http://www.dnrec.delaware.gov/swc/Shoreline/Pages/Shoreline.aspx

**Private Lands Assistance Program**

*(302) 284-4795*

The DNREC Private Lands Assistance Program assists private landowners in improving and protecting their lands for wildlife. The program's biologists are dedicated to informing landowners about available programs, providing technical assistance for developing habitat projects, and securing financial assistance as incentives for participation. Landowners faced with inundation issues on their property who wish to choose a natural adaptation method are encouraged to consult with program scientists for ideas and funding. http://www.dnrec.delaware.gov/fw/dplap/Pages/default.aspx

**Delaware Coastal Programs**

*(302) 739-9283*

The DNREC Delaware Coastal Programs office provides technical assistance, guidance, data, training, and grants for a wide range of coastal issues, including planning and adapting to sea level rise. Technical assistance is available to communities, nongovernmental organizations, government agencies, and universities, and specific training for these audiences is announced periodically. Communities and agencies seeking to begin a planning process for sea level rise and coastal vulnerability or to develop specific adaptation solutions to existing flooding issues are encouraged to contact the program for assistance. www.dnrec.delaware.gov/coastal

**Wetland Monitoring and Assessment Program**

*(302) 739-9939*

The Wetland Monitoring and Assessment Program's (WMAP) goal is to assess the health of wetlands and the functions and ecosystem benefits that they provide. This information is used to inform the citizens of Delaware and to improve upon existing education, restoration, protection, and land use planning efforts. http://de.gov/delawarewetlands

**Species Conservation & Research Program**

*(302) 735-8658*

The SCRP is the state's most comprehensive, centralized source of information on rare plants, animals, and vegetation communities. This information is used by research scientists, conservation organizations, consulting firms and agencies to plan for the conservation of habitat for rare species and vegetation communities. http://www.dnrec.delaware.gov/fw/NHESP/services/Pages/EnvReviewRequests.aspx

### *Delaware Department of Agriculture*

**Delaware Forest Service**

*(302) 698-4500*

The Delaware Forest Service provides a wide range of services to help Delawareans manage and improve their forest resources. These services are divided into three categories: conservation, protection, and education. http://dda.delaware.gov/forestry/

### *University of Delaware*

**Delaware Sea Grant Marine Advisory Service**

*(302) 645-4235*

The Delaware Sea Grant Marine Advisory Service is a resource provided by the University of Delaware that advocates for the wise use, conservation, and development of marine resources. Information and planning assistance is available to address flooding and sea level rise, as well as other coastal issues, including water quality, resource management, and sustainable communities. The Marine Advisory Service transfers science-based information and expertise of the university's researchers to local citizens, resource managers, and business owners in a variety of ways, such as workshops, publications, trainings, and consultations. http://www.deseagrant.org/outreach

**Delaware Cooperative Extension**

*(302) 831-2501*

Cooperative Extension supports Delaware's agricultural sector through education, research, and outreach. Resources are available for agriculture and natural resources, lawn and garden, 4-H youth development, and family and consumer sciences. http://extension.udel.edu/

## Funding Resources

### *Financing Approaches*

Green infrastructure projects can be funded through a variety of financing approaches, including:

- Taxes and general funds
- Fees
- Stormwater utilities
- Credits and Incentive programs
- Bonds
- Grants
- Loans
- Public-private partnerships

These funding options are described, with examples, in a recent EPA report:

US Environmental Protection Agency. 2014. Getting to Green: Paying for Green Infrastructure Financing Options and Resources for Local Decision-Makers. http://www2.epa.gov/sites/production/files/2015-02/documents/gi_financing_options_12-2014_4.pdf

### *Delaware Funding Resources – Grants and Loans*

#### DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL (DNREC)

**Green Project Reserve**

*(302) 739-9941 – contact Terry Deputy*

The DNREC Environmental Finance offers below-market rate loans for state, county, and municipal agencies to assist with the planning and construction of green infrastructure, water efficiency, and environmentally innovative projects. A wide range of adaptation strategies could be funded through this program. To be eligible, projects must first be placed on the Project

Priority List; development of the list begins in January each year. http://www.dnrec.delaware.gov/fab/Pages/Green-Project-Reserve.aspx.

**Surface Water Matching Planning Grants**

*(302) 739-9921 – contact Jim Sullivan*

The DNREC Environmental Finance provides competitive grants of up to $50,000 annually for planning and engineering design of projects that seek to improve surface water quality within the state. Adaptation projects that have a water quality component, including stormwater retrofits, wetland restoration, drainage plans, and green infrastructure, would qualify for funding through this program. Funding is available to state, county, and municipal agencies. A 1:1 cash match is required for the grant. http://www.dnrec.delaware.gov/fab/Pages/Surface-Water-Matching-Planning-Grants.aspx.

**Wastewater Matching Planning Grants**

*(302) 739-9941 – contact Greg Pope*

The DNREC Environmental Finance provides competitive grants of up to $50,000 annually to municipal and county wastewater utilities for wastewater planning projects. Projects that propose to modify facilities to adapt to sea level rise would qualify for funding under this program. A 1:1 cash match is required for the grant. http://www.dnrec.delaware.gov/fab/Pages/Wastewater-Matching-Planning-Grants.aspx.

## DELAWARE DEPARTMENT OF AGRICULTURE (DDA)

http://dda.delaware.gov/forestry/conser.shtml

**Urban and Community Forestry**

*(302) 698-4500*

The Delaware Forest Service administers an Urban and Community Forestry grant program that provides funding to cities, towns, communities, developers, and local governments. Grant funding can be utilized for urban tree planting and/or tree management. This program is offered annually and generally allocates approximately $40,000-$80,000 in funding.

**Forest Land Enhancement Program**

*(302) 698-4500*

The Delaware Forest Service's Stewardship Program offers forest landowners cost share funding to help with reforestation, afforestation, agroforestry implementation, water quality protection and other special practices related to forestry. Property owners must have less than 1,000 acres and at least 5 acres of non-industrial forest land.

## DELAWARE EMERGENCY MANAGEMENT AGENCY (DEMA)

**Pre-Disaster Mitigation Program**

*(302) 659-2213*

The Federal Emergency Management Agency offers competitive grants for projects seeking to reduce risk to people and structures from hazard events, including storms and inundation. These grants are available to states, territories, tribal governments, local communities, and universities. The application period is June through December each year. In most cases, applicants for funding must provide matching funds no less than 25 percent of the total project cost. http://www.fema.gov/pre-disaster-mitigation-grant-program.

## SUSSEX CONSERVATION DISTRICT

*(302) 856-3990*

Sussex Conservation District, in cooperation with DNREC – Division of Water Resources and Division of Watershed Stewardship are providing cost-share assistance for vegetative shoreline stabilization. http://www.sussexconservation.org/programs/cost-share-program

## Technical Guidance References


US Environmental Protection Agency. 2014. **Coastal Stormwater Management through Green Infrastructure: A Handbook for Municipalities.** http://water.epa.gov/type/oceb/nep/upload/MassBays_Handbook_combined_508-opt.pdf?utm_source=listserv&utm_medium=email&utm_campaign=product

US Environmental Protection Agency. 2014. **Enhancing Sustainable Communities with Green Infrastructure: A Guide to Help Communities Better Manage Stormwater While Achieving Other Environmental, Public Health, Social, and Economic Benefits.** http://www2.epa.gov/smart-growth/enhancing-sustainable-communities-green-infrastructure

US Environmental Protection Agency. 2015. **Green Infrastructure Opportunities that Arise During Municipal Operations.** http://epa.gov/owow/ocpd/green_infrastructure_roadshow.pdf

Delaware Department of Natural Resources and Environmental Control. 2013. **Post-Construction Stormwater BMP Standards and Specifications.** http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx

Delaware Sea Grant and US Environmental Protection Agency. 2009. **Protecting Water Quality with Smart Growth Strategies and Natural Stormwater Management in Sussex County, Delaware.** http://www.deseagrant.org/products/protecting-water-quality-smart-growth-strategies-and-natural-stormwater-management-sussex

Delaware Sea Grant. 2014. **Natural Hazard and Climate Change Adaptation Tool Kit for Delaware Communities.** http://www.deseagrant.org/products/natural-hazard-and-climate-change-adaptation-tool-kit-delaware-communities

National Oceanic and Atmospheric Administration. 2015. **Economics of Green Infrastructure: A Guide to Assessing Green Infrastructure Costs and Benefits for Flood Reduction.** http://coast.noaa.gov/digitalcoast/publications/gi-cost-benefit

Clean Water America Alliance. 2011. **Barriers and Gateways to Green Infrastructure.** http://www.uswateralliance.org/pdfs/gireport.pdf

Center for Neighborhood Technology. **Rain Ready: Ten Actions for Cities and Towns.** http://rainready.org/for-cities-and-towns

Center for Watershed Protection. **On-line library of stormwater and watershed resources.** http://www.cwp.org/online-watershed-library/cat_view/63-research

University of Massachusetts Extension. 2007. **Restoring Old-Growth Characteristics** http://harvardforest.fas.harvard.edu/sites/harvardforest.fas.harvard.edu/files/publications/pdfs/Damato_umassextension_2007.pdf

University of Delaware. **Flora of Delaware.** online database: http://www.wra.udel.edu/de-flora/Introduction

## Resources for Site Scale Practices

| | |
|---|---|
| Bioretention/ rain gardens | University of Delaware – Cooperative Extension<br>**Fact sheet – Rain Gardens** (2009) – 8 pages<br>http://ag.udel.edu/udbg/sl/hydrology/Rain_Gardens.pdf<br><br>**Rain Ready: Techniques for Capturing Rainwater**<br>http://rainready.org/sites/default/files/factsheets/Factsheet-RainReady-CapturingRainwater_0.pdf<br><br>Connecticut NEMO Program<br>**Rain Gardens: A Design Guide for Homeowners**<br>http://nemo.uconn.edu/tools/publications.htm |
| Tree trenches and tree boxes | Delaware Department of Natural Resources and Environmental Control<br>**Post-Construction Stormwater BMP Standards and Specifications**<br>http://www.dnrec.delaware.gov/swc/pages/sedimentstormwater.aspx<br><br>New Jersey Cooperative Extension<br>**Green Infrastructure Practices: Tree Boxes**<br>https://njaes.rutgers.edu/pubs/fs1209/<br><br>City of Lancaster Green Infrastructure Plan<br>**Fact sheet – Tree Trench**<br>http://www.dcnr.state.pa.us/cs/groups/public/documents/document/dcnr_004822.pdf |
| Vegetated swales | Delaware Department of Natural Resources and Environmental Control<br>**Fact sheet – How to maintain private roadside swales**<br>http://www.dnrec.delaware.gov/swc/SiteCollectionDocuments/Soil/Sediment%20Stormwater/SwaleBrochure.pdf |
| Green roofs | University of Delaware – Cooperative Extension<br>**Fact sheet on Green Roofs**<br>http://ag.udel.edu/udbg/sl/hydrology/Green_Roofs.pdf<br><br>US EPA – **green roof info**<br>http://www.epa.gov/heatisland/mitigation/greenroofs.htm<br><br>**Green Roofs for Healthy Cities: Green Roofs policy brochure**<br>http://greenroofs.org/index.php/about/green-wall-benefits/2-uncategorised/328-policy-brochure-2014 |

| | |
|---|---|
| Rain barrels, cisterns, and downspout disconnections | University of Delaware Cooperative Extension<br>**Fact Sheet: Rain Barrels**<br>http://ag.udel.edu/udbg/sl/hydrology/Harvesting_Water.pdf |
| | University of Delaware – Sea Grant<br>**Report on Natural Stormwater Management**<br>http://www.deseagrant.org/products/protecting-water-quality-smart-growth-strategies-and-natural-stormwater-management-sussex |
| Riparian buffers | University of Delaware – Sea Grant<br>**Delaware NEMO Guide: Chapter 3 – Maintaining Riparian Areas and Wetlands**<br>http://nemo.udel.edu/manual.aspx |
| | Delaware Riverkeeper<br>**Fact sheet: Riparian Buffers**<br>http://www.delawareriverkeeper.org/resources/Factsheets/Riparian_Buffers.pdf |
| Living shorelines | Delaware Department of Natural Resources and Environmental Control (DNREC)<br>**Living Shorelines of Delaware Tour** (on-line story map)<br>http://dnrec.maps.arcgis.com/apps/MapJournal/?appid=371a244682084370a78d0a54c5edb27a |
| | Partnership for Delaware Estuary<br>**Living Shorelines in the Delaware Estuary: Best Practices and Lessons Learned** (2013)<br>https://delawareestuary.s3.amazonaws.com/pdf/Living%20Shorelines/living_shorelines_best_practices.pdf |
| | National Oceanic and Atmospheric Administration (NOAA)<br>**Living Shoreline Planning and Implementation**<br>http://www.habitat.noaa.gov/restoration/techniques/lsimplementation.html |
| | Chesapeake Bay Foundation<br>**Living Shorelines for the Chesapeake Bay Watershed**<br>http://www.cbf.org/Document.Doc?id=60 |

## Resources for Watershed/Landscape Scale Practices

Floodplains

The Nature Conservancy
**A Flood of Benefits: Using Green Infrastructure to Reduce Flood Risks**
https://www.conservationgateway.org/ConservationPractices/Freshwater/HabitatProtectionandRestoration/Documents/A%20Flood%20of%20Benefits%20-%20J.Opperman%20-%20May%202014.pdf

Delaware Department of Natural Resources and Environmental Control
**Delaware Floodplain and Drainage Standards and Recommendations**
http://www.dnrec.delaware.gov/swc/Shoreline/Documents/Floodplain%20and%20Drainage%20Code%20WG/FDAC%20Report%20Rev%20032613.pdf

Wetlands

Delaware Department of Natural Resources and Environmental Control
**Wetland Restoration in Delaware: A Landowner's Guide**
Part 1: Restoration Stories
http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/restoration%20guidebook%20part%201%20all%2024%20pages.pdf

Part 2: Resources for Restoration
http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/restoration%20guidebook%20part%202%20all%2028%20pages.pdf

Delaware Natural Resources and Environmental Control
**Wetland Monitoring and Assessment Program** - Education and Outreach web page
http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Pages/Library_Education_Outreach.aspx

Forests

Delaware Forest Service
**Delaware Urban and Community Forestry**
http://delawaretrees.com/
tree canopy maps: http://delawaretrees.com/publications-2/tree-canopy-maps/
urban tree grant program: http://delawaretrees.com/programs-and-services/urban-grant-program/

Delaware Center for Horticulture
**Community Tree Program**
http://www.thedch.org/what-we-do/community-trees

US Environmental Protection Agency
**Stormwater to Street Trees: Engineering Urban Forests for Stormwater**
http://water.epa.gov/polwaste/green/upload/stormwater2streettrees.pdf

## Mapping Resources

### *Delaware Department of Natural Resources and Environmental Control*

**Delaware Environmental Navigator**

http://www.nav.dnrec.delaware.gov/DEN3/

**Delaware Sea Level Rise Inundation Map**

www.de.gov/slrmap

### *National Oceanic and Atmospheric Administration (NOAA)*

**NOAA Digital Coast - Coastal Flood Exposure Mapper**

http://coast.noaa.gov/digitalcoast/tools/flood-exposure

Delaware Division of ENERGY & CLIMATE

DELAWARE DEPARTMENT OF NATURAL RESOURCES AND ENVIRONMENTAL CONTROL

# Green Infrastructure Primer

A Delaware Guide to Using Natural Systems in Urban, Rural, and Coastal Settings