USDA
United States Department of Agriculture

Changing Landscapes

Land use planning curriculum for natural resource professionals

P rinciples, people, and policies
L and planning and pressures
A pproaches
N atural resource planning tools

A3: Managing Stormwater with Green Infrastructure

Green infrastructure, such as this rain garden in Austria, can help manage stormwater. (Photo: http://www.epa.gov)

Overview

This factsheet discusses stormwater and its associated environmental and social costs. It highlights the use of nonstructural techniques, such as Low Impact Development, and structural techniques, such as retention basins. Both systems incorporate using nature's green infrastructure as major stormwater management tools. This factsheet also discusses best management practices (BMPs) for stormwater management and municipal stormwater ordinances.

The Importance of Green Infrastructure in Stormwater Management

In the past, most stormwater management relied on using the grey infrastructure of pipes, channels, and detention basins to move stormwater quickly offsite and into streams and other waterways. Detention basins are designed to collect and detain stormwater, releasing it quickly at predetermined rates. These impoundments drain completely soon after a storm with limited nutrient and pollutant removal. Detention basins and pipes allow most stormwater to enter streams quickly with little, if any, retention, infiltration, or evaporation of water onsite.

Today, retention basins, infiltration practices, and other structural systems are being coupled with new planning approaches to greatly reduce stormwater volumes through onsite water infiltration and evaporation. Unlike detention basins, retention basins store and retain stormwater so infiltration can occur. They use vegetation and porous soils to increase infiltration and evaporation of water onsite. In both structural and nonstructural stormwater management systems, the green infrastructure of trees and open space play an important role in retaining and infiltrating water. Trees and forests offer a more cost-effective alternative for managing stormwater onsite, compared to the costs of building and maintaining pipes and detention basins to move water offsite and into adjacent waterways.

> The green infrastructure of trees and open space plays an important role in retaining and infiltrating water.

Forest Service
Northeastern Area State and Private Forestry
11 Campus Blvd., Suite 200
Newtown Square, PA 19073
October 2014
http://www.na.fs.fed.us

NA–TP–01–14 A3
USDA is an equal opportunity provider and employer.

What Is Stormwater Management?

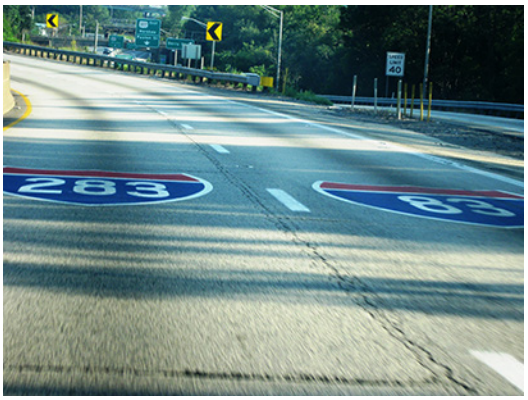
Stormwater management is the systematic control and reuse of runoff from impervious surfaces to prevent flooding, property damage, and stream degradation. Proper stormwater management activities can contribute to much-needed stream base flows and groundwater recharge in highly urbanized areas.

Conversion of Forest to Turf

In a 1980 study of the conversion from forest and leaf litter to managed turf in a North Carolina watershed conducted by Barrett Kays, the mean soil infiltration rate went from 12.4 in/hr to 4.4 in/hr. Each year 232,000 acres of new turf cover are created in the Chesapeake Bay watershed.

Stormwater Problems and Costs

Converting and developing forests and other landscapes through tree removal, grading, soil compaction, and construction impacts stream health and structure. Development affects both the quantity (volume) and quality (pollutant levels and temperature) of water entering streams and rivers by removing vegetation and the tree canopy with its buffering capabilities. Development also creates impervious surfaces. For example, from 1990 to 2000, impervious cover in the Chesapeake Bay watershed increased by 41 percent while the population grew only 8 percent.



Impervious surfaces such as asphalt prevent water from entering the soil.

Impervious surfaces are areas such as asphalt and roofs that either prevent or retard the entry of water into the soil. As impervious surfaces increase, stormwater runoff travels to streams with greater volume and speed, collecting sediment, nutrients, toxic chemicals, garbage, and other pollutants. Greater stormwater volume increases both "point" pollution from one single, discernible location and "nonpoint" pollution from dispersed, multiple sources of pollution.

As impervious surfaces increase, stormwater runoff travels to streams with greater volume and speed.

Increases in both point and nonpoint pollution sources contribute to a waterway exceeding its required Total Daily Maximum Load (TDML)—the total amount of pollution a stream or other body of water can receive without exceeding Federal water quality standards. Stream water temperatures also rise as rainwater that has traveled across parking lots and other surfaces flows into the waterway. As stream temperatures increase, nutrients such as phosphorous are released from sediment in greater quantities. These nutrient loads cause algae blooms and reduce oxygen levels that are critical for aquatic organisms.

Impervious surfaces not only increase the volume and temperature of stormwater, they also shorten the amount of time it takes the water to enter a stream, which leads to increased peak flows. A peak flow or discharge is defined as the maximum rate of stormwater runoff that occurs during a specific storm event. Increased peak flows from impervious surfaces cause water to move quickly to and through a stream, which can lead to flooding, streambank erosion, stream widening, sediment deposition, loss of fish habitat, and decline in water quality. In Pennsylvania, for example, there are over 4,127 miles of streams that are impaired and damaged by stormwater runoff.

It's also important to consider the costs of building and maintaining stormwater piping and detention systems. The city of Philadelphia estimates that the annual cost of collecting stormwater and performing maintenance for stormwater services exceeds $100 million. Municipalities large and small face increased permitting requirements and financial penalties from both Federal and State governments. These requirements are in place to reduce peak flows and TDMLs as well as repair inadequate stormwater and sewer systems.

Many municipalities have been classified by State and Federal Departments of Environmental Protection as MS4s or Municipal Separate Storm Sewer Systems communities. Under the U.S. Environmental Protection Agency's National Pollution Discharge Elimination Program (NPDEP), these communities are required to obtain an NPDEP Phase I or II Permit based on population, the size of their MS4 systems, industrial uses, and number and size of new construction sites. The objective of these permits is to use municipal stormwater management plans and programs to reduce the discharge of untreated, polluted stormwater into streams and other waterways.

Forests and Trees Reduce Stormwater

Whether they are preserved during development or newly planted afterwards, trees, forests, and other green infrastructure reduce the volume and speed of stormwater entering waterways. They also remove pollutants that would otherwise wind up in our waterways. Planting and preserving landscapes to reduce peak flows and meet TMDLs is a basic concept behind stormwater management today. Forests and trees—even trees around sidewalks and parking lots—filter, slow, and reduce the flow of stormwater because their root systems and leafy canopy capture rainfall. This allows water to be removed from a landscape through both transpiration and evaporation. Transpiration is the movement of water in a plant from the roots up and out through the leaves into the air. Evaporation removes some of the water held on leaf, branch, and stem surfaces. Together, transpiration and evaporation are called evapotranspiration.

> Planting and preserving landscapes to reduce peak stormwater flows is a basic concept behind stormwater management today.

The ability of trees and other green infrastructure to intercept and remove stormwater has been well studied. A single mature oak can transpire over 40,000 gallons of water annually. Average interception and evaporation of annual rainfall by a forest canopy ranges from 10 to 40 percent depending on the type of trees and leaves, time of year, and amount of rain in a storm event.

In northern deciduous forests, about 60 percent of annual rainfall is intercepted, or removed, through evapotranspiration. If the forest is removed, evapotranspiration drops to about 35 percent. In urban and suburban landscapes, a single deciduous tree can intercept from 500 to 760 gallons of rainwater per year; a mature evergreen can intercept more than 4,000 gallons annually. Even young, small trees help. In a recent Forest Service study, a single small tree, only 9 years old, was able to intercept 58 gallons of stormwater from a ½-inch rain event, or 67 percent of the rain that fell on its canopy.

In urban and suburban landscapes, a single deciduous tree can intercept between 500 and 760 gallons of rainwater each year.

By reducing and slowing the fall of rainwater to the forest floor, tree canopies increase rainwater infiltration. Infiltration is the percolation of water into the soil. Infiltration helps remove pollutants, cool runoff, and lower the volume and speed of stormwater that flows into stream channels. If the forest floor is properly protected from soil compaction, vegetative removal, and other injury, it acts like an enormous sponge, allowing large amounts of rainwater to infiltrate before gradually releasing water to natural subsurface channels and recharging ground water.

"Forests are the most beneficial land use for protecting water quality, due to their ability to capture, filter, and retain water, as well as remove air pollution from the air. Forests are also essential to the provision of clean drinking water to over 10 million residents of the watershed and provide valuable ecological services and economic benefits including carbon sequestration, flood control, wildlife habitat, and forest products."

—Chesapeake Bay Executive Council in 2006

Increasing Canopy Coverage for Stormwater Management

Canopy coverage is the percentage of ground surface covered by tree canopy. Increasing canopy coverage is a green infrastructure goal in stormwater management. In new developments, preserve onsite trees and woodlots, and properly select and plant street, parking lot, and other trees. In older, existing communities, increase tree canopy cover along streets, in yards and vacant lots, and in parking lots. Where growing space permits, plant large canopy trees that provide the most benefit—eight times that of small maturing trees. A U.S. Forest Service study in Oakland, CA, is monitoring 1,800 newly planted trees for 40 years to determine if their canopy can reduce the volume of contaminated stormwater entering the San Francisco Bay by 9 million gallons each year. New York City's street trees intercept rain, reducing stormwater runoff by **890.6 million gallons annually**, with an estimated value of $35.6 million. Citywide, the average tree intercepts 1,432 gallons of stormwater each year.

Stormwater Management Guidelines

Manage stormwater to protect water quality and treat it as an important resource. Understand, preserve, and use natural features and processes to address stormwater during the planning phase of site development. Manage stormwater as close to the source as possible. Protect and restore the infiltration capacity of surface areas. Disconnect, decentralize, and distribute stormwater discharges to reduce and slow runoff.

New BMPs for Stormwater Management

Until recently, stormwater management strategies focused on using the grey infrastructure of pipes and detention basins to move large volumes of water quickly offsite. These types of strategies do little to reduce water volume, speed, or pollution levels. Today, many States and the Federal government advocate for and require the use of nonstructural and structural stormwater best management practices, or BMPs. These BMPs promote combining nonstructural practices, such as clustered development density and riparian area preservation, with structural elements, such as retention areas, bioswales, rain gardens, and infiltration basins, to manage stormwater onsite. They also support using high-quality engineering and hydrologic information such as soil permeability tests when applying for a subdivision or other development permit.

Nonstructural BMPs revolve around Low Impact Development (LID), which includes concepts found in Smart Growth and the design philosophies of Ian McHarg's *Design With Nature* and Randall Arendt's *Conservation Subdivision Design*. LID is a land planning and engineering design approach that emphasizes understanding how onsite trees, wetlands, and other natural features can retain, infiltrate, filter, and evaporate stormwater.

Nonstructural BMPs encourage the use of existing forests, trees, and vegetation; riparian areas; wetlands; and the natural contour of the land in development. These BMPs are fully integrated into conservation subdivision design principles that promote activities such as clustering development density to minimize site disturbance; minimizing vegetation removal, grading, and soil compaction; and reducing the size and number of impervious surfaces such as streets and parking lots.

Research at Villanova University highlights the importance of structural BMPs. Structural BMPs promote infiltration and evaporation of stormwater onsite through the use of retention basins, bioretention areas, rain gardens, "Green Streets" infiltration planters,

and bioswales that use green infrastructure to actively absorb stormwater and remove pollutants. Bioretention is the use of pollutant-tolerant vegetation in retention areas to increase infiltration and evapotranspiration, and remove pollutants and sediment. Trees and vegetation can also be incorporated into detention basin retrofits to promote management of stormwater onsite. Other structural practices include green roofs, rain barrels or cisterns, wetlands, riparian buffers, and floodplain restoration.

This bioswale increases infiltration and evaporation of stormwater. (Photo: Chris Kitchen Photography)

Phytoremediation: Removal of Pollution by Plants

Many plants, especially woody plants, are very good at removing nutrients (nitrates and phosphates) and contaminants (metals, pesticides, solvents, oils, and hydrocarbons) from both soil and water. These pollutants are either used for growth and other biological functions, or are stored in wood. In one study, a single roadside maple removed 60mg of cadmium, 140mg of chromium, 820mg of nickel, and 5,200mg of lead in a single growing season. Studies in Maryland showed reductions of up to 88 percent of nitrate and 76 percent of phosphorus after agricultural runoff passed through a streamside forest buffer. Over 100 million tons of chemical fertilizer and 80 million tons of synthetic pesticides are applied to lawns each year in the United States. It is important to consider the role of trees and vegetation in removing excess fertilizers and pesticides. Excess nutrients from lawns and agricultural fields are one of largest sources of nonpoint source pollutants impacting water quality in our streams, rivers, lakes, and the Chesapeake Bay.

Stormwater Ordinances

Although the States of Minnesota, New Jersey, and Wisconsin have enacted statewide ordinances regulating the application of nonagricultural fertilizers in an effort to control phosphorus and other nonpoint pollution, stormwater BMPs are most often incorporated into municipal zoning, subdivision and land development ordinances, or both. These ordinances are comprehensive and mandate the use of both nonstructural and structural systems in subdivisions and other development to increase onsite retention, infiltration, and evaporation rather than just detention. These ordinances emphasize managing 2-year, 24-hour rain events so that post-development peak flow volumes are equal to pre-development peak flow volumes in associated stream channels.

Many ordinances mandate designing for and managing stormwater on new and redevelopment projects where 5,000 or more square feet of impervious surfaces are being constructed. These ordinances typically include development application, design, and construction requirements. Examples of common ordinance requirements include determining and reporting on overall hydrologic site conditions such as soil permeability tests, depth to bedrock, and pre- and post-development stormwater runoff computations; assessing and mapping natural resources on the development parcel including steep slopes, riparian areas, and hydric soils; and providing an overall stormwater management plan or design for the project. These plans often require designers to provide detailed drawings and specifications of all stormwater BMPs whether they are large, such as retention basins, or small, such as rain gardens.

Stormwater ordinances typically mandate the use of Low Impact Development design and construction techniques. Examples of these techniques include clustering development density on no more than 50 percent of the developable parcel; preserving sink holes, trees, woodlots, and riparian areas; avoiding development on slopes over 15 percent; and site grading that is engineered to decrease the travel time of runoff and direct runoff to pervious areas. Stormwater ordinances also limit the size of sidewalks, driveways, and streets, and mandate the use of porous paving, swales, rolled curbs, and trees and other landscaping besides turf.

Managing Stormwater: Parking Lots and Riparian Forest Buffers

Parking lots, among the fastest growing land uses, are a major cause of stormwater and stream degradation. Nonpoint source pollutants such as petroleum hydrocarbons, nitrates, and heavy metals (cadmium, copper, lead, and zinc) from brakes and rusting automobiles all wash into our streams and rivers. Even a small storm of less than half an inch will wash these pollutants into streams. The runoff from 1 acre of paved parking generates the same amount of annual runoff as 36 acres of forest, 20 acres of grassland, or a 10-acre subdivision with ½-acre lots. One inch of rainfall on an acre of parking produces 27,000 gallons of stormwater. Planting large trees in and around parking lots, especially in bioretention areas where stormwater is allowed to infiltrate into the soil, reduces the costs of managing stormwater. This positive impact can be further increased by using structural soils made from fractured gravel mixed with a clay loam soil when designing parking lot and other in-ground tree planters. This engineering solution can support the weight of concrete and asphalt and increase both rooting space for trees and water infiltration in tree planting areas. Research of these engineered soils at Cornell University, UC Davis, and Virginia Tech is showing deeper rooting and infiltration rates as well as substantial pollution removal rates.

The runoff from 1 acre of paved parking generates the same amount of annual runoff as 36 acres of forest.

Parking lots, among the fastest growing land uses, are a major cause of stormwater and stream degradation.

Research at the Stroud Water Research Center, Center for Watershed Protection, and elsewhere has illustrated that stream health is dependent on streambanks having a riparian buffer of woody vegetation. Riparian forest buffers filter sediment and remove nitrogen and phosphorous that leaches from adjacent land uses. Woody root systems provide streambank stability and shade, modify stream temperatures critical for habitat, and reduce stream velocity and downstream flooding. Preserving riparian buffers that extend at least 50 feet from the top of the bank along waterways in developed areas helps minimize stormwater that directly enters waterways and protects stream health.

Riparian buffers are often protected in development through municipal zoning ordinances, but some States like Pennsylvania are moving to protect special, high-quality designation steams by State law rather than individual municipal ordinance. Retrofitting retention basins, parking lots, and other structures as well as planting new buffers as a part of stormwater management has become a common practice in most States over the last 10 years. In many cases, this approach has proven to be more cost effective compared to constructing new retention basins and other structures. The Baltimore Ecosystem Study reported that the average cost of six inner city urban retrofits to increase stormwater infiltration and decrease surface flow was $137,000. The study also reported that stream restoration was $15,000 per acre, while forest buffers could cost less the $1,200 per acre.

Retrofitting retention basins, parking lots, and other structures, combined with planting new buffers to manage stormwater, has become a common practice in most States over the last 10 years.

Case Study — Philadelphia Stormwater Management: Green City, Clean Waters

Green City, Clean Waters

Like many cities, Philadelphia has maintenance, operational, and environmental costs associated with its combined MS4 sewer system and NPDES permits. The city spends about $125 million a year on stormwater operations and maintenance. The environmental costs of combined sewer overflows, stream degradation, and flooding are large, but difficult to estimate.

For many years, the city charged an average stormwater fee for residential water users, while nonresidential water users were charged a fee based on the size of their water meter. The revenue raised from these fees was used to fund investments in pipes and treatment plant expansions as well as operations and maintenance. In 2011, the city enacted its *Green City, Clean Waters* program, which calls for a $2 billion investment over the next 25 years in trees, green streets, and other green infrastructure. Goals of the program are to convert vacant lots to open space, enact standards for stormwater management in redevelopment, restore streams to support healthy aquatic communities, and preserve open space to manage stormwater at the source. The program seeks to disconnect 10,000 acres of properties from the city's combined sewer system. It is estimated that these actions would ultimately reduce pollution that results from combined sewer overflows by about 85 percent and save the city about $10 billion in stormwater costs.

To support this new plan and the traditional costs of infrastructure investment and maintenance, the city recently reallocated its stormwater fees for nonresidential properties to reflect both the parcel size and the amount of impervious surface on the parcel. Philadelphia's 80,000 to 90,000 nonresidential property owners now pay stormwater fees per 500 square feet of parcel and per 500 square feet of impervious surface located on the parcel. In 2012, residential property owners paid an average of about $13.00 a month for stormwater. To accompany the city's parcel-based billing, stormwater credits are offered if a customer has or installs pervious paving, bioretention basins, trees, or other stormwater features on his or her property that manage the first 1 inch of runoff. This is not a tax credit, but a discount directly on the stormwater charge. This fee structures generates about $125 million in municipal revenue a year.

For more information about the Philadelphia Green City, Clean Waters Plan, visit the Web site: http://phillywatersheds.org/what_were_doing/documents_and_data/cso_long_term_control_plan.

Relevant Factsheets

A1 – *Using Smart Growth Principles to Plan Sustainable Communities* – Discusses approaches that can be used to manage growth in concert with conservation, ecology, and quality of life values.

N3 – *Regulatory Approaches to Protecting Natural Resources* – Many of these regulatory tools are important in stormwater management (e.g., steep slope, riparian area, impervious surface ordinances).

N6 – *Planning Tools to Protect Water Quality* – Many of these tools can also be used to help manage stormwater.

Resources

Alliance for the Chesapeake Bay. https://allianceforthebay.org/. (30 October 2014).

Bormann, H.; Balmori, D.; Geballe, G. 2001. Redesigning the American lawn: a search for environmental harmony. 2d ed. New Haven, CT: Yale University Press. 192 p.

Cappiella, K.; Schueler, T.; Wright, T. 2005. Urban Watershed Forestry Manual, Part 1: Methods for increasing forest cover in a watershed. NA–TP–04–05. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry. 140 p.

Center for Watershed Protection. http://www.cwp.org. (8 August 2012).

Low Impact Development Center. http://www.lowimpactdevelopment.org. (8 August 2012).

Maryland's Stormwater Management Program. http://www.mde.state.md.us/programs/Water/StormwaterManagementProgram/SedimentandStormwaterHome/Pages/Programs/WaterPrograms/SedimentandStormwater/home/index.aspx. (8 August 2012).

National Association of State Foresters. 2011. Trees, forests and stormwater: a primer for State foresters. NASF–2011–02. 6 p. http://www.stateforesters.org/urban_forest_stormwater_primer.pdf. (8 August 2012).

Pennsylvania Stormwater Best Management Practices Manual. http://www.portal.state.pa.us/portal/server.pt/community/best_management_practices_manual/10631. (8 August 2012).

Stroud Water Research Center. http://www.stroudcenter.org/. (8 August 2012).

University of Connecticut Nonpoint Education for Municipal Officials (NEMO). http://nemo.uconn.edu/tools/publications.htm. (8 August 2012).

USDA Forest Service Urban Ecosystems and Processes. http://www.fs.fed.us/psw/programs/cufr/research/water.shtml. (8 August 2012).

Xiao, Q; McPherson, G. 2003. Rainfall interception by Santa Monica's municipal urban forest. Urban Ecosystems. 6: 291–302.

Xiao, Q.; McPherson, G.; Simpson, J.; Ustin, S.1998. Rainfall interception by Sacramento's urban forest. Journal of Arboriculture. 24(4): 235–244.

Acknowledgements

Authors

William Elmendorf, Ph.D., Associate Professor of Urban and Community Forestry, Penn State
Vincent Cotrone, Urban Forester, Penn State Cooperative Extension

Editors

Donna Marie Foster, U.S. Forest Service, Northeastern Area State and Private Forestry
Sandra Clark, U.S. Forest Service, Northeastern Area State and Private Forestry

Designer

Deborah Muccio, U.S. Forest Service, Northeastern Area State and Private Forestry