Soil Science Society of America

GREEN INFRASTRUCTURE

Bioswales, such as this one in Greendale, WI, are green infrastructure systems that use soils and plants to manage stormwater naturally. Photo: Aaron Volkening (www.flickr.com)

Before we began using pipes, drains, pumps, and other "**grey infrastructure**" to manage stormwater, nature provided the "green infrastructure" to slow, filter, and move water to where it belonged. In forests and wetlands, water is still **managed naturally**. The foundation of this network is the soil. It is the drain, the pipe, the pump, and the water treatment plant all in one.

As we've continued to **pave over our soils**, however, demands on both natural and manmade stormwater management systems have increased. In cities the use of green infrastructure to alleviate strain on these systems has become a popular alternative to costly grey infrastructure expansion. These green infrastructure techniques rely heavily on the inherent and unique qualities of soil. (**Read about an alternative to traditional paving.**)

Certain soil properties determine how quickly and how much water can be infiltrate, or permeate, the ground—preventing flooding, and the overloading of streams and water treatment plants, as well as recharging groundwater supplies. The soil is also responsible for much of the filtering of contaminants in urban stormwater, which can otherwise lead to serious water quality issues.

Moreover, soil provides the nutrients and water holding capacity needed to support plants, which help prevent erosion, reduce runoff by using and storing water, clean and cool the air, and provide an aesthetic quality to urban spaces. Hence the soil is responsible both for **reducing water quantity and improving water quality**—the primary goals of stormwater management.

HOW NATURES MANAGES WATER

Why is green infrastructure becoming so important now? Our urbanized areas have greatly expanded to accommodate growing populations. But this growth has come at the cost of forests, wetlands, and undisturbed soils capable of managing stormwater naturally. As a result, water movement in the city is much different from in a field or forest. This is primarily due to the permeability of the surface the rain is falling on.

How water moves in the forest

When it rains in a forest or on fields, the rainwater soaks into the soil. The soil then stores a portion of the water, while the remainder moves slowly to streams or into groundwater reserves.

Once water is in the soil, the speed of its flow slows down. After most storms, the water that soaks into the soil stays there and is taken up by plants. Even after heavier rains, most of the rain will stay in fine-textured and well-developed soils, or move very slowly through them. When heavier rains fall on coarsely textured or sandier soils, the water will move through the soil more quickly as shown in Figure 1.

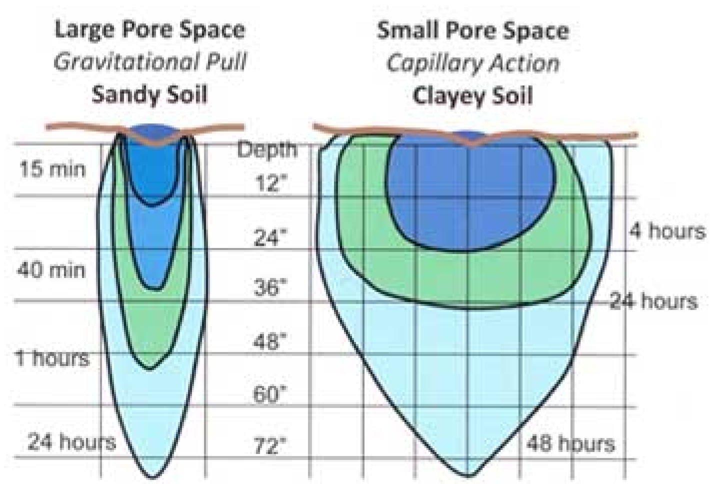


Figure 1: Comparison of water movement in sandy versus clayey soils. Water moves more quickly through sandy soils due to larger pore spaces and the force of gravity. In finer textured soils, water moves more slowly and is drawn through by capillary action. Figure: Colorado State Extension

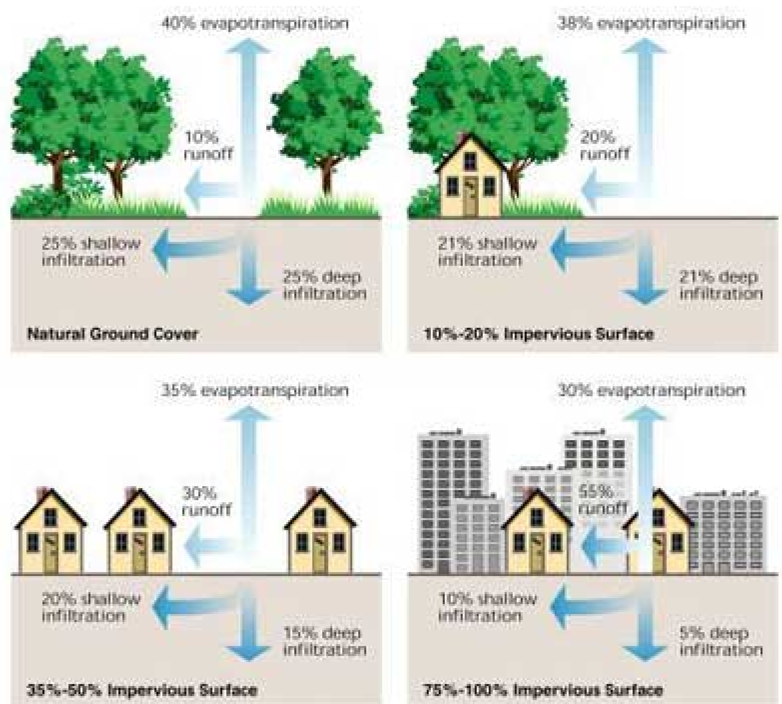
In either case, water is able to enter the soil because of the soil's permeability. This movement of water through the soil is called "subsurface flow." Subsurface flow moves rainwater to streams, lakes, and other surface waters. It can also move water to groundwater where it is stored for centuries. The storage of water in soil is a critical type of water storage, providing water for streams, plants, and people long after the rain has stopped.

If the water travels instead over surfaces such as city streets or bare hillsides, it can carry sediment, nutrients, and other contaminants with it. When this water enters healthy soil, the soil acts as a filter, removing sediment and many of the nutrients and contaminants the water has picked up.

Many of these particulates are absorbed onto soil surfaces where they can either be taken up by plants and soil organisms or incorporated into the soil, making them unavailable to water or living things. That filtered water that results then slowly and steadily recharges groundwater and river systems, helping to keep streams cool, clean, and consistently full for people, fish, and other organisms.

HOW WATER MOVES IN CITIES

When it rains in a city, the story is very different. Much of the land in urban areas is covered by pavement or asphalt. Because rain can't soak into the soil underneath, these covered areas are referred to as impermeable surfaces. As the amount of impermeable surface increases with urbanization, so too does the amount of runoff (see figure at right).



Runoff volumes will increase based on the percent of impervious surface. Higher volumes of runoff result in flooding, water pollution, and erosion. Photo courtesy of LEARN NC, www.learnnc.org

Even when urban soil is not covered by houses, stores, parking lots, or roads, it's often compacted. Compaction reduces the pore space in the soil, which drastically slows the rate at which water can infiltrate, or percolate, into the soil. Because compacted soils only let minimal amounts of water percolate through, they act more like asphalt than functional soils.

When only limited places exist where water can infiltrate into the ground, stormwater moves over the ground instead. This process is called "overland flow." During overland flow, water picks up speed and objects that get in its way, including trash, sediment, and other contaminants such as motor oil, nutrients, and metals.

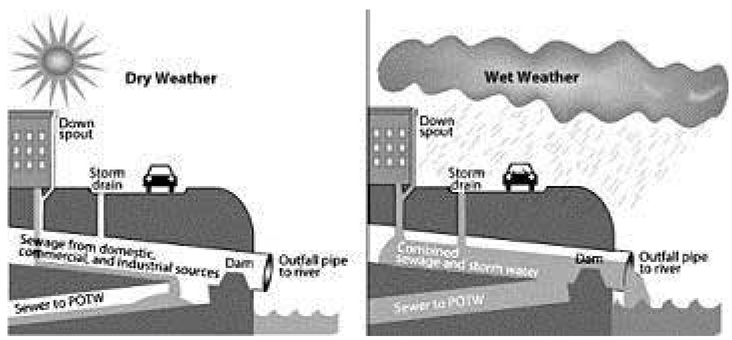
Many cities have also increased the speed of overland flow and the amount of runoff because gray infrastructure has been designed to move water off streets as quickly as possible through gutters, storm drains, and sewer pipes.

So where does all that runoff go?

The fate of urban stormwater runoff

Urban stormwater that does not percolate into urban soils often flows directly into streams, lakes, or the ocean either by overland flow or through storm drains that discharge directly into natural waters.

Most municipalities also have combined sewer systems, in which stormwater may be carried via pipes to water treatment facilities. This ends in one of two ways: 1) municipalities expend money and resources to clean the stormwater, or 2) large volumes of stormwater, combined with normal sewage levels, overload treatment facilities.



Many cities use combined sewer systems to move both stormwater and sewage to water treatment plants. This can result in overflows during heavy rains called combined sewer overflows (CSO). When such events occur, both dirty, urban runoff and sewage discharge directly into rivers, lakes, and oceans. Source: U.S. EPA

In the first case, dilute stormwater is energy-intensive to treat as wastewater plants are designed to treat more concentrated influent. The dilute stormwater reduces the operating efficiency of the plants and so wastes energy.

In the second case, large volumes of stormwater can overwhelm the capacity of a wastewater treatment plant, causing it to release a portion of the stormwater, combined with untreated sewage, into natural waters. This type of event is called a "combined sewer overflow," or CSO. Municipalities are allowed a certain number of these events each year. But **regulations** are also tightening due to concerns over water quality.

So, to summarize, if a soil has been compacted or paved over it will have low to zero permeability, preventing water from infiltrating into the soil. This results in larger volumes of water moving across the surface, which in turn causes flooding, water pollution, increased erosion, and decreased storage of water in the ground for later use. In other words, there are two major problems with the methods most municipalities use to manage stormwater: issues of water quantity and water quality. We'll explore these effects further in the next section.

IMPACTS ON WATER QUANTITY AND QUALITY

The way water moves in cities has large effects on both water quantity and water quality.

Water quantity

Urbanization can result both in too much water and too little water reaching streams.

In many cities, subsurface flow has nearly been eliminated as a result of so many paved or other impervious surfaces. So, instead of water gradually entering streams through subsurface flow, much more water from a storm enters streams quickly through overland flow.

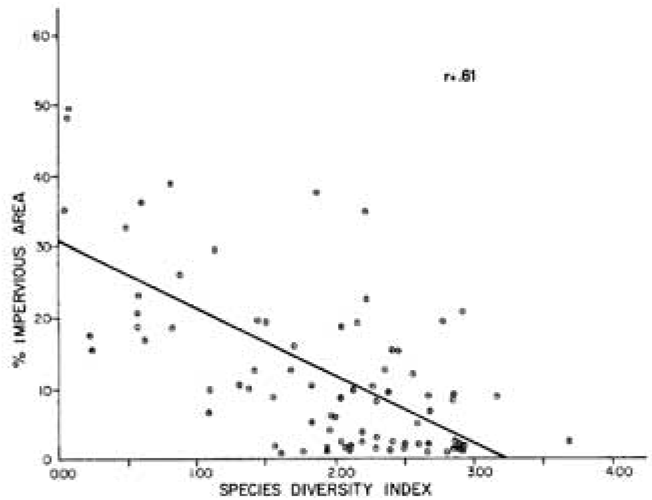
Flooding in urban areas has several negative impacts on both humans and wildlife. Green infrastructure technologies can reduce flooding and increase subsurface flow by replacing impervious areas in cities with permeable soil. Photo: Center for Neighborhood Technology (www.cnt.org)

Water flowing off streets directly into streams causes water levels to rise quickly, making streams much more likely to flood during heavy rains. In periods without rain, in contrast, streams have a tendency to fall below normal levels because of reduced subsurface, or soil, flow. This type of behavior results in streams being described as "flashy"—meaning their water levels rise and fall quickly.

Below are some of the negative impacts flooding can have on both people and wildlife.

Economic costs to communities and individuals from flooding can be high. Floods may risk human life, damage property, and wreak havoc on daily routines in urban areas—causing additional economic costs to people and businesses. Flooding in the United States alone costs about $2 billion per year.

In a 2002 report, the U.S. Environmental Protection Agency estimated that stormwater controls would save $14 million dollars annually.



Increased sedimentation carried by floodwaters leads to shallower streams that are more prone to flooding.

Stress to wildlife caused by changing stream dynamics reduces biodiversity in streams. In the figure at right (Source: **Klein, R.D**, 1979), an increasing percentage of impervious area due to urbanization correlates with reduced biodiversity in streams. Sedimentation, for example, results in shallower, warmer water with less available oxygen, which in turn creates a stressful environment for aquatic life. Sediments may also carry contaminants, including metals and organic chemicals, that are harmful to fish and other organisms.

Stream shape changes caused by flooding make streams more prone to flooding in the future.

Water quality

Water washing off city streets, rooftops, eroded hillsides, and other urban surfaces will carry all sorts of things with it, including metals, dirt, and debris. **Collectively termed contaminants**, these materials are either dissolved in water or more commonly are attached to particles in water. Water-borne contaminants can be divided into a few basic categories.

Runoff carrying contaminants. Source: http://SoilScience.info

» Plant nutrients, particularly nitrogen (N) and phosphorus (P)

» Metals, most commonly copper (Cu), zinc (Zn) and lead (Pb)

» Organic chemicals primarily related to gasoline products, but also pesticides and industrial products used in manufacturing and construction

» Pathogens from animal feces

» Trash and debris, especially plastics

A quick way to assess how contaminated water may be is by measuring the amount of total suspended solids (TSS). TSS is a measurement of how many particles are floating around in water. A turbidity meter is used to quantify the amount of particles in a water sample, based on how much light passes through the sample. Whether these contaminants are "bioavailable" (can be taken up by plants and animals) depends on the chemistry of the water and how the contaminants are attached to other particles.

Contaminants can have a negative impact on both humans and wildlife including:

Beach closures caused by contamination, particularly from pathogens, can result in loss of recreational opportunities and economic costs to businesses that depend on tourism.

Behavioral changes in fish and other harmful impacts on wildlife have been connected to metal exposure. For example, researchers in Washington have observed that metals are particularly harmful to spawning Coho salmon, and copper has been shown to inhibit salmons' ability to detect predators.

Built up trash and debris can clog drains, threaten wildlife, and be aesthetically displeasing.

Eutrophication of water because of excess nutrients may lead to suffocation of fish and other aquatic biota, as well as water unfit for recreation.

How soil can help

Soil can play an important role in removing suspended solids and dissolved contaminants before they reach natural waters. By slowing the movement of water down, soil gives sediments time to settle out and allows chemicals to adsorb to soil surfaces.

The amount of contamination in stormwater will depend on surrounding land uses as well as the frequency and duration of storm events. Runoff from an industrial site, for example, may carry more metals, whereas runoff from a golf course or residential area may contain more pathogens and pesticides.

Contaminants, their sources, and potential concentrations in runoff are described in Table 1 below.

Contaminant	Source	Total Concentration
Copper	Brake pads, roofing materials, pesticides	0.005 - 0.02 mg/L[1]
Lead	Roofing materials, legacy soil contamination from lead paint and leaded gasoline	0.1 – 6.0 mg/L[2]
Zinc	Roofing materials, tire wear	0.02 - 2.6 mg/L[1]
Phosphorus	Fertilizers, soil particles and organic matter	180-350 ug/L[3]
Nitrogen	Fertilizers and organic matter	~2 mg/L[3]

Sources and typical concentrations of common contaminants in stormwater. The type and amount of contamination will depend on land use as well as the size and frequency of storm events. Sources: WSDOE (2008), Invertson (2011).

So the question is...

How do we get our cityscapes to manage water more like a forest?

MIMICKING THE SOIL WITH GREEN INFRASTRUCTURE

Green stormwater infrastructure refers to the network of green spaces in our cities that collectively provide stormwater management, recreation, and wildlife habitat. Central to this concept is the intentional practice of using natural or nature-inspired systems to manage stormwater on site.

This method is quickly being recognized as a low-cost alternative to traditional engineered systems, often termed **grey infrastructure**. Unlike these traditional solutions, green infrastructure increases the permeability of our cityscapes so that they behave more like natural soils—slowing, holding, and purifying stormwater. By managing stormwater where it falls, runoff to natural waters and the burden on wastewater treatment facilities is also reduced.

Rain gardens (like the one on the right) intercept, filter, and infiltrate stormwater from downspouts, which would otherwise flow onto

Types of green infrastructure

city streets. Photo: Wisconsin Dept. of Natural Resources

Green stormwater infrastructure includes permeable pavement, **green roofs**, **urban forests**, wetlands, and **rain gardens and bioswales**. Green infrastructure can be engineered, as with a bioswale, or nature-made, such as a preserved wetland. Preserved, natural systems have the advantage of not requiring upfront construction and design costs. Depending on their size, they may also provide more recreational opportunities and be capable of processing larger quantities of water.

Manmade systems, on the other hand, can be customized to meet a particular need and may require less land area to be effective.

Central to the success of any individual system is that it's interconnected with others to create a more powerful whole. This requires strategic planning involving many **community** stakeholders. To learn how communities around the country are expanding their green infrastructure through highway projects, land preservation, and urban renovations, visit the **Conservation Fund's Green Infrastructure Project Profiles**.

The soil in a bioswale must be carefully designed to infiltrate water quickly (but not too quickly), resist compaction, and support plant life. Photo: Kristine Paulus (www.flickr.com)

The importance of soil

All these tools rely directly or indirectly on soil to achieve stormwater management strategies that are more affordable and effective than traditional grey infrastructure systems. While projects like urban forests rely on native soils, the soils used in green infrastructure systems, including rain gardens and bioswales, are specifically designed to infiltrate water quickly to reduce flooding. At the same time, these special soil mixtures must retain water long enough to remove contaminants and clean the water.

As the ratio of soil surface to rainwater is a lot smaller in cities than in natural systems, more is expected of these soils. For example, a bioswale will be designed to filter stormwater from a surrounding area much larger than the bioswale itself. Therefore these soils must be carefully designed both to manage stormwater quantity and quality.

When designing soil mixtures for bioswales, there are a few system requirements to keep in mind. **Bioswale soils must:**

» Infiltrate water quickly, but not too quickly. Water needs to travel slowly enough through the soil for filtering and adsorption of contaminants but must also infiltrate fast enough to prevent flooding.

» Resist compaction. Compaction of soils can greatly reduce infiltration rates, making a rain garden or bioswale ineffective.

» Hold enough water and nutrients to maintain healthy plant life. While soil alone can significantly reduce water pollution, no one will want a “rain garden” of bare soil or half dead plants in their front yard.

So what are these special soil mixtures composed of? Two specific soil ingredients are necessary to achieve the objectives above: **sand** and **compost**. Other ingredients might include **topsoil** and **other ingredients** such as water treatment residuals, wood chips, or perlite.

SAND

Purpose in a green infrastructure soil: Drainage
Suggested volume: 60% of total mix
What to look for: Coarse, gravelly sand without too many smaller particles (fines) as these may clog pores.

Sand generally refers to the coarse-textured (less than 2-millimeter) mineral fraction of soil. Sand’s main job in a green stormwater or "bioswale" soil mix is to provide high infiltration rates and resist compaction. Sand has a low surface area and hence a low “cation exchange capacity” (CEC), meaning it does very little to filter contaminants such as metal pollutants and plant nutrients. The large pore space found in sandy soil is also poor at holding water. This makes for good drainage, but can also make for sad-looking, nutrient- and water-starved plants in the garden.

It’s best to select a coarse, gravelly sand for your soil mixture so that water can infiltrate at the desired rate (approximately one inch per hour). Washed, concrete sand is often recommended as it is coarse, clean, and a recycled product available locally in most areas. While sand may make up the majority of these mixes—frequently 60% or more by volume—**compost** is the real workhorse of any bioswale stormwater treatment system.

COMPOST

Purpose in a green infrastructure, or "bioswale," soil: Filter pollutants and nutrients, and hold water in soil for plants and microbes
Suggested volume: 30 to 40% by volume of total mix
What to look for: Homogeneous, dark compost that smells earthy. Beware of composts with lots of woody debris, trash, or with a sour or ammonia smell.
What is Compost?

Compost is manmade organic matter. It's the result of recycling carbon-containing wastes such as food scraps, yard debris, biosolids, and manure. These wastes are termed "feedstocks" when used as ingredients for making compost.

Compost is the real workhorse of a green stormwater treatment system. Photo: Kate Kurtz

In aerobic composting, micro- and macro-organisms break down the carbon-containing matter, creating a dark, *homogeneous* substance from a *heterogeneous* mixture of feedstocks. While the same process occurs in nature, composting accelerates decomposition by providing the ideal mix of air and moisture to foster a microbial feeding frenzy.

The organic matter that compost adds to a bioswale soil is the chemically and biologically active part of these systems. Organic matter in compost is extremely chemically reactive with a large electrically charged surface area per unit volume. This means organic matter can pull metals, organic chemicals, and nutrients out of solution (water). These bound chemicals can then be absorbed onto soil surfaces, broken down by soil microbes, or used for growth by plants and microbes.

Read more about compost in our blogs:

» **What is compost?**

» **What happens to toxins in compost and soil?**

» **What is "vermicompost"?**

Organic matter in bioswale soil mixes:

» Binds contaminants such as copper, zinc, and hydrocarbons that are potentially harmful to aquatic life.

» Absorbs and slowly releases water, providing moisture for healthy plant growth, regulating the rate at which groundwater recharges streams, and preventing flooding.

» Provides the microbial environment necessary for the breakdown of organic contaminants such as pesticides, herbicides, and hydrocarbons.

» Speeds soil aggregation to prevent compaction and erosion.

» Supplies the necessary nutrients for plant growth, resulting in systems that provide habitat for wildlife, reduced erosion, increased soil pore space, air filtration, and aesthetic appeal.

» Reduces maintenance of systems by supporting plant growth without the use of irrigation and synthetic fertilizers.

Composts Vary

As feedstocks and decomposition processes vary depending on the season, local resources, and composting method, it's important to keep in mind that the resulting product will also vary. Such variations include the amount of available nutrients and metals in the compost, the maturity and stability of the finished product, and the final **carbon to nitrogen or C:N ratio**.

For example, composted biosolids will contain more phosphorus, copper, and zinc than compost made mostly of yard debris. While these elements can be potential pollutants, it's important to know that they are often bound tightly to the organic matter and other compounds (e.g., iron and aluminum oxides) that are present in feedstocks, particularly biosolids. These pollutants tend to stay put as a result. But compost may also contain some trash, which can clog bioswales, harm wildlife, and result in aesthetically displeasing gardens.

Choosing a Compost

Prior to choosing a compost, you should evaluate which compost will be best under the given circumstances. General criteria for evaluating compost include: the C:N ratio, pH, stability, maturity, and whether the compost is contaminated with trash or weeds.

Chemical attributes of the compost may also be specified by local standards, and some municipalities have vendor lists for suppliers of approved materials. The U.S. Composting Council also sponsors a compost testing program. Composts that have received the Seal of Testing Assurance, or STA, stamp are generally suitable materials for use in green infrastructure (**http://compostingcouncil.org/seal-of-testing-assurance**). Below are requirements for compost used in Seattle, WA, bioswales set forth by Seattle Public Utilities:

» C:N: ratios between 20:1 and 45:1, depending on type of compost and plants used

» pH: 6.0 to 8.5

» Maturity: Solvita score of 5 or 6, depending on compost type

» Stability: Carbon dioxide evolution rate below 7

» Contamination: No more the 1% contamination by volume

TOPSOIL

Purpose in bioswale soil mixes: Provides growing medium for plants
Suggested volume: Depends on the amount of organic matter and fines in topsoil and other amendments
What to look for: Loamy topsoils with adequate organic matter and minimal clay will provide some water filtration and support plants without hindering infiltration rates.

Topsoils, particularly native topsoils found on site, can be used in a bioswale soil mix. Incorporating native soils into a soil mix reduces the need for hauling away excess soil and purchasing additional amendments.

A native topsoil being spread back over a restored site. Photo: Dave Ledig, U.S. Fish and Wildlife Service

Topsoil will contain a specific mixture of sand, silt, clay, and organic matter depending on the soil type. The amount of topsoil to add is generally determined by the total organic matter, clay, or silt components desired in the final soil mix, as these components can hinder infiltration by clogging pore spaces.

Like organic matter, the silt and clay particles in native soils have much higher surface areas—and hence cation exchange capacity—than sand. Depending on its chemical composition, topsoil may provide nutrients and assist with binding metals, as well as hold water for use by plants, but not to the same degree as the organic matter in compost.

In addition, topsoil is not teeming with microbes to the same extent as organic matter, and thus does little to aggregate soil and remove organic pollutants.

OTHER INGREDIENTS

Purpose in bioswale soil mixes: Provide additional pollutant removal and other benefits
Suggested volume: 5 to 10% of total mix
What to look for: Which amendments to use will depend on characteristics of your base mixture of sand and compost.
Water treatment residuals

Water treatment residuals (WTR) are aluminum or iron oxides used in purifying water for drinking. Like clay and organic matter, they have a high surface area and can adsorb both negatively charged anions like PO3- (phosphate) and N03- (nitrate), as well as positively charged cations, such as metals. Even after their use in water treatment these compounds are still highly reactive.

While WTR are traditionally landfilled, they have been reused to reduce the mobility of phosphate in agricultural soils where phosphorus has built up overtime. WTR are also being explored as an additive to soil mixes to reduce

Adding vermiculite (the tan material on top) or other porous, mineral materials to your mix can can provide drainage attributes similar to sand, while also helping retain water. Photo: Kim Kruse (www.flickr.com)

nutrient loss and enhance contaminant removal in bioswales that use composts.

Results from one study indicate that WTR can be an effective method for both purposes, without reducing water infiltration rates significantly.

Wood Chips
Wood chips can be added to increase the **carbon to nitrogen (C:N) ratio** in a soil mix, thus reducing the potential for nitrogen to leach from the system. Wood chips are often also added as a mulch layer over bare soil to reduce erosion and help soils retain moisture during dry periods. Wood chips, however, often have a low pH (are acidic). Additions of wood chips should therefore be monitored so that they don't lower the pH of a bioswale soil enough to reduce its capacity to bind pollutants, such as metals. Compost, however, can provide buffering capacity against fluctuations in pH, reducing the risk of creating acidic conditions through wood chip amendments.

Porous Minerals
Perlite, vermiculite, or other porous, mineral materials may also be used in green infrastructure soil mixes. These volcanic materials are more porous than sand and can provide drainage attributes similar to sand, while at the same time offering increased water-holding capacity. Their ability to hold more water than sand comes from the higher surface areas provided by the particles' nooks and crannies. Their bulk density is also lower than sand, meaning they are lighter and well-suited for mixes such as those used on green roofs where weight is an important consideration.

WHAT'S THE RIGHT MIX?

What specific recipe or mix of soil ingredients is best depends on several factors. Important considerations include:

How will the soil be used?

If the soil will be used in a residential rain garden, likely topsoil can be used with subtle amendments of sand and compost to provide adequate infiltration rates and organic matter to support plants. If the mix will be used in a bioswale meant to capture and treat larger volumes of water, an engineered soil mix is more appropriate and often required by local standards.

What products are available locally?

When deciding what type of sand or compost to use it's important not only to consider the qualities previously described, but what is available locally to reduce the environmental and economic impacts of transportation.

What are local requirements for soils?

Some states and local jurisdictions have established specific standards (see table below) for meeting water infiltration goals and to address concerns about nutrients loss from green infrastructure soils, which can contribute to **eutrophication** (the overloading of nutrients into water bodies). The ability of a soil blend to infiltrate water, remove contaminants, and support plants will depend on the ratio of sand to compost and other amendments. A general rule of thumb is that a healthy soil contains about 5% organic matter by weight. In a 60:40 mix of sand and compost that goal is just being met.

State	%Sand	%Compost	%Top Soil	%Clay	%Silt
Washington	60	40	--	--	--
Oregon	60	40	--	--	--
Virginia	85 to 88	3 to 5**	--	--	8 to 12*
North Carolina	85	3 to 5**	10*	--	--
Delaware	40 to 80	1 to 4**	NA	5 to 15	20 to 40*
Pennsylvania	--	20 to 30	70 to 80	--	--
*Soil Fines					
**Organic Matter					

Comparison of bioswale soil mix standards from several U.S. states. DE, PA, and VA standards courtesy of http://daily.sightline.org/2013/06/21/its-the-soil-stupid/.

Several institutions and government agencies have also participated in research to determine what makes an ideal bioswale soil mix. Many of these studies have focused on reducing nutrient loss from bioswales by adjusting the amount of organic matter and restricting compost feedstocks to yard debris and foodwaste.

Phosphorus is typically the nutrient that limits the growth of algae and plants in fresh water—meaning that an excess of phosphorus may cause "blooms" of these organisms. So, a possibly more effective approach is to use a simple method called the **phosphorus saturation index (PSI)**, a tool used to assess the mobility of phosphorus in agricultural soils. Researchers at the University of Washington are currently **testing this method** for application to bioswale soils. If the PSI does prove useful, it would provide builders of green stormwater infrastructure certainty that phosphorus leaching is not a problem, and allow for more customized soils mixes to be developed.

WHAT CAN YOU DO?

Now that you understand the role of soil in green infrastructure, what can you do to reduce stormwater runoff in your community?

Step 1: Conserve the soil

Like any sustainable strategy, the most important starting point is conservation. Conserving our green spaces and caring for the soil that's already in place is central to creating healthy ground for improved stormwater management. This includes reducing soil compaction and erosion, and promoting soil health. Strategies for improving soil include:

» Amending soils with compost

» Letting leaves and grass clippings decompose in place to restore soil organic matter

» Using compost socks and berms to prevent erosion in areas under construction

» Planting trees and native plants in areas where soil is bare

Additional strategies for building healthy soils can be found at **www.soilsforsalmon.org**.

Step 2: Install a rain garden or other green infrastructure feature

The next step in improving stormwater management in your community is to incorporate green infrastructure, such as rain gardens, in your landscape. Residential rain gardens not only reduce flooding in your neighborhood but can increase property values and are a charming landscape feature. Other green infrastructure tools for reducing runoff include use of rain barrels or cisterns, disconnecting downspouts, and installing green roofs.

Neighbors and volunteers in Eatonville, WA, gather to construct a cluster of rain gardens with the

In recognition of the value of these tools, many municipalities have developed incentive programs to share the cost of construction. For example, **RiverSmart Homes**, an incentive program in Washington, DC, provides homeowners with $1,200 towards installing a rain garden or other green infrastructure system on their property. Other communities with incentive programs include:

help of 12,000 Rain Gardens (www.12000raingardens.org).

Anchorage, AK

Elkhart County, IN

Fort Wayne, IN

Greenville County, SC

Lake Champlain Basin, VT

Seattle, WA

Thurston County, WA

Step 3: Create a community

The impact of these strategies will be enhanced if they are implemented on a community level. Many of the municipally supported incentive programs are targeted toward neighborhoods where the impacts of green stormwater management will be greatest. **Clustering rain gardens** in a designated area such as a neighborhood block allows pooling of resources, the potential for shared maintenance, and a greater collective impact on runoff.

Tips for inspiring community stormwater projects:

Communicate! Talk to your neighbors or hold a community event to educate the neighborhood about the issues surrounding stormwater runoff. Such events might include a presentation by a master gardener trained in rain-wise landscaping or just a simple potluck. It sounds obvious but this is a great way to share ideas and find partners.

Collaborate! Once you have identified neighborhood partners, reach out to landscapers, nurseries, and other vendors who might be willing to give you bulk discounts for group projects. Local non-profits or government agencies may also be helpful in getting your project off the ground.

Educate! Post signage in yards or parking strips where projects have been built to bring attention to the economic and environmental values of green infrastructure.

Share! Organize a tour of your rain garden project to inspire other communities to create their own projects.

ADDITIONAL RESOURCES

Research

In order to better manage stormwater, continual research is being conducted at centers across the country. Topics of special interest include emerging technologies, such as permeable pavement, and ideal soil mixtures for features like rain gardens and green roofs. Centers currently contributing to stormwater research include:

Low Impact Development Mid-Atlantic Research Consortium

Washington State University Puyallup LID

University of Central Florida Stormwater Academy

The EPA is also leading research, in partnership with **universities and other government agencies,** to analyze the impact of green infrastructure technologies and policies on economic development and the environment.

Additional Resources

Several resources are available for individuals, communities, and municipalities interested in implementing green infrastructure to better manage stormwater runoff. A good place to start is the **EPA's Green Infrastructure** website, which includes tools for defining and explaining green infrastructure, calculating economic savings, connecting with your local community, and exploring existing projects.

Below are other helpful resources on specific topics:

Design and Construction
» **Low Impact Development Urban Design Tools**

Community Organizing and Public Outreach
» **Water Environment Research Foundation**

Maintenance
» **Rain Garden Care: A Guide for Residents and Community Organizations**

Economic Evaluations
» **Center for Neighborhood Technology Green Values Calculator**

» **The Value of Green Infrastructure: A Guide to Recognizing its Economic, Environmental and Social Benefits**

» **WERF's Review of Methods for Evaluating Economic Benefits**

For Municipalities

» American Planning Association **Green Infrastructure Planning: Recent Advances and Applications**

» EPA's **Green Infrastructure Case Studies: Municipal Policies for Managing Stormwater with Green Infrastructure**

» EPA's **Water Quality Scorecard: Incorporating Green Infrastructure Practices at the Municipal, Neighborhood, and Site Scales**

» **Low Impact Development Urban Design Tools**

» **Water Environment Research Foundation**

REFERENCES

Below is a list of articles that were reviewed during the creation of these green infrastructure pages. They are provided for those who may want more in-depth, technical and scientific information.

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