

# Green Infrastructure

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Il ruolo del verde urbano  
Giulio Senes



UNIVERSITÀ DEGLI STUDI DI MILANO

Dipartimento di Scienze Agrarie e Ambientali

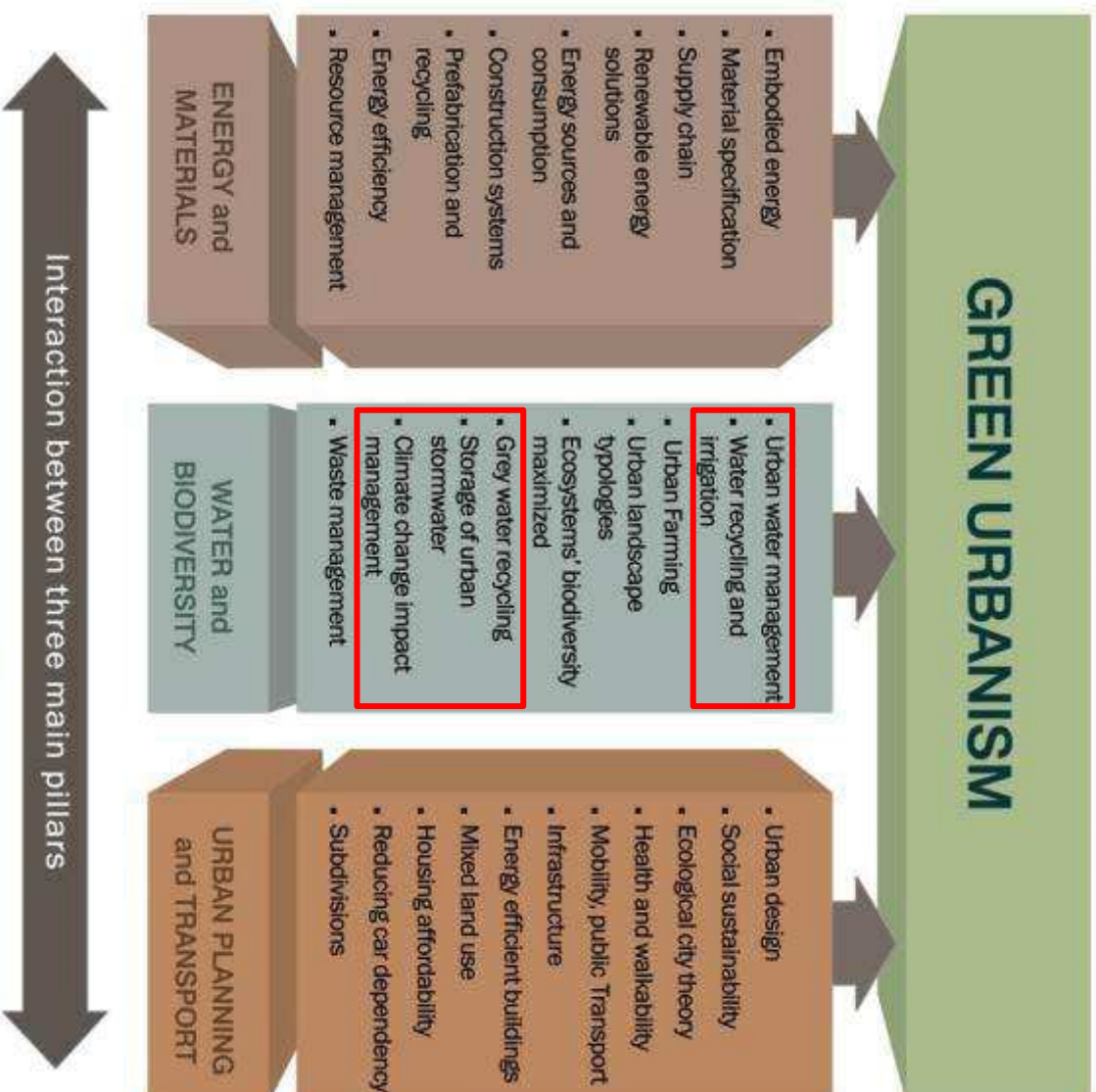
# Green Infrastructure

An integrated approach to land use

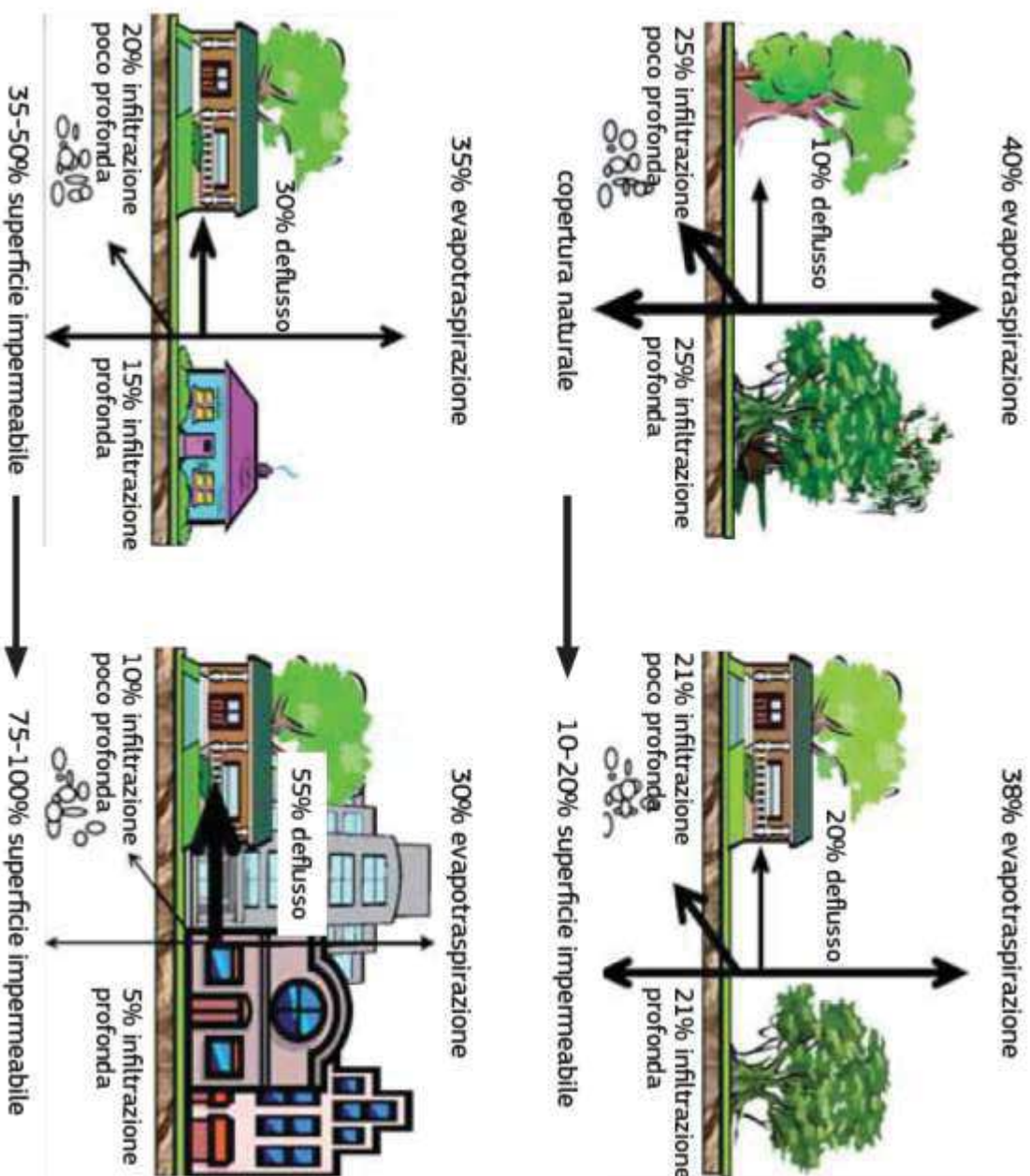
Landscape Institute Position Statement



# Green Infrastructure



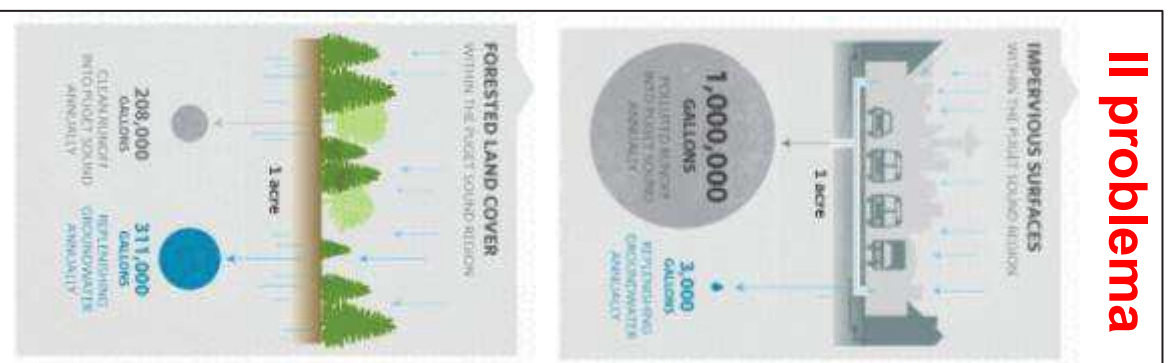
# Green Infrastructure for stormwater managing





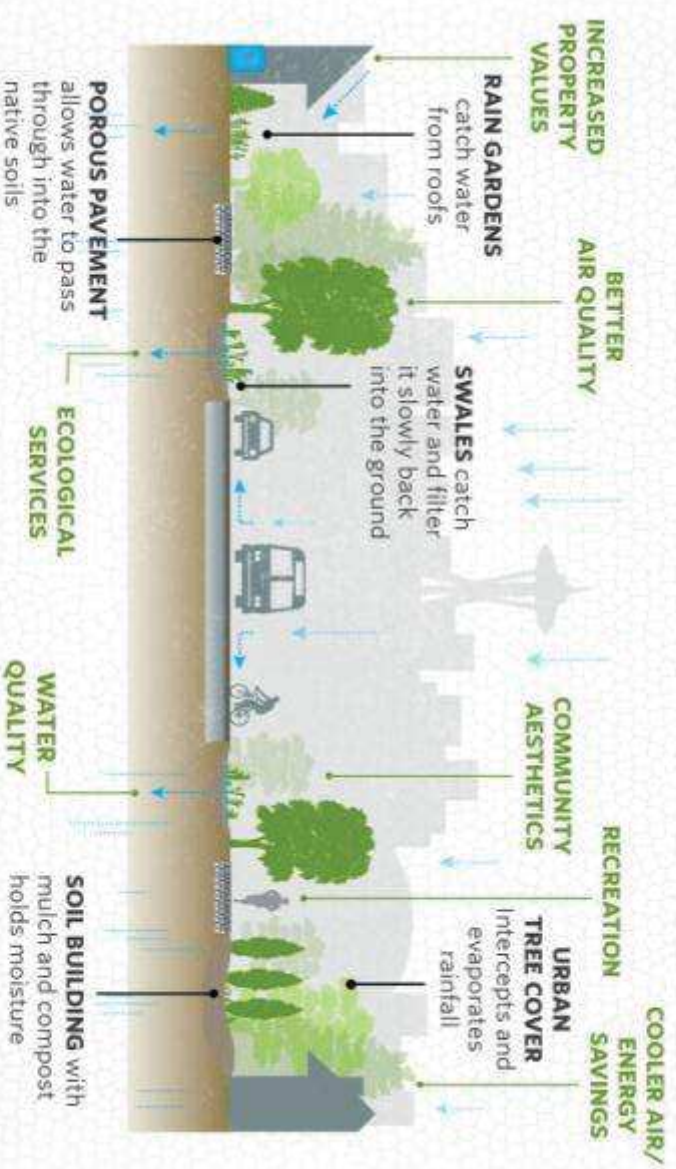
# Green Infrastructure for stormwater managing

## Il problema



## HOW ARE WE RETHINKING THE PROBLEM?

Re-envisioning and re-designing cities to function more like forests, so water is absorbed back into the ground, in addition to treating stormwater through traditional means, will solve our region-wide stormwater problem.



**GREEN & GRAY STORMWATER INFRASTRUCTURE**

A study by the city of Philadelphia has shown a hybrid approach of green and gray infrastructure can get the same freshwater solutions as gray infrastructure, plus additional benefits to the community.

Data Source: City of Philadelphia Water Department  
Infographic © TMC/Drlica Simsek Shonker

# Green Infrastructure for stormwater managing

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Table 1 Green Infrastructure solutions for water resources management

Water management issue (Primary services to be provided)	Green infrastructure solution	Location				Corresponding City Infrastructure solution (at the primary service level)	
		Watershed	Floodplain	Urban	Coastal		
Water supply regulation (incl. drought mitigation)	Re/afforestation and forest conservation					Dams and ground-water pumping Water distribution systems	
	Reconnecting rivers to floodplains						
	Wetlands restoration/conservation						
	Constructing wetlands						
	Water harvesting*						
	Green spaces (bioretention and infiltration)						
	Permeable pavements*						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
Water quality regulation	Wetlands restoration/conservation					Water treatment plant	
	Constructing wetlands						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
	Wetlands restoration/conservation						
	Constructing wetlands						
Erosion control	Green spaces (shading of water ways)					Reinforcement of slopes	
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
	Wetlands restoration/conservation						
	Constructing wetlands						
	Green spaces (shading of water ways)						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
Biological control	Wetlands restoration/conservation					Dams	
	Constructing wetlands						
	Green spaces (shading of water ways)						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
	Wetlands restoration/conservation						
	Constructing wetlands						
	Green spaces (shading of water ways)						
	Re/afforestation and forest conservation						
Water temperature control	Green spaces (shading of water ways)					Dams and levees	
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
	Wetlands restoration/conservation						
	Constructing wetlands						
	Green spaces (shading of water ways)						
	Re/afforestation and forest conservation						
	Riparian buffers						
	Reconnecting rivers to floodplains						
Riverine flood control	Wetlands restoration/conservation					Dams and levees	
	Constructing wetlands						
	Establishing flood bypasses						
	Green roofs						
	Water harvesting*						
	Permeable pavements*						
	Protecting/restoring mangroves, coastal marshes, and dunes						
	Protecting/restoring reefs (coral/oyster)						
	Urban stormwater runoff						Urban stormwater infrastructure
	Coastal flood (storm) control						
Moderation of extreme events (floods)	Urban stormwater runoff					Urban stormwater infrastructure	
	Coastal flood (storm) control						Sea walls





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## REGIONAL GREEN INFRASTRUCTURE STRATEGIES

Green infrastructure strategies capture stormwater, provide natural flood management, and bring a multitude of benefits to municipalities and residents. Each strategy shown below has already been implemented throughout the region, and much more is needed to achieve the 2035 Vision goals. The Plan focuses heavily on the strategies that would treat impervious surfaces and turf grass areas to provide economic, social, and environmental benefits to the region.

### GREEN ROOFS

Business owners and public property owners with large flat roofs were included in the Plan and are encouraged to participate in the Regional Green Roof Initiative Program.

### POROUS PAVEMENT

The Plan recommends use of porous materials for public and private streets and parking lots.

### GREEN ALLEYS, STREETS, AND PARKING LOTS

The Plan calls for green alleys, streets, and parking lots that include several green infrastructure strategies, offering multiple economic, social, and environmental benefits.

### RAIN GARDENS AND SOIL AMENDMENTS

The Plan encourages residents to plant rain gardens to prevent stormwater from entering the sewer system too quickly. The Plan includes soil amendments to increase water holding capacity in lawns and improve grass growth where native landscaping is not preferred.

### WETLANDS

Wetlands (not quantified in this Plan) also known as bays, marshes, and lagoons allow stormwater to pool and slowly infiltrate into the ground.

### RAINWATER CATCHMENT

The Plan encourages residents and business owners to harvest rainwater. Doing so reduces energy costs and reduces untreated stormwater from entering the sewer system.

### NATIVE LANDSCAPING

The Plan encourages the public, business owners, and municipalities to replace turf grass with native landscaping to reduce runoff and save money through reduced landscape maintenance.

### BIORETENTION/BIOSWALES

Retention and bioswales can be used along transportation corridors and parking lots.

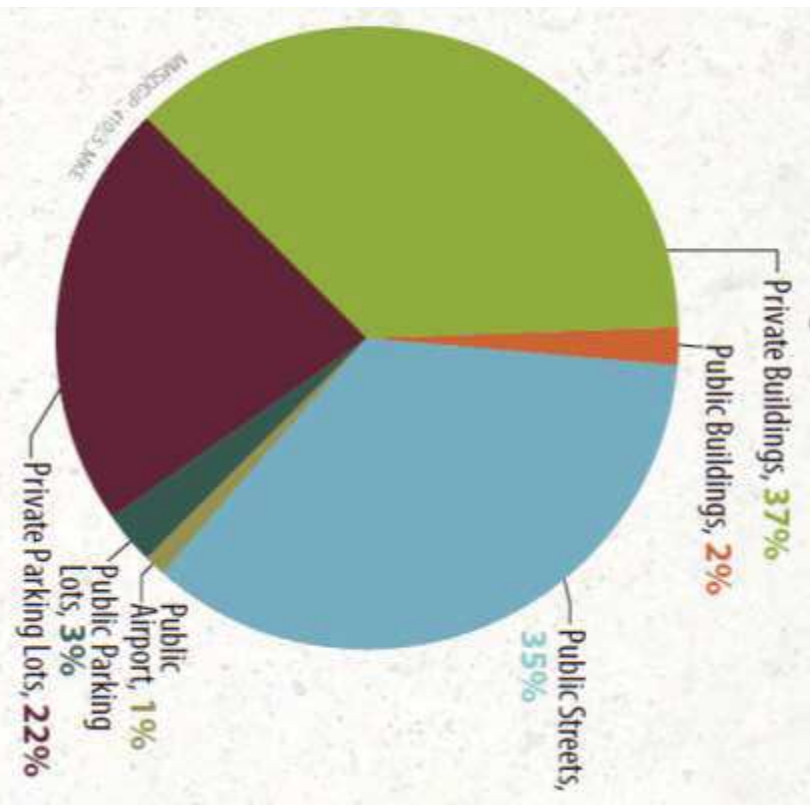
### STORMWATER TREES

The Plan encourages municipalities to plant trees. They hold stormwater on their leaves and branches, infiltrate it into the ground, absorb it through root systems and evaporate it to the atmosphere.

### GREENWAYS

Greenways (not quantified in this Plan) include riparian and non-riparian buffer zones and retain their store and from stormwater runoff into the ground naturally.

Impervious Area by Type and Ownership  
in the MMSD Planning Area



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# Green Stormwater Infrastructure

GSI Tool	How it Works	Benefits	GSI Tool	How it Works	Benefits
<b>Bio-retention</b>	<p>SOAKS IN SLOWS CLEANS</p>	<ul style="list-style-type: none"> <li>Can manage large amounts of runoff</li> <li>Can be designed for site traffic</li> <li>Adds beauty, shade, and green space</li> <li>Provides additional stormwater storage</li> <li>Can be used for Green Factor requirements</li> </ul>	<b>Permeable Paving</b>	<p>SOAKS IN</p>	<ul style="list-style-type: none"> <li>Manages runoff and increases absorbable storage for cars and people</li> <li>Can add visual interest/design detail</li> </ul>
<b>Rain Gardens</b>	<p>SOAKS IN SLOWS CLEANS</p>	<ul style="list-style-type: none"> <li>Manages runoff from roofs, patios, driveways</li> <li>Adds beauty and habitat to your property</li> <li>No technical knowledge is required for maintenance</li> </ul>	<b>Green Roofs</b>	<p>SLOWS LIMBS/RETAINS</p>	<ul style="list-style-type: none"> <li>Adds more green space to your property</li> <li>Adds habitat for birds and beneficial insects</li> <li>Improves air quality</li> <li>Has potential for LEED® credits</li> <li>May be integrated for food production</li> </ul>
<b>Stormwater Cisterns</b>	<p>SLOWS STORES + RELEASES</p>	<ul style="list-style-type: none"> <li>Easy to design, install, and maintain</li> <li>During storms, cisterns store water to prevent additional runoff</li> <li>During storms, water can be used for irrigation and can reduce overall water use</li> </ul>	<b>Depaving</b>	<p>SLOWS SOAKS IN</p>	<ul style="list-style-type: none"> <li>Removes up to 90% of runoff from paved areas for trees, plantings, and other uses, including GSI</li> <li>Allows stormwater to sink into the ground where it helps recharge aquifers and carry pollutants less readily to and within streams</li> <li>Can restore habitats for birds, insects, and other wildlife</li> </ul>
<b>Dispersion</b>	<p>SLOWS SOAKS IN</p>	<ul style="list-style-type: none"> <li>Manages runoff from roof gutters and downspouts</li> <li>Integrates well with other GSI</li> </ul>	<b>Tree Canopy</b>	<p>SLOWS EVAPORATES</p>	<ul style="list-style-type: none"> <li>Tree planting and care is easy and fun</li> <li>Maximize tree spacing for quality</li> <li>Plant other cool shade in summer and protect against harsh wind in winter</li> <li>Add beauty and green space to urban areas</li> </ul>
<b>Dry Well/ Infiltration Trench</b>	<p>SLOWS SOAKS IN</p>	<ul style="list-style-type: none"> <li>Manages runoff from roof gutters and downspouts</li> <li>Integrates well with other GSI</li> </ul>	<b>Compost &amp; Mulch</b>	<p>SLOWS SOAKS IN</p>	<ul style="list-style-type: none"> <li>Mulching is easy</li> <li>Applying soil with compost helps soil work in and holds moisture back in place</li> <li>Soils needed by reducing need for irrigation, fertilizers and pesticides</li> </ul>
<b>Biofiltration</b>	<p>SLOWS CLEANS</p>	<ul style="list-style-type: none"> <li>Open large amounts of runoff</li> <li>Can add beauty and habitat to a range of sites</li> </ul>			

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## Green Stormwater Infrastructure in Seattle

[www.700MillionGallons.org](http://www.700MillionGallons.org)

Working Together to Protect our Waterways



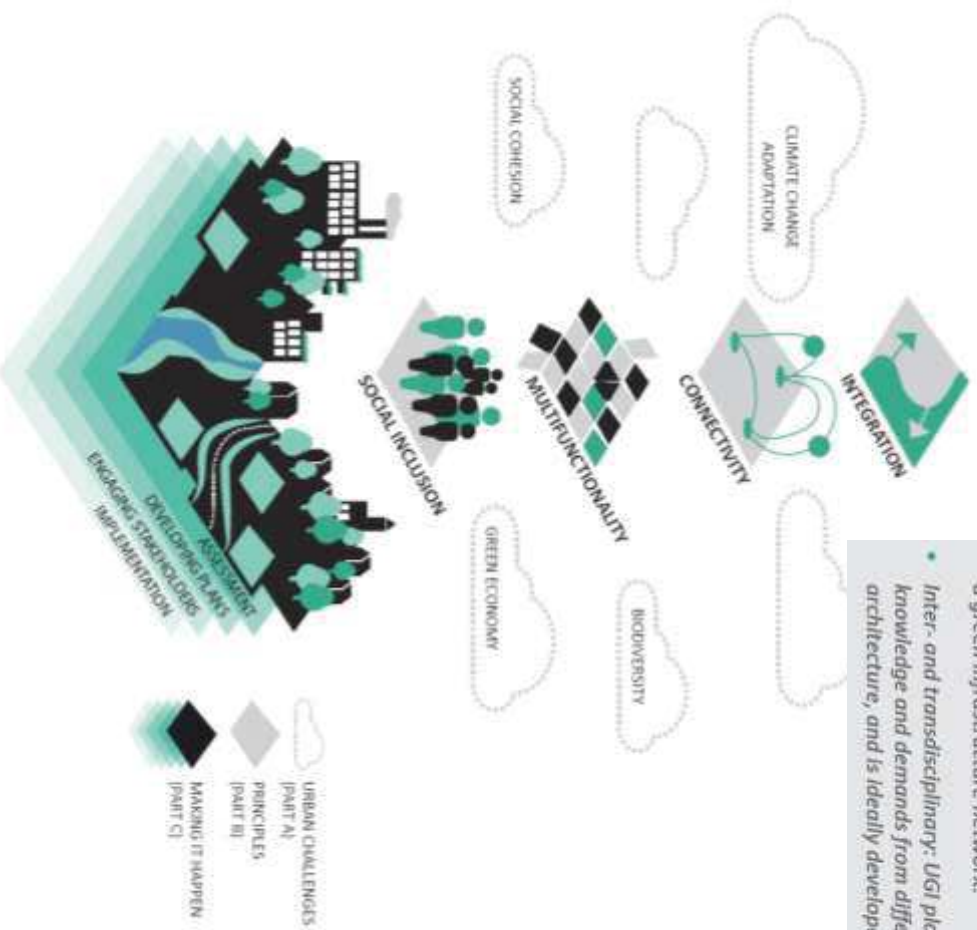
# Urban Green Infrastructure

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## SUPPORTING PRINCIPLES

While the four core principles provide a fundamental basis for UGI planning, certain supporting principles should be also taken into account:

- **Multi-scale:** UGI planning aims to link different spatial levels, ranging from metropolitan regions to individual sites.
- **Multi-object:** All types of urban green and blue spaces, regardless of ownership and origin, can be considered as part of a green infrastructure network.
- **Inter- and transdisciplinary:** UGI planning aims at linking disciplines, as well as science, policy and practice. It integrates knowledge and demands from different fields, such as landscape ecology, urban and regional planning, and landscape architecture, and is ideally developed in partnership between local authorities and other stakeholders.



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# Urban Green Infrastructure

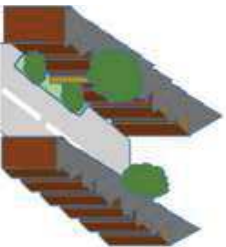
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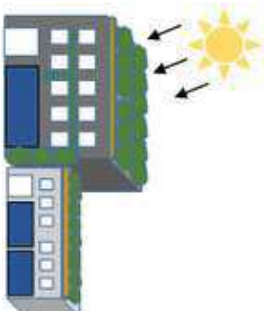
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Roadside vegetation in the form of bioswales can reduce runoff from impervious surfaces. The key factor is degree of permeability of the soil which can be enhanced through the selection of different vegetation.



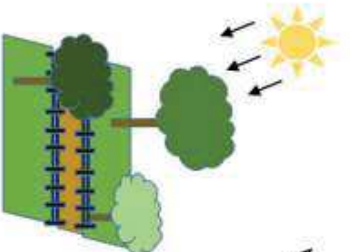
Street vegetation can help to provide shade, as well as a greater sense of wellbeing for residents in urban areas. It can also be used to create green corridors to improve biodiversity.



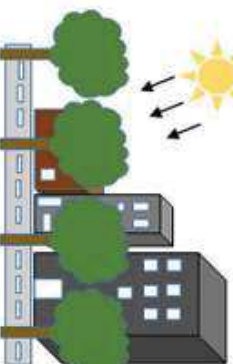
Direct application of plants to the building envelope. Green walls (vine coverage or specially designed modules), and green roofs can contribute to building thermoregulation.



Courtyards have been part of vernacular architecture in tropical climates for centuries. When combined with passive ventilation systems they provide cooler air at ground level.



Urban parks can be vital to biodiversity in the urban ecosystem as well as providing space for recreation. Green spaces like parks can sequester more CO<sub>2</sub> than previously assumed and also contribute heavily to absorbing storm water.

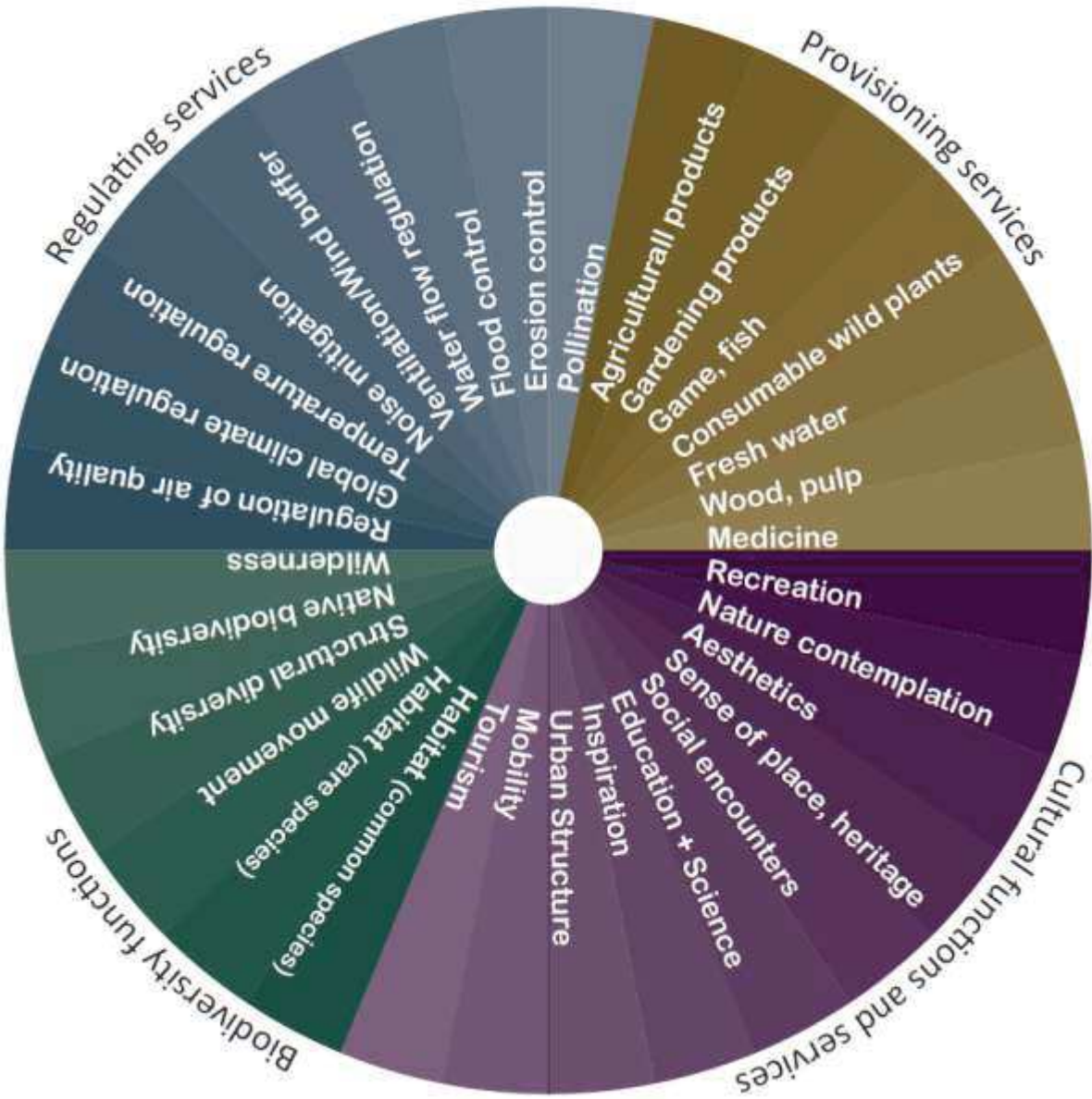


Street trees contribute to the fixation of CO<sub>2</sub> and remediation of air pollution. When designed correctly they also provide shading and run-off reduction benefits. Different species are more suited to these application than others

**Green Infrastructure.**  
**The integration of plants**  
**in the urban environment**



# Urban Green Infrastructure



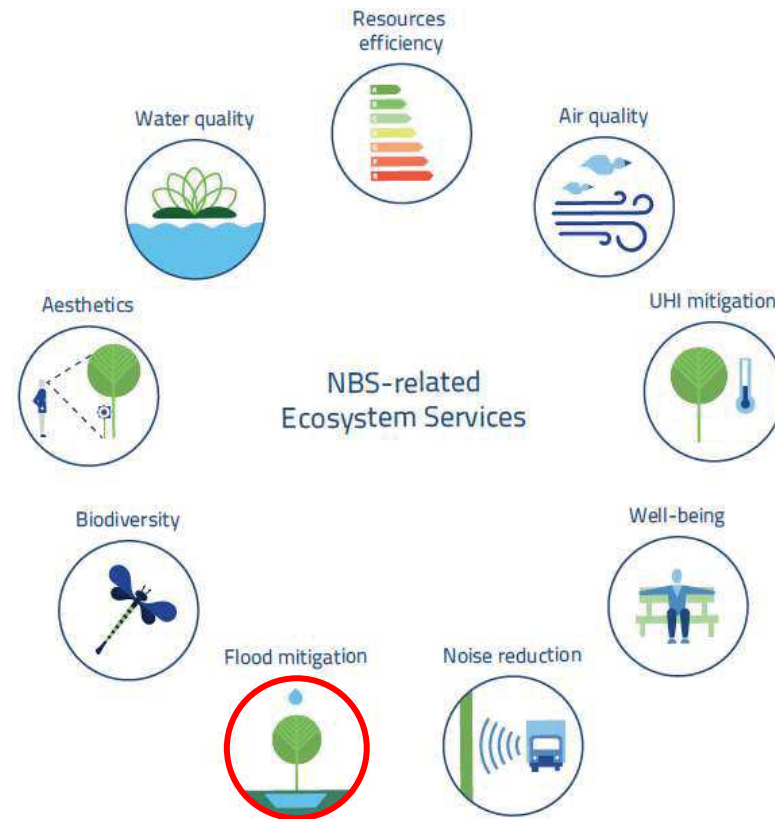
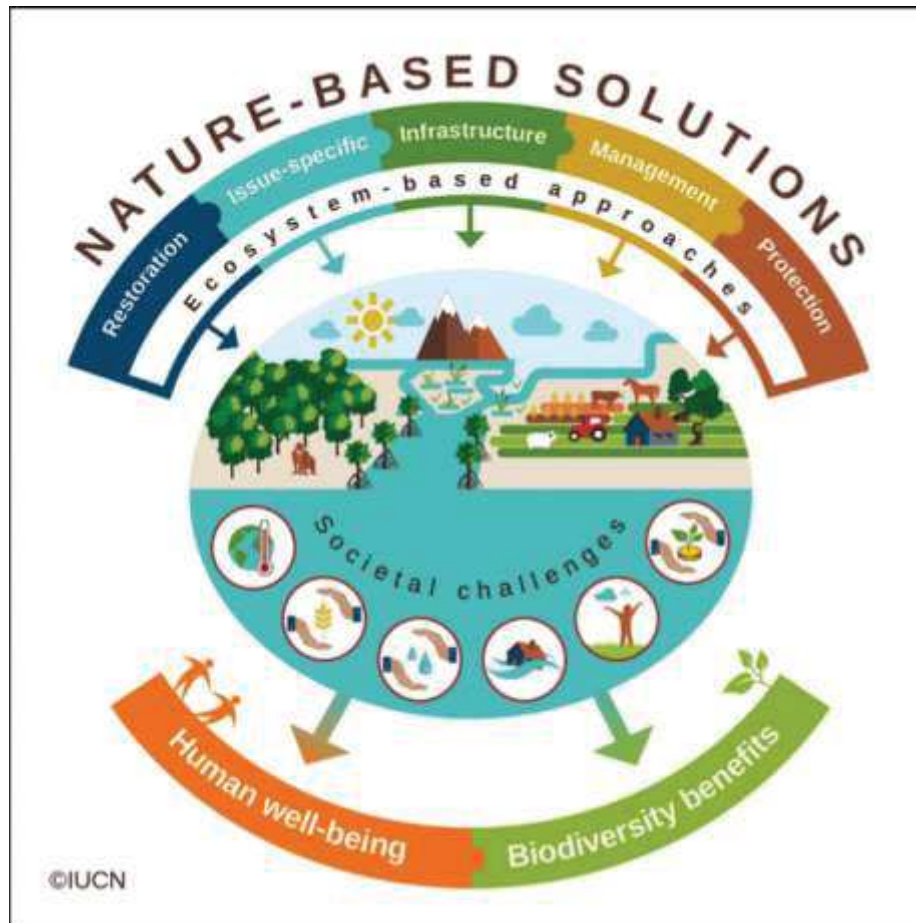
Urban green spaces provide a range of functions and services which can be grouped into four broad types.  
Credit: Rieke Hansen



# NatureBased Solutions

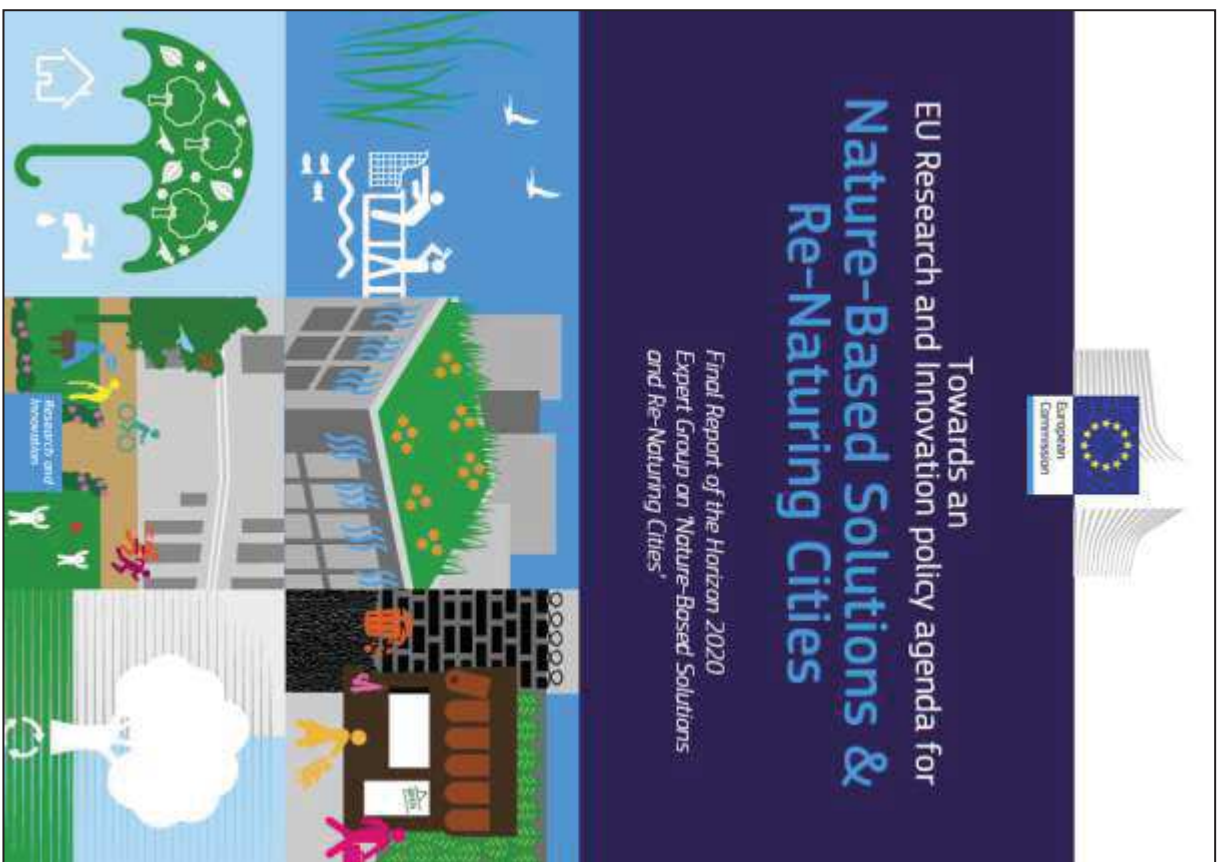
NatureBased Solutions (NBSs) are **actions** to **protect**, sustainably **manage**, and **restore** natural or modified **ecosystems**, that address societal challenges effectively and adaptively, **simultaneously providing human well-being and biodiversity benefits** (IUNC, 2016).

NBSs **range in scale**, from individual street **trees**, **green roofs** and **private gardens** through to **parks**, **rivers** and **woodlands**, **transport corridors**, and, at the larger scale, **wetlands**, **forests** and **agricultural land**.



# NatureBased Solutions

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Research & Innovation Agenda on Nature-Based Solutions and Re-Naturing Cities	
Goals	Research & Innovation Actions
Enhancing sustainable urbanisation	Urban regeneration through nature-based solutions
Restoring degraded ecosystems	Nature-based solutions for improving well-being in urban areas
Developing climate change adaptation and mitigation	Establishing nature-based solutions for coastal resilience
Improving risk management and resilience	Multi-functional nature-based watershed management and ecosystem restoration
	Nature-based solutions for increasing the sustainable use of matter and energy
	Nature-based solutions for enhancing the insurance value of ecosystems
	Increasing carbon sequestration through nature-based solutions



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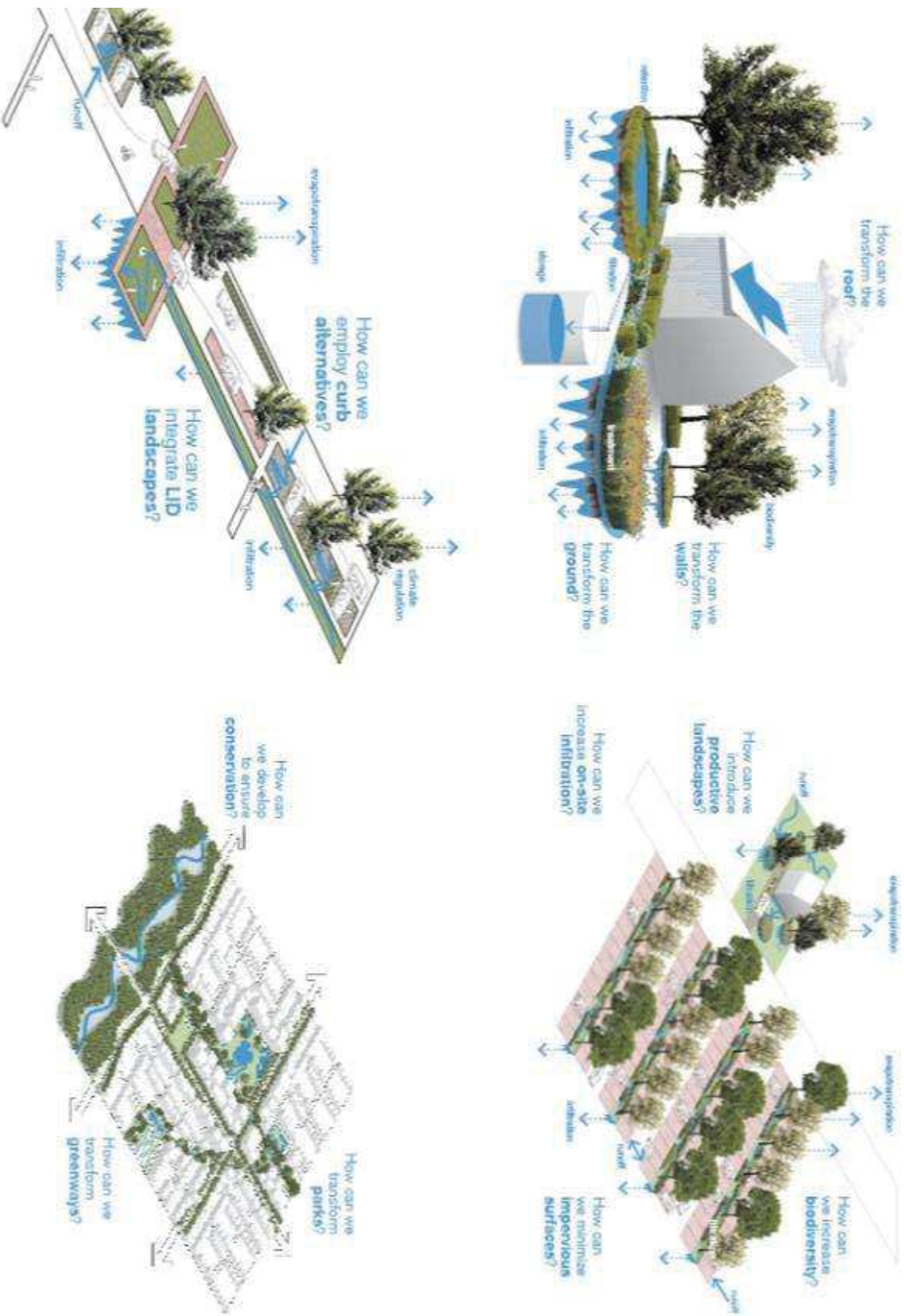
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# NatureBased Solutions at different scales

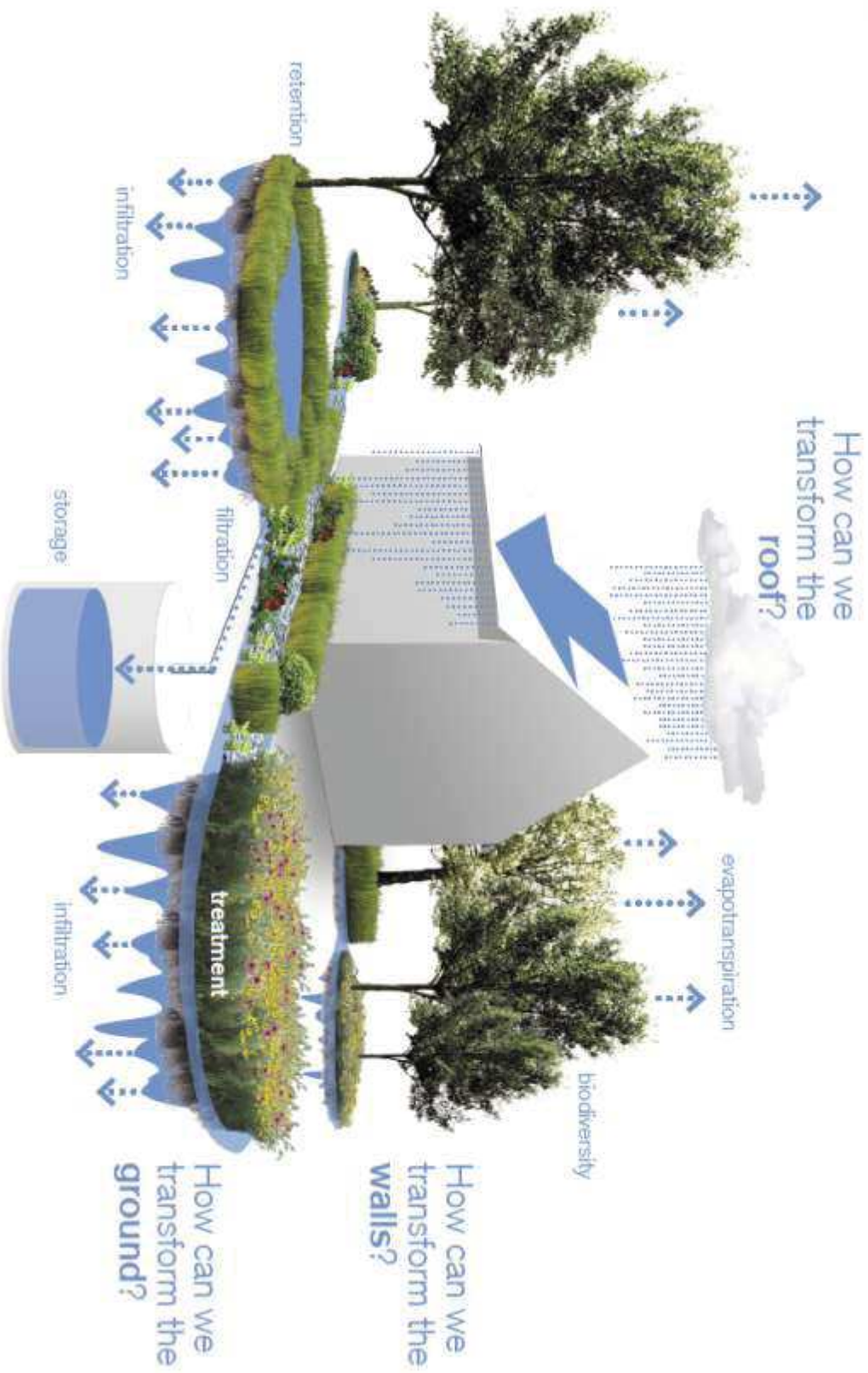
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# NatureBased Solutions at different scales



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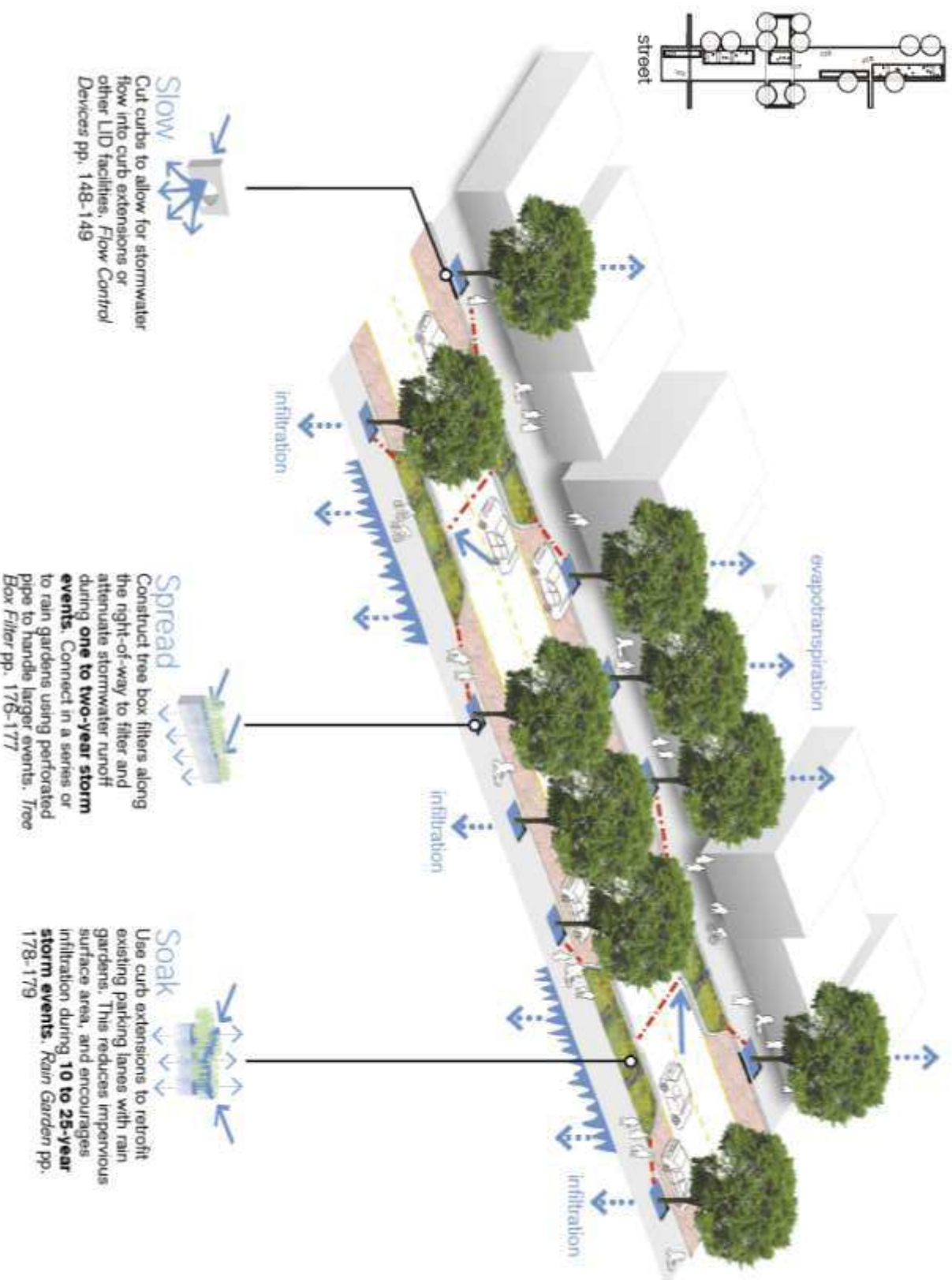
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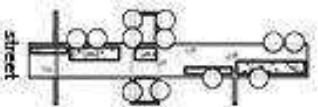
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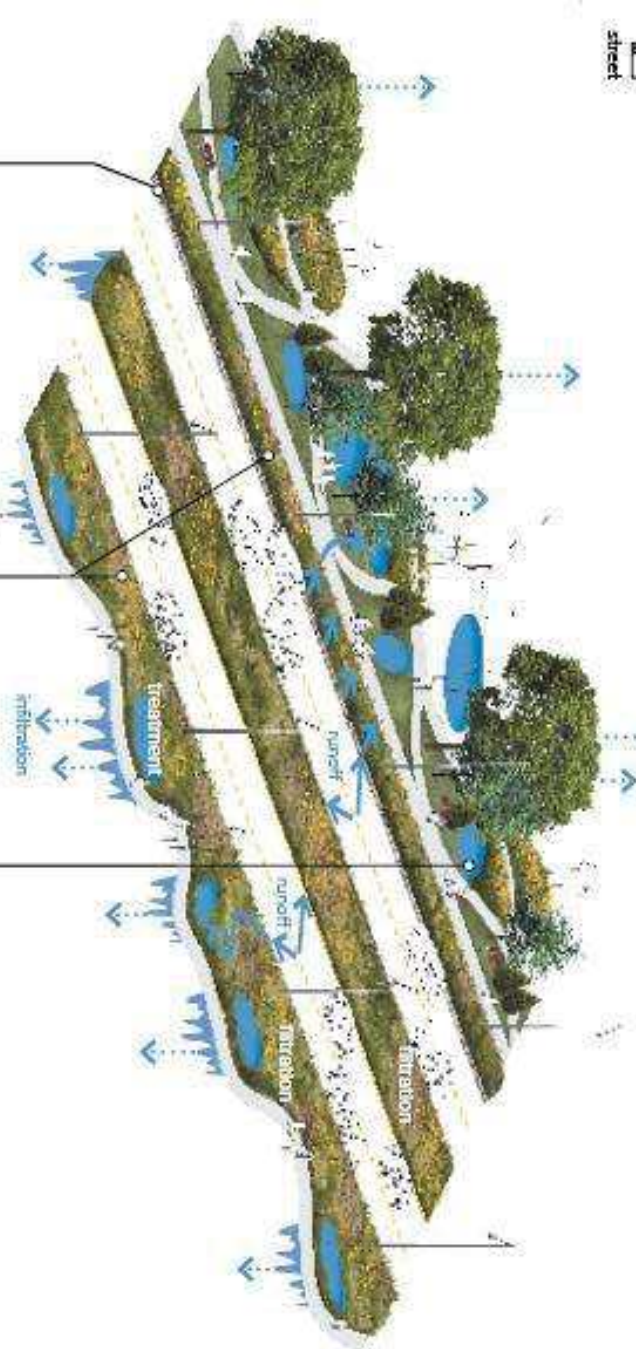
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# NatureBased Solutions at different scales



evapotranspiration



**Slow**  
Use a level appender to transform concentrated stormwater runoff into sheet flow for distribution over a filter strip. Flow Control Devices pp. 148-149



**Spread**  
Use filter strips to filter pollutants out of stormwater runoff and safely separate bicycle lanes from faster automobile traffic. Filter Strip pp. 162-168



**Soak**  
Design infiltration facilities along the highway that encourage outdoor exercise and alternative modes of transportation, managing stormwater runoff from 25 to 30-year storm events. Infiltration Basin pp. 184-185



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# NatureBased Solutions at different scales

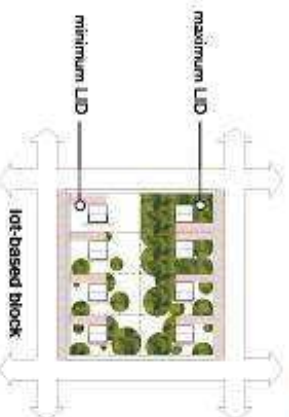
## Lot Design



residential water use in the US is currently used for landscaping.

One-third of all

Property owners can implement varying degrees of LID on their lots.



**F**or property owners, one of the easiest ways to adapt LID to existing sites is by installing rain gardens in low lying areas. More holistic measures involve replacing existing lawns with native or local vegetation as well as replacing drives and walks with pervious paving. Before digging, however, make sure to contact a central agency or your local utility companies to locate all existing underground utilities.

For new construction, site planning should include measures that minimize impervious surfaces, protect ecologically sensitive areas of the site, and increase infiltration through the use of vegetation. Consider measures like reducing the length of driveways, limiting regrading of existing topography, minimizing building footprints, and protecting existing vegetation.



**Slow**  
Use pervious parking for water and trees. Pervious Parking Pp. 172-178

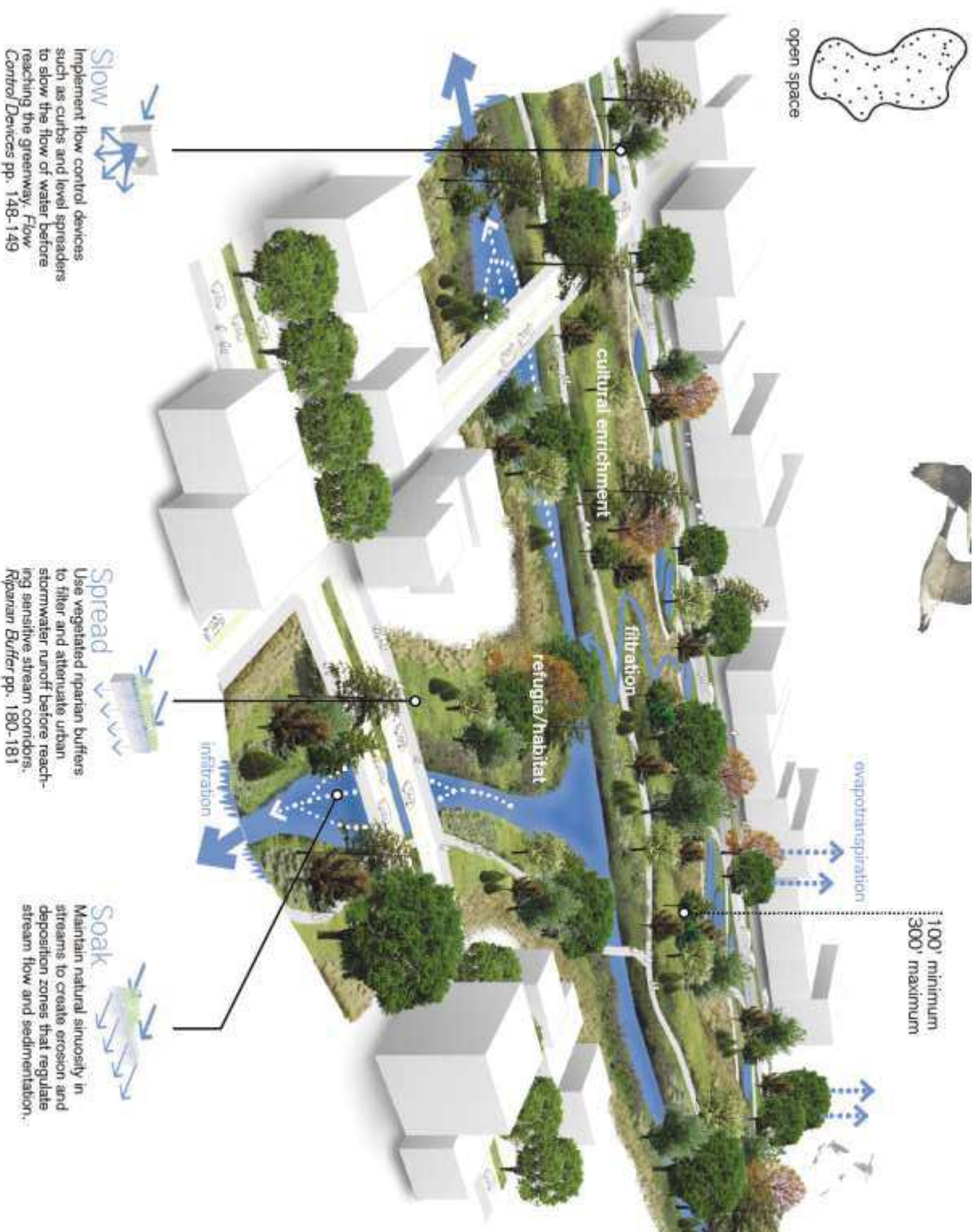


**Spread**  
Use rain gardens to treat the first flush of any storm event and mitigate runoff from one to ten-year storm events. Rain Garden pp. 178-179



**Soak**  
Replace residential lawn with xeriscape lawn to treat and mitigate runoff from one to twenty-five-year storm events. Consult local nurseries or a landscape design professional for optimal seed mix and plants.

# NatureBased Solutions at different scales



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# NatureBased Solutions at different scales



The building – home, garden or workspace	Connections	The street	Connections	Neighbourhood	Connections	Strategic places
<ul style="list-style-type: none"> <li>• Green roofs</li> <li>• Living walls</li> <li>• Landscaping or grounds</li> <li>• Rainwater harvesting systems</li> <li>• Bioremediation (detachable)</li> </ul>	<ul style="list-style-type: none"> <li>• Pedestrian paths and rights of way</li> <li>• Cycling routes</li> <li>• Green Links and corridors</li> </ul>	<ul style="list-style-type: none"> <li>• Bioretention basins for runoff</li> <li>• Street trees</li> <li>• Verges</li> <li>• Swales</li> <li>• Pervious paving</li> <li>• Sustainable urban drainage systems (SUDS)</li> </ul>	<ul style="list-style-type: none"> <li>• Pedestrian paths and rights of way</li> <li>• Cycling routes</li> <li>• Green Links and corridors</li> </ul>	<ul style="list-style-type: none"> <li>• Activity greenhouses</li> <li>• Historic recreation spaces</li> <li>• Playparks</li> <li>• Allotments, community growing spaces</li> <li>• Playing fields</li> <li>• Sports areas</li> <li>• Urban parks</li> <li>• Rural grounds, cemeteries</li> <li>• Swales</li> <li>• Urban woodlands</li> <li>• Parks</li> <li>• Water channels</li> </ul>	<ul style="list-style-type: none"> <li>• Pedestrian paths and rights of way</li> <li>• Cycling routes</li> <li>• Green Links and corridors</li> <li>• River and canal corridors including their banks</li> </ul>	<ul style="list-style-type: none"> <li>• Civic open spaces</li> <li>• Public parks and gardens</li> <li>• Green Networks</li> <li>• Country &amp; Regional Parks</li> <li>• Natural/semi-natural green spaces</li> <li>• Forests and Woodlands</li> <li>• Grasslands</li> <li>• Designed landscapes</li> <li>• Formal gardens</li> <li>• City farms</li> <li>• Blue Networks</li> <li>• Rivers, lochs and Wetlands</li> </ul>



# NatureBased Solutions

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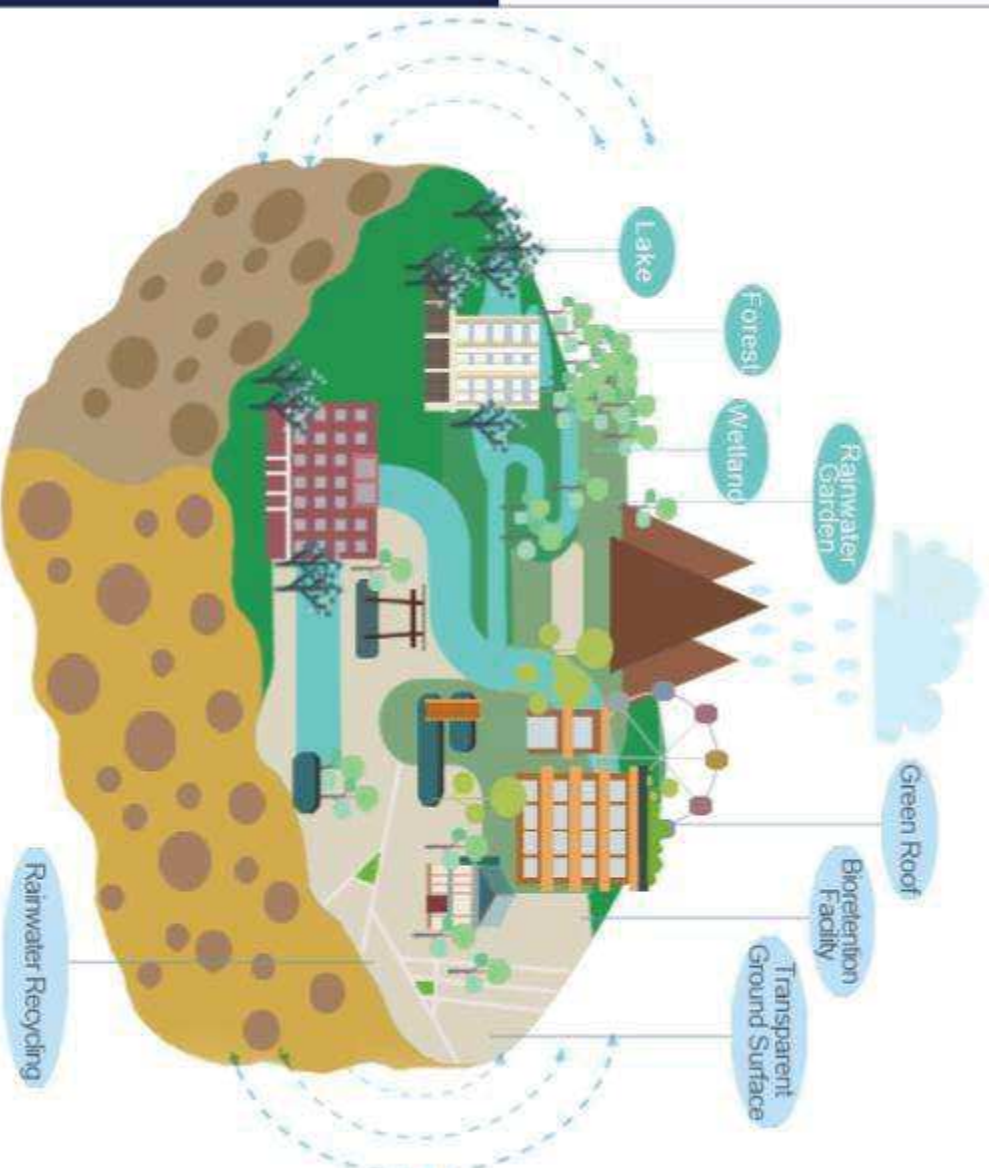
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# NatureBased Solutions - Sponge City

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A "Sponge city" refers to a city where its urban underground water system operates like a sponge to absorb, store, leak and purify rainwater, and release it for reuse when necessary.

**WILSON CENTER**  
CHINA'S PUSH FOR GREEN (NOT GRAY) INFRASTRUCTURE

30 Chinese cities will each receive 400-600 million RMB to pilot green roofs, constructed wetlands, increased tree cover, and permeable pavements to capture, slow down and filter storm water.

**SPONGE CITIES**

EXPERT PANEL: MASDAR AS A LEADER IN RESOURCE MANAGEMENT

Source: Wilson Center, China Daily

**Source**  
The magazine of the International Water Association

**Sponge cities**  
Can China's model go global?

Why Tehran's planners should look to the past

How to make your city water-wise

When relocation is the best form of resilience

May 2, Aug 2017

ISSN 1523-1566



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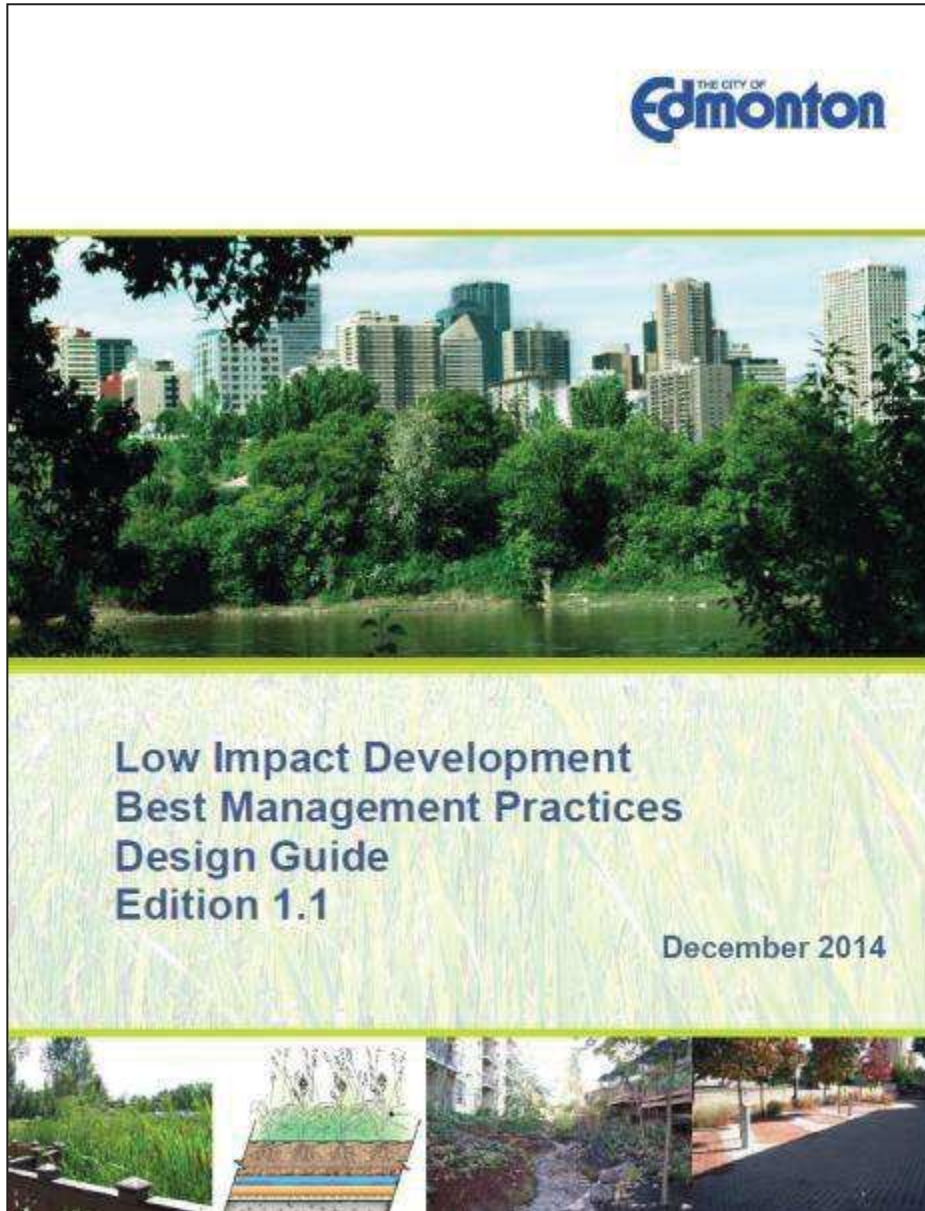
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# Low Impact Development

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The U.S. Environmental Protection Agency defines **Low Impact Development (LID)** as “*an approach to land development (or re-development) that **works with nature** to manage stormwater as close to its source as possible*” (US EPA, 2010).



# Low Impact Development

conventional development

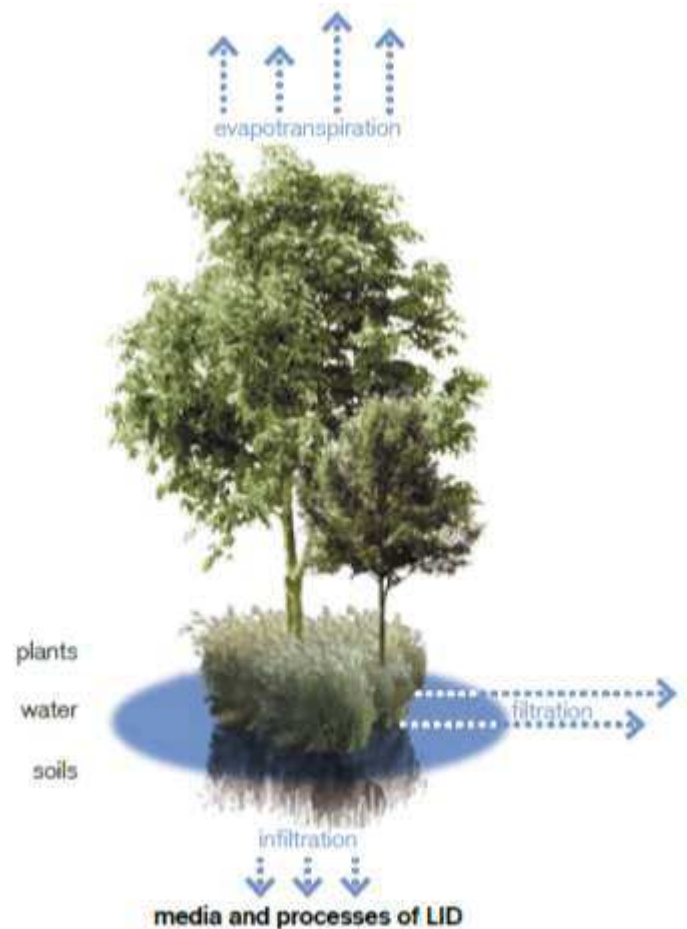


Conventional Development	
142 Lots	
0% Shared Open Space	
29% ImperVIOUS	
\$400K Stormwater Infrastructure	
\$2M Pavement Construction	

Comparative Site Data	
142 Lots	
50% Shared Open Space	
15% ImperVIOUS	
\$164K Stormwater Infrastructure	
\$663K Pavement Construction	

LID

# Low Impact Development - BMPs



The U.S. Environmental Protection Agency defines **Low Impact Development (LID)** as “*an approach to land development (or re-development) that works with nature to manage stormwater as close to its source as possible*” (US EPA, 2010).

**LID** best management practices (**BMPs**) are **techniques** that rely on **natural processes to manage water quantity and quality** (absorption, infiltration, evaporation, evapotranspiration, filtration).



# Low Impact Development - BMPs



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## LID-BMPs

- (1) bioretention/ rain gardens;
- (2) bioswales;
- (3) green roofs;
- (4) permeable pavements;
- (5) box planters;
- (6) naturalized drainage ways;
- (7) rainwater harvesting for re-use.



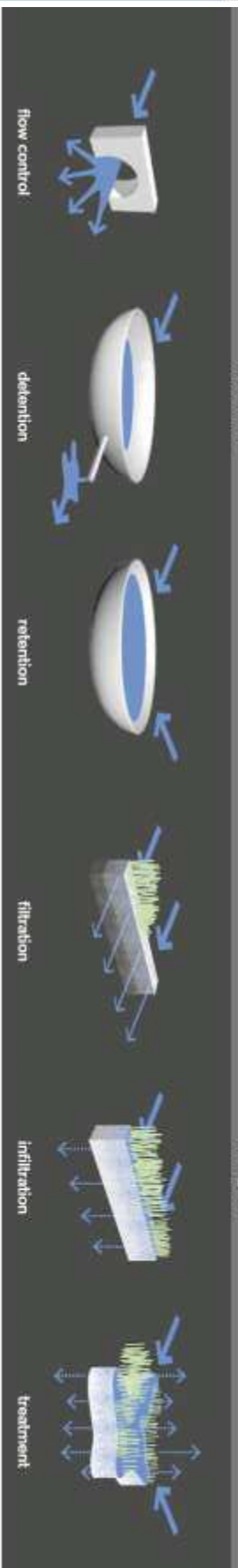
# Low Impact Development - BMPs

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mechanical

biological



slow

spread

soak

**flow control:** The regulation of stormwater runoff flow rates.

**detention:** The temporary storage of stormwater runoff in underground vaults, ponds, or depressed areas to allow for metered discharge that reduce peak flow rates.

**retention:** The storage of stormwater runoff on site to allow for sedimentation of suspended solids.

**filtration:** The sequestration of sediment from stormwater runoff through a porous media such as sand, a porous rock system, or a man-made filter.

**infiltration:** The vertical movement of stormwater runoff through soil, rootwings groundwater.

**treatment:** Processes that utilize phyto remediation or bacterias colonies to metabolize contaminants in stormwater runoff.



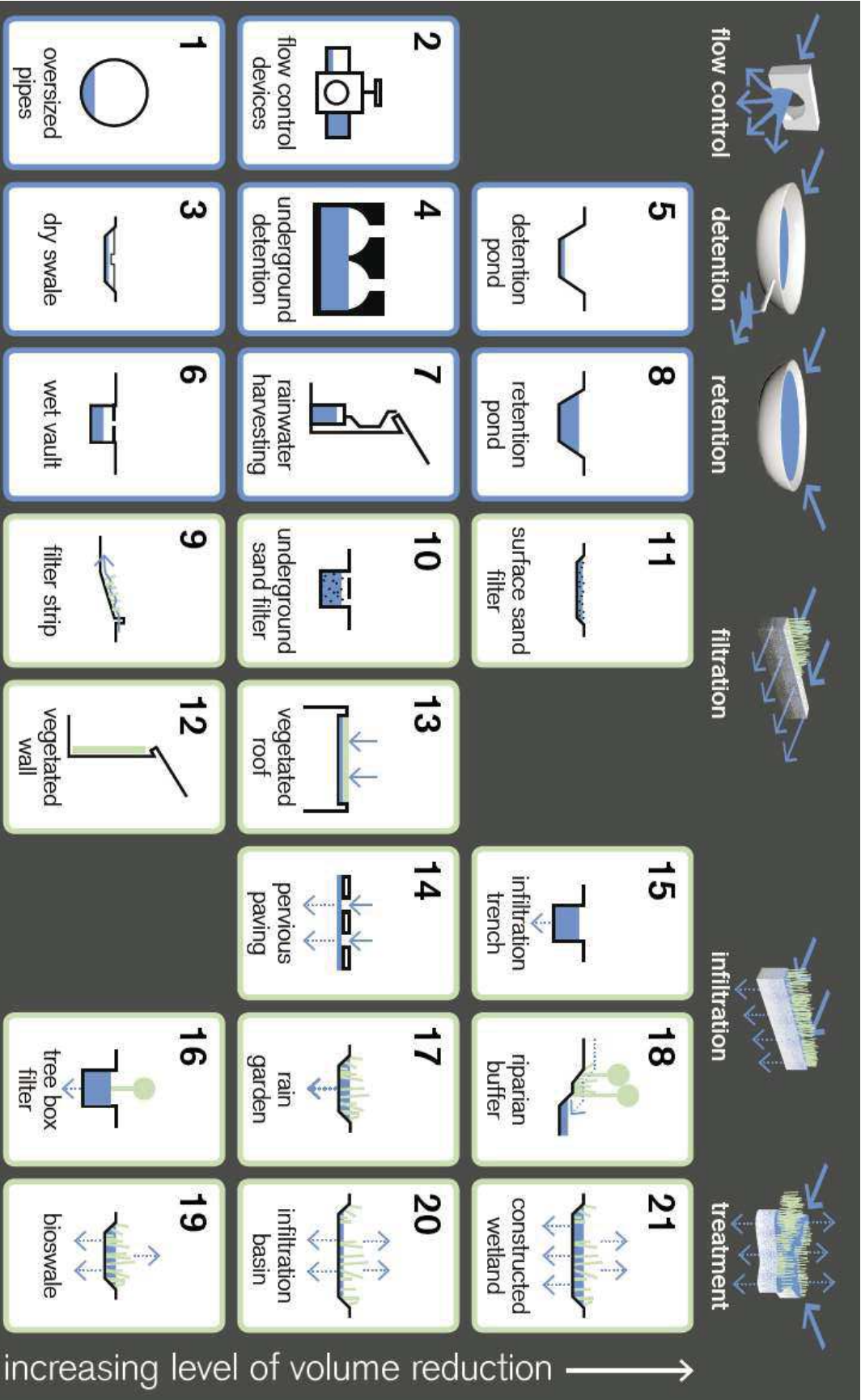
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# Low Impact Development - BMPs

Il ruolo del verde urbano  
Giulio Senes



from mechanical

LID facilities menu

to biological



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# Natural Water Retention Measures

**Natural Water Retention Measures** or NWRM are measures with the primary function of **enhancing and/or restoring the retention capacity of natural and man-made soil and aquatic ecosystems**. As a result, they deliver a range of services and multiple benefits to people while contributing to the achievement of the objectives of different environmental strategies and policies.

The application of NWRM **supports green infrastructure**, improves the quantitative status of water bodies as such, and reduces the vulnerability to floods and droughts.

(European Commission, 2014)



A2	Buffer strips and hedges	F1	Forest riparian buffers
A3	Crop rotation	F4	Targeted planting for catching precipitation
U3	Permeable surfaces	N2	Wetland restoration and management
U11	Retention ponds	N4	Re-meandering





# Natural Water Retention Measures

Natural Water Retention Measures or NWRM are measures with the primary function of enhancing and/or restoring the retention capacity of natural and man-made soil and aquatic ecosystems.

The application of NWRM **supports green infrastructure**, improves the quantitative status of water bodies as such, and reduces the vulnerability to floods and droughts.

(European Commission, 2014)

		Mechanisms of Water Retention							Biophysical Impacts Resulting from Water Retention									
		Slowing and Storing Runoff				Reducing Runoff			Reducing Pollution		Soil Conservation		Creating Habitat		Climate Attenuation			
		BP1	BP2	BP3	BP4	BP5	BP6	BP7	BP8	BP9	BP10	BP11	BP12	BP13	BP14	BP15	BP16	BP17
		Direct runoff	Over runoff	Storm flow volume	Over river water	Increase evapotranspiration	Increase infiltration and/or groundwater recharge	Increase soil water retention	Reduce Pollution Source	Interrupt Pollution Pathways	Reduce Erosion and/or Sediment Delivery	Improve Soils	Create Aquatic Habitat	Create Riparian Habitat	Create Terrestrial Habitat	Enhance Precipitation	Reduce Peak Temperature	Absorb and/or Retain CO <sub>2</sub>
U1	Green roofs	Medium	Medium	None	None	High	None	None	None	None	None	None	None	None	None	None	None	None
U2	Rainwater harvesting	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U3	Permeable paving	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U4	Soaks	None	High	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U5	Channels and silt	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U6	Fiber strips	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U7	Soakaways	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U8	Infiltration trenches	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U9	Rain gardens	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U10	Detention basins	High	High	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U11	Retention ponds	High	High	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None
U12	Infiltration basins	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None	None

Legend: Qualitative Scale

High	Dark Blue
Medium	Light Blue
Low	Very Light Blue
None	White
Negative	Red



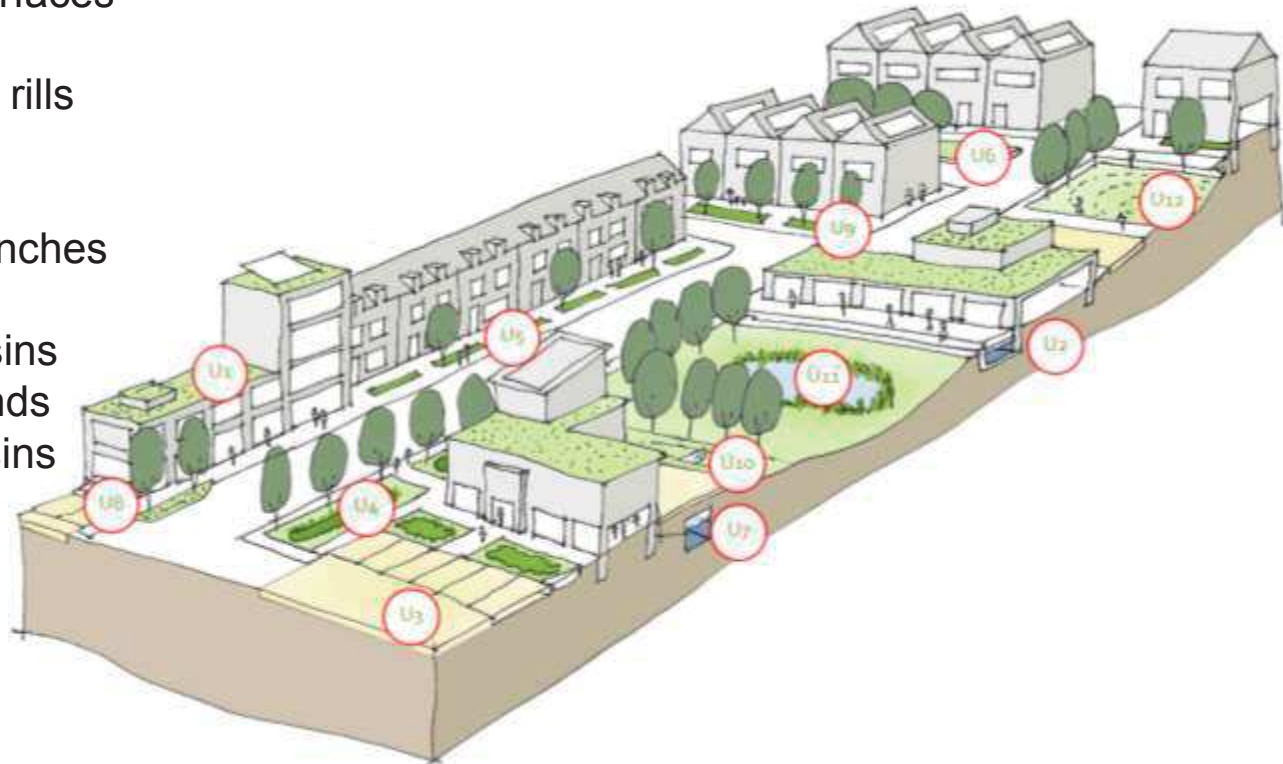
# Natural Water Retention Measures

**Natural Water Retention Measures** or NWRM are measures with the primary function of enhancing and/or restoring the retention capacity of natural and man-made soil and aquatic ecosystems.

The application of NWRM **supports green infrastructure**, improves the quantitative status of water bodies as such, and reduces the vulnerability to floods and droughts.

(European Commission, 2014)

- U01 Green Roofs
- U02 Rainwater Harvesting
- U03 Permeable surfaces
- U04 Swales
- U05 Channels and rills
- U06 Filter Strips
- U07 Soakaways
- U08 Infiltration Trenches
- U09 Rain Gardens
- U10 Detention Basins
- U11 Retention Ponds
- U12 Infiltration basins



# Rain gardens

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# Rain gardens



A rain garden may look similar to a street tree pit or a small garden, but there are some key differences. Here's how you can tell the difference:

- 1. Curb inlet** - The inlet allows water to flow into the rain garden as it flows down the curb toward the catch basin.
- 2. Outlet** - Larger rain gardens also have an outlet. If the rain garden fills to capacity, water can exit through the outlet and continue into the catch basin on the street corner.
- 3. Stone Strip** - The stone strip allows people to step out of their cars without damaging the plants

- 4. Plants** - All rain gardens have plants and grasses which have been carefully selected to ensure they can survive on busy New York City streets.
- 5. Soil** - The soil is graded so that water ponds in the center of the rain garden.
- 6. Tree Guard** - All rain gardens have tree guards around them that protect the plants and keep people and dogs from walking inside of it.
- 7. Tree** - DEP plants trees in rain gardens as often as possible. Trees benefit neighborhoods by lowering temperatures in hot summer months, improving air quality, and providing habitat for birds and butterflies.

# Rain gardens

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**Rain gardens are planted areas designed to collect and manage stormwater that runs off the streets and sidewalks when it rains.**









# Residential rainwater harvesting



## + Benefits

### STORMWATER MANAGEMENT

- Runoff reduction
- Retention

### ADDITIONAL

- Aesthetic quality
- Stores stormwater for alternative use

## + Cost & Maintenance Considerations

- Cost: Low
- Stormwater as irrigation supply offsets utility costs
- Maintenance: Low
- Inspect after storm events for debris and proper inflow/outflow
- Install gutter screens to minimize debris
- Install a first flush diverter to minimize debris and potential contaminants
- Periodically drain unused water to prevent insect breeding
- Disconnect inlet and drain in freezing temperatures

## + Construction & Site Considerations

- Use a dark colored, opaque storage device and locate in shade to decrease algae growth
- Locate near landscape areas requiring frequent irrigation
- Petroleum-based and treated wood products are known to leach toxins into rainwater that pose health risks if consumed. Rainwater collected from these surfaces is only suitable for irrigating ornamental landscapes. Metal roofs (except copper and those with lead components) are generally regarded as ideal for rainwater harvesting. Consult with a professional regarding allowable uses and potential treatment requirements for harvested rainwater



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# Permeable paving

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## PERMEABLE PAVING

Benefits:

### STORMWATER MANAGEMENT

- Runoff reduction
- Retention
- Infiltration
- Filtration

### ADDITIONAL

- Aesthetic quality
- Provides additional pervious surfaces
- Improves air quality
- Educational opportunity

### Cost & Maintenance Considerations

- Cost: Medium to High
- Maintenance: High
- Vacuum twice annually to maintain permeability
- Pre-treat water flowing onto permeable paving with a filtration BMP

### Construction & Site Considerations

- Not suitable for sites with hazardous materials or high sediment runoff
- Variations on construction details are available for sites with soils with low infiltration rates
- Adaptable to a wide variety of site designs
- Research load-bearing capacity of pervious materials against anticipated vehicle types and traffic pattern
- Parking lots sloped greater than 5% require special consideration for subsurface grading and drainage



# Permeable paving

## Permeable Pavement

Permeable Asphalt

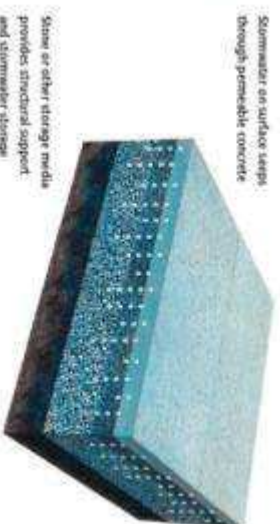
Stormwater on surface seeps through permeable asphalt



Stone or other storage media provides structural support and stormwater storage

Permeable Concrete

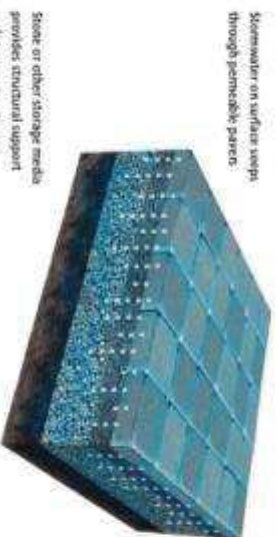
Stormwater on surface seeps through permeable concrete



Stone or other storage media provides structural support and stormwater storage

Permeable Paver

Stormwater on surface seeps through permeable pavers



Stone or other storage media provides structural support and stormwater storage



Waterview Recreation Center





# Green roofs



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## VEGETATED ROOF

### + Benefits

#### STORMWATER MANAGEMENT

- Runoff reduction
- Retention
- Evapotranspiration
- Filtration
- Extended biological treatment

#### ADDITIONAL

- Aesthetic quality
- Provides additional pervious surfaces
- Improves air quality
- Educational opportunity

### + Cost & Maintenance Considerations

- Cost: Medium to High (extensive), High (intensive)
- Added insulation and evaporative cooling may reduce utility costs
- Maintenance: Low to Medium (extensive), High (intensive)

### + Construction & Site Considerations

- Requires adequate roof structure; consult with a structural engineer for both new construction and potential retrofit applications
- Intensive green roofs can provide additional habitable amenity space



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# Tree box



## TREE BOX



### Benefits

#### STORMWATER MANAGEMENT

- Runoff reduction
- Retention
- Evapotranspiration

- Extended biological treatment

#### ADDITIONAL

- Aesthetic quality
- Provides additional pervious surfaces
- Improves air quality



### Cost & Maintenance Considerations

- Cost: Medium
- Maintenance: Medium
- Periodically test soil for high contamination levels and replace if necessary
- Periodically aerate soil
- Remove litter and debris after storm events



### Construction & Site Considerations

- Tree boxes can be implemented in dense urban areas
- Research and choose trees appropriate to site cultural conditions
- Provide grate over root zone if implemented in high foot traffic areas
- Avoid low spots



### Contaminant Removal

- Suspended Solids
- Nutrients
- Heavy Metals



# Tree box

## Stormwater Tree



Stormwater Tree Precedent

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# Bioretention cell



## BIORETENTION CELL

### Benefits

#### STORMWATER MANAGEMENT

- Runoff Reduction
- Retention
- Infiltration
- Evapotranspiration
- Extended biological treatment

#### ADDITIONAL

- Wildlife habitat
- Aesthetic quality
- Provides additional pervious surfaces
- Improves air quality
- Educational opportunity

#### Cost & Maintenance Considerations

- Cost: Medium to High
- Maintenance: Medium to High
- Inspect monthly and after large storm events
- Inspect inlet/outlet for blockages such as plant debris/litter

#### Construction & Site Considerations

- Locate at least 2 feet above groundwater table
- Site slope should be less than 20%.

#### Contaminant Removal

- Suspended Solids
- Nutrients
- Heavy Metals



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# Bioretention cell

## Stormwater Planter



Columbus Square

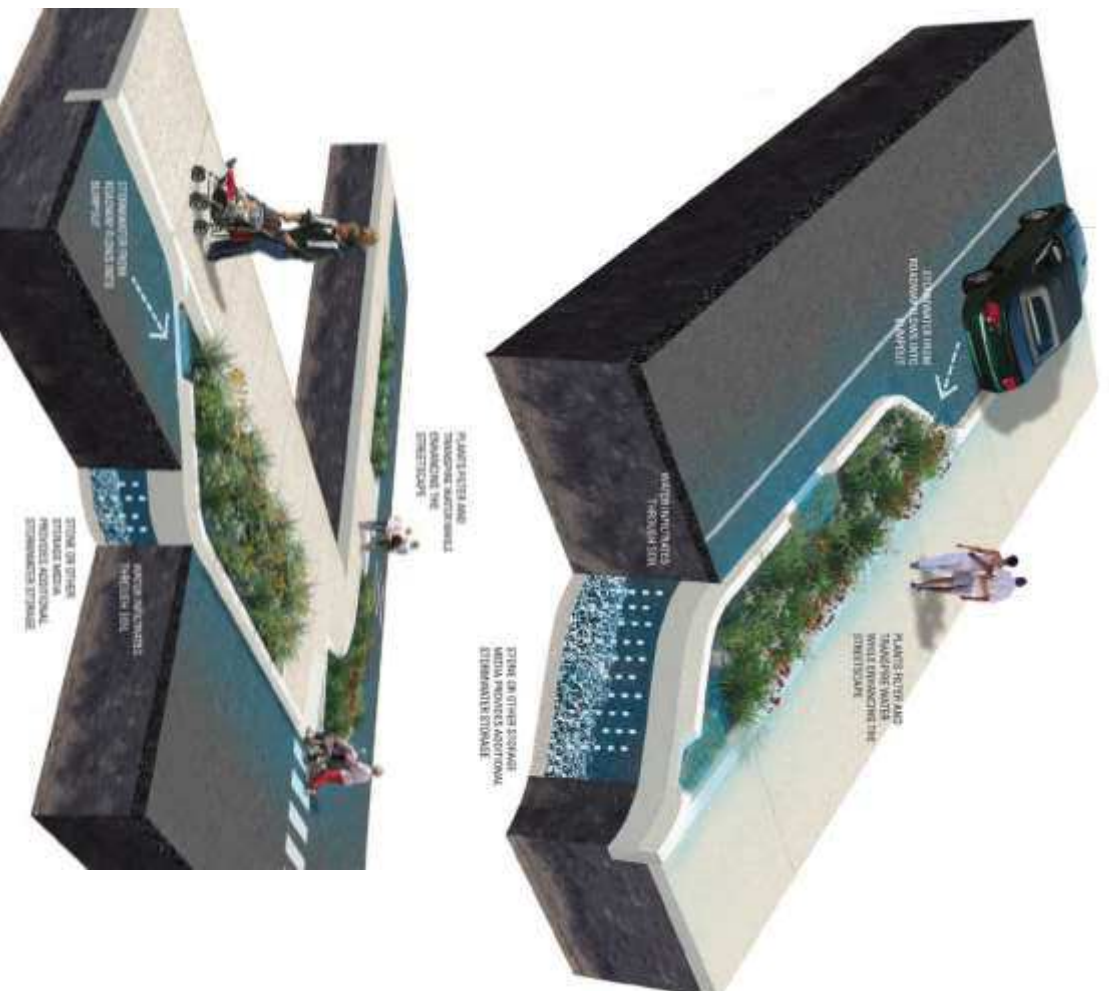


The Philadelphia Navy Yard



# Bioretention cell

## Stormwater Bump-out



Shepard Recreation Center Corner Bump-out



Queen Lane Mid-Block Bump-out



# Bioretention cell

## Green Gutter



# Bioretention cell

## Stormwater Drainage Well



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# Vegetated swale

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Stormwater Swale with Typical Features





# Stormwater trench

## Stormwater Tree Trench

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*Shissler Recreation Center*



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# Stormwater swale

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Figure 2.4.3: Installing the soil support system under the sidewalk on part of the Queensway in Toronto. (Source: Deep Root Inc.)



Figure 2.4.4: Sidewalk following construction, showing healthy trees. (Source: Deep Root Inc.)



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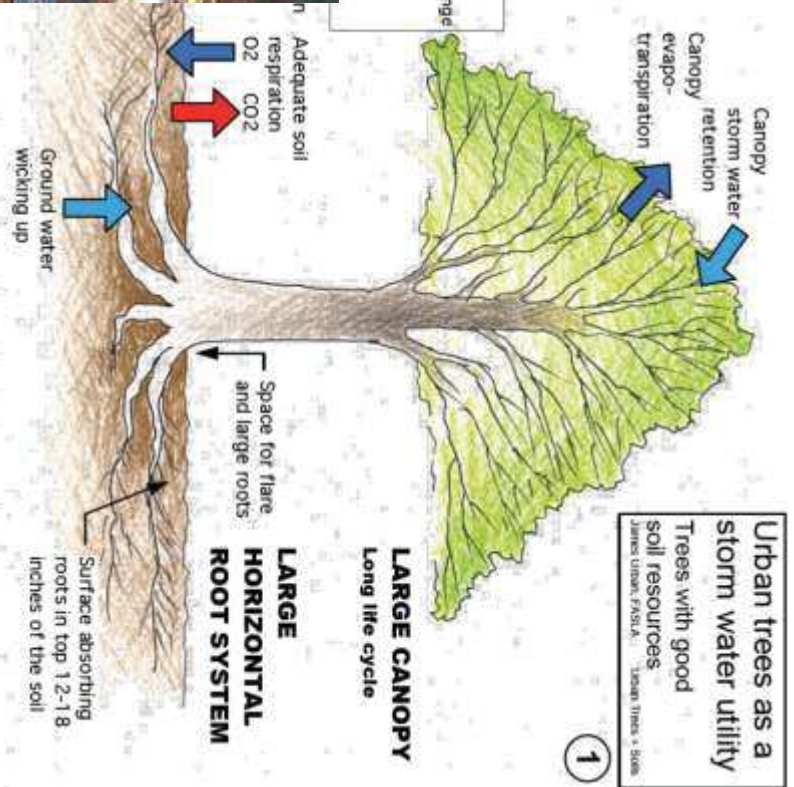


# Stormwater swale

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**SOIL CONDITIONS**  
Diverse, healthy soil biology  
High cation (nutrient) exchange capacity  
High water holding capacity  
Organic replacement  
Low Compaction



“Isola vegetativa”



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# Commercial rainwater harvesting



## COMMERCIAL RAINWATER HARVESTING



### Benefits

#### STORMWATER MANAGEMENT

- Runoff Reduction

- Retention

#### ADDITIONAL

- Stores stormwater for alternative reuse
- Aesthetic Quality

- Educational opportunity



### Cost & Maintenance Considerations

- Cost: Medium to High
- Irrigation with harvested rainwater can offset utility costs
- Maintenance: Medium
- Inspect after storm events for debris and proper inflow/outflow
- Install gutter screens to minimize debris
- Install a first flush diverter to minimize debris and potential contaminants
- Periodically drain/treat unused water to prevent insect breeding
- If located above freeze/thaw line, disconnect inlet and drain in freezing temperatures



### Construction & Site Considerations

- Size of storage facility based on rainfall patterns, rainfall intensity, roof size, and anticipated usage
- Possible odor if left stagnant and unused
- Storage vaults can be located above or below ground
- If above ground, use a dark colored, opaque storage device and locate in shade to decrease algae growth
- May be connected to an irrigation system
- Consult with a professional regarding allowable uses and potential treatment requirements for harvested rainwater



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# Sand filter

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## SAND FILTER

### Benefits

#### STORMWATER MANAGEMENT

- Extended biological treatment
- Sedimentation
- Filtration

### Cost & Maintenance Considerations

- Cost: Medium (Surface) to High (Underground)
- Maintenance: Medium to High
- Inspect at least once a month, or after large storm events
- Special disposal method may be required in cases of severe contamination

### Construction & Site Considerations

- Size: Approximately 2-3% of drainage area
- May require forebay in areas of high sediment runoff
- Vehicles should not drive on top of underground facilities
- Provide access to the devices for inspection/maintenance

### Stormwater Management Characteristics

- Suspended Solids
- Nutrients
- Heavy Metals
- Hydrocarbons

# Infiltration structure

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## INFILTRATION STRUCTURE



### Benefits

#### STORMWATER MANAGEMENT

- Runoff Reduction
- Retention

- Infiltration

#### ADDITIONAL

- Provides additional pervious surfaces
- Educational opportunity



### Cost & Maintenance Considerations

- Cost: Low to High
- Maintenance: Medium to High
- Can be difficult to access and perform maintenance
- Sub-surface storage decreases land area needed for stormwater management; opportunity to add value to property by preserving buildable space
- Maximum drainage area is approximately 2 acres
- Pre-treat contaminated runoff flowing onto infiltration structure with a filtration BMP



### Construction & Site Considerations

- Inspect for underlying karst topography
- Ideal for urban settings with limited space



### Contaminant Removal

- Hydrocarbons
- Heavy Metals



# Dry pond

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## VEGETATED DETENTION BASIN (Dry pond)

### Benefits

- Peak flow reduction
- Detention
- Sedimentation

### STORMWATER MANAGEMENT

- Wildlife habitat
- Aesthetic quality

### ADDITIONAL

- Provides additional pervious surfaces
- Improves air quality



### Cost & Maintenance Considerations

- Cost: Low to Medium
- Maintenance: Medium to High
- Long lasting and durable
- Annual sediment removal
- Inspect inlet/outlet for blockages such as plant debris/litter after storm events

### Construction & Site Considerations

- Size: Approximately 1-3% of drainage area
- Inspect for underlying karst geology
- Locate at least 2 feet above groundwater table
- Needs differential inlet and outlet elevation
- Locate in full sun

### Contaminant Removal

- Suspended Solids



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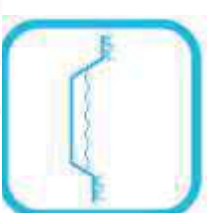
# Wet pond

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## WET POND



Benefits

**STORMWATER MANAGEMENT**

- Peak flow reduction
- Retention

- Sedimentation

**ADDITIONAL**

- Wildlife habitat

- Aesthetic quality



**Cost & Maintenance Considerations**

- Cost: Medium
- Maintenance: Medium to high
- Vegetation upkeep
- Pond aeration often required
- Inspect inlet/outlet for blockages such as plant debris/litter after storm events
- Requires base flow to prevent stagnation
- Avoid fertilizer use around wet pond
- Dredging necessary once a percentage of pool is replaced with accumulated sediment



**Construction & Site Considerations**

- Requires an impermeable liner/membrane or soil layer
- Inspect for underlying karst geology
- Permanent standing water may pose safety liability



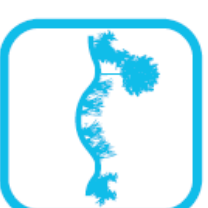
**Containment Removal**

- Suspended Solids



# Wetland

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## CONSTRUCTED WETLAND



Benefits

### STORMWATER MANAGEMENT

- Extended biological and chemical treatment
- Evapotranspiration
- Sedimentation
- Straining
- Filtration
- Peak flow reduction

### ADDITIONAL

- Wildlife habitat
- Aesthetic quality
- Improves air quality
- Educational opportunity



### Cost & Maintenance Considerations

- Cost: High
- Maintenance: Medium
- Soil may need to be replaced every 5-10 years due to buildup of contaminants
- Periodic removal of debris and trash
- Maintenance of vegetation to prevent undesirable species



### Construction & Site Considerations

- Applicable to large drainage areas
- High educational opportunity; good for school yards
- Safety challenges posed by standing water need to be considered and addressed
- Locate in full sun



### Contaminant Removal

- Suspended Solids
- Nutrients
- Heavy Metals



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# Filter strip

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## FILTER STRIP

### Benefits



#### STORMWATER MANAGEMENT

- Sedimentation
- Filtration

- Straining

#### ADDITIONAL

- Wildlife habitat

- Provides additional pervious surfaces



#### Cost & Maintenance Considerations

- Cost: Low
- Maintenance: Low
- Mow only in late winter, frequent mowing reduces effectiveness
- Stable groundcover must be maintained to ensure proper functioning of filter strip
- Occasional soil aeration may be required



#### Construction & Site Considerations

- Size: 50-100% of drainage area
- Drainage area not to exceed 150 linear feet
- 50% maximum slope
- Not applicable to high-density sites due to high square-footage required



#### Contaminant Removal

- Suspended Solids
- Nutrients (Incidental)
- Heavy Metals (Incidental)
- Litter





# Synthesis

## Cost Benefit Comparison

Direct Benefit Rating: ● High ○ Moderate ○ Low ⊖ None

### Boulevard bioretention units and permeable paver driveway:

- Direct benefits:**
- Volume reduction
  - Erosion control
  - Water quality
  - Flood control
- Indirect benefits:**
- ✔ Climate change mitigation & adaptation
  - ✔ Protect Great Lakes
  - ✔ Increase amenity value
  - ✔ Street greening
- Municipal Considerations:**
- ✔ Groundwater recharge
  - ✔ Improve baseflow
  - ✔ Helps to meet or exceed environmental strategic plan objectives
  - ✘ Impaired function from owner encroachment or lack of maintenance
  - ✘ Long-term soil replacement

**Best value \$895,000**

### Curb-and-gutter with stormwater management pond:

- Direct benefits:**
- Volume reduction
  - Erosion control
  - Water quality
  - Flood control
- Indirect benefits:**
- ✔ Maintains traditional road aesthetic
  - ✔ Protect Great Lakes
  - ✔ Help meet environmental strategic plan objectives
  - ✔ Open space amenity
- Municipal Considerations:**
- ✘ Higher maintenance costs
  - ✘ Increased erosion control costs
  - ✘ No groundwater recharge
  - ✘ Pond sediment clean out

**High cost, moderate benefits \$1,090,000**

### Conventional road reconstruction (curb-and-gutter):

- Direct benefits:**
- Volume reduction
  - Erosion control
  - Water quality
  - Flood control
- Indirect benefits:**
- ✔ Maintains traditional road aesthetic
- Municipal Considerations:**
- ✘ Downstream flood risk
  - ✘ Increased erosion control costs
  - ✘ Impaired water quality
  - ✘ Beach closures
  - ✘ Harm to fisheries
  - ✘ No groundwater recharge

**Lowest cost, few benefits \$635,000**

Figure 1.2.1: Comparison of road retrofit alternatives for a local residential road converting from a rural cross section to an urban cross section





# Biodiverse green roofs

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The image shows the cover page of the 'City of Toronto GUIDELINES for Biodiverse Green Roofs'. The title is prominently displayed in a green banner. Below the title, there are four icons: a blue cloud, a yellow sun, a blue square with white dots, and a green square with a white tree. To the right of these icons are four small images: a close-up of green plants, a view of a city skyline with a tree in the foreground, a cross-section diagram of a green roof, and a close-up of a green roof with plants. The background of the cover features a large photograph of a vibrant green roof with pink and white flowers. At the bottom, there are logos for 'Livegreen Toronto' and 'City of Toronto', along with two more cross-section diagrams of green roof structures.

# Biodiverse green roofs



**Increase Depth of Growing Media**

**Provide Microclimates**

rocks plants  
lots buildings elements

**Provide Nesting Opportunities**

Tall grasses and shrubs  
Logs and branches  
Bee nest boxes  
Birdhouses  
Open soil areas

**Vary Composition (Structure) of Growing Media**

vary granule size  
vary mixtures  
incorporate bare areas of gravel

**Provide Perching Habitat**

rocks forbs, grasses and shrubs  
branches and platforms logs

**Provide Topographic Variety**

**Diversify Plant Species**

**Provide Water Source(s)**

naturally pitted cap rock water features bird baths basins



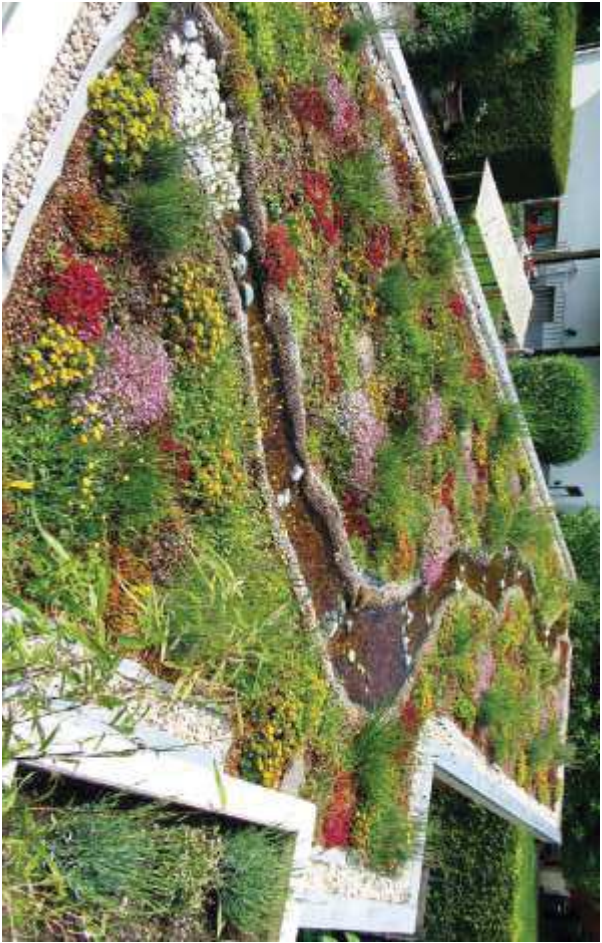


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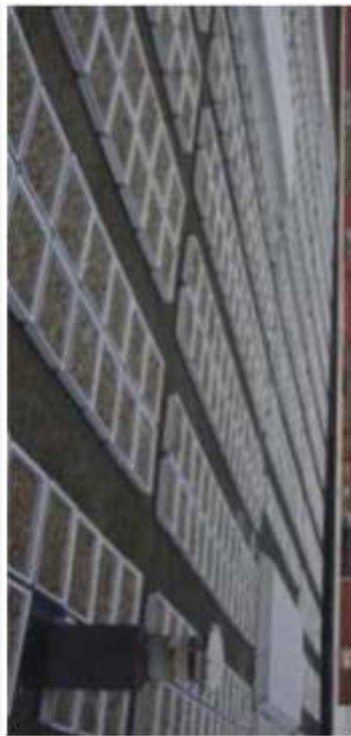
# Biodiverse green roofs





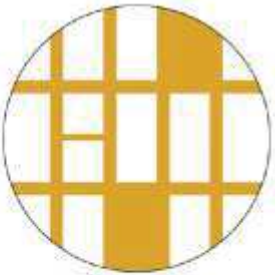


# Blue roofs

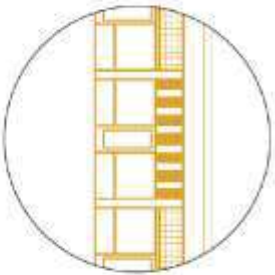




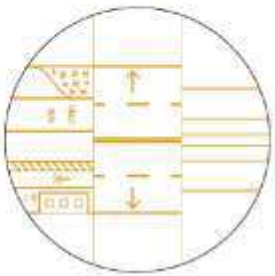
# Complete Streets



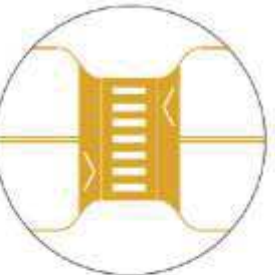
Streets Are  
Public Spaces



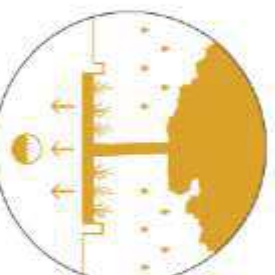
Great Streets are  
Great for Businesses



Streets Can  
Be Changed



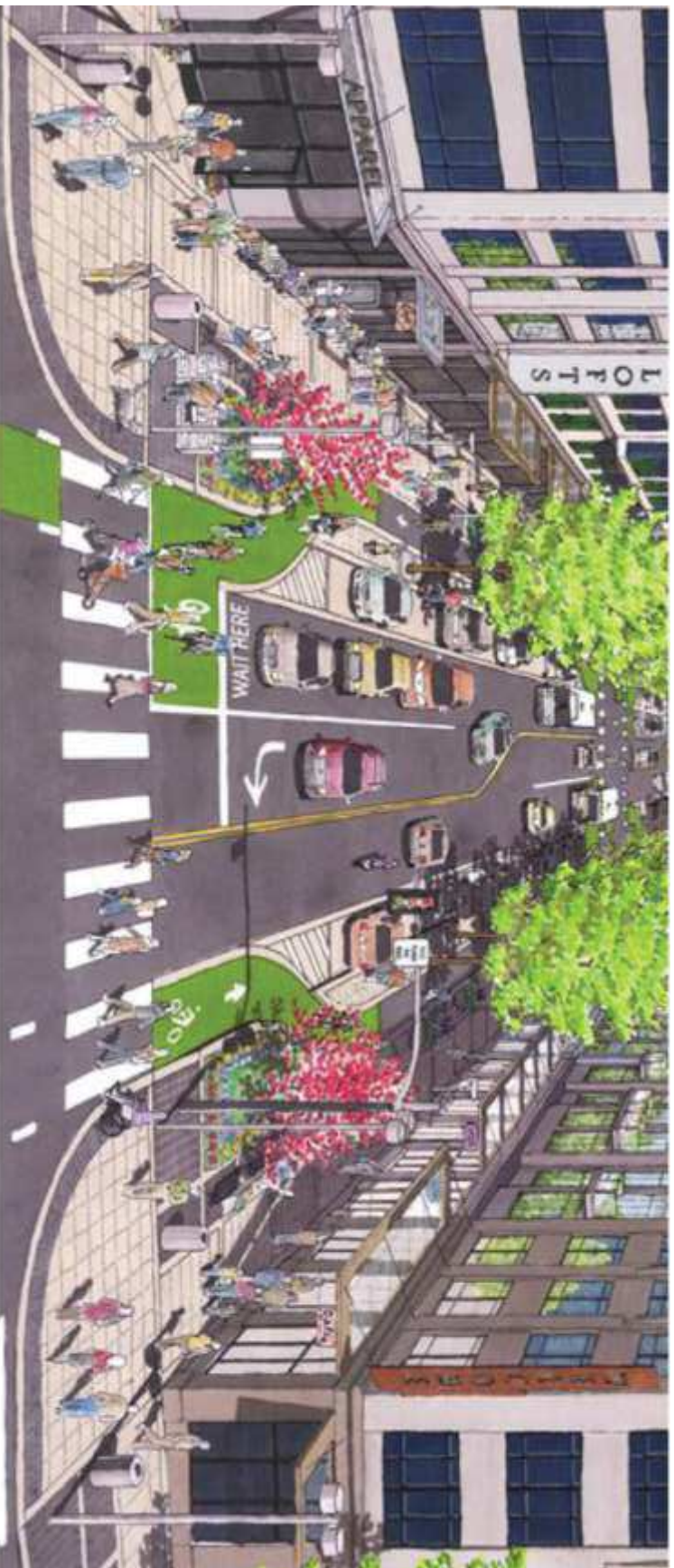
Design for  
Safety



Streets are  
Ecosystems



Act Now!



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Il ruolo del verde urbano  
Giulio Senes

# Complete Streets

Il ruolo del verde urbano  
Giulio Senes

Plazas - Rain  
Gardens



Planter Strips –  
Swales, Rain  
Gardens, Trees



Curb  
Extensions –  
Rain Gardens



Linked Tree  
Wells/Curbed  
Planters



Parking Lane –  
Permeable  
Paving, Rain  
Gardens



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# Green Streets





# Green Streets

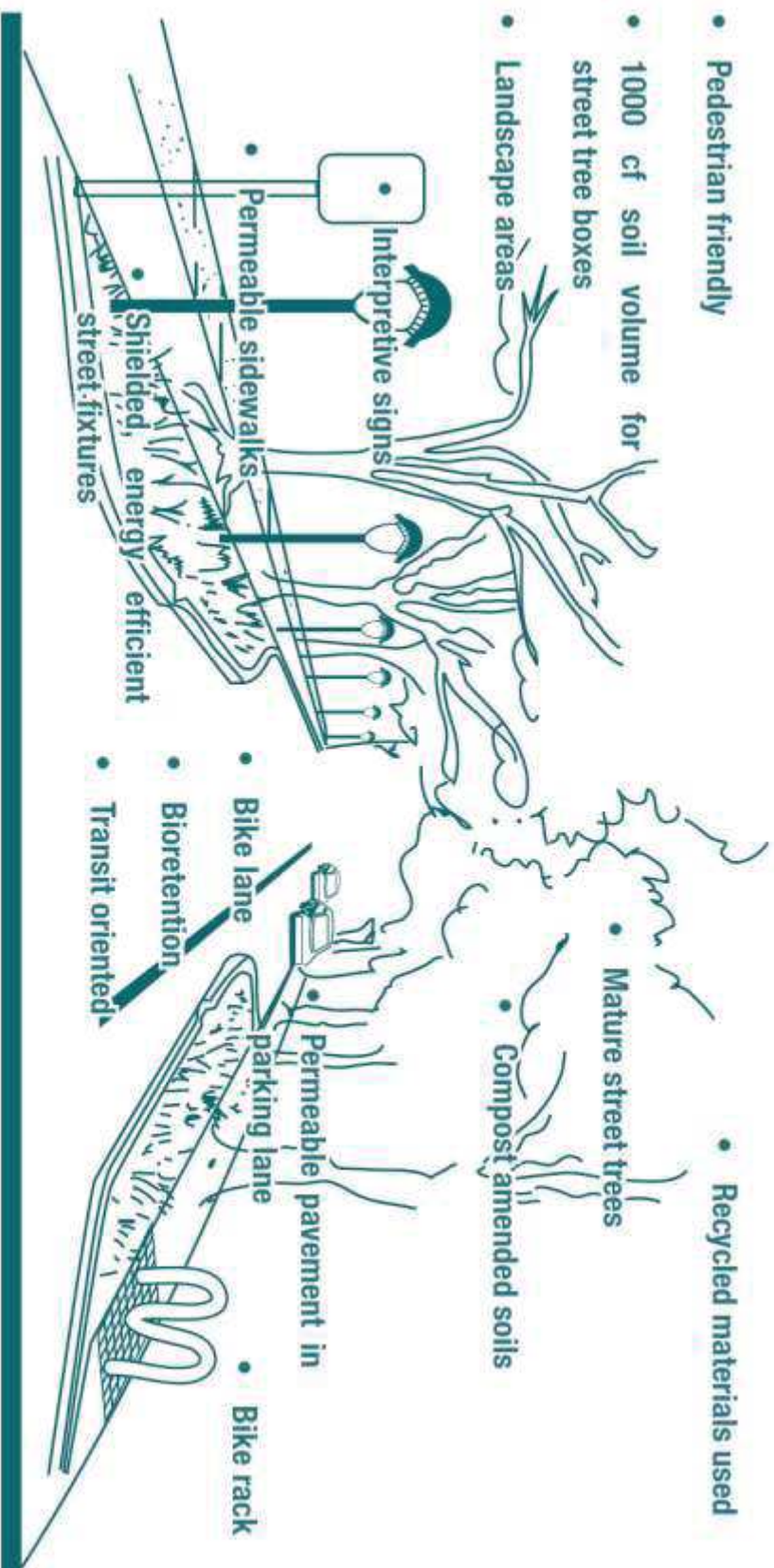


Figure 4.3.1: Anatomy of a Green Street. (Source: Ann English)

# Green Streets

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Una strada per le auto . . .

Il ruolo del verde urbano  
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# Green Streets

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Una strada per la gente . . .

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# Green Streets

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Una strada per l'acqua . . .

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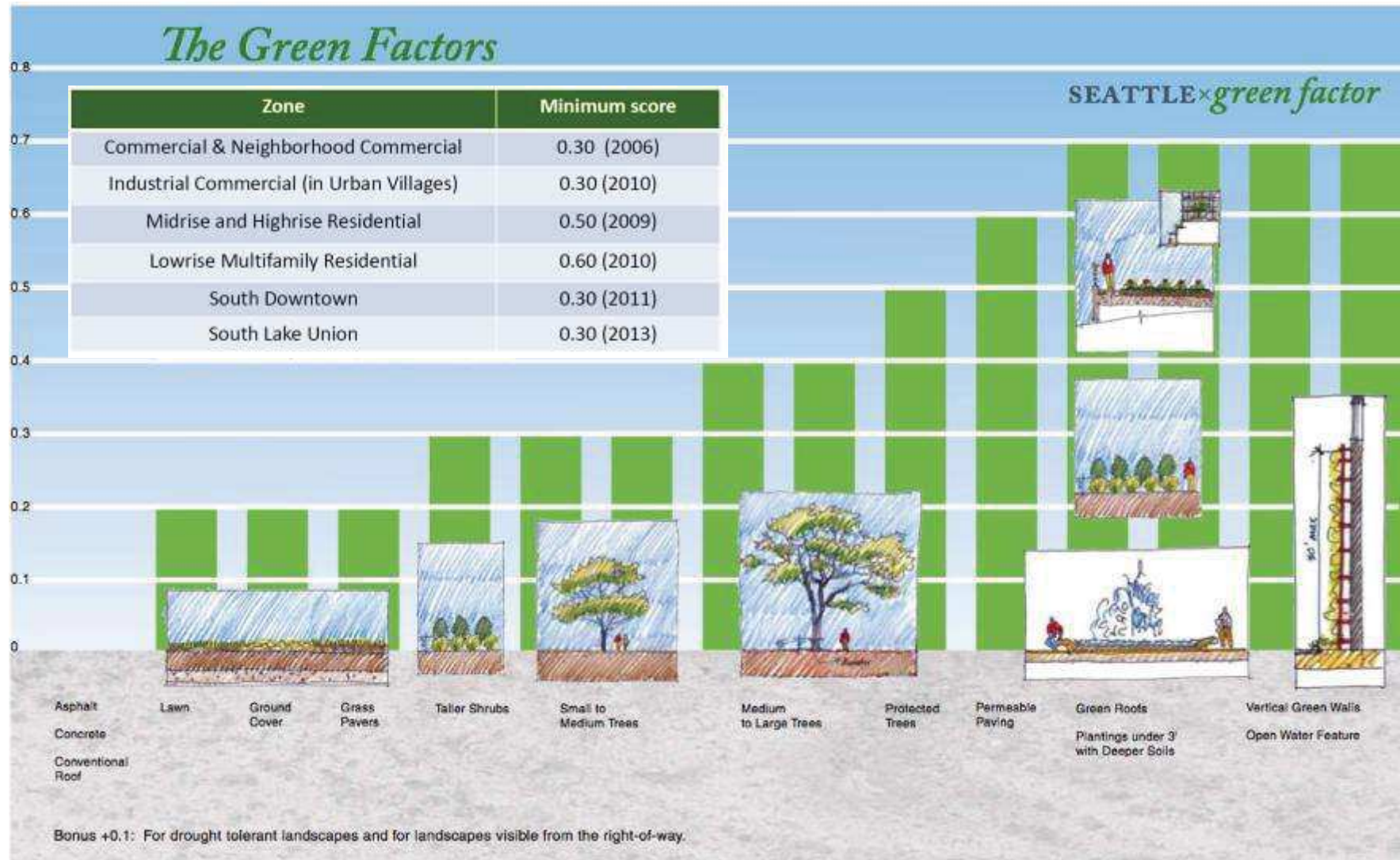
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# Seattle Green Factor



Seattle's Green Factor requires 30 percent parcel vegetation in business districts. Property owners can use various practices to reach the 30 percent threshold, with bonuses for rainwater harvesting, drought tolerant plants, tree preservation, green roofs and more. Image from the City of Seattle.







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Dipartimento di Scienze Agrarie e Ambientali

## Il ruolo del verde urbano

*Giulio Senes*

SEMINARIO DI APPROFONDIMENTO

PROGETTARE PER L'INVARIANZA

REGOLAMENTO REGIONALE N. 7 DEL 23.11.2017:

CRITERI E METODI PER IL RISPETTO DEL PRINCIPIO DELL'INVARIANZA IDRAULICA E IDROLOGICA

AI SENSI DELL'ART. 58 BIS DELLA L.R. 12/2017

11 Aprile 2018 - Sala Congressi Assolombarda - Confindustria Milano Monza e Brianza, via Petrarca 10 - Monza



COMUNE DI  
MONZA



PROVINCIA  
MONZA BRIANZA

ATomb

INU Lombardia  
Istituto Nazionale di Urbanistica

ordine degli architetti  
paesaggisti, pianificatori  
e conservatori della provincia  
di Monza e della Brianza

Ordine degli  
Ingegneri  
Monza e Brianza

