HAIL THE SWALES

Swales are an excellent way to treat stormwater on-site before it becomes potentially destructive runoff. These swales along Division Street in Portland, collect rain from the roadway and let it slowly infiltrate back into the ground. These swales also provide habitat for native species, act as buffers between the street and pedestrians, and help create a lush and green streetscape. Portland, Oregon.

2.32
GREEN STORMWATER INFRASTRUCTURE (GSI)

Resolving runoff locally

Green Stormwater Infrastructure (GSI) is designed to intercept stormwater runoff before it enters natural waterways or sewer systems and treats the runoff in ways that mimic natural processes. GSI reduces the volume and velocity of stormwater runoff, mitigates heat and pollution carried by runoff, and helps return runoff to the hydrologic cycle via infiltration and evapotranspiration. Fundamentally, GSI treats stormwater as a resource to be managed rather than a waste product in need of disposal. Individual GSI applications can function independently or can be combined to form a Robust Stormwater Management Network.

MEASUREMENT
GSIs are typically measured by how much runoff they divert away from traditional stormwater systems. Combining multiple GSI applications to form a robust stormwater management network can impact additional metrics regarding water velocity in local streams, groundwater recharge, and combined sewer overflow events.

Stormwater Runoff Volume
A measure of the change in amount of runoff flowing into local waterways and local sewers.

RELATED URBAN DESIGN ELEMENTS

INFLUENCED BY
1.13 Balanced Vehicular Networks
1.22 District-Scale Parking Mgt & Design
Vehicular networks and high parking ratios increase impermeable surfaces and runoff.

1.301 Pedestrian-Friendly Streets
1.302 Bicycle-Friendly Streets
1.303 Transit-Friendly Streets
Bike, transit and pedestrian infrastructure provide sites for GSIs and can act as effective buffers between modes.

1.32 Site-Scale Parking Design
Parking lots generate runoff and provide sites for GSIs that mitigate runoff.

2.30 High Surface Permeability
Increasing permeable surfaces reduces runoff, reducing strain on GSIs.

2.31/3.31/4.31/5.31 Robust Urban Forest
Trees can prevent runoff by storing precipitation in their canopy as well as taking up water from the soil.

2.40 Rainwater Capture & Reuse
Rainwater capture reduces runoff, reducing strain on GSIs.

5.30 Active & Attractive Open Space
Open spaces can be designed to also act as GSI.

INFLUENCES
2.20 Robust Stormwater Networks
GSI applications are the building blocks for larger stormwater networks.

3.20 Ecological Corridors & Patches
3.32 Microhabitat Creation
GSIs can act as micro habitat and be part of larger ecological corridors and patches.

3.34 Robust Ecological Area Buffers
GSIs reduce runoff and protect buffers from degradation. GSI interventions could also act as buffers themselves.

IMPLEMENTATION

GREENFIELD
COST
DIFFICULTY

Low cost and low difficulty
A series of small GSI interventions is generally less costly or equivalent to traditional pipe infrastructure, although this can be an added cost if codes require traditional systems to also be installed.

RETROFIT
COST
DIFFICULTY

Low cost and low difficulty
Small GSI interventions added to intercept runoff before it goes into traditional infrastructure can be implemented at low cost and typically face little public resistance.

1. Runoff outflow from building downspouts
2. Rock river conveyance channel
3. Metal sidewalk grate identifies channel, supports maintenance
4. Rocky outflow into curb-side flow-through planter
5. Native plants and street trees with deep roots to filter runoff and pollutants

Figure 1: Using green stormwater infrastructure to convey rooftop runoff from a building through a conveyance channel beneath the sidewalk to a street-side planter. Eugene, OR.

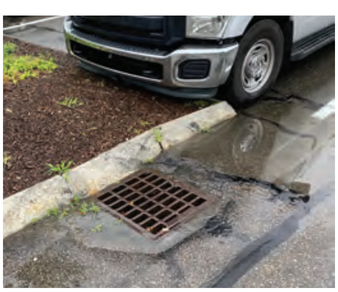

Figure 2: Typically, runoff is drained directly from an impervious surface into the storm system, carrying pollutants and heat into nearby waterways.

RECOMMENDED APPROACH

The aim of green stormwater infrastructure (GSI) is to capture stormwater immediately so that it may be slowed, cooled, filtered, and directed back to waterways, into traditional greywater systems, or into the ground near where it fell. Supplementing and replacing stormwater infrastructure of pipes, drains, gutters and culverts with soft, green, open-air infrastructure helps mitigates urban development's impact on local habitats and hydrological functions. It also has additional benefits including the creation of habitat, the reduction of heat island effect, public engagement with natural systems, and perhaps most noticeably, the transformation of hard, unpleasant, and expensive infrastructure into lush, living amenities in our streets and public spaces.

TYPICAL APPROACH

Stormwater is typically handled as a waste product with the primary function of most traditional infrastructure is conveyance: to quickly move water away from where it fell. Runoff is often concentrated and moved long distances along underground pipes to either be dumped into a nearby watercourse, or to be stored in or treated by large, often expensive "end-of-pipe" infrastructure. Because this approach ignores the way that water naturally moves through, across, and over the earth, it bypasses critical aspects of the hydrologic cycle, including groundwater recharge, evapotranspiration, and natural filtration. As water runs over roofs, streets, parking lots and lawns, it takes with it heat, heavy metals, hydrocarbons, pesticides, and fertilizers, often concentrating and carrying these pollutants long distances. This, along with the volume and velocity of the runoff, is detrimental to the health and ecological function of natural waterways and associated ecosystems.

IMPORTANCE

GSI are key elements of a broad stormwater management strategy. They are the workhorses that mitigate runoff and its negative impacts. Implementing GSI elements can reduce runoff volumes coming off of a site.[1] Through retention or detention strategies, GSI can also delay the arrival of peak flow to water bodies and/or traditional gray infrastructure by slowing the movement of water through a series of depressions and basins.[2] Both of these strategies reduce flood risk resulting from development.[3] GSIs can also protect the quality of groundwater and surface water, protect local habitat, and can provide savings as they are more affordable than traditional stormwater systems.[4] Additionally, GSI elements are shown to have secondary benefits to human physical and mental health.[5]

BACKGROUND

TYPES OF GSI INTERVENTIONS

Though a wide range of GSI interventions exist, they can be generally differentiated by structures focused primarily on retention versus structures focused on conveyance.

Bioretention Cells

Any shallow, vegetated depressions designed to receive stormwater from a small contributing area and infiltrate it through a specific soil mix. Bioretention cells are designed to flood and hold runoff until it infiltrates into the ground or is put back into the atmosphere through evaporation and evapotranspiration.

Rain Gardens - Planted, shallow depressions that allow water infiltration back into the soil. These are typically placed in landscaped areas of a site or plaza but are also possible in underutilized urban spaces such as parking lots or green slivers. Rain gardens are also popular strategies in single-family neighborhoods.

Figure 3: Rain Garden. This planted depression captures and infiltrates stormwater. The morning after a rainstorm, the water has almost entirely soaked back into the soil. (Alex Brooks)

Infiltration Planters - Similar to rain gardens, except that these are planted in a constructed box, (usually bounded by curbs, small walls, or seating) with an open bottom. Infiltration planters are appropriate for space-limited sites with good drainage. Planters may vary widely in size and are useful in creating friendly, attractive pedestrian spaces. Narrow planters can be found adjacent to sidewalks, and larger planters are often utilized to define spaces or create seating in plaza or courtyard areas.

Figure 4: Infiltration Planter. A large, constructed planter provides storage capacity for runoff from the surrounding plaza and rooftops. Its open bottom allows water to soak back into the ground.

Bioretention Cells *(continued)*

Flow-through Planters - Rather than infiltrate runoff into the ground, water is drained slowly to the gray infrastructure system via an underdrain, first allowing the plants to take up and eventually return substantial amounts of water to the atmosphere through evapotranspiration. Because these interventions don't allow infiltration, flow through planters are appropriate in areas with poor drainage, close to building foundations, on steep sites, or in contaminated areas. These interventions are often placed at the receiving end of roof downspouts to act as vegetated catch basins.

Figure 5: Flow-through Planter. This planter box is sealed on the bottom. Water is admitted from the street, collects in the box, is taken up by the roots of plants or evaporates, and excess water drains out to the stormwater sewer via an overflow drain.

Curb Extension Planters - These are curbed, structured planters specifically set into the street right of way that are designed to capture and detain runoff from the street. Curb extension planters can be combined with pedestrian bulb-outs, traffic chicanes, medians, and other traffic-calming devices. They allow infiltration and limited sedimentation/ filtering.

Figure 6: Curb Extension. This commonly used urban GSI strategy not only detains runoff from the sidewalk and the street, but it also narrows the street, slowing traffic and creating a more comfortable crossing distance for pedestrians. (Greenworks)

Conveyance

Though similar to bioretention cells, the primary function of these GSI interventions is to move water from one area to another at slower speeds, allowing for evapotranspiration and some degree of filtration.

Swale - A broad, shallow, vegetated depression that conveys water. Generally linear in form, a swale ideally slows water flow, filters sediments, and allows for infiltration. Swales are commonly placed in areas that can accommodate their long, linear form, such as along streets and between rows of parking

Figure 7: Swale. Commonly used in parking lots and at the sides of roads, swales are linear, vegetated depressions that are designs to slowly convey water from one point to another. Because most GSI interventions are open air and vegetated, they require maintenance to keep them both attractive and functional. (Roxi Thoren)

Trenches / Sand Filters - Trenches are shallow excavations designed to temporarily store and convey water through a void-rich material such as sand, gravel, or rubble. Unlike most GSI interventions, trenches are not vegetated, and are generally not visible to the public. Their primary goal is to filter runoff as it is conveyed. Trenches are often used in contaminant hot spots (usually due to automobiles) to pre-treat runoff before it enters vegetated GSI interventions.

Figure 8: Trench. The rubble in this trench helps to slow runoff moving through it. Sand can also be used to filter finer grain pollutants. These trenches can be visible or buried and are often used to pre-treat runoff before it interacts with vegetated stormwater infrastructure. (Alta Planning)

Filter Strips - Filter strips are gently sloped grassy areas that allow runoff to flow in an even spread, called sheet flow, into a swale, trench, or bioretention cell. A low to moderate velocity flow across a strip is capable of filtering out significant amounts of particulate pollution.

Figure 9: Filter Strips. This gently sloped grassy area slows, cools, and distributes the flow of runoff from the adjacent area into a gentle sheet flow that allows particulate pollution to settle out before it reaches the canal beyond. Hammarby Sjöstad, Stockholm, Sweden.

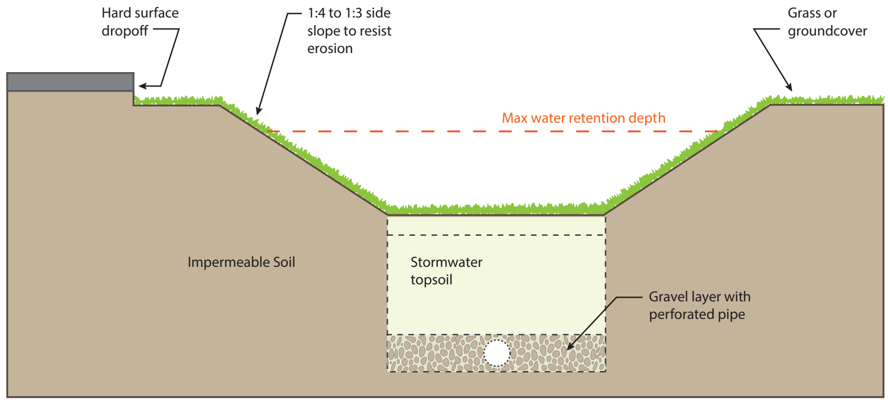

Figure 10: **Section diagram of a typical dry swale,** based on SuDS Manual. (Construction Industry Research and Information Association, 2015).

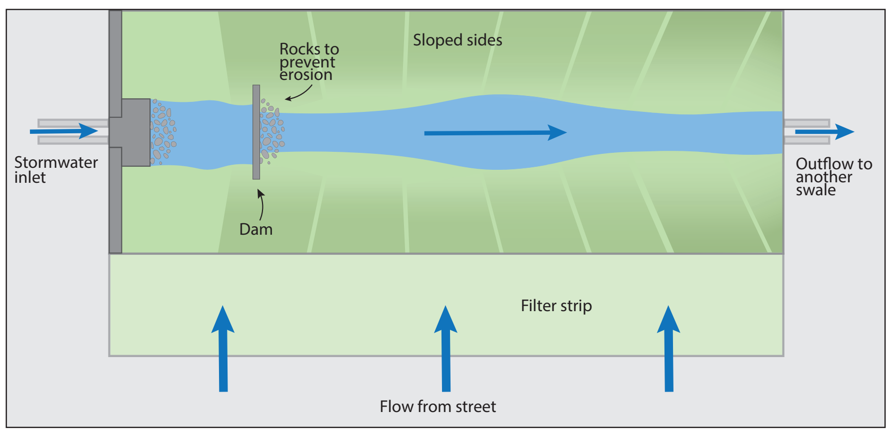

Figure 11: **Plan diagram of typical swale** based on SuDS Manual. (Construction Industry Research and Information Association, 2015).

In addition to the this range of GSI interventions, large landscape elements such as vegetated detention basins, ponds and constructed or natural wetlands can also serve as GSI elements, retaining or conveying stormwater. Architectural elements such as rain barrels, green roofs, and dry wells can serve a similar role.

LAND USE AND GSI

Land use has a significant impact on GSI as it is often related to the quality and cleanliness of runoff. Uses such as roads, highways, construction sites and industrial sites often have high potential for pollution and contamination, and may need containment or extra stages of runoff treatment before water is either allowed to infiltrate into the ground or is incorporated into natural water bodies. [6]

A common misconception of GSI is that it only works with low density development. In fact, it is possible that an area of high development that uses GSI strategies produces less runoff that a highly paved, low-density development. Although lower density areas typically have lower pollution levels than more densely populated and developed areas, the amounts of impervious surface can often be similar.

SITE CHARACTERISTICS AND GSI

Not all sites are equal in their ability to manage stormwater runoff. Soil permeability, site slopes, water table height (which can vary by season), and available land area can all affect the amount of water that can be infiltrated into the landscape. To minimize erosion along steep slopes, for instance, swales should be placed along contour lines instead of across them. Similarly, high water tables may require more water retention and conveyance than on-site infiltration.

VEGETATION AND GSI

Vegetation is imperative to sustainable stormwater management as it mitigates stormwater runoff at every stage. Vegetation mitigates runoff generation, slows its movement, is capable of filtering and cleaning runoff, as well as assisting runoff infiltration into the soil and returning it to the atmosphere via evapotranspiration.

CONSIDERATIONS + CAVEATS

ELEMENT INTERACTIONS

- The amount of stormwater runoff generated within an area will severely affect the design and success of any GSI elements. By reducing runoff through high surface permeability, limiting the amounts of impermeable surfaces and increasing tree canopy cover, the burden on robust GSI elements is reduced.
- Most GSI elements can also act as habitat. Consider how plantings can help maximize this potential.

POLITICAL ISSUES

- Many codes still legally require traditional, piped stormwater infrastructure or require GSI to overflow into one of these systems, with no capacity benefit calculated for the reduced runoff generated by GSI elements. Policy changes or code updates may be required for GSI elements to be compliant with city codes, to maximize the potential benefits of GSI systems, or to allow these systems to be in proximity of other built structures.

MAINTENANCE/OPERATIONS ISSUES

- Many GSI interventions require routine maintenance. Caring for vegetation, clearing filters and monitoring water quality are some of the actions required to keep GSI working effectively. Responsibility for the continued care for facilities should be laid out clearly. City workers, property groundskeepers, and neighborhood volunteers are possibilities for maintenance.
- Hydrological experts should be consulted before implementing GSI, as improperly designed or maintained stormwater facilities could lead to localized flooding and pollution of soils and natural waterways.
- GSI and management practices that mimic natural hydrologic cycles are relatively new and their performance is still being studied and understood. The ability of GSI to mimic pre-development hydrology for large storms and during extended wet periods is not well documented.
- Infiltration may not always be the best option depending on topography or water table level. For example, infiltration is not recommended in a hilly area with loose soil where landslides are possible. Check with your local planning and environmental agencies.
- Proper soil conditions and construction practices are imperative for the actual functioning of GSI. Consult experts and technical references.

OTHER ISSUES

- Because hydrology varies greatly from place to place, there are no universally effective solutions. Understanding how local climate, topography, soil, and vegetation conditions affect how water moves in around, over and through the area is essential for creating an effective GSI.

GUIDELINES FOR URBAN DESIGN

1. **Understand local conditions and conserve existing water flows where possible.**
   a. Understand local topography, runoff flows, typical site precipitation profiles, soils, and vegetation conditions.
   b. Retain an area's natural drainage features and flows, where possible, allowing existing drainage patterns to organize buildings, roads, and GSI interventions.

2. **Locate GSI interventions.**
   a. Evaluate key catchment areas within the site.
      - Consider that the closer design interventions are to the place where runoff is generated, the smaller they can be. Multiple smaller elements are typically better than fewer and larger elements.
      - Consider GSI options along roadways and paths, within large impervious surfaces such as parking lots and plazas, and to treat stormwater coming off building roofs.
   b. Consider areas that can support infiltration and areas that will need conveyance or will need to eventually flow into traditional stormwater systems.
      - Sites that are not rocky or heavily compacted are good candidates for infiltration.
      - Sites with slopes greater than 3% will need GSI elements located along contour lines or may need a series of dams or weirs to slow water flowing through the element.
   c. Identify areas that can provide storage capacity where needed.
      - Select areas that are low-lying or can accommodate depressions to collect water.
      - Select locations that are adjacent to large areas of impervious surface.
   d. Consider use of parks and open space for larger GSI elements and as locations that can receive water from the surrounding areas.

Figure 12 and 13: A large-scale GSI intervention can accept water from a large surrounding area. This park is completely flooded during significant storm events and water is then slowly infiltrates into the soil. Phoenix, Arizona.

3. **Look for opportunities to integrate stormwater with other design interventions.**
   a. Consider opportunities for habitat, recreational, and educational spaces.

4. **Maximize area and vertical complexity of vegetation.**
   a. Retain existing native vegetation where possible.
   b. Use GSI elements to expand areas of robust vegetation.
   c. Maximize vertical complexity within GSI elements where possible.

5. **Look for opportunities to link individual GSI elements together into a larger network.** See *2.20 Robust Stormwater Networks*.

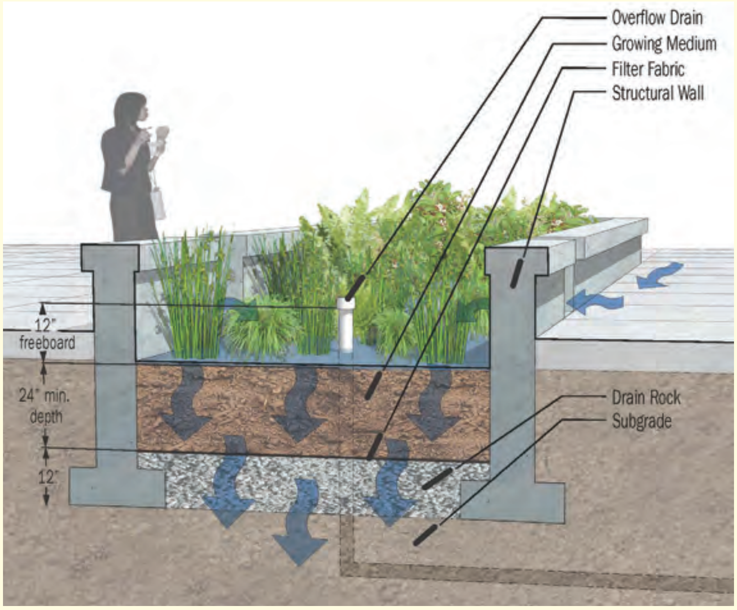

Figure 14: Section through an infiltration planter. The level of the planter is below the level of adjacent construction, allowing water to pool inside the planter. Plantings are selected to survive brief periods of flooding. (Greenworks)

KEY TERMS

DETENTION POND
Water storage intervention designed to hold and infiltrate stormwater.

INFILTRATION
Process by which water on the surface enters the ground.

RETENTION POND
Water storage intervention designed to slow stormwater and reduce downstream flooding.

ADDITIONAL RESOURCES

The Minnesota Stormwater Manual

The SuDS Manual, Construction Industry Research and Information Association (CIRIA), 2015

Low Impact Development Technical Guidance Manual for Puget Sound. Hinman, Curtis, 2005

San Mateo County Sustainable Green Streets and Parking Lots Design Guidebook, San Mateo Countywide, 2009.

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