Sustainable Urban Drainage Systems (SUDS)

INTERVENTION CATEGORY: CREATED HABITATS

DESCRIPTION

Sustainable Urban Drainage Systems (SUDS) are drainage systems aiming to mimic natural drainage in a developed area, where rainfall soaks into the ground and saturates soil and vegetation before significant runoff occurs. The systems are designed to manage the environmental risks resulting from urban runoff and to contribute wherever possible to environment enhancement. SUDS elements are generally small scale and relatively shallow. They usually require the use of relatively simple engineering construction and landscaping operations, such as excavation, filling, grading, topsoiling, seeding and planting.1 Examples of SUDS include:

- **Green roofs** are building roofs that are fully or partially covered with vegetation. Intensive roofs (soil depths of >15cm contain more resilient vegetation, whereas extensive roofs (5-15 cm soil depths) serve more of an aesthetic purpose.[2]
- **Permeable pavements** are made of materials that allow for water to infiltrate, be filtered and recharge groundwater. Suitable materials include pervious concrete and asphalt, permeable interlocking concrete pavers (PICPs), concrete grid pavers, and plastic reinforced grass pavement.[2]
- **Water harvesting** refers to redirection of rainwater and stormwater runoff, and storage for productive use. *In situ* rainwater harvesting aims to increase the amount of rainfall stored in the soil by trapping and storing it in the desired location. *Ex situ* water harvesting, which is more common in urban contexts, uses systems where rainwater is captured in areas external to the final water storage. Capture areas in this case include natural soil surfaces or rooftops, roads and pavements in urban areas. Water is stored in natural or artificial reservoirs, although only storage in natural reservoirs is considered green water infrastructure.[2]

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- **Bioswales** are ditches with vegetation and a porous bottom, designed to concentrate and convey stormwater runoff while removing debris and pollution. They often contain check dams for enhancing stormwater infiltration.
- Other examples of SUDS are **green spaces** (parks), **sediment traps**, and **detention basins**.

WATER SECURITY CHALLENGES (WSCs) ADDRESSED

TYPE		IMPACT	MAGNITUTE	DEPTH OF EVIDENCE BASE
Water availability	Groundwater recharge	Increased mean annual groundwater recharge	★★☆	★★☆
	Dry season flows	Maintained dry season flows	★★☆	★★★
Disaster risk	Flood risk	Reduced peak discharge	★★★	★★★
Water quality	Erosion and sedimentation	Reduced on-site erosion and sediment yields	★★☆	★★☆
	Nutrients and pollutants	Reduced in-stream nutrient and pollutant concentrations	★★☆	★★★

A common feature of all SUDS is that they reduce stormwater runoff by enhancing infiltration and/or storage of excess water, thereby preventing overburdening of sewers and reducing flood risk. Green roofs and parks release stored water through evaporation from the soil or by transpiration of the vegetation. Water harvesting methods address WSCs by enhancing water infiltration and water holding capacity in the soil, resulting in higher soil fertility. *Ex situ* water harvesting allows the captured water to be available for productive use. Improved infiltration also reduces runoff from slopes and facilitates groundwater recharge, where the hydrogeological setting of the SUDS affects the magnitude of the latter. Green roofs can reduce annual roof stormwater runoff by up to 50-60% through retention of up to 90% of runoff from storms up to 2 5mm, and at least 30% for large storms.[2, 3] Permeable pavements can provide important alternatives to conventional runoff control infrastructure in urban environments, as they reduce storm runoff by 70–90%.[3]

Excess runoff in an urban setting also poses sanitation risks through accumulation of contaminants. Many SUDS mitigate potential negative water quality impacts, relieve the loads of water treatment plants, and reduce the risk of combined sewer overflows. Permeable pavement layers, and underlying upper soil, can effectively capture pollutants present in the runoff water. A comprehensive review is available, evaluating different materials, designs and pollutants.[4] Detention basins and ponds remove pollutants through sedimentation and biological uptake mechanisms.[1]

OTHER BENEFITS

WHAT?	HOW?
Biodiversity	Green spaces provide habitat for various species and allow for enhanced connectivity / creation of corridors. Green roofs also increase biodiversity and attract birds and insects.[5, 6]
Aesthetic quality	Increased vegetated cover and water bodies add to the aesthetic quality of urban environments largely comprised of grey infrastructure

Improved air quality	Vegetation on green roofs can remove several air pollutants, including particulate matter, NO_X, SO_2, CO and O_3.[3]
Reduced noise pollution	Permeable pavements reduce noise levels due to the porous nature of the material.[2]
Carbon sequestration	SUDS involving planting of vegetation increase the capacity for sequestering carbon. This is particularly the case for green spaces and roofs7, although surface areas usually remain small.
Energy savings	Green roofs provide insulation and cooling benefits to buildings. Energy requirements for water treatment are reduced by SUDS that store water and enhance water quality.[7]
Reduced urban heat island effect	Converting to green roofs can reduce surface temperature of the roofs by up to 30–60°C and ambient temperature by up to 5°C. Permeable pavements absorb less heat and help reduce temperatures through evaporation. In general, evaporation from stored water (e.g., in ponds and basins) contributes to a cooling effect for most SUDS.[8]

LINKAGES TO CLIMATE CHANGE

Mitigation: SUDS contribute to climate change mitigation by sequestering carbon and reducing energy requirements. The latter concerns, among others, reduced energy needs for water treatment and cooling of buildings.

Adaptation: SUDS particularly contribute to adaptation to temperature and extreme precipitation in urban settings, by attenuating peak flows caused by extreme rainfall and regulating the surrounding microclimate by reducing temperatures, thus improving livability.[9]

DESIGN-ENABLING CONDITIONS AND TYPICAL CONSTRAINTS

SUDS is an umbrella term for a range of drainage systems. Therefore, design-enabling conditions, common constraints, and maintenance needs vary per system. Some generally applicable considerations in the design and construction phases are:

- Temporary drainage of silt-laden waters during construction is critical both to the success of SUDS and to the avoidance of pollution downstream.[1]
- Runoff from the construction site must not be allowed to enter SUDS drainage systems (unless it has been allowed for in the design and specification), as it can clog infiltration systems, build up in storage systems and pollute receiving waters.[1]
- Careful levelling and grading is crucial to the performance of many SUDS features to ensure that water flows through the system without ponding, which can damage vegetation and cause muddy zones to develop.[1]
- Before runoff is allowed to flow through SUDS with surface features such as ditches, they must be fully stabilized by planting or temporary erosion protection. This prevents erosion and clogging of the system.1
- High groundwater tables limit opportunities for infiltration. In those cases, SuDS selection should focus on surface and shallow features that avoid infiltration.[10]
- Maintenance required for many SUDS includes the removal of clogging material, e.g., in ditches or permeable pavements.4 Green roofs and green spaces commonly need to be weeded and watered.

RELATION TO GREY INFRASTRUCTURE

INFRASTRUCTURE?	SERVICE PROVIDED BY GREY SOLUTIONS	TYPE OF RELATION
Water treatment facilities	Improving water quality for domestic use	Complementary
Storage tunnels	Water storage	Complementary, Alternative
Artificial reservoirs	Water storage	Complementary, Alternative
Sewers	Drainage and conveyance to treatment plants	Complementary
Stormwater conveyance systems	Drainage	Complementary

COMMON RISKS AND TRADE-OFFS

- Sites downstream of surface water flows conveyed by SUDS can be at risk of flooding. This risk can be mitigated by managing surface water at (sub-)catchment scale.[10]
- Cases of mold in green roofs, or roof collapses, have occurred. These are usually caused by poor installation or maintenance.[11]
- Depending on the site, installation of permeable pavements may involve potential groundwater and soil contamination due to the high permeability. For example, there is a risk that salts used in de-icing of roads can reach groundwater, or increase mobility of some heavy metals in the soil.[2]
- In cold climates, there is a risk of harsh winter weather conditions causing permeable pavements to act as a waterproof slab.[4]

MONITORING OPPORTUNITIES

A perceived lack of appropriate monitoring and evaluation of SUDS projects is often a barrier to their implementation.[12] Still, there are multiple solutions for monitoring the effectiveness of SUDS, for example:

- Flow monitoring can be installed in drainage networks. Water levels in ponds and reservoirs can be measured. Sensors must be resistant to water and chemicals.[12]
- Monitoring of downstream water quantity and water quality is required to evaluate catchment-scale impacts of SUDS. Also, piezometers can be installed to measure impacts on groundwater levels.
- Green roofs can be monitored with weather stations and thermal sensors.[13]
- Performance of permeable pavement in absorbing and detaining rain runoff and improving water quality can be monitored by installing a network of embedded perforated pipes.[14]

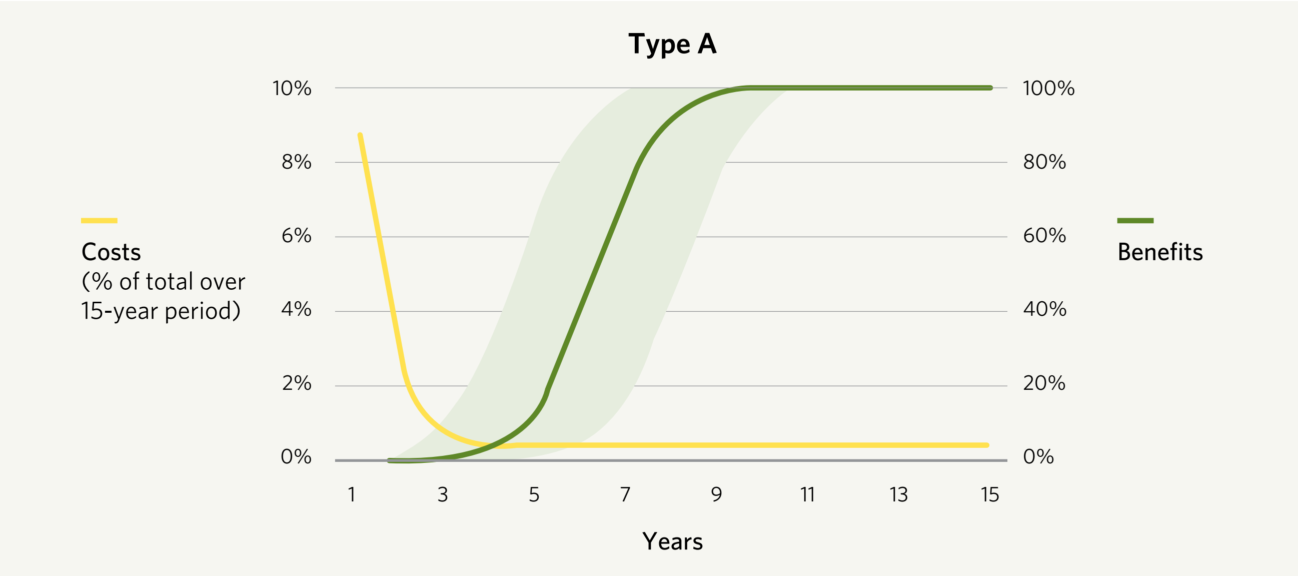
IMPLEMENTATION COSTS AND TIMING OF BENEFITS

The magnitude, nature and timing of SUDS costs and benefits varies with the type of drainage system implemented and site-specific conditions. In general, SUDS are considered low-cost solutions, where a substantial part of investment costs are incurred in the construction phase.15 Some examples are:

- Costs of establishing green roofs differ depending on the geographic location, the type of roof, local labor and material costs. In the U.S. costs were estimated at USD 65–450 per m^2 for constructing extensive roofs and USD 200–900 per m^2 for intensive roofs.[3] In Europe, capital costs are 90–130 €/m^2 for extensive design and 130–180 €/m^2 for intensive design.[16] Costs in Germany were however reported significantly lower at 20 €/m^2.[17]

Maintenance costs are also variable, with an example reported of 2–3% of initial investment costs annually.[3] Benefits accrue from reduced costs in stormwater management, lower energy consumption and improved air quality. Payback time is reported between 3 and 13 years, depending on whether wider public benefits are considered.[18]

- Estimated costs of installing a permeable pavement are 30–150 USD/m2 in the U.S., and 40–90 €/m² in Europe,[19] with an estimated lifetime between 7 and 35 years. Costs and lifetime depend on the type of pavement and required maintenance.[3] Maintenance should prevent pores from becoming clogged and ensure that the pollutants captured by the pavements do not migrate to the underlying soils.[2]
- Urban water harvesting installation costs may consist of expenses related to storage tanks, cisterns, pumps, as well as distribution pipes, where applicable. Recurring costs may occur related to energy for pumping, protection to deter mosquitos and water pre-treatment, where needed. However, many systems are passive and require minimal maintenance. Average costs in the UK for a household rainwater harvesting system amount to USD 2,400–3,300, whereas costs in India for one building's rainwater harvesting system are estimated between USD 50–550.[2] Cost-benefit ratios are generally favorable, particularly in densely-populated urban areas with low-rise buildings.[20]



Green roof of Chicago City Hall (source: Wikipedia)

EXAMPLES

Documentation of SUDS implementation including costs and benefits is clearly geographically biased to North America and Europe. Still, usage of SUDS is not uncommon in urban centers in Asia, South America and Africa, although this use is often of an informal nature.[21] Some examples of well-documented cases:

Berlin, Germany[17]

Brief description: Costs and benefits of three scenarios for SUDS implementation were evaluated for a specific neighborhood, to inform planning processes for urban water management. The scenarios consist of individual measures of SUDS including green roofs, façade greening, tree drains, swales, trough-trench systems, ponds, permeable pavement, rainwater harvesting, and retention soil filters. Each scenario comprises differences in the spatial implementation of the individual measures.

Lessons learnt:

- Economically feasible SUDS at the neighborhood level can be achieved.
- In this particular small-scale case, especially relatively cheap measures such as tree drains and ponds, which contribute directly to a reduction of stormwater runoff, were found to be cost-effective.

Durban, South Africa[22]

Brief description: The city of Durban requested a study to evaluate Durban's natural capital and its role in Green Urban Development (GUD). The study provided an updated, spatial estimate of the value of natural capital in the eThekwini Municipal Area and analyzed different scenarios to evaluate the potential returns to investing in GUD with a focus on the role of natural systems. Different categories of SUDS are disaggregated in the development of these scenarios (source controls, local controls, regional controls).

Lessons learnt:

- Source controls (green roofs, permeable pavements, sub-surface soakaways, and others) and detention basins had a measurable impact on flooding, with the former reducing flood peaks by about 10%, and the latter by up to 35%. These measures, coupled with treatment wetlands, were also effective at improving water quality in the catchment.
- Implementation costs of these measures are relatively high compared to expected cost savings and only detention basins could be justified in terms of their direct cost savings. For other SUDS measures, further innovation or incentives are required to bring costs down to levels where their widescale implementation in Durban can be made possible.

New Hampshire, United States[23]

Brief description: A drainage system was installed on a retail shopping center site, which included two porous asphalt installations along with catch basins, a sub-surface reservoir for rooftop runoff, and a large gravel wetland for the treatment of nitrogen. Although paving costs for the porous asphalt drainage systems were estimated to cost an additional $884,000, the SUDS option provided significant cost savings for earthwork ($71,000) and stormwater management ($1,743,000). Total project cost savings were around $930,000, a 26% decrease in the overall cost for stormwater management

Lessons learnt:

- A combination of porous asphalt with a sub-surface gravel wetland can be more economically feasible than a conventional sub-surface stormwater management detention system.
- Results from three years of monitoring show that the system is functioning well both from a durability and a water quality perspective, with a very high level of treatment achieved.

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