Sustainable urban drainage systems

In a nutshell

SUMMARY
It is best practice to reduce the flow of storm water reaching combined and separate sewers by improving water infiltration into soil (e.g. reducing soil sealing). This allows the limiting of overflows to situations of very heavy rainfall and ensuring that all discharges of urban run-off are well managed in order to avoid relevant emissions of pollutants to the receiving water body. Local authorities can promote sustainable urban drainage by including appropriate provisions, based on a holistic approach at the river basin level, in the local policies for land use.
Target group
Public administrations responsible for waste water management and urban drainage.
Applicability
This best practice is applicable to all local authorities responsible for urban drainage and land use planning. The sustainable urban drainage measures can be implemented in new and existing developments. However, in existing built areas there may be some constraints (e.g. lack of space available for local infiltration).
Environmental performance indicators
• Percentage of artificial surfaces (i.e. any kind of impermeable built area: buildings, roads, any part with no vegetation or water) in the territory of the municipality (km2 of artificial surface/km^2 of total surface) • Annual percentage of estimated rainwater which is retained and infiltrated into the ground locally out of the total estimated rainwater falling on the urban area of the municipality (%)
Benchmarks of excellence
N/A

Description

From the historical point of view, most cities started on the water management path by ensuring water supply and over time they incorporated additional measures such as sewerage, drainage, and more recently pollution abatement and natural resource protection. The ideal end point of the sustainable transition framework is the water-sensitive city, a city where water management is adaptive, multi-functional and aligned with the principles of urban design (Figure 1).

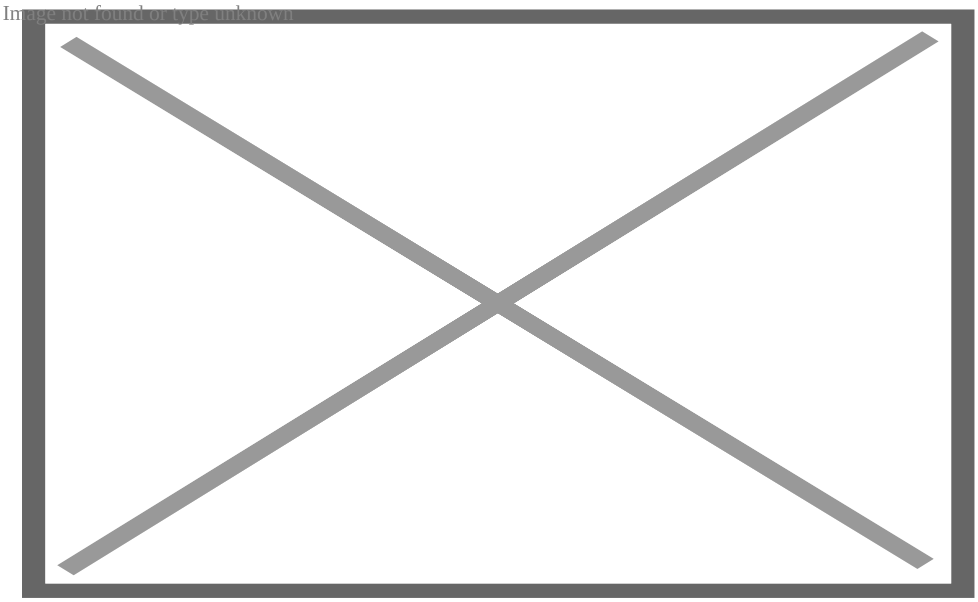

Figure 1: A framework for the transition of water management towards more sustainability (Brown et al., 2009)

In the USA, this transition is a substantial part of the so-called low impact development (LID), in Australia of the water sensitive urban design (WSUD) and in the UK of the sustainable urban drainage system (SUDS) (Marsalek, 2013). In the EU, the Water Framework Directive (EU, 2000) also asks for this transition towards a water sensitive city. Consequently, there is a need for an integrated approach within the urban water cycle (EC, 2012).

An important impact of urban development is the reduction of permeability of the land surface by replacing free ground (permeable) with impermeable roofs, roads and paved zones, which have to be drained through piping systems in order to collect and to discharge the runoff water (Figure 2). The phenomenon of increased impervious surface is known as land or soil sealing, which occurs not only as a consequence of the reduction of infiltration but also because of the removal of the green coverage, which decreases evapotranspiration. This can be defined as "the destruction or covering of soils by buildings, constructions and layers of completely or partially impermeable artificial material (asphalt, concrete, etc.)" (EC, 2011).

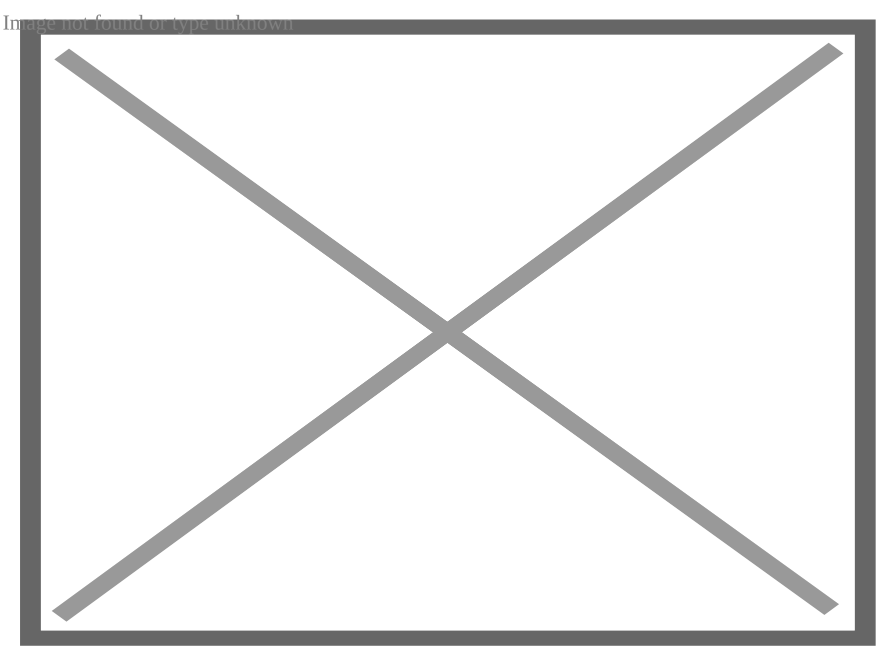

Figure 2: Impact of impervious area on hydrologic flows (Dane Waters, 2009)

In general, drainage systems should be considered in local, regional and national policies, allowing the following characteristics:

- the drainage system is part of a holistic approach for the management of the water environment, which should be based on river basins.
- it integrates quantitative and qualitative objectives. Thus, all discharge activities of urban runoff will need to be managed in order to avoid damages on the receiving environment (e.g. surface waters).

The impervious surface, used for human activities, is an important source of chemical pollution, where, in addition, natural filters have been removed. Chemical pollutants may be present in runoff, such as rain water from roads with heavy traffic or from contaminated areas of industrial sites, spillages, solid depositions on roofs, animal faeces, sediments from erosion etc. (Welker, 2005).This is associated with the following impacts (Woods-Ballard et al., 2007):

- Changes to stream flow: fast urban area drainage with reduced infiltration triggers the increase of runoff volumes, i.e. discharges which are orders of magnitude higher than those from natural sources.
- Changes to stream morphology: widening channels to accommodate for increased runoff would increase erosion, increasing sediment in natural water ways and exposing trees' roots. Stream banks may be eroded as well.
- Impacts to aquatic habitat: e.g. by washing away biological communities, impacting on riparian vegetation, sedimenting solid deposits, reducing oxygen levels, reducing water quality, etc.
- Impacts on water quality: reduced oxygen levels, increased sediments, increased eutrophication, increased pollutants and toxic chemicals, etc.

In addition, climate change impacts on water resources will reduce the availability of fresh water, increase evaporation, increase the periods of intense rainfall (with higher erosion impacts), increase the amount of pollutants fed to water ways, increase flooding, and increase the amount of untreated wastewater discharged to the environment. Relevant policy approaches regarding best practices are shown in Table 1.

Table 1: Relevant policy approaches regarding best practices to avoid soil sealing and improve water drainage (EC, 2011)

Measure	**Development**
Reduction of urban sprawl (e.g. Austria)	• New spatial planning regulations to improve land use efficiency: (i) Building permits with expiration date, (ii) contracts between municipalities and land owners and (iii) real estate funds at provincial level. • New funding schemes for housing to improve intensification of settlements • “Soil efficient” business developments
Reuse of brownfield land (e.g. Belgium)	Brownfield Covenant: agreement between the regional (in this case, the Flemish) government and one or more private or public parties which lays out arrangements in order to promote a smooth and efficient realisation of a brownfield project

Protection of the best agricultural land and landscape fragmentation (e.g. Czech Republic)	Three policy documents which protect the utilisation of green land inside and outside city boarders and give priority to inner urban developments: namely, the building code, the act on nature conservation, and the act on the protection of agricultural land. This also translates in the improvement of water drainage by: • High quality soils in the outer city belt are protected by the act on the protection of agricultural land. • Green areas are protected within city boarders • Priority is given to the development of abandoned areas (brownland, i.e. old industrial estates) instead of developing green land.
Management of flood risks (e.g. Germany)	Example in Saxony: building activities in flood risk areas are banned, retention zones were extended, soil sealing rates in flood risk area are being monitored with the aim of avoiding any increase in sealing, meanwhile desealing of abandoned developed land is encouraged.
Water drainage (e.g. Ireland, UK)	Proposals for housing estate development or for the development of a large number of houses in a particular area, shall be required to submit a flood impact assessment and proposals for a so-called sustainable urban drainage system (SuDS)

The use of overarching approaches can be considered as a best environmental management practice on land planning. Surface water drainage systems, developed in accordance to a sustainable development policy, managing environmental risks resulting from urban runoff and contributing to environmental enhancement, have the best example on the developed "Sustainable Drainage Systems" (SuDS) philosophy in the UK (Woods-Ballard et al., 2007). This is an exemplary approach, consisting of a three-way concept (improve water runoff quality, optimise water quantity and maximise amenity and biodiversity), replicating, as closely as possible, natural drainage of sites before development. Apart from the evident environmental benefit, it has a cost justification, as the need for large flow attenuation and flow control structures is to be effectively minimised.

Management hierarchy for water drainage management, given also by SuDS, usually refers to the techniques which should be preferred in a new development, e.g.:

- **Prevention**: good design practices and site housekeeping measures prevent runoff and pollution, e.g. rainwater harvesting or dust removal. Overall prevention policies should be considered as a technique for that.
- **Sourcecontrol**: highly polluted (or large amounts of) runoff should be controlled at their source, for instance, green roofs or car parks.
- **Site control**: control of water flows on site, for instance, piping water flow to infiltration or detention basins. This is also called decentralised runoff management (Sieker et al., 2007; Sieker et al., 2008).
- **Regional control**: to send excess runoff water to a pond or to a wetland, shared by several sites.

Techniques to be consider for environmentally friendly drainage systems are listed in Table 2 and are referred to improve water quality or to affect water quantity. This table is also reflecting the position at the management hierarchy and the main benefit to be achieved on water quality or quantity control.

Table 2: Techniques to be considered as best environmental management practice for water drainage systems, based on (Sieker, 2004; City of Hamburg, 2006; Woods-Ballard et al., 2007)

Technique	Description	Type of management	Main benefit
Water butts, site layout and management	Good housekeeping and good design practices.	Preventive, source control	Increase wat infiltration. Possible benefits c water quali and biodiversity
Pervious pavements	Allow inflow of rainwater into underlying construction/soil	Preventive and source control	Avoid pollutio and increas infiltration.
Filter drain	Linear drains/trenches filled with a permeable material, often with a perforated pipe in the base of the trench.	Conveyance and source control.	Allows conveyance ar detention ar avoids wat pollution.
Swales	Shallow vegetated channels that conduct and/or retain water and permit infiltration when un-lined. Filter for particulates.	Conveyance, source control and site control	Allows conveyance, detention, infiltration ar reduce pollutio
Filter strips	Vegetated strips of gently sloping ground designed to drain water evenly from impermeable areas and filter out silt and other particulates	Pretreats and allows source control.	Improves wat quality.

Technique	Description	Type of management	Main benefit
Ponds	Depressions used for storing and treating water. They have a permanent pool and bankside emergent and aquatic vegetation.	Site control. Regional control.	Detention ar harvest wate Improves quality.
Wetlands	Like ponds, but the runoff flows slowly but continuously through aquatic vegetation that attenuates and filters the flow. Shallower than ponds.	Site control. Regional control.	Detention ar harvest wate Improves quality.
Soakaways	Subsurface structures that store and dispose of water via infiltration	Site control.	Infiltration. Ma improve wat quality.
Infiltration trenches	As filter drains, but allowing infiltration through trench base and sides	Site control. Source control.	Infiltration ar detention. Ma improve wat quality.
Infiltration basins	Depressions that store and dispose of water via infiltration	Site control. Regional control.	Detention ar infiltration. Ma improve wat quality.
Green roofs.	Vegetated roofs reducing runoff volume and rate	Site control. Regional control.	Detention.

Technique	Description	Type of management	Main benefit
Bioretention areas	Vegetated areas for collecting and treating water before discharge downstream or to the ground via infiltration.	Site control. Source control.	Detention ar infiltration. Improves wat quality.
Sand filters	Treatment devices using sand beds as filter media.	Pretreatment and site control	Detention ar improves wat quality.
Silt removal devices.	Manhole and/or proprietary devices to remove silt.	Pre-treatment	Improves wat quality.
Pipes and storage.	Conduits and accessories as conveyance measures.	Conveyance and site control.	Conveyance and detention.

Environmental benefits

The described environmentally friendly and more sustainable water drainage approach and the techniques and technologies that are associated with it deliver a number of environmental benefits. The retention, detention and infiltration of storm water reduce peak discharge and prolong the lag time of urban runoff during high precipitation events. This provides flood control and helps to prevent erosion, siltation and high turbidity in streams and rivers as is typically caused by conventional drainage channels due to the high velocity discharge of large volumes of storm water into receiving water bodies.

Many aforementioned techniques treat storm water to various degrees by removing pollutants such as oils, metals and nutrients through natural treatment processes within vegetation, soils and ponds. This improves water quality in receiving water bodies thereby protecting ecosystems and recreational facilities. They also reduce the impact of urbanization on the natural water cycle. The impact of soil sealing is mitigated through systems designed to increase rainfall infiltration to underlying aquifers (de-centralised systems). Such groundwater recharge also provides an additional source of water supply, reducing the need to abstract (and often treat) water from other sources

Side effects

The increase of infiltration rates in urbanised areas frequently produces an undesired cross effect: groundwater contamination and soil pollution. Rainwater is usually polluted when it is in contact with the urban area, increasing the concentration of heavy metals, taking away organic compounds as lubricating oils, and dragging along suspended solids.

Although some of the aforementioned techniques are based on vegetation have filtering capabilities, special attention should be paid to the infiltration of polluted water. For rainwater management, there are devices that include an automatic valve that conducts heavily polluted water produced during the first minutes of a storm to the sewerage.

Applicability

The described techniques can be applied to new construction developments. In principle, they can also be retrofitted to existing built areas but there are often constraints (space, costs etc.) which do not allow their implementation or only to a limited degree.

Economics

Environmentally friendly and more sustainable water drainage techniques are often more cost-effective to install and maintain than conventional ones; for example, a comparison of a centralised (sewer) versus a decentralised (swale) solution found a cost of €19 versus €17/m2 (Sieker, 2010). Moreover, reducing the amount of storm water inflow into wastewater treatment plants (in cities with combined sewer systems) allows these to operate more cost-effectively. A study carried out by the US Environmental Protection Agency concluded that environmentally friendly drainage techniques produce cost savings in the range of 15 up to 80 %, which is attributed to lower site grading and preparation costs and lower costs for paving and storm water infrastructure (EPA, 2007). Nevertheless, the application of best techniques for drainage do not always produce cost savings, as it depends on the amount of infrastructure needed and the availability of natural drainage systems, and whether it is normally planned for several sites in the same local area. Also, the preparation of soil, the availability of space and connectivity to municipality network may require additional efforts.

In general, the use of more natural driven drainage requires less materials and less conveyance infrastructure, which also require lower installation costs. As for other environmentally sound techniques, it is necessary to implement a life cycle cost perspective when implementing water drainage techniques. According to (Woods-Ballard et al., 2007), this approach gives an overview to the developer of the long-term investment required, while implementing robust decision-making procedures due to enhanced knowledge of techniques. Also, this can be integrated in a long-term risk assessment, which may modify the site management plan. The implementation of techniques such as those covered by SUDS will benefit from gained expertise, further reducing uncertainties.

Correct planning of environmentally friendly and more sustainable water drainage techniques should, therefore, take into account whole life cycle costs. Figure 3 outlines the magnitude of the different costs.

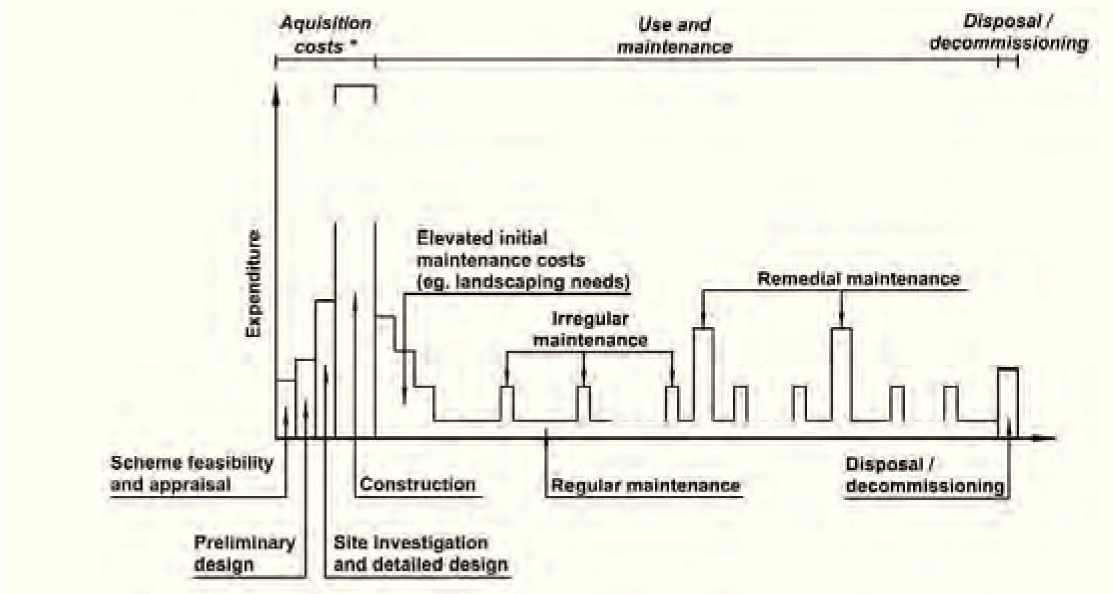

Figure 3: Life cycle expenditure profile (Woods-Ballard et al., 2007)

Many factors can affect the construction of a drainage system, such as soil type, groundwater management, design criteria, availability of space, hydraulic control characteristics, etc. A range of costs are shown in Table 4. This includes construction costs in addition to actual installation, materials, erosion and sediment control during construction, planting and landscaping.

Table 4: Water drainage construction and regular maintenance costs (Woods-Ballard et al., 2007)

Drainage element	**Construction cost, EUR**	**Regular maintenance cost (annual), EUR**
Filter drain, per m^3 stored volume	130 - 180	0.3 - 1.5 (per m^2)
Infiltration trench, per m^3 stored volume	70 85	0.3 - 1.5 (per m^2)
Soakaway, per m^3 stored volume	>130	0.15 (per m^2)
Permeable pavement, per m^2 surface	40 - 50	0.6 - 1.5
Infiltration basin, per m^3 detention volume	10 - 20	0.15 - 0.4 (per m^2)
Detention basin, per m^3 detention volume	20 - 30	0.15 - 0.4 (per m^2)
Wetland, per m^3 treated volume	30 - 40	0.15 (per m^2)
Retention pond, per m^3 treated volume	19.5 - 32.5	0.6 – 2 (per m^2)
Swale, per m^2	10 - 20	0.15
Filter strip, per m^2	5 - 20	0.15

Driving forces for implementation

There are a number of drivers for the implementation of environmentally friendly drainage systems, especially those gathered under the term sustainable drainage system. In general, these systems drive implementation in several ways:

- Environmentally:
  - To prevent adverse effects of climate change, that will have an impact on the availability of fresh water. This, combined with increase pressure to water resources, will produce also undesired effects because of groundwater availability and pollution.
  - To prevent storm events, that will be more frequent, with high rainfall peaks. Improved drainage should also allow avoiding erosion, thereby reducing water pollution and flood risks.
  - To preserve and create new habitats, while protecting species.
  - To recharge groundwater at the same time of maintaining or increasing its quality.
  - To fulfil regulations, national, regional or local, in line with the Water Framework Directive (EU, 2000).
- Economically:
  - To reduce downstream flooding and, therefore, preventing property damage.
  - To increase the real estate value through the aesthetic value of created amenities
  - To reduce the conventional drainage system costs
- Socially:
  - To create public spaces and to increase quality of life.

Reference organisations

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