Structural surface water management measures

Pennine Water Group, University of Sheffield in collaboration with the partners of the FloodResilienCity, MARE and SKINT projects

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Summary

This is a catalogue of structural surface water management measures containing brief descriptions of how they perform in terms of flooding and water quantity and pollution and water quality. A summary of other potential benefits is included. Links to other web pages containing more information about the different measures are provided. A more detailed description of hybrid measures known as Mulden-Rigolen in Germany, Wadis in the Netherlands and can be best described as Trench-Troughs in English is provided. Finally, a table summarising performance of all the measures in accordance with a performance based classification of structural water management measures is included at the end.

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1 Measures associated with buildings

The following measures are designed to manage rain water falling onto the roofs of buildings

- Green roofs
- Blue roofs
- Water butts
- Rainwater tanks

2 Measures for developed urban surfaces

These measures are appropriate for use in and around developed urban surfaces where space is often at a premium

- Gutters
- Hollow roads
- Permeable pavements / surfaces
- Pervious surfaces
- Rain gardens
- Trench-Troughs (Mulden-Rigolen)

3 Measures for urban and near urban green space

These measures are appropriate for use in new developments and in urban and near urban green space

- Rain gardens and bio-retention areas
- Swales
- Filter strips
- Filter drains
- Infiltration trenches
- Soakaways
- Ditches
- Ponds
- Retention ponds and detention ponds / tanks
- Detention basins
- Infiltration basins
- Reed beds – horizontal and vertical flow
- Wetlands
- Trench-Troughs (Wadis)

4 Sub surface conveyance measures

These measures are components of what is often called traditional drainage

- Surface water sewers and drains
- Combined sewers and drains
- Combined sewer overflows
- Sub surface storage
- Culverted watercourses

5 Inlets

Inlets connect surface with sub surface water management measures

- Inlets
- Gullies
- Gulley grates
- Gulley pots
- Screens

6 Landscaping measures

These measures are used to control water when the capacity of other measures are exceeded

- Terraces

7 Descriptions of measures

7.1 Green roofs

Flooding and water quantity

Roof level storage measures covered in vegetation rooted in soil with an underlying substrate in which the storage is provided. In normal operational conditions the measure is empties by means of evapotraspiration, which in winter can be low or even negligible. In extreme operational conditions the runoff bypasses or overflows the green roof into a downstream conveyance system

Pollution and water quality

Pollution in the collected roof water is subject to physical treatment processes like filtration and biochemical treatment processes such as biodegradation and uptake by plants

Other benefits

Green roofs are classed as multi functional green infrastructure a depending on the type of planting regime and accessibility of roof, can provide biodiversity and amenity benefits. In addition, they can help with the mitigation of urban heat island effects and improve air quality. Also provides a degree of sound adsorption and heat insulation.

Green roof in Norwegian wilderness

Green roof in Kronsberg, Hannover

Green roof on car park in Berlin (Harald Sommer)

For more information go to the IWA/SAWA Water Wiki at http://www.iwawaterwiki.org/xwiki/bin/view/Articles/greenroofs1 or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Small_Scale_SuDS.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Small_Scale_SuDS.pdf

7.2 Blue roofs

Flooding and water quantity	Pollution and water quality	Other benefits
Roof level storage measures that in normal operational conditions can be emptied for harvesting or using a flow control to limit the rate of flow into a conveyance measure. In extreme operational conditions the discharge bypasses or overflows the blue roof into a downstream conveyance measure.	Pollution in the collected roof water is transferred into the system which receives the harvested water.	Reduces demand for potable water with consequential benefits for energy, and potential benefits associated with reducing future demand for additional water supply. Potential economic benefits for users of water. May provide cooling effects. Multifunctional use of space.

For more information go to the New York City website at http://www.nyc.gov/html/dep/html/stormwater/green_pilot_project_ps118.shtml
You can also read about the potential benefits of rain water harvesting in these web pages.

7.3 Water butts

Flooding and water quantity

Small scale above ground on or offline storage measure for roof water that in normal operational conditions can be emptied for harvesting or using a flow control to limit the rate of flow into a conveyance measure. In extreme operational conditions the discharge bypasses or overflows the water butt into a downstream conveyance measure

Pollution and water quality

The minimal pollution in the collected roof water is transferred into the system which receives the harvested water.

Other benefits

Although the benefits are small for an individual water butt, they reduce demand for potable water with consequential benefits for energy, and potential benefits associated with reducing future demand for additional water supply. Potential small economic benefits for users of water.

Typical water butt draining a roof

Australian large scale water butt for rainwater harvesting (Tony Weber)

For more information go to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Small_Scale_SuDS.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Small_Scale_SuDS.pdf . You can also read about the potential benefits of rain water harvesting in SKINT WebPortal.

7.4 Rainwater tanks

Flooding and water quantity

Property scale on or off line storage measures for roof and/or surface water that in normal operational conditions can be emptied for harvesting by pumping if the tank is below ground or by gravity if the tank is solely for roof water and is located above ground level. In extreme operational conditions the discharge bypasses or overflows the tank into a downstream conveyance measure

Pollution and water quality

The minimal pollution in the collected roof and/or surface water is transferred into the system which receives the harvested water.

Other benefits

Reduces demand for potable water with consequential benefits for energy, although if the tank is below ground there is a negative effect on energy because of the need for pumping. Potential benefits associated with reducing future demand for additional water supply. Potential economic benefits for users of water. No additional land-take is required.

Industrial application of rainwater tanks at Hume depot, Australia (Tony Weber)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/RainwaterHarvesting_0 or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Small_Scale_SuDS.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Small_Scale_SuDS.pdf . You can also read about the potential benefits of rain water harvesting in these web pages.

7.5 Gutters

Flooding and water quantity

Small hard engineered open channel conveyance measures in paved urban surfaces such as footways public space and highways. In extreme operational conditions the gutter will overflow onto the surrounding surface and enter another surface water conveyance system

Pollution and water quality

Effective use of gutters in combination with other surface water management measures reduces the potential for pollution by eliminating the need for local surface water drains and sewers into which wrong connections and uncontrolled discharge of pollutants can be made.

Other benefits

Can contribute to urban design and there are economic benefits through elimination of local surface water drains and sewers

Highway edge gutter in Hurricane Territory

Roof drainage running into street gutter in Enschede (Mick Parr)

Gutter running into a Wadi in Enschede (Mick Parr)

7.6 Hollow roads

Flooding and water quantity

Roads which are lower at the centre than the edge to improve the conveyance capacity in extreme operational conditions and which distance surface water from buildings. Hollow roads may be used to convey water under extreme operational conditions

Pollution and water quality

There are no real benefits for water quality

Other benefits

Can be used effectively in urban design to enable level access to properties whilst providing protection against flooding. Economic benefits can also be achieved by reducing the number of inlets and connections to sewers. Flood water is kept further away from properties, potentially reducing the risk of damage from waves caused by vehicle movement

Hollow road in Nijmegen

Hollow road in Hurricane Territory

Hollow road in Hameln

7.7 Permeable pavements / surfaces

Flooding and water quantity

Hard engineered urban surfaces that are constructed of impervious surface containing voids that convey water downwards into the ground or into sub surface storage. In extreme operational conditions or if the pores within the pavement become blocked runoff flows along surface conveyance systems.

Pollution and water quality

Filtration, adsorption, biodegradation and sedimentation occur within the surface structure, and underlying layers.

Other benefits

No additional land take is required. Potential economic savings because the need for local inlets and connections to sewers reduced.

Permeable pavement construction in Arnhem

Permeable pavement construction in Arnhem

Permeable pavement reinstatement after utility works

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/PermeablePaving or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Permeable_Pavements.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Permeable_Pavements.pdf .

7.8 Pervious surfaces

Flooding and water quantity

A surface that allows water to soak through it into the ground or into sub surface storage. In extreme operational conditions or if the pores within the surface become blocked runoff flows along surface conveyance systems.

Pollution and water quality

Filtration, adsorption, biodegradation and sedimentation occur within the surface structure, and underlying layers.

Other benefits

No additional land take is required - provide multifunctional use of space. Can be used within urban design.

Pervious surfaces in Kronsberg, Hannover

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SurfaceInfiltration .

7.9 Rain gardens and bio-retention areas

Flooding and water quantity

Planted basins used to collect rainwater and treat it prior to infiltration into the ground and or discharge into a conveyance system. In extreme operational conditions rain gardens may overflow into the surrounding area and the flow may enter a surface conveyance system

Pollution and water quality

The main pollution removal mechanisms within this measure are; Filtration, aerobic degradation of pollutants by biodegradation and uptake by plants.

Other benefits

Provide amenity and ecological benefits. May also help mitigate urban heat island effects by providing shading depending on the planting strategy used. Used to create features within urban design, and provide a multifunctional use of space.

Street scale rain garden in Berlin. The water enters the rain garden through a gulley (Harald Sommer)

Estate scale rain garden (Bio-retention) in Utrecht

Estate scale rain garden (Bio-retention) in Kronsberg

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Bio-retention.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Bio-retention.pdf .

7.10 Swales

Flooding and water quantity

Vegetated or non vegetated channels with gently sloping sides that can convey or store water. Stored water may also infiltrate into the ground or into a sub soil storage system. In extreme operational conditions swales overflow into other surface conveyance systems

Pollution and water quality

The key pollution removal mechanisms within swales are filtration, sedimentation and some uptake by plants

Other benefits

Swales may provide some amenity and biodiversity benefits depending on the planting strategy used. They also can be used within urban design. Potential economic benefits through elimination of local surface water drains and sewers

Swale under construction in Devonshire Park, Bradford

Stepped swale in Mayfield Road, Bradford

Swale under construction in Arnhem

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Swales.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Swales.pdf .

7.11 Filter strips

Flooding and water quantity

Vegetated strips of land designed to accept runoff as overland sheet flow. They are placed between a hard-surfaced area and receiving water/treatment or conveyance system.

Pollution and water quality

Treat runoff by vegetative filtering, and can promote settlement of particulate pollutants and infiltration.

Other benefits

May provide some amenity and ecological benefits. Potential economic benefits through elimination of local surface water drains and sewers

Filter Strip followed by a Swale in Dundee, Scotland (University of Abertay)

Filter Strip followed by a Filter Drain at Hopwood England

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures

7.12 Filter drains

Flooding and water quantity

Storage measures in the form as trenches filled with a matrix such as granular material which under normal operating conditions are emptied through a perforated or un-jointed pipe into a piped conveyance system. In extreme operational conditions the water will overflow from the trench into a surface conveyance system

Pollution and water quality

Filtration and biodegradation may occur.

Other benefits

Potential economic benefits through elimination of local surface water drains and sewers

Filter Drain near Linburn Pond at DEX, Scotland (University of Abertay)

Filter Drain at J4M8 Industrial Estate, Scotland (University of Abertay)

Filter Drain at Residential area at Fort Collins, USA (University of Abertay)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Filter_Drains.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Filter_Drains.pdf .

7.13 Infiltration trenches

Flooding and water quantity

Storage measures in the form as trenches filled with a matrix such as granular material which under normal operating conditions are emptied by infiltration into the ground. In extreme operational conditions the water will overflow from the trench into a surface conveyance system

Pollution and water quality

Filtration and biodegradation may occur.

Other benefits

Potential economic benefits through elimination of local surface water drains and sewers

Infiltration Trench at Hamburg, Germany (University of Abertay)

Infiltration trench under construction in the Netherlands

Filter Trench off-road, Scotland (University of Abertay)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Infiltration_Trenches_Soakaways.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Infiltration_Trenches_Soakaways.pdf .

7.14 Soakaways

Flooding and water quantity	Pollution and water quality	Other benefits
Sub surface structures designed to allow surface water to infiltrate into the ground. In extreme operational conditions the infiltration rate may not be sufficient and water will rise in the drainage system until it overflows into a surface conveyance system.	These structures are not suitable for the treatment of highly contaminated runoff due to risks to underlying groundwater, especially where the groundwater is used for water supply. The main pollutant removal mechanisms within soakaways are; filtration and biodegradation.	Can increase groundwater recharge, do not require any additional land take.

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/Infiltrationandretentionstructures or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Infiltration_Trenches_Soakaways.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Infiltration_Trenches_Soakaways.pdf .

7.15 Ditches

Flooding and water quantity	Pollution and water quality	Other benefits
Small to medium sized steep sided artificial drainage channels which can convey and/or store surface water. Stored water may be removed by infiltration if the ditch is unlined or by evapotranspiration if it is planted.	The main pollution removal mechanisms are physical removal – e.g. filtration and sedimentation. Pollution, especially from oil can be readily seen in ditches and action taken. Ditches can be designed to trap oil.	Ditches provide an excellent way of trapping supermarket trolleys, old bicycles and drink drivers. The can then be removed and recycled.

7.16 Ponds

Flooding and water quantity

Depressions in which water can be stored above a permanently wet area. The storage area can be emptied by conveyance, but evapotranspiration and harvesting may also contribute. The water level is controlled by the level in the downstream conveyance system or a control such as a weir. In extreme operational conditions the water may flood out onto the surrounding land.

Pollution and water quality

Pollution uptake by emergent and submerged aquatic vegetation and sedimentation are the main pollutant removal mechanisms

Other benefits

Amenity and ecological benefits as well as potential to reduce urban heat island effects. Provide green infrastructure benefits and can be incorporated into urban design.

Urban ponds at Malmo (Virginia Stovin)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SUDSPond .

7.17 Retention and detention ponds

Flooding and water quantity

Retention ponds are large ponds designed for pollution and water quality purposes. Detention ponds have inlets which are higher than the outlet, even in extreme operational conditions. This prevents flooding from migrating upstream. The storage area can be emptied by conveyance, but evapotranspiration and harvesting nay also contribute. A detention tank is a sealed pond in which case it is solely emptied by conveyance

Pollution and water quality

Ponds through which the time of flow is long enough and the velocity of flow is low enough to allow the settlement and biological treatment of some pollutants.

Other benefits

Amenity and ecological benefits as well as potential to reduce urban heat island effects. Provide green infrastructure benefits and can be incorporated into urban design.

Cascade Ponds at DEX, Scotland (University of Abertay)

Retention Pond against the buildings in Tewkesbury, England (University of Abertay)

Retention pond at Kronsberg, Hannover

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SUDSPond or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Retention_Ponds.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Retention_Ponds.pdf .

7.18 Detention basins

Flooding and water quantity

Sometimes referred to as dry ponds, these are depressions which are normally dry in which water can be stored during periods of rainfall. They are normally vegetated, but may be sealed in which case conveyance is the only way in which it can be emptied. The water level is controlled by the level in the downstream conveyance system or a combination of controls such as an orifices and weirs. In extreme operational conditions the water may flood out onto the surrounding land.

Pollution and water quality

Sedimentation/pollutant settling may occur.

Other benefits

May function as a recreation/amenity facility or simply areas for nature in dry weather – multifunctional use of space.

Roadside Detention Basin at DEX, Scotland (University of Abertay)

Detention Basin at Malmo (Virginia Stovin)

Detention Basin with curved flow path for attenuation and to hold the water for long time. Stirling, Scotland (University of Abertay)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SUDSBasin or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Detention_Basins.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Detention_Basins.pdf .

7.19 Infiltration basins

Flooding and water quantity

Storage areas which are normally dry and which are designed to infiltrate surface water into the ground. In extreme operational conditions, the infiltration rate may not be sufficient and the water will rise and flood the surrounding area, or alternatively may enter a surface water conveyance system.

Pollution and water quality

Filtration of pollutants contained within runoff via filtration through soil. However, effective pre-treatment is required to remove sediments and fine silt prior to infiltration.

Other benefits

Ecological and amenity benefits may be possible.

Concrete lined infiltration basin in dense urban area (Floris Boogaard)

Infiltration Basin at Angmering, England

7.20 Reed beds – horizontal and vertical flow

Flooding and water quantity	Pollution and water quality	Other benefits
Horizontal flow reed beds are shallow ponds containing reeds through which the water flows horizontally and enters a conveyance system. Vertical flow reed beds are transient shallow ponds containing reeds through which the water flows vertically and infiltrates into the ground	Detain flow for significant periods allowing sediments to settle. Further pollutant removal is achieved via adhesion/uptake by plants as well as aerobic biodegradation.	High potential for amenity, ecological and aesthetic benefits. Provide green infrastructure benefits and can be incorporated into urban design. Horizontal flow reed beds are perhaps the public ideal of a wetland, an open area of water surrounded by reeds. However, vertical flow reed beds are perhaps the naturalists' ideal of a wetland, a boggy, sometimes water logged area providing the parental for a wide ranging biodiversity.

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/SoilFilters

7.21 Wetlands

Flooding and water quantity

Depressions which are covered in water for much of the time, but which are shallow enough to support the growth of bottom rooted plants. They are often built up from a combination of different measures such as ponds, reed beds and basins and have the characteristics of the component parts.

Pollution and water quality

Detain flow for significant periods allowing sediments to settle. Further pollutant removal is achieved via adhesion/uptake by plants as well as aerobic biodegradation.

Other benefits

High potential for amenity, ecological and aesthetic benefits. Provide green infrastructure benefits and can be incorporated into urban design.

Wetlands providing storage for water quantity and water quality purposes at Kronsberg, Hannover

Constructed wetlands for water quality purposes at Bradford prior to planting

Urban wetland at Malmo (www.cabe.org)

For more information go to the IWA/SAWA Water Wiki http://www.iwawaterwiki.org/xwiki/bin/view/Articles/ConstructedWetlands or to the UK SuDS site at http://geoservergisweb2.hrwallingford.co.uk/uksd/information/Stormwater_Wetlands.pdf or the Irish SuDS site at http://www.irishsuds.com/information/Stormwater_Wetlands.pdf .

7.22 Surface water sewers and drains

Flooding and water quantity	Pollution and water quality	Other benefits
Pipelines conveying surface water from sources to an outlet at a water body or a soakaway. In extreme operational conditions the pipe surcharges to ground level at low spots, either causing flooding or flow to enter surface conveyance systems. However, because they are not affected by loss of capacity through saturation of the ground, their capacity is unaffected by prolonged periods of rainfall.	Pollution is conveyed within the pipe structure to the outlet. Some physical pollutant removal processes such as sedimentation may occur depending on the flow rates within the pipe.	Can be used appropriately within the design of a surface water drainage system. The conveyance of water below ground during normal wet weather operation is viewed by many as an amenity and improves road safety

7.23 Combined sewers and drains

Flooding and water quantity	Pollution and water quality	Other benefits
Pipelines conveying surface water and sewage from sources to an outlet at a sewage treatment plant or combined sewer overflow. In extreme operational conditions the pipe surcharges to ground level at low spots, either causing flooding or flow to enter surface conveyance systems. However, because they are not affected by loss of capacity through saturation of the ground, their capacity is unaffected by prolonged periods of rainfall.	Pollution is conveyed within the pipe structure to the sewage treatment works. Some physical pollutant removal processes such as sedimentation may occur depending on the flow rates within the pipe.	Combined sewers and drains are one of the two foundations of healthy life in dense modern cities (the other being public water supply). Between them they have possibly made a larger contribution to increased life expectancy and quality of life than any other factor, other than secure food supply. The conveyance of water below ground during normal wet weather operation is viewed by many as an amenity and improves road safety

7.24 Combined sewer overflows

Flooding and water quantity	Pollution and water quality	Other benefits
Structures which divert storm sewage into water bodies during periods of rainfall to limit the flow to sewage treatment works to manageable quantities.	Combined sewer overflows can release pollutants untreated into receiving waters, but if properly designed with appropriate sub surface storage (6.26), screens (6.33) and chamber design can reduce the frequency of discharge and can contain gross solids and oil within the sewer system	As an essential part of combined sewer systems, they have the same benefits as combined sewers and drains (6.25)

7.25 Sub surface storage

Flooding and water quantity	Pollution and water quality	Other benefits
Storage associated with sewers and drains which can be used in flood management and to limit the number of CSO discharges, retaining the stored volume for treatment when flow levels decrease.	Physical treatment such as sedimentation and oil separation will occur within the storage.	They have the same benefits as the system in which they are constructed.

7.26 Culverted watercourses

Flooding and water quantity

Watercourses have been culverted for many reasons, such as improving accessibility across the watercourse and to stop abuse of the watercourse, through littering and pollution within urban areas. Culverting reduces the connectivity between urban surfaces and watercourses, and in extreme operational conditions can cause surface flooding if the inlets do not operate properly or if the capacity of the culvert is inadequate or reduced through sediment or blockage.

Pollution and water quality

Additional pollution may not be able to get into the watercourse where culverting has occurred. Depending on the flow regime some sedimentation may occur.

Other benefits

The main reason for culverting is to provide accessibility across watercourses. Hence they may be viewed as providing significant amenity values. Without culverts our dense cities would very different than they are today.

Culvert on Bradford Beck, enabling levelling of land and development to take place

Built over culvert at Leuven

High water levels due to blockage of culvert inlet

7.27 Inlets

Flooding and water quantity	Pollution and water quality	Other benefits
Inlets provide the links between surface and sub surface drainage systems. They may be used to control flows, and if not properly maintained will control flows in an unplanned manner.	Inlets can be used to manage the pollution in surface water before it enters sub surface drainage systems. The surface water management measures described in this document which are normally emptied through sub surface conveyance systems can act as inlets including: Green roofs Blue roofs Rain gardens Trench –Troughs Filter drains Ditches Ponds (retention and detention) Detention basins	The benefits depend on the type of inlet used

7.28 Gullies

Flooding and water quantity	Pollution and water quality	Other benefits
Gullies are the main form of inlet between urban surfaces and sewers and culverted water courses. The capacity of the inlet is controlled by the connecting pipe and/or the grate, especially if it becomes blocked by lack of maintenance. If surface water fails to enter the gulley it flows down a conveyance pathway, possibly to the next gulley which in turn may become overloaded.		They have the same benefits as the system in which they are constructed.

7.29 Gulley Grates

Flooding and water quantity

Gulley grates are designed to keep litter out of the sub surface drainage system, but if not maintained properly may become blocked. They may also become blocked during extreme operational conditions by the amount of litter, including leaves carried in the flow.

Pollution and water quality

Removal of gross solids from surface water runoff

Other benefits

They have the same benefits as the system in which they are constructed.

Gulley grate in Hull (Chrichton 2007)

Gulley grate in Bradford

Gully grate in Kassandria, Halkadiki, Greece

7.30 Gulley pots

Flooding and water quantity

Gulley pots are designed to provide a water seal to prevent odours from being emitted from the sub surface drainage system. This arrangement also traps pollution attached to sediment, and oil washed off road surfaces. This is most beneficial to surface water drainage systems rather than combined sewers. Poor maintenance can allow too much sediment to accumulate and this can cause blockages, causing water to flow along surface conveyance systems.

Pollution and water quality

Removal of sediment and oil from surface water runoff

Other benefits

They have the same benefits as the system in which they are constructed.

Typical old UK gulley pot

German gulley pot with "Innolet" cartridge filter

Modern trapped UK gully (375mm diameter, 750mm depth) with 150mm diameter outlet

7.31 Screens

Flooding and water quantity

Screens are used to remove debris and litter from fat the inlets to culverts, from the storm sewage diverted at combined sewer overflows and at sewage treatment works. They can be manually or automatically cleaned. If too much debris causes blinding either due to inadequate maintenance or to rapid build up during extreme operational conditions, then the water level may rise causing flooding.

Pollution and water quality

Protection of culverts from blockage by removal of gross solids

Protection of receiving water from sewer solids at CSOs

Protection of sewage treatment processes from gross solids

Other benefits

They contribute to the benefits of the system in which they are constructed.

Makeshift screen at culvert entrance

CSO screen in full scale test rig

Inlet screen at large culvert under pressure

7.32 Terraces

Flooding and water quantity

Terraces provide flat compartments in a sloping landscape within which water can be controlled and directed. Other surface water management measures may be built within terraces, but the main purpose of a terrace is to control the flow once the capacity of the other measures is exceeded. Under normal operation a terrace will store water at shallow depth over a large area. Under extreme operational conditions, when it's capacity is exceeded, it may be designed to overflow into designed pathways linking a chain of terraces and discharging into appropriate off site pathways. Such pathways could include roadways , pathways and other amenity features

Pollution and water quality

Terraces provide a wide range of pollution and water quality benefits, depending on the type of surface water measures and surfaces that they contain

Other benefits

Terraces can provide a wide range of benefits including:

- Rainwater harvesting
- Green infrastructure
- Amenity
- Multifunctional spaces usage

They also have economic benefits as developments have to be landscaped and the unit cost per cubic metre of earthworks is much less than that for drainage excavation.

Multi functional terraced play space in Berlin (Photo Harald Sommer)

Terrace in Kronsberg, Hannover

Terracing on a steep slope in Northern England

7.33 Trench-Troughs (Mulden-Rigolen and Wadis)

An effective way of linking the management of surface water quantity and quality

Acknowledgement. The photographs and illustrations in this information sheet have been provided by the partners in the Interreg 3b projects NORIS and UWC.

History

Trench trough drains have been used in Germany for many years. Known as Mulden-Rigolen, they migrated over the border into the Eastern Netherlands in the mid 1990s as a result of a study tour from the City of Enschede which wished to introduce more sustainable drainage systems into its communities.

Inevitably there were concerns that the City was going to create mosquito infested swamps and that malaria would become rife. But with overwhelming evidence from Germany that this would not be the case, the first systems were installed

Known as Wadis in the Netherlands, these system have become almost ubiquitous with over 85% of municipalities having systems installed

In 2004, transnational collaborations between Germany, the Netherlands and the UK brought Wadis to the attention of a small number of water engineers in Bradford and at Sheffield University

The initial application of these versatile systems in Bradford was to control excess runoff from urban green space which was causing flooding.

How they work

The term Wadi is apt. For most of the time the Wadis are dry, only filling with water when heavy, prolonged rainfall occurs. Even then they empty within a reasonable period of time once the rainfall has abated,

They provide both flood and water quality management through a combination of filtration and what is effectively off line storage

Cross Section

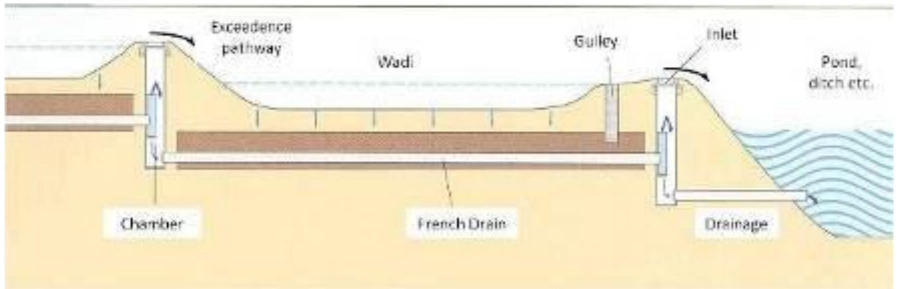
- A trough (swale) is constructed above a filter drain
- The ground is improved to permit slow infiltration into the drain
- The drain may be allowed to infiltrate into the ground or may be sealed
- A high level connection links the trough to the drain when it fills to a determined level
- The trough also has a connection to an exceedence pathway

Cross section through a Wadi (UWC)

Wadis in dry and wet weather (UWC)

Long section

- At low flows the runoff infiltrates into the French drain and then into the ground
- As runoff increases the water level in the Wadi increases and some water may flow along the drainage pipe
- With more runoff the water runs through the gulley into the French Drain
- The chambers may contain oil traps and/or flow controls as required
- During intense rainfall the water may flow through the chamber inlet
- Eventually it flows along the exceedence pathway
- The receiving water may take a variety of forms



Long section through a *Wadi* (UWC)

Perspective

- The water enters the Wadi via surface pathways.
- The expense of surface water drains can be avoided
- The risk of wrong connections can be eliminated
- It can be used in conjunction with permeable surfaces
- It can provide an amenity feature

Perspective of a Wadi (UWC)

Application

- Wadis are extremely versatile .
- They can be large or small
- They can be used to drain highways
- They can drain whole estates whilst providing high amenity public realm
- They can help control ground water levels
- Larger ones might just find those fissures in stiff clays that will allow you to infiltrate where otherwise you couldn't

Mulden Rigolen providing street drainage in Berlin (Photo Harald Sommer)

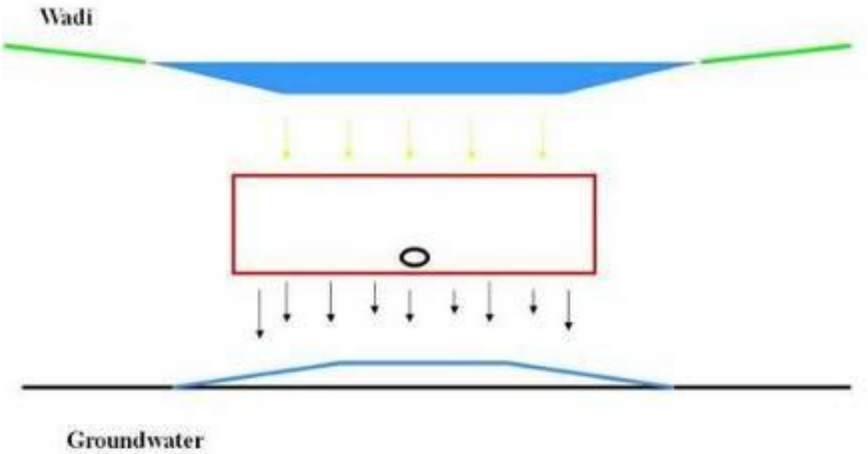
Mulden Rigolen providing street drainage in Kronsberg, Hannover

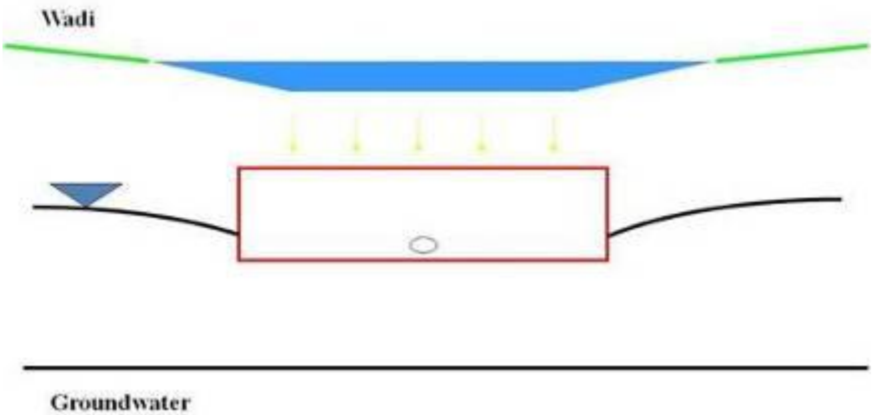
Wadis in Enschede after heavy rainfall (UWC)

Mulden Rigolen in a factory unit in Berlin (Harald Sommer)

A Wadi in Enschede in normal conditions (Tony Poole)

Infiltration and groundwater control





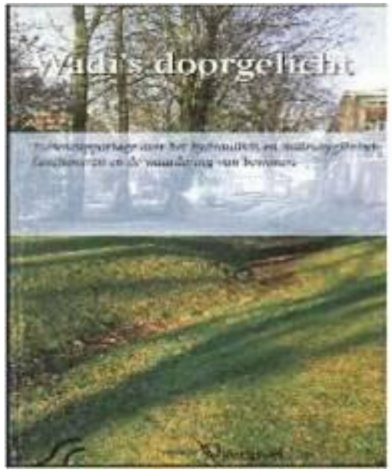
Construction details

- Chambers can be detailed to meet site specific requirements
- Drainage media can include stone, light duty honeycombs or heavy duty crates
- Choice of geotextiles is site specific
- With a bit of attention to detail you can ensure that the water goes where it is intended to go.

Examples of construction

Technical literature

- The Dutch have amassed a considerable body of research about Wadis.



An example of surface flow routing into aWadi

8 Table summarising performance and other benefits of measures

Legend

Relevance and appropriateness	
The measure is relevant and appropriate	Green
The measure is relevant and may or may not be appropriate	Amber
The measure is relevant and may be inappropriate	Red
The measure is not relevant	

8.1 Building scale measures

		Water Quantity										
		Conveyance				Storage				Controls		
		Surface		Sub-surface		Conveyance	Evaporation/Evapotranspiration	Infiltration	Flow harvesting	Level control	Discharge control	Inlets
Measure	Operational condition	Sheet flow	Channel flow	piped	ground flow							
Green roofs	Normal						Green					
	Extreme					Green				Green		
Blue roof	Normal					Green			Green		Green	
	Extreme					Green				Green		
Water butts	Normal								Green		Green	
	Extreme					Green				Green		
Rainwater tanks	Normal								Green			
	Extreme					Green				Green		

		Water Quality											
		Physical treatment						Biochemical treatment					
		Litter and debris removal	Oil and grease removal	Sedimentation	Precipitation	Filtration	Pollutant capture and diversion	Adsorption	Aerobic biological processes		Anaerobic biological processes	Nutrient removal	UV treatment
Measure	Operational condition								Biodegradation	Uptake by Plants			
Green roofs	Normal					Green			Green	Green			
	Extreme					Green			Green	Green			
Blue roof	Normal												
	Extreme												
Water butts	Normal												
	Extreme												
Rainwater tanks	Normal												
	Extreme												

		Urban design and other								
Measure	Operational condition	Water supply	Green Infrastructure	Amenity	Nature	Cooling	Air Quality	Energy	Economic	Multifunctional space usage
Green roofs	Normal		Green	Green	Green	Green	Green	Green		Green
	Extreme		Green	Green	Green	Green	Green	Green		Green
Blue roof	Normal	Green						Green	Green	Green
	Extreme	Green						Green	Green	Green
Water butts	Normal	Green				Amber			Green	Green
	Extreme	Green				Amber			Green	Green
Rainwater tanks	Normal	Green						Amber	Green	
	Extreme	Green						Amber	Green	

8.2 Measures for developed urban surfaces

		Water Quantity										
		Conveyance				Storage				Controls		
		Surface		Sub-surface		Conveyance	Evaporation/Evapotranspiration	Infiltration	Flow harvesting	Level control	Discharge control	Inlets
Measure	Operational condition	Sheet flow	Channel flow	piped	ground flow							
Gutters	Normal		■									
	Extreme		■							■		
Hollow roads	Normal		■									
	Extreme		■									
Permeable pavements / surfaces	Normal				■							
	Extreme	■										
Pervious surfaces	Normal											
	Extreme	■	■									
Rain gardens and bio-retention areas	Normal					■	■	■		■	■	
	Extreme					■						
Trench-Trough (Mulden Rigolen and Wadis)	Normal					■	■	■		■	■	
	Extreme		■									

		Water Quality											
		Physical treatment						Biochemical treatment					
		Litter and debris removal	Oil and grease removal	Sedimentation	Precipitation	Filtration	Pollutant capture and diversion	Adsorption	Aerobic biological processes		Anaerobic biological processes	Nutrient removal	UV treatment
Measure	Operational condition								Biodegradation	Uptake by Plants			
Gutters	Normal						■						
	Extreme						■						
Hollow roads	Normal												
	Extreme												
Permeable pavements / surfaces	Normal			■		■		■	■				
	Extreme			■		■		■	■				
Pervious surfaces	Normal			■		■		■	■				
	Extreme			■		■		■	■				
Rain gardens and bio-retention areas	Normal					■			■	■			
	Extreme					■			■	■			
Trench-Trough (Mulden Rigolen and Wadis)	Normal			■		■			■	■			
	Extreme			■		■			■	■			

		Urban design and other								
Measure	Operational condition	Water supply	Green Infrastructure	Amenity	Nature	Cooling	Air Quality	Energy	Economic	Multifunctional space usage
Gutters	Normal								■	
	Extreme								■	
Hollow roads	Normal			■					■	■
	Extreme			■					■	■
Permeable pavements / surfaces	Normal								■	■
	Extreme								■	■
Pervious surfaces	Normal								■	■
	Extreme								■	■
Rain gardens and bio-retention areas	Normal		■	■	■	■				■
	Extreme		■	■	■	■				■
Trench-Trough (Mulden Rigolen and Wadis)	Normal		■	■	■	■			■	■
	Extreme		■	■	■	■			■	■

8.3 Measures for urban and near urban green space

		Water Quantity											Water Quality												Urban design and other								
		Conveyance				Storage				Controls			Physical treatment							Biochemical treatment					Water supply	Green Infrastructure	Amenity	Nature	Cooling	Air Quality	Energy	Economic	Multifunctional space usage
		Surface		Sub-surface		Conveyance	Evaporation/Evapotranspiration	Infiltration	Flow harvesting	Level control	Discharge control	Inlets	Litter and debris removal	Oil and grease removal	Sedimentation	Precipitation	Filtration	Pollutant capture and diversion	Adsorption	Aerobic biological processes		Anaerobic biological processes	Nutrient removal	UV treatment									
Measure	Operational condition	Sheet flow	Channel flow	piped	ground flow															Biodegradation	Uptake by Plants												
Rain gardens and bio-retention areas	Normal					green	green	green		green	green						green			green	green					green	green	green	green				green
	Extreme					green																											
Swales	Normal		green		green	green		green		green					green		green				orange					green	green	green	green			green	green
	Extreme		green			green				green																							
Filter strips	Normal	green													orange		green									green	green	green	green			green	green
	Extreme	green																															
Filter drains	Normal					green											orange			orange												green	
	Extreme					green																											
Infiltration trenches	Normal							green						red			orange	red		orange												green	
	Extreme					green		orange																									
Soakaways	Normal							green						red			orange	red		orange													
	Extreme					green		orange																									
Ditches	Normal		green			green	green	green		green	green			orange	green		green									green		green					
	Extreme		green			green	orange	orange																									
Ponds	Normal					green	green		green	green	green				green						green					green	green	green	green				
	Extreme		green			green																											
Retention ponds	Normal					green	green		green	green	green				green						green					green	green	green	green				
	Extreme		green			green																											
Detention ponds / tanks	Normal					green	green		green	green	green				green						green					green	green	green	green			green	
	Extreme		green			green																											
Detention basins	Normal					green		green		green	green				orange											green	green	green				green	green
	Extreme		green			green																											
Infiltration basins	Normal							green							red		green									green	green	green				green	green
	Extreme		green			green																											
Reed bed – horizontal flow	Normal					green	green								green					green	green					green	green	green					
	Extreme		green			green																											
Reed bed – vertical flow	Normal						green	green							green					green	green					green	green	green					
	Extreme		green			green																											
Wetlands	Normal					green									green					green	green					green	green	green					
	Extreme		green			green																											
Trench-Trough (Mulden Rigolen and Wadis)	Normal					green	green	green		green	green				green		green			green	green					green	green	green	green			green	green
	Extreme		green																														

8.4 Sub surface conveyance measures

		Water Quantity											Water Quality												Urban design and other								
		Conveyance				Storage				Controls			Physical treatment							Biochemical treatment					Water supply	Green Infrastructure	Amenity	Nature	Cooling	Air Quality	Energy	Economic	Multifunctional space usage
		Surface		Sub-surface		Conveyance	Evaporation/Evapotranspiration	Infiltration	Flow harvesting	Level control	Discharge control	Inlets	Litter and debris removal	Oil and grease removal	Sedimentation	Precipitation	Filtration	Pollutant capture and diversion	Adsorption	Aerobic biological processes		Anaerobic biological processes	Nutrient removal	UV treatment									
Measure	Operational condition	Sheet flow	Channel flow	piped	ground flow															Biodegradation	Uptake by Plants												
Surface water sewers and drains	Normal																																
	Extreme																																
Combined sewers and drains	Normal																																
	Extreme																																
Combined sewer overflows	Normal																																
	Extreme																																
Sub surface storage	Normal																																
	Extreme																																
Culverted watercourses	Normal																																
	Extreme																																

8.5 Inlets

		Water Quantity											Water Quality												Urban design and other								
		Conveyance				Storage				Controls			Physical treatment						Biochemical treatment						Water supply	Green Infrastructure	Amenity	Nature	Cooling	Air Quality	Energy	Economic	Multifunctional space usage
		Surface		Sub-surface		Conveyance	Evaporation/Evapotranspiration	Infiltration	Flow harvesting	Level control	Discharge control	Inlets	Litter and debris removal	Oil and grease removal	Sedimentation	Precipitation	Filtration	Pollutant capture and diversion	Adsorption	Aerobic biological processes		Anaerobic biological processes	Nutrient removal	UV treatment									
Measure	Operational condition	Sheet flow	Channel flow	piped	ground flow															Biodegradation	Uptake by Plants												
Inlets	Normal												Depends on the type of inlet																				
	Extreme																																
Gullies	Normal												See gulley grates and gulley pots																				
	Extreme																																
Gulley Grates	Normal																																
	Extreme																																
Gulley pots	Normal																																
	Extreme																																
Screens	Normal																																
	Extreme																																