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D.T1.3.1 Technical Training Manual on Urban Circular Water Management for Municipalities

fbr, Association for Rainwater Harvesting and Water Utilisation

MODULE 2: RAINWATER MANAGEMENT

- Introduction
- Centralised discharge in combined and separate sewer systems
- Decentralised rainwater management
- Decentralised rainwater management measures
    - Rainwater harvesting and utilisation
    - Rainwater retention
    - Rainwater infiltration

Conventional (combined) sewer systems

- Contribute to unnatural water balances
- Increased sealing of urban surfaces results in the quick discharge of rainwater away from the city, thus intensifying the heat island effects
- The evaporative characterisitcs of rainwater are lost in the process
- Overloading of the combined sewer system due to increased incidence in floods and heavy rainfall events in urban areas:
  - ⇒ increased pollution load of surface waters
  - ⇒ negative impacts on flora and fauna
  - ⇒ infrastructure and property damages
- Recycling of water, energy and nutrients becomes difficult once wastewater flows are combined and not separated at the source
- High capital costs
- High operation and maintenance costs

INTRODUCTION

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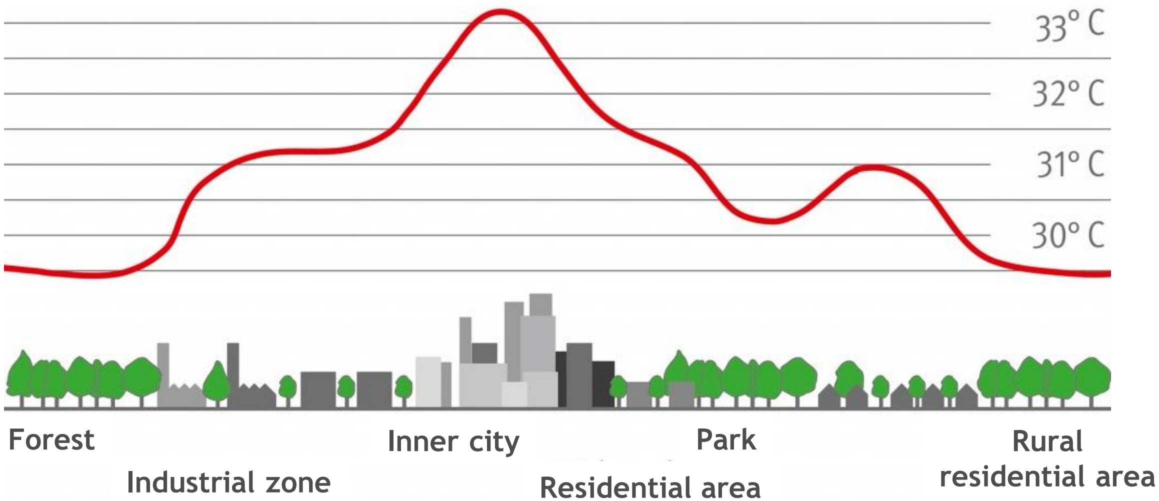
Heat island effects



Increased sealing of surfaces, less green and rapid discharge of rainwater away from city will increase the heat island effects

(Source: https://klimawandelanpassung.at/index.php?id=26977)

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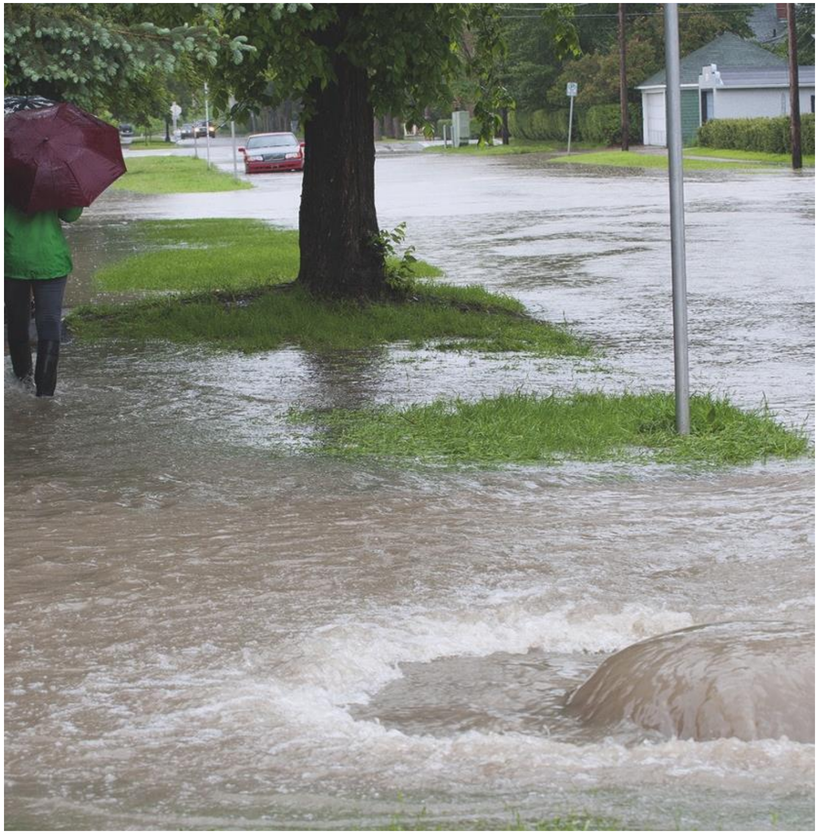
Increase in frequency of extreme weather events

Wet scenario



Dry scenario

Impacts of climate change on the conventional sewer system

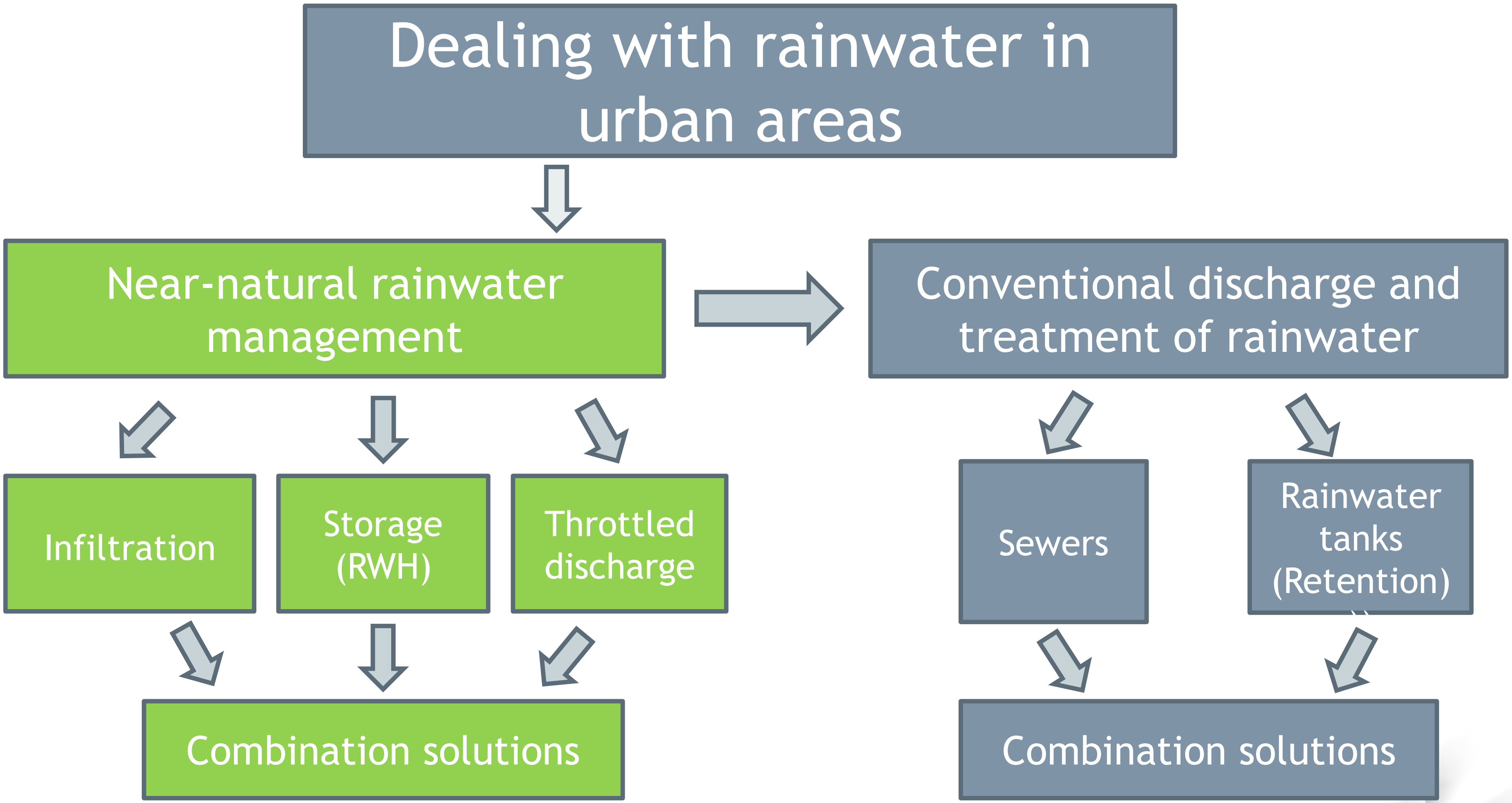
Extreme rain and flood events

Flooded streets in Bonn in 2013 (Photo: Stephan Knopp GA/Bonn)

INRODUCTION

Damage caused by drought!

INTRODUCTION



(Source: Adapted from Londong & Nothnagel)

CENTRALISED DISCHARGE

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into combined sewer (without retention):

- Sewer overload due to increased frequency of heavy rainfall events
  e.g. in Berlin, ca. 40 sewer overflows/year
  ⇒ negative impacts on flora and fauna, fish mortality, etc.

- High pollutant load, especially from traffic surfaces, find ist way into water bodies (e.g. microplastics, heavy metals, …)

- Establishes unnatural water balances:
  reduces local evaporation process
  reduces local groundwater recharge

  Info: the natural water balance in Berlin is 80% evaporation, 20% groundwater recharge and 0% surface runoff.

CENTRALISED DISCHARGE

Fish mortality caused by sewer overflow discharges into water bodies

Rainwater sewer overflow, Schäfersee, Berlin

Combined sewer overflow, Landwehrkanal, Berlin
(Source: Landwehrkanal Blog)

CENTRALISED DISCHARGE

into **combined** sewer without treatment (retention):

Mixed water overflow basins in Berlin-Wedding (Photo: BWB)

Wall for storage space activation in Berlin-Wedding (Photo: BWB)

CENTRALISED DISCHARGE

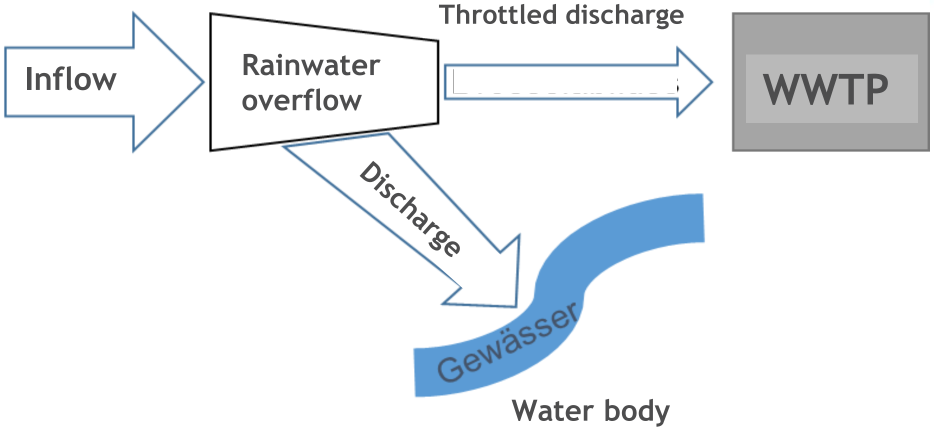
Into **combined** sewer (retention):

- Construction of expensive underground rainwater retention basins (Berlin storage sewers approx. 3,000 €/m³)
  - Rainwater retention basins reduce the overflow frequency, but
  - Require the development of WWTP resources (cost-intensive)
  - Do not contribute to improving the local water balance

CENTRALISED DISCHARGE

into **combined** sewer with retention:

Rainwater overflow basins and storage sewers slightly reduce the discharge of wastewater overflows into water bodies, but do not contribute at all to evaporation in the urban environment



Storage sewer in Mauerpark

Bau des Stauraumkanals im Mauerpark, Copyright: Berliner Wasserbetriebe/ Stephan Natz

(Source: BWB)

CENTRALISED DISCHARGE

into **rainwater (stormwater*)** sewer without treatment:

Has the disadvantage, that pollutants enter the surface water bodies.

- Significant pollutant load, especially from traffic surfaces, finds its way into water bodies (e.g. microplastics and heavy metals)
  → negative impacts on flora and fauna, fish mortality, etc.

- It also establishes unnatural water balances:
  reduces local evaporation process
  reduces local groundwater recharge

Info: the natural water balance in Berlin is 80% evaporation, 20% groundwater recharge and 0% surface runoff.

*Rainwater and stormwater are used here interchangeably

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into **rainwater** sewer with centralised pre-treatment:

Underground rainwater storage basins with lamella separators for pollutant load reduction (treatment mainly through sedimentation)

Rainwater clarification basin Schlierseestrasse, Berlin-Köpenick (Photo: BWB)

Lamella separator at Fennsee (Photo: BWB)

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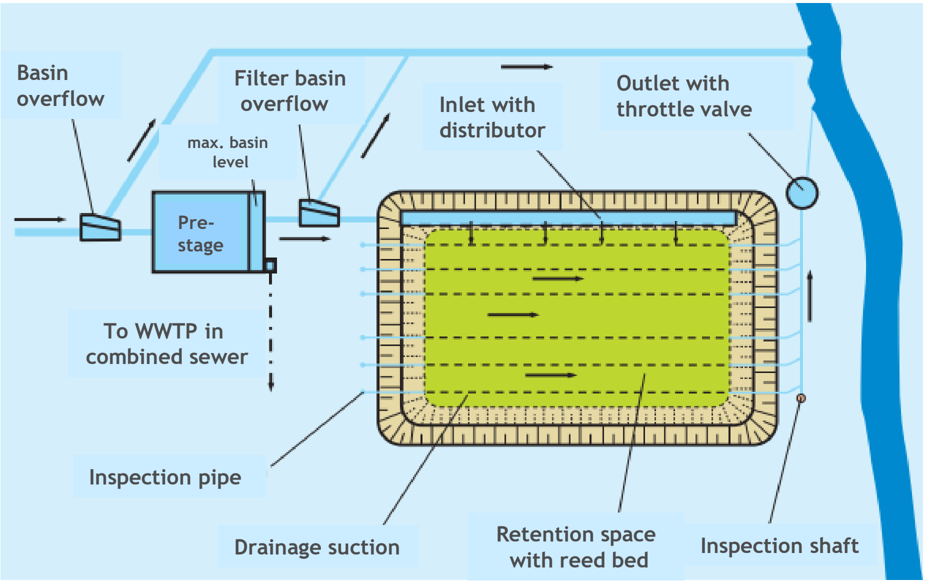
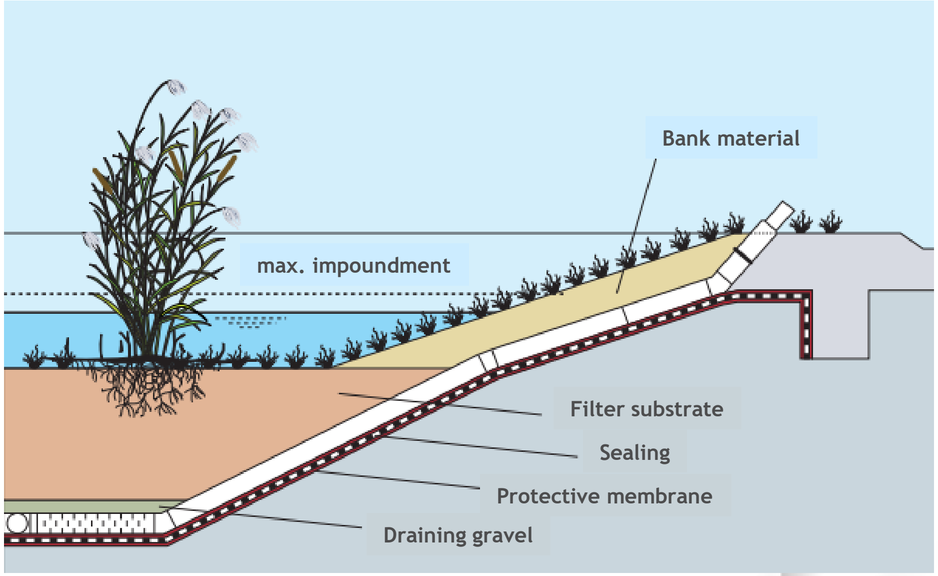
into **rainwater or combined sewer** (post-treatment in retention soil filters):

Retention soil filters treat wastewater from combined or stormwater sewer and reduce hydraulic and pollutant load entering water bodies

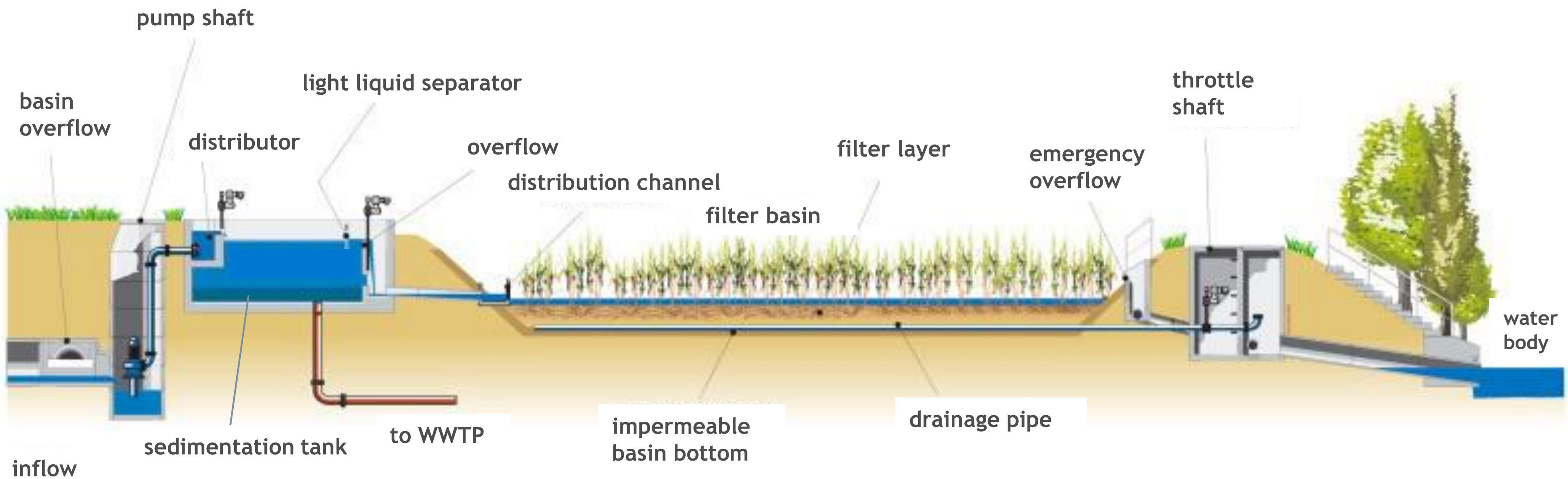




(Source: Retentionsbodenfilter : Handbuch für Planung, Bau und Betrieb, 2015. https://www.umwelt.nrw.de/fileadmin/redaktion/Broschueren/retentionbodenfilter_handbuch.pdf)

CENTRALISED DISCHARGE

Schematic diagram of a retention soil filter



(Source: BWB)

Retention soil filters

Retention soil filter Halensee, Berlin (Photo: Andreas Süß)

Retention soil filter Adlershof, Berlin (Photo: Andreas Süß)

CENTRALISED DISCHARGE

Retention soil filters

(Source: Retentionsbodenfilter : Handbuch für Planung, Bau und Betrieb, 2015)

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Rainwater retention basins

Rainwater retention basin in Business Park Berlin-Bohnsdorf (Photo: BWB)

Rainwater retention basin in Pillgramer Straße, Berlin-Mahlsdorf (Photo: BWB)

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with decentralised on-site pre-treatment (in street gullies):



Different systems of decentralised rainwater pre-treatment at Clayallee, Berlin (Photo: KWB, Sieker)

Decentralised Rainwater Management

Building/property level

(e.g. rainwater harvesting, green roofs and facades, local infiltation)

District level

(e.g. artificial water bodies, infiltration, decentralised treatment systems)

Priorities in Rainwater (Stormwater)* Management

1. Unsealing of urban areas and avoiding new sealings
2. On-site rainwater harvesting and utilisation
3. Rainwater retention
4. Rainwater infiltration (groundwater recharge)
5. Throttled discharge into a water body or wastewater treatment plant

*Rainwater and stormwater are used here interchangeably

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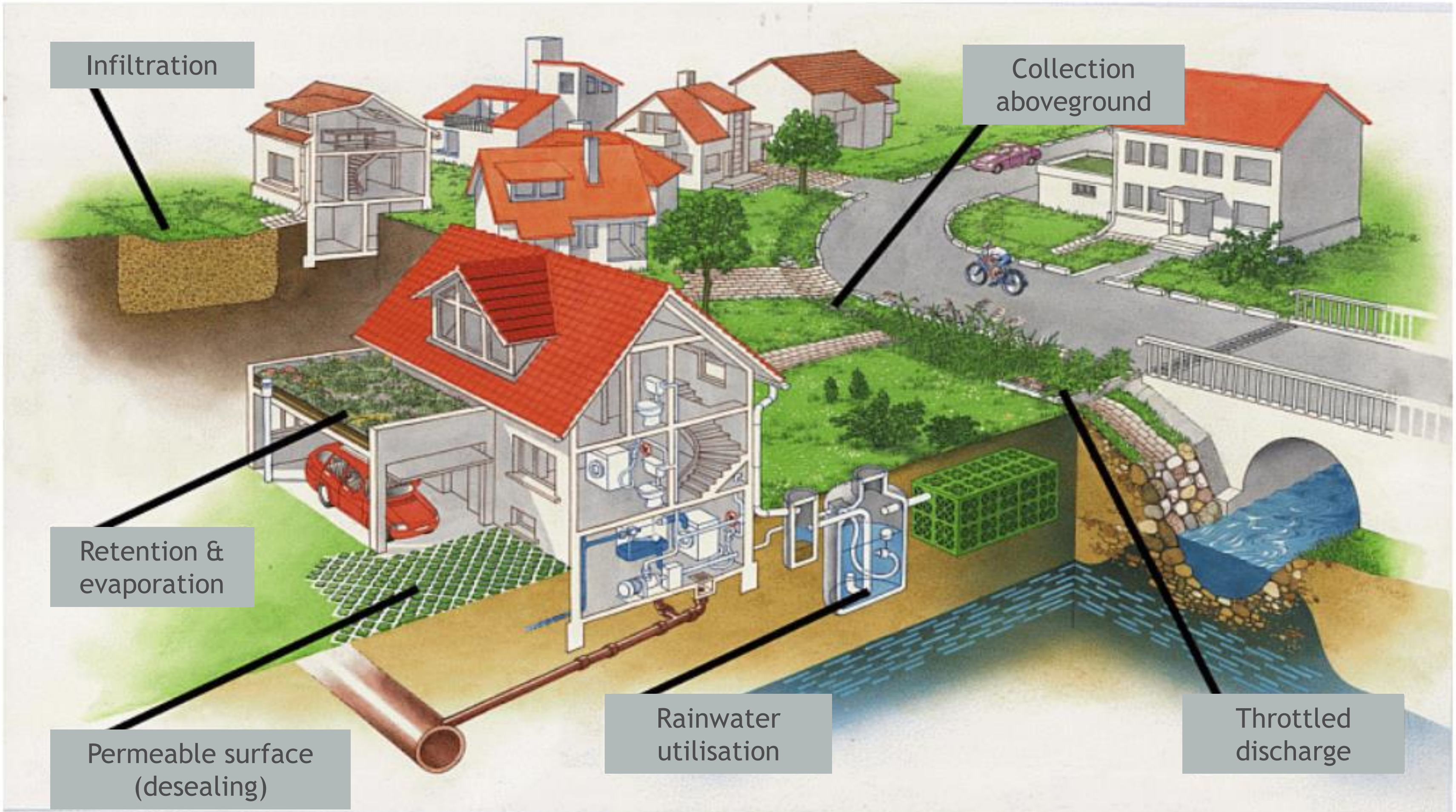
Decentralised rainwater management in urban areas



(Source: fbr)

Decentralised rainwater management measures

1. Rainwater harvesting and utilisation
2. Rainwater retention (and evaporation): green roofs, green walls, rain gardens, ponds and wetlands, adiabatic cooling, …
3. Rainwater infiltration: permeable surfaces, infiltration basins, infiltration trenches, swales, swale-trench systems for impermeable soils, …

There is no single best technique for a specific site, in most cases a combination of techniques is required.

1. Rainwater harvesting (RWH)

(Source: fbr)

Substitution of over **50 %** of the potable water demand in households (120 L/P/d):

- 40 L for toilet flushing
- 15 L for laundry (soft water)
- 3 L for cleaning
- 4 L for irrigation

Overview

- Rainwater harvesting systems range from simple rain barrels for garden irrigation to more advanced structures consisting of tanks, pumps and filters
- Simple treatment: sieves and sedimentation in the tank
- Advanced treatment: systems also include membrane and UV disinfection units to treat rainwater for potable and non-potable use in households
- Water quality is mainly dependent on site, roof material, technology used and system maintenance
- Plain rooftops are the preferred catchment surfaces for household RWH
- Ground runoffs can also be used for non-potable applications following simple treatment

Overview (2)

- RWH can be installed in new and existing buildings
- In public sector: toilet flushing in schools, community centres and other buildings, also for irrigation of open spaces, sports facilities and sewer cleaning
- In industry and trade: RW can be reused for cooling purposes, steel cleaning, as service (process) water in the production process, or as operational water for fire fighting

RAINWATER HARVESTING

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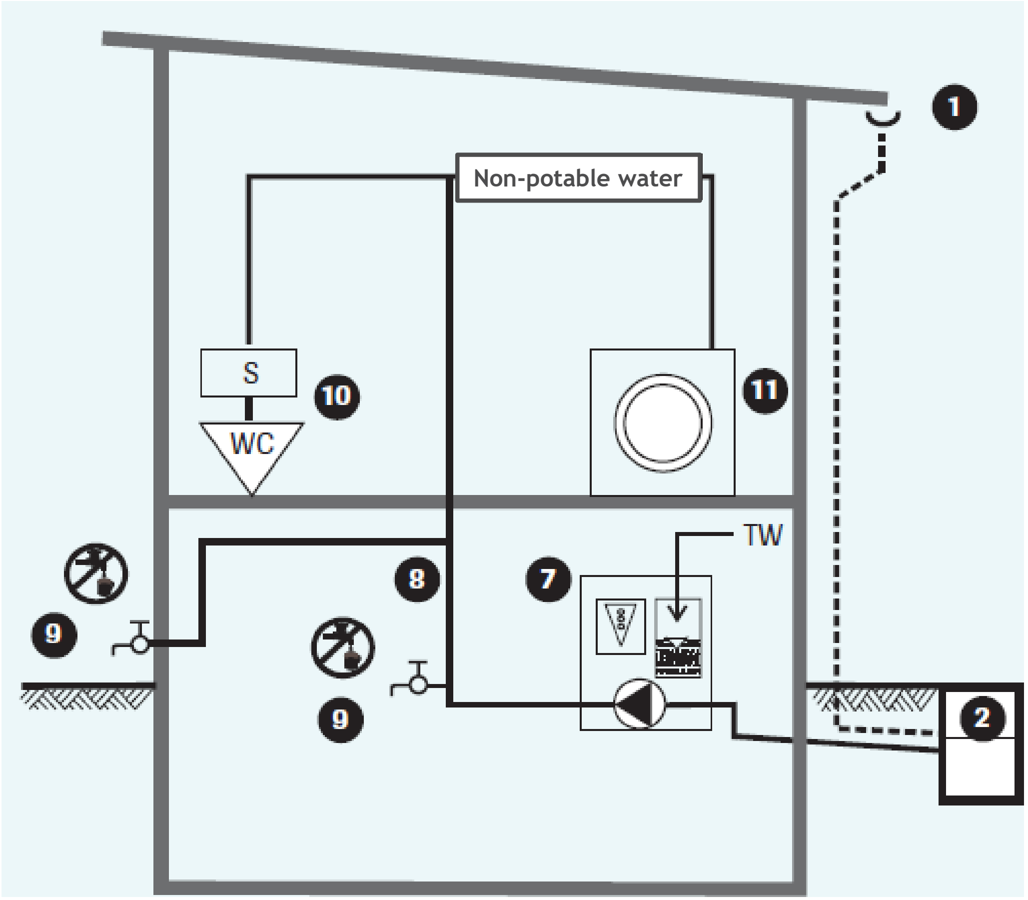
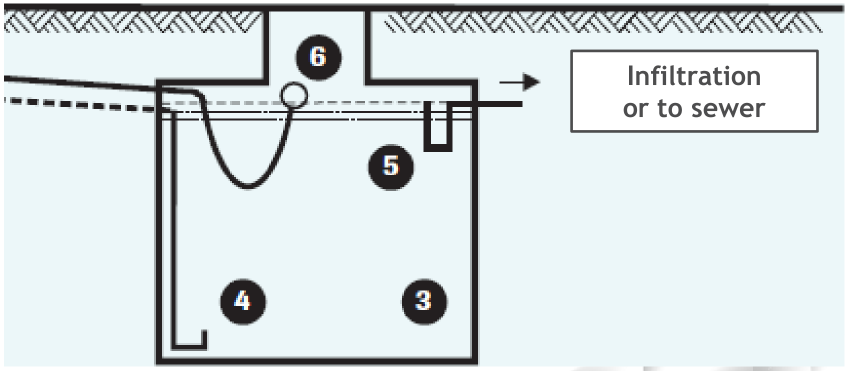


(Source: fbr)

Household rainwater harvesting system components:

1 Roof gutter
2 Filter
3 Rainwater reservoir (e.g. concrete or plastic)
4 Calmed inlet
5 Overflow with odour trap
6 Suction filter (floating extraction)
7 Rainwater supply system incl. pump, control panel and mains backup supply according to DIN
8 Rainwater distribution
9 Tapping point
10 Toilet
11 Washing machine



RWH components

Typically, a RWH system consists of four basic elements (public, private, industiral use):

- **Collection** system: a catchment surface where rainwater runoff is collected (roof and/or ground surface); roof surface collection preferably from slate, glass, concrete or clay tile roofs
- **Conveyance** system: a delivery system for transporting the water from the catchment to the storage reservoir, e.g. gutters and downpipes
- **Storage** system: tanks/cisterns should be protected from light and for indoor use preferably placed in a cool environment (underground, celler in new buildings); reinforced concrete and plastic (PE) sheets are most commonly used
- **Pump** system: to deliver the treated rainwater to the point of use

Other RWH components

- **Filters:** to hold back debris from roofs and trees in the rainwater, preferably with low maintenance, high filter performance and water yield (e.g. downpipe filters, in-tank, pre-tank filters)
- **First flush** device: a valve that ensures that runoff from the first spell of rain (usually highly polluted) is flushed out and does not enter the system
- A **calmed inlet**
- **A Control panel**, which unites a fill level display, mains backup system and dry run protection
- **Dual-pipe system** for service water

Quality aspects of the catchment area

- Slightly contaminated and smooth rooftop surfaces should be preferably used
- Runoffs from contaminated surfaces should be treated accordingly
- Green roofs usually produce a brownish colouring of the runoff, bitumen roofs a yellowish colouring; with uncoated copper and zinc roofs there is an increased concentration of metal ions in the runoff; rough surfaces collect more dirt and dust especially during dry periods
- With normal atmospheric pollutant load, suitable collection surfaces and a well constructed and designed rainwater harvesting system, a hygienic risk from using rainwater is extremely low

Factors influencing system and storage design

- Rainfall quantity (mm/year) depending on the region
- Rainfall pattern and distribution over a year
- Collection surface area (m^2)
- Daily water consumption rate (litres/capita/day)
- **Runoff coefficient**: calculates the maximum amount of rainfall that can be harvested from the roof (and other surfaces)
- Storage capacity (m^3)
- Cost

The achieved rainwater yield is dependent on the amount of rainfall, the size and setup of the rainwater collection area as well as on the efficiency of the rainwater filter.

Runoff coefficients for different types of roofs

A coefficient of 1 indicates all water falling on the roof is drained via the gutter; a factor of 0.5 indicates only half of the rainfall is collected from rooftops while the rest is lost (e.g. via evaporation)

Roof material	Runoff coefficient (%)
Sloped hard roof*	0.8
Flat roof without gravel layer	0.8
Flat roof with gravel layer	0.6
Intensive green roof	0.3
Extensive green roof	0.5
Paved roof/interlocking paving (smooth surface)	0.5
Asphalt roof	0.8
*Deviations depending on absorbency and roughness	

(Source: Adapted from DIN 1989-1)

Cistern sizing

- The daily rainwater yield is calculated from the rainfall amount [mm = l/m²], roof surface area [m²], roof runoff coefficient and the filter efficiency divided by 365 days per year
- Sizing of a RWH system is simply made by comparing the amount of rainwater which can be collected from a specific surface area with the household/user water demand
- For private homes and dwellings an estimation is usually sufficient:

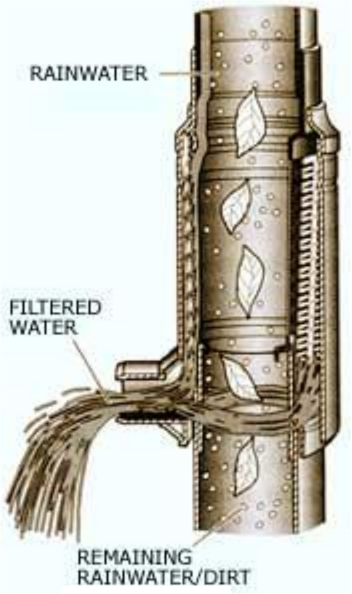
  e.g. cistern volume = 1 m^3 for 20 m^2 of roof surface area or cistern should have a rainwater stock for a period of 4 weeks (no rainfall)
- For larger systems with more complex boundary conditions, a simulation of the rainfall data (e.g. data of last 20 years, daily/monthly) and water consumption data using a computer model is necessary (DIN 1989-1)

Cistern sizing (2)

- According to DIN 1989-1, for a single-family or a two-family house an effective volume of 800 to 1000 litres must be provided for. For a 4-person household about 4 m^3 of usable rainwater storage volume is required
- During high rainfall amount and low water demand, cistern overflow should be collected and evaporated or infiltrated on site. Mains backup supply is rarely required
- During low rainfall amount and high water demand, cistern overflows are usually rare when using a larger cistern. However, the RWH system will be dependent on regular backup water supply
- In spite of balanced amounts of rainwater and water demand and an appropriate tank sizing, cistern overflows and backup supply can also be frequent and high due to unpredictable weather conditions

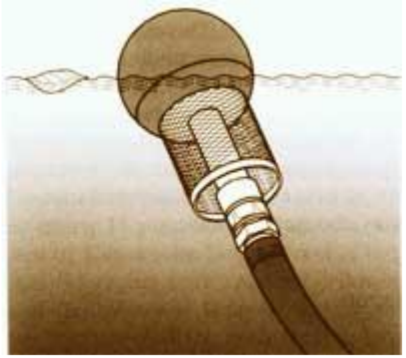
Rainwater filters

Various types of mechanical filters for different reuse scale (downpipes, in-tank, pre-tank, post-tank filters, …)

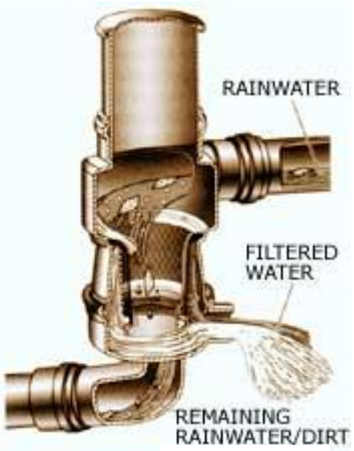


to sewer

A downpipe filter collector diverts 90% of the rainwater to a storage tank through a 0.17 mm stainless steel mesh filter



A floating fine suction filter ensures that rainwater is pumped from cleanest level of the tank and is free of particulates



to sewer

A large vortex fine filter diverts 90% of rainwater runoff from roof areas of up to 500 m^2

(WISY AG filters. Source: John Gould and Erik Nissen-Petersen (1999) Rainwater Catchment Systems for Domestic Supply - Design, Construction and Implementation)

RAINWATER HARVESTING

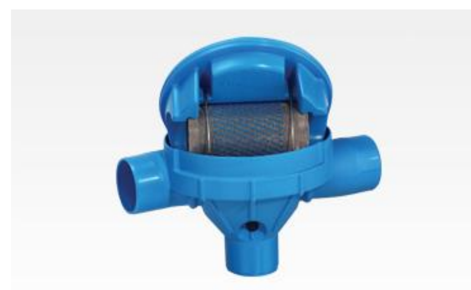
Rainwater filters

Rainwater filter for roof areas up to 500 m² (Source: Otto Graf GmbH)

Rainwater filter for roof areas up to 6000 m² (Source: INTEWA GmbH)

Downpipe filter

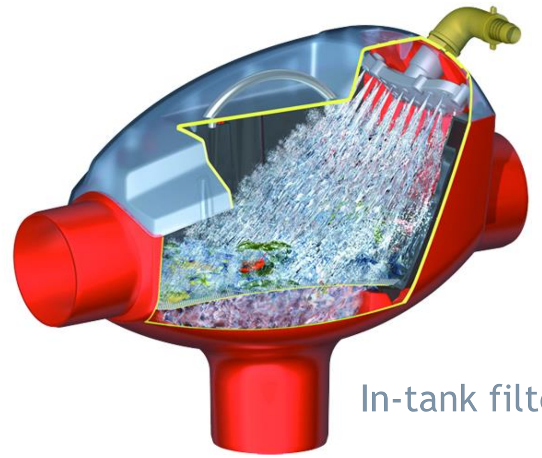
(Source: Wisy, AG)



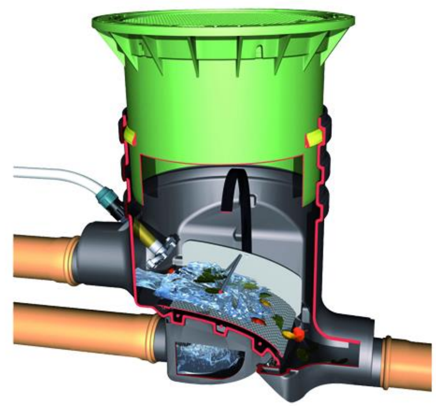
Integrated filter for rainwater tanks
(Source: 3P Technik Filtersysteme GmbH)

Rainwater filters for large roof areas

Wisy Vortex filter (WISY)

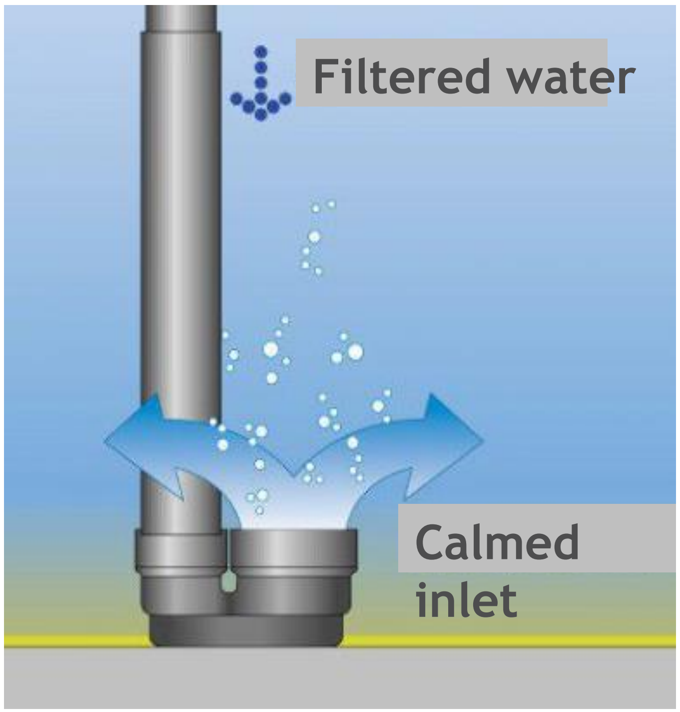


In-tank filter (GRAF)

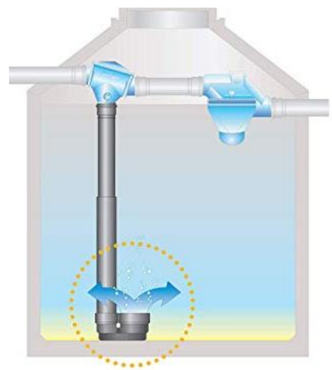


External filter (GRAF)

Calmed inlet

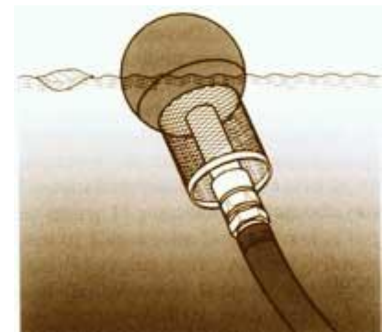


(Source: 3P Technik Filtersysteme GmbH)



A calmed inlet prevents whirl up of sediment at the bottom of the rainwater tank

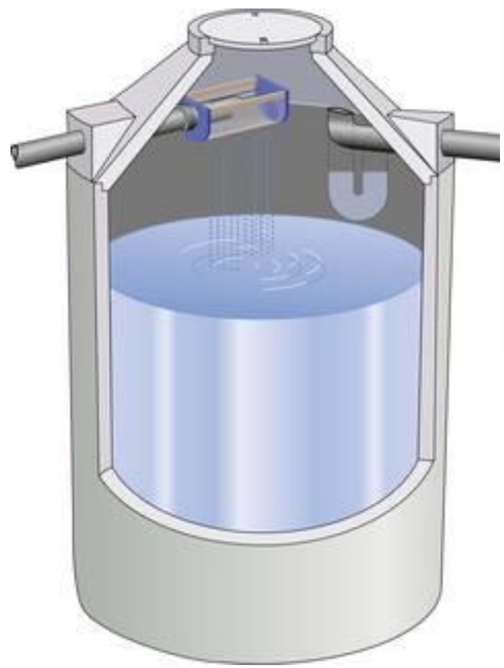
Suction filter



A floating fine suction filter ensures that rainwater is pumped from cleanest level of the tank and is free of particulates

Rainwater tanks

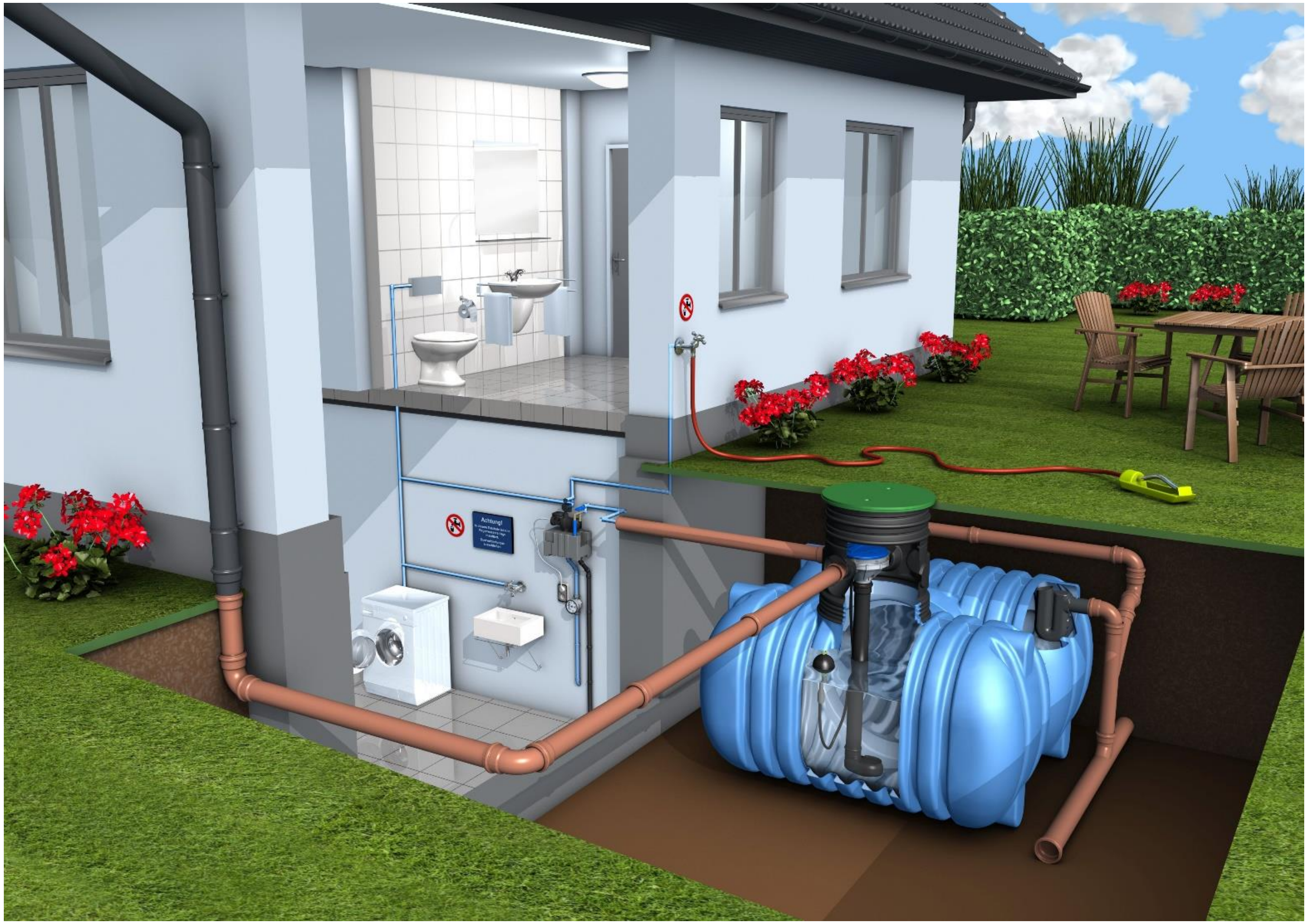
Aboveground tanks preferred for garden irrigation (Graf)



Concrete underground (Mall)

Underground plastic tank (GreenLife)

Underground household rainwater tank



(Source: fbr)

Rainwater tanks for small-scale RWH

Concrete tank

Plastic tank

(Source: fbr)

RAINWATER HARVESTING

Rainwater tanks for small-scale RWH


Underground tank (Mall)

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Rainwater tanks for large-scale RWH

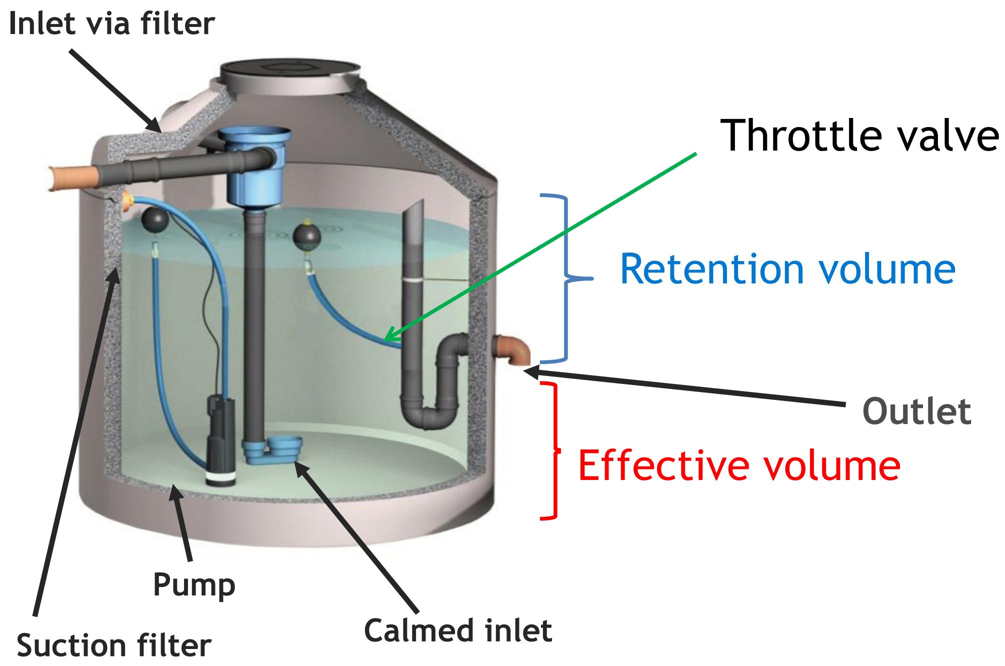
Office building

Airport Charles de Gaulle

(Source: fbr)

Rainwater harvesting in combination with retention

Cistern with throttle valve

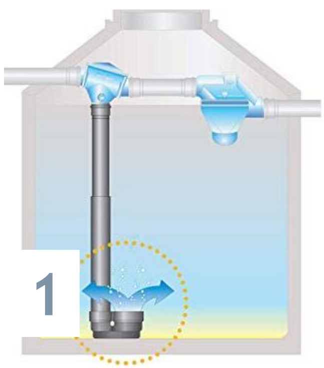


A conflict exists between rainwater utilisation (cistern should be full at all times) and the hydraulic relief of sewer (cistern should preferably be always empty, in order to collect new runoff). Retention cisterns are constructed as a combination structure to fulfill both demands. They have a specific **retention volume**, which can be throttled discharged into sewer and an additional fixed **effective volume** for reuse.

RAINWATER HARVESTING

Essential cistern parts:

1. Calmed inlet
2. Floating fine suction filter
3. Angled overflow pipe for discharge of floatables
4. Drain trap to sewer
5. Backwater protection
6. Protection against animals



A floating fine suction filter ensures that rainwater is pumped from cleanest level of the tank and is free of particulates

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RAINWATER HARVESTING

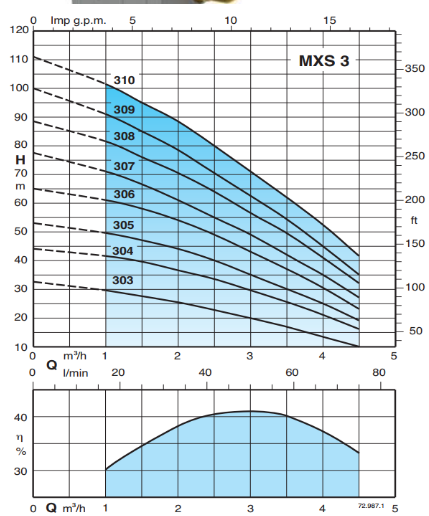
Pumps

ESPA

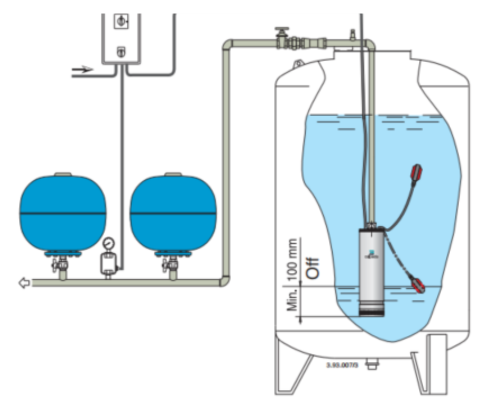
GreenLife

Intewa Rainmaster

Calpeda



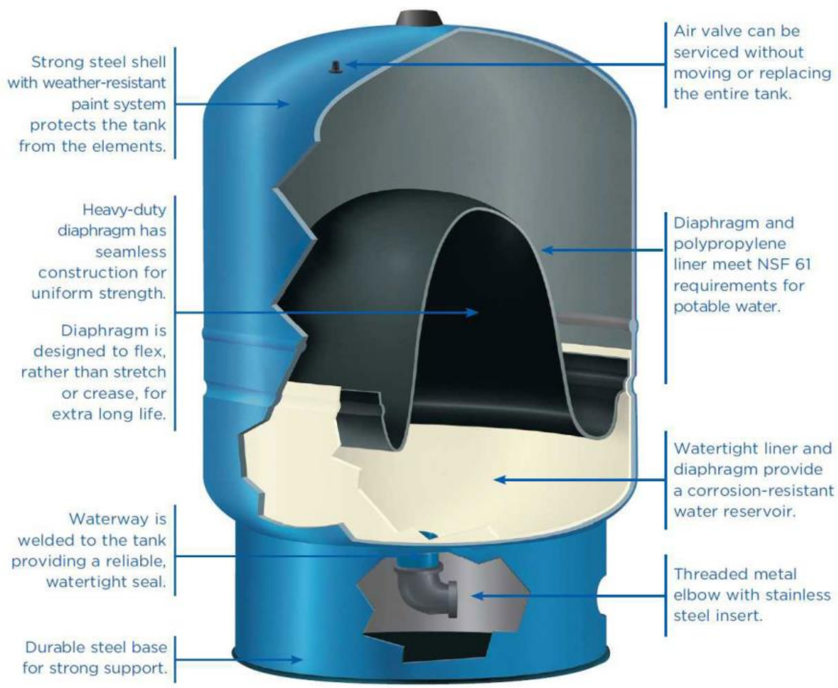
Characteristic curve



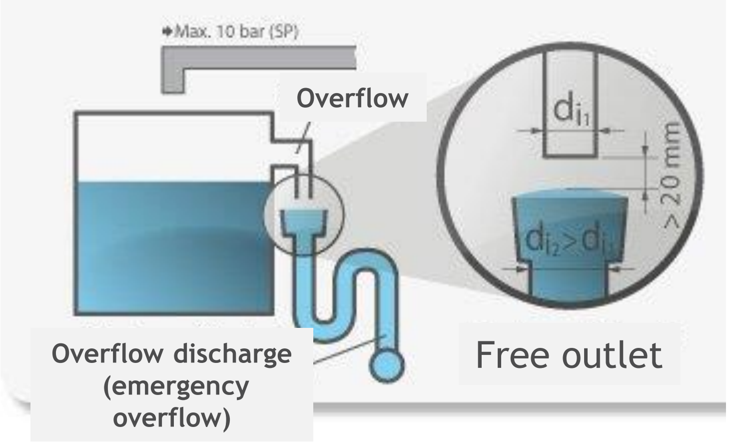
Installation example

Pumps

Dry or wet pumps always include a **diaphragm expansion tank** for a long service life and low energy costs



Avoid cross connections (with drinking water network)



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Rainwater to potable water (and beer)

Clear water tank with Rainmaster Favorit SC, AQUALOOP control system and UV disinfection

AQUALOOP Tap Comfort 1,600 l/d

AQUALOOP single-membrane station with membrane and control system

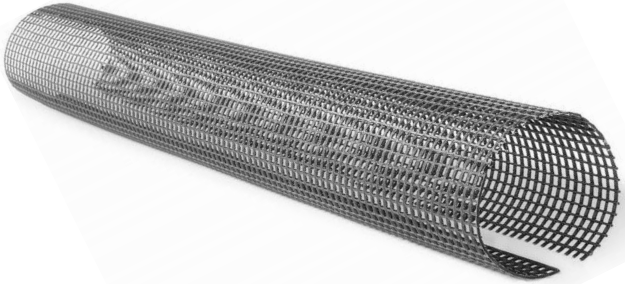
(Source: INTEWA GmbH; https://www.intewa.de/produkte/aqualoop/referenzen/projekte/ihre-haus-wasserquellen/)

Maintenance

- Filters should be cleaned 1-2 times a year depending on the load from tree cover, pollen, dust etc.
- Gutters and downpipes need to be kept free of debris (cleaning 2-3 times a year)
- A visual inspection of the tank is recommended once a year and excessive sediment should be removed
- Check pumps for leaks and function once a year
- Cleaning of tank every 10 years

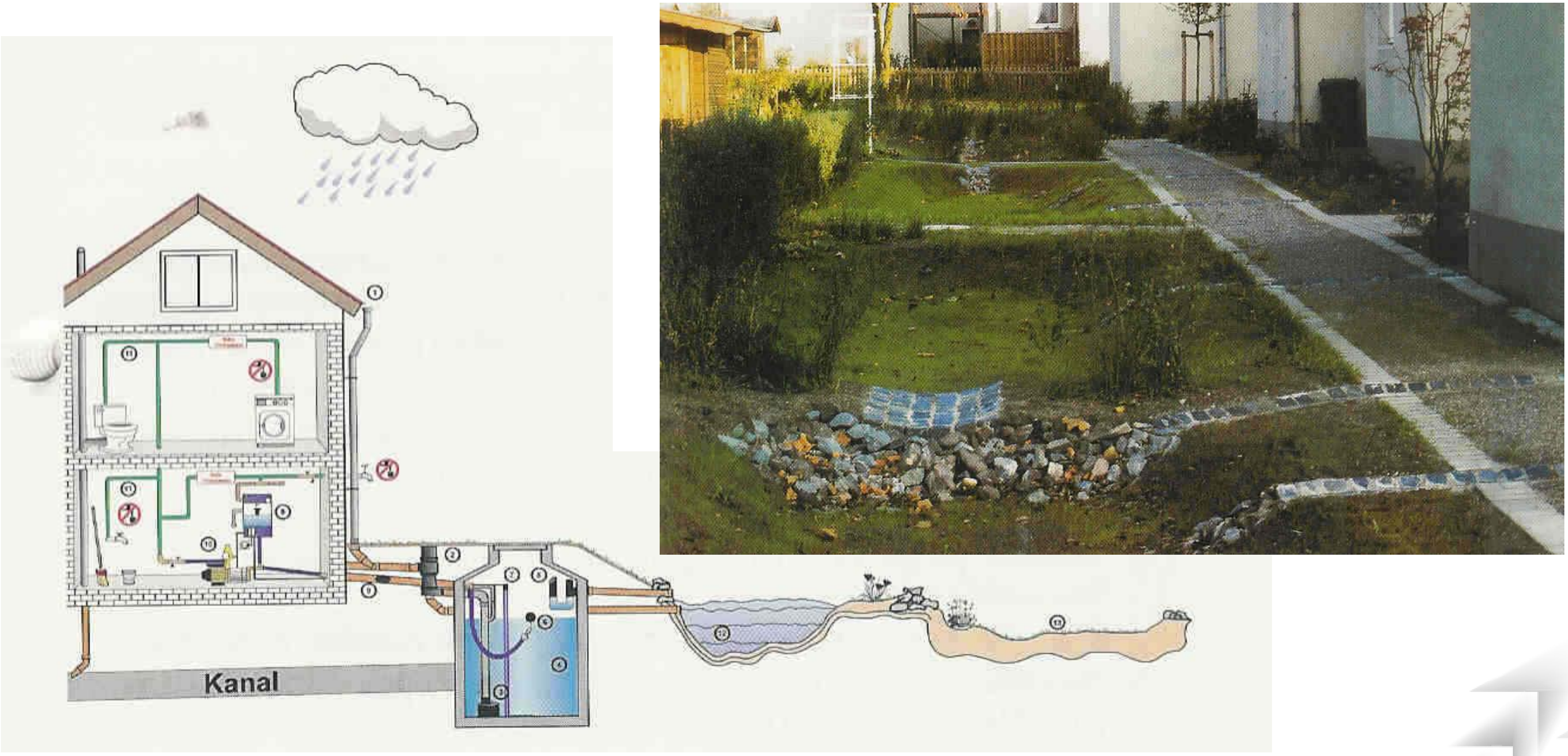
RAINWATER HARVESTING

Leaves protective grating reduces maintenance



RAINWATER HARVESTING

Rainwater harvesting in combination with infiltration of the overflow water



TAKING **COOPERATION** FORWARD

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Adiabatic cooling with rainwater

Energy production needs much water

Water demand for cooling [1]:

Fossil energy : 2.6 Litre / $kWh_{elec.}$

Atomic energy: 3.2 Litre / $kWh_{elec.}$

Cooling with service water saves much electricity.

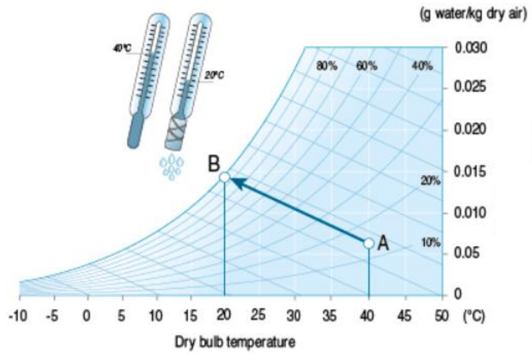
680 kWh thermal energy is needed for evaporating 1 m^3 of water

[1] (Source: http://www.energieverbraucher.de/de/Umwelt-Politik/Umwelt-und-Klima/site__894/)

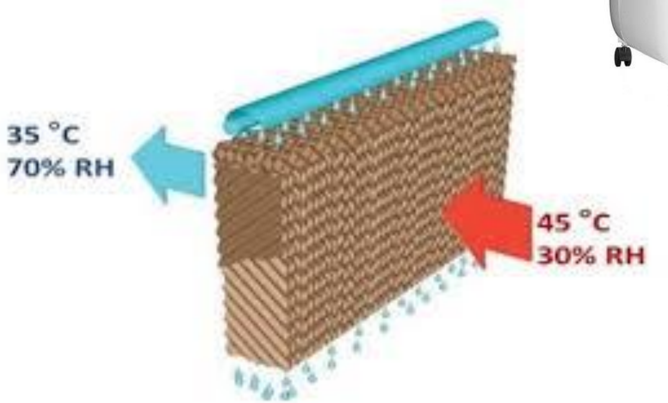
RAINWATER HARVESTING

Adiabatic cooling with rainwater

1 $kW_{elec.}$ + 100 litres of water has a cooling power of 70 kW

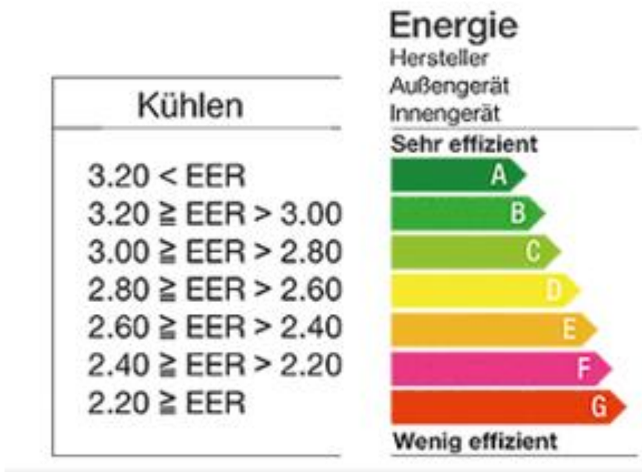


Adiabatic humidification



Cooling with electricity

1 $kW_{elec.}$ has 3.2 kW cooling power

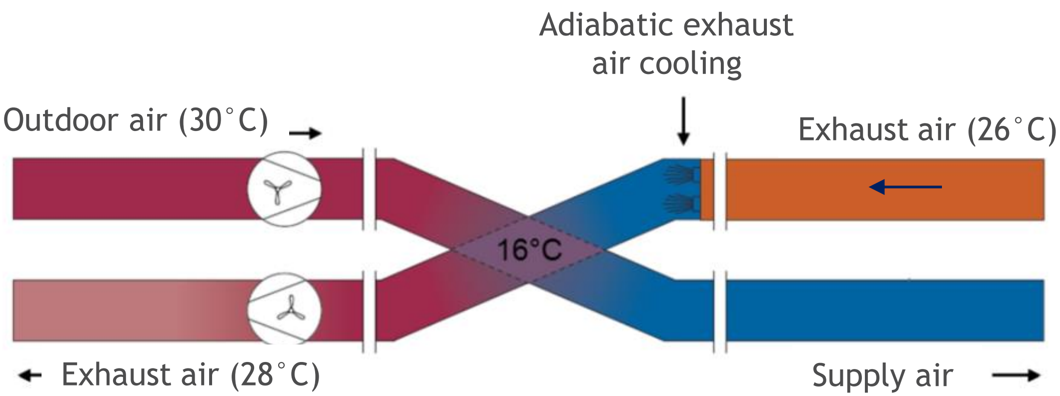


Rainwater harvesting for adiabatic cooling in buildings

- Adiabatic (evaporative) cooling is the process of reducing heat through a change in air pressure caused by volume expansion
- Rainwater, preferably collected from roof surfaces and treated can be used for cooling buildings
- This process of “air conditioning” is effective in cooling incoming air to a temperature of 21 - 22 °C with outside temperatures of up to 30 °C
- For the process of adiabatic cooling, rainwater is sprayed on the building's exhaust air, whereby fresh air entering the building is cooled via a heat exchanger
- The use of rainwater for cooling saves both drinking water and wastewater
- It can save up to 80 % of energy

Rainwater harvesting for adiabatic cooling in buildings

Adiabatic exhaust air cooling, Institute of Physics at the HU, Adlershof, Berlin (Photo: M. Schmidt)



Principle of adiabatic exhaust air cooling (Source: Berlin Senate Department for Urban Development and Housing)

EVAPORATIVE COOLING

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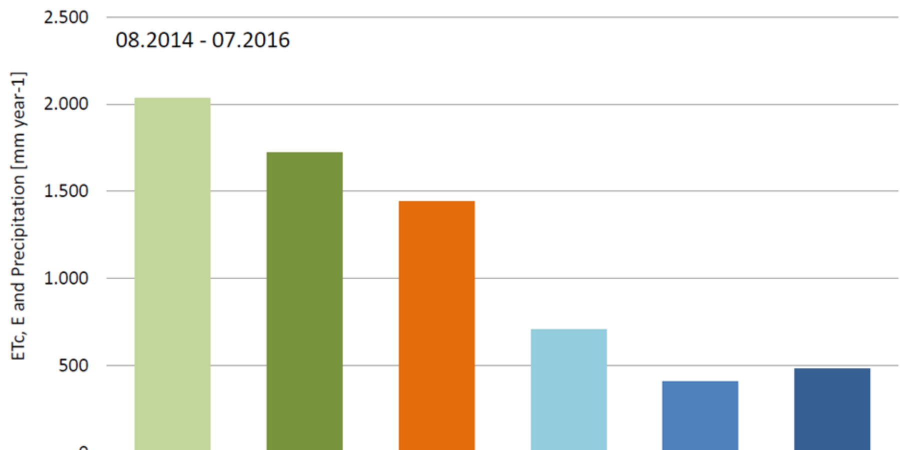
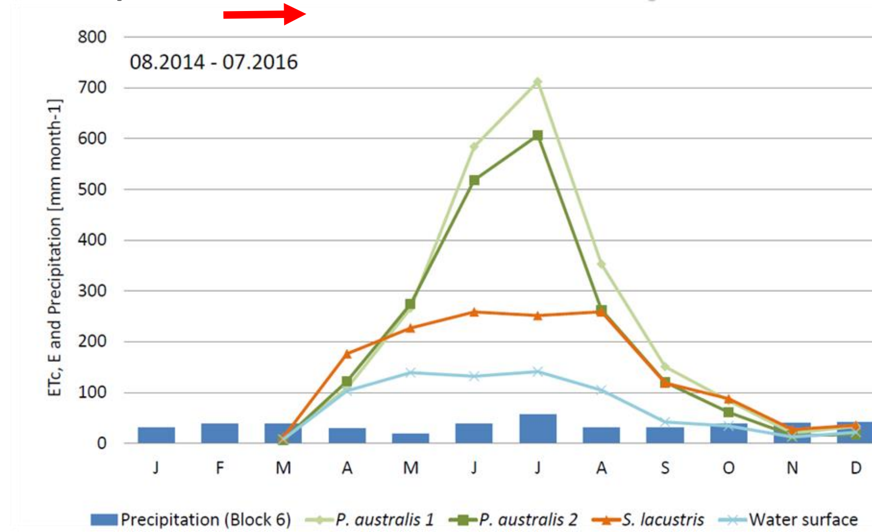
Evaporation of rainwater in densely populated urban areas



	P. australis 1	P. australis 2	S. lacustris	Water surface	Precipitation (Block 6)	Precipitation (Tempelhof)
mm	2.034	1.721	1.445	710	409	483

Evaporation in summer about 20 mm/d



Reed evaporates during one single Summer month as much as a single tree does the whole year!

EVAPORATIVE COOLING

During dry periods plants will not survive without irrigation

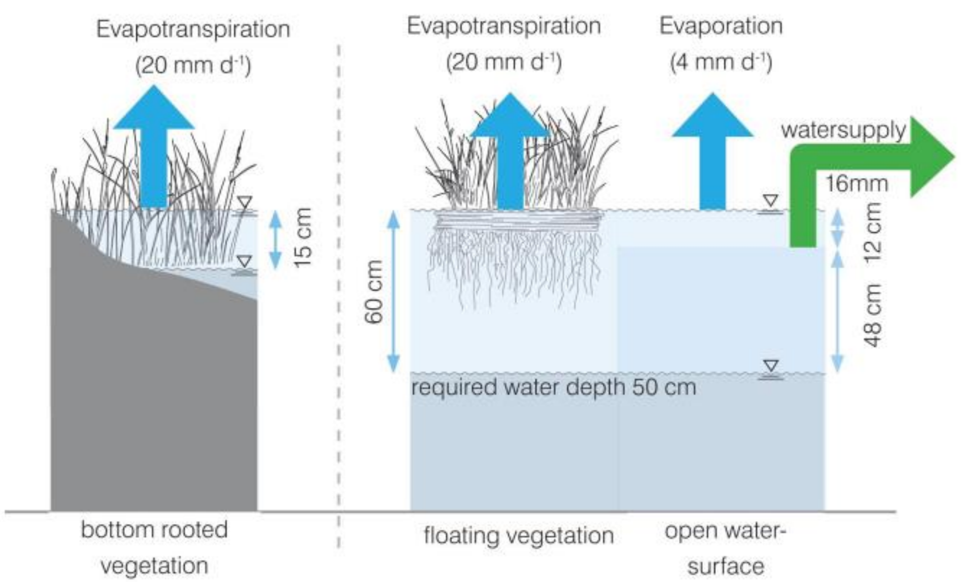


Fig. 34: Water level fluctuation in a CSW during a 30 day drought with bottom rooted vegetation (left) and floating mats with macrophytes (right) (Günther, 2013, p.25)

Benefits of rainwater harvesting

- Rainwater is relatively clean and its quality is usually sufficient for many applications with little or even no treatment
- Rainwater has a low salinity and can be reused in many applications where soft water is required such as for laundry, cooling and in industry (instead of RO, ion exchanger, etc.)
- Can save up to 50 % of the household water demand
- Reduces energy costs for cooling:
  1 m^3 of **evaporated** RW **releases 680 kWh of energy**
- Reduces drainage load on sewer and flooding in urban areas
- RWH is a flexible technology and can be designed to meet almost any requirement
- Contribute to self-sufficiency in water supply

RAINWATER RETENTION

Extensive green roofs

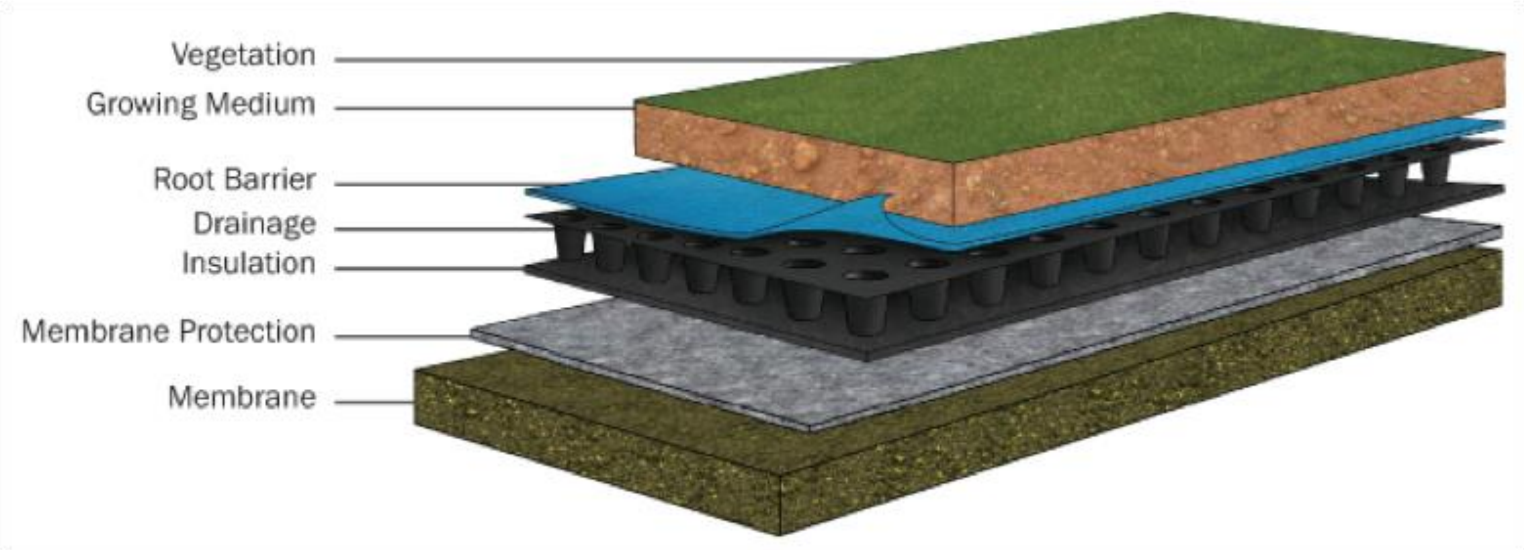
(Source: Nolde & Partner)

2. Rainwater retention

2.1 Green roofs

- A multilayer system that includes vegetation top layer, soil or a suitable substrate, drainage, protection, waterproofing and insulation layers
- High retention capacity
- Reduce and delay runoff during peak flow
- Can be installed on most roofs of buildings (most commonly on flat roofs)
- In summer, green roofs can retain 70 to 80% of rainfall and in winter between 25 and 40% depending on the growing medium, its depth and type of plants used

Schematic diagram of a multilayer system of a green roof



(Source green building alliance https://www.go-gba.org/resources/green-building-methods/green-roofs/#lightbox/1/)

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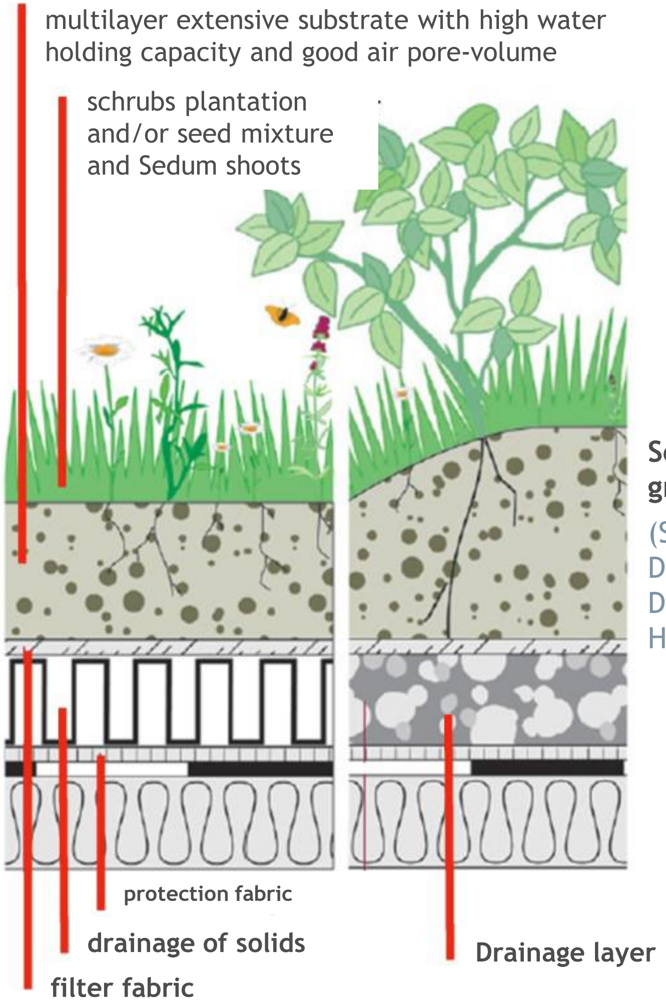
Extensive green roofs

Extensive green roof, Alexa, Berlin (Photo: FBB, G. Mann)



Setup of an extensive green roof
(Source: Berlin Senate Department for Urban Development and Housing)

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Extensive green roofs

- Cover the entire roof area with low growing, low maintenance plants using a thin growing medium
- Typically require 8 –15 cm thick soil layer
- Drought-tolerant, low and hardy plants are suitable vegetation
- Require minimal maintenance and irrigation
- Have lower installation costs than intensvie green roofs

Intensive green roofs

(Source: Optigrün)

Intensive green roofs

- Include roof gardens that have soil deep enough to support the growth of trees and shrubs
- Require extra loading requirements within the supporting structure
- Typically require 15 – 100 cm thick soil layer
- Require a complex irrigation system
- Require ongoing maintenance and care of the vegetation and water system
- More costly than extensive green roofs

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General criteria requirement for green roof types

	Extensive green roof	Intensive green roof
Costs	Low	High
Irrigation	No	Regularly
Maintenance	Low	High
Vegetation	Drought-tolerant succulents and grasses	Lawn or perennials, shrubs and trees
Uses	Ecological protection layer	Park-like garden
Bearing load (water saturated)	90 – 180 kg/m^2	> 180 kg/m^2

Benefits of green roofs

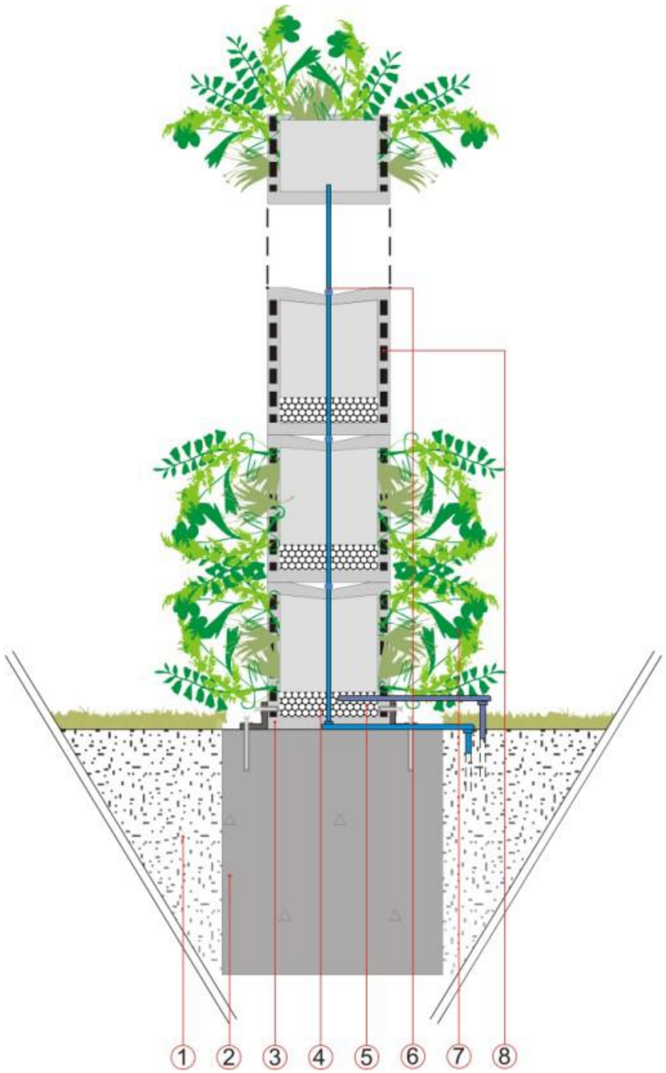
- Enable rainwater harvesting
- Reduce urban heat island effect through evaporation and improve microclimate
- Improve thermal insulation and increase lifespan of a roof or building
- Provide a pleasant green space in urban environments
- Contribute positively to CO_2 emission reduction into the atmosphere
- Act as a sink for fine dust
- Compensate for increased surface sealing in urban areas
- Enhance biodiversity in the city
- Reduce rainwater fees

Facade and wall greening

Ground-bound facade greening with Virginia creeper in Berlin-Schöneberg (Photo: D. Kaiser)

System-bound facade greening in containers, Institute of Physics in Berlin Adlershof (Photo: M. Schmidt)

RAINWATER RETENTION

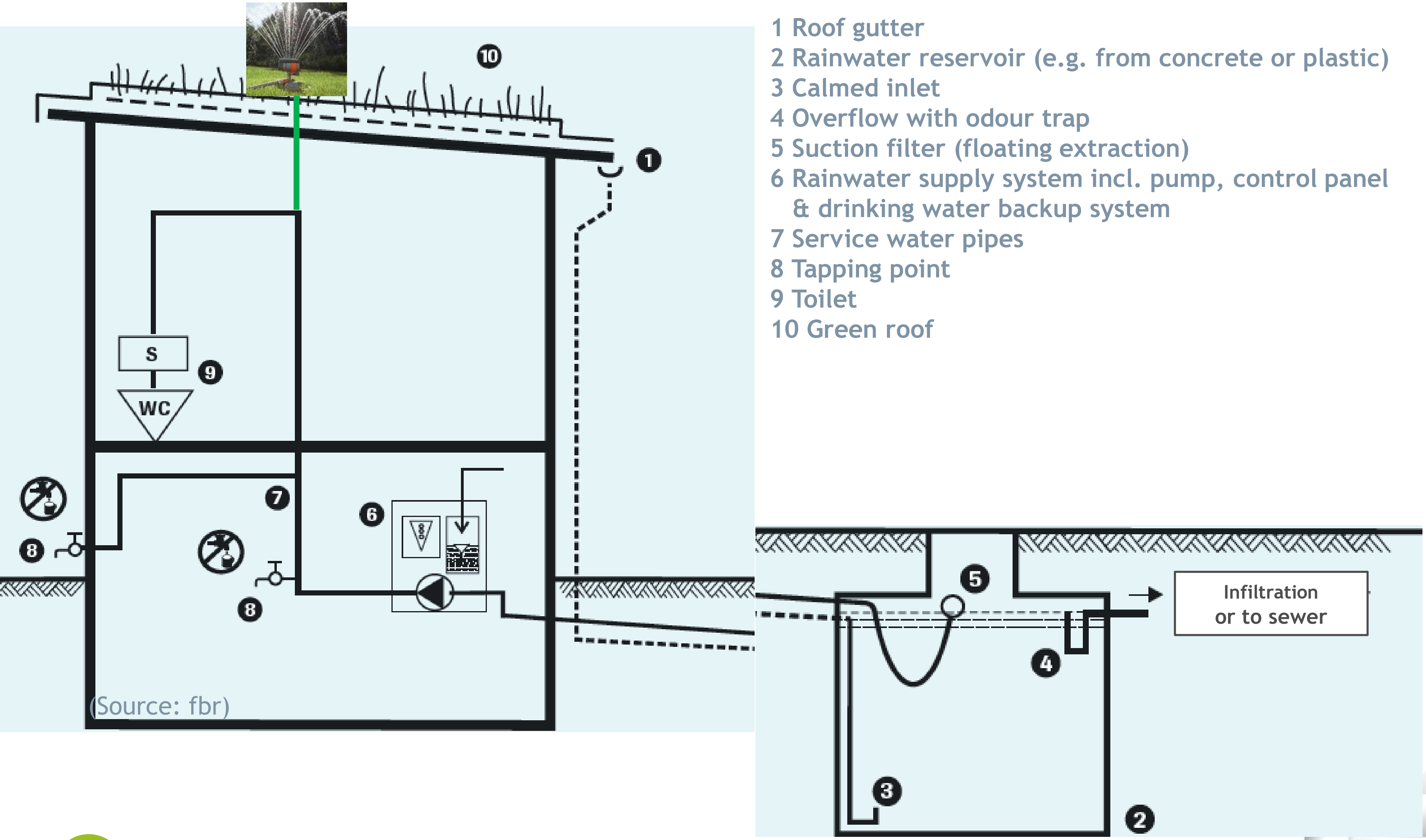


Side view of system-bound facade greening (here with the addition of a foundation)

1 grown soil
2 foundation
3 frame construction
4 drainage and substrate
5 drainage channel
6 irrigation inflow
7 planting
8 planted wall structure

(Source: Köhler et al., 2012)

COMBINATION OF RAINWATER HARVESTING WITH GREEN ROOFS



(Source: fbr)

1 Roof gutter
2 Rainwater reservoir (e.g. from concrete or plastic)
3 Calmed inlet
4 Overflow with odour trap
5 Suction filter (floating extraction)
6 Rainwater supply system incl. pump, control panel & drinking water backup system
7 Service water pipes
8 Tapping point
9 Toilet
10 Green roof

RAINWATER HARVESTING AND EVAPORATION

Combination of rainwater harvesting and evaporation

(Source: city tree)

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Block 6 – Berlin: 100% disconnection from sewer
Green roofs, evaporation, infiltration and biodiversity





Retention pond

2.2 Retention ponds and wetlands

- Are relatively shallow ponds and marshland areas which are covered entirely in aquatic vegetation
- Have a high flood-storage capacity
- Can be designed to accommodate considerable variations in water levels during storm events (sufficient detenton time)
- Vegetation (plants and algae) provides for good biological treatment and nutrient removal
- Provide habitat for wildlife in urban areas
- Vegetation requires cultivation and care
- Use of inlet and outlet sumps enhance performance by trapping silt and prevent clogging of outlet
- They are cost-effective solutions for areas with ample space

Constructed wetland in the centre of Berlin

Constructed wetland - City of Perth

(Source: https://www.visitperth.com.au/see-and-do/parks-gardens-and-reserves/Venues/urban-wetland)

Artificial water features

Artificial water body for rainwater collection at Potsdamer Platz, Berlin (Photo: Andreas Süß)

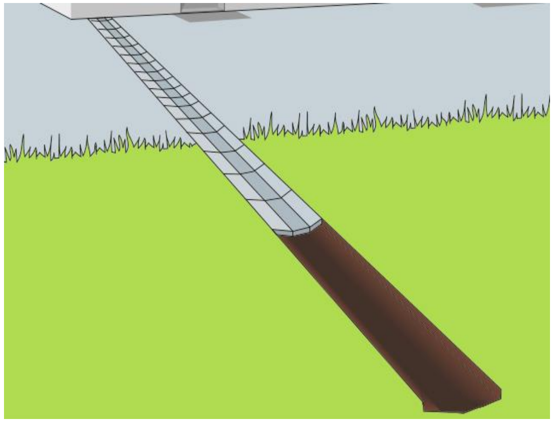
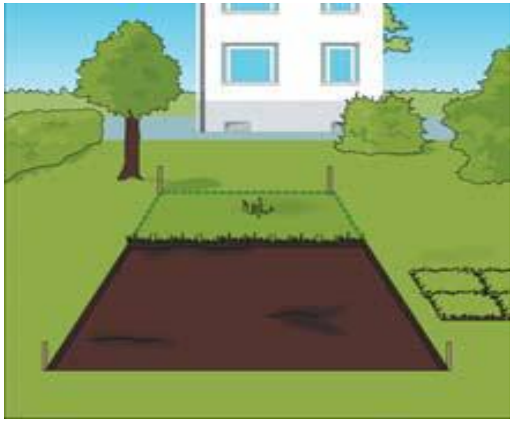
Water-bearing trench in the urban district Arkadien, Winnenden (Photo: Ramboll Studio Dreiseitl)

3. Infiltration

Vegetated swales and surface infiltration






INFILTRATION

Selection of infiltration technologies under different soil and area conditions

Permeability				Selection procedure for rainwater management system	
Class	Permea-bility	k_f from	k_f to	Low area availability (1)	High area availability (2)
II	high	$1 \cdot 10^{-5}$	$5 \cdot 10^{-6}$	Swale infiltration	Swale infiltration 10 : 1
II	medium	$5 \cdot 10^{-6}$	$2 \cdot 10^{-6}$	Swale-trench infiltration without discharge	Swale infiltration 6: 1
III	moderate	$2 \cdot 10^{-6}$	$7 \cdot 10^{-7}$	Swale-trench infiltration with partly throttled discharge	Swale infiltration 4 : 1
IV	low	$7 \cdot 10^{-7}$	$2 \cdot 10^{-7}$	Swale-trench infiltration with throttled discharge (3)	Swale infiltration 2 : 1

(1) Ratio of connected sealed area to infiltration area is 10:1
(2) Ratio of connected sealed area to infiltration area as indicated
(3) K_f value without limitation downwards

(Source: Adapted from Londong & Nothgnagel, 1999)

General characteristics

- Infiltration allows rainwater to percolate slowly through the topsoil layer covered with vegetation into the underground
- Significantly reduce pollutant entry into surface waters
- Contribute to groundwater recharge
- Rainwater is treated during infiltration through the topsoil layer by means of several processes such as adsorption, precipitation, microbial degradaton and filtration before it seeps into groundwater
- Most suited to areas where runoff is relatively unpolluted
- A fall-off in infiltration rates with time as a result of clogging of soil should be considered during the planning process

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General characteristics (2)

- Groundwater conditions and soil types can be limiting factors, especially in high groundwater level and clayey soils with low permeability
- It is recommended that the distance to the groundwater should be at least 1 – 1.5 m so that rainwater filtration occurs prior to reaching the groundwater
- It is recmmended that a distance to buildings of at least 6 m be held to avoid any impacts on their foundation
- Usually a geotextile or other filter layer is used around the perimeter which should be located at 15 - 30 cm depth to trap sediment

Technology selection

For rainwater infiltration, several technologies exist as single measures or in combination with other techniques.

The choice of the technology is maily dependent on:

- Topography of the site
- Soil permeability
- Proximity to the groundwater table
- Availability of space

Soil permeability

- The permeability of the soil is the major influencing factor which determines whether rainwater infiltation is applicable at a specific site and it also affects the choice of technology
- The permeability of the soil is measured as the **filtration coefficient k_f**
- The technically relevant k_f range for rainwater infiltration lies between **1×10^{-3} (86 m/d)** and only **1×10^{-6}** m/s (86 **mm/d)**

For example, with k_f values larger than 10^{-3} rainwater infiltrates without it being sufficiently treated by physical/chemical and biolgoical processes in the topsoil layer. With k_f values smaller than 10^{-6}, rainwater will accumulate in the soil and flow very slowly into the ground.

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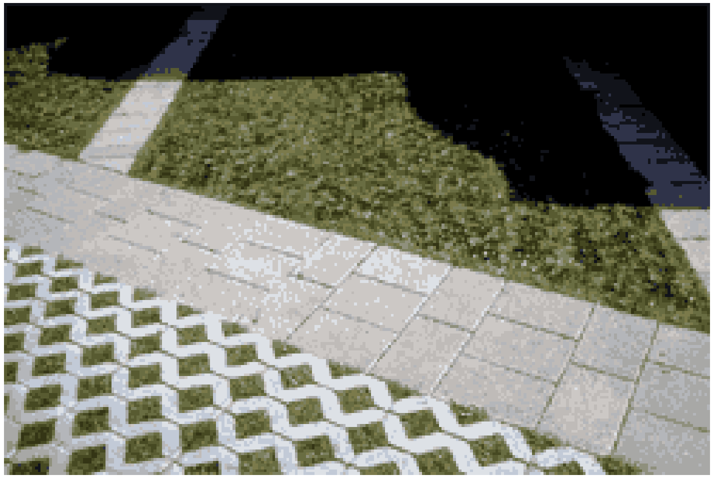
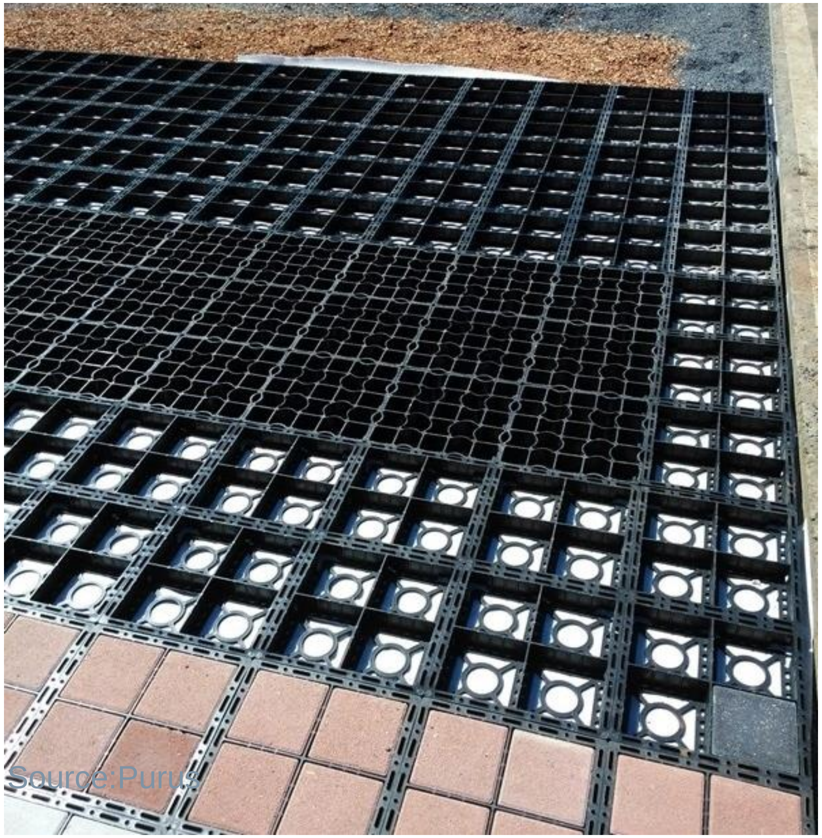
3.1 Permeable pavements



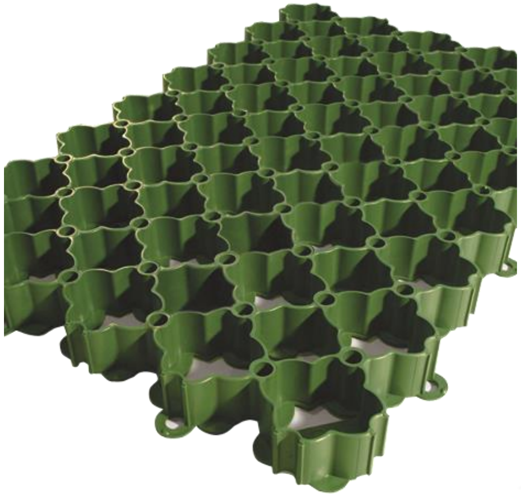
(Source: Sieker)

INFILTRATION

Sealing-free pavement



Combination with paving or vegetation



Permeable pavements

(Source: USGS Wisconsin Water Science Center)

Permeable pavements (pervious/porous surfaces)

- Stormwater is infiltrated into the ground through a permeable pavement layer made from porous concrete blocks, crushed stones, porous asphalt or grass-concrete blocks
- Depending on ground conditions, water may infiltrate directly into the subsoil or stored (retention) in an underground reservoir (e.g. a crushed stone layer) before slowly soaking into the ground
- If infiltration is not possible, an impermeable membrane can be used with an overflow to keep the pavement free from water
- Application area: parking lots, walkways, street surfaces for light traffic

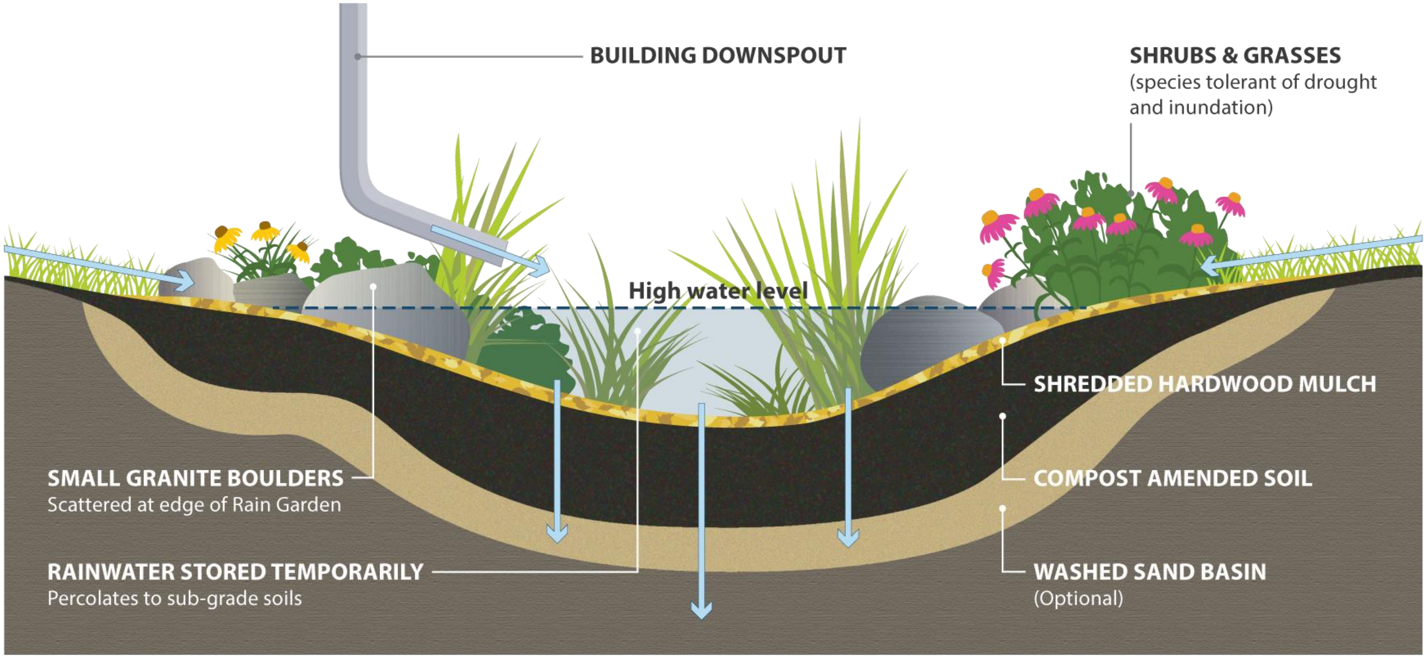
Replacing (desealing) sealed surfaces and considering the sealing problem in urban areas when planning new constructions is a **priority**!

3.2 Rain gardens

(Source: https://www.surfrider.org/coastal-blog/entry/cape-fear-chapter-installs-york-residential-rain-garden-in-north-carolina)

INFILTRATION

Cross section in a rain garden



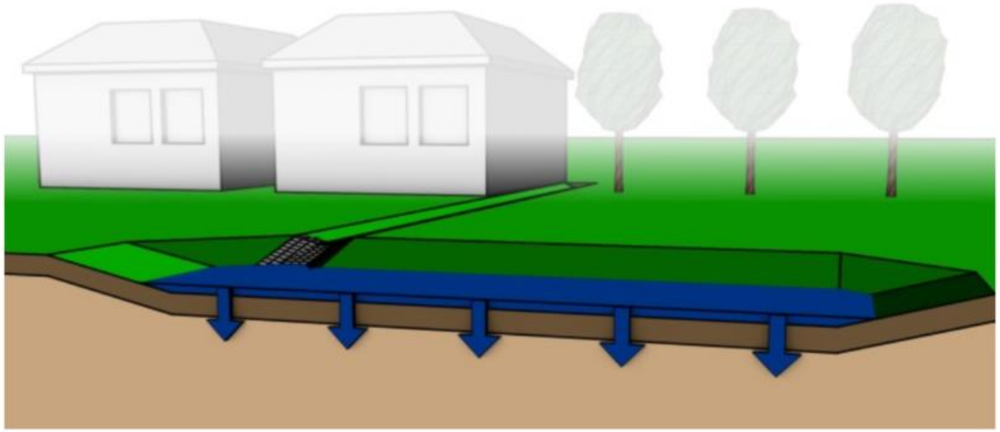
(Source: Toronto and Region Conservation Authority; https://trca.ca/news/complete-guide-building-maintaining-rain-garden/)

Rain gardens

- Are landscaped features designed to collect runoffs from impervious surfaces such as roofs, walkways and parking lots and infiltrate it into the ground
- They are strategically placed with a slight depression in order to temporarily collect runoff which infiltrates slowly into the underlying soil layer
- They use engineered or mixed soils consisting of a mix of sand, topsoil and compost to capture and infiltrate runoff
- Rain gardens are planted with trees, shrubs, and perennials before being covered in a layer of mulch
- Properly constructed rain gardens are designed to allow overflow in a large rain event and hold standing water for no more than 48 hours
- Provide food and habitat for wildlife
- A low-cost measure requiring regular maintenance

3.3 Vegetated swales

Vegetated swale at Rummelsburger Bucht, Berlin (Photo: Sieker)



Schematic diagram of an infiltration swale: with inflow, aboveground retention space and infiltration (Source: Sieker)

Vegetated swales

(Source: Sieker)

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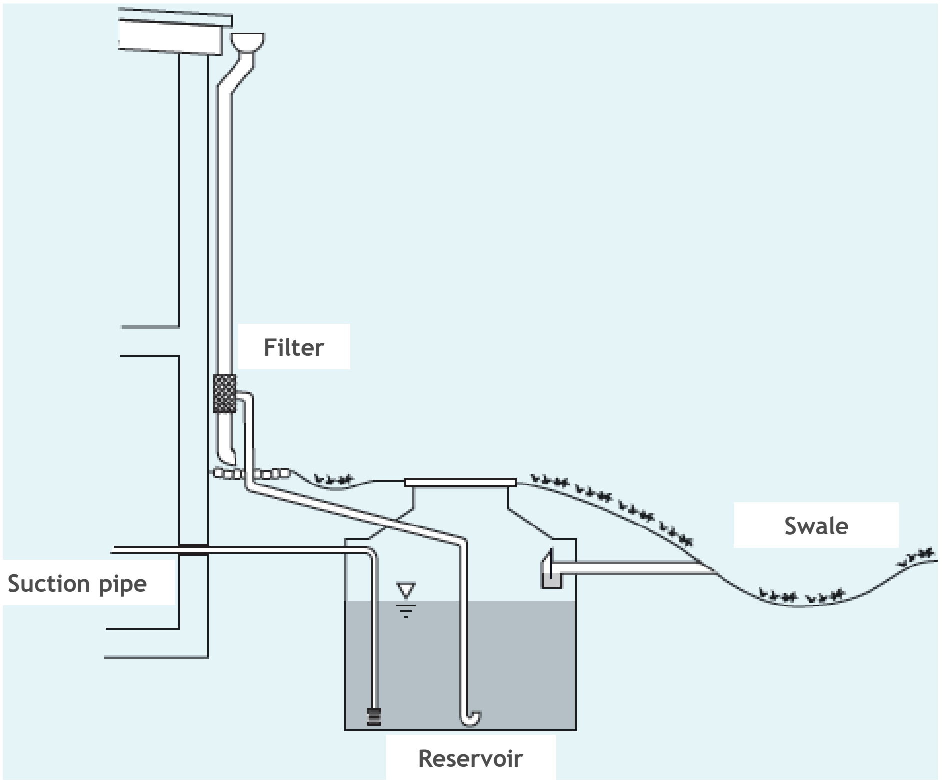
Rainwater harvesting with downstream vegetated swale



(Source: fbr)

Vegetated swales

- Are long, shallow and gently sloped vegetated channels which provide temporary storage of rainwater
- Rainwater is infiltrated into the ground over a period of days (max. 72 h)
- Reduce stormwater peak flow to receiving waters
- Enhance sedimentation, microbial decomposition and filtration of pollutants
- Allow for evapotranspiration
- Require less space and a lower permeability of soil compared to surface infiltration
- Easy to construct and a low-cost technology
- Provide effective drainage for sidewalks, highways, parking lots, building foundations and other areas of extensive paving

3.4 Infiltration basins

(Source: https://stormwater.pca.state.mn.us/index.php/BMPs_for_stormwater_infiltration)

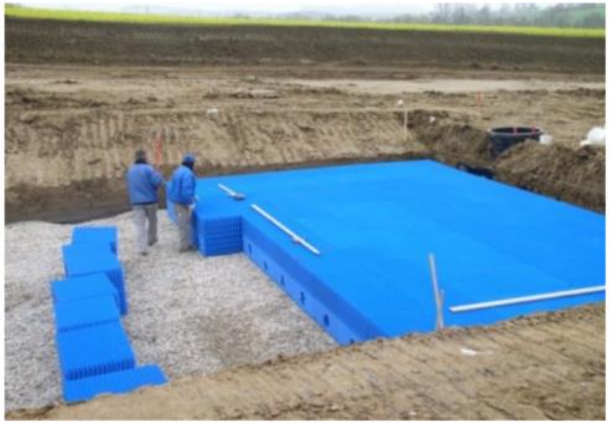
(Source: Schueler, 1987)

Infiltration basins

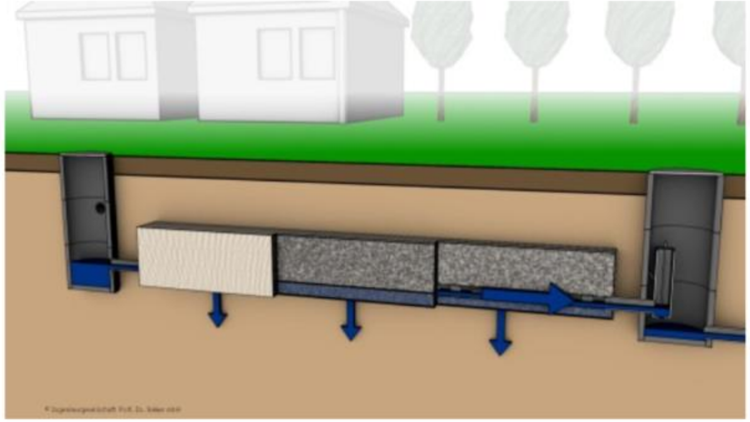
- Are vegetated, natural or constructed depressions that temporarily store runoff and allow it to infiltrate slowly into the ground
- Require a large coverage area
- Reduce peak flows
- Promote filtration of pollutants and microbial decomposition in subsoil
- They are ussually dry except in periods of heavy rainfall
- A Simple and cost-effective technology

3.5 Infiltration trenches

View of the bottom of a soakaway (Photo: Sieker)



Setup of an infiltration trench with filling material (Photo: Sieker)



Schematic diagram of an infiltration trench with a sedimentation chamber at inflow and throttled outflow (Source: Sieker)

Infiltration trenches

(Source: https://sustainablestormwater.org/2007/05/23/infiltration-trenches/)

(Source: Minnesota Stormwater Manual)

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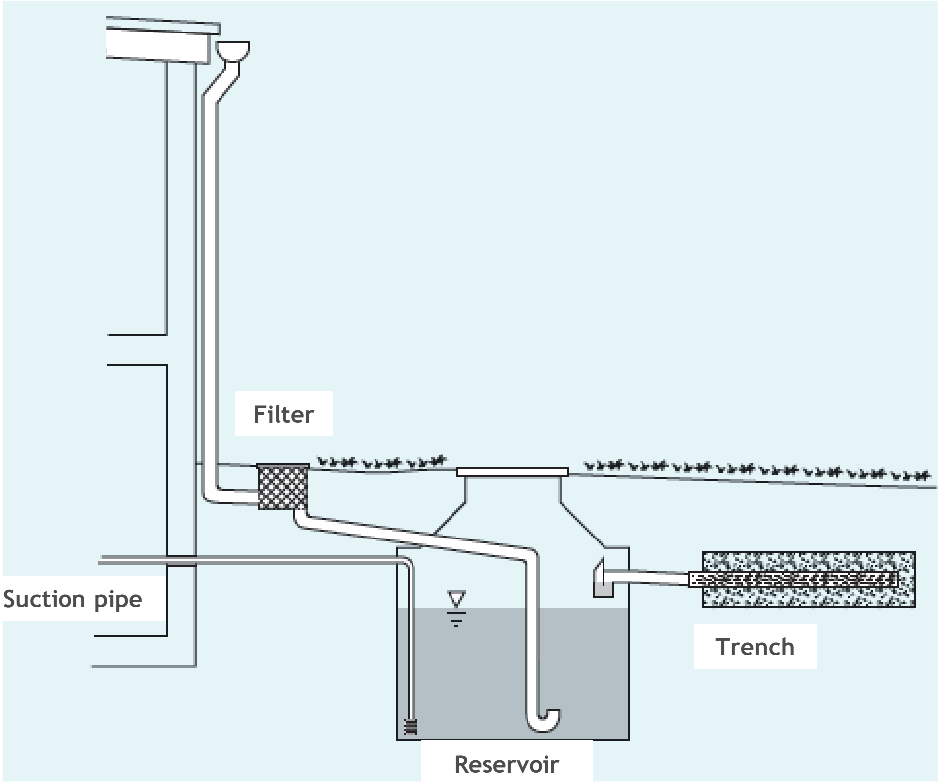
Rainwater harvesting combined to an infiltration trench



(Source: fbr)

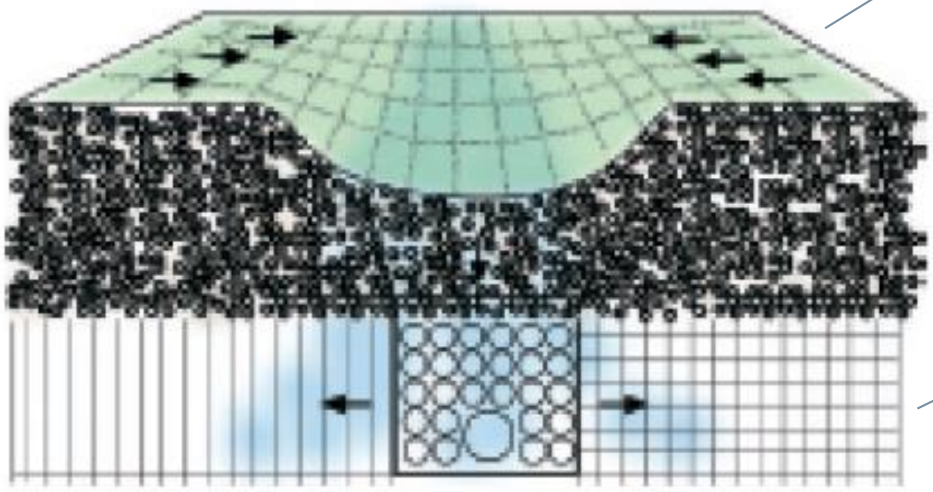
Infiltration trench

- A shallow, excavated trench backfilled with highly porous material such as gravel or synthetic elements allowing temporary storage of runoff in the void spaces of the porous material
- Discharge occurs through gradual infiltration into the ground
- Because there is no cleansing through a living soil layer, only low polluted rainwater should be infiltrated
- Limited to relatively small catchment areas (usually combined with other measures)
- A filter fabric (geotextile) is usually used to protect the surrounding soil
- Longevity is enhanced by incorporating a filter strip, gully or sump pit to remove excess solids at the inflow
- No trees should be planted on site and the space should not be used intensively
- Traditionally found in house gardens and alongside roads, which receive runoff from impermeable surfaces such as roofs and roads
- High clogging potential without effective pre-treatment

3.6 Swale-trench infiltration system

(Source: Sieker)

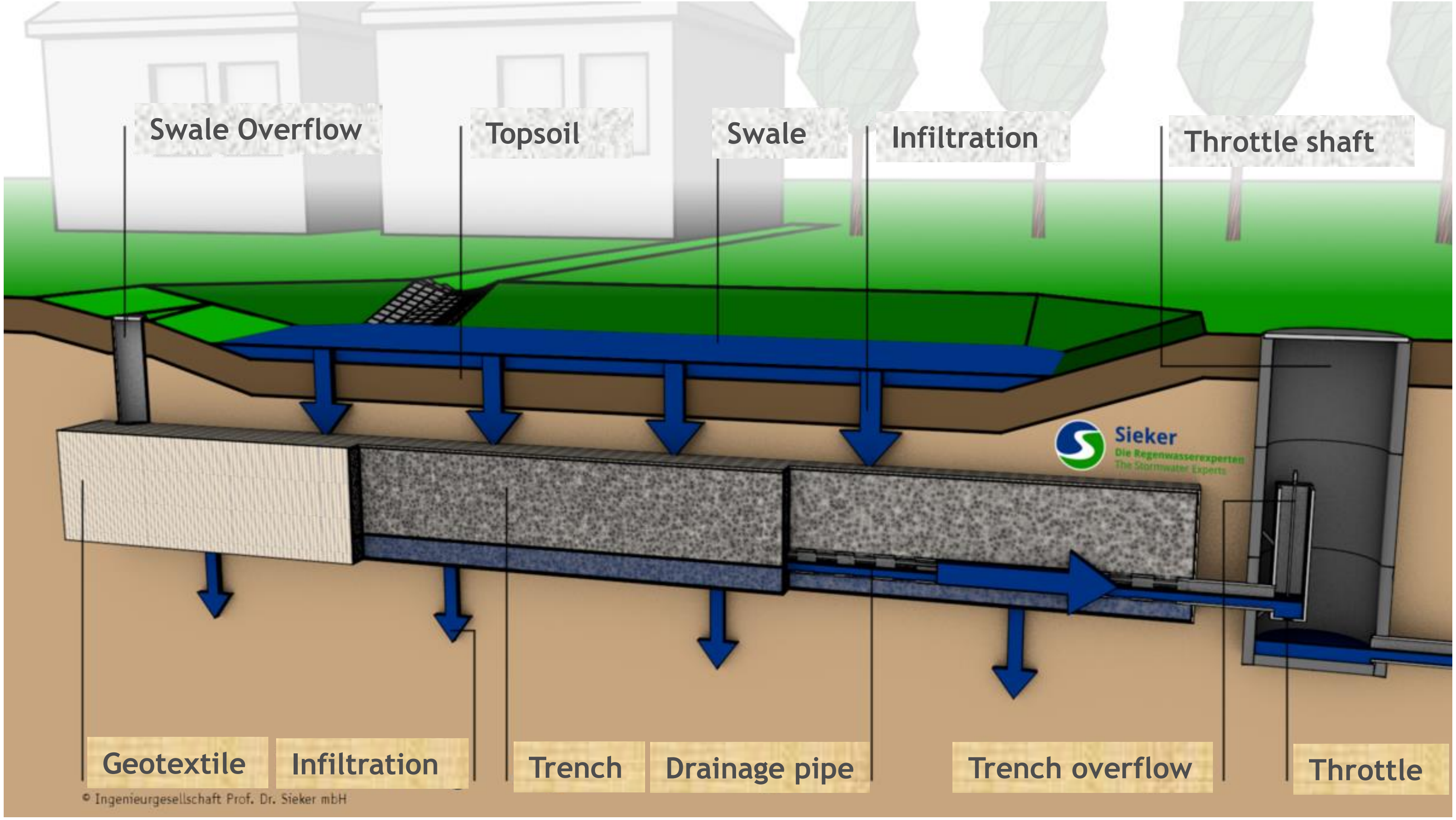
A cross section in a swale-trench infiltration system



(Source: fbr)

INFILTRATION

Cross section in a swale-trench infiltration system



(Source: Sieker)

Swale-Trench elements

(Source: Sieker)

Filling material for swale-trench infiltration system

(Source: ENREGIS)

Swale-trench system (combination systems)

- A combination of surface retention and cleaning capacity of a swale and the underground retention of a trench
- Are designed and dimensioned to allow the highest possible infiltration of stormwater runoff. This is achieved through the short-term storage in the vegetated swale and the long-term storage provided by the trench
- Allow the passage of water through the top soil of the swale into a permeable trench zone, where water is either infiltrated into deeper layers or throttled to a river or a drainage system
- Usually applied for soils with low permeability
- Provides good cleaning capacities and require less space than surface or swale infiltration

INFILTRATION

Combination systems

Irrigation, evaporation and infiltarion combined

Swale-trench-deep bed system in Birkenstein, Brandenburg (Photo: Sieker)

Schematic diagram of a tree-trench system (tree box) (Source: Sieker)

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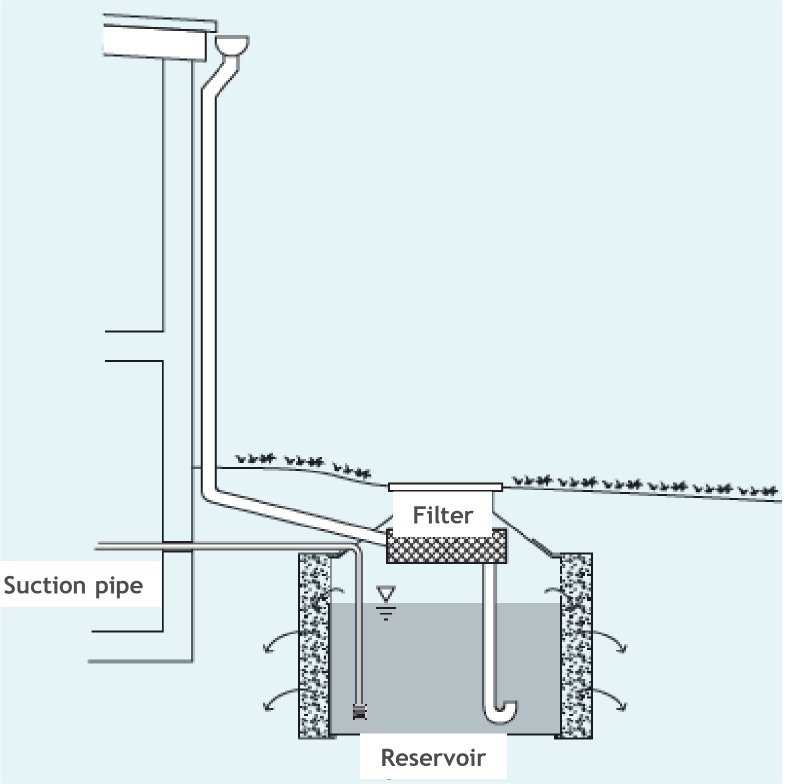
Rainwater harvesting in combination with an infiltration reservoir



(Source: fbr)

Benefits of decentralised rainwater management

- Reduce flooding impacts by retention, storage and soil conservation
- Enhance groundwater recharge by artifical infiltration
- Relieve the burden on combined sewer systems and WWTP
- Reduce environmental pollution/damage resulting from sewer overflows
- Improve the micro-climate and promote evaporative cooling
- Promote livability of urban areas
- Enhance agricultural productivity and as such increase food security
- Increase access to water supply for potabe and non-potable uses
- Higher community and environmental resilience and self-sufficiency
- Provide an integrated approach to surface water design problems and consider quality, quantitiy and amenity aspects equally

Which rainwater management technolgy is most suitable for my project?

- Usually it is not a single measure, but a combination of several different measures to get best results under the given conditions
- Here, is an economic study useful, which besides the monetary goals also considers the non-monetary goals for a specific measure. Assessment of the economic efficiency should not be solely based on the size of the investment but should also include the future operating costs and savings made.

See Module 5: Decision-making tool