Water Sensitive Urban Design (WSUD): Adaptation to Climate Change

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Purpose Statement

- The purpose of this work is to introduce Sustainable Drainage Systems (SuDS), Low Impact Development (LID) and Water Sensitive Urban Design (WSUD) to Egypt.
- The consequences of Urbanization and Climate Change are the main motive to address the subject matter to Egyptian researchers, educators and professionals.
- The subject is multidisciplinary, covering urban planning, sanitary engineering, water and irrigation engineering, ecologists, sociologists and environmental economist.

Outline

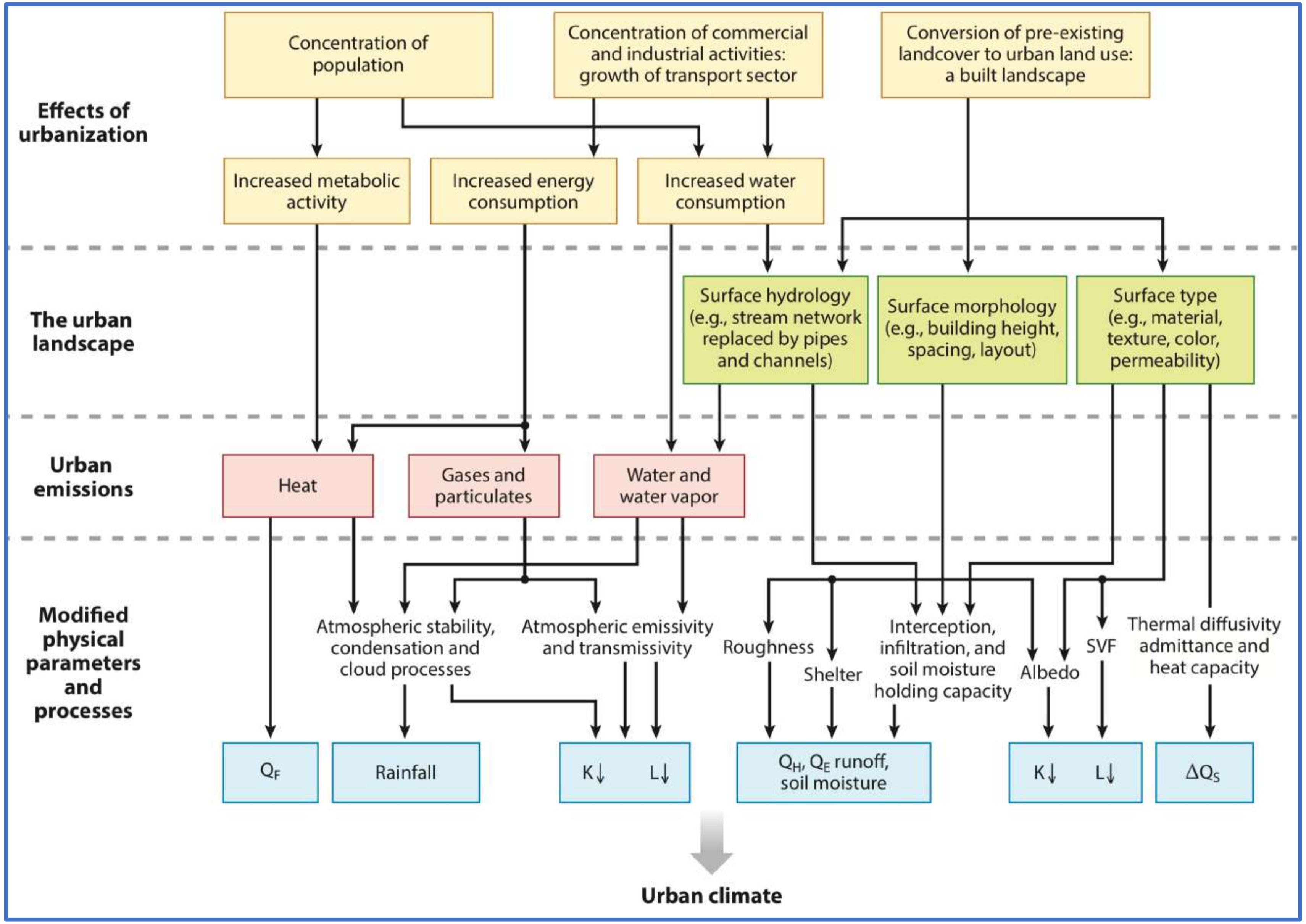
1. Urbanization Impact on Water and Ecology
2. Facing Urbanization Impact on Water and Ecology
3. Technologies
4. Country Experience
5. Technology Transfer to Egypt
6. Sources of Information

Annex: Recent Flooding Photos in Egyptian Cities

1. Urbanization Impact on Water and Ecology

Linking Urbanization and the Environment

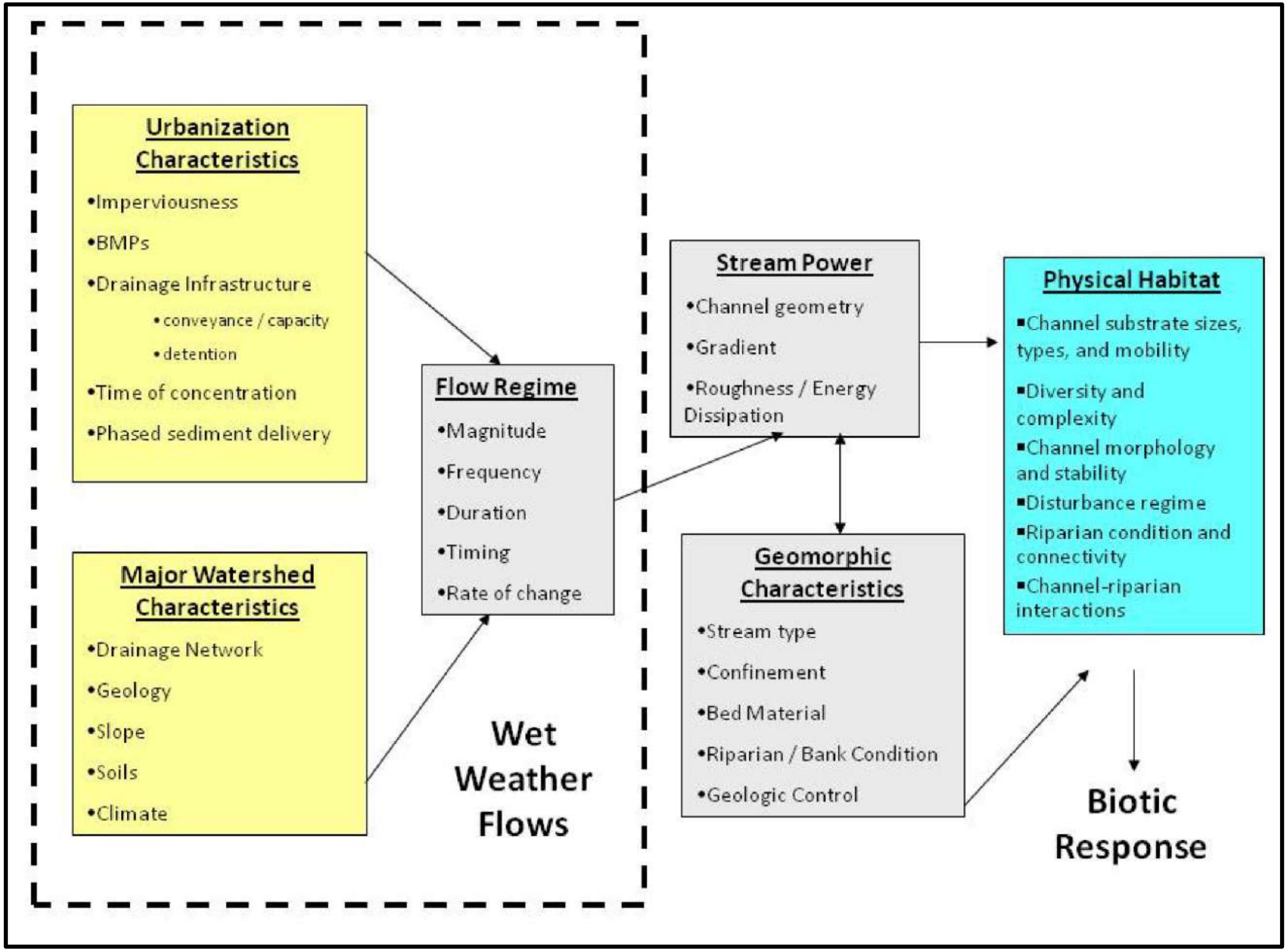
Physical processes that affect urban and regional climate: these links have been clearly established via theoretical, measurement and modeling. Symbols: QF, QE, QH, QS: fluxes of anthropogenic heat, latent heat, convective and stored heat, respectively; K↓ and L↓: downwelling shortwave and longwave radiation; K↑ and L↑: reflected shortwave and emitted longwave radiation. Albedo is the ratio of incoming to outgoing solar radiation for a given surface



Source: Bai, XX., et al., Linking urbanization and the environment: conceptual and empirical advances, Annu. Rev. Environ. Resour, 40, 2017

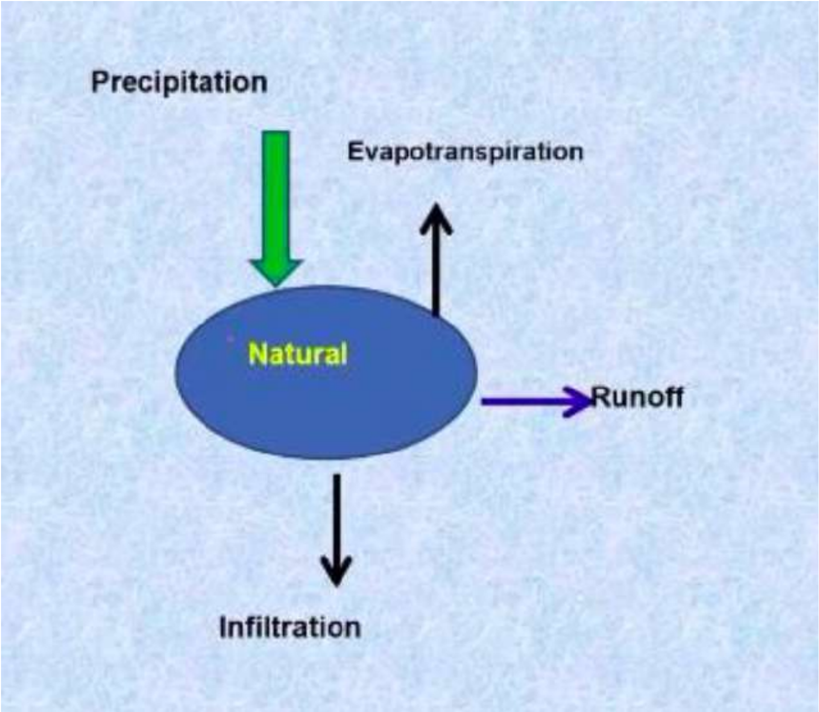
Physical effects of urbanization on streams and habitat

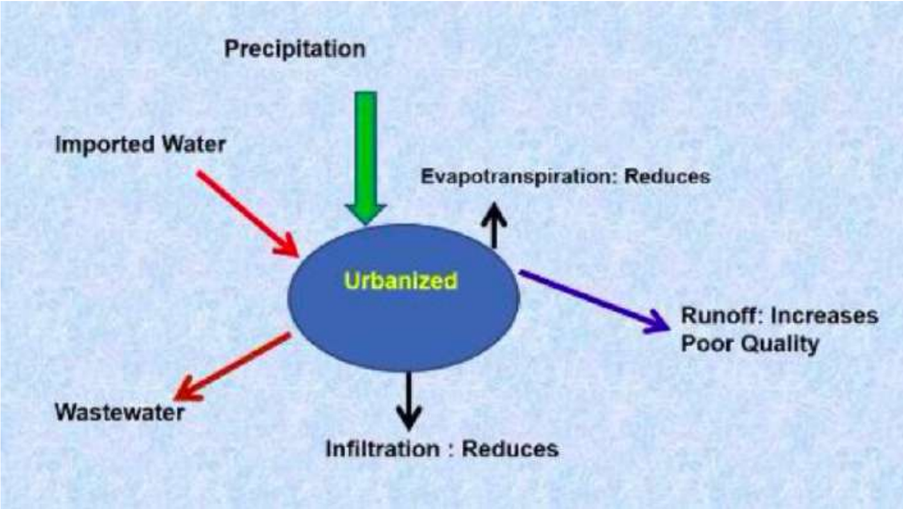
Source: Roesner, L. A. and B. P. Bledsoe. 2003. *Physical Effects of Wet Weather Flows on Aquatic Habitats*. Water Environment Research Foundation: Alexandria, VA. Co-published by IA Publishing: United Kingdom.)



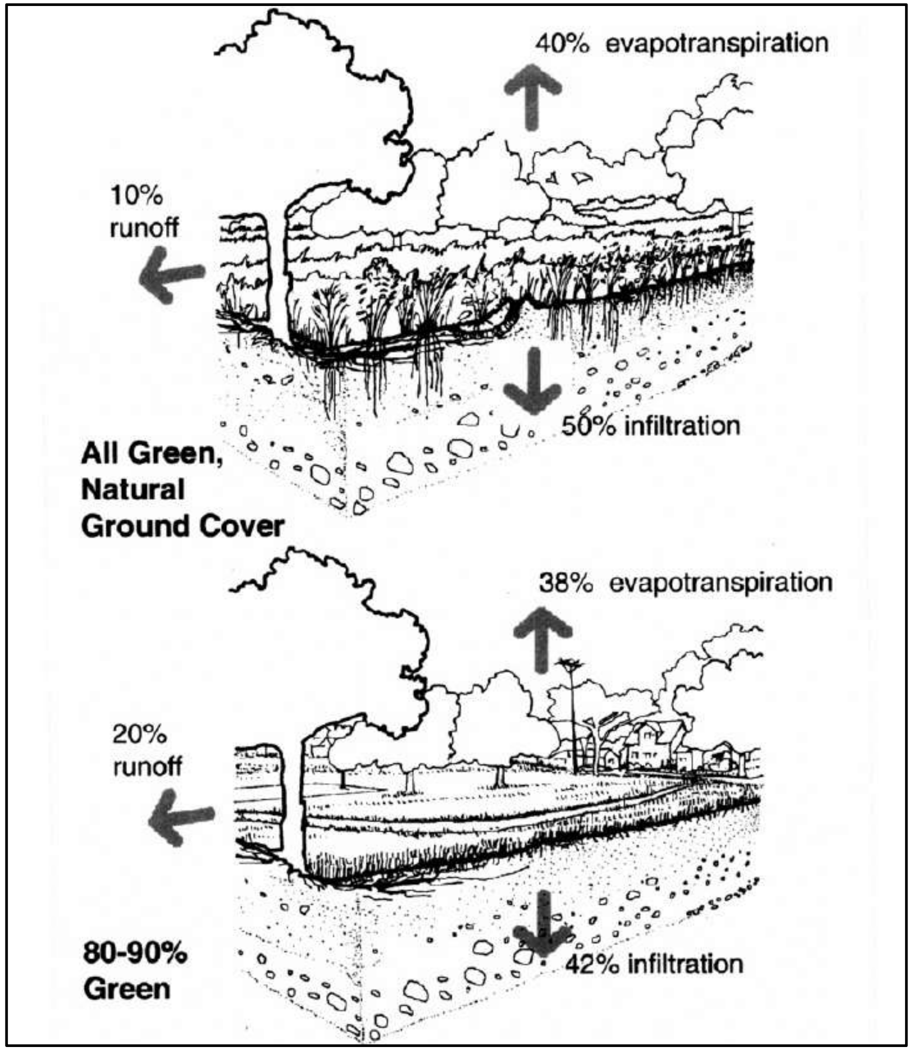
Impact of urbanization

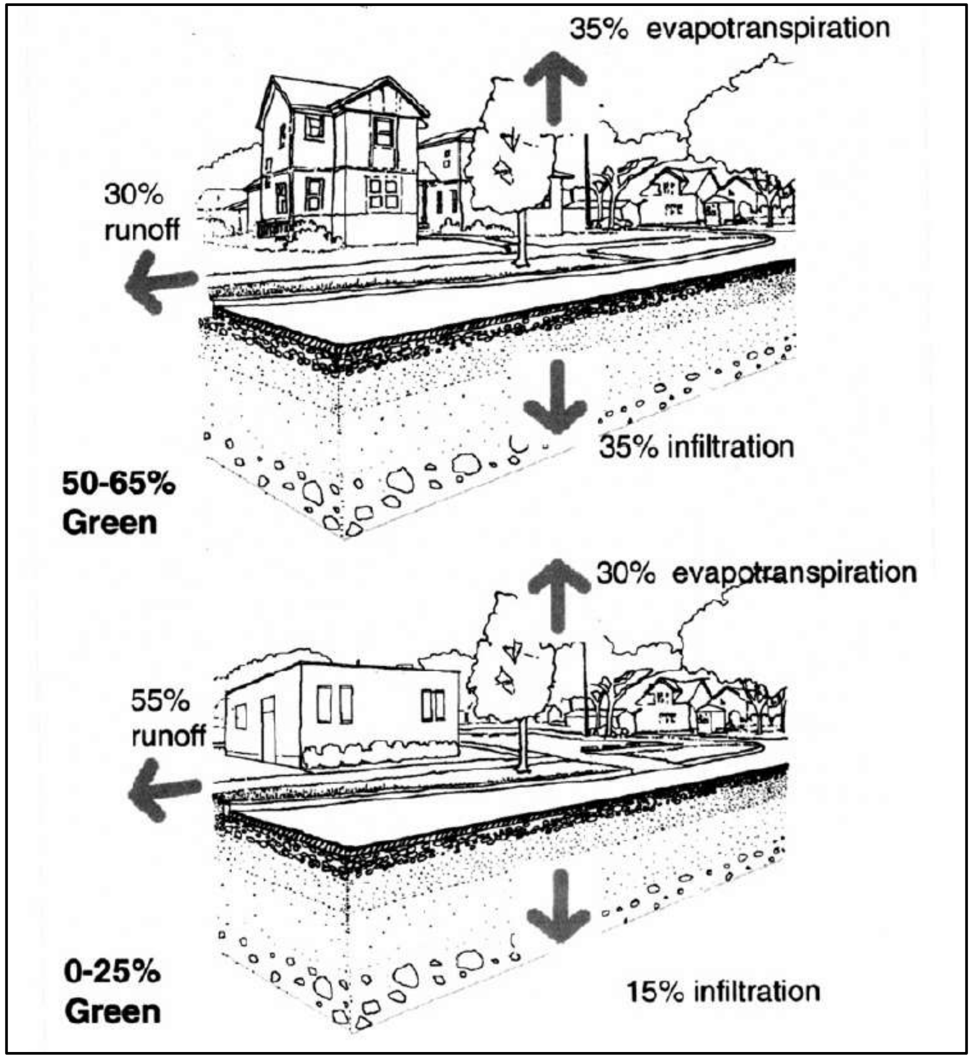
Aspect	Impact
Hydrological	• Drop in groundwater level • Deterioration in water quality
Ecological	• Land erosion • Loss of aquatic resources and vegetation
Physical	• Flooding • Loss of property • Loss of open space
Climatological	• Increase temperature (urban heat inland effect) • Increase rainfall • Decreased windspeed
Socio-economic	• Loss of health • Loss of productive man-days • Loss of employment





Comparison Among Different Levels of Impervious Soil





Total imperviousness (TI), is the fraction of the watershed area covered by an impervious surface.
TI has been used as a way to quantify the degree of urbanization. It is both integrative and easily measurable.

In the natural habitat the infiltration rate is high, in the urban context the runoff rate is the predominant.

http://www.irbnet.de/daten/iconda/CIB9095.pdf

Impact of Soil Sealing (1)

Aspect	
Biodiversity	• Loss of fauna and flora
Global Climate	• Removal of topsoil and subsoil during the process of sealing eliminate the potential to serve as natural fix of atmospheric carbon
Urban Climate	• The complete or partial inhibition of the infiltration of rain water reduces in evapotranspiration and storage of water in the subsoil destroying natural refrigeration • Increased absorption of solar energy by rooftops and dark asphalt surfaces and the residual heat generation by cooling systems (pumps), industry and traffic all contribute to the "urban heat island" effect.
Filter Capacity	• Urban activities lead to numerous pollutants (such as oil, sediments, fertilizers, pesticides, animal waste and litter) that can cause diffuse pollution and adversely affect the environment, which is not managed by traditional piped drainage. • Pollutants or contaminants can be washed into sewers and eventually watercourses through surface water run-off making it difficult to comply with water quality legislation.
Water	• Sealing reduces the amount of rainfall that can be absorbed by the soil, and the time it needs to reach rivers, increasing the amount of surface run-off and the peak flow, and therefore, the risk of flooding

Impact of Soil Sealing (2)

- The ability of a soil to store water depends on a range of factors including its texture, structure, depth and organic matter content. A cubic meter of a porous soil can hold between 100 and 300 liters of water.
- Built-up areas can be up to 4 times more impermeable than green areas.
- It has been suggested that to maintain satisfactory rates of surface infiltration, a minimum share of open space of as much as 50 % of the paved surface is required.
- The continued impermeability of built areas has produced a rise in the number of flooding events and their catastrophic consequences in Europe in recent years. This situation is expected to worsen in coming years due to an increase in the intensity of rains predicted. Some studies predict that rains will generate increase of between 20 and 40% in the volume of run-off water. This means that countries which currently have high average rainfall need to look for alternatives to manage rainwater.
- To solve this problem, progressive investment in the enlargement of sanitary networks has been necessary in order to be able to evacuate the ever increasing volume of run off originating from continued urbanization. Despite this, the collection system has always proved to be insufficient, generating a model of unsustainable management.

2. Facing Urbanization Impact on Water and Ecology

19th Century Solutions to Urban Water Management

<table>
<tr><th>Conventional stormwater in cities</th><th>Problems associated</th></tr>
<tr><td>Combined Sewerage Systems</td><td rowspan="2">Reduction in groundwater infiltration
Flooding risk during heavy periods of rain
Overflow to receiving water bodies might cause pollution
Efficiency measured on how rapidly the system can move the stormwater runoff “out of sight, no value associated</td></tr>
<tr><td>Separate Sewerage Systems</td></tr>
</table>

Three Basic Questions:

1. How Urban Development would be planned and executed in a manner that would lower the hydrological impact of urbanization?
2. How to maximize the benefits from rainwater within the urban boundary (cities as a water supply catchment)?
3. How to apply effective flood mitigation and control mechanisms in normal and emergency situations?

The Emergence of Sustainable Urban Drainage Systems (SuDS) in Europe

- SuDS have gained popularity in recent years as a way of solving the environmental problems associated with Soil Sealing, especially those related to the water cycle.
- These systems are a sequence of water management practices and facilities designed to drain surface water in a manner that will provide a more sustainable approach than what has been the conventional practice of routing run-off through a pipe to a watercourse.
- SuDS aim is improve the interaction between urban water cycles and city planning and landscaping, integrating SuDS in Urban Planning.

Sustainable Urban Drainage Systems (SuDS)

- SuDS purpose is to reduce the runoff volume, to provide natural ground water recharge, to minimize the flood risk, to minimize the erosion risk, to reduce the stormwater pollutant concentration, to enhance the biodiversity, to safeguard water and air quality, to decrease the stormwater treatment and pipe capacity costs, and to increase the amenity and aesthetic value of the developed areas.

(Cont.'d) Sustainable Urban Drainage Systems (SuDS)

- SuDS can predominately focus on reducing stormwater pollutant level at the source by cleaning street, spill and dumping control, and awareness campaigns. Such kinds of approaches are known as non-structural SUDS. The structural SUDS, on the other hand, apply different technologies as a source control, site control, and off-site control. For instance porous pavements, swales, ponds, wetlands, infiltration trenches/basins, filter strips, and treatment techniques are all considered structural SUDS.

(Cont.'d) Sustainable Urban Drainage Systems (SuDS)

- SuDS are considered as a solution to Soil Sealing and as a more sustainable alternative to the management of run-off, trying to restore the natural hydrological cycle which has been altered by the continued impermeability of cities.
- These systems fundamentally consist of <u>harvesting</u> rainwater (by <u>filtration</u> through permeable materials and or pipes, channel it and <u>store</u> it for the maximum amount of time possible, <u>retaining</u> the run-off for later use or simply to let it filter in subsoil and replenish the aquifers.
- European countries have been using these systems for more than a decade, thus improving the environmental quality of their cities. The implementation of these systems has <u>numerous benefits</u> that are summarized in:

Sustainable Urban Drainage Systems (SuDS) Benefits (1)

Aspect	Benefits
Flood risk management	SUDS schemes can be designed to slow water down (attenuate) before it enters the watercourse and SUDS can be used to allow water to soak (infiltrate) into the ground or evaporate from surface water and transpire from vegetation (known as evapotranspiration).
Water quality management	Some SUDS components provide water quality improvements by reducing sediment and contaminants from run-off either through settlement or biological breakdown of pollutants
Amenity and biodiversity	SUDS can improve a development by creating habitats that encourage biodiversity and simultaneously provide open spaces and opportunities to create visually attractive green (vegetated and landscape) and blue (water) corridors in developments connecting people to water. Furthermore, the permeability of surfaces helps to reduce the Heat Island Effect.
Water resources	Some SUDS components that soak water into the ground can replenish underground aquifers (where there is no risk of polluting the aquifer) and capture, or harvest rainwater that can be used for functions that do not require treated water from the mains (flushing toilets, irrigation, etc.).

Sustainable Urban Drainage Systems (SuDS) Benefits (2)

Aspect	Benefits
Community benefits	Well-designed SUDS can incorporate attractive public open spaces that create better places to live, work and play.
Recreational benefits	SUDS can deliver recreational benefits through the dual use of components and facilities such as using attenuation and storage areas and overland conveyance routes for play and/or sports areas. Also, multifunctional use of SUDS components can have other benefits such as the incorporation of recreational open spaces into a development that otherwise may be deemed impractical by a developer.
Educational benefits	In addition to improvements to the visual appearance of a development, many SUDS components have been used for recreational and educational purposes with schemes located in school grounds with very favorable results.
Benefits for developers	SUDS can provide savings on the overall construction and maintenance of drainage schemes, and can be integrated into strategies for public open space and green infrastructure within developments, linking urban areas through the development of blue/green corridors.

The Emergence of Low Impact Development (LID) in USA

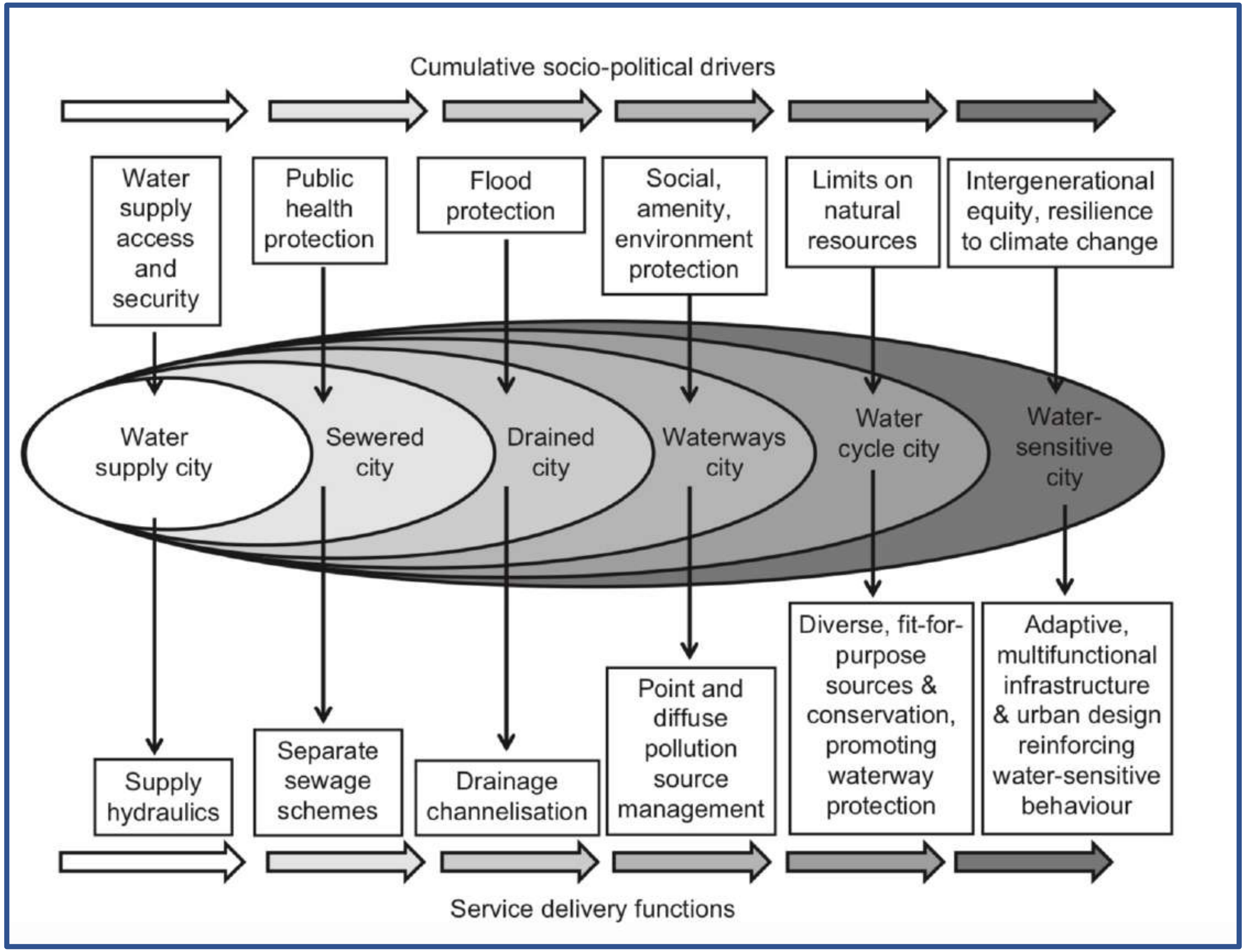
- At its most ambitious, LID aims to return the developed watersheds to pre-development hydrological conditions (i.e. to mimic natural water cycles or achieve hydrologic neutrality)
- LID is often used as a retrofit designed to reduce the stress on urban stormwater infrastructure and/or create the resiliency to adapt to climate changes.
- In order to achieve stormwater objectives, LID relies heavily on infiltration and evapotranspiration and attempts to incorporate natural features into design. Compared with traditional urban stormwater management patterns, LID alternatives have the function of return the runoff to the natural hydrologic cycle, including reduction in runoff volume, infiltration improvement, reduction in peak flow, extending lag time, reduction in pollutant loads and increase in baseflow.

LID: Infiltration and Retention Based

Basis	Description
Infiltration-Based LID	Infiltration-based LIDs can be characterized as techniques that assist in the restoration of baseflows through recharging of subsurface flows and groundwater. Infiltration-based techniques are highly dependent on site conditions, which is why the range of performance reported for infiltration-based techniques is very large. Infiltration- based LID practices include swales, infiltration trenches, basins, unlined bioretention systems (rain-gardens), sand filters, and porous pavements.
Retention-Based LID	Retention-based LIDs can be characterized as techniques that retain stormwater to reduce outflow. Retention-based technologies include wetlands, ponds, green roofs, and rainwater harvesting (tanks, storage basins).

The Emergence of the Water Sensitivity Concept in Australia

The concept of water sensitivity provides a vision to identify the most viable options for managing water availability (either too little or too much) and water quality. In urban areas it is vital to link this with urban design, place-making and livability, potentially moving towards sustainable urban water management within a sustainable, water-sensitive city.



Source: Ashly, R. et al, Water sensitive urban design: opportunities for the UK, Municipal Engineer, 166, 2012

Would Water Sensitive Urban Design be the Answer?

Sustainable Water Management				
Ensure Water Supply	Manage Storm-water	Treat/ Recycle Waster-water	Ensure/ Improve Waterway Health	Protect Surface-water-bodies and Ground-water
Environmental Engineers	Environmental Scientists	Environmental Planners		

Urban Planning			
Consider Ecological Demands	Consider Economical Demands	Consider Social Demands	Consider Cultural Demands
Urban and Landscape Planners	Administrative Officers	Architects/ Engineers	

Landscape Design	
Provide Aesthetic Quality	Contribute to the Cities' Amenity
Landscape Architects	Urban Designers/ Architects

Integrate

⇩

Manage whole water cycle

Contribute to sustainability in urban areas

Provide conditions for attractive, human-scale living environments

What is WSUD?

Water Sensitive Urban Design (WSUD) is the interdisciplinary cooperation of water management, urban design, and landscape planning. It considers all parts of the urban water cycle and combines the functionality of water management with principles of urban design. WSUD develops integrative strategies for ecological, economical, social, and cultural sustainability.

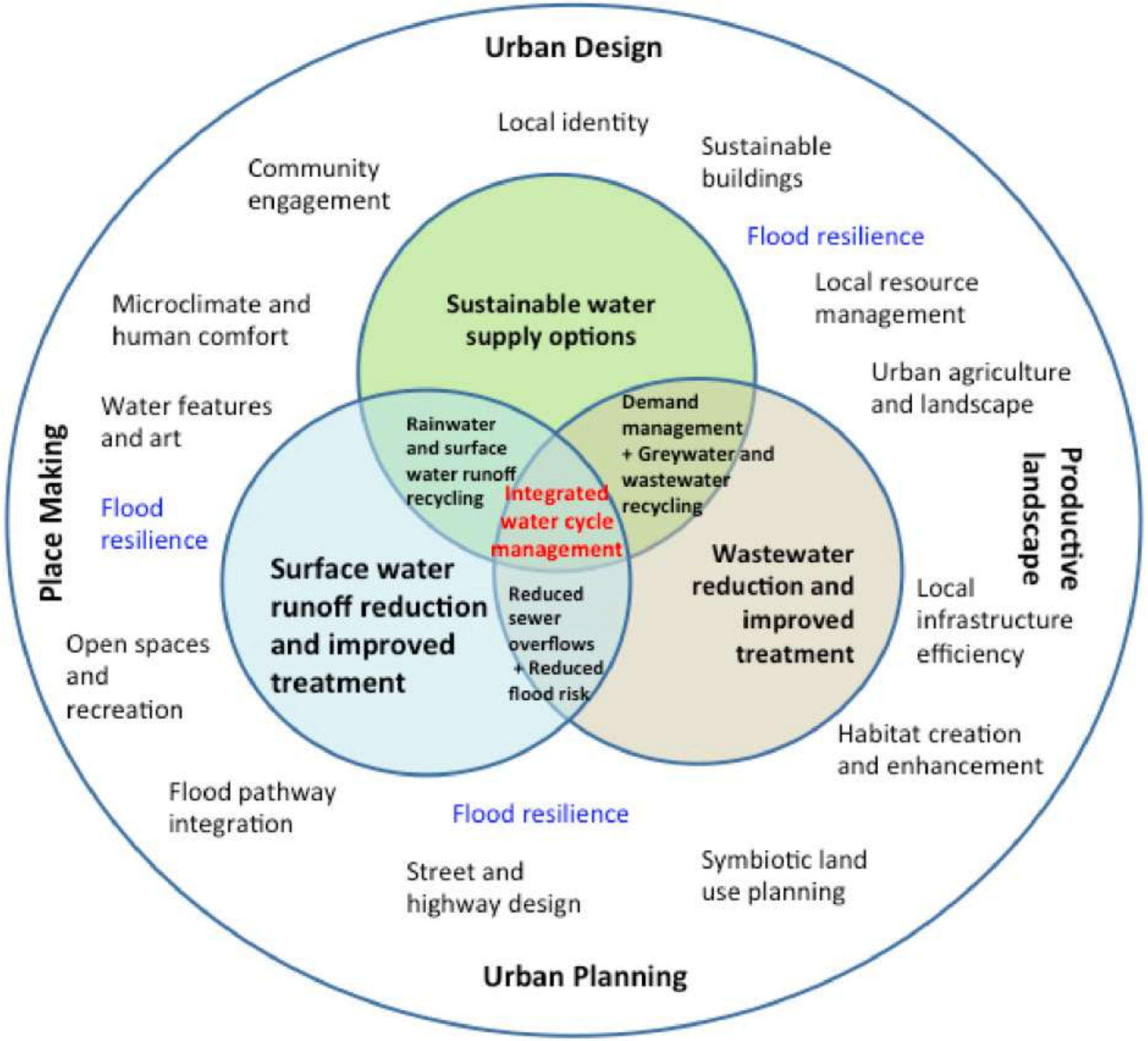
Water Sensitive Urban Design combines the demands of sustainable stormwater management with the demands of urban planning, and thus bringing the urban water cycle closer to a natural one. Originally, the term "Water Sensitive Urban Design" considers the management of entire water systems (drinking water, storm water run-off, waterway health, sewerage treatment and re-cycling), but is concerned mostly with issues of rainwater management.

(Cont.'d) What is WSUD?

- WSUD is practiced through both structural (green infrastructure systems e.g. raingardens, wetlands) and non-structural measures (i.e. policies aimed at improving efficiency of water use).
- WSUD is associated with the integration of multiple objectives that have traditionally been addressed separately: water security, public health, flood protection, waterway health, amenity, economic vitality, equity and long-term sustainability.
- There are two fundamental aspects to WSUD: best management practice and best planning practice. While the former refers to the structural and non-structural measures, the latter refers to urban planning aspects of the implementation of green, distributed systems.

WSUD: The UK Context

Components of water sensitive urban design and their interactions highlighting the place of flood resilience and other aspects of WSUD (Ashley et al., 2013a)



The three main principles of WSUD that are the most relevant to UK (and EU) applications are

- Manage water to deal with both water scarcity and water excess, managing both water quantity and quality, con- currently and in an integrated way
- Manage and utilize the water cycle as locally as possible as all aspects and occurrences of water are potential opportunities (exploit local opportunities)
- Deal with water appropriately and synergistically in urban environments, including ecosystems, and across urban services, design and planning processes (maximize wider value opportunities and more effective integration and utilization in urban areas).

South Africa WSUD Framework

- Stormwater management – taking the approach which incorporates elements such as the enhancement of amenity and biodiversity, and flood mitigation.
- Sanitation / wastewater minimization – including effluent quality improvement, and use of treated wastewater / recycled water.
- Groundwater management – artificial recharge, use of groundwater.
- Sustainable water supply options – including water conservation (WC) / demand management (WDM), reduction of NRW, alternative water sources, e.g. rainwater / stormwater harvesting.

WSUD Objectives

Water Sensitive Urban Design (WSUD) is increasingly being adopted taking climate change into consideration with the aims of:

- Providing flood control
- Flow management
- Water quality improvements
- Enhancing the opportunities to harvest stormwater for non-potable uses.

3. Technologies

WSUD Technologies

Demand reduction

Description:

- There are a number of steps to be taken in determining the demand reduction measures which are most appropriate for a particular development or redevelopment. The steps include:
  - ✓ Site analysis;
  - ✓ Determining objectives and targets;
  - ✓ Technique selection;
  - ✓ Meeting with local council and other relevant authorities;
  - ✓ Identifying funding opportunities; and
  - ✓ Review of objectives.

(Water Sensitive Urban Design Technical Manual, 2010)

Example:

Measures	Development Type				
	Residential blocks	Multi-unit residential	Estate development works	Commercial, industrial and institutional developments	Capital works (roads, ponds, earthworks, public areas)
Water efficient fittings and fixtures	Yes	Yes	-	Yes	-
Water efficient mechanical plant	-	-	-	Yes	-
Water efficient landscaping	Yes	Yes	Yes	Yes	Yes
Rainwater storage and use	Yes	Yes	Yes	Yes	Yes
Stormwater storage and use	Yes	Yes	Yes	Yes	Yes
Use of greywater	Yes	Yes	Yes	Yes	-
Use of treated wastewater (if available)	Yes	Yes	Yes	Yes	-

Possible applications in Egypt: Can be applied in urban and rural areas.

WSUD Technologies

Processes: Detention, filtration, infiltration and retention

Rain Garden

Description:

- A rain garden is one of the wide variety of soil-absorption/filter systems. It is a designed depression storage or a planted hole with native shrubs, perennials, and flowers that allows rainwater runoff from impervious urban areas to be absorbed and treated.
- Sizing of the rain garden will depend on the depth of the rain garden and the percolation rates at the site.
- Rain garden is widely used in Australia, UK and USA.

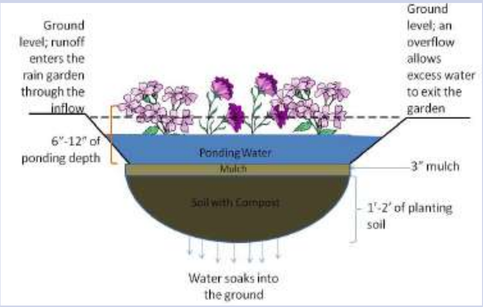
- Rain Garden to Capture Runoff from:
  - ✓ Yard $$\frac{\text{Yard Square Footage (ft}^2\text{)}}{\text{Rain Garden Depth (in)}} = \text{Rain Garden Area (ft}^2\text{)}$$
  - ✓ Downspouts $$\frac{\text{Contributing Roof Area (ft}^2\text{)}}{\text{Rain Garden Depth (in)}} = \text{Rain Garden Area (ft}^2\text{)}$$

Type of Soil	3-5 in. deep	6-7 in. deep	8 in. deep
Sandy	0.19	0.15	0.08
Silt Loam	0.34	0.25	0.16
Clayey	0.43	0.32	0.20

Type of Soil	Size of Rain Garden as % of Roof Area	Infiltration Rate, in/hr
Sandy	20% (5:1)	0.4
Silt Loam	30% (3:1)	0.20
Clayey	60% (2:1)	0.05

(Rain Garden Manual, Wisconsin Department of Natural Resources, 2003)

Example:



Possible applications in Egypt: Can be applied in all the coastal areas in Egypt, such as Alexandria, New Alamein, etc.

WSUD

Process: Retention

Green Roof

Description:

- The main benefits of green roofs are from significant rainfall volume retention, evapotranspiration, and reduced peak discharge from rooftops. Green roofs tend to retain (on average) between 45 and 75 percent of annual rainfall.
- It is applied in many cities around the world such as Chicago, Toronto, NYC, etc.
- Green roofs are extensive (lighter and included resistant and durable plants) or intensive (heavier and include thinker plants and have a thick media layer to protect vegetation's that have deep roots).
- The maintenance of green roofs is perceived to be one of the greatest barriers to their installation, but it is necessary to clear gutters and drains and remove any unwanted debris or litter.
- The required size of a green roof will depend on several factors, including the size of roofs, the maximum water retention of the growing media and the underlying drainage and storage layer materials (i.e. prefabricated water cups or plastic modules).

$$Sv = \frac{SA \times [(d_m \times \eta_1) + (d_{dl} \times \eta_2)]}{12}$$

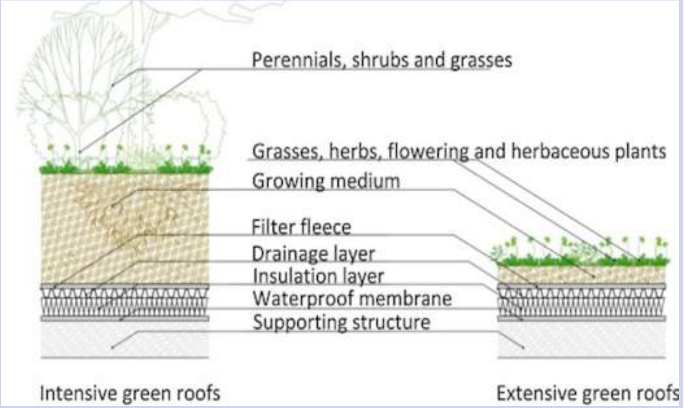
where:

Sv	=	storage volume (ft³)
SA	=	green roof area (ft²)
d_m	=	media depth (in) (minimum 3")
η_1	=	verified media porosity maximum water retention
d_{dl}	=	drainage layer depth (in)
η_2	=	verified drainage layer porosity maximum water retention

Note: If verified maximum water retention values are not available, a value of 0.25 may be used.

(The Green Roof Manual: A Professional Guide to Design, Installation, and Maintenance, 2010)

Example:



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WSUD

Process: Retention

Rainwater harvesting tank

Description:

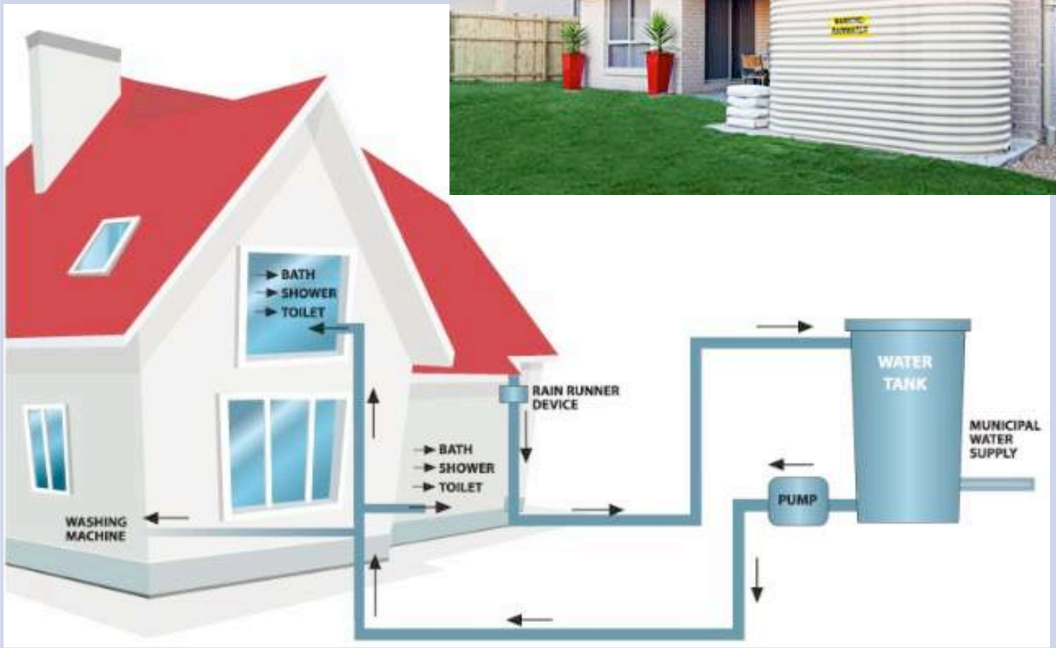
- The system consists of a rainwater catchment surface, conveyance system, and water storage tank(s).
- Water is drawn from the tanks by means of taps at the base of the tanks. In some cases rainwater may be reticulated within a house using a pump/pressure system.
- The collected water can be used for low consumption purposes, such as garden irrigation and yard washing.
- Sizing the tank:

Annual rainfall (in millimetres) x Roof surface area (in square metres) = Roof catchment capacity

- It is applied in many countries, such as Brazil, Singapore, China, Germany, Australia, etc.

(Virginia Rainwater Harvesting Manual, 2009)

Example:



Possible application in Egypt: Can be used in the residential compounds and tourist areas located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD	Process: Retention

Rainwater harvesting underground system

Description:

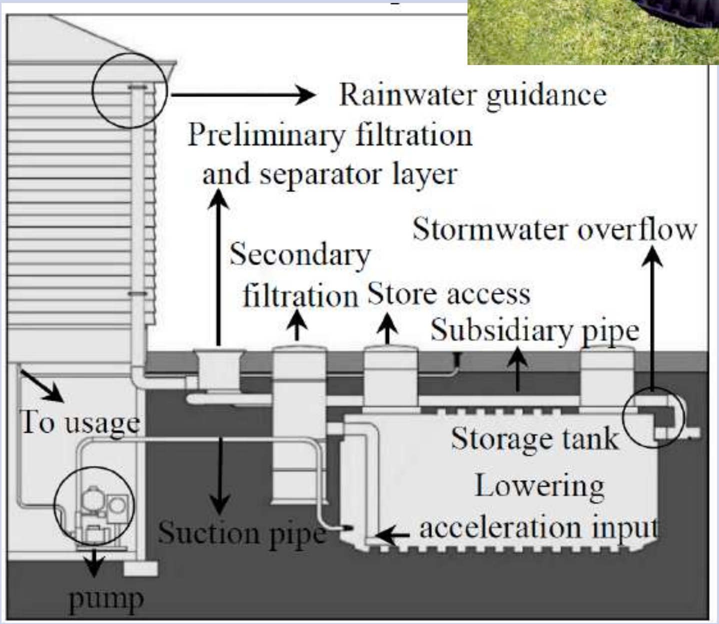
- The system consists of a rainwater catchment surface, conveyance system, and water storage tank(s).
- Harvesting rainwater falling on the rooftop to be stored in underground storage tanks.
- A submersible pump is used to transport water from an underground tank to bathrooms, washing machines, etc. if treated.
- Sizing the tank:

Annual rainfall (in millimetres) x Roof surface area (in square metres) = Roof catchment capacity

- It is applied in many countries, such as Malaysia, India, Kabale, Southern Uganda, etc.

(Virginia Rainwater Harvesting Manual, 2009)

Example:



Possible application in Egypt: Can be used in the residential compounds and tourist areas located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

Permeable paving

Description:

- Permeable pavements are alternative paving surfaces that allow stormwater runoff to filter through voids in the pavement surface into an underlying stone reservoir, where it is temporarily stored and/or infiltrated/drained. Average permeability rate could reach 1,200 mm/hr.
- Permeable paving includes asphalt, concrete or some other types of paving martials.
- Depth of reservoir layer:

$$d_p = \frac{\left(\frac{P \times Rv_I \times DA}{A_p}\right) - \left(\frac{i}{2} \times t_f\right)}{\eta_r}$$

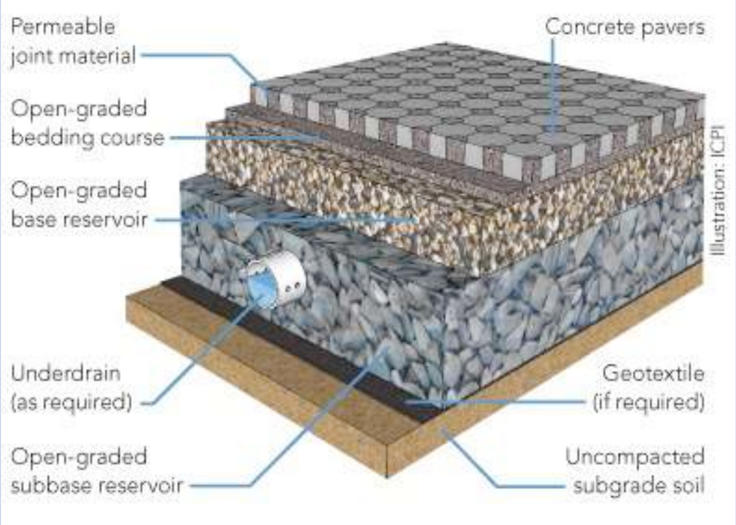
where:

d_p	=	depth of the reservoir layer (or depth of the infiltration sump for enhanced designs with underdrains) (ft)
P	=	rainfall depth for the design storm (ft)
Rv_I	=	runoff coefficient for impervious cover (0.95)
DA	=	total contributing drainage area, including permeable pavement surface (ft²)
A_p	=	permeable pavement surface area (ft²)
i	=	field-verified infiltration rate for the subgrade soils (ft/day). If an impermeable liner is used in the design then i = 0.
t_f	=	time to fill the reservoir layer (day) (assume 2 hours or 0.083 day)
η_r	=	effective porosity for the reservoir layer (0.35)

- Permeable concrete is now used in multiple cities throughout the U.S.

(Minnesota Stormwater Manual, 2016)

Example:



Possible applications in Egypt: Can be used in the residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

Pervious pavement

Description:

- Pervious pavement is a specific type of pavement with a high porosity that allows rainwater to pass through it into the ground below.
- Pervious concrete pavement consists of cement, a coarse aggregate, and water, with little to no fine aggregates (sand or clay). That is why pervious pavement has a very rough and uneven appearance.
- If not adequately designed, the water table below the pavement can rise, preventing stormwater from being absorbed into the ground.
- Average permeability rate could reach 36,000 mm/hr.
- It is not recommend in areas which are going to be used for activities such as stockpiling sawdust or in areas where there will be heavy silt loads, but is suitable for most other applications.
- Itis now used in multiple cities throughout the U.S.
- The ASTM has a set of standards for pervious concrete pavement: (American Society for Testing and Materials (ASTM))

Example:

Possible applications in Egypt: Can be applied in roads that are subjected to high rains, such as Qena-Sohag, Al Ain Al Sokhna, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

Modular pavement

Description:

- Modular pavement comes in pre-formed modular pavers of brick and concrete. When the brick or concrete is laid on a permeable base, water will be allowed to infiltrate.
- Grass can be planted between the pavers, allowing structural support in infrequently used parking areas.
- Average permeability rate could reach 7,000 mm/hr.
- Modular pavement are now used in multiple cities throughout the U.S.

(Minnesota Stormwater Manual, 2016)

Example:

Possible applications in Egypt: Can be applied in parking areas in residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

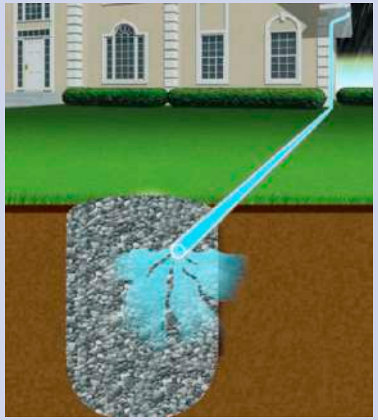
Soakaway

Description:

- A rainwater soakaway removes excess levels of water from gardens and roofs. Quite simply, it is a hole in the ground that is filled with rubble that allows water runoff to slowly drain and redistribute itself into the soil.
- Rainwater soakaways tend to deal with large volumes of water and are generally reinforced with concrete chambers and perforated on the bottom to help allow the water to escape effectively. Maximum infiltration rate could reach 180 mm/hr.
- The size of a rainwater soakaway is dependent on several factors, including the size of the property, number of occupants and the ease with which water drains through the soil.
- Storage must equal or be greater than inflow minus outflow.
- Inflow to the soakaway: $I = A \times R$ where: A = the impermeable area drained to the soakaway; R = the total rainfall in a design storm
- Outflow from the soakaway: $O = a_{s50} \times f \times D$ where: a_{s50} = the internal surface area of the soakaway to 50% effective depth; f = the soil infiltration rate; D = the storm duration
- Soakaway is now used in UK, France, Nigeria, Spain

(The Soakaway Design Guide, kent county council, 2000)

Example:



Possible applications in Egypt: Can be used in the residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

Infiltration trenches

Description:

- Infiltration trenches, are long and narrow trenches that are fill by coarse sand and rock fragments inside it. These trenches retain runoffs in basins and aquifer temporary, before infiltrate into the soil around.
- Some of infiltration trenches drain and direct runoffs through the pipes that are installed into it. Maximum infiltration rate could reach 180 mm/hr.
- The design standards in this field depend on rainfall intensity, local soil conditions and available spaces.
- Trench depth:

$$d_{max} = \frac{f_d \times T_{max}}{V_r}$$

d_{max} = maximum allowable trench depth (ft)
f_d = design infiltration rate (in/hr)
T_{max} = maximum allowable drain time (48 hours)
V_r = void ratio of the stone trench

- Trench bottom surface area:

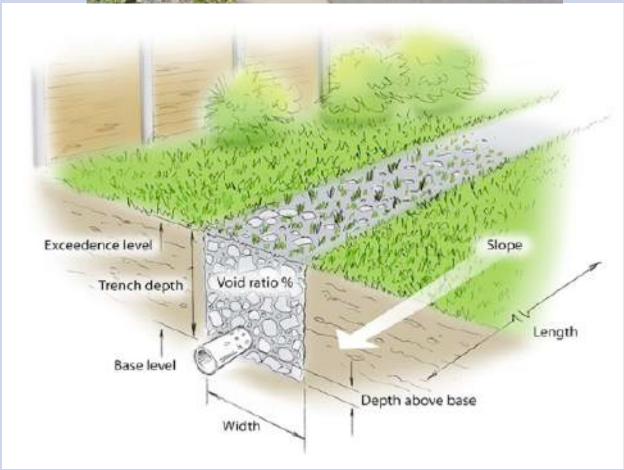
$$SA_{min} = \frac{WQV}{(f_d)(T_{max})}$$

SA_{min} = minimum basin bottom surface area (ft^2)
WQV = treatment volume (ft^3)
f_d = design infiltration rate (in/hr)
T_{max} = maximum allowable drain time (48 hours)

- Infiltration trenches are now used in multiple cities throughout the U.S.

(Minnesota Stormwater Manual, 2016)

Example:



Possible applications in Egypt: Can be used in the highways, residential compounds, cities, as well as tourist areas located along the coast or susceptible to high rain intensity.

WSUD Technologies

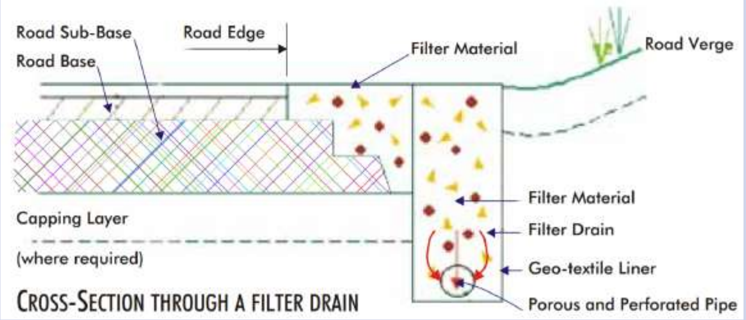
Processes: Detention, filtration and infiltration

Filter drain

Description:

- Gravel trench which collects and conveys rainwater as well as allowing water to drain into the surrounding ground. It is widely used in France and U.S., etc.
- They also reduce pollution by slowing down flows and filtering the rainwater run-off prior to entering watercourses.
- As they are typically shallow they can be relatively cheap and straightforward to install.
- Filter drains should be laid 3 m away from the property foundations. They shouldn’t be laid close to or underneath trees or shrubs.
- A geotextile material should be used to line the trench just below the surface to prevent sediment in the gravel fill. Maximum infiltration rate could reach 180 mm/hr.
- A perforated pipe of at least 75 mm diameter should be incorporated into the base of the drain to act as an overflow.
- The slope of the drain should not be less than 1 m vertical for every 400 m horizontal to maximize the slowing effect.

Example:



Possible applications in Egypt: Can be applied in cities located near watercourse, such as New Alamein and New Mansoura, etc.

WSUD Technologies

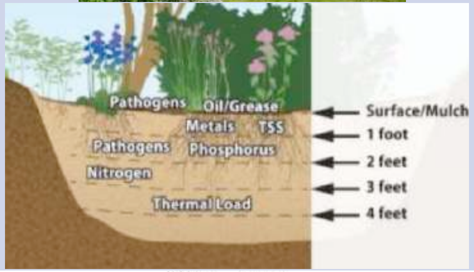
Processes: Filtration, infiltration and retention

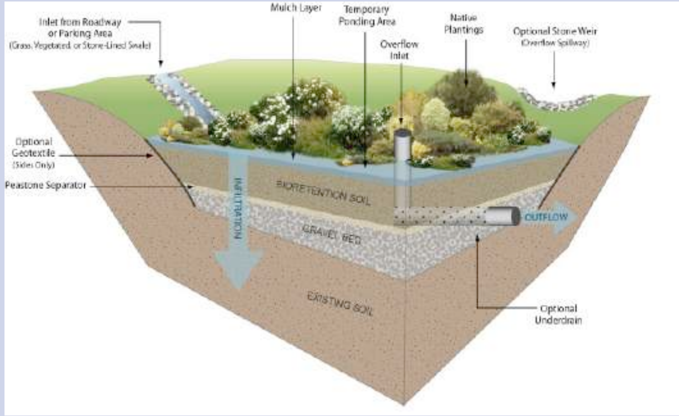
Bioretention

Description:

- Bioretentions are shallow landscaped depressions, which typically drain from below and rely on engineered soils and enhanced vegetation and filtration to remove pollution and reduce downstream runoff.
- The system consists of pretreatment system, surface ponding area, mulch layer, and planting soil media.
- Pollutants are removed through a variety of physical, biological, and chemical treatment processes.
- Infiltration rates typically > 13 mm/hr. When subsoil infiltration rates are < 13 mm/hr, filtered water is directed toward a stormwater conveyance system.
- Drawdown time: surface water between 12–24 hrs, and subsurface between 48–72 hrs.
- Bioretentions are appropriate for relatively flat or gentle slope areas.
- Limitations: design, construction and maintenance of these practices can be complex. In particular, maintenance personnel may need additional instruction on routine "operation and maintenance" requirements.
- Bioretention are now used in multiple cities throughout the U.S.
- Detailed design of Bioretention: (George's County, Maryland Manual, 2018).

Example:





Possible applications in Egypt: Can be applied in parking areas in residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Filtration and infiltration

Swales

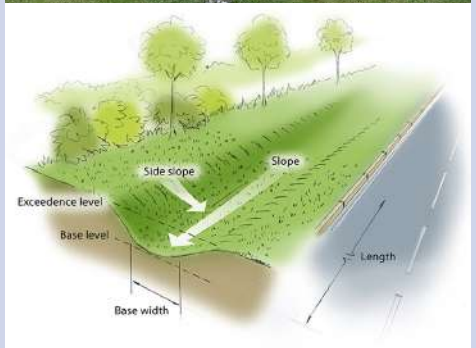
Description:

- A swale is a shallow vegetated channel with gently sloping sides. A swale may be either natural or man-made. Artificial swales are often infiltration basins, designed to manage and transport water runoff, filter pollutants, and increase rainwater infiltration. Drawdown time (usually 12 to 48 hours).
- It is widely used in U.S. and it is created by digging a ditch on contour and piling the dirt on the downhill side of the ditch to create a berm.
- The promotion of settling is enhanced by the use of dense vegetation, usually grass, which promotes low flow velocities to trap particulate pollutants. Trees and shrubs along the swale can provide shade and mulch which decrease evaporation.
- The flow depth for the peak flow generated by the storm must be maintained at 10 cm or less.
- Minimum Width (ft): $W = \dfrac{n \times Q}{1.49 \times D^{5/3} \times S^{1/2}}$
- Minimum swale length (ft): $L = 540 \times V$

where:

Q	=	design storm peak flow rate (cfs)
V	=	design storm flow velocity (ft/s)
W	=	channel width (ft)
D	=	flow depth (ft)
n	=	roughness coefficient (0.2, or as appropriate)
S	=	channel slope (ft/ft)

Example:



Possible applications in Egypt: Can be constructed along highways and roads that are subjected to high rains, such as Qena-Sohag, Al Ain Al Sokhna, etc.

WSUD Technologies

Process: Conveyance

Rill

Description:

- Open vegetated channel to transport rainwater to infiltration areas.
- Rill is drilled and then lined on the bottom and sides with a layer of builder's sand.
- A concrete layer may be also used.
- Creeping plants or trailing plants are installed at the edges of the rill to create a water garden.
- Manning equation is used for channel design:

$$Q = \frac{1}{n} A R^{2/3} S_o^{1/2}$$

- Rills can be found in many cities throughout the U.S.

(Design manual, City of Griffin, Georgia, 2007)

Table 4.4-2 Maximum Velocities for Comparing Lining Materials

Material	Maximum Velocity (ft / s)
Sand	2.0
Silt	3.5
Firm Loam	3.5
Fine Gravel	5.0
Stiff Clay	5.0
Graded Loam or Silt to Cobbles	5.0
Coarse Gravel	6.0
Shales and Hard Pans	6.0

Table 4.4-3 Maximum Velocities for Vegetative Channel Linings

Vegetation Type	Slope Range (%)[1]	Maximum Velocity[2] (ft / s)
Bermuda grass	0 -> 10	5
Bahia	0 - 10	4
Tall fescue grass mixtures[3]	0 - 5	4
Kentucky bluegrass	5 - 10	6
Buffalo grass	> 10	5
	> 10	4
Grass mixture	0 - 5[1]	4
	5 - 10	3
Sericea lespedeza, Weeping lovegrass Alfalfa	0 - 5[4]	3
Annuals[5]	0 - 5	3
Sod		4
Lapped Sod		5

Example:

Possible applications in Egypt: Can be applied in the new residential compounds, new cities, as well as tourist areas.

WSUD Technologies

Process: Conveyance

Channel

Description:

- Channel to transport rainwater to infiltration areas.
- These channels may be made:
  - ✓ Entirely of concrete;
  - ✓ With concrete sides and an exposed bottom;
  - ✓ With riprap sides and an exposed bottom; or
  - ✓ Completely unlined.
- Manning equation is used for channel design:

$$Q = \frac{1}{n} A R^{2/3} S_o^{1/2}$$

- Channels can be found in many cities throughout the U.S.

Table 4.4-2 Maximum Velocities for Comparing Lining Materials

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Shales and Hard Pans	6.0

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Sericea lespedeza, Weeping lovegrass Alfalfa	0 - 5[4]	3
Annuals[5]	0 - 5	3
Sod		4
Lapped Sod		5

(Design manual, City of Griffin, Georgia, 2007)

Example:

Possible applications in Egypt: Can be applied in the new residential compounds, new cities, as well as tourist areas located along the coast or susceptible to high rain intensity.

WSUD Technologies

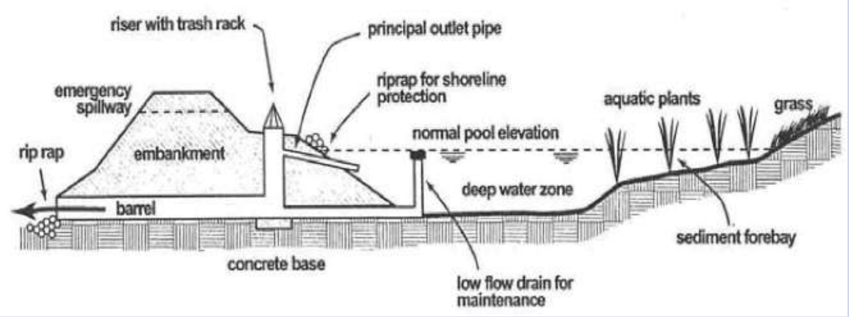
Processes: Filtration, infiltration and retention

Retention pond

Description:

- Retention ponds maintain a pool of water throughout the year and hold stormwater runoff following storms. It is widely used in the U.S.
- Runoff from each rain event is detained and treated in the pool. The retention time promotes pollutant removal through sedimentation and the opportunity for biological uptake mechanisms to reduce nutrient concentrations. Infiltration rate ranges from 9-20 mm/hr.
- Although they make good flood control facilities, they are not completely effective to filter pollutants, especially soluble ones.
- Improperly maintained detention ponds can become breeding grounds for pests.
- Regular checking for erosion, and damage to the slopes and outlet devices has to be checked. The setup also has to be checked for accumulation and blockage by sediment or debris.
- Detailed design of retention pond: (Retention Pond T-7 – UDFCD, 2015)

Example:



Possible applications in Egypt: Can be applied in new cities and compounds subjected to heavy rains, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention, filtration and infiltration

Infiltration basin

Description:

- A shallow artificial pond that is designed to infiltrate stormwater through permeable soils into the groundwater aquifer. They are widely used in some states in U.S.
- Infiltration basins do not release water except by infiltration, evaporation or emergency overflow during flood conditions. Average infiltration rate of 125 mm/h.
- They may be less effective in areas with: high groundwater levels, close to the infiltrating surface; compacted soils; high levels of sediment in stormwater; or high clay soil content.
- Basin depth: $d_{max} = f_d \times T_{max}$

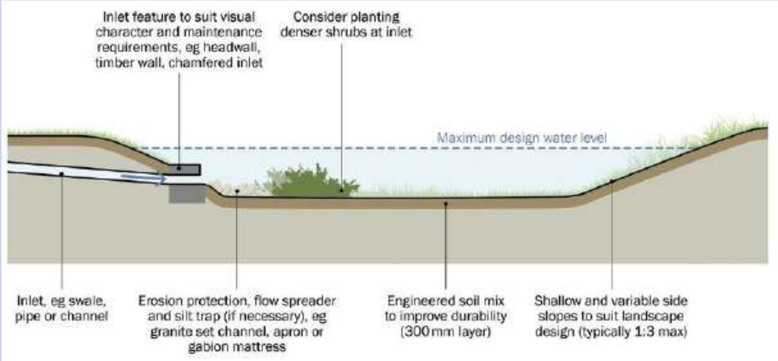
d_{max} = maximum allowable basin depth (ft)
f_d = design infiltration rate (in/hr)
T_{max} = maximum allowable drain time (48 hours)

- Basin bottom surface area: $SA_{min} = \frac{WQV}{(f_d)(T_{max})}$

SA_{min} = minimum basin bottom surface area (ft^2)
WQV = treatment volume (ft^3)
f_d = design infiltration rate (in/hr)
T_{max} = maximum allowable drain time (48 hours)

(Minnesota Stormwater Manual, 2016)

Example:



Possible applications in Egypt: Can be applied in new cities and compounds subjected to heavy rains, such as Alexandria, New Alamein and New Mansoura, etc.

WSUD Technologies

Processes: Detention and filtration

Detention pond

Description:

- Detention ponds hold water for a short period of time; this pond temporarily holds water before it enters the stream in order to reduce peak flows. It is widely used in the U.S.
- The design criteria for storage facilities should include: release rate, storage volume, grading and depth requirements, safety considerations and landscaping, outlet works, and location.
- Also, an emergency spillway is usually required to allow for safety during flood events. Average infiltration rate of 125 mm/h.
- Limitations: inefficient at removing dissolved solids, not applicable in high water tables, and need periodic maintenance (dredging accumulated sediment and vegetation management).
- Detailed design of Detention pond: (BMP Design Manual - Virginia Department of Transportation, 2013).

Example:

Possible applications in Egypt: Can be applied in cities and compounds located in arid areas, such as Cairo, Giza, etc.

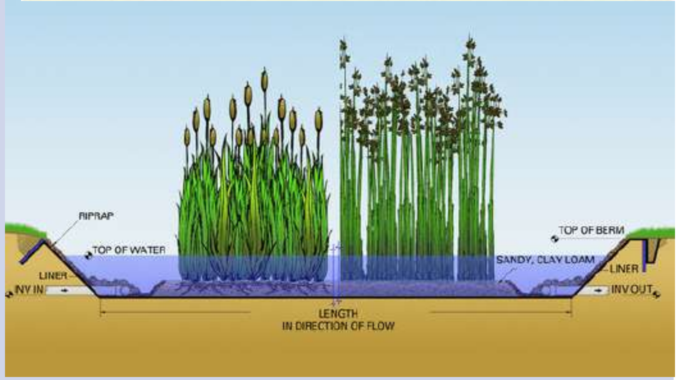
WSUD Technologies

Processes: Detention and filtration

Wetland

Description:	**Example:**

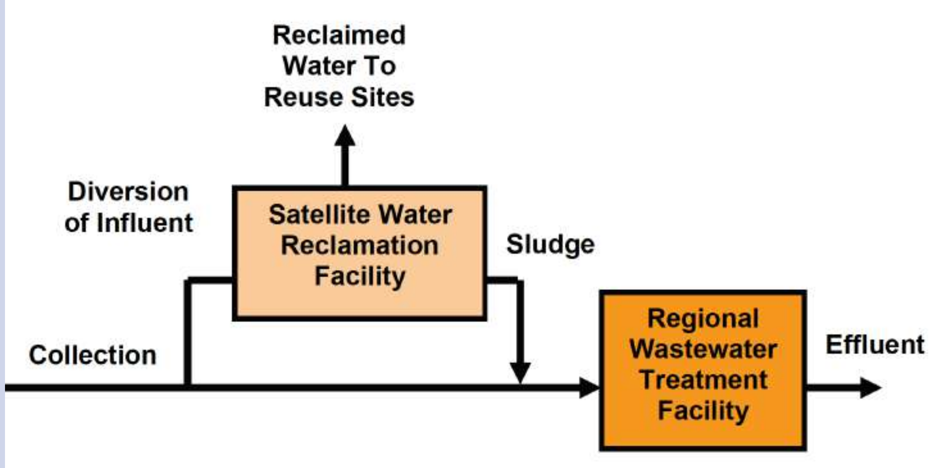
- Retention pond with aquatic vegetation to treat rainwater.
- Usually, the constructed wetland has three primary components: an impermeable layer (generally clay), a gravel layer that provides a substrate (i.e., an area that provides nutrients and support) for the root zone, and an above-surface vegetation zone.
- The impermeable layer prevents infiltration of wastes down into lower aquifers. The gravel layer and root zone is where water flows and bioremediation and denitrification take place. The above ground vegetative layer contains the plant material which removes sediments and nutrients. Infiltration rate ranges from 9-20 mm/hr.
- Limitations: expensive to implement, requires large areas of land, and high water table limit this system.
- Detailed design of wetland: (Wetland Design Manual, Melbourne Water, 2017)



Possible applications in Egypt: Can be applied in open spaces in new residential compounds.

WSUD Technologies

Satellite WW Treatment (Scalping)

Description:	**Example:**
Scalping or stellate WWTP treats a diverted flow of raw wastewater from a regional collection system. The capacity and level of treatment are chosen according to the reuse requirements of the treated stream. The sludge produced from the satellite plant is returned back to the main collection system. (Decision Support System for Selection of Satellite vs. Regional Treatment for Reuse Systems)	

Possible applications in Egypt:
In the case of distant location of central WWTPs in the new cities, treated effluent is pumped for long distance to be used for irrigation purposes. Satellite treatment could be applied in major gated communities.

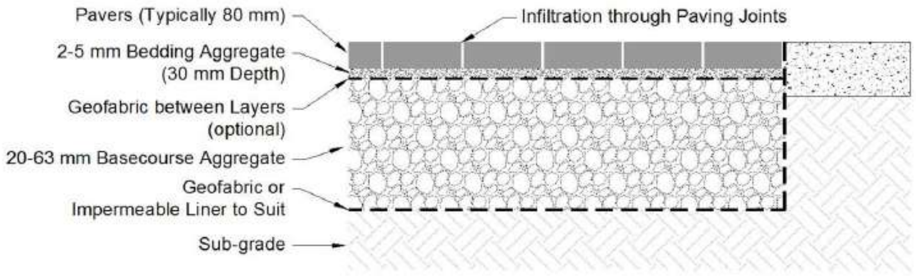
4. Country Experience

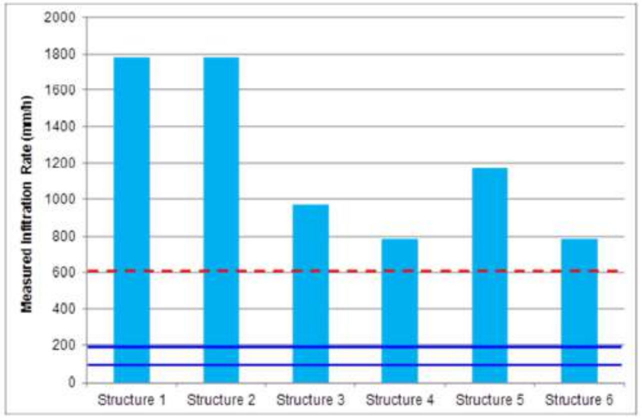
Permeable Interlocking Concrete Pavers (PICP) in Germany mitigates the consequences of urbanization

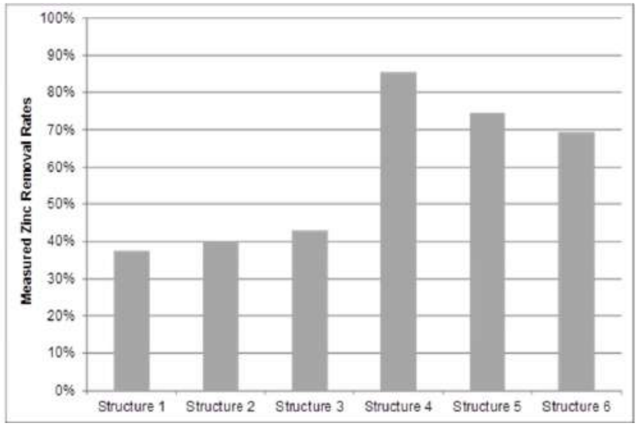
PICPs remove pollutants (TSS, TP, TN, heavy metals and motor oils) from stormwater runoff by allowing it to infiltrate through the paving surface where it is filtered through the various layers.

	Structure 1*	Structure 2	Structure 3	Structure 4	Structure 5	Structure 6
Joints	Basalt (1-3 mm)	Zeolite (0-4 mm)	Zeolite (0-4 mm)	Mix** (0-4 mm)	Adsorber (0-4 mm)	Granite (0-4 mm)
Bedding	Basalt (2-5 mm)	Basalt (2-5 mm)	Basalt (0-5 mm)	Basalt (0-5 mm)	Basalt (0-5 mm)	Basalt (0-5 mm)

** No longer allowed under German Paving Regulations*
*** Mix of adsorber and granite*







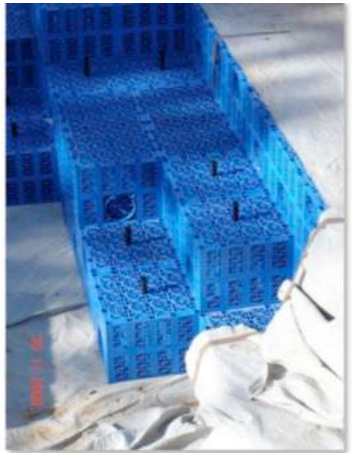
To ensure that the infiltration capacity of permeable pavements remains sufficient they generally need to be cleaned periodically. They typically require cleaning at least once every 10 years.

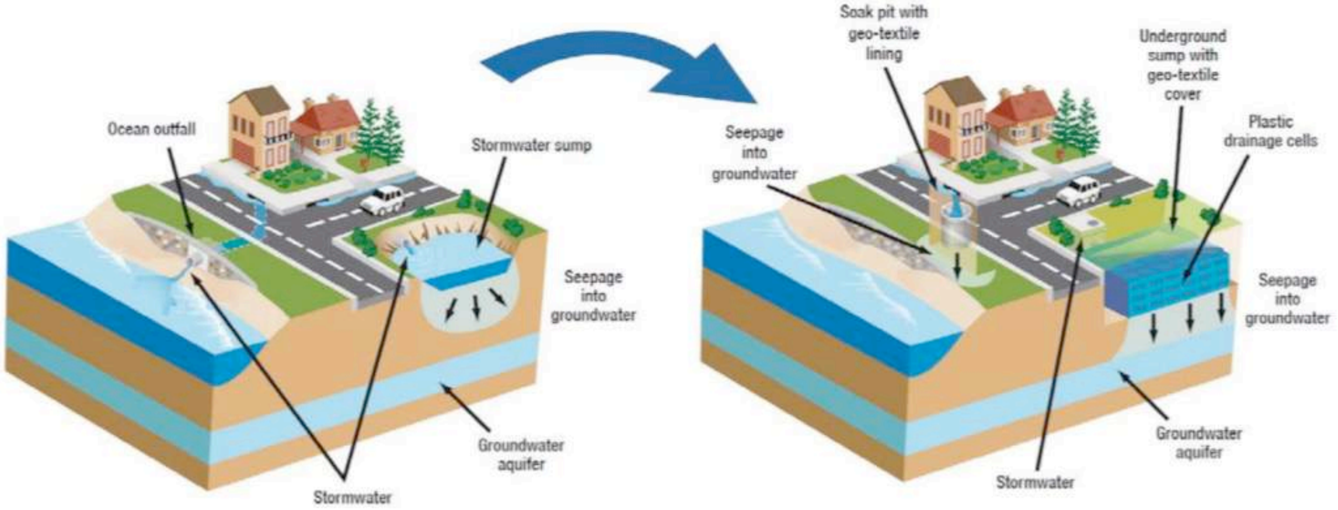
Source: Lucke and Dierkes (2015). Addressing The Demands Of The New German Permeable Pavement Design Guidelines And The Hydraulic Behaviour Of A New Paving Design. Journal of Engineering Science and Technology. ACEE 2015 Conference August, 14 – 28.

Cottesloe Aquifer Recharge, Australia

Improve groundwater quality and prevent the intrusion of saltwater

- ✓ Pollutants are managed by seven underground sumps and 400 stormwater pits which act as gross pollutant traps and aid stormwater infiltration for aquifer recharge.
- ✓ Approximately 180 ML per year of untreated stormwater was directed into ten ocean outfalls prior to the development of the Cottesloe Aquifer Recharge project. As a result of using the stormwater for aquifer recharge, the ten ocean outfalls no longer discharge in small and minor events.

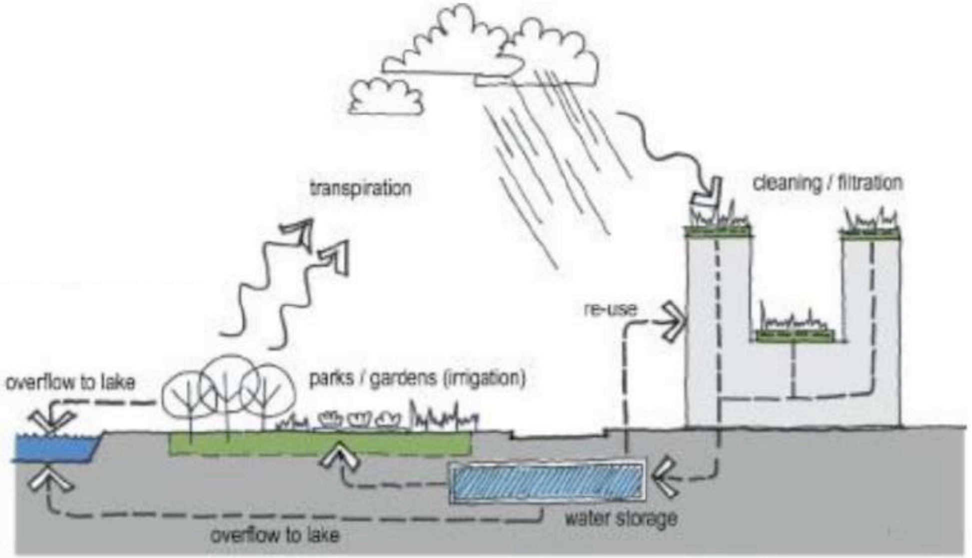




Source: New WAter Ways, https://2exng84502273uappbxzksve-wpengine.netdna-ssl.com/wp-content/uploads/2017/09/CAR_final_Sep2011.pdf

Fiona Stanley Hospital, City of Melville, Australia

Issue: No drainage connections were available to accommodate stormwater removal offsite.
Solution: WSUD principle was applied through utilizing the existing hydrology and natural systems to transfer stormwater from major events into low points, Lake Park and the bushland, and recharging the groundwater resources. On site infiltration is further facilitated via underground concrete infiltration tanks. The water in the tank is used for irrigation purposes and is recycled after passing through Reverse Osmosis (RO) water plant to be used for toilet flushing.
Outcomes:
- ✓ Stormwater captured and stored on site for irrigation purposes.
- ✓ 10% of scheme water use is recovered and combined with RO wastewater for toilet flushing
- ✓ Reduced scheme water consumption and flow to sewers
- ✓ Retention of vegetation, landscape and optimisation of urban form

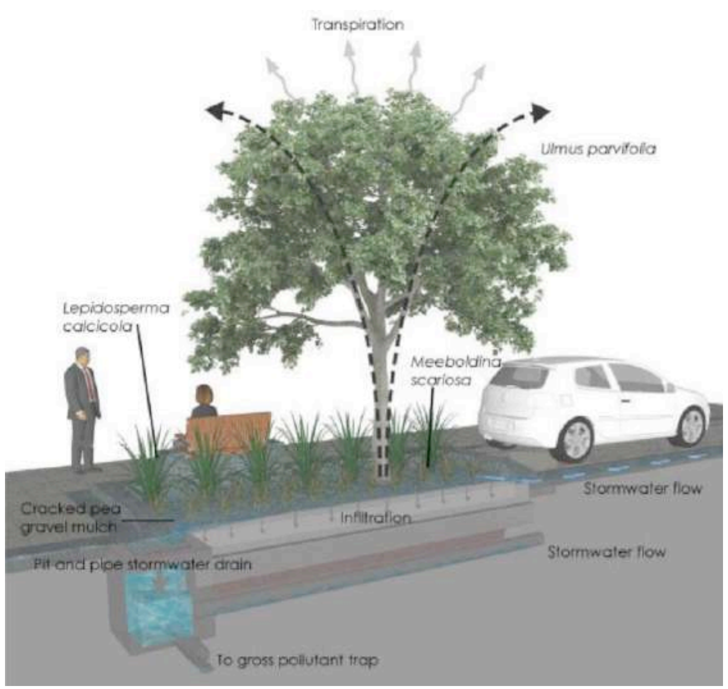


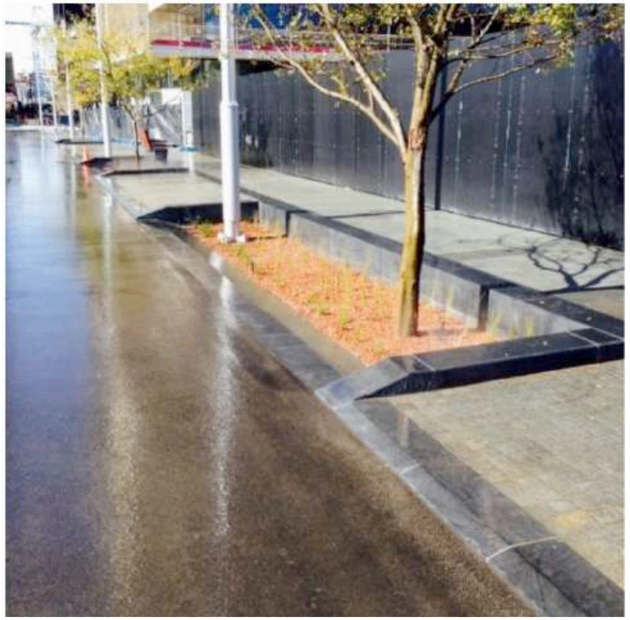
Source: New WAter Ways, https://2exng84502273uappbxzksve-wpengine.netdna-ssl.com/wp-content/uploads/2017/09/Case-study-Fiona-Stanley_-Final.pdf

Kings Square raingardens, City of Perth, Australia

Network of raingardens integrated with street parking

- ✓ These raingardens provide retention, filtration, litter management and bioremediation outcomes.
- ✓ There are 10 raingardens ranging in length from 4 m to 9 m and a width of 2.5 m. This equates to approximately 1:2 ratio of infiltration area to parking area.





- ✓ They can catch the first flush events which account for approximately 95% of rainfall.
- ✓ The materials carried by the first flush are the most damaging to the environment including hydrocarbons, heavy metals, litter, nutrients, dust and leaf litter.

Source: New WAter Ways, https://2exng84502273uappbxzksve-wpengine.netdna-ssl.com/wp-content/uploads/2017/09/King-Square-Rain-Gardens_FINAL.pdf

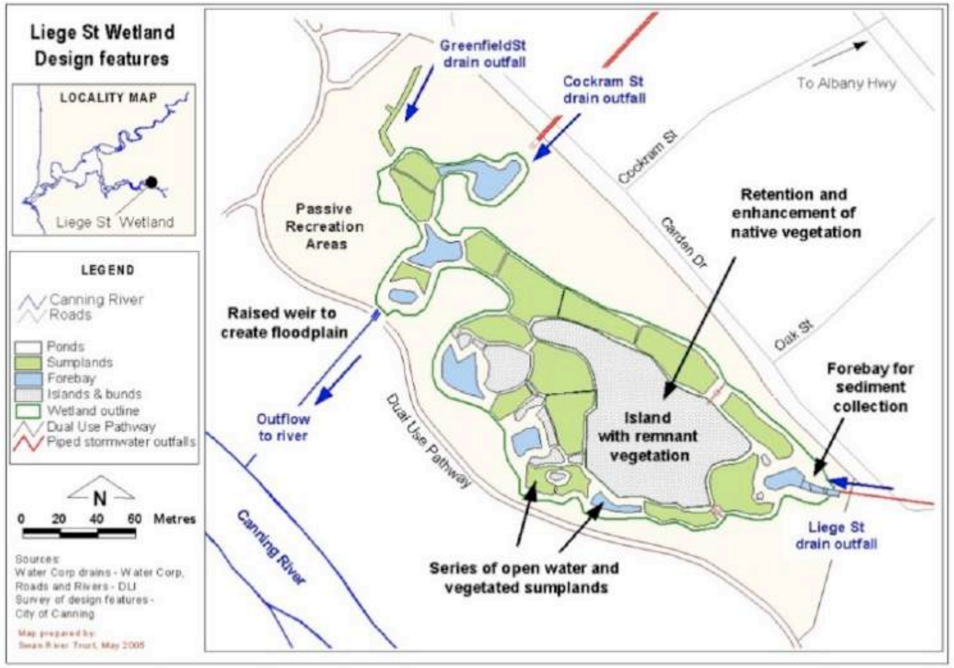
Liege Street Wetland , City of canning, Australia

Issue: Flows with elevated levels of nutrients and other pollutants from a large urban catchment (5.3 km²) are conveyed into the Canning River.

Solution: Retrofitting of an area of public open space into a constructed wetland (approximately 1 ha) to improve stormwater quality. Design of the wetland ensures that during high flows, the water will be conveyed quickly through the wetland to minimise the risk of flooding

Outcomes:

- ✓ Measurements within the sedimentation forebay were exhibiting high levels of metals and nutrients accumulation indicating the effectiveness of its design to reduce pollutants.
- ✓ The site has also become a place where many species of fauna can be seen. Nesting turtles and birds are a strong indication of the success of the project in creating habitat.
- ✓ Creation of a passive recreation area for public use which also has educational benefits for the community.



Source: New WAter Ways, https://2exng84502273uappbxzksve-wpengine.netdna-ssl.com/wp-content/uploads/2017/09/Liege-street-wetland-final-Nov-2011.pdf

6. Technology Transfer to Egypt

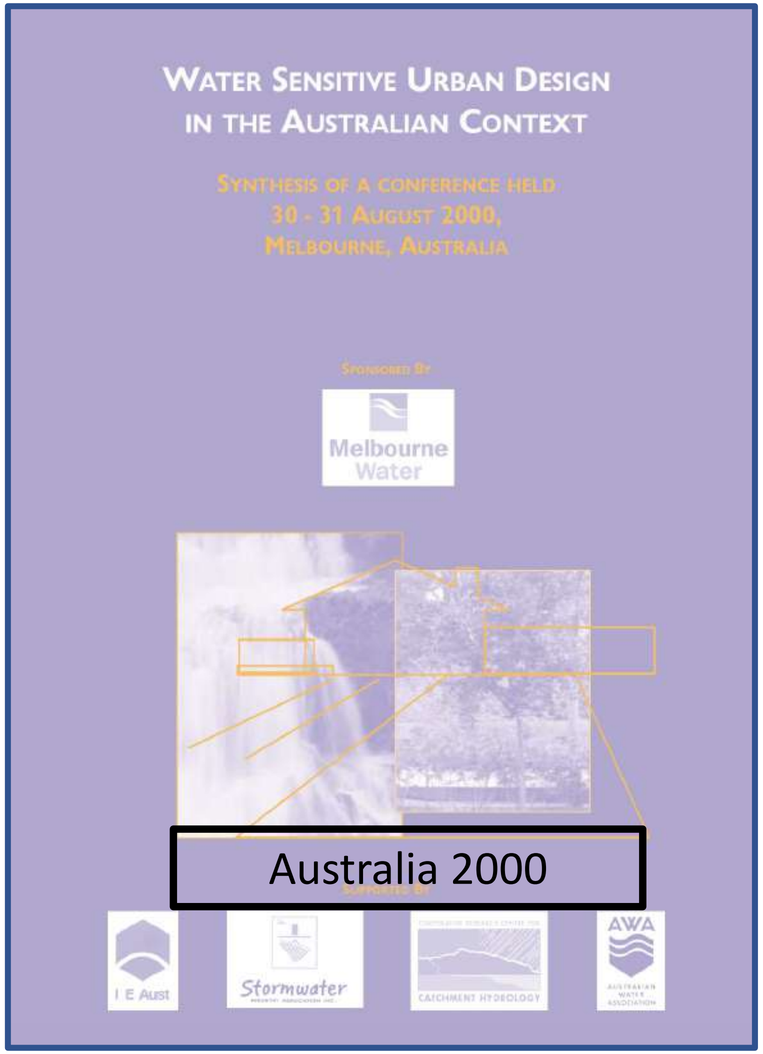
Stormwater Management Alternative	Advantages	Disadvantages	Suitability in Egyptian conditions
Bioretention (Rain gardens and bio swales)	1. Reduction in runoff volumes and peak flows 2. Generally requires less space and is more economical 3. Requires less maintenance 4. Removes pollutants 5. Has aesthetic value 6. Offers good retrofit opportunities for existing urban landscapes	1. High sediment may cause premature failure 2. Cannot be provided for large drainage areas	Can be applied in parking areas in residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.
Grass swales	1.Reduces runoff volume, peak flow and pollutants 2.Application is primarily along residential streets and highways 3.Adaptable to a variety of site conditions 4.Flexible in design and layout 5.Less costly than conventional storm drain pipe system	1.Open channels may be potential nuisance problems 2.Moderate or high maintenance cost	Can be constructed along highways and roads that are subjected to high rains, such as Qena-Sohag, Al Ain Al Sokhna, etc.

Stormwater Management Alternative	Advantages	Disadvantages	Suitability in Egyptian conditions
Green roofs/Vegetated roof covers	1.Reduces percentage of impervious spaces in urban areas 2.Reduction in runoff volume 3.Reduce peak discharge rates 4.Provides aesthetic benefits 5.Better thermal performance 6.Decrease in total energy consumption of buildings 7.Mitigates the urban heat island effect 8.Increases the longevity of roof membranes	1.High initial cost 2.Moderate maintenance cost 3.Climatic condition	Can be applied in all the coastal areas in Egypt, such as Alexandria, New Alamein, etc.
Permeable/Porous Pavements	1.Effective in reducing imperviousness in a drainage basin 2.Recharges the groundwater 3.Improves the quality by arresting the pollutants	1.Costlier than conventional pavements 2.Suitable for low traffic areas such as parking lots and sidewalks 3.Clogging problems may arise due to high sediment load 4.Maintenance is costly	Can be used in the roads, parking areas, as well as residential compounds and cities located along the coast or susceptible to high rain intensity, such as Alexandria, New Alamein and New Mansoura, etc.

Stormwater Management Alternative	Advantages	Disadvantages	Suitability in Egyptian conditions
Infiltration devices (Leaky wells, Retention trenches, Infiltration basins)	1.Reduces peak flow 2.Recharges the groundwater 3.Improves the groundwater quality 4.Reduces runoff volume	1.Require pretreatment to remove sediment 2.Unsuitable for soils with very low hydraulic conductivity 3.Cannot be installed on steep slopes 4.Not suitable in areas with rising water table or where salinity of groundwater is increasing	Can be applied in new cities and compounds subjected to heavy rains, such as Alexandria, New Alamein and New Mansoura, etc.
Detention Basins (dry ponds, extended detention basins, detention ponds, extended detention ponds)	1.Attenuates peak flow 2.Simple to design and construct 3.Easy to maintain 4.Can also function as a recreational facility 5.Can be used with lining where groundwater is vulnerable	1.Little reduction in runoff volume 2.Has large space requirement hence may not be suitable in ultra-urban areas 3.Provides moderate removal of pollutants 4.May turn into mosquito breeding sites if improperly managed 5.Normally provided towards the end of sustainable urban drainage management train	Can be applied in cities and compounds located in arid areas, such as Cairo, Giza, etc.

Stormwater Management Alternative	Advantages	Disadvantages	Suitability in Egyptian conditions
Retention Ponds (stormwater ponds, wet retention ponds, wet extended detention ponds)	1.Reduces peak flow 2.Provides good stormwater treatment 3.Provides high amenity and aesthetic benefits 4.Adds value to local properties	1.Land requirement may limit use in dense urbanized landscapes 2.Pose health and safety risks	Can be applied in new cities and compounds subjected to heavy rains, such as Alexandria, New Alamein and New Mansoura, etc.

6. Sources of Information


WATER SENSITIVE URBAN DESIGN
IN THE AUSTRALIAN CONTEXT
SYNTHESIS OF A CONFERENCE HELD
30 - 31 AUGUST 2000,
MELBOURNE, AUSTRALIA
SPONSORED BY
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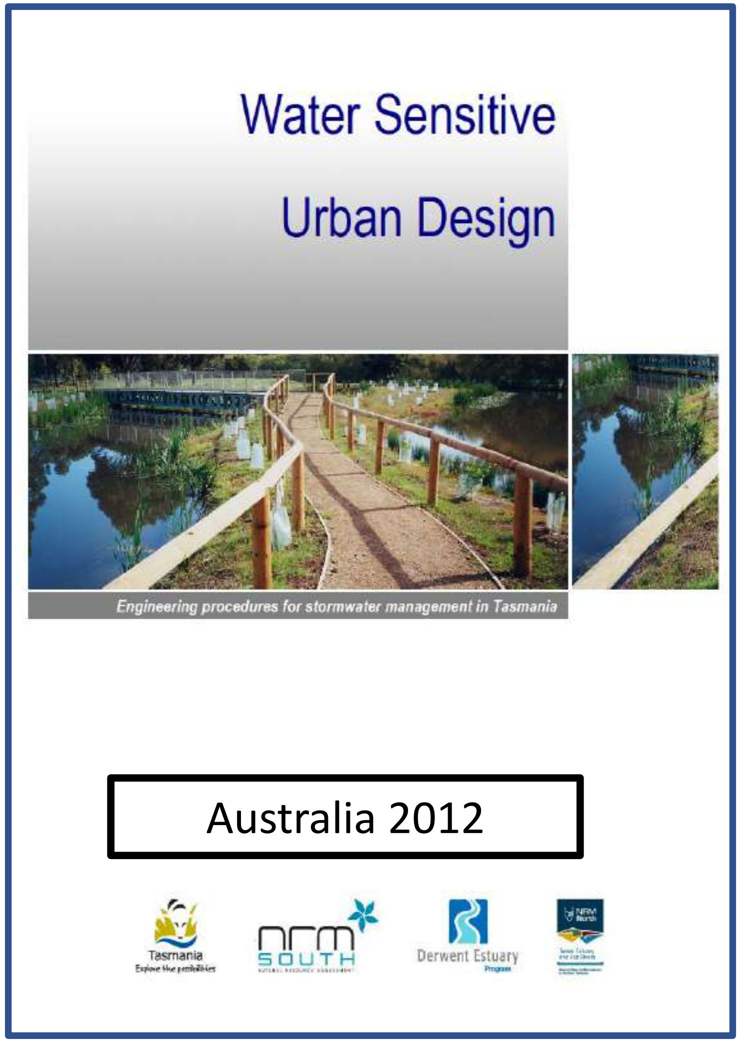
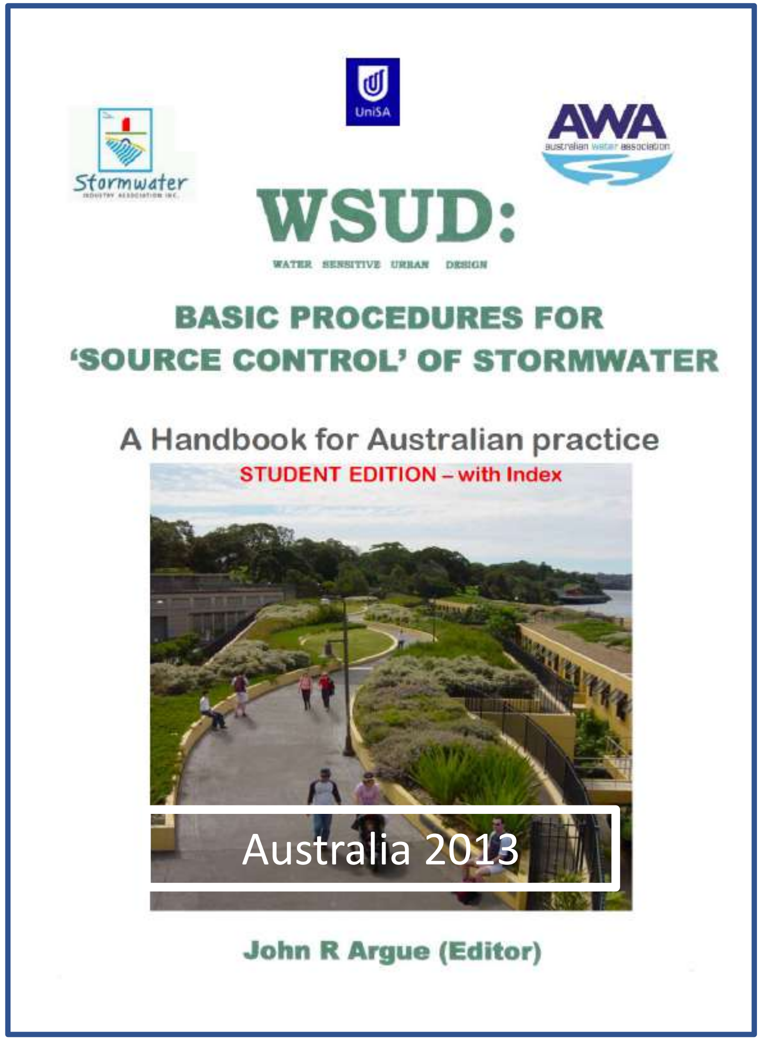
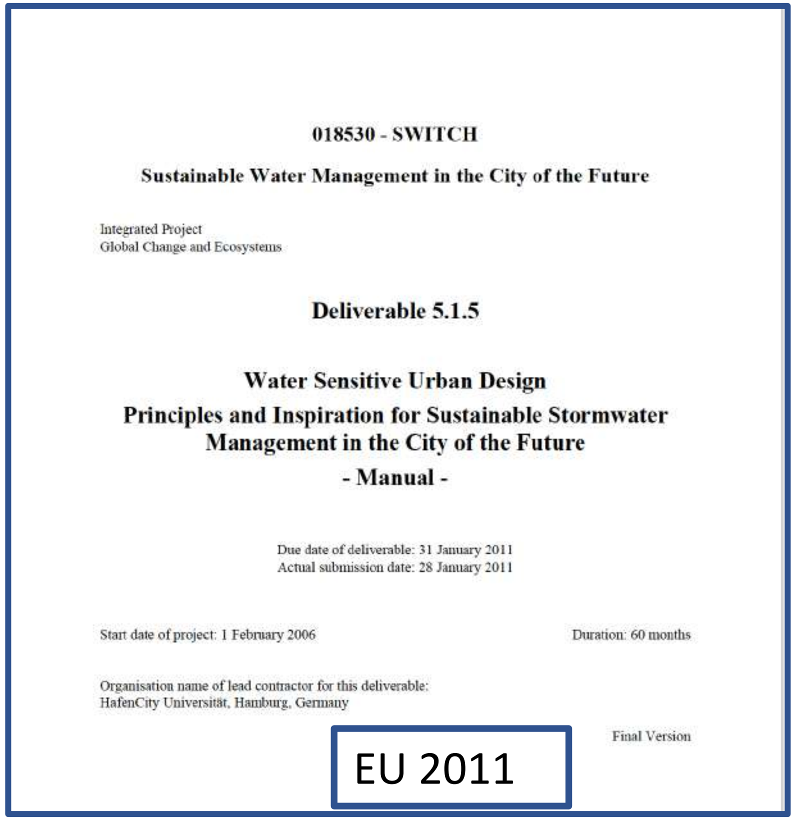

Water Sensitive
Urban Design
Engineering procedures for stormwater management in Tasmania
Australia 2012
Tasmania
Explore the possibilities
nrm SOUTH
Derwent Estuary
Program


Stormwater
UniSA
AWA
australian water association
WSUD:
WATER SENSITIVE URBAN DESIGN
BASIC PROCEDURES FOR
'SOURCE CONTROL' OF STORMWATER
A Handbook for Australian practice
STUDENT EDITION – with Index
Australia 2013
John R Argue (Editor)


018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable 5.1.5

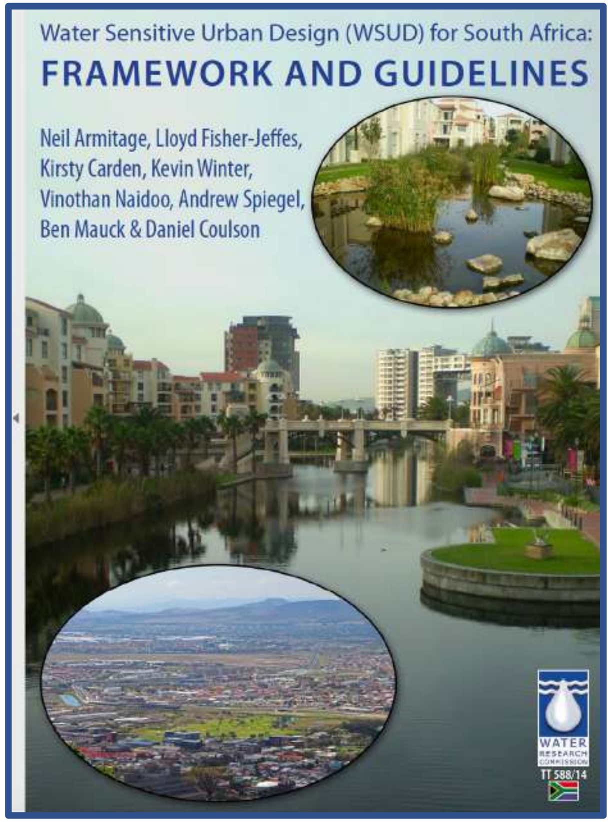
Water Sensitive Urban Design
Principles and Inspiration for Sustainable Stormwater Management in the City of the Future
- Manual -

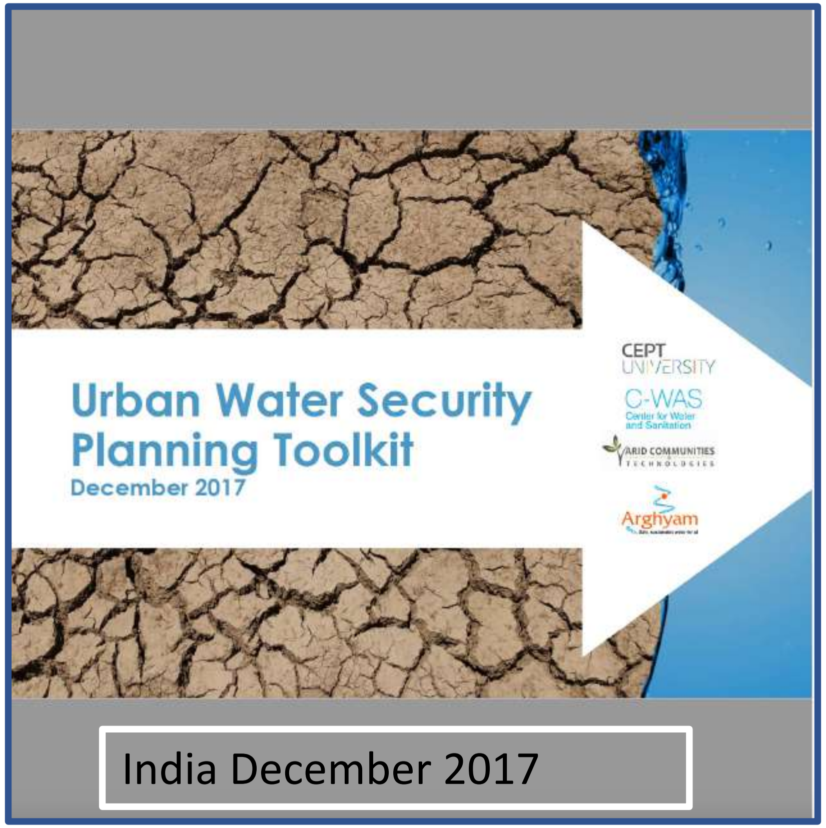
Due date of deliverable: 31 January 2011
Actual submission date: 28 January 2011

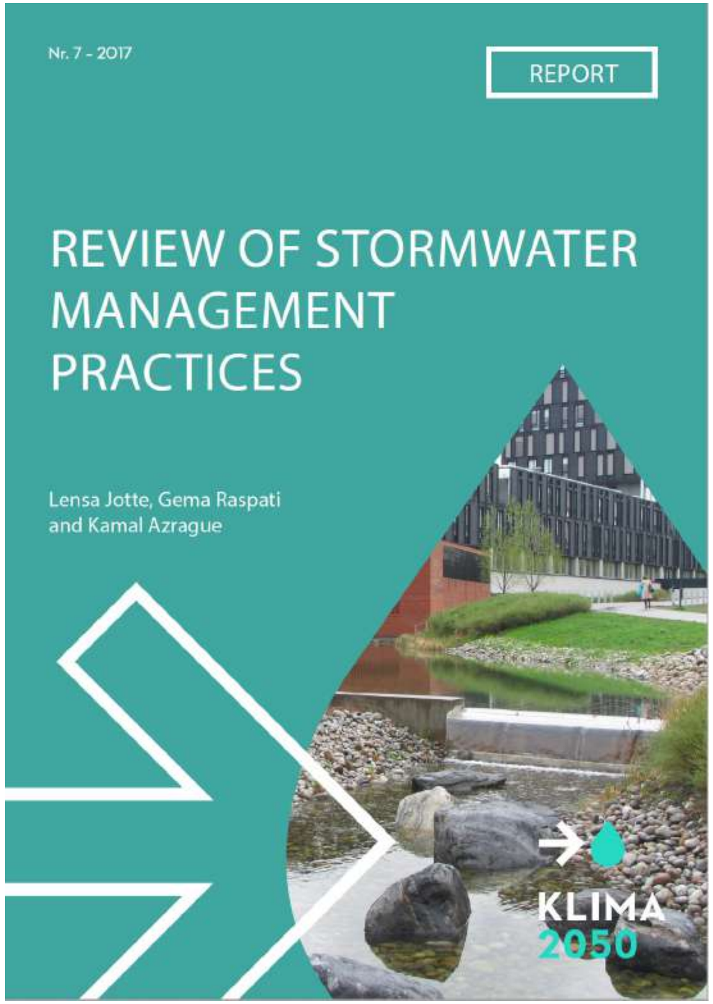
Start date of project: 1 February 2006 Duration: 60 months

Organisation name of lead contractor for this deliverable:
HafenCity Universität, Hamburg, Germany

Final Version






Nr. 7 - 2017
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REVIEW OF STORMWATER MANAGEMENT PRACTICES
Lensa Jotte, Gema Raspati and Kamal Azrague
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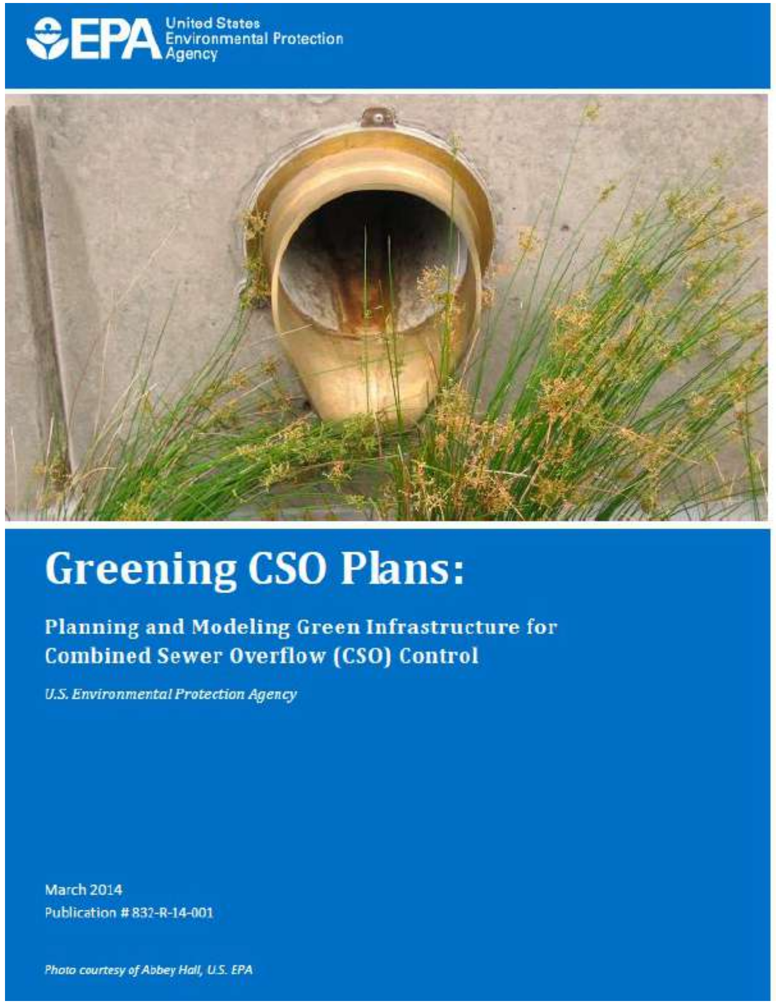
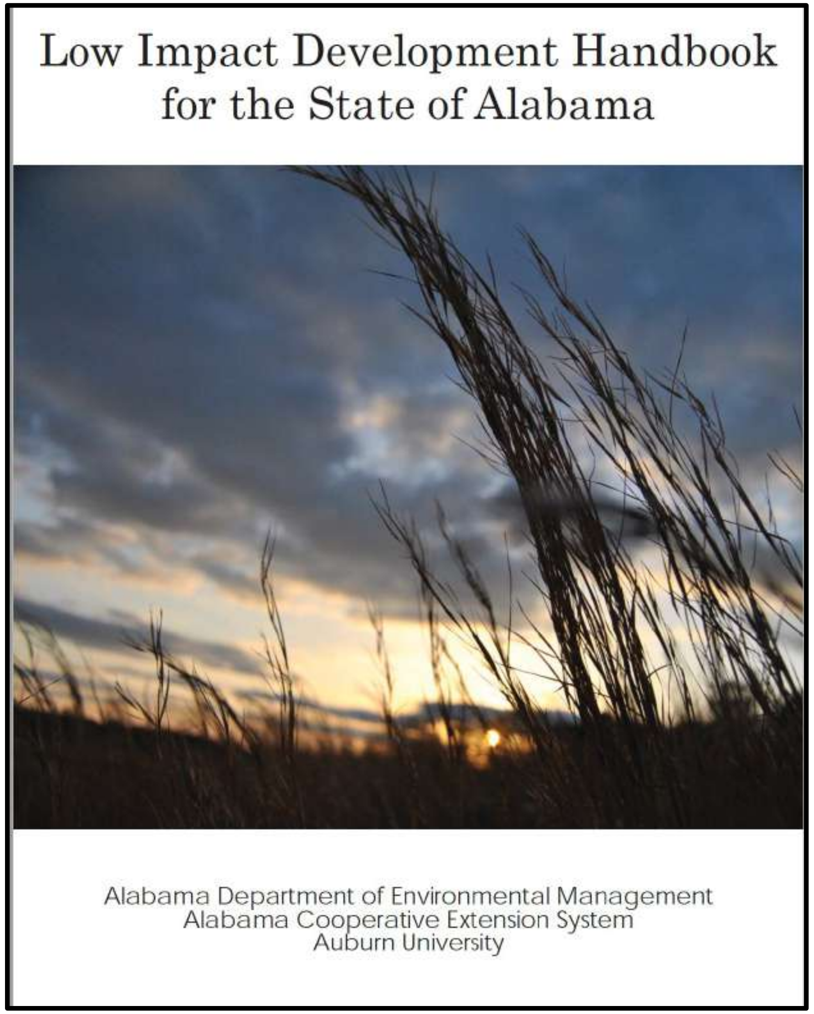

EPA United States Environmental Protection Agency
Greening CSO Plans:
Planning and Modeling Green Infrastructure for Combined Sewer Overflow (CSO) Control
U.S. Environmental Protection Agency
March 2014
Publication # 832-R-14-001
Photo courtesy of Abbey Hall, U.S. EPA


Low Impact Development Handbook for the State of Alabama
Alabama Department of Environmental Management
Alabama Cooperative Extension System
Auburn University

Annex: Recent Flooding Photos in Egyptian Cities

Alexandria, 2015


Al Gaish Road, November 7, 2015


Moharam Bek Road, October, 2015

Foad Road, October, 2015

Gamal Abdel Naser Tunnel, October, 2015

Al Mandara Bridge, October, 2015

New Cairo, 2018

El Masrawya compound, April 24, 2018

Fifth Settlement, April 24, 2018

Fifth Settlement, April 24, 2018

Al 90 Road, April 24, 2018

Ras Ghareb City, Red Sea Governorate, 2016

Ali Rafi School, October 30, 2016

Ras Ghareb Club, October 30, 2016

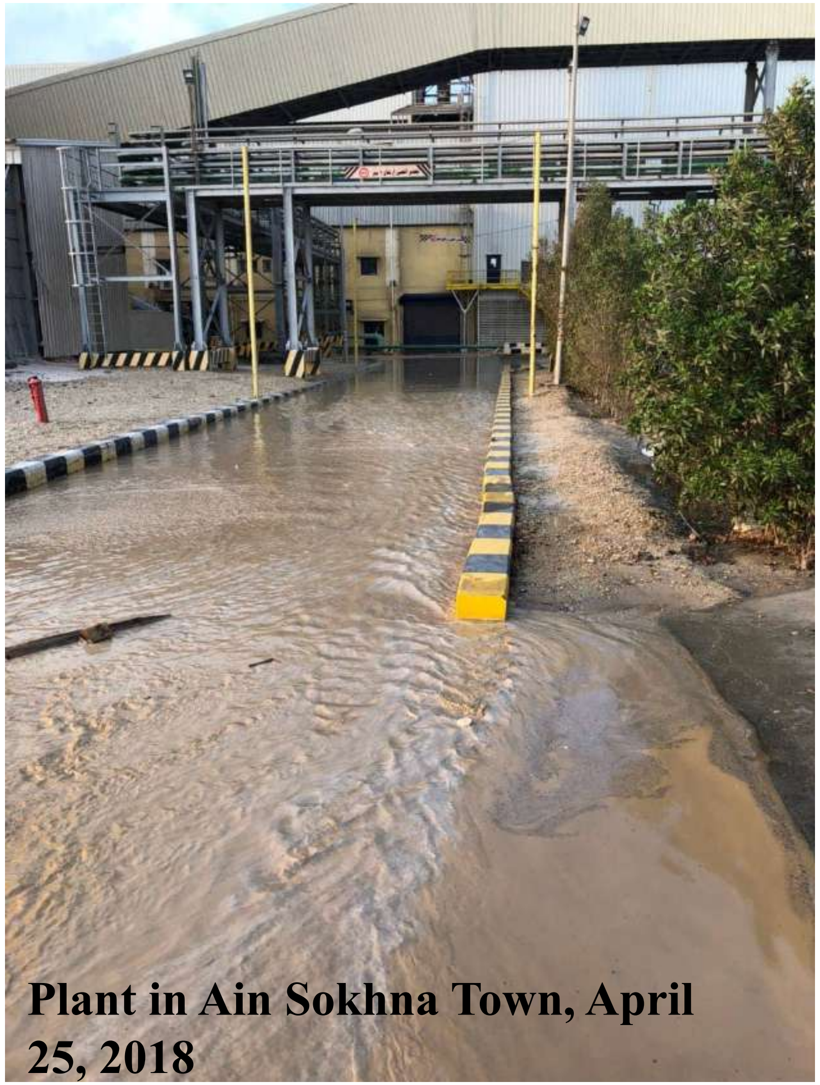
Residential buildings at Ras Ghareb, October 30, 2016

Ras Ghareb road, October 30, 2016

Ain Sokhna Town, Suez Governorate, 2018

Tourist village, April 25, 2018

Chalet in Ain Sokhna Town, April 25, 2018



Plant in Ain Sokhna Town, April 25, 2018